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Smart Antenna System Management utilising Multi-Agent Systems

by

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Abstract

Cellular communication networks are large and distributed systems that provide billions of people around the world with means of communication. Antennas as used currently in cellular communication networks do not provide efficient resource management given the growth in the current communication network scenario. Most of the problems are related to the number of devices that can connect to an antenna, the coverage map of an antenna, and frequency management.

A smart antenna grid can cover the same area as traditional cellular system towers with some enhancements. Smart antenna grids can include a device in an area that requires connectivity rather than covering of the entire area. Frequencies are handled per antenna base, with more focus on providing stable communication. The objective of the dissertation is to improve resource management of smart antenna grids by making use of a multi-agent system.

The dissertation uses a simulation environment that illustrates a smart antenna grid that operates with a multi-agent system that is responsible for resource management. The simulation environment is used to execute ten scenarios that intends to place large amounts of strain on the resources of the smart antenna grid to determine the effectiveness of using a multi-agent system.

The ten scenarios show that when resources deplete, the multi-agent system intervenes, and that when there are too many devices connected to one smart antenna, the devices are managed. At the same time, when there are antennas that have frequency problems, the frequencies are reassigned. One of the scenarios simulated the shutdown of antennas forcing devices to disconnect from the antenna and connect to a different antenna. The multi-agent system shows that the different agents can manage the resources in a smart grid that is related to frequencies, antennas and devices.

Keywords: multi-agent system, frequencies, smart antennas, smart antenna grid, cellular communication network.

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List of Acronyms

AI	Artificial Intelligence
AMPS	Advanced Mobile Phone System
CDMA	Code-division Multiple Access
EAA	Environment Analysis Agent
FMA	Frequency Management Agent
GSM	Global System for Mobile Communications
NAMPS	Narrowband Analog Mobile Phone Service
MIMO	Multiple input, multiple output
NMTS	Nordic Telecommunication System
OFDM	Orthogonal frequency-division multiplexing
RAN	Radio Access Network
SID	System Identification Code
SDMA	Space Division Multiple Access
SGMS	Smart Grid Management System
SSA	Service Switching Agent
TACS	Total Access Communications
WCN	Wireless Carrier Network

Chapter 1 - Introduction

1 • Introduction

Literature

2 • Cellular communication network

3 • Smart antennas

4 • Frequencies in communication networks

5 • Software agents

6 • Machine learning

Model Overview

7 • Smart Grid Management System Model Overview

8 • Environment Analysis Agent (EAA)

9 • Service Switching Agent (SSA)

10 • Frequency Management Agent (FMA)

Implementation and results

11 • Smart Grid Managment System protoype implementation overview

12 • Prototype results overview

13 • Conclusion

1.1 Introduction

Communication systems have grown from small and simple systems into large, complex and highly distributed systems that operate over vast areas since the invention of the first telephone. Communications systems are responsible for providing fast and stable communication between different devices (Ahmed, 2015).

Communication systems are not all implemented using the same management techniques and hardware. Some variants of software and hardware operate better in specific environments to provide communication. The different software and hardware combinations are adapted to perform optimally in a communication system (Ahmed, 2015).

Considering that communication systems are highly distributed and complex, there is room for better management of resources to ensure a more stable environment. Important aspects of a communication system are covered in the dissertation to understand where improvements can be made in a mobile communication system.

Chapter 1 focuses on the problem that is going to be solved in the dissertation. Chapter 1 also focuses on the approach that was followed to solve the problem, and the structure of the dissertation. Chapter 1 also gives a breakdown of this research, to facilitate the achievement of the research objectives as set out.

1.2 Problem statement

In the current implementation of cellular communication networks many different devices are focused upon simultaneously. Current cellular networks have the tendency to disconnect devices. In 2013 there were more than 6 billion users operating within cellular networks around the globe. It is expected that by 2020 there will be more than 11 billion users on mobile networks who will be connected to the internet globally (Rula, Bustamante & Steiner, 2017). A mobile system should strive to handle more significant numbers of devices.

In a cellular network, the ideal scenario is one where a large geographic area is covered utilising a set of antennas. These antennas that cover larger areas can also provide the ability to handle more significant numbers of users in communication networks (Okoro, 2013; Dogadaev, Checko, Popovska Avramova, Zakrzewska, Yan, Ruepp, Berger, Dittmann & Christiansen, 2013).

One of the newest generation networks deployed in 2018 are 5G networks. In general, implementing new generation networks can ensure that more people can utilise a frequency, because the frequency can cater for more people in a communication network. While modern generation networks increase the number of users, they should be able to handle this higher demand from users in a fast and efficient manner (Mubarak, 2017; Dogadaev al., 2013).

Other than the ability to support more user's, newer generation antennas should provide stable connections to cellular environments without the possibility of a device being disconnected from an antenna. Devices are generally disconnected from an antenna's frequency when the antennas have too many connected devices (Dogadaev et al., 2013).

Antennas are operating under high user loads when a set of users that moves around on a geographic map connect to different antennas that are already under high load. The antennas should be able to handle a large number of users, and mobile devices should also have the ability to move between two different antennas without having a significant break in cellular service.

However, it is not always plausible for an antenna to be able to cover a larger geographic area efficiently. Sometimes an area cannot be efficiently covered since physical structures can influence the coverage that an antenna provides. When physical structures affect an antenna signal the antenna's coverage area is significantly decreased, meaning that there is a requirement for more antennas or antennas that can cover a larger area (Chavan, Chile & Sawant, 2011; Alsamhi & Rajput, 2014).

Even with the latest generation 5G networks, each antenna has limited space available for devices to communicate. Antennas manages the available space by disconnecting users from an antenna until there is space available of the same antenna for it to reconnect to. The devices that get disconnected from the antennas are dependent on the type of software that the different antennas are running.

The disconnected device has the responsibility to regain connection to the same or another antenna once it has been disconnected. At this stage the device has disconnected and gone into roaming mode where it is searching for a new compatible antenna to communicate with (Wang, Hossain & Bhargava, 2016). A device might not always be able to communicate immediately with an antenna since there might not be any available space on other antenna frequency bands.

Antennas are not always in an operational state to communicate with mobile devices. Sometimes antennas are placed in a non-operational state due to maintenance or something being wrong with the antenna. In this case, all the connected devices will disconnect until the antenna is back up, or there is another antenna available. Bringing the antenna back to an operational level will take a while, forcing neighbouring antennas to take up the disconnected devices if they are in range (Harris, 2011; Do-Duy & Vazquez-Castro, 2015).

In response to the above-mentioned cellular communication grid problems, this research study proposes to investigate an option for improving the resource usage in a smart antenna grid. Examining the current implementation of cellular networks will help understand how cellular networks work, and how antennas form part of cellular networks.

Examining the different kinds of antennas that are utilised in a smart grid and how frequencies are managed in a smart antenna grid, will provide a better understanding of how smart antennas can be utilised in communication systems. Considering all the different components that form a smart antenna grid will enable a better understanding of the operations and the sections where improvement is possible.

A prototype smart antenna grid with a set of agents integrated is used to determine if a multi-agent system can effectively manage a smart antenna grid. To build a prototype system, the different agents that can be used to control the smart antenna grid and the tasks each one of the agents will have in the management process need to be examined. Therefore, a study of smart antenna grids and software agents should provide insight to how software agents can be utilised in smart antenna grids.

1.3 Aims and Objectives

The primary objective of this dissertation was to build a multi-agent system that enables a smart antenna grid to obtain an optimal solution. The multi-agent system that operates in the smart antenna grid should make use of different intelligent software agents to manage resources. The multi-agent system then helps to ensure that the system works in an optimal state with minimal communication drops.

The list of objectives covered in this dissertation were:

- Identifying components that make up a communication network;
- Identifying smart antenna components and operations;
- Understanding what software agents are, and where in a smart antenna grid the software agent can be integrated;
- Defining and implementing the different agents in the multi-agent system; and
- Developing the simulation environment's implementation and determining the results.

1.4 Research questions

The primary research question that the smart antenna grid system attempts to answer is:

Can smart antenna grid resource management be achieved by using a multi-agent system?

The research question above can be broken down into three sub-questions, as follows:

- Question 1:
  How do smart antennas operate in a cellular network?
- Question 2:
  How can a multi-agent system be integrated into a smart antenna grid system?
- Question 3:
  Is resource management improved by using a multi-agent system prototype level?

This dissertation aimed to answer all the above-mentioned questions. The questions are revisited in the last chapter of the dissertation. The research methodology followed is discussed in the following section.

1.5 Research Methodology

Research in information technology is vastly different from performing research in other fields such as the natural and social sciences. The intention of research in information technology is to prove that a set of objectives can be reached in an elegant way. Software models are one of the most common techniques used in information technology to reach the set of objectives (Olivier, 2009).

The research methodology set out to discuss and clarify the different aspects that relate to smart antennas and radio frequency antennas. It also defined some of the models with regards to their creation. The following section of this chapter focuses on the research methodology.

Olivier (2009) stated that there is greater importance in focusing on research aspects that are related to the problem rather than focusing on issues that are not essential. The primary objective of the dissertation was to create a model that efficiently and effectively distributes resources in a smart antenna grid. The methodology set out to discuss and clarify different aspects relating to smart antennas and radio frequency antennas. It also defined some of the models with regard to their creation.

Olivier (2009) placed importance on research methodologies that can be used in computer science, as they aid in structuring a research document. Oliver (2009) also states that using variation and amalgamation of different research approaches can improve the research.

The research methodology followed the methodology proposed by Olivier (2009). The dissertation started with an evaluation of the problem of smart antennas and cellular networks. The focus on cellular systems and smart antennas identified the underlying problems and directed the dissertation. Elements related to cellular networks and smart antennas illustrates how the current implementation manages resources. Forming this understanding allows a better understanding of how to best implement a resource management model.

Elements identified in the literature study included best practice in radio frequency distribution and identifying resource distribution methodologies. To prove that resource management and frequency distribution management are achieved in a smart antenna grid, a model was implemented to demonstrate the results that were achieved from the multi-agent system execution. This approach provided ideas and insights that had not been looked at, or that were unknown.

The literature review also provided insight into the existing techniques, focusing on what works well in current techniques and what does not work so well in the existing techniques. The literature review also focuses on software agents and machine learning in terms of the different types of software agents and how the software agents operate.

Forming a good understanding of the different software agents in terms of how they work provides knowledge on how to use software agents to manage smart antenna grid resources. This understanding helps to shape an understanding of how a multi-agent system can manage resources. The proposed solution made use of generated data to manage and distribute resources.

1.6 Dissertation Layout

The dissertation is presented in three parts, each containing a number of chapters. The first part covers the literature review, the second part focuses on the model's implementation, and the third part focuses on the results. Figure 1.1 shows the layout of the dissertation. The following section provides further information on the three parts.

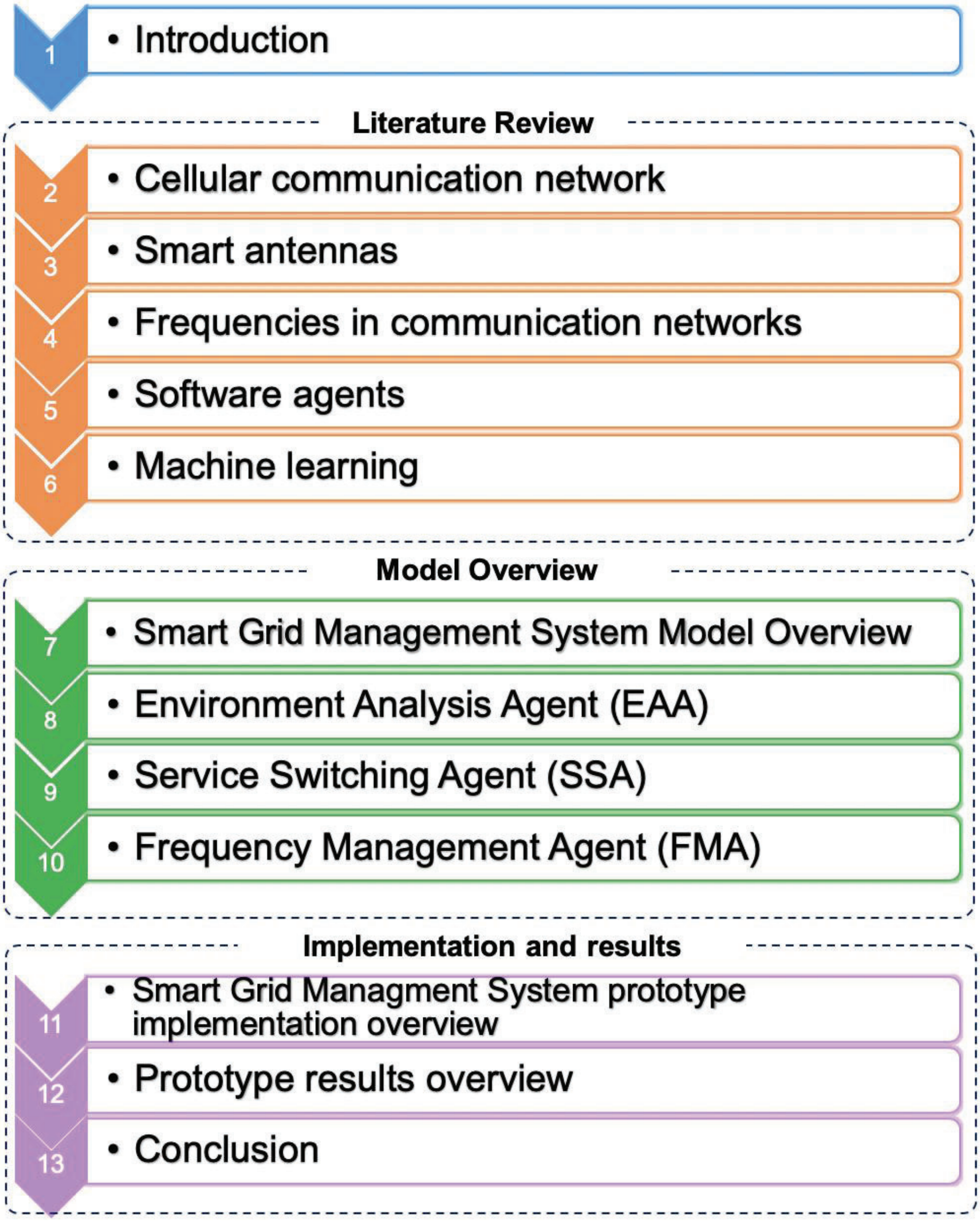

Figure 1.1: Research dissertation structure

1.6.1 Literature Review

The literature review focused on current cellular network implementation and the components that make up cellular networks. Part 1 covers aspects relating to the model implementation.

The literature review is divided into the following chapters:

- *Cellular communication networks*: focuses on how a cellular communication network operates and looks.
- *Frequencies in communication networks*: focuses on what frequencies are and how frequencies work in a cellular communication network.
- *Smart antennas*: focuses on what smart antennas are and how smart antennas operate in a cellular network. It also focuses on how smart antennas manage frequencies.
- *Software agents*: focuses on what a software agent is and how the different types of software agents function. The section also focuses on how intelligent agents and multi-agent systems function and discusses different types of intelligent agents.
- *Machine learning*: focuses on what machine learning is and how different machine learning models function.

1.6.2 Model Overview

The model overview constitutes the second part of the dissertation that focuses on the various agents that form part of the smart antenna grid prototype. Part 2 focuses on how the various agents are integrated into the smart antenna grid.

The following chapters cover the model overview:

- *Smart Grid Management System (SGMS) model overview*: focuses on the model and the various agents that made up the model implementation, and how these different agents integrate.
- *Environment Analysis Agent (EAA)*: focuses on the EAA, and how the EAA integrates into the multi-agent system.

- *Service Switching Agent (SSA):* focuses on how the SSA is integrated into the multi-agent system, and when it executes.
- *Frequency Management Agent (FMA):* focuses on how the FMA is integrated into the multi-agent system and when it executes.

1.6.3 Implementation and results

The third part of the research dissertation focuses on the implementation of the prototype system. This part also focuses on the results of the prototype and on answering the research question mentioned earlier in Chapter 1.

The implementation and results part is split up into the following chapters:

- *Model implementation overview*: focuses on the implementation of the Smart Grid Management System (SGMS) model implementation, which includes some of the requirements to execute the prototype.
- *Model result overview:* focuses on the different execution scenarios of the prototype environments, and the results after execution.
- *Conclusion*: focuses on the closing of the research dissertation by answering the research questions set out in Chapter 1.

1.7 Conclusion

Smart antenna grids are large and complex systems that are responsible for providing cellular communication to users. As shown in Chapter 1, cellular communication networks might always have limitations concerning the number of users that are supported, and the availability of antennas at all times.

The focus throughout this dissertation is on ensuring that the research performed creates a clear understanding on how cellular systems operate and how smart antennas operate. The research also shows how different agents can be integrated into a smart antenna grid with the objective of managing resources.

The chosen study methodology set out the structure of this dissertation in its aim to meet the objectives and to ensure that all research questions are answered. Once a broad overview of the content has been discussed, these answers can be found in various chapters of the dissertation, and in the final chapter.

Chapter 2 - Cellular communication networks

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2.1 Introduction

In 1973 Mr Martin Cooper, a Motorola employee, invented the first commercial mobile phone. The phone was tested in New York, when Mr Cooper made a phone call to Bell Laboratories in New Jersey, using a 900 MHz base station. It is safe to say that were it not for Mr Cooper, there would have been no mobile phones (Farley, 2005; Harris & Cooper, 2018).

Most people did not have a fast and efficient way to communicate with each other before Mr Cooper's invention. In the early communication networks, it was not as simple as typing the number into a keypad and hoping that the call recipient would answer the phone. One had to speak to a person who was on a switchboard and ask to be connected.

A tower is a physical structure that contains a set of antennas used to distribute a signal to devices that need connection in a cellular communication network. The antennas can be arranged in a way that covers the greatest area for the most efficiency, depending on the type of antenna used in the cellular communication system.

Different antennas have different properties that affect their use case. Some antennas are used in smart areas, such as for Wi-Fi antennas. Others can be used over vast distances. An example of a vast distance is between a satellite and space.

The cellular towers containing the antennas are crucial pieces of hardware that make mobile communication possible. Chapter 2 focuses on the cellular towers and antennas that allow devices to communicate with each other, and how they form part of the cellular network. Chapter 2 also focuses on the different types of antennas that are used in a cellular network, and some of their properties. Understanding the terms and properties of cellular networks aided in answering the research question: *How do smart antennas operate in a mobile network?* by first understanding what a mobile network is.

2.2 Cellular towers

In 1980, licenses were provided to two cellular providers to make use of frequencies which enabled them to build communication towers. To build a cellular network, many different cellular towers and antennas were implemented (Bakalela, 2017; Campanelli, 1997). To define and understand how communication antennas manage resources, several characteristics, including software and hardware characteristics, were considered. In the following paragraphs, hardware and software components of cellular towers and their characteristics are discussed.

2.2.1 Towers

Towers are very tall structures that have sets of antennas attached to their tops and sometimes on the sides. They are located on land where cellular communication is required (Bakalela, 2017; Yuvarani & Latha, 2013). The placement of a tower is critical because it influences the area that it covers. The different elements affecting the operations of cellular towers are discussed below.

2.2.2 Location

A cellular tower contains a single radio frequency antenna or a group of radio frequency antennas that are arranged on a tower. There are many different ways in which antennas can be arranged on towers that influence the coverage area. Figure 2.1 below illustrates a cell site network with a hexagon layout. A hexagon layout area is achieved by arranging antennas on six corners of an antenna (Bakalela, 2017).

One tower manages different connected devices by making use of a set of frequencies that allow for communication between antennas and towers (Ghosh, Mangalvedhe, Ratasuk, Mondal, Cudak, Visotsky, Thomas, Andrews, Xia, Jo, Dhillon & Novlan, 2012). Because there can be thousands of remote devices connected to the same base station, i.e. the base station is the actual tower on which the antenna are mounted. The base station must be able to manage many different frequencies simultaneously.

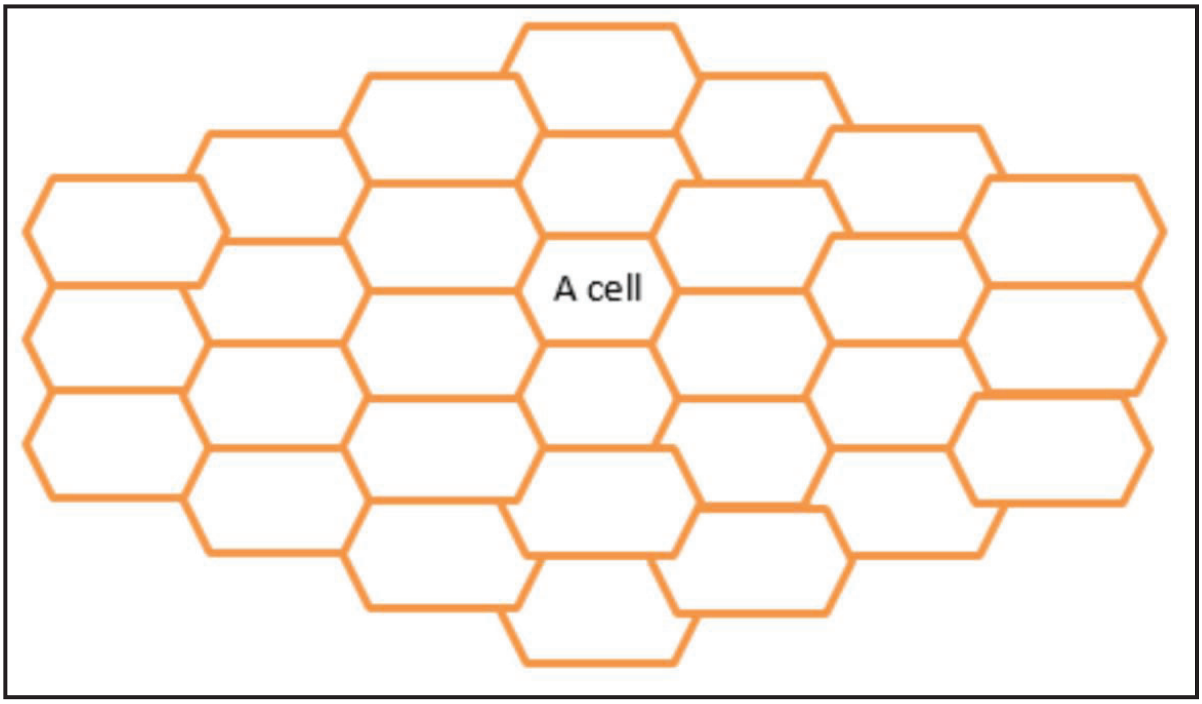


Figure 2.1: Communication network cell layout (Bakalela, 2017)

2.2.3 Antennas

Antennas are pieces of hardware equipment that are placed on the tops of cellular towers. The primary objective of an antenna in a cellular network is to receive and send radio frequency signals to be utilised by different devices (Jeffery, 2014). Various devices that can connect to antennas include mobile phones, smartwatches, cars and many others.

Different antennas can cover different spans due to the signal strength that they generate. Antennas can influence the placement of an antenna (Alsmadi & Saif, 2015). Table 2.1 shows the various ranges that a single antenna can generate.

Table 2.1: Different antenna types (Harris, 2011)

Tower Type	Meaning	Where it is used
Microcells	1.6 Kilometres	Urban
Picocells	230 Meters	Office, schools etc.
Femtocells	In building	Home

The number of devices an antenna can communicate with is dependent on the frequency the antenna utilises (Alsmadi & Saif, 2015). To minimise the limitation, engineers make use of stronger and better antennas. The purpose of stronger antennas is to cover a larger area, thus facilitating more devices. Stronger antennas make the implementation more expensive, as complex hardware and management software is needed. An alternative solution is to make use of many antennas, each handling fewer people (Harris, 2011).

2.2.4 Antenna Power/Gain

Gain is the conversion of signals from electrical waves to radio frequency waves and vice versa. Antenna gain is a technique used to ensure that the best possible conversions are performed. Antenna power gain plays a critical role in communication between different towers, as it can pick up on low or weak cellular network signals in a communication cell (Proxicast, 2013).

High gain antennas have the ability to identify different signals from roaming devices and determine which of the signals are weak. At the same time, high gain towers can improve communication speed and the quality of communication between different towers.

2.2.5 Types of Antennas

Three of the most common antennas used in a cellular network are Yagi, Directional, and Omni-Directional antennas. The Omni-Directional antenna, commonly used in a cellular network, can propagate the signal in a 360-degree radius. A directional antenna only covers a 180-degree radius, with a higher gain, meaning that antennas have stronger and higher quality cellular signal strengths. Yagi antennas only cover 10 degrees making it a weak antenna for mobile communication usage (Proxicast, 2013). The following section covers some of the different types of antennas that can be utilised in a cellular network.

2.2.5.1 Active Antennas

Active antennas utilise improved circuitry and amplification techniques to enhance signal strength for incoming and outgoing frequencies. Active antennas also boost signal strength, allowing for larger coverage areas. Apart from the active antennas' ability to amplify signals, they manage interference at the entrance phase of the signal, for enhanced performance (Reckeweg, 2016).

2.2.5.2 Corner Reflector Antenna

A corner reflector antenna has a layout where two dipoles are formed in a corner, as can be seen in Figure 2.2. This layout has a high gain in the forward direction, with a front to back layout design (Kulkarni, Boisse, Oo & Flanagan, 2005; Patil, Mangalgi, Kamat & Melinmani, 2014).

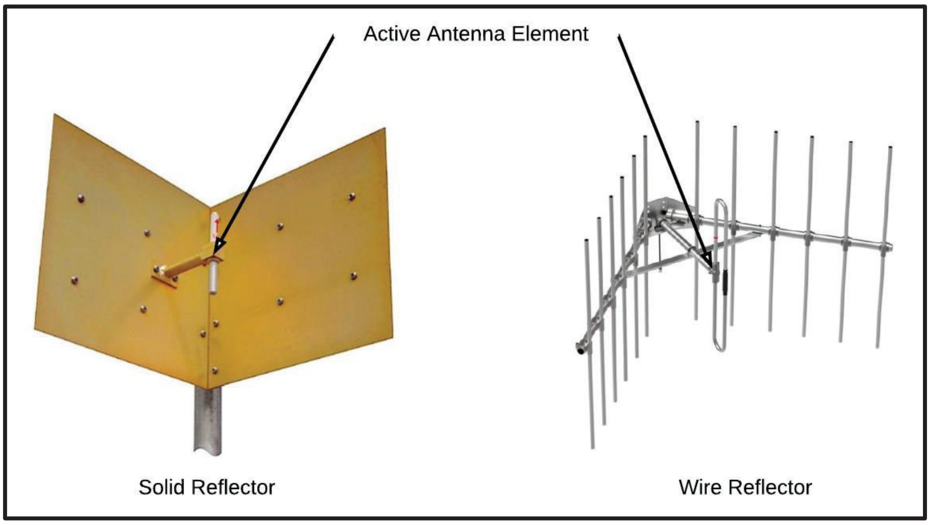


Figure 2.2: Antenna elements

2.2.6 Radio Access Network

Cellular towers are connected utilising a Radio Access Network (RAN). The RAN allows for antennas to communicate in a wireless network infrastructure, and can be seen as a standard for providing digital mobile services (D'oro, Restuccia, Melodia & Palazzo, 2018). The services include a Global System for Mobile Communications (GSM), and Code Division Multiple Access (CDMA). Each communication generation, similar to 3G, 4G, 5G, runs on a different standard (Harris, 2011; Wu, Zhang, Hong & Wen, 2015).

2.2.7 The Wireless Network

Wireless communication networks are highly interconnected, utilising a Wireless Carrier Network (WCN). A WCN is also known as a data centre or a Network Operations Centre (NOC), and is the one central point in a wireless communication network that is used for communication. Communication is done utilising a processing point known as a base station. The base station is connected to the NOC using a physical cable or wireless technologies similar to cellular networks (Harris, 2011). The connection can be seen in Figure 2.3

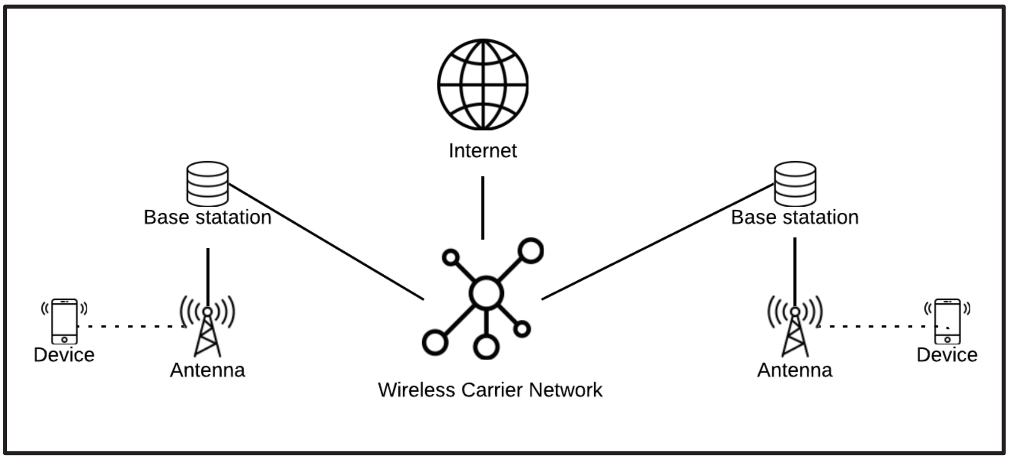


Figure 2.3: Cellular system structure (Harris, 2011)

2.2.8 Remote devices

A remote device is commonly known as a cell phone, but there are many other different remote devices, including routers, televisions, and others. They are known as remote devices because there is no physical connection between the cellular towers and the mobile device. Remote devices are usually not static, meaning that the devices move around in an operational area (Tehrani, Uysal & Yanikomeroglu, 2014). Remote devices can perform many other functions that require connectivity to a cell tower.

Having discussed cellular towers in terms of how they operate to provide service to mobile devices, and some of the hardware that aids in providing service, it is important to look at the communication between antennas.

2.3 Antenna-to-antenna communication

Many aspects influence communication in a communication network. Some issues that need to be considered when looking at the efficiency of a mobile system are the connection channels used, and the techniques used to change from one tower to another. The different aspects that form part of a mobile system are discussed in the following section.

2.3.1 Full duplex

Full duplex communication devices similar to cellular towers are ubiquitous in large distributed communication environments. They act as a commonly used quick reuse method to reduce radio frequency dependencies. Tasks are stacked where one frequency can be used to send data, and the other frequency can be used to receive data. This is useful because both these frequencies can then run at the same time without affecting each other (Ali, Rajatheva & Latva-aho, 2014).

2.3.2 Handoff

The handoff is what happens when a device changes between two different antennas on a cell network. This act can be performed many times over a period. The act of switching between two adjacent antennas can cause the communication links between a tower and a device to drop (Ali, Rajatheva & Latva-aho, 2014). Having discussed some of the aspects that influence communication between antennas, it is important to discuss the techniques that are used to provide mobile devices.

2.4 Services providing techniques

A service is a technique used to provide mobile service to communication networks and the techniques that are employed for handoffs and frequency assigning. Different services are used in mobile communication systems, similar to the Advanced Mobile Phone Service and Narrowband Analog Mobile Phone Service, discussed below.

2.4.1 Advance Mobile Phone Service - AMPS

AMPS is one of the older first-generation implementations, running at a constant frequency band of 700Hz. Apart from the frequency band, its operations are fully automated. It was one of the most common cellular applications that was mainly in service in small cities (Mitra, 2009; Prasad & Manoharan, 2015).

In addition to being one of the earlier implementations, it made use of extensive resource reuse. The most significant difference between modern applications and this implementation is that data usage is extensive, there is no communication privacy for users, and it has a small capacity, meaning that the tower cannot support many users at one time (Mitra, 2009; Prasad & Manoharan, 2015).

2.4.2 Narrowband Analog Mobile Phone Service - NAMPS

NAMPS is an improvement on the first-generation Advanced Mobile Phone Services, making NAMPS the second-generation mobile service that has been implemented and used (Prasad & Manoharan, 2015).

NAMPS attempts to improve on one key point from AMPS by increasing the number of connected and communicating devices to the towers. This solution provides three times more capacity over the first-generation implementation, and an increased range in signal interference (Prasad & Manoharan, 2015).

2.5 Conclusion

Chapter 2 has shown that many different aspects, both hardware and software, make up a cellular network. These aspects include the placement of a cellular tower in a cellular network, and what influence the arrangement has on the network's coverage. Many different types of antennas can form part of a cellular network.

Not all antennas are identical, as they all have different properties and advantages. Some towers can broadcast a frequency 360-degrees around a tower, whereas other towers can only transmit in one single direction. The antennas also manage the coverage area and the number of possible users that communicate with the tower.

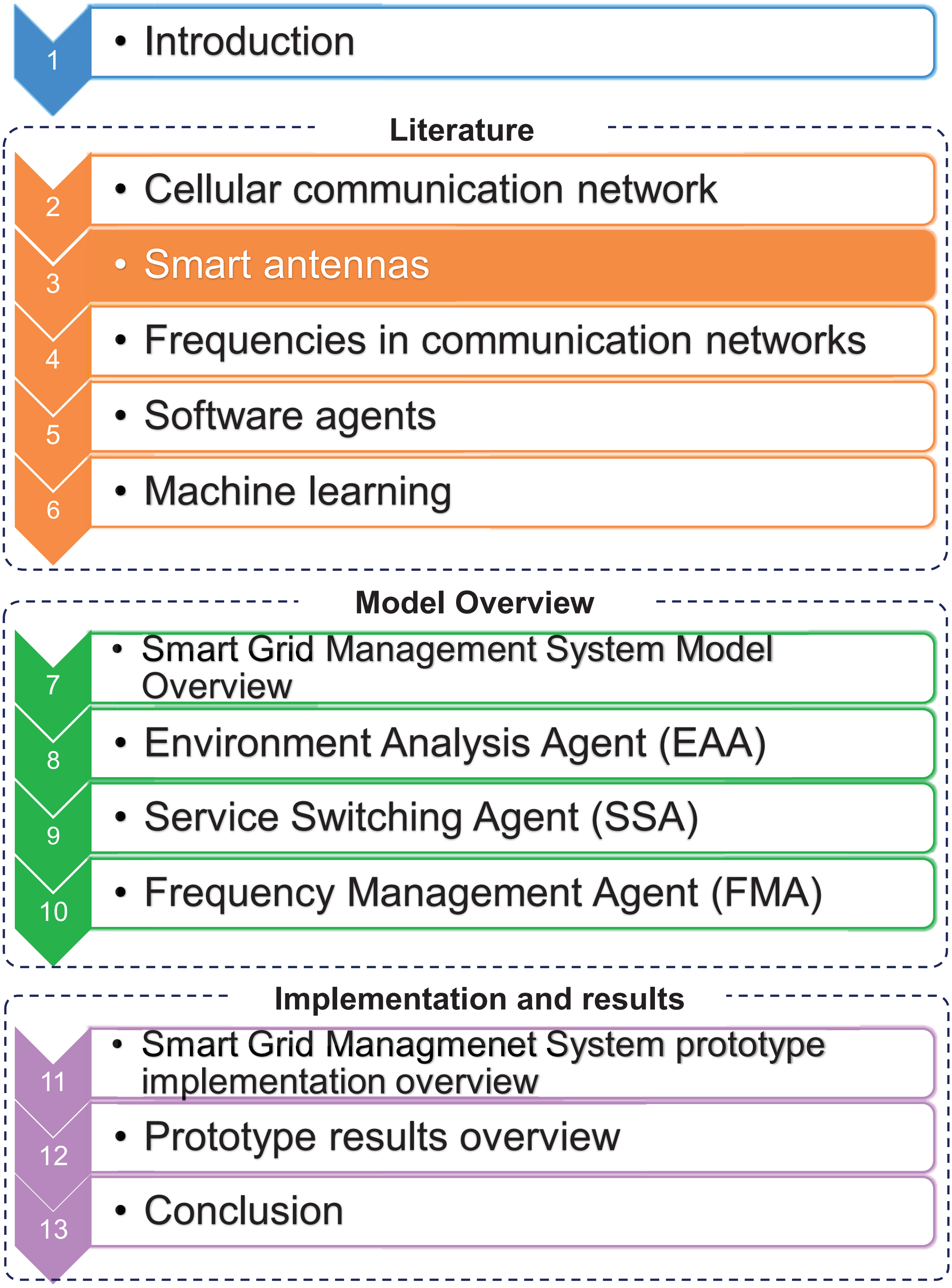
Understanding the different kinds of antennas can help to understand how they can operate in a cellular network. Understanding how antennas work and how the resources are managed in the current implementation of a cellular network, indicates that smart antennas can be integrated in the cellular network.

The research question that Chapter 2 aided in answering is: *How do smart antennas operate in a cellular network?* Before answering how smart antennas operate in a mobile network, the cellular network must first be explored and understood. Chapter 2 aided in the understanding of current cellular networks by breaking existing cellular networks down into different components. The chapter focused on the physical structures that form part of a cellular network specifically pertaining to antennas.

Chapter 2 also explained the different antenna technologies used in cellular communication systems; it described how a mobile network works concerning antenna-to-antenna communication, and explained service providing techniques ranging from AMPS to NAMPS. By focusing on the different components that form part of a cellular network, the objective of identifying the elements that form part of a communication network was achieved.

Chapter 3 focuses on smart antennas. The chapter covers what smart antennas are, how smart antennas operate, some of the advantages of smart antennas, and some of the technologies associated with smart antennas. The chapter focuses on achieving the objective of identifying smart antenna components and operations and provides an understanding of how smart antennas can operate in a cellular network.

Chapter 3 - Smart antennas



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3.1 Introduction

With the current implementation of cellular towers making use of a hexagon design to propagate signals to devices and providing excellent geographic coverage, users are afforded switching technologies between mobile towers. However, it does not mean that this implementation is best for a significant amount of traffic.

The one crucial aspect that can be improved upon in hexagon designed towers is the possibility to minimise power usage and increase the number of supported users. Achieving more users with better power usage is a difficult task that requires a combination of better hardware and better software.

Smart antennas offer a better solution in terms of power usage. Depending on the type of smart antenna that is used in a communication system, a smart antenna does not always continuously cover an area waiting for people to connect to it. Smart antennas can send out a single beam to a user. A smart antenna is not perfect, as some of the signals sent to users can have a lot of interference from other signals bouncing off physical structures in the environment.

To understand if smart antennas are a good hardware solution in communication systems, Chapter 3 focuses on what a smart antenna is, and how a smart antenna works. The chapter also focuses on different smart antenna implementations, and what makes a smart antenna implementation efficient. This chapter intends to show that smart antennas could be a viable technology to focus on as well as how they are implemented in a cellular network.

3.2 Smart Antennas

An antenna alone is quite a simple object that does not offer much use regarding communication or processing power. An antenna system is smart because the antennas communicate with other antennas and remote devices. Smart antennas are used in communication for better performance management and improved power saving. Because of these advantages, smart antenna systems have improved the base for communication (Ding, Zhong, Wing Kwan Ng, Peng, Suraweera, Schober & Poor, 2015).

What makes smart antennas unique, is that they can operate in diverse signal environments, ranging from small towns to whole countries. The smart antenna is diverse because smart antennas cover an area with a beam design instead of a hexagon design. What this means is that an antenna sends out a signal in the direction of a device, similar to an arrow (Stevanović, Skrivervik & Mosig, 2003; Sharma, Sarkar, Maity & Bhattacharya, 2014). Depending on the beam implementation, each beam will manage a single or set of devices, making it efficient.

When comparing a smart antenna to the traditional implementation, a smart antenna is better as it uses a Multiple Input, Multiple Output (MIMO) system. MIMO means that an antenna is part of a broad array of antennas that allow for the transfer of information between two different points (Bliss, Forsythe & Chan, 2005; Li, 2015). It enables devices to communicate with antennas more efficiently.

There are two types of smart antennas that can be used in a mobile network:

- Switched beam systems
- Adaptive beam systems

What both switched beam and adaptive beam systems succeed in doing is to dynamically allow each station (tower) to alter any single beam to suit a device (Mitilineos and Capsalis, 2007; Sharma et al., 2014). In general, each communication system attempts to minimise the amount of noise from outside sources.

Both the switched beam and adaptive beam systems try to connect to remote devices and focus on transmitting radio frequencies and enhancing those frequencies using increased frequency reuse. Additional benefits of smart antennas in comparison to traditional antennas are (Sharma et al., 2014):

- Smart antennas improve signal gain, meaning that there will be better coverage over a broad geographic location by adjusting the power used by each smart antenna.

- Smart antennas minimise interference of the signal or the connection between the roaming device and the antenna using frequency reuse, also known as beam reuse.
- Smart antennas reduce the delay of the communication channel, meaning that there is an opportunity for faster data transfer.
- Smart antennas are much cheaper to run and are considered more reliable than traditional antennas.

Having discussed some aspects relating to smart antennas, it is important to look at one of the problems that can affect smart antenna signals.

3.3 Multipath problem

Smart antenna signals can bounce off solid objects that might include mountains, cars, buildings, and other structures. The multipath problem arises from other signals propagated from smart antennas (Ghosh et al., 2012; Aminu, Secmen & Husein, 2015). Other beams from a smart antenna can bounce off an object towards a device that is already connected to the smart antenna. That device has different beams that want to communicate with the remote device, as can be seen in Figure 3.1.

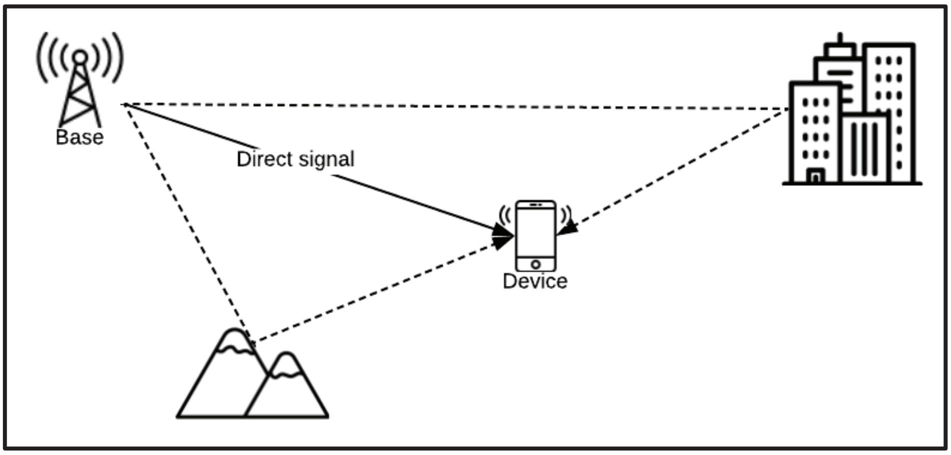

Figure 3.1: Signal disruption (Ghosh et al., 2012)

The meaning of this multipath problem is that the beams that arrive at the roaming device are not the same as what was propagated by the smart antenna. If a signal from the initial point is weaker than a different message, then the weaker signal is the reflective signal (Chavan, Chile & Sawant, 2011). The reflection is also known as fading, where the one signal gets worse.

Another issue that is caused by the multipath problem is phase cancellation, where different signals cancel each other out. It is not possible for non-reflective beams to create a multipath problem (Chavan, Chile & Sawant, 2011) Typically, the desired signal and the reflected signal cancel each other out, meaning that there will not be any connection to the remote device. Having discussed how the multipath problem influences a smart antenna system, it is essential to examine how multiple antennas can be used to send data.

3.4 Multiple Input, Multiple Output - MIMO

The primary goal of MIMO systems is to send and receive data using multiple antennas. MIMO increases the number of possible roaming devices that one antenna can hold. Many communication standards use MIMO, and many MIMO implementations are adapted for newer generation cellular service. One example of an adapted MIMO is Multiple Input, Multiple Output Orthogonal Frequency-division Multiplexing (MIMO-OFDM) (Bliss, Forsythe & Chan, 2005; Li, 2015). Having discussed how antennas can send and receive data, it is essential to examine smart antenna communication links.

3.5 Smart antenna communication links

For a roaming device to connect and communicate with a smart antenna, an uplink and a downlink is needed on the antenna. Uplink refers to the sending of information similar to sending voice packets. Downlink is when a device receives information (Jain, Katiyar & Agrawal, 2011). Uplink beamforming is the action of creating a channel that allows sending of information. Downlink beamforming is the action of creating a channel for receiving information.

3.5.1 Uplink Beamforming

Uplink beamforming is a critical way to identify the channel between an antenna and a device by using radio frequency management techniques. Beamforming functions by shaping a signal to a receiver based on a set of properties such as distance and tower location. Beams can harm performance since it creates a concentrated signal. The concentrated beams have the potential of bouncing off physical structures reaching a receiver, causing the multi-path problem (Sharma et al., 2014). Uplink is sending information to a remote device from an antenna.

3.5.2 Downlink Beamforming

Channel information that is needed to form a downlink makes use of statistical data. To find the best possible beamforming and power-saving link, the power that is provided by the link must be minimised, which will also ensure that no other devices are affected. Since the power is minimized, the link can be affected by the multi-path problem. The signal will be weakened by the multi-path problem not reaching the antenna in some instances (Sharma et al., 2014). Having discussed communication link forming in smart antennas, it is essential to discuss techniques of signal propagation in smart antennas. Having discussed some of the different smart antenna beamforming techniques between devices and antennas, it is essential to discuss how a smart antenna can distribute a signal.

3.6 Smart Antenna Signal Distribution Techniques

Growth in smart antennas has led to different types of antenna beam applications. The most commonly used beam applications are switched beam antennas and adaptive array antennas, with both implementations having their own application style and benefits. The two beam applications are discussed in the following two sections.

3.6.1 Switched Beam Antennas

Switched beam antennas work in a fixed style. Fixed switched beam antennas have a set number of beams that point out a fixed distance from a central point. When a device moves over a single beam, it will connect to the base station via that new beam. The changing of beams is not efficient (Jain, Kaitiyar & Agrawal, 2011; Sharma et al., 2014).

Switched beam systems can be altered by selecting a pattern for the beams (Jain, Kaitiyar & Agrawal, 2011; Sharma et al., 2014). Picking a new pattern will still force the implementation to be static, with no dynamic beam changes. The beam pattern can be altered by changing it when the power usage changes (Stridh, 2003; Sharma et al., 2014). Figure 3.2 shows that the fixed beam antenna has multiple beams pointing out from the antenna in a flower format.

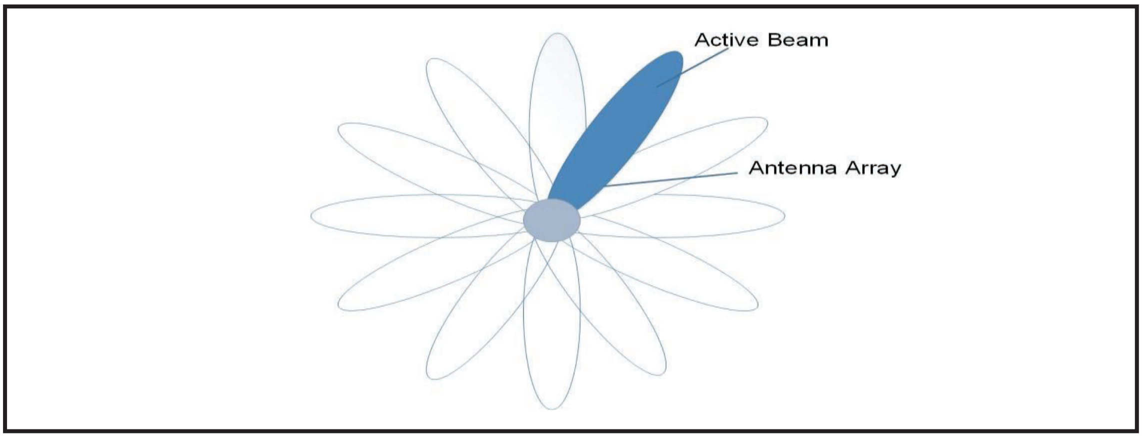

Figure 3.2: Smart antenna beam distribution (Stridh, 2003)

3.6.2 Adaptive Array Antennas

Adaptive array antennas can dynamically find remote devices and connect with a single beam to that device. At the same time, adaptive array antennas prevent other beams from interfering. The adaptive array implementation has the responsibility of ensuring stable communication to devices (Stridh, 2003; Sharma et al., 2014).

What makes the adaptive antenna unique is that from a broad range of signals, the algorithm can smoothly identify one single device that requires connection. Similar to the switched beam antenna, this antenna can perform tasks with the least amount of interference (Stridh, 2003; Sharma et al., 2014).

Figure 3.3 shows the layout of the adaptive array antenna. The target device is the connected device, and the interfering user is merely a user that is not connected but has an influence on the array.

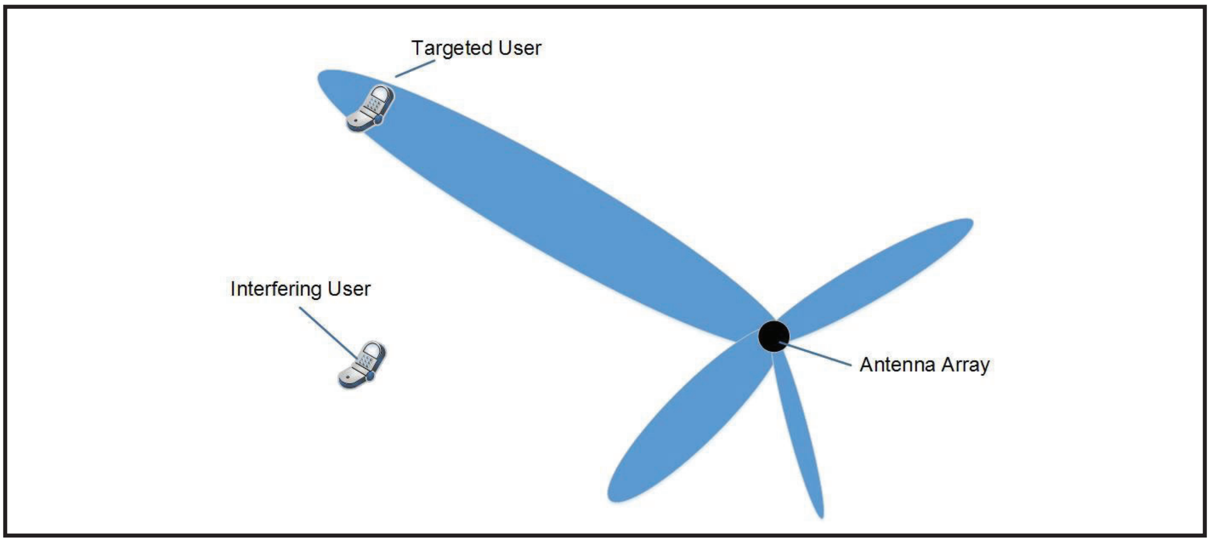

Figure 3.3: Adaptive smart antenna beams (Stridh, 2003)

The adaptive array antenna approach makes use of technology that minimises interference by using dynamically altering signal patterns. It is not a hardware-based technology but instead focuses on an intelligent algorithm. The algorithm can recognise different devices that need to connect to the antennas, as well as identify multiple paths that aid in increasing performance. This approach leads to smooth remote device tracking (Panahi, Eshtiaghi & Zarabi, 2005; Patra, 2015). Having discussed the two smart antenna frequency distribution techniques, it is important to discuss the benefits of smart antennas.

3.7 Benefits of smart antennas

Integrating switched beams antennas is slightly more straightforward than adaptive array antenna systems, allowing for less hardware redundancy. The switched beams system addresses the needs of mature networks as well (Panahi, Eshtiaghi & Zarabi, 2005; Renukadas, 2016).

Switched beam antenna systems have 20% to 200% range increase, but this is dependent on the base station software used and the hardware. Adaptive arrays antenna systems can have the same coverage as switched beam antenna systems, and can also have a broader area (Panahi, Eshtiaghi & Zarabi, 2005; Renukadas, 2016).

Because switched beams antenna systems have fixed beams, there is expected interference, whereas with adaptive array antenna systems there is less interference, forcing switched beam antenna systems to suppress interference more. Figure 3.4 shows their effects of interreference on individual antennas. Adaptive array antenna systems tend to perform better than switched beam antenna systems, as they offer a finite number of combinations (Panahi, Eshtiaghi & Zarabi, 2005; Renukadas, 2016).

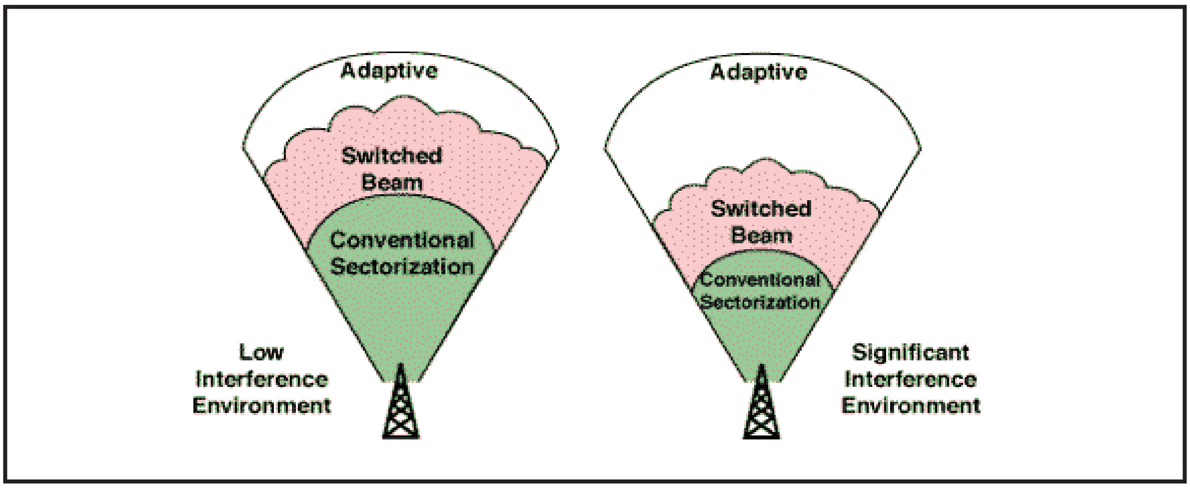

Figure 3.4: Environment interference (Panahi, Eshtiaghi & Zarabi, 2005)

3.8 Space Division Multiple Access - SDMA

Space Division Multiple Access (SDMA) is a relatively new access technology that is used with smart antenna systems relating to mobile communication, that improves the performance of communication channels and focuses on channel access (Hartmann, 2003; Chen & Haas, 2015).

A single large message, commonly known as a package, cannot be sent over a network. The package must be broken down into smaller packets that are transmitted to a receiver, only to be reassembled by the receiver. SDMA allows for the transfer of packets to a receiving node, with no collisions (Bana & Varaiya, 2001; Chen & Haas, 2015).

SDMA allows tracking of mobile terminals by utilising intelligent processing techniques. Other than this intelligent processing, it also has a significant effect on interference from sources that can influence the communication between terminals and devices. SDMA impacts the interference by adaptive steering of signals from the terminal. The SDMA system must take advantage of the smart antenna to separate the various signals (Cheng, Jiang, Jin & Huang, 2015). Typically, a traditional communication system has a problem with frequencies, whereas SDMA allows for multiple nodes or endpoints to operate on the same frequency (Cheng et al., 2015).

From a general viewpoint, newer applications of SDMA systems make use of a slicing technique for beams, where each beam in the system has one device with the same frequency. Use of the same frequency still allows for excellent performance because of reduced resources (Singh, 2013).

3.9 Conclusion

Based on the content of this chapter, smart antennas can cover an area with minimal power usage and hardware dependency with conventional antennas, allowing for more substantial area coverage. Aspects that influence the performance and effectiveness are dependent on the various techniques used to distribute the radio frequencies.

Smart antennas have a broader range to cover by using different coverage techniques. Switched beam antennas cover an area at a constant rate with high power usage, whereas adaptive array antennas only connect to a device that needs connection. Per device, connection means that smart antennas are more efficient concerning power usage.

Making use of smart antennas means that there are some advantages, but also some disadvantages. Chapter 3 showed that signal disruption is caused by antenna signals being reflected off a physical structure, which could interrupt connections. Signals reflected off physical structures are known as the multipath problem, which allows two different signal beams to converge on the same device. The device is usually smart enough to know that the beam with the best signal is the one to use.

Chapter 3 focused on how smart antennas aided in answering the research question: *How do smart antennas operate in a cellular network?* Understanding what a smart antenna is, how a smart antenna operates concerning providing communication to devices, what the advantages are of smart antennas, and some of the problems with smart antennas, helped to form a better understanding of smart antennas.

Chapter 3 showed that smart antennas can be used in a cellular network by making use of smart antennas on cellular towers instead of using directional antennas that provide a hexagon coverage area. The purpose of smart antennas in a cellular network forms a smart antenna grid that allows for communication between antennas and devices.

Because all antennas make use of frequencies to provide a medium of communication, Chapter 4 focuses on frequencies by concentrating on what frequencies are, some of the technologies that manage frequencies, how frequencies form part of the current cellular implementation, and some of the techniques used to manage frequencies.

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4.1 Introduction

One fact that can be relied upon in the current implementation of cellular networks is that all mobile towers contain a set of antennas that enable users to communicate with each other. The technology used to connect to the antennas is implemented by using the frequencies that the antennas provide.

Frequencies are a widely used technology that can be used to perform tasks other than providing mobile communication networks with a method of communication. They are used by walkie-talkies to communicate, and by radio stations to broadcast.

A critical aspect is that mobile devices do not interfere with other technologies that make use of frequencies since interference can degrade or stop functionality that is provided by other technologies. Interference is also known as noise. Radio frequencies are a limited commodity and only a specific band width of frequencies are available to network operations. Thus, management techniques are required to ensure that available frequencies are managed efficiently. Many implementations have been used over the years to manage frequencies.

One of the techniques introduced to manage frequencies was to provide licences to organisations that own or make use of frequencies. This licensing system is intended to ensure higher quality frequencies and is used by government organisations across the world.

In the current mobile communication network, different generations of services are provided. The intention of these different generations is to offer more people faster and better connection, which is achievable through changing how frequencies are handled.

Chapter 4 describes radio frequencies and how they work. The chapter outlines the different ways used to consume radio frequencies, and the different techniques used to manage frequencies in terms of software and government organisations. The chapter also focuses on how mobile implementations make use of radio frequencies, and how they have evolved.

4.2 Frequencies

Radio frequencies are critical in smart antennas as they enable device-to-antenna connections. Radio frequencies have many different advantages and many different properties that influence frequencies (Hallock, Deshpande, Saville & Chastain, 2015). Some of the properties are discussed in the following sections.

4.2.1 Radio Frequencies

Radio frequencies is a pervasive communication technology that is relatively new to the modern world. Radio frequencies is one of the most common data transfer or data exchange techniques used in radio and cellular communication antennas (Hallock et al., 2015).

4.2.2 Radio

Sending data and receiving data are common aspects of radios. For sending and receiving, there is a requirement for a destination and a source (Hallock et al., 2015). In computer terminology, the user of a device is the source, and the computer is the destination of the communication.

4.2.3 The Basics

The creation of radio signals and the transmission and receipt of radio frequencies are two of the main concerns. Sending and receiving radio frequencies requires advanced hardware that can handle transmitted frequency signals. These radio frequencies are part of an electromagnetic spectrum, which is discussed in the following section (Hallock et al., 2015). Having discussed some of the properties that influence frequencies, it is important to discuss different electromagnetic spectrums.

4.3 Electromagnetic Spectrum

Frequencies are divided into different wavelengths that can range from as low as 1 hertz. The range of frequencies is known as the electromagnetic range (Stoehr, 2013). Radio frequencies are primarily electromagnetic systems that include TV and radio frequencies.

Low frequency waves are normally air pressure waves that the human eye cannot see. Air pressure waves are characteristics of low frequencies. The high-frequency waves are normally light that the human eye can see (Hallock et al., 2015).

Sound waves or controlled waves are formed by controlling the change of electrical strength that is sent over a short time. Electrical signals recursively grow to a maximum and shrink to a minimum over time (Broky & Zarka, 2014). The time that this signal takes to go through one entire cycle of minimum to maximum is known as the Hertz.

Figure 4.1 demonstrates the different radio frequency bands that propagate signals by using air waves to send out signals. It shows that from 1kHz to 100GHz the signal propagates air, whereas after 100GHz, the frequency propagates infrared. After infrared propagation, visible light is formed.

This electromagnetic signal that is propagated can have a significant effect on the ability of communications, and at the same time, many different implementations and types of hertz can be used, as seen in Table 4.1.

It is critical to comprehend how frequencies have relevance to Smart antennas in communication networks. Radio frequencies are always dependent on different types of antennas and the way in which the antennas are set up (Hill, 2007; Oluwole & Srivastava, 2015).

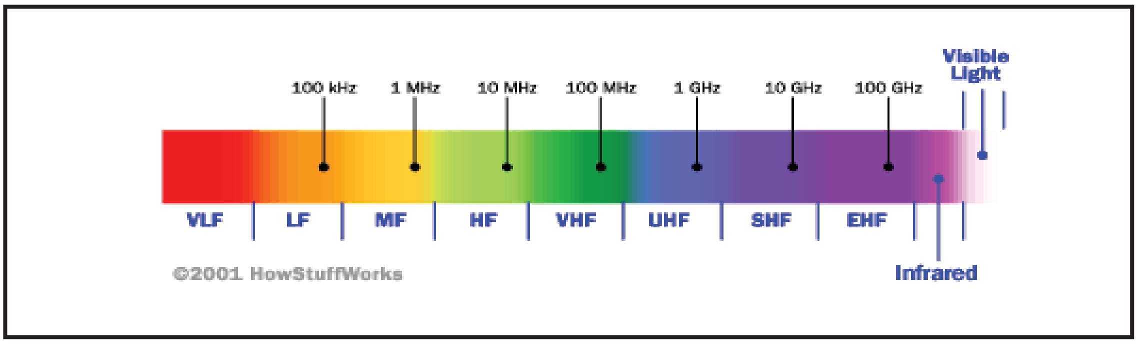


Figure 4.1: Frequency ranges

4.3.1 Radio Frequency Dependency

Radio frequencies are dependent on various factors that determine the positioning of antennas and the type of antennas that are used. The four factors that affect radio frequency are the used antenna type, the antenna height, antenna tilt and the power (Nguyen, Medbo, Peter, Karttunen, Haneda, Bamba, D'Errico, Iqbal, Diakhate & Conrat, 2018).

4.3.2 Radio Spectrums

Without any radio frequencies, there would be fewer communication channels. There would also not be any Wi-Fi, as Wi-Fi operates using radio frequency (Stine & Portigal, 2004; Davies, 2015). The number of devices that communicate via radio frequencies possibly increased more than ten times between 2014 and 2019. What this means, is that radio frequencies are adequate for significant amounts of traffic (Stine & Portigal, 2004; Davies, 2015). Radio waves are only one part of an electromagnetic spectrum; other items that are part of the electromagnetic waves include x-ray waves, light, and infrared waves.

4.3.3 Measuring Spectrums

Different types of electromagnetic fields have vastly different implementations and frequency fields. Radio and ultraviolet frequencies run on different bands in comparison to other frequency applications. Higher frequency offers different propagation techniques.

The different frequency waves are:
•KHz (kilohertz) is a thousand waves per second
•MHz (megahertz) is a million waves per second
•GHz (gigahertz) is a billion waves per second.

Wireless communication runs in a frequency band of gigahertz known as a spectrum, where frequency can be used for the wireless to transfer information (Davies, 2015). A limited amount of data can be transferred on 87.5 – 108 MHz frequency band, with broader frequencies allowing more data transfer.

Mobile devices mostly use high-frequency bands for communication to allow for more data propagation. Mobile devices also work with lower band frequencies (GSMA, 2016). Making use of higher frequency towers for mobile communication is considered advantageous as they can accommodate more connected devices. The increase in connection accommodation makes higher frequencies more suited for highly populated areas (Lie, Kelly & Goodrick, 2004; Davies, 2015). Having discussed some of the different electromagnetic spectrums, it is important to discuss how spectrums can be managed.

4.4 How are spectrums used and managed?

Governments usually take responsibility for managing radio frequencies and setting out ground rules. They generally follow International Communication Laws which means that they adapt to international standards to ensure that costs decrease over time.

4.4.1 Licensed Spectrums

The primary goal of the government licensing authority is to provide licensing to individuals or companies for a frequency range. Licences are a tool to ensure that users take responsibility for their actions on the network and to ensure the quality of service (Benkler, 2012; Zhou, Guo & Honig, 2017). There are possible penalties for non-licence holders that attempt to use registered frequencies.

4.4.2 Unlicensed Frequencies

Unlicensed frequencies are also very common. With no licensing, there is still a requirement to follow standards. The most common devices that make use of unlicensed frequencies are Wi-Fi and Bluetooth frequencies. One reason why these frequencies are unlicensed is that they generally cover a small area, meaning that there is no guarantee of quality, whereas a licensed frequency offers higher quality (GSMA, 2016; Zhou, Guo & Honig, 2017). Having discussed how spectrums are used and managed, it is important to discuss the various mobile networks.

4.5 Mobile networks

Different services similar to Internet services tend to run on different frequencies, and the frequencies are licensed to provide the best possible spread and service. Some of the best known are 1G, 2G, 3G, 4G and 5G networks, with each G referencing the generation of the network. Each generation handles frequencies using different management techniques and different network speeds (Qualcomm, 2014). The system focuses on the communication and communication speeds. The following section briefly discusses these systems.

4.5.1 1G Network

Five years after the first mobile device was created, 1G was announced and put into use for mobile devices. 1G networks did not constantly operate on the same frequency, but were rather split into different frequencies. The reason for this splitting was that at the time the mobile network load was not under high command, which meant there was a smaller area coverage of mobile network antennas (Balapuwaduge & Li, 2018; Qualcomm, 2014).

The set of frequencies used by a 1G network are:

- AMPS: Advanced Mobile Phone System making use of 800MHz
- NMTS: Nordic Telecommunication System using 450 MHz to 900MHz
- TACS: Total Access Communications using 900MHz

The above-mentioned three frequencies used by 1G networks are not utilised by the other networks that are discussed.

4.5.2 2G Networks

With the introduction of 2G networks in the 1990s, more devices could connect in comparison to 1G network implementations. 2G networks were the first to make use of binary code, meaning that the data was transmitted using zeros and ones. Binary code promotes data encryption and allows for some advanced compression on data. The compression of data size and increased security enabled 2G to send more data on a cellular network (Balapuwaduge & Li, 2018; Qualcomm, 2014).

Some 2G networks use the Global System for Mobile communication (GSM) to enable systems to run on the same static frequency to support several different users on the same frequencies, which allowed for equipment reuse. Initially, 2G systems were intended for voice communication, but were adapted for other data streams similar to messages. 2G GSM networks have many different frequency bands available to utilise, including 900MHz, 1800MHz, 850MHz and 1900MHz frequency bands (Pereira, Sousa, Mendes & Monteiro, 2004).

4.5.3 3G networks

3G networks were introduced in the early 2000s and were run on Code-division Multiple Access (CDMA) networks that operate differently from the 2G network in terms of frequency usage. 2G systems mainly run on a single frequency to allow a service similar to a voice or data service. The 3G network was a slight improvement, where the different functions similar to voice or messages were split up to run on different frequencies, making frequency management simpler (Qualcomm, 2014).

These 3G networks run on static bands, 800MHz, 850MHz, 900MHz, 1800MHz, where data runs on one of the bandwidths and voice runs on another band. Splitting frequencies for different functions allows for better data transmission speeds and for more users to utilise the frequencies (Pereira et al., 2004). 3G networks are still used in cellular networks.

4.5.4 4G Networks

Instead of having a frequency per feature, 4G networks are responsible for wireless broadband sending and receiving data on frequencies. Older devices still require 2G and 3G networks, meaning that frequencies similar to 850Hz are needed. The usage of all the different frequencies means that frequencies are running out, raising the requirement for a broader spectrum to allow more users to connect to the network. (Jain, V., Jain, S., Kurup & Gawade, 2014).

4.5.5 5G Networks

The 5G network is the latest generation that has the primary objective of providing faster communication to users. It also provides the ability for handling higher broadband and supports almost 65 000 connections (Gohil, Modi & Patel, 2013). 5G networks are a vast improvement over 4G networks, whilst still using some of the same architecture as 4G networks.

5G networks operate on Orthogonal frequency-division multiplexing (OFDM). OFDM makes use of a single data stream to send and receive large amounts of data at the same time. The way the data is transferred over a single frequency is by splitting a frequency into various smaller sub-signals (Patil, Wankhade, Mumbai, Sapgaon & Dist-Thane, 2015).

4.5.6 Heterogeneous Networks

Most mobile users are located over vast geographic areas. These vast areas can be covered by utilising a single 3G or 4G tower, which is not very efficient. Heterogeneous networks improve on this concept by deploying multiple networks that include 1G, 2G, 3G, 4G and 5G networks on the same tower (Chowdhury, Rahman, Muntean, Trinh & Cano, 2019). Not all mobile towers should operate as heterogeneous networks as most cell towers operate in a microcell, meaning that the size of the cell is smaller and handles fewer users on one tower. With fewer connecting users, the tower provides better service. Heterogeneous networks' implementation within smaller cells can include more users on a single mast, and provides better performance (Jain et al., 2014). Having discussed some of the types of mobile networks that are operational in public, it is important to discuss how frequencies can be reused.

4.6 Frequency Usage Optimisation

Frequencies are a limited resource that should be managed to ensure that many different users can use a frequency simultaneously. Some of the techniques to optimise frequency usage in a cellular network are mentioned in the following section.

4.6.1 Frequency Reuse

Frequencies do not have an infinite band to communicate, thus frequencies have to be reused to extend the lifespan. This can be done by reducing the number of possible people that are on a single frequency at the same time (Stine & Portigal, 2004; Hindia, Khanam, Reza, Ghaleb & Latef, 2015).

Cellular service providers attempt to configure each cell differently, mainly focusing on setting up the frequencies differently. Problems on a single cell can become more apparent where the cellular communication network becomes busy and most of the frequencies are under pressure. Utilising directional antennas is the technique used by mobile service providers to reuse and reduce frequencies (Harris, 2011).

4.6.2 Frequency Borrowing

Because cellular service providers usually have overcrowded antennas, the antennas must kick off several users to allow other users to have space. To ensure that fewer people are kicked from the frequency, an antenna will borrow frequencies from other antennas. This means that one antenna copies another antenna's frequency, and lets devices connect (Mani & Lai, 2002).

4.7 Frequency utilisation in cellular networks

A device such as a mobile phone utilises a frequency to ensure that the device has communication. A phone searches for a cellular tower on start-up using radio frequencies, but most service providers run on different frequencies to provide a service. The device will connect to a frequency with which it is familiar. Once the instrument is connected, there should be a way to jump between different towers when moving. If there are no frequencies to connect to, then the device has no connection available (Davies, 2015).

The phone and the connected channel which has both an up link and downlink frequency must have the same System Identification Code (SID) in order to connect. If the two devices do not have the same SID, then the device cannot connect to the frequency. The SID is almost similar to a community that a service provider and a device have. Once the device is connected, the device can be used for communication via voice or data. If the device's signal starts diminishing, then the antenna will notice that the device is moving away. The device will then search for a stronger frequency by checking all other available frequencies to which the SID matches (Davies, 2015).

4.8 Conclusion

Frequencies are an essential aspect of a mobile network, as mobile devices utilise frequencies to communicate with antennas. Frequencies are split into different bands, where each band can be used to perform specific actions. The various mobile networks usually run on a licensed spectrum.

A frequency is licensed to make global management of frequencies easier. These licensed spectrums use static frequencies for communication. The static frequencies are reused in mobile networks that include 1G, 2G, 3G, 4G and 5G. These networks use static frequencies that are managed differently according to their generation, using frequency reuse or frequency borrowing.

Since smart antennas utilise frequencies for communication purposes, understanding how frequencies operate reveals where weaknesses lie within communication networks. One of the most common weaknesses of frequencies is their minimal number of available frequency bands that can be used for communication in cellular networks.

This chapter has answered the research question: *How do smart antennas operate in cellular networks?* by clarifying how frequencies are managed in current generations of cellular networks. Understanding how the frequencies are integrated and managed defines how frequencies operate in a smart antenna grid. Frequencies are one of the critical resources that have to be controlled by a multi-agent system, and because of the set number of frequencies available, an understanding how they are currently handled was facilitated.

Most of the objectives set out in Chapter 1 focused on whether the multi-agent system can be used to manage resources. The following Chapter 5 focuses on defining a software agent, the different kinds of software agents, and the multi-agent system. It thus deals with some of the study's objectives while focusing on the research questions in Chapter 1.

Chapter 5 - Software agents

1. Introduction

Literature

2. Cellular communication network
3. Smart antennas
4. Frequencies in communication networks
5. **Software agents**
6. Machine learning

Model Overview

7. Smart Grid Management System Model Overview
8. Environment Analysis Agent (EAA)
9. Service Switching Agent (SSA)
10. Frequency Management Agent (FMA)

Implementation and results

11. Smart Grid Management System prototype implementation overview
12. Prototype results overview
13. Conclusion

5.1 Introduction

As humans, we all make decisions daily that might have a profound effect on many different aspects of our lives. Most of the time we make decisions without thinking about what the impact might be. Making choices is a natural instinct. However, getting computer software to react like a human is a tricky process.

A core problem that existed many years ago when computers first came into circulation was the problem that software was not considered to be intelligent, since decisions were based only on a set of predefined rules or based on user interactions. This is not the case with many of the software packages that are created for today's users.

Many software systems now implemented do not make use of an agent to make decisions as they do not have a requirement to do so; however, there has been a significant surge of applications that make use of software agents to make decisions. There is a high possibility that individuals making use of software today have some sort of software agent integrated to solve problems. Google assistant and Siri are two popular virtual personal assistants that make use of agents (Knote, Janson, Eigenbrod & Söllner, 2018).

Agents do not always have to solve large and complex problems alone. Software agents can work together to address issues. The way that this can be performed is by making use of multi-agent systems, where different agents are used together to make decisions by sharing information.

In this chapter, focus is placed on defining software agents and the different types of software agents. Multi-agent systems and all their different implementations are explained. How they operate and their requirements to achieve a goal are examined. This chapter sets out to prove that multi-agent systems can be used in smart antenna grids to make decisions based on the environment in which the software agent operates.

5.2 Concepts related to agents

Agents are made up of different components with each component providing a unique feature that aids in reaching a common goal.

Some of the essential concepts that relate to agents are (Russell, Norvig & Davis, 2010):

- *Environment*: the problem domain within which the agent operates.
- *Sensors*: the physical or virtual points in an environment that are used to gather information.
- *Agent*: an independent and autonomous piece of software.
- *Actions*: a set of operations that are sent through to the environment from the agent to reach some result.
- *Effectors*: is used to carry out actions.

5.3 Software Agents

'Agent' is a widely used term in information technology. Even though most people consider that an agent is mainly concerned with artificial intelligence, agents are also involved in computer science. An agent in information technology is a broadly used term that can have many meanings, depending on where or how it is used.

Because there is no universal definition of an agent, agents have been described in many different ways over the years. There is a good deal of ongoing debate on the term. One conclusion reached by all the discussions is that autonomy is an essential part of agents (Russell, Norvig & Davis, 2010).

Even though there is much controversy around the term agent, Jennings and Wooldridge (1998) stated that an agent is a computer system situated in some environment that is capable of some autonomous action to meet a set objective. This statement is focused on agents and not intelligent agents, and the environment of the agent is not specified in the declaration (Mostafa, Mustapha, Onn & Mohammed, 2017).

Figure 5.1 shows the underlying framework of an agent regarding the flow of an agent, and that an agent takes sensor input that comes from the environment. Thereafter, some computation sends actions that must be performed in the background to the environment (Wooldridge & Rao, 2011; Mostafa et al., 2017). An agent has some control over the environment by sending actions to the environment.

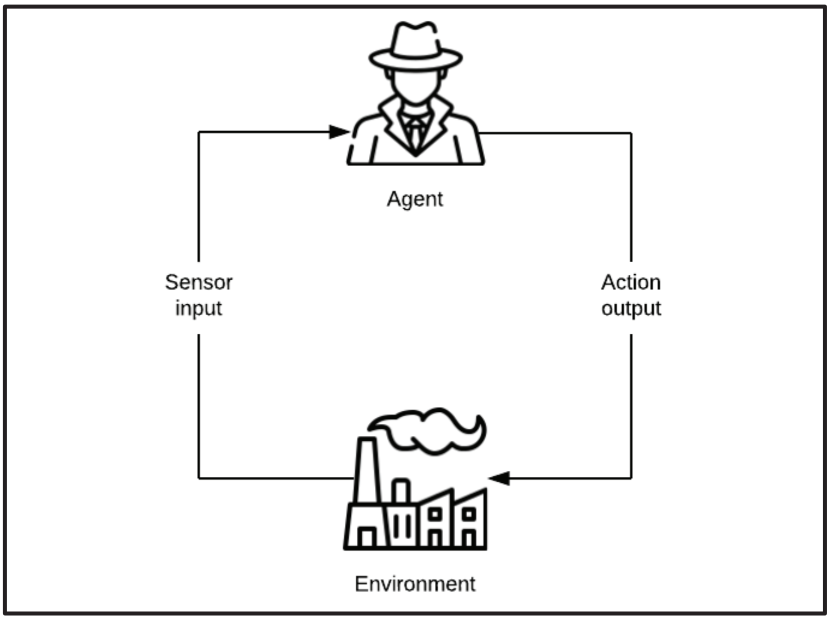


Figure 5.1: Agent structure (Adapted from: Wooldridge, 2012)

The cycle seen in Figure 5.1 is a continuous cycle of information, which means that there is continuous data transfer in the hope that the action output allows for success. Sometimes failure is a possibility, the most significant effect of failure being felt by the environment. Agents have the simple problem of deciding what actions to perform as the actions that are executed in the environment determine if the environment is successful or a failure (Wooldridge & Rao, 2011; Mostafa et al., 2017).

5.4 Environmental Properties

An environment is an important aspect to an agent as it has a big influence on an agent. Since environmental properties are one of the primary factors that influence the success or failure of an agent's actions, some focus on the different components that make up an environment. The following section focuses on the different environmental properties.

5.4.1 Accessible vs Inaccessible

An agent needs full access to an environment. If an agent does not have full access to an environment, then the agent is able to have valuable influence on the environment, as the agent depends on environmental information. When an agent does not have full access to the environment the results of the environment will be flawed, thus the agent is not enabled to reach its goal (Russell, Norvig & Davis, 2010; Rovatsos, 2016). Software simulations that contain agents normally do not have the same problems with agent- to-environment communication as physical environments.

5.4.2 Deterministic vs. Non-deterministic

A non-deterministic property in an agent is one that has some degree of randomness when it comes to an environment’s actions. A deterministic property is one where the actions determine the outcome (Russell, Norvig & Davis, 2010; Rovatsos, 2016). In a deterministic property an action has a single guaranteed result similar to moving a chess piece, whereas non-deterministic properties do not.

5.4.3 Episodic vs. Non-episodic

An episodic property is when an agent’s performance is split into different tasks with all tasks being independent and the agent not having any memory of past actions that were performed in the environment. The actions performed are actions with only the latest information being relevant. A non-episodic environment, also known as a sequential environment, is one where there is knowledge of the previous actions performed. Previous actions have an influence on the future actions of the agent in the environment (Russell, Norvig & Davis, 2010; Rovatsos, 2016).

5.4.4 Static vs. Dynamic

A static environment is not one that cannot change. It is when an agent controls a change in the environment, similar to voice analysis. Dynamic environments don't operate on their own. There are other actions from external sources that influence the environmental data (Russell, Norvig & Davis, 2010; Rovatsos, 2016). Having discussed some of the environmental properties that influence an agent, it is important to discuss rational agents.

5.5 Rational Agents

An agent should perform the action that has the most success. How and when to analyse the performance of an agent is one problem that should be considered (Russell, Norvig and Davis, 2010). A performance measure is used to determine the success of an agent. This measure is not a set measure that can be employed by all the different agents, but is an actual measuring technique.

The timing of when the performance is measured is crucial. If the performance measurement is executed early in an experiment, there will not be enough information to make judgements. In some instances, performance measurements are made throughout the environment's execution. The amount of time taken to execute a performance measurement is dependent on the environment (Russell, Norvig & Davis, 2010).

A rational agent is an agent that makes decisions. An example of a rational agent is a person who makes decisions based on environmental inputs. The following section outlines the different aspects that form a rational agent.

5.5.1 Autonomy

The most important part of a rational agent is its built-in logic. An agent can be autonomous when it makes use of its built-in logic and the dynamic information that is received from the environment to make decisions (Russell, Norvig & Davis, 2010). An agent's success is highly dependent on the results that it achieves in an environment.

The only way that an agent can have a successful influence on an environment is if a set of predefined assumptions holds. When an assumption is violated, unsuccessful behaviour will preside. A genuinely autonomous agent should be successful in any environment if it has enough time to collect information from that environment, adapt to that environment, and to send actions to the environment to be performed (Russell, Norvig & Davis, 2010).

5.5.2 Classification of Software Agents

Many different software agents are used to perform various functions. Each one of the agent types is unique, and each one has a different set of individual properties. These properties are used to determine which type to use to solve a problem (Mahmoud, 2000; Endara & de Lucena, 2015). The following section focuses on the different types of agents

5.5.2.1 Interface Agents

Interface agents focus on learning and autonomous aspects. Interface agents are intelligent as they are capable of learning helpful shortcuts to perform actions. The interface agent makes use of findings from observations by the agent (Mahmoud, 2000; Endara & de Lucena, 2015).

The interface agent learns by:

- observing users;
- receiving feedback from users;
- getting instructions from users; and
- asking for advice from agents.

The agent is dependent on the results that are generated by the observations and instructions that are performed.

5.5.2.2 Collaborative Agents

The collaborative agent’s primary goal is to solve common problems that exist between different agents. The main aim is to connect different agents to solve problems. The collaborative agent works best in a highly distributed environment (Jawahar & Nirmala, 2015).

5.5.2.3 Information Agents

The primary objective of information agents is to manage and control information on the Internet. The need for information agents was raised when a significant amount of data was sent over the web and a need arose for tools to manage the information (Singh, Gulati & Niranjan, 2012).

5.5.2.4 Reactive Agents

Reactive agents use environmental events to determine actions for agents to execute. Using environmental data to make decisions forces reactive agents to react at a fast pace in order to have up-to-date information (Fox & Tishby, 2015).

Some problems exist in reactive agents:

- The agent leads the environment to perform some functionality based on observations that are made by the agent.
- Reactive agents only respond to some sets of sensors and calculations, meaning that the agents will react when something happens in the environment.
- Their operation is mostly performed with raw data.

5.5.2.5 Hybrid Agents

A hybrid agent has properties of different agent types that is used to solve complex problems. The main reason for using a hybrid agent is to have a mix of attributes and capabilities to solve a problem, meaning that the agent will be capable of performing better in some situations (Tarimoradi, Zarandi & Türkşen, 2014).

5.5.2.6 Continuous Agents

As the name suggests, a continuous agent runs continuously to address an issue. When a continuous agent executes, there are situations where the agent can go to sleep, usually while in a transaction (Mahmoud, 2000; Luo & Saigal, 2017). Saving the state in a continuous agent for when something fails or goes wrong, allows the agent to continue at the last saved state (Mahmoud, 2000; Luo & Saigal, 2017).

All the above-mentioned different agents have specific use cases that can be utilised, with each agent having its own set of advantages and disadvantages. Some of the mentioned agents are perfect for being utilised in distributed environments, whereas other agents are better utilised in environments that require action based on some action that was performed.

5.6 Intelligent Agents

An intelligent agent or an abstract intelligent agent is one that attempts to meet objectives set by a creator performing flexible actions. An agent can be considered intelligent when it is able to make decisions relatively proactively, and with a social ability (Wooldridge, 2012).

5.6.1 What makes an agent intelligent?

To classify an agent as intelligent, the agent should be (Jennings & Wooldridge, 1998):

- Responsive: for an agent to be intelligent it must be able to provide actions to the environment in a timely fashion, and the environment must act promptly.
- Proactive: agents should take some initiative regarding operations that must still be performed.
- Social: agents should be able to interact with other agents that operate in the same environment, as interaction will provide better and up-to-date data. Other agents' actions could also steer an agent's actions.

5.6.2 Structure of Intelligent Agents

There should be a good understanding of the actions that must be performed in the environment, as well as an understanding of the performance requirements, before an intelligent agent can be created.

The agent's domain can have a vast array of possible actions that can be performed. An agent that controls a simulator can have a broad variety of actions that it can perform. The agent operates in a productive environment (Elmahalawy, 2015).

In the early 1990s it was found that environments blur the distinction that exists between real life and artificial life. The agent should choose the action, but the agent is not aware of shortcomings. The environment can contain an item that cannot be physically possible (Russell, Norvig & Davis, 2010). Having discussed the structure of intelligent agents and what makes an agent intelligent, it is important to discuss some types of intelligent agents.

5.7 Classes of Intelligent Agents

There are many different intelligent agents, each one suited to different environments because intelligent agents are a comprehensive concept that can be applied to many things. One could split up different agents into different classes, based on the agent's degree of intelligence.

The various types of intelligent agents that are covered in the following section are:

- Simple Reflex Agents
- Goal-based Agents
- Utility-based Agents
- Learning Agents

5.7.1 Simple Reflex Agents

Simple reflex agents are the most basic form of intelligent agent. Simple reflex agents operate on the concept of:

"If … then …"

Russell, Norvig and Davis (2010) compare the simple reflex agent to human actions, with a perceived requirement and conceived action that is performed. The environment will provide the percepts. The agent will then use the rules to ensure the condition is met. The situation that must be met can either be straightforward, or it can be a complicated list of conditions with many different consequences (Galba, Solic & Lukic, 2015).

This model is not ideal for all problem domains as it is limited to make an intelligent decision based on some matrix, with possible perceptions and actions making this a rule-based solution.

5.7.2 Goal-based Agents

Goal-based agents expand upon Simple Reflex Agents as simple reflex-based agents are not always the answer to solving any problem. The knowledge that is available to the agent is crucial, as it leads the agent to the best results. Sometimes the agent requires information that relates to the goal of an environment (Golpayegani & Clarke, 2016). This goal is considered an essential aspect of a goal-based agent by Russell, Norvig and Davis (2010). It takes more than one iteration by the agent to reach its set out goal.

The goal-based agent appears to be less efficient than the reflex agent because it considers the goal. But at the same time, it is more flexible than the reflex agent because if there is a change in the environment, the information is updated, which fundamentally changes the actions. If the environment changes, a lot of rework on the agent is required, as a set of new rules and measures must be added to accommodate the changes (Golpayegani & Clarke, 2016).

As can be seen in Figure 5.2, the behaviour can be modified based on the environment results. With goal-based agents being more flexible regarding actions, they have a larger problem domain in which goal-based agents can be used.

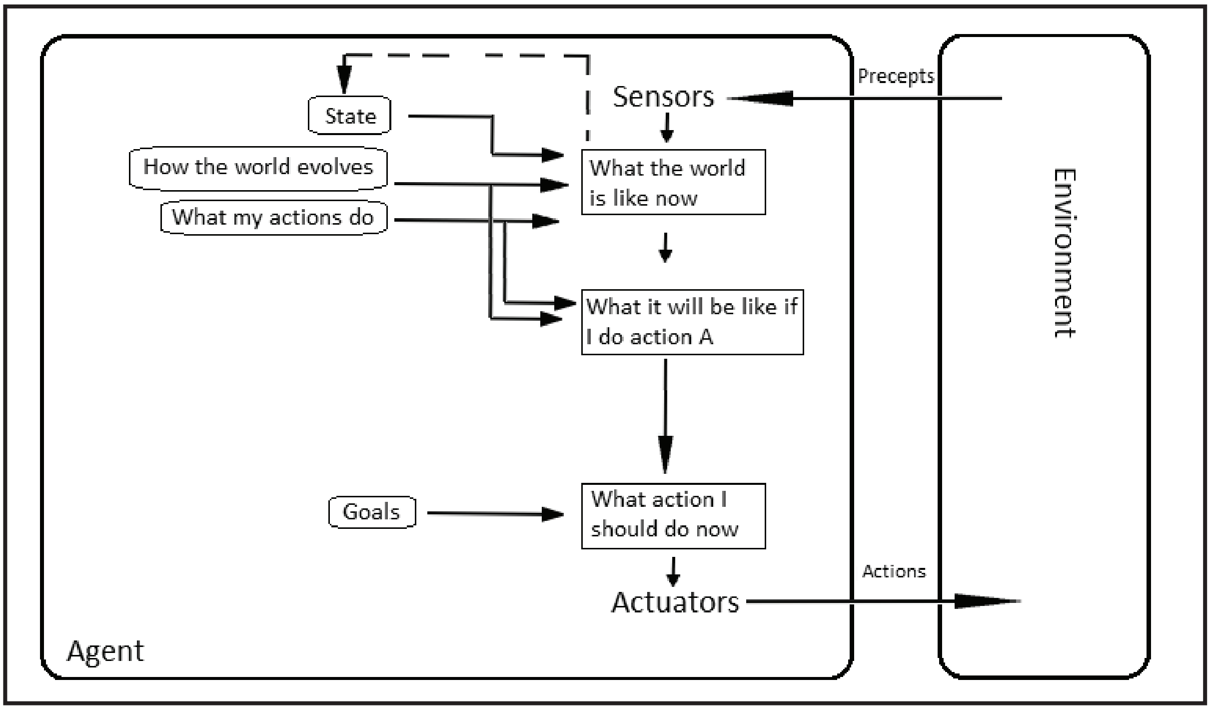


Figure 5.2: Goal-based agent (Russell, Norvig & Davis, 2010)

5.7.3 Utility-based Agents

Russell, Norvig and Davis (2010) state that a goal-based agent is not the best solution due to low quality. The reason for this is due to the rules that goals contain. The state of the goals are the main issue because the agent does not consider the other possibilities, neither does it consider aspects that might influence the environment. If there is a human component, issues similar to speed and wellbeing are not considered. In goal-based agents, two core states, goal and non-goal states, were improved upon by allowing the inclusion of different aspects similar to performance.

The utility is thus the level of happiness that is achieved by an agent. It allows agents to make rational decisions based on the input from the environment, but the rational choice is not always as easy because there is still a possibility that the goals are conflicting. Conflicting goals are when one aspect that is considered by the agent is reached, but another issue that is reviewed by the agent cannot be achieved. The agent can reach the goal of safety, but not the goal of performance (Russell, Norvig & Davis, 2010).

Another aspect that affects the goal of the agent is the agent's attempt to reach a goal that cannot be reached, or where there is going to be a great difficulty to reach it, or it cannot be achieved with certainty. The influence of the utility is vast, as the utility is what influences the actions that must be taken by the environment.

Figure 5.3 shows the basic layout of utility-based agents. The basic design consists of the environment and the agent, and thus is similar to a reflex agent. The utility-based agent also looks similar to the goal-based agent. The only visible difference is the input of utility in the method to verify if the state is better or worse (Russell, Norvig & Davis, 2010). Figure 5.3 shows that the utility will influence the actions that will be performed.

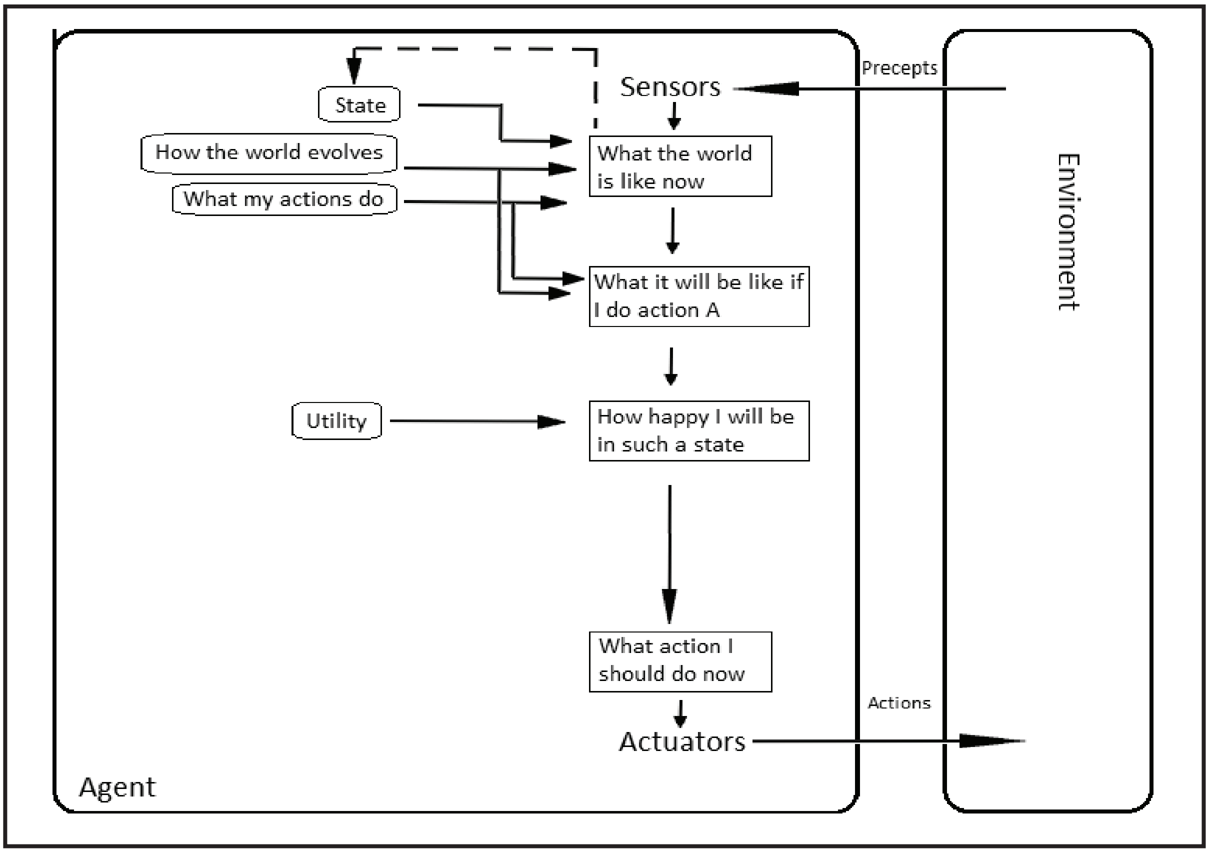


Figure 5.3: Utility-based agent (Russell, Norvig & Davis, 2010)

5.7.4 Learning Agents

Learning agents enable better results and actions to the environment. The agent starts off knowing little about the environment from where the information comes from, which means that the agent must adapt and improve (Russell, Norvig & Davis, 2010). The way that the agent modifies and improves can be seen in Figure 5.4.

Learning agents are entirely focused on improving the environment, leading to a new and informative experience, and are considered one of the smartest intelligent agents.

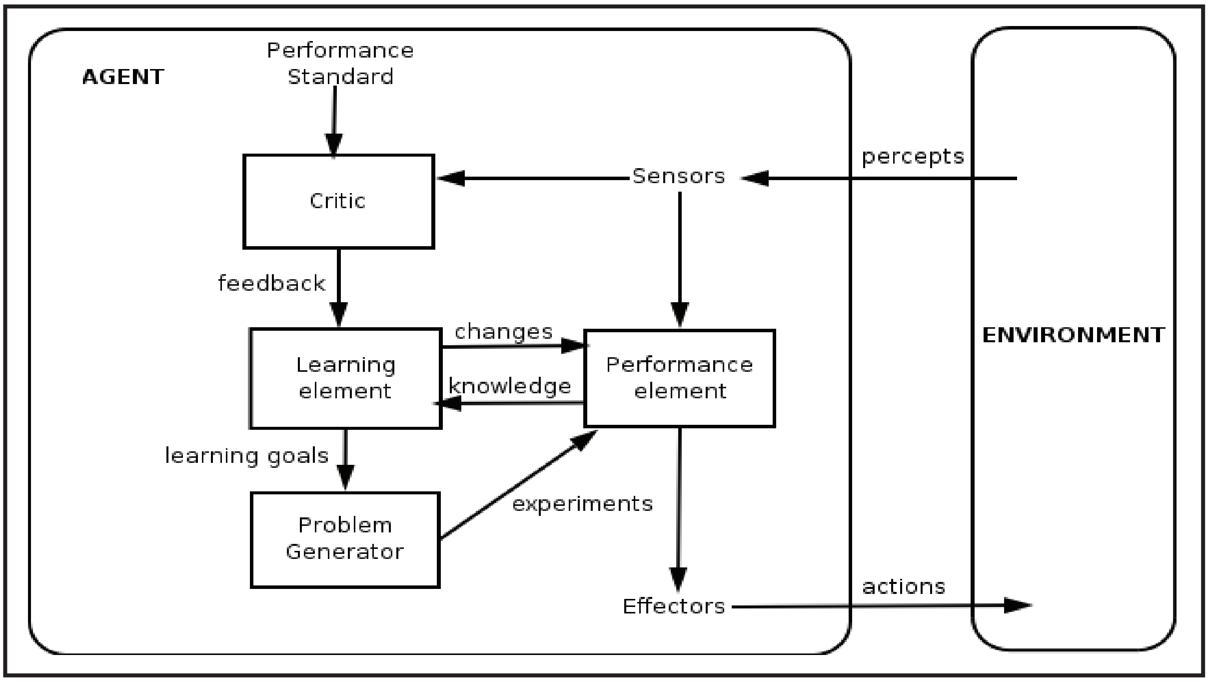


*Figure 5.4: Learning agent (*Russell, Norvig & Davis, 2010*)*

5.8 Multi-agent Systems

Maalal and Addou (2011) define a multi-agent system as:

> *A multi-agent system is a system that contains a set of agents that interact with communications protocols and can act on their environment.*

Multi-agent systems are domain dependent, and the agents must have control over the operating environment (Maalal & Addou, 2011). Multi-agent systems are used to solve more complex problems. As the definition states, a multi-agent system is a composition of multiple different connected agents. These systems are complicated, as the system requires each possible agent to communicate to find a universal solution that has the best possible outcome for the environment and the agents (Garro, Mühlhäuser, Tundis, Baldoni, Baroglio, Bergenti & Torroni, 2018).

Each agent in a multi-agent system operates independently as the agents should make their decisions, but agents in the multi-agent system share information. However, each agent in a multi-agent system can still be autonomous (Wooldridge, 2012).

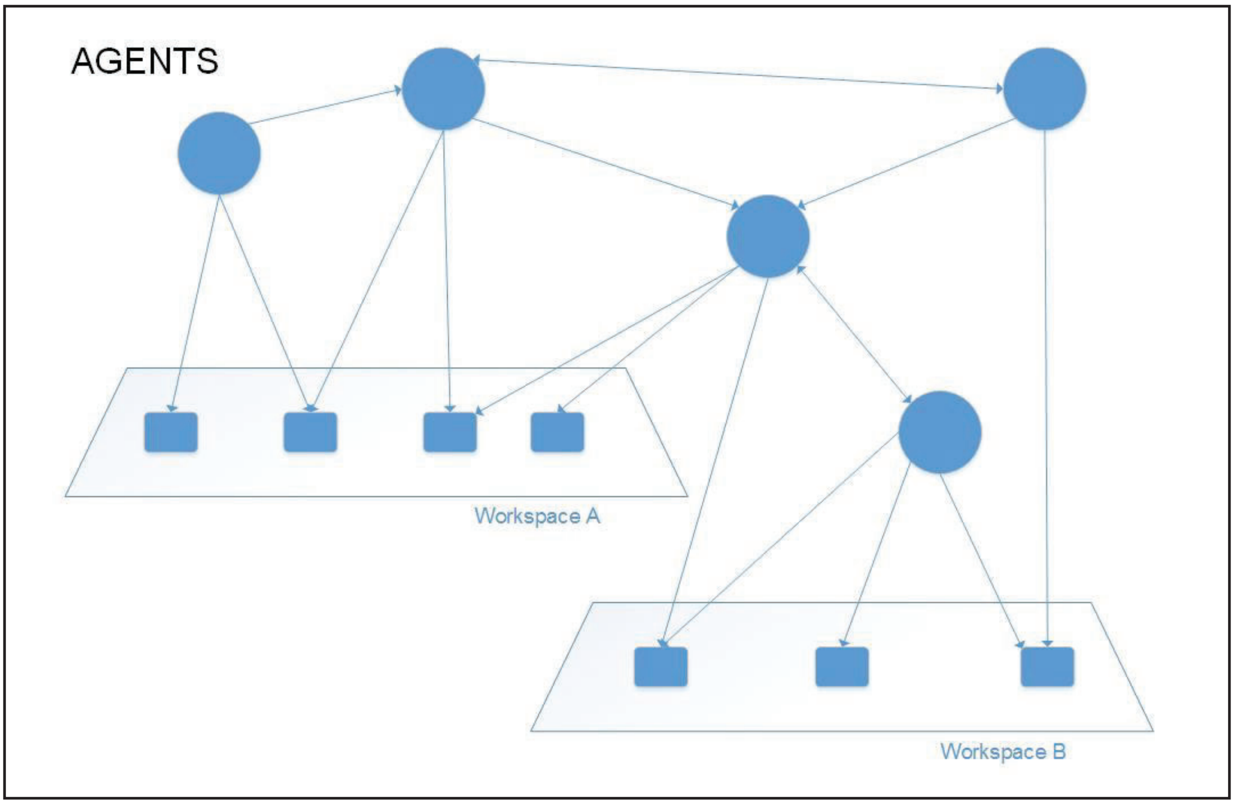


Figure 5.5: Multi-agent structure (Adapted from: Wooldridge: 2012)

Figure 5.5 shows that agents are interconnected to each other using some communication protocol. The communication protocol is dependent on the problem that must be solved and on the environment in which the agent operates.

5.8.1 Multi-agent systems vs Single agent systems' characteristics

Some characteristics might differ between single agent systems and multi-agent system (Vlassis, 2007; Garro et al., 2018).

The characteristics are:

- *Agent design*: the agents that compromise a multi-agent system are known as heterogeneous because the agents are not designed the same. Agents that don't operate the same way but operate on the same hardware, makes them heterogeneous instead of homogeneous.
- *Environment*: the environment in which agents should operate is static, especially for single agents. Multi-agent systems are more likely to run in a dynamic environment, meaning that the agent should have a minimum delay to deliver information.
- *Perception*: one problem that arises from multi-agent systems concerns the data that the agent utilises. The data can arrive from a different section in the environment or at a different time stamp, meaning that the agent can set out wrong actions. Thus, agents must combine their perceptions to gain collective knowledge.
- *Control*: there is no central point in multi-agent systems that collects data and decides what to do with the data. The agents themselves should, therefore, have control over the information that is received from the environment. Collective decision-making is possible.
- *Knowledge*: in a multi-agent system, some agent's knowledge might be different. Thus, there is a requirement for common knowledge
- *Communication*: multi-agent systems should have protocols in place for the agents to communicate with one another. But at the same time, an agent must be able to send and receive information and not be self-interested.
- *Collaborative:* in a multi-agent system the agent can work together to achieve a combined objective by sharing knowledge and perceptions.
- *Competitive:* a multi-agent system can have a group of competing agents that competes to reach a collective goal.

These characteristics make a multi-agent system unique, and the features should be visible (Vlassis, 2007; Garro et al., 2018).

5.9 Conclusion

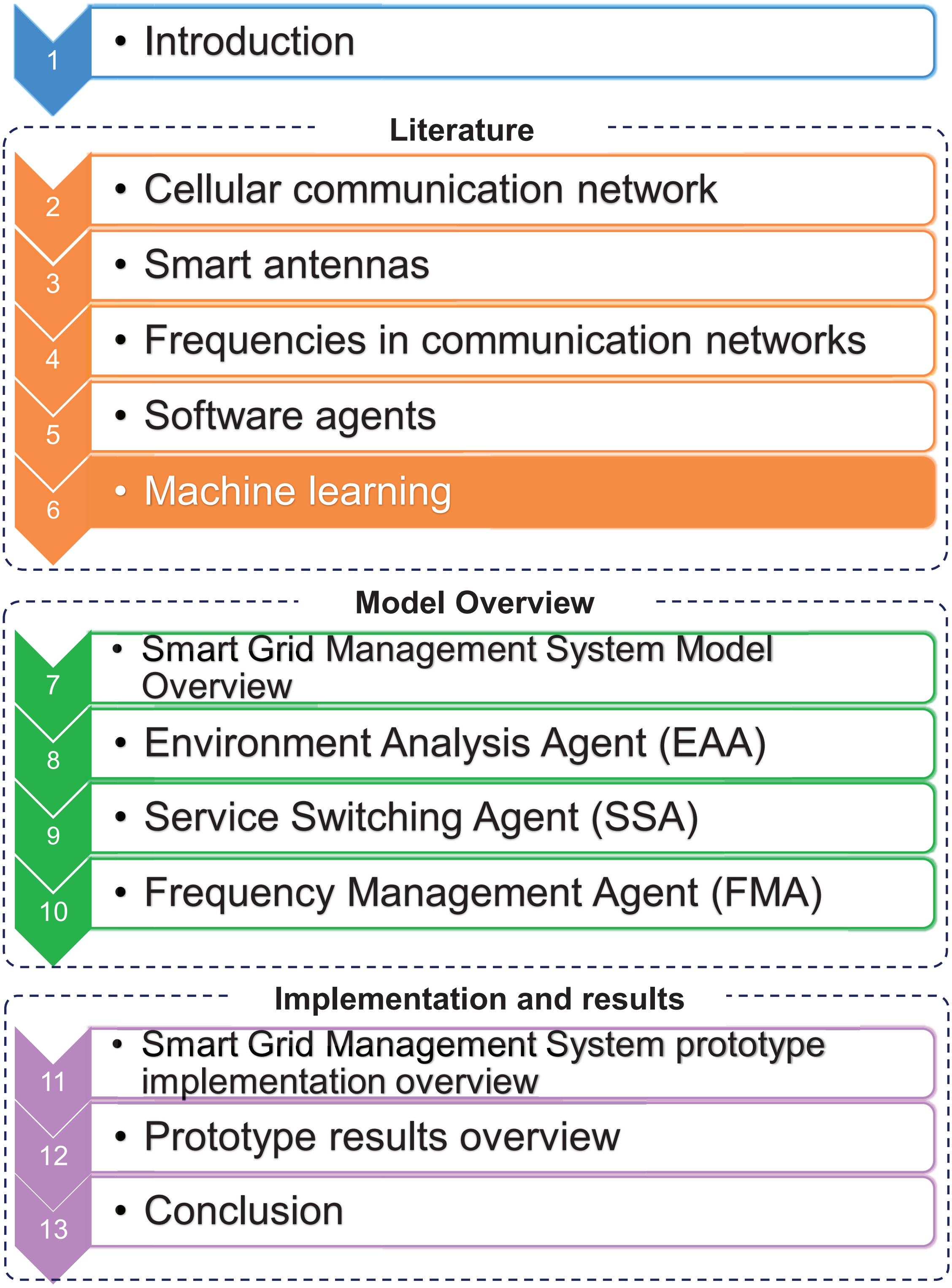
Agents can be implemented with trivial tasks and solutions that can be carried out with critical and complex tasks. What this means is that an agent is usable in many different situations to analyse an environment, which is not to say that an agent must be used in all possible implementations to solve problems. This chapter has shown the many different agents that can be used to address a range of various issues. The biggest issue is in selecting the most advantageous agent.

A multi-agent system is a combination of communicating agents that all attempt to achieve a common goal. The agents that make up a multi-agent system are not always a combination of reflex agents; they can be a combination of different agents. Understanding the different agents and how they operate in their own respective environment, helps to understand which agents could operate in a smart antenna grid.

The content of this chapter helps to answer the research question: *How can a multi-agent system be integrated into a smart grid system?* Chapter 5 does not entirely solve this research question, but it focuses on what a multi-agent system is and the different items that form part of a multi-agent system. To answer the research question: *How can a multi-agent system be integrated into a smart grid system?* it is essential to understand multi-agent systems and how multi-agent systems can be integrated into a smart grid system. Chapter 5 does achieve a research objective by defining a software agent and where software agents fit in.

An agent should pick up on patterns and determine an appropriate action to be followed by the environment. It is not always possible for agents to pick up on patterns in an environment. Patterns are picked up more easily by machine learning, which is a section of Artificial Intelligence (AI). Chapter 6 focuses on the different types of machine learning and some of the algorithms that can be used for pattern recognition.

Chapter 6 - Machine learning



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6.1 Introduction

Value is gained from data in an environment only when the data is analysed. Either people or software programs can perform the analysis of data but with smartphones, smartwatches and smart computers, analysis on data does not often have to be performed.

Analysing data allows a means of technological advancement in this modern day and age. Data that is gathered from existing products can show a need for different software goods or hardware products, with data analysis being a necessary ingredient for technical progress (Smola, Vishwanathan & Shai, 2014).

Machine learning is an application of artificial intelligence (AI) that provides the tools to gather and analyse the data from an environment. Machine learning provides the ability for software to learn and adapt on its own, to progressively improve over an existing task, and to make decisions with the help of data without any human interaction. Machine learning performs the learning amongst other methods by making use of statistical techniques.

Machine learning can be used in a wide array of applications that can span from data analysis to problem domains that require pattern analysis. Determining when to use machine learning is dependent on the operational environment. One of the most common environments in which machine learning is integrated, is in online search engines like Google. It does this by observing what people search for on Google and how people respond to the results provided.

Chapter 6 intends to understand machine learning by defining the different machine learning methods. The chapter also covers how machine learning works. All the information covered in Chapter 6 will aid in understanding where machine learning can be integrated and how machine learning can be integrated into a smart antenna system.

6.2 Machine Learning

Machine learning is not a new concept. It has been used by many large companies to improve their software and the way that their software operates and, in some cases, interacts with the user. Machine learning can be effectively used in linguistics systems, such as Apple's Siri and Android's Google Now, since there is a need for continuous learning to improve voice recognition.

Machine learning can be seen as the ability of a software system to learn and improve on existing functionality. The way in which functionality is improved is by utilising data generated by the system and deriving ways to improve upon a solution. In some cases, similar to self-driving cars, machine learning is a critical aspect that should be as accurate and secure as possible (Murphy, 2012). If they are accurate, machine learning algorithms can be used to minimise human error.

6.2.1 When to use Machine Learning

Machine learning has many different applications. One of the main objectives of making use of machine learning is to apply human or animal functions to software, to extract well-defined programs (Shalev-Shwartz & Ben-David, 2014).

Machine learning can also be used with tasks that are beyond human capabilities. When looking at what lies beyond human capacities, there are many possible implementations for machine learning, for instance large sets of data that must be analysed or predicting weather (Smola, Vishwanathan & Shai, 2014).

Humans are not ideal for analysing large data sets. Humans can interpret large data sets, but are not able to find hidden information that is nested deep within data sets. Humans cannot interpret the information at the same speed as a machine learning algorithm could (Shalev-Shwartz & Ben-David, 2014).

Machine learning is advantageous concerning pattern analysis. It is possible for machine learning algorithms to pick up patterns in a problem domain. Patterns are beneficial to solving problems and improving on the implementation. Machine learning can also be used to enhance the performance of solutions (Smola, Vishwanathan and Shai, 2014).

Machine learning algorithms must use data gathered from applications and environments to make smart decisions. Applications that make use of machine learning can adapt the way different situations are handled (Shalev-Shwartz & Ben-David, 2014). Having discussed what machine learning is and when to make use of machine learning, it is important to look at the different machine learning parameters.

6.2.2 Machine Learning Aspects

Machine learning is not a single solution implementation that can solve all problems at once. It is used to address different scenarios by utilising strategies and methods. Machine learning has four parameters, as noted in the following sections.

6.2.2.1 Supervised vs. Unsupervised

When looking at supervised learning, one can extrapolate when observing an environment continuously that some pattern will be picked up. Information that is gained from the situation will only contain significant details once the environment is supervised (Shalev-Shwartz & Ben-David, 2014).

Supervised learning is a form of providing training to the 'learner' to gain a better insight into gathered information. When the environment is unsupervised, no extra information is provided for it to obtain valuable data. Data must be processed without distinction between training and test data. The primary goal of the learner in an unsupervised environment is to generate a summary of the data (Shalev-Shwartz & Ben-David, 2014).

6.2.2.2 Active vs. Passive Learners

All the different learning paradigms vary depending on the various domains in which the learning system is used. Active and passive learners have two completely different implementations that provide different results. Active learners perform experiments in a simulated environment to obtain results (Hsu, 2010).

Passive learners do not interact with the environment using experiments. Passive learners observe the environment to gather information from the environment. The environment is not influenced by the learner, as the learner is there simply to observe and report. With a passive environment, the student will mark a spam email as spam with no other information or processing, whereas an active learner will go as far as questioning what the spam is, or what kind of spam is being marked as spam (Hsu, 2010). Active learners display more human characteristics than passive learners.

6.2.2.3 Helpfulness of the teacher

In a learning environment, teachers have the responsibility of relaying information to learners. The information that is relayed to the learners must be used to analyse input data to provide valuable output. The quality of the information relayed by the teacher is a crucial aspect for both the environment and the learner. If the teacher is of low quality, then the analysis results will not be accurate (Mitchell, 1997; Hsu, 2010).

6.2.2.4 Online vs. Batch Learning

Online processing and batch learning processes are two entirely different methods that have different operations and procedures. Online processing is situation dependent. With online processing, there is usually a requirement for the learner to respond online. What makes this unique is that the processing will be distributed online. Sometimes significant data sets are processed by learners (Duchi & Singer, 2009).

The different types of machine learning are each implemented with a unique set of advantages. Online learning is a better implementation for social media systems than a batch learner.

6.2.3 Computational Structures of Machine Learning

It is essential to understand what is being learned by the learning system. The focus is on different computational structures that include:

- functions;

- logic programs and rule sets;
- finite state machines;
- grammar; and

  problem solving systems

Having discussed some of the parameters and some of the computational structures of machine learning it is important to look at the different machine learning models.

6.3 Machine Learning Models

A critical aspect of the various models is that the different models are usually mathematically based.

The various models discussed in the following sections are:

- Linear-based models
- Neural Networks
- Decision tree models

6.3.1 Linear Models

Linear models are not optimal for all different types of application areas. The key for a linear algorithm to work is the linear separator. The algorithm will be executed until the optimal linear separator is found (Daume, 2012).

> *“This is called a linear classifier. There are many hyperplanes that might classify (separate) the data. One reasonable choice as the best hyperplane is the one that represents the largest separation, or margin, between the two sets.”* (Daume, 2012).

The goal of the linear function is to take input and split the information into different sections. One problem with using a linear model is the domain. A linear model cannot be employed in a problem domain where a linear separator cannot separate input data.

6.3.2 Neural Networks

Neural networks are one of the more common machine learning models. In neural networks, the researcher divides the inputs and the outputs using intersecting nodes so that it would become a multi-layer system. Neural networks can handle a lot of functions, thus making them more flexible (Daume, 2012).

6.3.3 Bio-Inspired Multi-Layer Networks

Linear machine learning models are not very adaptable, as there is only one layer that they are concerned with: minimal depth. Multi-layer models are more adaptable, but they offer a significant amount of complexity to a problem domain (Daume, 2012). A multi-layer neural network is just a more complex neural network implementation.

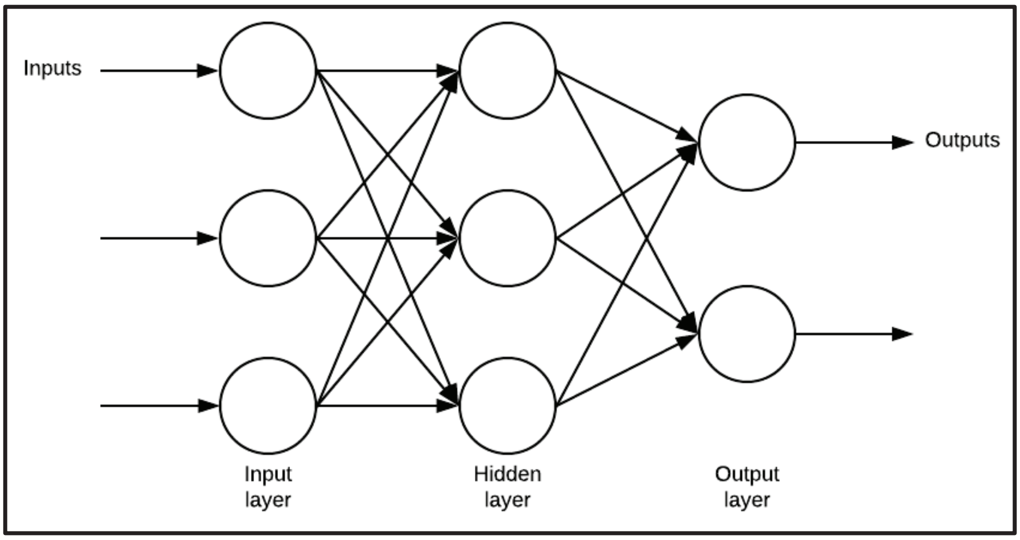

Figure 6.1: Multi-layer network (Daume, 2012)

Figure 6.1 demonstrates a two-layer network that consists of five different inputs. These inputs are fed into two separate hidden units that are responsible for feeding up to one single unit. The group at the top is known as an output unit that is responsible for providing the feedback.

The calculation that takes place at the two hidden nodes is known as activation computation, which makes use of input from the other five input nodes. An activation function looks at the data that are passed to it, and then if it notices that the input is within some limit then it 'activates'. The activation function is typically nonlinear in this multi-layer network, making it an efficient implementation as all the data runs through a different unit, meaning that there is better coverage (Daume, 2012).

6.4 Training Neural Networks.

There are not many algorithms that can effectively and efficiently train neural networks. One very efficient training algorithms used with neural networks is the back-propagation algorithm. Back-propagation can propagate gradients backwards, meaning that the inputs into the neural network are not sent to the network in the order that they arrive, but are transmitted in reverse order.

6.4.1 Initialising and convergence of neural networks

Neural networks make use of weights. Weight is a value that is given to an item or a feature in a neural network. In a linear model, weights are initially initialised to zero. Neural networks do not follow the same implementation structure as linear models. The initialisation to zero is never a good idea in a neural network system because the algorithm gets stuck with an unwanted solution and the results will not be accurate (Nilsson, 1998). When setting the weight to zero and running the neural network, the results will lean more towards a linear system.

6.4.2 Decision Trees

The basic premise of machine learning is to predict the future based on past events. In some cases, this is just a guessing game. To gain a better understanding of what machine learning is, we must look at decision trees (Nilsson, 1998).

Decision trees are a simple underlying implementation of machine learning that offer excellent results. As with most cases, a model should be able to solve a simple problem utilising processes and rules. The most natural kind of problems that decision trees attempt to address are known as binary problems. Binary problems have two simple answers to a question, usually being yes or no (Daume, 2012).

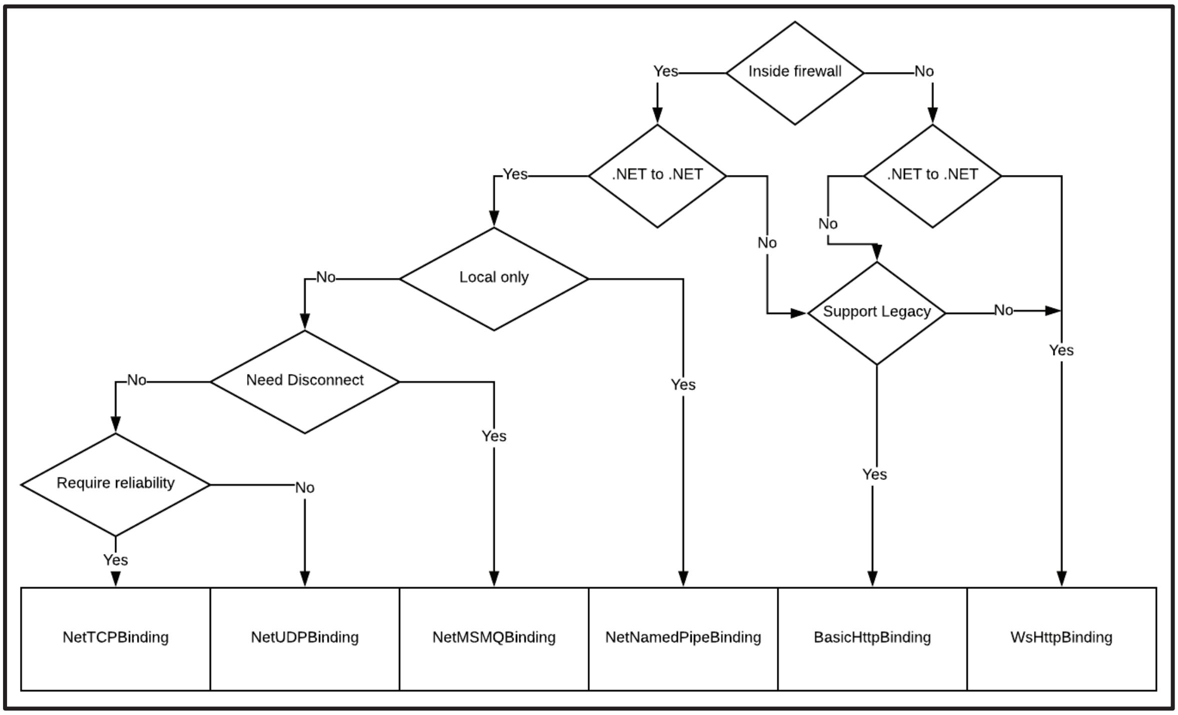

Figure 6.2: Decision tree (Daume, 2012)

The decision tree's outcome and implementation are performed in a tree format (Daume, 2012). Figure 6.2 shows an example of a decision tree. In the implementation of decision trees, it can be decided whether the decision trees can make assumptions. If the assumption is purely random, then the result will not provide any valuable information. It will merely cause unwanted effects to be generated.

Using a decision tree on binary problems is a good idea, as it provides excellent and relevant information that can be used to predict results. However, a decision tree does not come without its unique set of problems.

6.4.3 Learnability

The success or failure of an algorithm depends on the environment's properties. In cases where an environment makes use of sensors, noise in the environment can cause the outcome to be incorrect. One of the most common places where noise might occur is in the actual data that is being analysed by the machine learning algorithm. In the data set, a typo is considered as noise, and it can have a profound influence on the results that are found in the analysis, and can cause tainted effects (Daume, 2012).

One aspect that rarely affects the results of a machine learning algorithm is bias. Bias might pull the correct result away from the actual result. Changing the learning algorithm will not create less bias because the teacher must provide some helpful information related to the environment. If the teacher is biased, the algorithm tends to lean in an incorrect direction (Daume, 2012).

6.5 Conclusion

Minimising human error in a software system helps to promote higher quality results. Having little or no interaction with humans, software systems are one of the solutions to minimise human error. Machine learning has the ability to operate in an environment with no human intervention. One place where human intervention always occurs is in an environment where a user is used for machine learning.

Machine learning is not only good at analysing data with less errors than users, but it can also recognise patterns in an environment better than a human can. The most common way that patterns are recognised is by means of analysing data from the environment using some statistical theory.

The techniques that can be used to achieve less human error when analysing data and picking up effective patterns, are dependent on the problem domain. Machine learning has three major models that can be used to achieve these two goals.

Machine learning can be implemented in a multi-agent system to help solve the problem of managing resources in a smart antenna grid. Understanding the different models that can be used in systems aids in understanding which model can be used in a smart antenna grid.

Since the prototype makes use of machine learning to determine patterns in device movement in the smart grid a short chapter is required to discuss machine learning. This chapter has helped to answer the research question: *How can multi-agent systems be integrated into a smart antenna grid system?* Understanding machine learning, the different types of machine learning, and when to use it, has helped to form an understanding of where machine learning might fit into a smart antenna grid, as machine learning forms part of the multi-agent system.

Chapter 6 was the final chapter of the literature review. The next part of the dissertation is the model overview, which focuses on the implementation of a model that attempts to improve resource management in a smart antenna grid. The model overview looks at the different agents that formed part of the resource management and the results generated by the model.

Chapter 7 discusses the Smart Grid Management System (SGMS) model concentrating on the agents that were used to operate in the system, and some of the components that formed part of the different agents. The chapter focuses on answering the research question: *How can multi-agent systems be integrated into a smart antenna grid?*

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7.1 Introduction

Smart antenna grids are an extensive complex collection of components that operate together. Integrating a multi-agent system to perform in a smart antenna grid requires a comprehensive understanding of the different agents that will serve in the smart antenna grid, and what the different agents' operations will be in the environment.

Developing complex software solutions that integrate into a large software environment requires some prework to ensure that the software solution does what it intends to do without negatively influencing the software system. One method used to ensure that the software does what it plans to do, is by developing a software model. A software model is a software implementation that is used to emulate an environment (Seidewitz, 2003).

This chapter focuses on a multi-agent model that is proposed to manage a smart antenna grid. The different components that formed part of the multi-agent model are discussed in order to have a better understanding of the component’s functions.

The various agents that formed part of the multi-agent system model are discussed in terms of the actions of the different agents. There is also focus on how the various agents communicate in the model, as well as an overview of the different components that make up the different agents.

Understanding how the model operates and the different components integrated to make up the software model, helps to understand how a multi-agent system can be integrated into a smart antenna grid, which aids in answering the research question.

7.2 Model Rationale

A multi-agent system is best suited for problems that are distributed (Balaji & Srinivasan, 2010). A multi-agent system also works in an infinitely adaptive environment. To address a problem domain, the different agents in a multi-agent system must be deployed to solve a problem.

The agents deployed in a multi-agent system are not considered to be independent of each other. In the Smart Grid Management System Model the multi-agent system can best reach a result when different agents implemented on different nodes communicate. In a multi-agent system, the different agents do not purely rely on communication to choose actions to perform, or on the accessible environmental data.

More than one node operates in a smart grid that enables actions ranging from antennas to devices. Each one of the nodes in the smart grid are unique items that can operate with an antenna and are independent of the other nodes. A large environment forms a good platform that allows for a group of agents to be deployed to manage resources in a smart grid.

The multi-agent system model mentioned in a research paper called *Design of Multi-Agent Framework for Cellular Networks* by A.K. Sharma and D. Juneja (2005), described how multi-agent systems could be used to manage communication in a mobile network. The major difference between the Sharma/Juneja model and this study's proposed model is that the SGMS is not focused on peer-to-peer communication between devices, but rather on the efficient management of smart grid resources.

7.3 Smart Grid Management System (SGMS) Model Overview

The Smart Grid Management Agent model is made up of different layers. The graphical layer is what is shown to the user. The graphics layer includes analysis graphs and the simulation environment. The multi-agent system layer is responsible for handling the three agents that are responsible for managing the resources of the management system. The simulation layer is responsible for setting up the smart grid to perform experiments on, and on which to build the multi-agent system.

Multi-agent systems function best when there is communication between the various agents that operate in the multi-agent system to ensure that the environment will reach its own goal. With a set of well-defined agents in a smart grid, the multi-agent system will have no problem communicating within the environment. Figure 7.1 shows that the physical layer containing the devices, antennas and other external factors are part of the initial setup phase. The agents that are responsible for managing the SGMS resources are set up after the physical environment are initialised. Each one of these agents has a set of components that they rely on. The setup of the agents is covered in later chapters of the dissertation.

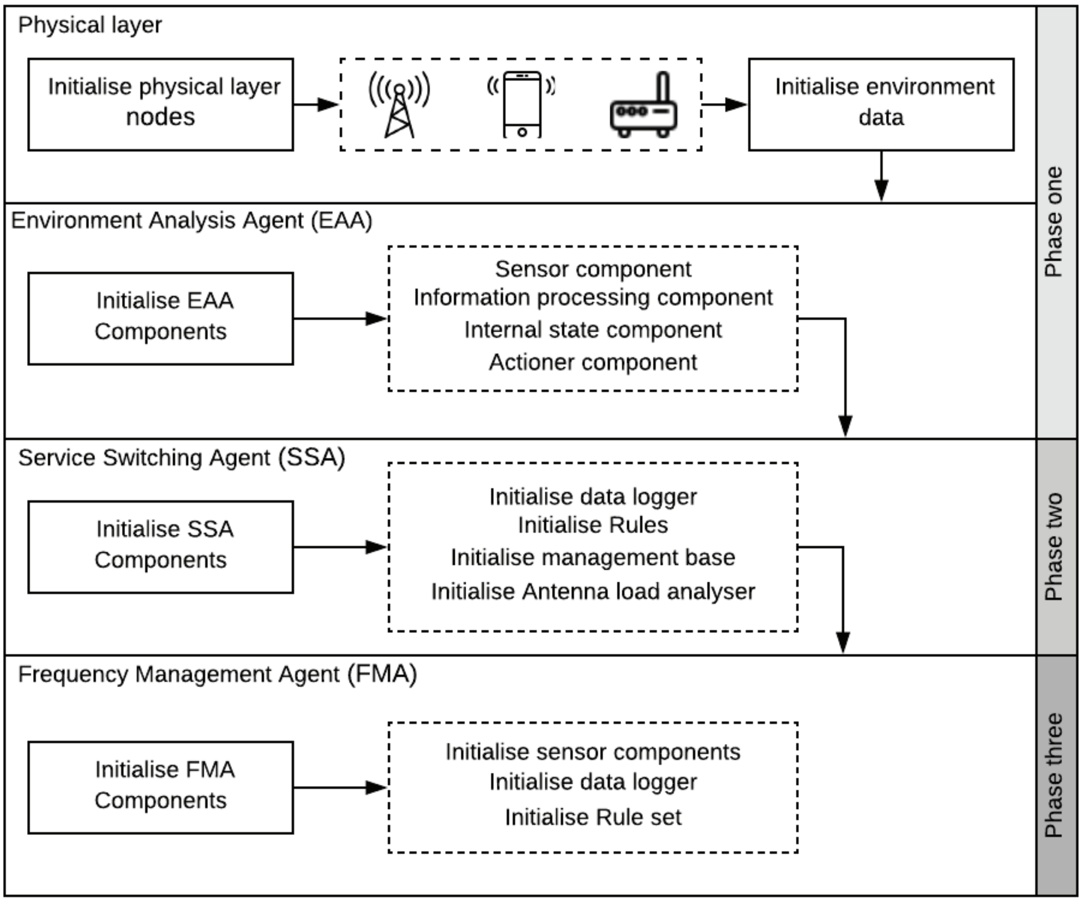


Figure 7.1: SGMS Model Overview

The different components that make up the SGMS are mentioned in the following sections.

7.3.1 Physical Structures

Physical structures can relate either to the smart grid components or the external physical structure that affects the smart grid's operation. Some smart grid structural components are the towers, the physical lines, and the connected devices. External structures include buildings, physical terrain similar to mountains, and other structures that influence the signal in a grid.

7.3.2 Network Edges

Network edges are the connections that exist between different nodes in the network. These network edges might have different lengths, as separate nodes in a network can be located vast distances from each other. Network edges can be physical cable or wireless. In the SGMS, the network edges are simulated as wireless connection links.

7.3.3 Smart Antenna Communication Components

Smart antennas are systems that contain different components to perform tasks. Each element in a smart antenna (antenna, base station, telephone exchange also known as switches) acts as a node in a smart antenna. These are also classified as physical structures that can act as network points.

7.3.4 Cellular Devices

In a mobile communication network, the most crucial aspect is the cellular devices that need to communicate with antennas that are placed on the cellular towers. They are crucial to consume the resources made available by the mobile communication network, including frequencies. Some devices in mobile communication networks are mobile cell phones, internet dongles, and other items that are connected to the mobile network. The SGMS focuses on all of the mentioned devices.

Figure 7.2 shows the mobile environment containing all the relevant components, including the users, the physical structures, and the communication components. Figure 7.2 shows that the users communicate with the base stations and the base stations communicate with a controller. Because the environment is made up of many different nodes that need to communicate with each other to achieve one goal, the mobile communication grid provides the perfect building blocks for a multi-agent system.

The simulation contains a set of nodes that behave as part of the mobile communication system. The nodes that operate in the network are the cellular towers, also known as base stations, that contain a set of smart antennas, devices (cell phones and internet dongles), and an antenna switch. The antennas are independent but can still communicate with other. Devices cannot communicate with other devices directly, as communication between devices is completed by device to base station to device communication.

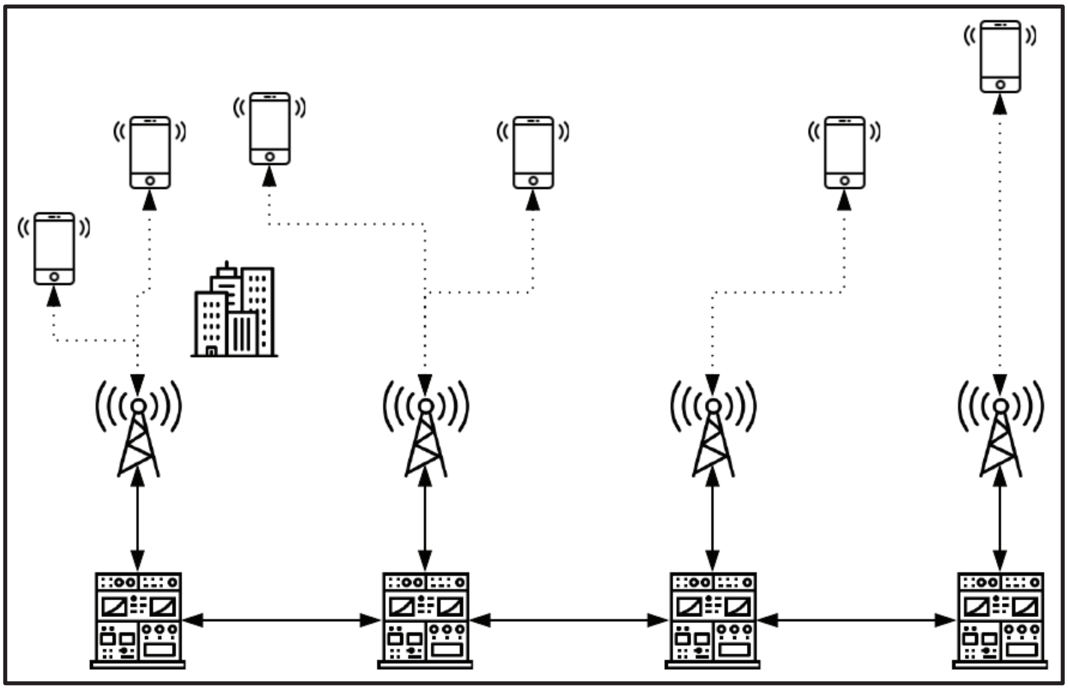


Figure 7.2: Smart Grid Management System environment

7.4 Smart Grid Management System Environment Setup

Many environmental aspects are of importance in the Smart Grid Management System. To ensure that the Smart Grid Management System can obtain the best possible results, a set of steps in the environment setup must be followed.

The steps for the environment setup that must be followed are:

1. Identify the environment to operate in.
2. Identify the components that will be running in the environment.
3. Deploy the different components that form part of the environment.

4. Measures and sensors should be set up to ensure that there are results.
5. Identify relationships between different components in the operational environment.
6. Define the rules, the controls and the different actuation requirements of the various elements in the environment.
7. Review and determine sequences that appear in the operational environment.
8. Deploy Smart Grid Management System agents that are responsible for managing resources.
9. Determine if an environment has been successfully managed.

7.5 Smart Grid Management System Agent Layout

The aforementioned research paper of A.K. Sharma and D. Juneja *(Design of Multi-agent Framework for Cellular Networks*) describes a model that manages the communication channels used for cellular phone communication in a mobile network between two different mobile device users. The proposed model follows a similar structure. Figure 7.3 demonstrates that the caller and the called have to run through an intelligent agent.

The most critical components in the Smart Grid Management Model are the antennas that provide a communication point, and the switches used to manage traffic and store information. They are the most important components because they have the responsibility of containing frequencies and connecting and routing mobile traffic on the network.

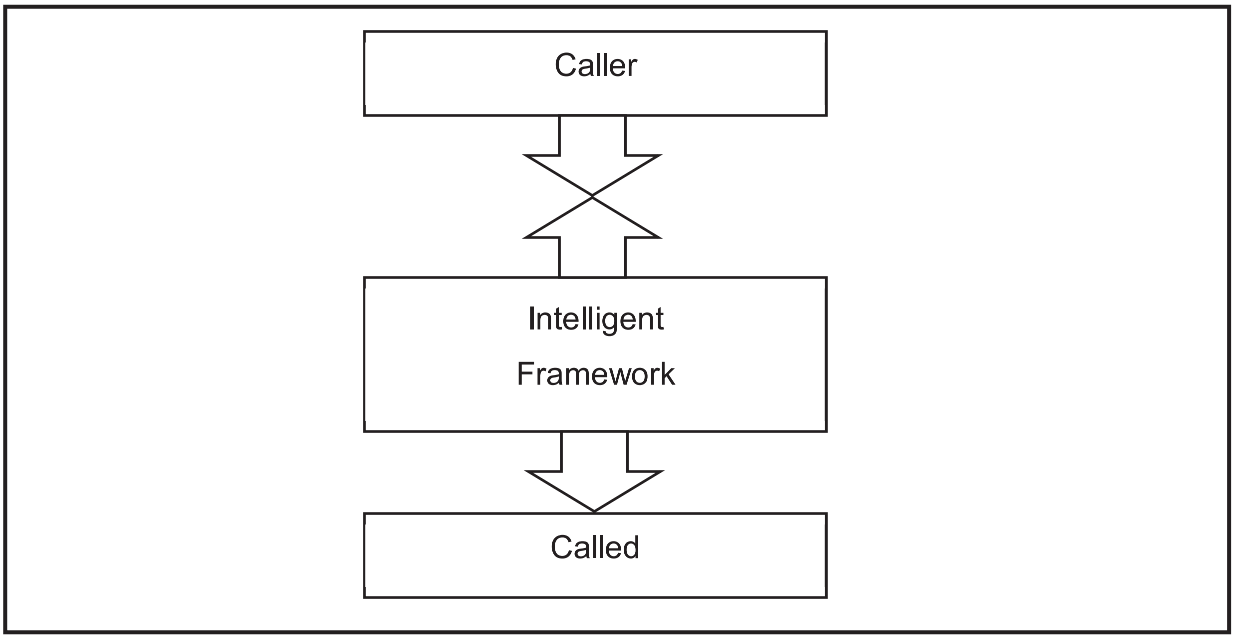


Figure 7.3: Communication structure architecture (Sharma and Juneja, 2005)

The different agents deployed on the components in the environment perform various tasks: they relay information to each other to ensure that a combined goal is reached.

The agents that operate in the Smart Grid Management System are:

- Environment Analysis Agent
- Service Switching Agent
- Frequency Management Agent

These agents attempt to achieve the common goal of improved resource management in a smart antenna grid. The agents' actions range from managing frequency resources to managing antenna loads in the smart grid.

In the environment, some of the agents are more important than others because some that operate in the SGMS have to inform other agents that an event has taken place and that something has to be done. The following section briefly describes the operations of the three mentioned agents.

7.5.1 Environment Analysis Agent

The Environment Analysis Agent (EAA) is the most important agent that operates in the smart grid management system. The EAA is deployed in the environment with the sole goal of analysing the environment. The analysis aids in deciding what other agents do to execute in the environment, with the goal of improved resource management. When the EAA is not in an operational state, the environment should not see any agent intervention to improve resource management

7.5.2 Service Switching Agent

The Service Switching Agent (SSA) takes some of the bulk and strain in the environment. It is responsible for ensuring that all the different antennas in the smart grid are not overloaded with users. It also makes sure that a higher percentage of users in the environment have connectivity to an antenna, even when an antenna is switched off. The SSA is only able to execute when the environment analysis agent requires it to run.

7.5.3 Frequency Management Agent

The Frequency Management Agent (FMA) is responsible for handling frequency distribution issues on the smart grid. These issues can include assignment of frequencies to an antenna that might have been shut down, and for resolving conflicts in the smart grid. As with the SSA, the FMA will only execute on command from the EAA. When there are frequency conflicts in the smart grid management system, the environment has to ensure that the devices which disconnected become reconnected.

All three of the above-mentioned agents communicate with each other through the EAA, which is the agent responsible for ensuring that communication is used when the communication data can be used.

7.6 Initialisation of the Agents

Figure 7.4 demonstrates the communication structure of the agents in the smart grid. The first agent to be executed in the environment is the environment analysis agent.

It has the responsibility of setting up the connection stream with the environment and the other two agents. The environment analysis agent takes the responsibility of analysing the environment, and is also the agent responsible for setting up the log database.

Following the deployment of the EAA, the SSA and the FMA are deployed. The deployment of the agents is sequential. When an agent is deployed in the system, it will not run until the EMA requests the other two agents to run.

As can be seen in Figure 7.4, there are no existing communication links between the FMA and the SSA. The two agents should not communicate with each other directly to ensure that the EAA has control over the execution.

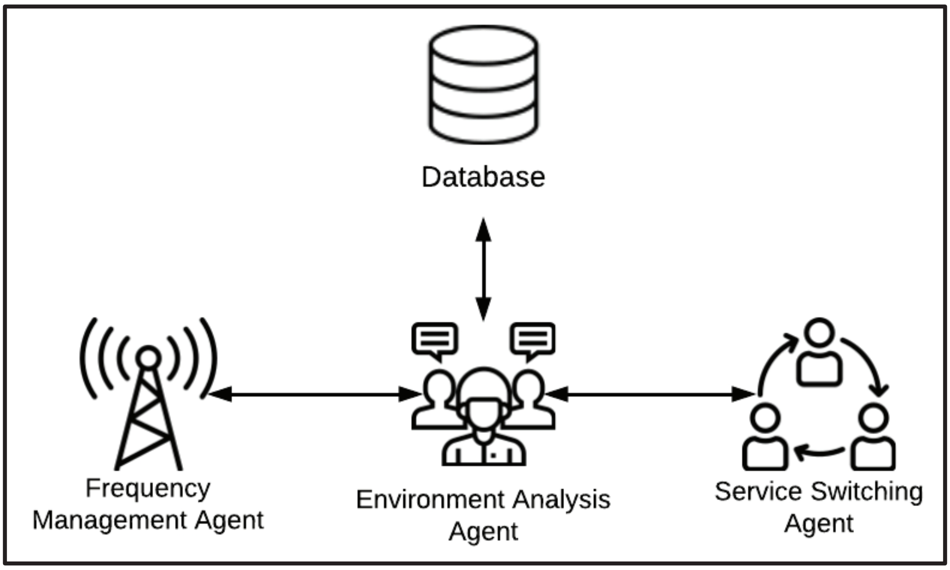


Figure 7.4: Agent deployment

7.7 Agent Types

The smart grid system uses different agents to manage resources that will ensure that the environment has better performance under load. Each one of the agents that form part of the multi-agent smart grid consists of a set of components similar to sensors, information processing, internal state, and actioner. The following section explains all the different components for all the different agents, and the responsibilities of these components.

7.7.1 Environment Analysis Agent.

The Environment Analysis Agent (EAA) is a goal-based agent. The EAA is responsible for informing other agents to execute, based on the environment's information. The EAA makes use of many different sensors to gather information from the environment that is shared between the different agents. The next section discusses the EAA components.

7.7.1.1 Sensor component

The EAA has access to the smart grid environment log, which contains data related to the operational environment. This data is generated by the different nodes in the multi-agent system. The information is essentially internally stored and accessed by the EAA.

7.7.1.2 Information processing component

The EAA compares and matches the generated data to gauge the environmental status of the agent. For the component to be useful, information filtering is needed to get rid of the noise that is logged in the environment. Noise is information that will not help improve resource management. The information processing component has the responsibility of formatting the noise. The EAA can have two possible results, as described in Table 7.1.

Table 7.1: EAA Message results

Positive result:	A positive message result is a message that provides information to the EAA that can aid in reaching a common goal.
Negative result:	A negative message result is one that does not aid the EAA in reaching its gaol.

7.7.1.3 Internal state component

In the EAA, the internal state component is responsible for logging the internal operations of the agent. Recorded messages are used by the information processing component to apply a set of rules.

The current state of an agent is dependent on the analysis of data that is generated by the EAA. The results might include a flag to force another agent to execute. The internal state of the EAA can be in a good or a bad state.

When the internal state is good, the messages have a positive result on the agent. These messages are logged and analysed. If the internal state is bad, then the messages do not allow a positive result causing the messages not to be logged.

7.7.1.4 Actioner component

The Environment Analysis Component is responsible for monitoring the internal and the external data to determine what other agents that operate in the model to trigger. The actioner is a component that has a set of actions that enables the agent to perform its duties.

These actioner components enable the EAA to access environment data for analysis. The different actioner components are listed and described in Table 7.2.

Table 7.2: EAA Actioner components

Retrieve data record:	A query instance always performs the retrieval of data records.
Initiate learning:	Learning is implemented to ensure that actions that are actioned are adapted and improved.
Analyse logged records:	To filter through the information to gain access to valuable information.
Flag data analysis:	Filtering through information to trigger an action.
Update agent state:	These update the state of the component.
Trigger rule base:	This initialises the next agent, based on the flagged rules.

7.7.2 Service switching agent

The Service Switching Agent (SSA) is a goal-based agent that is triggered by the EAA. This agent monitors antennas and connected devices to determine whether an antenna is overloaded. Depending on whether an antenna is overloaded, the devices on the smart grid will be reconnected to a lower loaded antenna. This antenna does not make use of an adaptive set of rules to know which antenna to connect to or what device to disconnect, but rather uses a static set of rules.

7.7.2.1 Sensor Component

The SSA makes use of the environment state which is accessed by a sensor component. The accessed state can be used by the SSA to act when one of the rules is broken. Actions are logged for future use.

7.7.2.2 Information processing component

The information processing component is responsible for retrieving flagged messages. These are analysed to determine real rules to follow. The actions are determined after analysis, based on the load state of the antennas and the devices connected to the antennas.

7.7.2.3 Internal state component

The internal state component is responsible for analysing the current state of the component and for keeping track of logged messages. If the SSA is not useful in the operational environment, the internal state component informs the EAA that the SSA has not achieved its own goal.

7.7.2.4 Actioner component

The actioner component is responsible for executing the commands that are set out by the SSA. Commands are executed using actuators that are placed in the environment. The SSA's different actioner components are listed and described in Table 7.3.

Table 7.3: SSA Actioner components

Message logger:	This tool does not have any effect on the environment. It has the responsibility of analysing login messages for a response.
Retrieve data:	The retrieved data is used to perform tasks.
Analyse messages:	Looks at messages that have been retrieved to determine the best possible action.
Trigger rule base:	Executes a command based on a rule that is observed.
Log information:	Information gathered can be used to influence the internal state.

7.7.3 Frequency Management Agent

The Frequency Management Agent (FMA) is a goal-based agent. The FMA is responsible for managing frequencies that are broadcasted by the antenna. The FMA compares antennas that are in proximity to ensure that they don't broadcast the same frequency because there is a set number of reusable frequencies that can be used by the antennas. Some antennas have a larger broadcast range forcing the FMA to adapt for this.

7.7.3.1 Sensor Component

Because the FMA requires a substantial amount of information to make accurate and useful decisions, the sensor component accesses the various hardware sensors in the environment to capture information. The FMA is an agent that is only triggered by the SSA.

7.7.3.2 Information processing component

When the FMA executes, there is much information that the agent must run through. The information processing component has the critical task of taking the logged records to filter out all the fluff and have only valid data. The types of messages are described in Table 7.4.

Table 7.4: FMA Message validity

Valid messages:	Messages will be used by the agent to make decisions with. The decisions will be executed by the actioner.
Invalid messages:	These messages are only invalid for the frequency management agent. These messages may be valid for another agent.

7.7.3.3 Internal state component

The internal state of the FMA helps keep track of messages that have been logged by the agent. These messages are not all used by the FMA, but can be very useful. The internal state may slightly alter the agent's response in the environment.

7.7.3.4 Actioner component

The actioner component in the FMA is responsible for executing commands. The actioner component has many tasks to complete to ensure that it is effective. The different actions that the FMA has to execute are described in Table 7.5.

Table 7.5: FMA States

Logging messages:	Messages must be logged pre-execution and post-execution.
Execute rule base:	The rule base defines the agent's actions in a situation.
Update agent state:	The agent can be in an active or non-active state. Once the FMA has ensured that neighbouring antennas does not have conflicting frequencies the agent is moved in to a non-active state.

7.8 Smart Grid Management System class layout

This chapter of the dissertation has shown that the Smart Grid Management System is made up of several different agents with each attempting to accomplish a combined goal of margin resources in a Smart Antenna Grid. The internal functioning and components of the agents that are responsible for managing resources are covered in the chapters that follow.

The model is broken down into separate sections as shown in the high-level class diagram in figure 7.5. There is a base helper class that is responsible for holding data that will be used by the FMA, SSA and the EAA. There is a ServiceSwitchingAgent class, a FrequencyManagementAgent class, and an EnvironmentAnalysisAgent class. Each of the agents has access to a distributed database as this is where information which includes what actions were taken and what the current state is of the Smart Grid Management System depicted as DatabaseUtility in the class diagram in figure 7.5

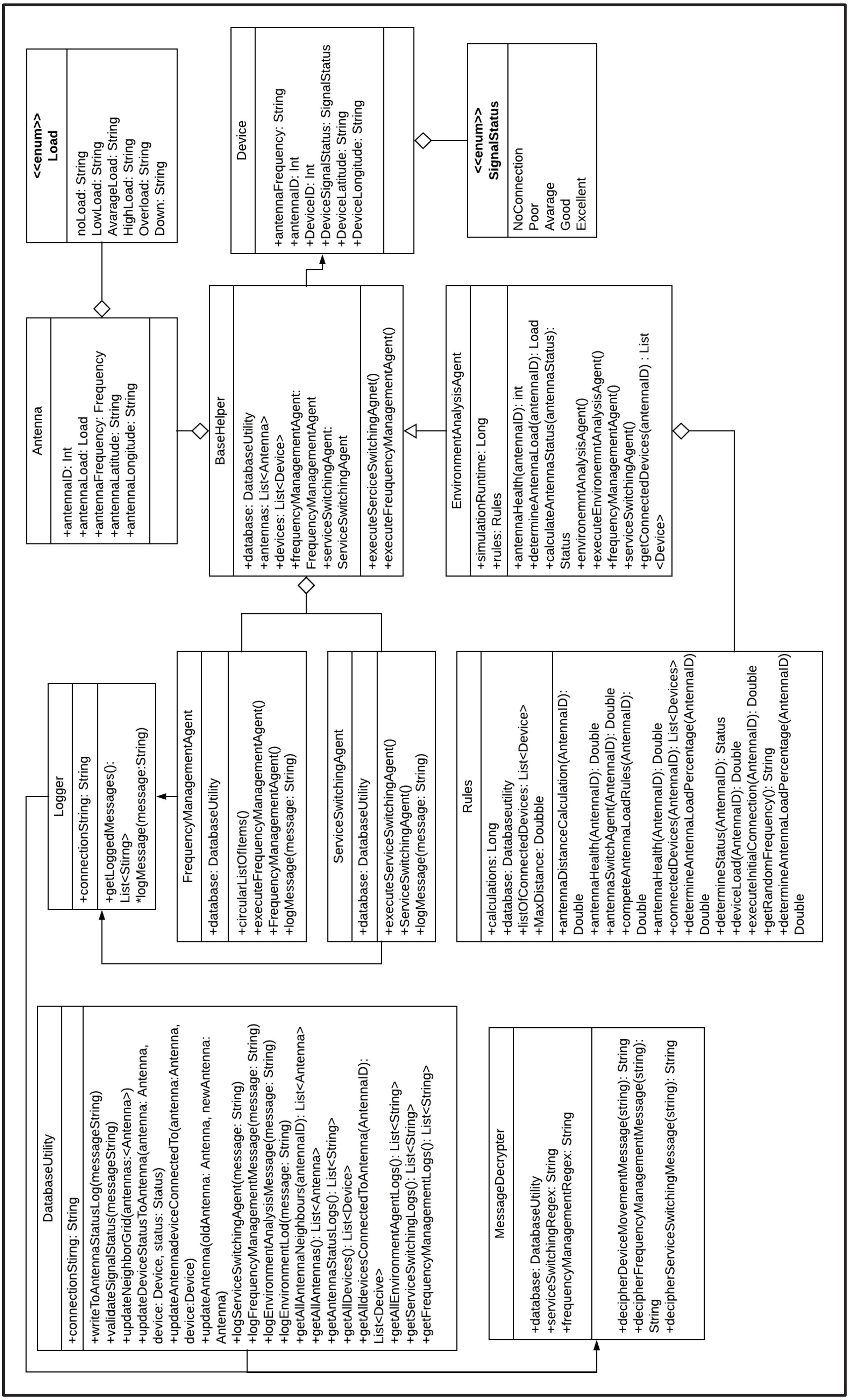


Figure 7.5: Class diagram of SGMS

7.9 Conclusion

The Smart Grid Management System (SGMS) is a multi-agent model made up of a set of various components. The physical structure component includes the different towers and buildings that influence the model. The different physical communication structures are the network edges component. The communication components are used for communication between the various parts, while the cellular components include the devices.

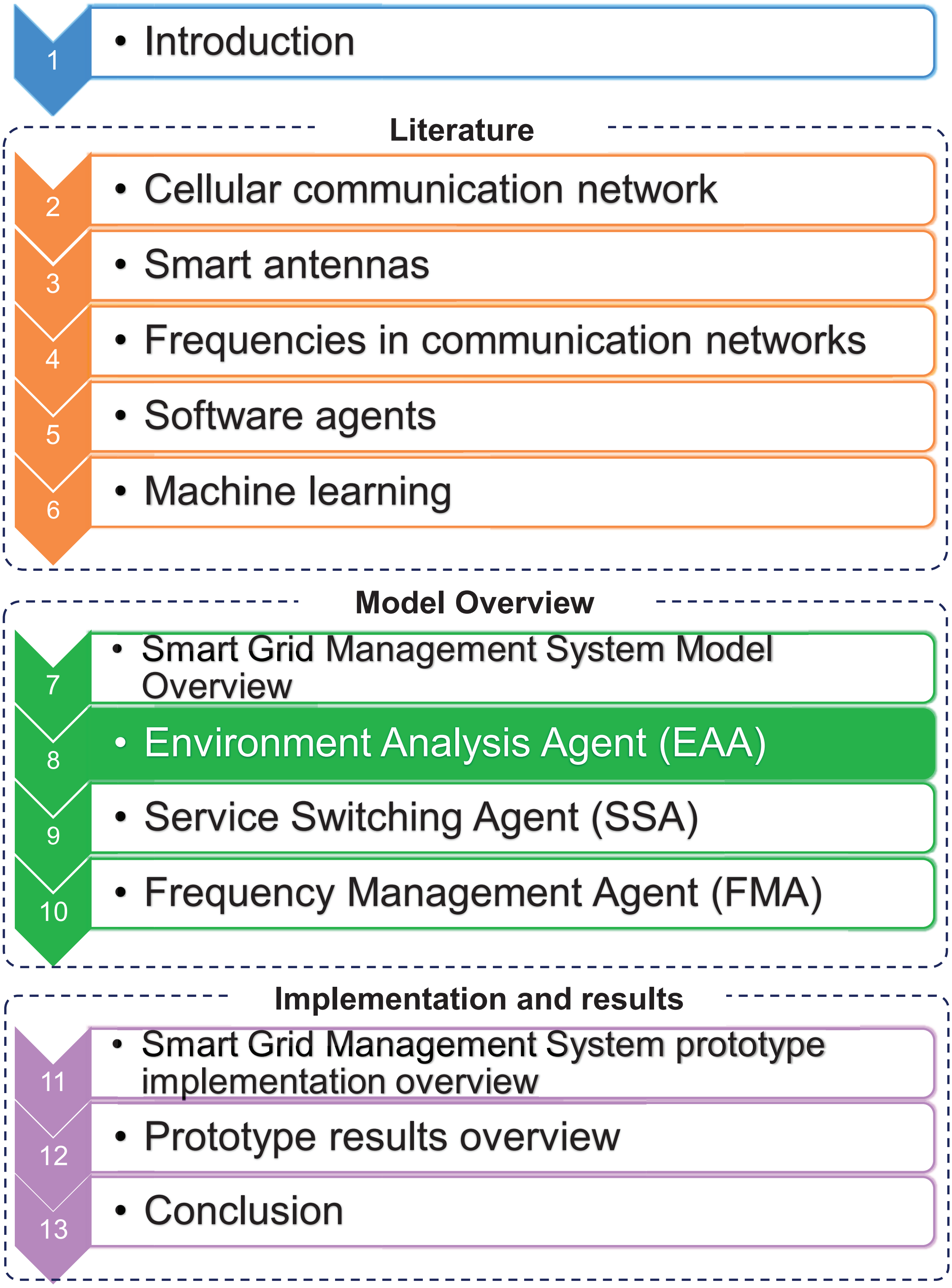
Three agents operate in the model to manage smart antenna grid resources. The FMA is used to control frequency conflicts and to ensure that frequencies are managed; the SSA is used to manage antenna loads and manage device connections; the EMA is the most important agent, and is responsible for analysing the environment to determine what the agents should execute. All the agents have the same goal of achieving improved resource management.

Each agent has a set of components that enables the performance of its actions, and a sensor component that is used to access information from the environment. Each one has an information processing component that is responsible for processing messages, and an internal state component that monitors the agent's state. The agents also have an actioner component that requests the environment to act.

Chapter 7 has helped to answer the research question: *How can a multi-agent system be integrated into a smart grid system?* The chapter focused on the different agents that form part of the multi-agent system. Understanding how the various agents operate indicates where the different agents fit into the multi-agent system. Chapter 7 has also aided in achieving the research objective of defining the implementation of the different agents in the multi-agent system.

Chapter 8 focuses on the Environment Analysis Agent concerning where the agent fits into the smart antenna grid. The chapter also focuses on some of the components that form part of the multi-agent system.

Chapter 8 - Environment Analysis Agent (EAA)



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8.1 Introduction

Most software agents rely on data that is gathered by sensors in the executing environment of the software agent to make decisions that will move the agent to achieve a goal. The Environment Analysis Agent (EAA) is the only agent that operates in the Smart Grid Management System (SGMS) that can utilise all available data. The other agents that operate in the environment only have access to their unique set of data.

The EAA needs all of the generated data. The required data includes the number of users operating in the smart grid, the frequency status of the different antennas in the smart grid, and the health of the antennas in the smart grid. The agent has access to the different communication lines between antennas.

The EAA's data is used to determine if another agent in the environment should execute, due to some rule met by the agent. Because of the EAA's ability to tell other agents in the environment to run, the agent must be deployed in the very first phase of the environment setup. If the agent is not deployed first, the other agent will not be able to execute.

This chapter focuses on the different components that form part of the EAA, and gives a general overview of the agent, including the deployment of the agent. By understanding the various components that form part of the agent, allows for a better understanding of the operations of the EAA. Chapter 8 also focuses on the internal operation of the agent in terms of when to execute a different agent in the smart grid.

8.2 Environment Analysis Agent Executing Environment

The EAA is the most important agent executed in the SGMS, since the agent is responsible for analysing environmental data to inform other agents in the multi-agent system to run. Figure 8.1 shows the steps taken in phase one of the model setup component. The figure also demonstrates the components deployed for the EAA in the first phase.

Since the EAA is part of the first setup phase, it does not have any dependency on any other agents to set up. In terms of environment initiation and setting up the different nodes that will operate in the environment before it can execute, the EAA depends on the simulation environment for initiation.

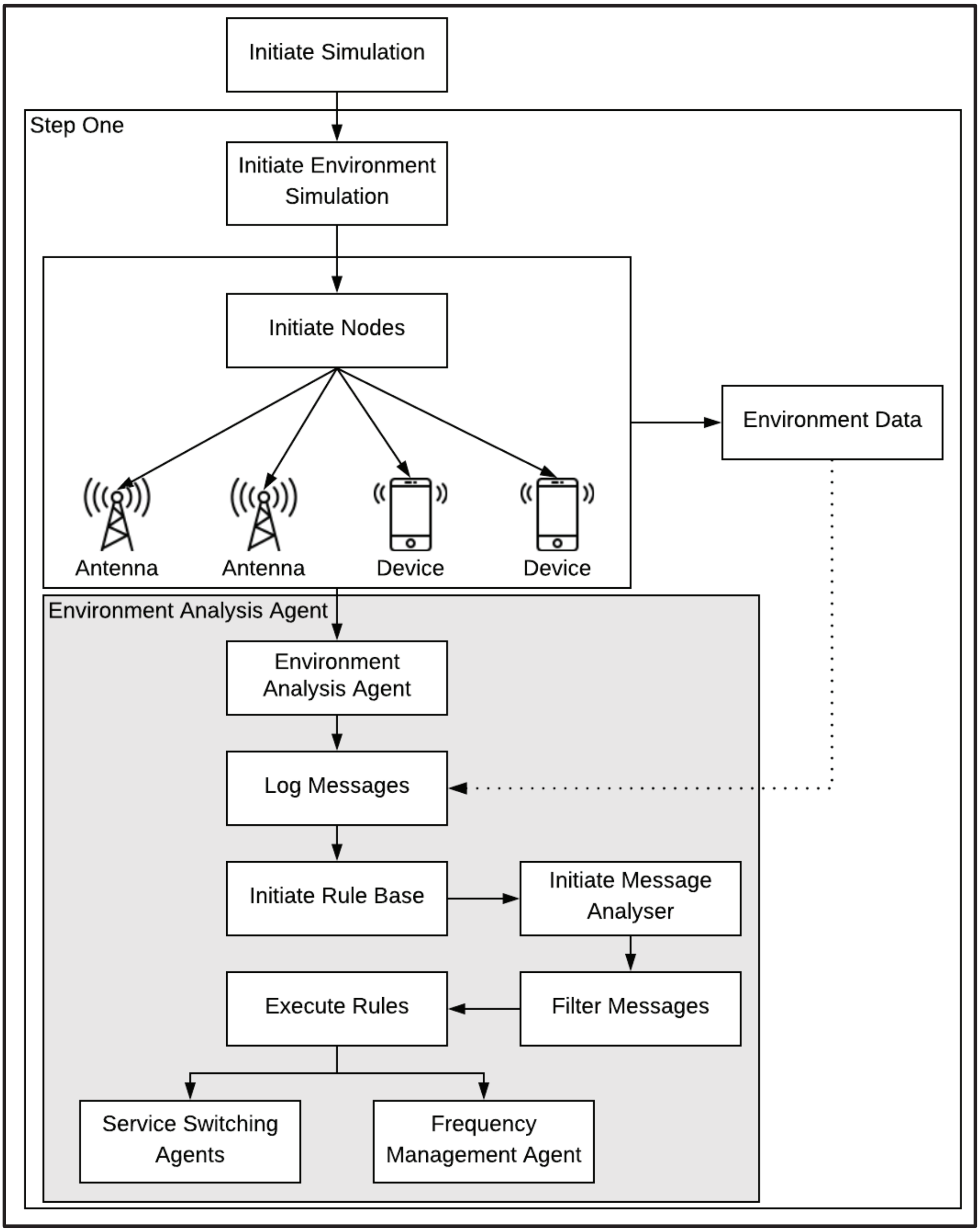

Figure 8.1: Environment setup phase one

The EAA has its own set of phases that must execute before the agent can operate effectively in the simulation environment. These phases include setting up sensors in the environment to gather information, setting up the agents' rule base and setting up message filtering and the analysing tools.

The sensors that are set up in the environment return essential information that can be used to make decisions related to agents that are dependent on the EAA. The decisions made by the agent determine which other agents should be executed in the environment.

Following the initialisation of the various sensors, the EAA sets up the rule base to be implemented in the multi-agent system. The rule base is a set of rules that are used by the EAA to make core decisions that ensure the core environment operates as required.

8.3 Environment Analysis Agent: Internal structure

The EAA cannot communicate commands to the environment, and is not used by any other components or agents to make the decision that makes the agent independent. The agent can make use of the elements as an aid to completing its tasks.

The EAA is composed of several of these different unique components. The components that make up the internal view of the EAA contain many different tools. Figure 8.2 shows all the various components that make up the internal state of the agent. Figure 8.2 also demonstrates the different component items that make up the component.

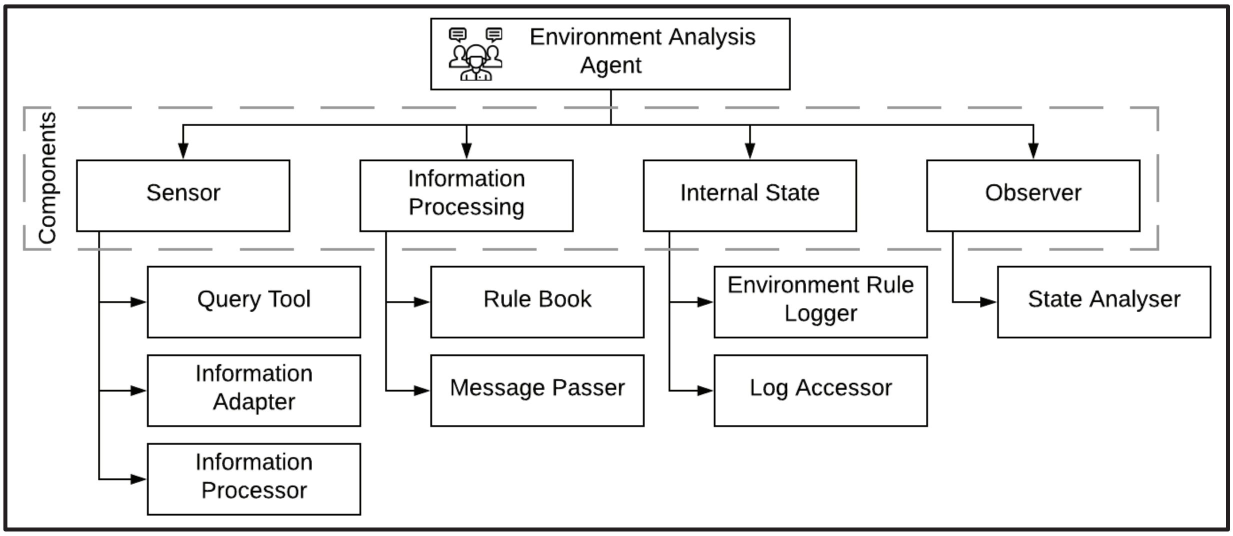

Figure 8.2: Internal structure of Environment Analysis Agent

8.3.1 Sensor Component

The sensor component has the responsibility of accessing environmental data that can be used by the agent. It focuses on internal and external factors relating to the environment. The sensor component uses a set of tools that allow for better control of the EAA sensor components. The set of tools used are listed and discussed in the following section.

8.3.1.1 Query Tool

The query tool has two responsibilities. It is responsible for the setup of the data access tools in the environment, and for gaining access to information and data that is consumed by the EAA.

8.3.1.2 Information Accessor

An information accessor is a tool that is responsible for accessing and collecting data stored in a database that is related to the environment in which the EAA operates.

8.3.1.3 Information Adapter

The information adapter is the tool that looks at the data gathered by the information accessor to decide which information is essential. The nonessential information is filtered out, and the agent uses only the essential information.

8.3.2 Observer Component

The observer component has most of the responsibility in the agent environment. It takes the responsibility of analysing logs via the environment analysis tool and, having filtered out the irrelevant records, for sorting out the essential records that will have a more significant effect on the environment. The observer component makes use of the sensor component to work as intended, since the data stored in the database is used by the observer component.

8.3.3 Information Processing Component

The Information Processing Component is responsible for handling information that was generated by the environment and ensuring that the information collected by the Internal State Component is in a clean and accessible state. The information processing component makes use of two components: a message parser and a rulebook to process the information. These two components are described in the next section.

8.3.3.1 Message Parser

The Message Parser is responsible for the sanitizing of information, making sure that only valuable and useful events are logged, and that all the unusable data removed. It does not tamper with the messages that were logged by the internal state logger component.

8.3.3.2 Rulebook

The Rulebook is a set of predefined rules that are applied to the logged messages. The component tells the message parser how to filter the messages by using a set of rules.

8.3.4 Internal State Component

The Internal State Component is a handler component which ensures that environment actions have consistent output. The internal state component is not accessible by other agents that operate in the smart grid management system, but the component does offer valuable information that will affect the other agents' operations.

The internal state component is made up of two logger components: the environment logger and the log accessor. These two components are explained in the following section.

8.3.4.1 Environment Logger Component

The Environment Logger Component continually executes in the environment to gather data regarding the actions and states of the environment. The stats and actions are stored for later use by the environment analysis agent.

8.3.4.2 Log Accessor Component

The logger tool allows the sensor component to access data logs that are stored in a database. The Log Accessor Component is responsible only for obtaining the data. It relies on other tools that form part of the information processing component to format the unrequired data.

Figure 8.2 shows the internal view of the agent and provides a broad overview of the agent's components. The components and tools are dependent on each other to perform their tasks. They are interconnected and communicate with each other to ensure that the required results are reached. Figure 8.2 has shown the connect between the different components, and where the different tools are associated. Having discussed the various components that form part of the EAA, it is important to look at how the EAA functions.

8.4 Functioning of the Environment Analysis Agent

The Environment Analysis Agent is the first agent that is executed in the smart grid management system. To make decisions, this agent has access to all the different sensors in the environment as well as the previous logs of the environment. One of the key objectives of the agent is to execute the service switching agent or the environment analysis agent, depending on sensor data from the environment.

Figure 8.3 shows an application flow diagram that illustrates the internal structure of the EAAs. The figure shows that once the agent starts up, it will be in a continuous loop, meaning that it will continuously execute on the smart antenna environment. This continuous loop ensures that the agent has the most up-to-date data available.

Figure 8.3 shows that the SSA has to fulfil a few different requirements before it can execute. The EAA accesses environment data per antenna, and counts the number of connected devices. Once the agent has the number of devices connected, it calculates the load of the antenna. The load is calculated by using the number of open spaces and the number of connected devices. When the load is more than 80% the SSA is requested to execute, otherwise it will again pull the environment data to determine the load.

The EAA also focuses on the devices that are connected to an antenna, and calculates the different load states of the devices that are in range of an antenna. When the number of connected devices is more than 25% of the devices, it will request the SSA to execute. When 30% or more of the devices have bad connections, the agent will check the antenna loads and execute the SSA when the load is more than 80%.

The agent also analyses the frequencies utilised by the antennas. When the frequency is pulled off an antenna, the EAA will check if the frequency is 0Hz. This means that the antenna went down for maintenance and came back up, or that the antenna disconnected all the connected devices, forcing the Frequency Management Agent (FMA) to execute. When the frequency is not 0Hz the neighbouring antenna's frequency is accessed and compared with the current antenna's frequency. When the frequency matches, the FMA is executed.

The EAA has to consider many different aspects before it can execute one of the other agents. The agent can only be successful when it has access to live, up-to-date environment data. When the agent attempts to make use of stored data to make decisions, the results will not always be considered beneficial.

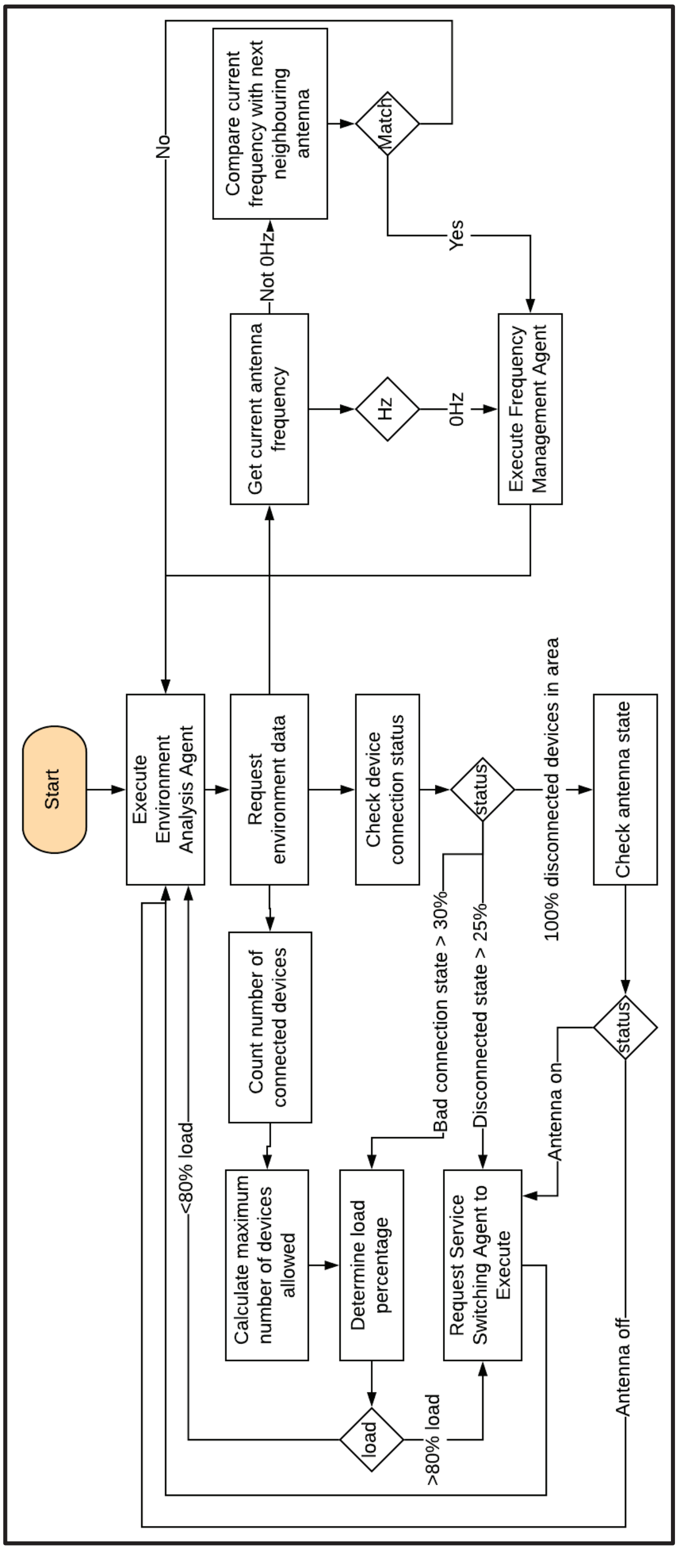

Figure 8.3: Environment Analysis Agent internal operations

8.5 Conclusion

The EAA can be described as the most important agent that operates in the SGMS, since it has the task of telling other agents what to do. The way it does this is by analysing the environment in which it executes and determining what agent should be triggered.

The EAA makes use of a set of components and tools to achieve this goal. The tools that operate in the environment are responsible for gathering data in log form from the environment, by making use of sensor components. The sensor components can access and adapt the data. The data gathered by the sensor component has to analyse the logs to filter out all of the unneeded logs.

The information that has been logged and filtered must be used to have a valuable impact on the environment. The information processing component has the responsibility of choosing how the data should be filtered, and it also has the burden of logging valuable events that will influence the other agents.

Understanding the internal structure of the EAA aids in understanding the different components and their tasks. The EAA adds value to the multi-agent system by aiding in knowing if a multi-agent system can be used to manage a smart grid's resource.

Chapter 8 has focused on answering the research question: *How can a multi-agent system be integrated into a smart grid system?* The research question can be broken down into different research questions. Chapter 8 shows the phase in which the EAA can be integrated into the smart antenna grid system. The chapter also focused on some of the components that form part of the agent. Chapter 9 covers the same research question covered in Chapter 8, but focuses on the Service Switching Agent.

Chapter 9 - Service Switching Agent (SSA)

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9.1 Introduction

The second phase of setting up the Smart Grid Management System (SGMS) sets up the Service Switching Agent (SSA). The SSA does most of the management since it is responsible for connecting devices to antennas. Apart from the device to antenna connection, the agent is also responsible for managing devices that have an inferior signal and disconnect from the antenna, while ensuring that there are not too many devices connected to one antenna at the same time.

The SSA requires some setup to ensure it executes as desired. The configuration of the agent includes setting up the different components, each with their own actions to manage. Some of the elements that form part of the SSA are responsible for handling messages, and others are responsible for accessing those messages. The structure of the agent and all the different components gives a clear overview of how the agent operates.

The structure and the execution phase are just as important as the internal operations of the smart antenna system. The internal structure of the SSA ensures that the agent can move devices to antennas that are available or under lower load. The agent makes decisions in the environment based on antenna loads and the device status in antennas.

Chapter 9 focuses on the structure of the Service Switching Agent and all the different components that form part of the SSA. Understanding the structure will aid in understanding where the agent fits into the smart grid management system.

9.2 Environment simulation setup

Figure 9.1 demonstrates the second phase of the SGMS setup. Phase one showed that the setup process starts by retrieving all the environmental information from all the various components that may contain some relevant data that might relate to some of the deployed nodes in the smart antenna grid, as well as some of the information that is exchanged between the different nodes in the environment.

The second phase entails initialising the SSA within some of the nodes in the network. in which the SSA has initialised the antennas and the devices. For the agent to be functional and active, there are a series of processes to follow which allow it to operate on the node.

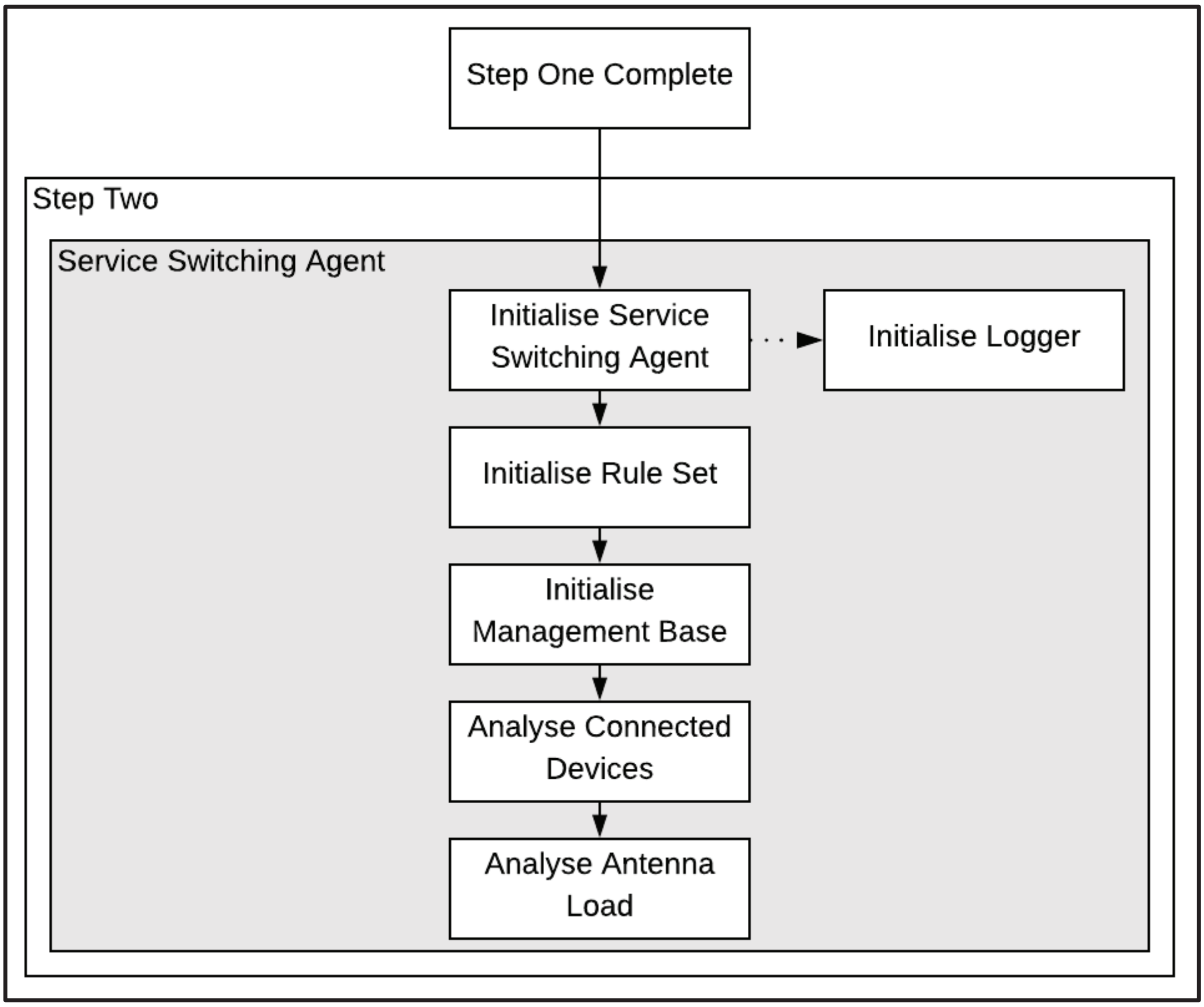

Figure 9.1: Environment setup phase two

The SSA initially starts by setting up the rules, which are predefined and enforced. As described in Chapter 7, the SSA has a set of tasks that enables better resource management, which includes ensuring that the environment is not under load and that the different devices are connected to the most suitable antennas. The rules set decides if the antenna is a suitable antenna.

Figure 9.1 also shows that the SSA is responsible for deploying and managing the rule set, which the agent must apply to the environment. The agent also has the responsibility of analysing the devices and the antennas to ensure that antennas are not number loaded and that the devices are connected to the antennas. The following section of Chapter 9 sets out to describe the internal view of the SSA.

9.3 Service Switching Agent internal overview

The SSA acts as a controller in the smart antenna environment that focuses on connecting devices and smart antennas to each other to ensure that the highest majority of devices are connected to an antenna. The SSA works with the EAA that flags the data of devices that are moving away from an antenna and into a new smart antenna sector. The EAA also flags antennas that have a large number of devices connected to them, so that the EAA can investigate if it can decrease the load by moving devices to different antennas.

Figure 9.2 shows all the components that make up a SSA. The components are configured to analyse for possible device disconnections in the environment, possible antenna overloads in the smart antenna environment, and any potentially weak connections between antennas and devices. The following section of the dissertation focuses on all of the components and tools that form part of the SSA.

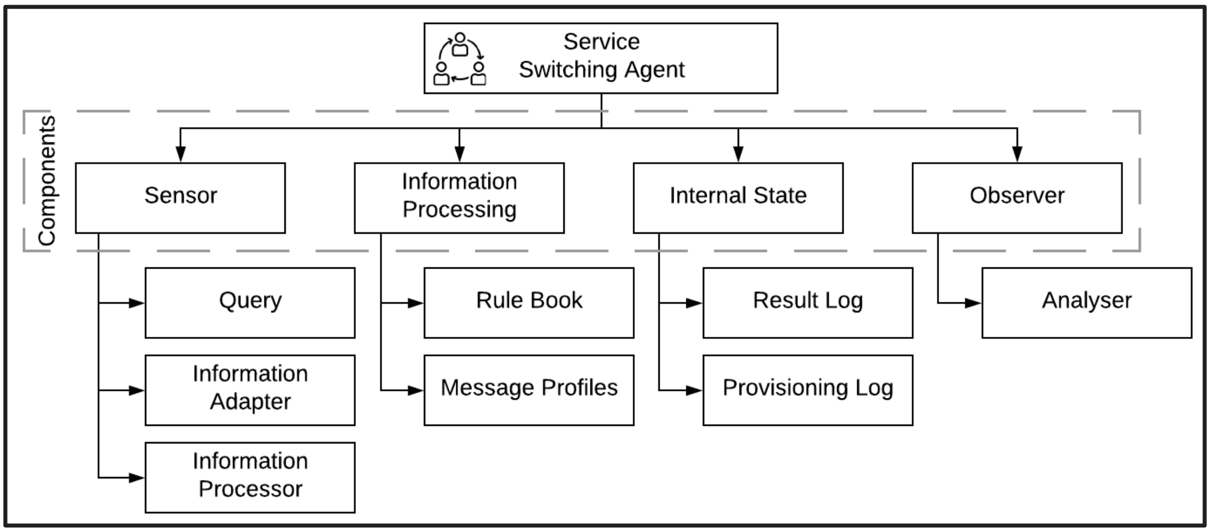

Figure 9.2: Internal Structure of Service Switching Agent

9.3.1 Sensor component

Figure 9.2 shows the sensor component as part of the agent hierarchy. The sensor component is responsible for accessing information from the environment by use of query access techniques. The sensor component can apply any information processing procedures to make the information more usable.

The sensor component is critical in the SSA, as it needs to send well processed and configured data to the agent to apply a set of rules. The following section focuses on the different tools that form part of the sensor component.

9.3.1.1 Query

The query is the component that is responsible for accessing data that is generated by the environment and the environment management agent. The way it does this is by making use of a SQL Query to retrieve data from a database.

9.3.1.2 Information Adapter

The information adapter has the sole responsibility of adapting the data format that is retrieved by the query tool. The information is adapted for use by other components to make an informed decision.

9.3.1.3 Information Parser

The information parser performs the act of parsing the information that is adapted or not adapted to the different components that required the data. Some of the components that receive the data from the parser can adapt the information as well.

9.3.2 Information processing component

The information processing component has most of the responsibility, as this component is responsible for comparing the current environmental data to the data that was processed in the sensor component to apply a set of predefined rules. The rules are used to determine if actions that the agent performed have made an impact in the environment. The information is logged as a measure of effectiveness. The following section contains short descriptions of the different tools that form part of the information processing component.

9.3.2.1 Rulebook

The rulebook contains a list of predefined rules. The rules defined in the rulebook can be applied to the agent or to data that was logged to ensure better results. The rulebook is used when processing valuable information.

9.3.2.2 State profiles

The state profiles are responsible for the classification of the messages that are logged by the Smart Antenna System. The classification rules are defined in the rulebook.

9.3.3 Internal state component

The internal state component is responsible for updating the information processing component and what state the agent is in after the agent has executed. All the data that has been generated by the internal state component can be logged using the query component. Recorded data are accessible to all the other agents in the smart antenna management system and can provide valuable information with regard to agent results. The two tools that form part of the internal state component are described in the following section.

9.3.3.1 Result Log

The result log shows the result the agent has achieved by executing a set of rules in the environment.

9.3.3.2 Provisioning log

The provisioning log is used to access the records that are generated in previous executions of the service switching agent.

9.3.4 Observer Component

The observer component continuously receives data from the information processing component to determine the actions to perform. It uses the set-out rule base. It decides whether to perform an action based on the information that is gathered and on a set of rules. The observer components do not make use of any tools to execute. Having discussed the various components that form part of the SSA it is important to look at how the SSA functions.

9.4 Functioning of the Service Switching Agent

The SSA is responsible for managing antenna and environment loads. There are many different aspects considered by the SSA before executing. At the same time, the agent does not operate in the same fashion as the EAA because the EAA operates at a constant rate without having to stop, whereas the SSA has an ending state, as can be seen in Figure 9.3.

The first thing the SSA does is to get an antenna's data and determine the state of the antenna. To determine the state, the agent checks the number of connected devices and the available space. If the antenna's load is more than 80% the antenna is considered to be under very high load. The agent will then need to gather all the devices that are connected to the weak state antenna, as well as all the antennas that are within its range.

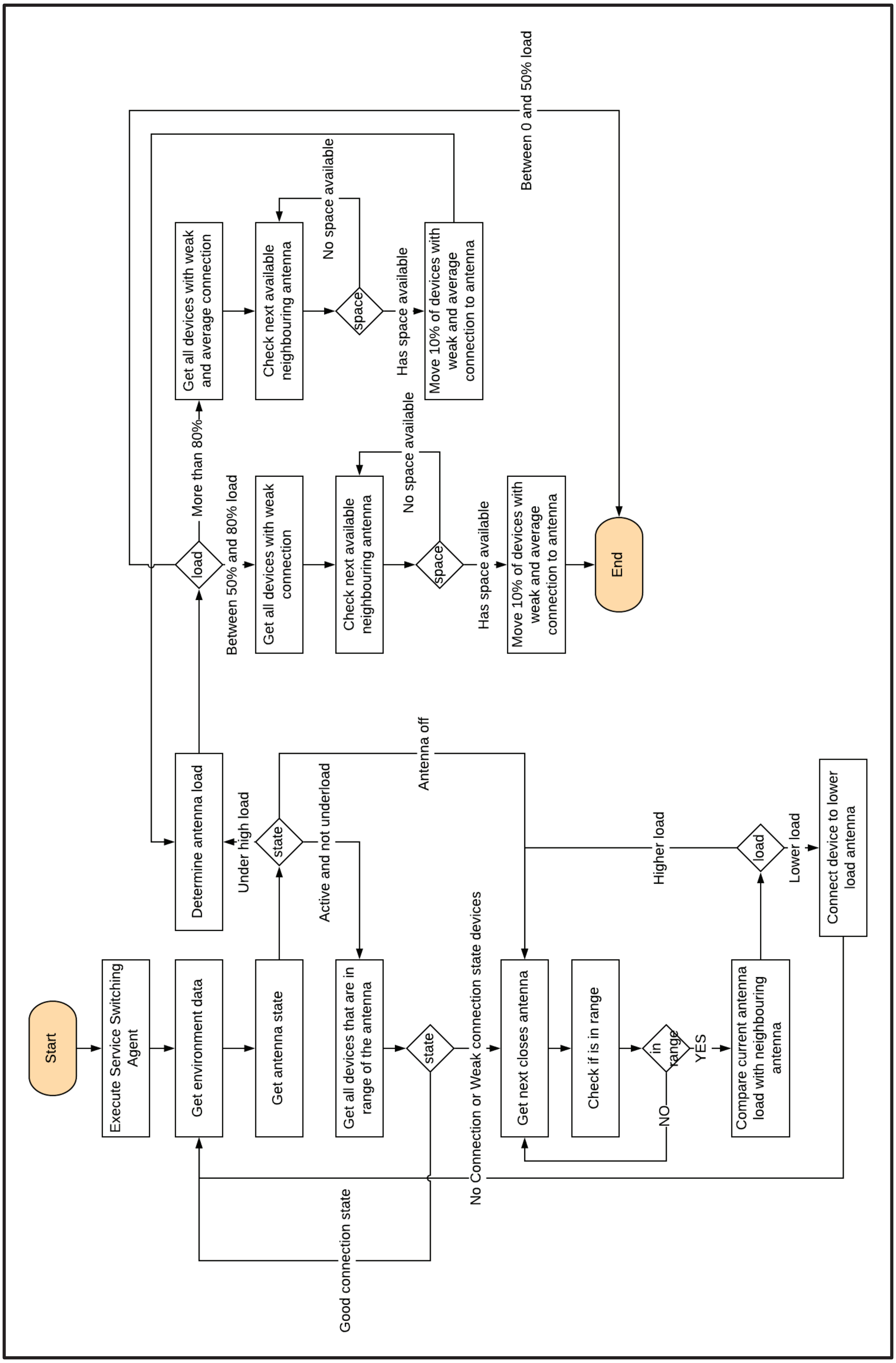

Figure 9.3: Service Switching Agent internal operations

If there is another antenna in range, the SSA connects the device to that antenna. When the antenna has a load of between 50% and 80% the agent will have the same action as when it is more than 80% load. The key difference is that the disconnected devices and the health of the neighbouring antenna are considered.

When an antenna is off in the environment the health of the environment will be affected, as there will be a large number of devices that will not have connections available. The SSA will check the antennas that are in range of the disconnected devices and move the devices to the other antennas if they have space available. which can cause the load to increase. The agent will check the antenna loads again to move a device. The agent’s execution will stop when the agent notices that there are no more possible changes.

9.5 Conclusion

The SSA is responsible for handling resources related to devices and antennas in the SGMS. It does this by moving devices to different antennas when there are too many antennas on one, and it takes responsibility for ensuring that all devices are connected to an antenna when it is in range of an antenna.

The SAA is made up of many different components. The sensor component is responsible for accessing the data of the environment that will be used by other components of the agent. The information processing component is responsible for gathering information. It also has the responsibility of ensuring that the information is cleaned up.

The internal state component is responsible for providing that the internal state of the agent is in good health, and logging the actions performed by the agent. The last component that forms part of the SSA is the observer component, which is responsible for ensuring that all operations delegated to the environment have a positive effect on the environment. Should all operations not have a positive effect on the environment, the observer component should take note and adapt.

Chapter 9 has focused on the Service Switching Agent with the primary goal of aiding in answering the research question: *How can a multi-agent system be integrated into a smart grid system?* Chapter 9 focused on one for the agents that form part of the multi-agent system and concentrated on how the agent forms part of the multi-agent system. The chapter does not, however, answer the research question, but helps to achieve the research objective of understanding how the SSA fits into the multi-agent system.

The following chapter focuses on the Frequency Management Agent, concerning what the agent does, how the agent is deployed, the different components that form part of the multi-agent system, and how the agent operates in different environmental scenarios. The aim of Chapter 10 is to aid in answering the research question: *How can a multi-agent system be integrated into a smart grid system?* The chapter also helps in achieving the research objective of defining how the FMA fits into a multi-agent system.

Chapter 10 - Frequency Management Agent (FMA)

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10.1 Introduction

The Frequency Management Agent (FMA) is the last of the three agents to be deployed in the Smart Grid Management System (SGMS), as it is part of the second phase. The environment analysis agent is responsible for notifying the FMA to execute when the environment notices frequencies of adjacent antennas that match, or when an antenna that was down is brought back up. When frequencies of adjacent antennas are conflicting, devices cannot easily switch between different antennas.

The FMA is made up of different components that contain various tools that help manage frequencies in the environment. The components are responsible for logging, formatting and analysing messages that have been logged to achieve a combined goal.

This chapter focuses on the structure of the FMA, and on the different components that form part of it. The structure of the FMA aids in understanding where the FMA fits into the multi-agent system.

10.2 Environment simulation setup

Figure 12.1 shows that the FMA is part of the third step in the environment setup, since it is dependent on the EAA. The first step was to collect environmental information using the various sensors that provide valuable information which aids decisions that the agent must make.

Most of the information that is used by this agent is related to the smart grid antennas and the connections between different smart grid antennas. Thus, the antennas and the link are initialised in the third phase, as can be seen in Figure 10.1.

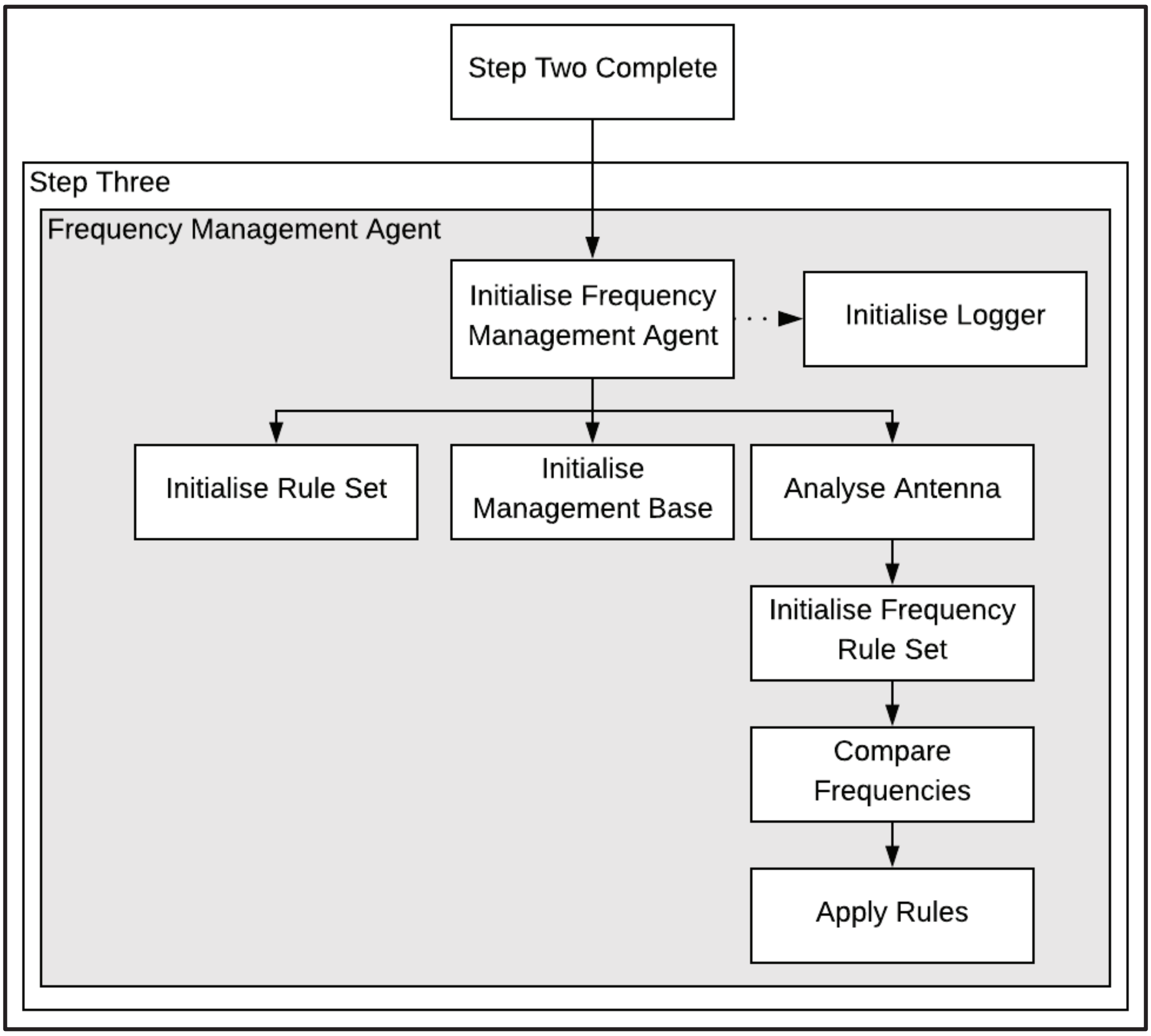

Figure 10.1: Environment setup phase three

Figure 10.1 shows that the environment setup requires that the FMA rule base is initialised. The rule base used by the FMA informs the environment to act. The rule base is set up as static, where rules will not change when running, because the smart antennas need to work in the same manner every time the agent is started up.

10.3 Frequency Management Agent internal overview

The FMA acts as a controller for frequency distribution in the smart antenna grid. Its primary focus in the smart grid is to ensure that neighbouring antennas do not utilise the same frequency, and if neighbouring antennas do use the same frequency, they should not overlap signals. The overlapping of frequencies is disruptive. The FMA should be used only by antennas, and not by the other nodes in the environment.

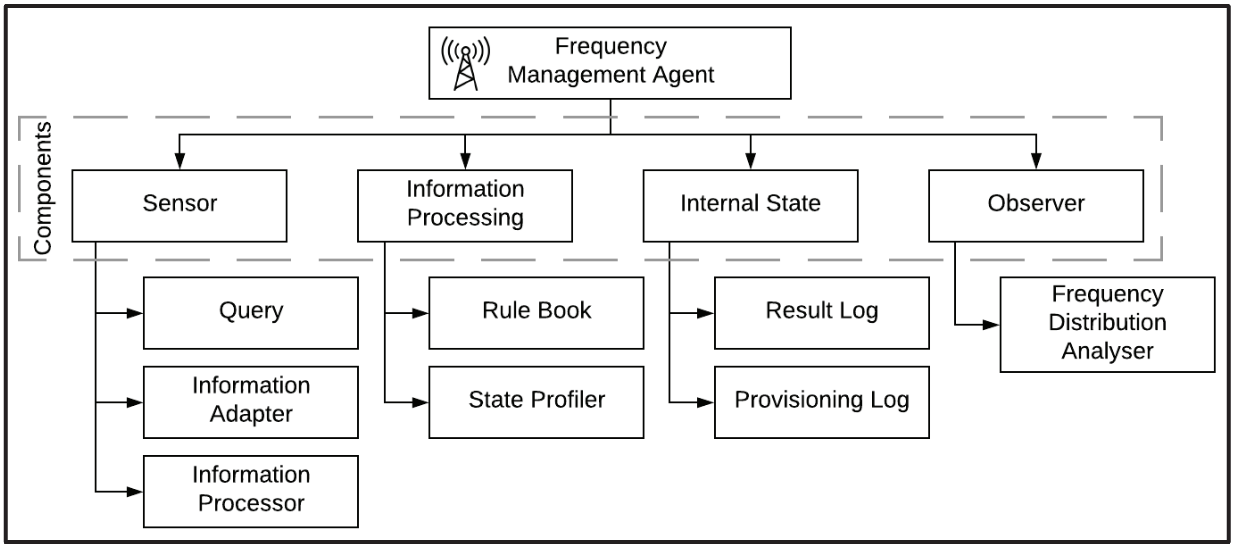

Figure 10.2: Internal Structure of the Frequency Management Agent

The FMA is composed of several different components containing different tools. All the components are directly focused on the FMA. Figure 10.2 shows the various components utilised by the FMA. The components analyse the smart antenna environment, searching for the best possible solution.

10.3.1 Sensor component

The sensor component is the analysing component that has the job of retrieving information that comes from internal and external factors. It utilises a set of tools to have better control. The sensor component's tools are discussed in the following section.

10.3.1.1 Query

The query component has the responsibility of accessing the correct data that is generated by the environment.

10.3.1.2 Information Adapter

The information adapter searches through the logged data captured in the antenna to find the correct data. The data is used to track the actions of the FMA.

10.3.1.3 Information Parser

The information parser is responsible for passing information extracted by the information adapter between different nodes in the environment.

10.3.2 Internal state component

The internal state component logs messages that are generated by antennas when the agent has executed and stored those messages in a database. The logs are accessible to all the other nodes that are part of the FMA. The internal state component makes use of various tools to complete its operations. These are listed in the following sections.

10.3.2.1 Results logger

The results logger is responsible for logging the results after the FMA has executed.

10.3.2.2 Provisioning logger

The provisioning logger is used to access logs that are generated by the FMA. It makes use of an SQL command to retrieve the information.

10.3.3 Observer component

The observer component is a continuously active component that keeps looking at the gathered logs while the agent executes. This data is then analysed by a frequency controller, which has the responsibility of flagging messages that need to be handled.

10.3.4 Information processing component

The information processing component takes the responsibility of decoding generated logs. It filters out unwanted results and focuses only on the usable data. The different tools that form part of the information processing component are discussed in the following sections.

10.3.4.1 Rulebook

The rulebook contains a list of rules that must be applied by the agent to ensure better results and cleaner logged messages. The rulebook in the FMA is static, as the requirement never changes.

10.3.4.2 State profiles

The state profiles are responsible for the classification of the messages based on the environment data. The classification determines if the agent action has a positive effect on the environment. Having discussed the various components that form part of the FMA it is important to look at how the FMA functions.

10.4 Functioning of the Frequency Management Agent

The FMA is responsible for handling frequency problems in the smart antenna grid environment. Figure 10.3 shows a flow diagram of the FMA, which illustrates that the agent is not a continuous executing unit, but rather that it executes once if triggered.

The FMA initially builds a list of frequencies that can be used by an antenna in the environment. Once the list has been set up, the agent checks an antennas frequency. If the antenna has a frequency of 0Hz it means that the antenna is down, and requires a new frequency assigned. The FMA will access a random frequency from the generated list to assign a frequency.

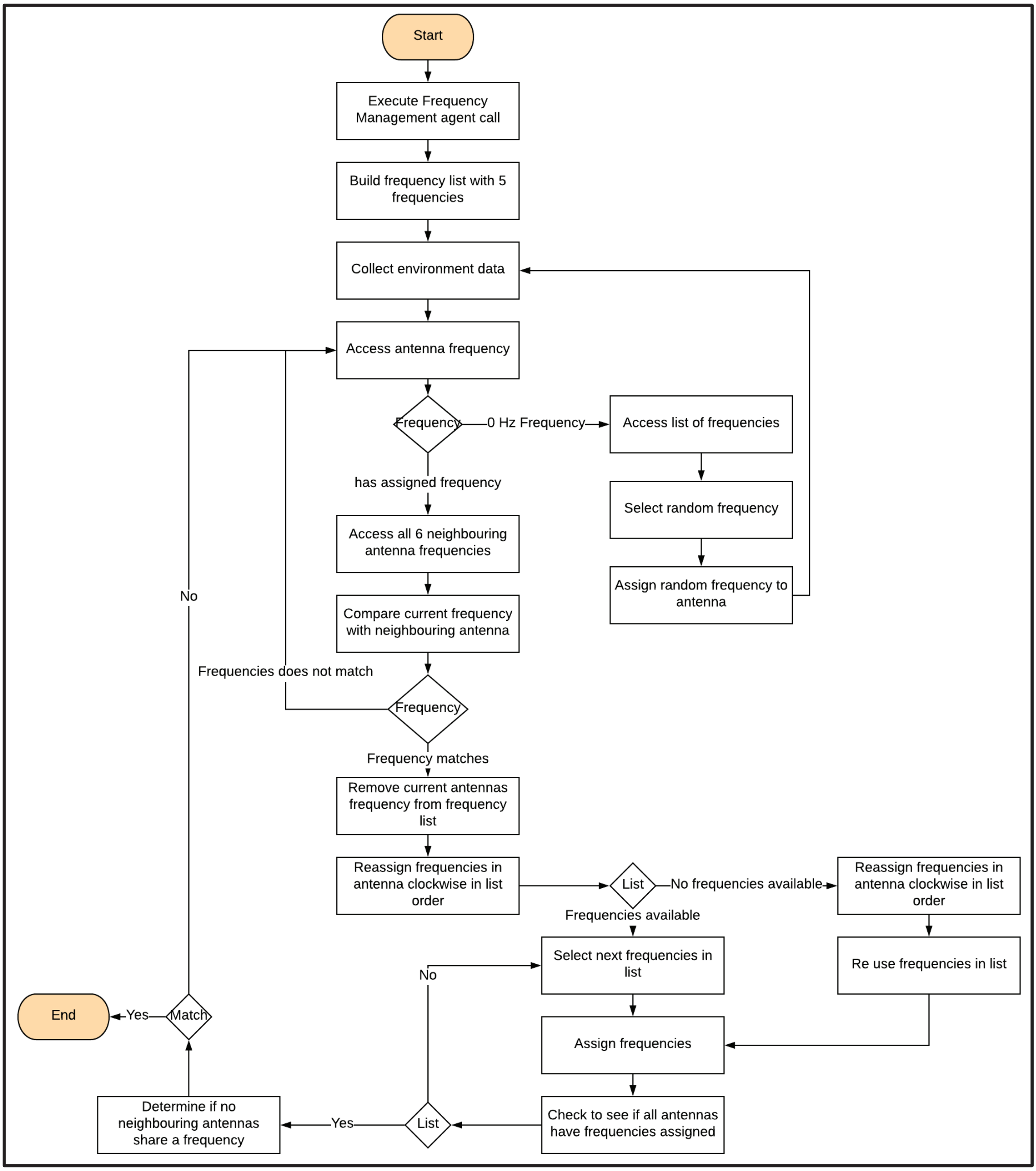

Figure 10.3: Frequency Management Agent internal operations

The agent will check one of the six neighbouring antennas' frequencies. When it sees that a frequency matches, the frequency is removed from the available frequency list. The agent will assign a new frequency to all the antennas in a clockwise fashion. Once all of the antennas have been assigned a new frequency, the agent checks for other conflicts in frequencies. Before it exits, the agent will execute until all antennas have a frequency that is not conflicting.

10.5 Conclusion

The FMA manages frequencies by comparing the frequencies of different agents to find a pattern to apply on the antennas. The components that allow frequency management include the sensor component that analyses environmental data to be used, and the internal state component that stores messages and saves states after executions.

The information processing component is responsible for filtering out unneeded data and logging necessary data, and the observer component uses the logged data to determine what the rulebook entails. The lagged information also helps the agent make decisions.

The FMA structure demonstrates how the agent will operate in the Smart Grid Management System. Showing where the agent fits into the multi-agent system aids in the understanding of how the agent will be integrated into the multi-agent system.

The FMA starts by generating a list of frequencies that it can use. The next phase is to check that the antenna frequency is 0Hz, meaning that the antenna is recovering from maintenance and requires a new frequency assigned to it. When the frequency is not 0Hz, the agent checks all the adjacent antennas. When the agents finds two antennas that share the same frequency, the agent will reassign the neighbours and the current antennas.

Chapter 10 focuses on the Frequency Management Agent. One of the chapter's main goals is helping to answer the research question: *How can a multi-agent system be integrated into a smart grid system?* The chapter focuses on the agent that forms part of the multi-agent system, and how the agent works.

Chapters 8, 9 and 10 in combination have explained how the different agents fit in to the multi-agent system by describing the phases in which the agents are deployed as well as their tasks in the system. Chapter 10 has contributed to achieving the research objective on understanding how the agents fit into the multi-agent system.

Chapter 11 focuses on the model implementation by examining the different components that form part of the smart antenna grid model simulation. The chapter covers the agents responsible for controlling the model environment, the components they use, and how the agents work.

Chapter 11 – Smart Grid Management System prototype implementation overview

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11.1 Introduction

The prototype implements the SGMS model that contains a set of agents that manages resources. The simulation contains a set of agents including device movement agents and antenna drop agents that aid in simulating the Smart Grid environment that was not discussed when the SGMS model was.

Simulations replicate a software solution, a hardware solution, or a combination, whereas a prototype focuses on a software or hardware solution to illustrate a concept. When a prototype is written using software, many different aspects must be considered and handled to ensure that a proper result is found. The simulation environment provides a visual representation of a smart grid system that demonstrates the operations of the different nodes.

Because the smart grid is a large and complex system which has many different users that rely on it providing a service, it is more feasible to use a prototype environment that allows experiments to be performed without influencing the actual operating environment.

A smart antenna grid is made up of different devices that should move around in the environment in a non-random fashion. The smart grid system also has communication channels and antennas that are placed in a geographic area. The simulation environment makes use of a set of agents that are not responsible for resource management in the smart grid, but rather execute the smart grid nodes and control them. Understanding the simulation environment and the different components that form part of it, aids in answering one of the research questions related to how different agents are integrated into a multi-agent system, since the various agents control the simulation environment.

This chapter focuses on all the different aspects that were used in the smart antenna system prototype, and what the various elements do in the prototype environment to ensure that the implementation reaches a result. Chapter 11 aims to give a clear image of the operation of the multi-agent system in the simulation. The chapter also demonstrates some of the visual interfaces that were used in the model's implementation.

11.2 Environmental states

A prototype environment can have different states to illustrate the health of an environment. The different states of the environment are shown in Table 11.1.

Table 11.1: Smart Grid Management System environment states

Well-functioning:	A smart grid is well functioning when the majority of communication devices have a communication link with antennas and are stable. The antennas must also manage an overloaded environment and keep many devices connected to antennas without disconnecting most of the devices. Frequencies that are not repeating between neighbouring antennas ensure that the frequency for the environment is in a well-functioning state. If demand in the smart antenna system cannot be met, and neighbouring frequencies are the same, then the environment is not well-functioning.
Risky:	A risky state in a smart grid is when the system starts to see a degrade in services provided to devices. When many devices cannot obtain a connection to an antenna, and when many devices get disconnected from antennas, then the environment enters a risky state. When antennas share frequencies in smart antennas that are next to each other, then the environment is at risk.
Dangerous:	A dangerous state in a smart grid means that the different hardware components that are responsible for the communication network fail. Failure between various nodes on the network makes the environment dangerous, which influences different device nodes on the grid by not being able to connect to antennas. The inability of antennas to manage and assign frequencies in the smart antenna grid can force the grid into a dangerous state.

11.3 Prototype Tools

The prototype was built using a set of software tools. The software tools used are listed in Table 11.2 below.

Table 11.2: Tools used in prototype

Tool	**Use**
C# using .NET framework 4.5	Programming language used to write the prototype.
Visual Studio 2015 Professional	Integrated Development Environment (IDE) that provided facilities that aided in the development of the prototype.
Microsoft SQL Server Express 2012	Storage mechanism that stored data that was generated by the agents or the environment of the prototype.
SQL Request	Used to write data to a database and to read data from a database.
Microsoft forms	Used to build the user interface.

11.4 Smart Antenna Grid Prototype

The prototype aims to ensure that the smart antenna environment is stable and that more users can connect to the smart antenna grid with fewer disconnections in the environment. Figure 11.1 shows the different layers that form part of the Smart Grid Management System prototype.

The simulation environment layer contains a set of agents that model the smart antenna grid simulation environment. The simulation environment also includes a set of agents that are used to model different scenarios which include creating frequency disputes between antennas in the environment. The other layers shown in figure 11.1 focus on the multi-agent system agents that manage resources in the smart antenna grid and the helper agents. The different layers are covered in the next section of this chapter.

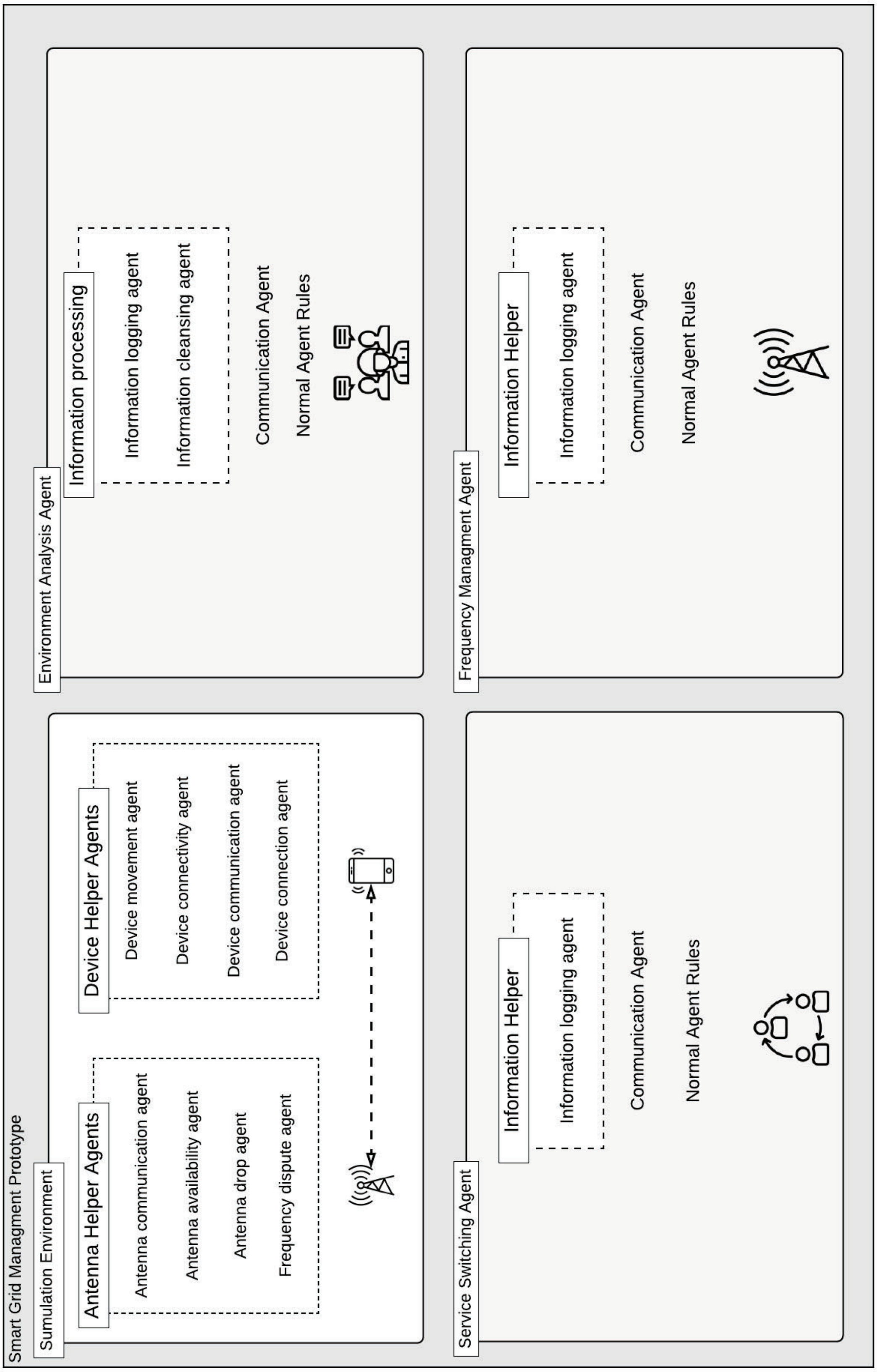


Figure 11.1: Smart Grid Management System Prototype environment structure

11.5 Simulation Environment

According to Perros (2009), a simulation is created with the idea of manipulating and changing variables known as controllable states. Simulating a smart antenna grid consists of many different components that include the physical hardware components and the software components of the simulation. A simulation model is the process of building and designing a new model based on the design of an existing model, to understand the implementation or to perform experiments on the simulation environment.

The smart antenna grid simulation environment contains many different agents to ensure that the simulated environment is as close to the real environment as possible, by having an implementation that interacts in the same way. The following section describes the various agents that make up the simulation environment.

11.5.1 Device helper agents

Because a device is not purely software related, the agents that operate in the environment do not entirely focus on the software aspect of the simulation, but also focus on the human interaction of the devices to make the simulation environment as realistic as possible. Each one of the devices in the smart grid system is independent of the other nodes in the smart grid system. They have their actions to take, and their actions are not influenced by other agents.

Figure 11.2 shows the different agents that make up the device. It shows that all the agents make use of the same simulation environment data to make decisions.

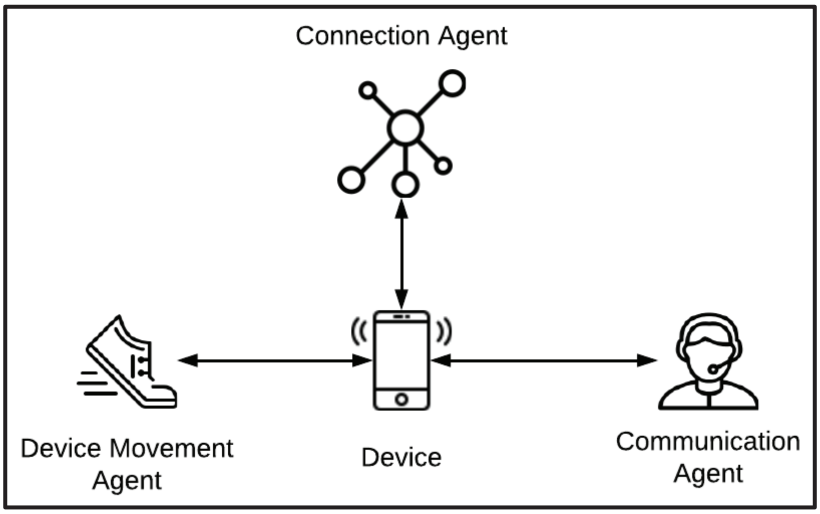


Figure 11.2: Agent communication

11.5.1.a Device movement agent

The device movement agent is responsible for simulating the movements of the different devices in the smart grid environment. It determines the devices' movements by using data that was generated in previous movements. The device movement characteristics are generated when the smart grid environment is initialised and movement gets assigned to devices.

The device movement agent requires a starting position that should be provided by the environment. The starting position is used to create a pattern for the device to follow, to ensure accuracy of the simulation. At the same time, the device will not be forced to use the same pattern all the time in all the runs. There will also be some other movements in the antenna's environment, based on randomisation. This movement is the only randomisation that runs in the smart antenna environment.

One of the main problems of having an agent to simulate movement is the lifelikeness and the movement speed of the devices. The agents regulate movement regarding times and speeds. Having a device moving at the same time in the same direction over the environment means that the other agents in the smart environment will repeatedly make use of the same data.

Figure 11.3 demonstrates the execution sequence of the device movement agent. It shows that there is a large dependence on previous movements to determine what the next movement is to be.

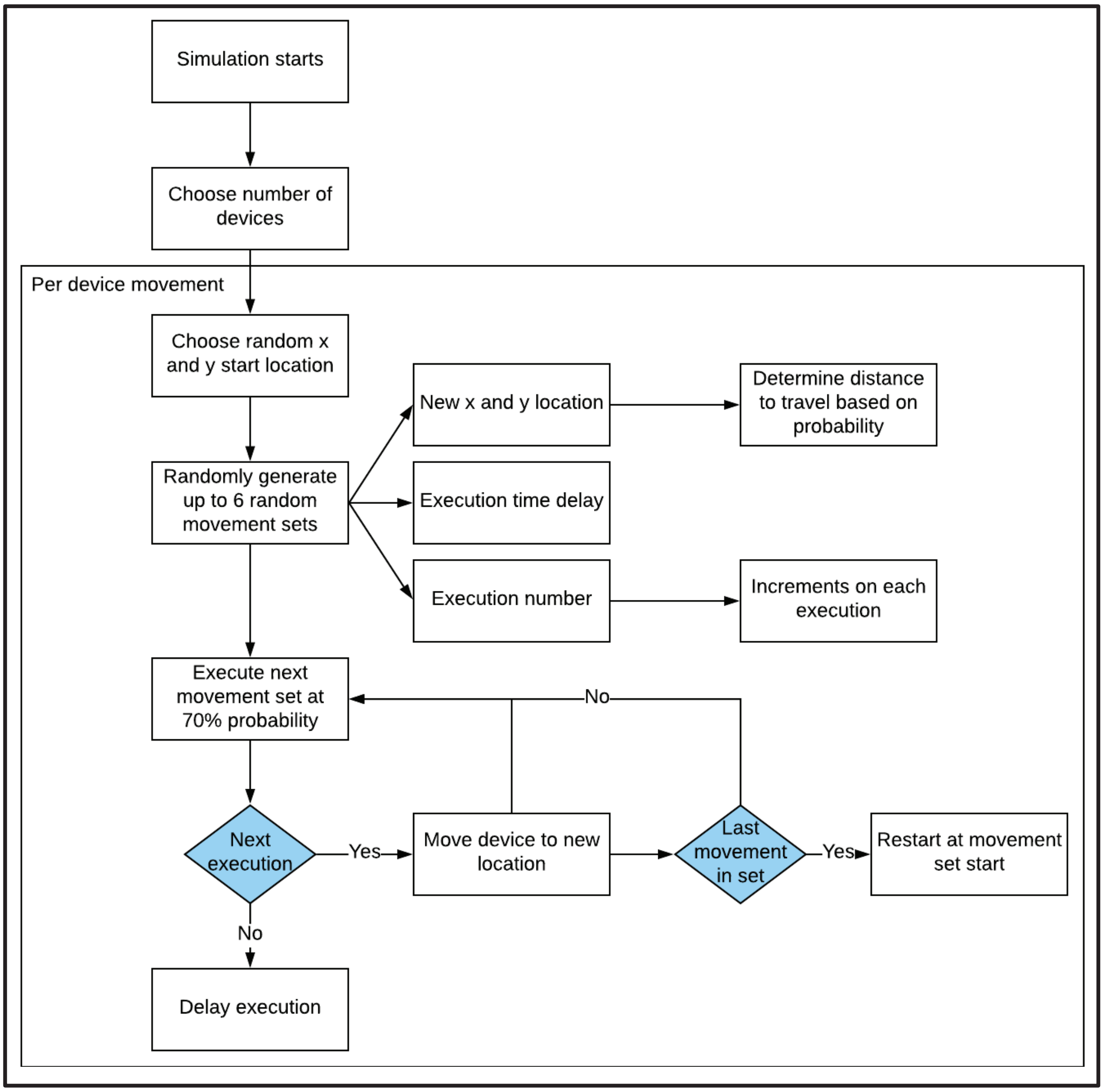


Figure 11.3: Device movement agent execution sequence

11.5.1.b Device connectivity agent

The device connectivity agent lives in the simulation environment, making use of a decision tree. The agent has the responsibility of connecting a device to an antenna. When a device relates to a smart antenna system, there is no certainty that the device will connect to an antenna, as the antenna determines if it wants to accept the connection.

The device will usually poll the antenna to see if a connection to the antenna is possible. Only when the antenna accepts a device, will the device connect to the antenna, thus changing the antenna's status to connected device. Figure 11.4 shows the connections between antennas and devices.

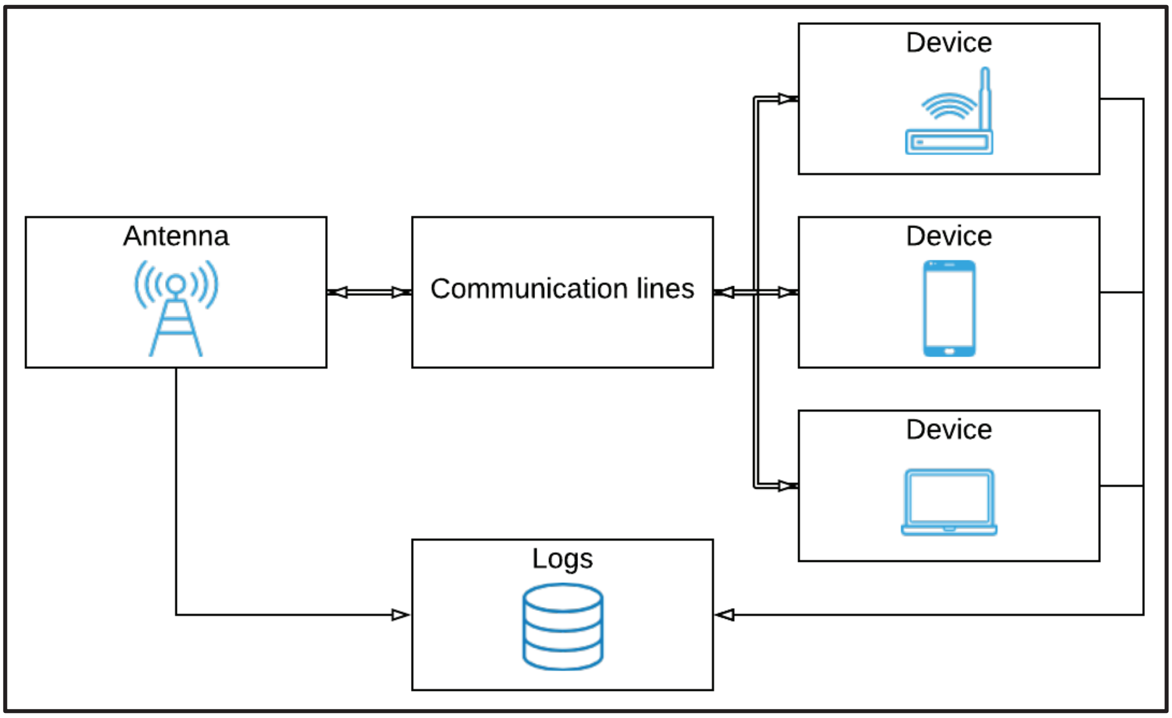


Figure 11.4: Device antenna connection

11.5.1.c Device communication agent

Devices in the simulation environment must have a way of initialising and ending communication between antennas and devices. This agent does not focus on phone calls on the smart antenna network, but instead focuses on network communication, including 5G and HSDPA communication standards.

The device communication agent only requires the device's current connection status and the information of the antenna to which it is connected. The device is solely responsible for communication between the device and the antenna. It is responsible for input and output of communication from the antenna, and communication to the antenna. The connection request occurs randomly. There are no patterns of communication, but preferably there is a wave of communication that dies down.

What makes a device-to-antenna communication complicated is that the communication points keep moving around in the environment. In the simulation environment, one device will not constantly be connected to the same antenna.

Communication between devices is done via an antenna. In some scenarios, many different antennas need to communicate with each other to make communication possible between two devices. Figure 11.5 shows that two devices can communicate with each other via an antenna and antennas can communicate with each other as well. The antenna to antenna communication is covered in the next section of the chapter.

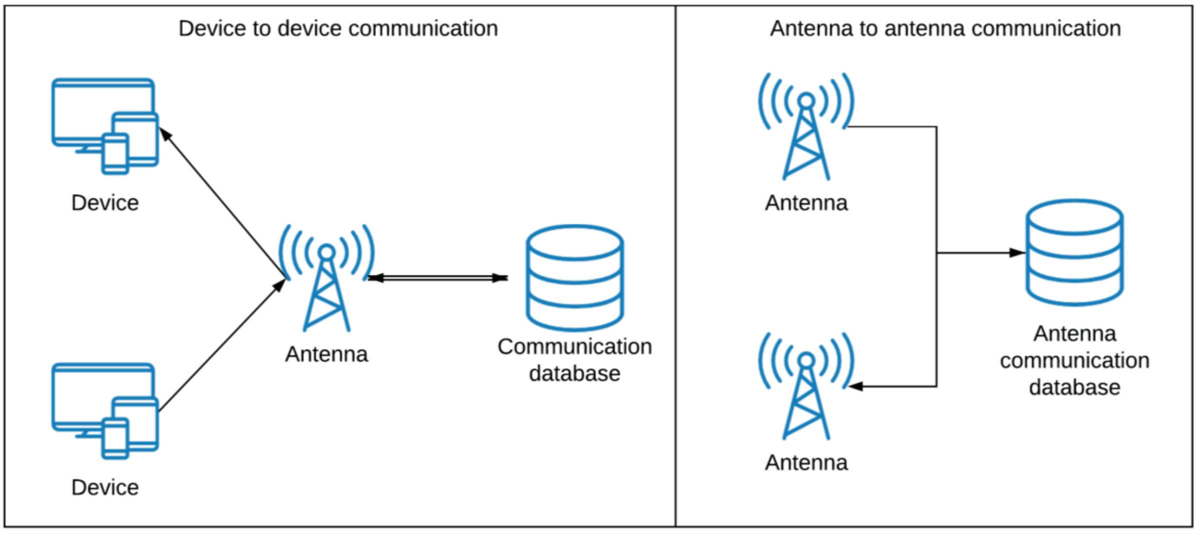


Figure 11.5: Device-to-device communication

11.5.2 Antenna helper agents

The antenna is the most crucial part of the simulation as it is responsible for most of the data that is run over the smart antenna grid. The antenna's simulation has many different components and aspects to consider. All the various agents that operate on the antenna are covered in the following section.

11.5.2.a Antenna communication agent

Antennas in a smart grid can communicate with other antennas to share agent information or device communication requests, making the antenna-to-antenna communication one of the most common communication lines in the smart antenna simulation. As with device-to-antenna communication, the connection sends and receives data. Figure 11.6 shows the communication structure between different antennas.

The interaction between different antennas requires constant contact to ensure that no message request is sent between antennas, but rather a continuous stream of data. Antennas can also communicate frequencies between each other to ensure that neighbouring antennas do not have the same frequency. At the same time, devices communicate with each other by using antennas, which places a great deal of pressure on the antenna.

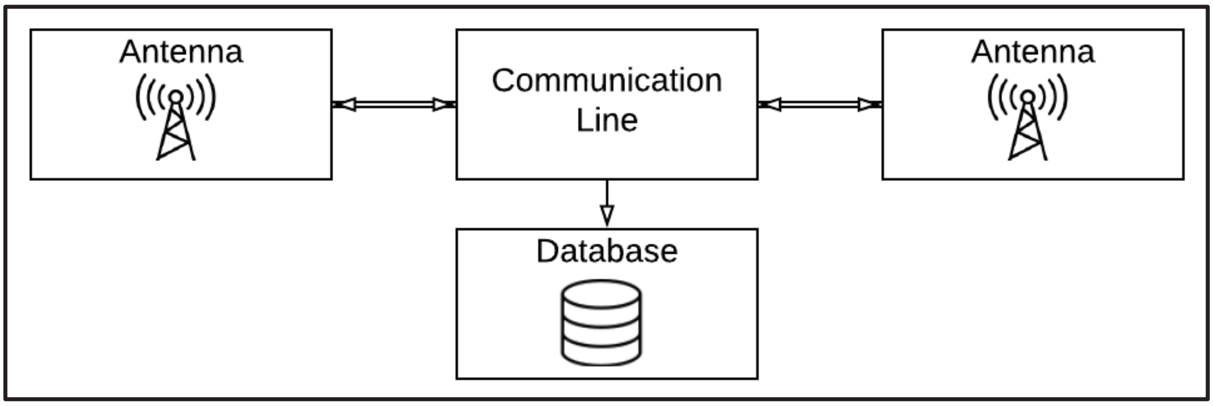


Figure 11.6: Antenna-to-antenna communication

11.5.2.b Antenna availability agent

Not all the agents that operate in the simulated environment have the responsibility of ensuring that the smart antenna system functions as desired. The antenna availability agent will simulate maintenance that might happen in the smart antenna system, by shutting down an antenna.

The antenna availability agent does not require a lot of environmental information to make decisions. The antenna availability agent only needs the current antenna state to make decisions. If an antenna is available, the antenna might be dropped, meaning that all the connected devices will be disconnected, and some other antennas might get a higher load.

The agent will monitor whether an antenna should go down by looking at the connected devices and the adjacent antennas. Once an antenna has gone down the agent must bring the antenna back up, which entails providing connections to the devices that get connected to the smart antenna systems.

11.5.2.c Frequency dispute agent

There is a small possibility that neighbouring antennas will share the same frequency in the smart antenna simulation. With a limited amount of frequencies available in the smart antenna environment, the antennas should manage the frequencies better.

In the simulation, the frequency dispute agent ensures that a scenario will happen, where one or more antennas will be forced to have the same frequencies as their neighbouring antennas. The selection of the antenna on which to execute the frequency dispute agent is not random, but somewhat selective. The agent will look at the agent’s neighbours and change its frequency to one of the neighbours'. The process to get two adjacent antennas to have the same frequency is demonstrated in Figure 11.7.

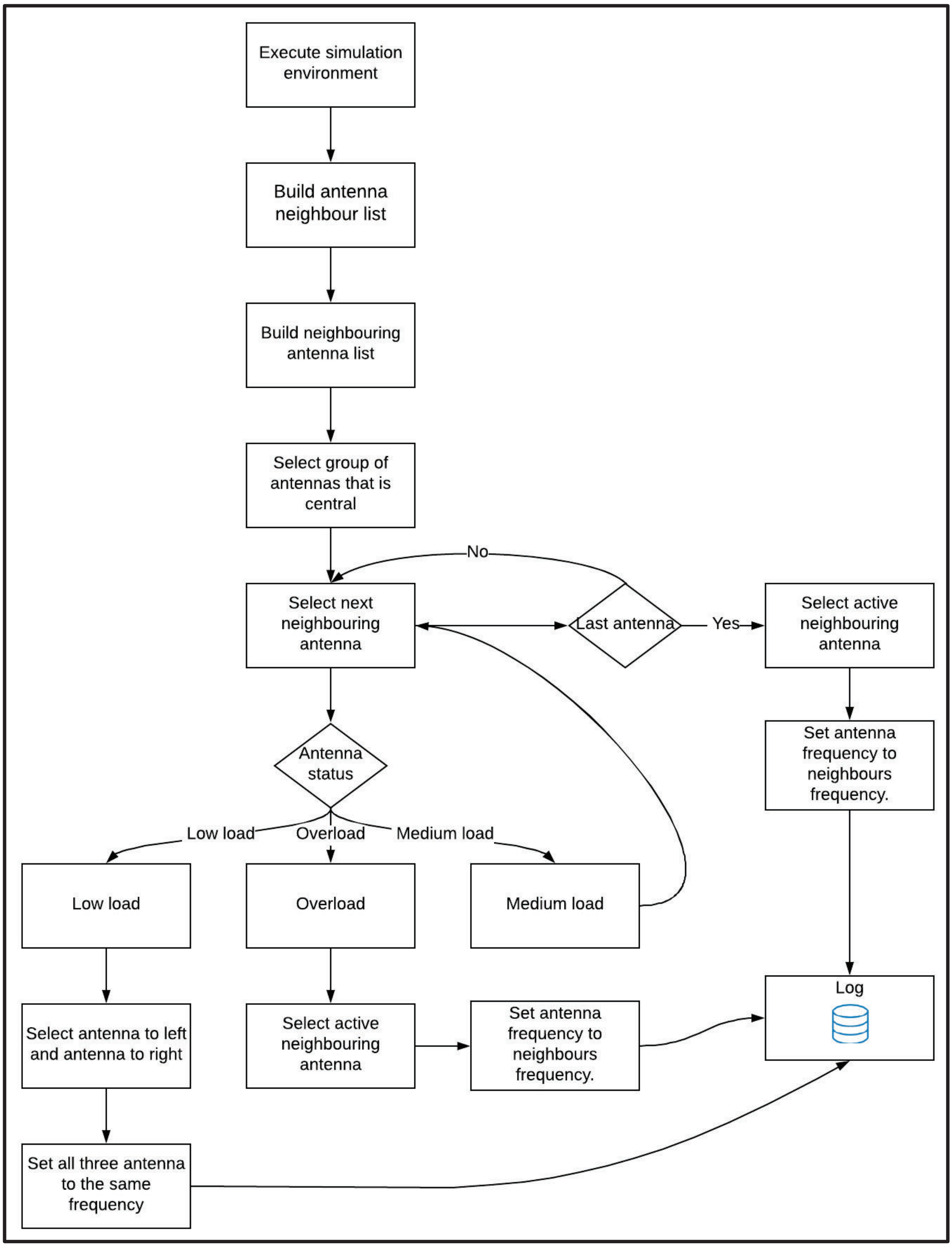


Figure 11.7: Agent overload structure

Once the frequency has been changed and the agent has been initiated, two adjacent antennas will have the same frequency. The FMA must ensure that the antennas change the frequencies so that the adjacent antennas don't have the same frequencies.

11.5.2.d Antenna drop agent

The antenna drop agent is responsible for selecting an antenna to drop. Figure 11.8 shows a flow diagram that illustrates how the agent selects an antenna to be shut down. The shutdown procedure is meant to simulate an antenna that is reset in the environment, or an antenna that experienced some technical difficulties.

The antenna drop agent is intended to test the frequency management agent in the simulation environment to ensure that it assigns frequencies correctly to the different antennas. An antenna's frequency will default to 0Hz, meaning that the environment management agent should see that there is an antenna with a frequency of zero and assign it a frequency. The frequency assignment is performed by the FMA.

Figure 11.8 shows that the user of the simulation environment has to execute the antenna drop option when the user wants the antenna drop agent to run. The agent operates in the background by dropping antennas at random time stamps. Before the agents select an antenna to drop in the environment, the agent has to pull a list of antennas and sort them in load order from lowest load to highest load.

Once the list is generated, the agent creates a probability amount which will tell the agent what antenna to drop or not. When there is a probability of more than 70%, the agent will drop the antenna with the highest number of devices connected, or one that has the lowest number of devices. When the probability is 30% to 70%, it will select one of the two antennas with the least number of devices to disconnect. When the probability is less than 30%, the agent will choose a random antenna to assign it a frequency of 0Hz.

The antenna drop agent helps to test how fast an antenna can be brought back up since the connected devices will disconnect from a device when the antenna drops. When the FMA takes too long to reconnect devices, the health of the environment will degrade.

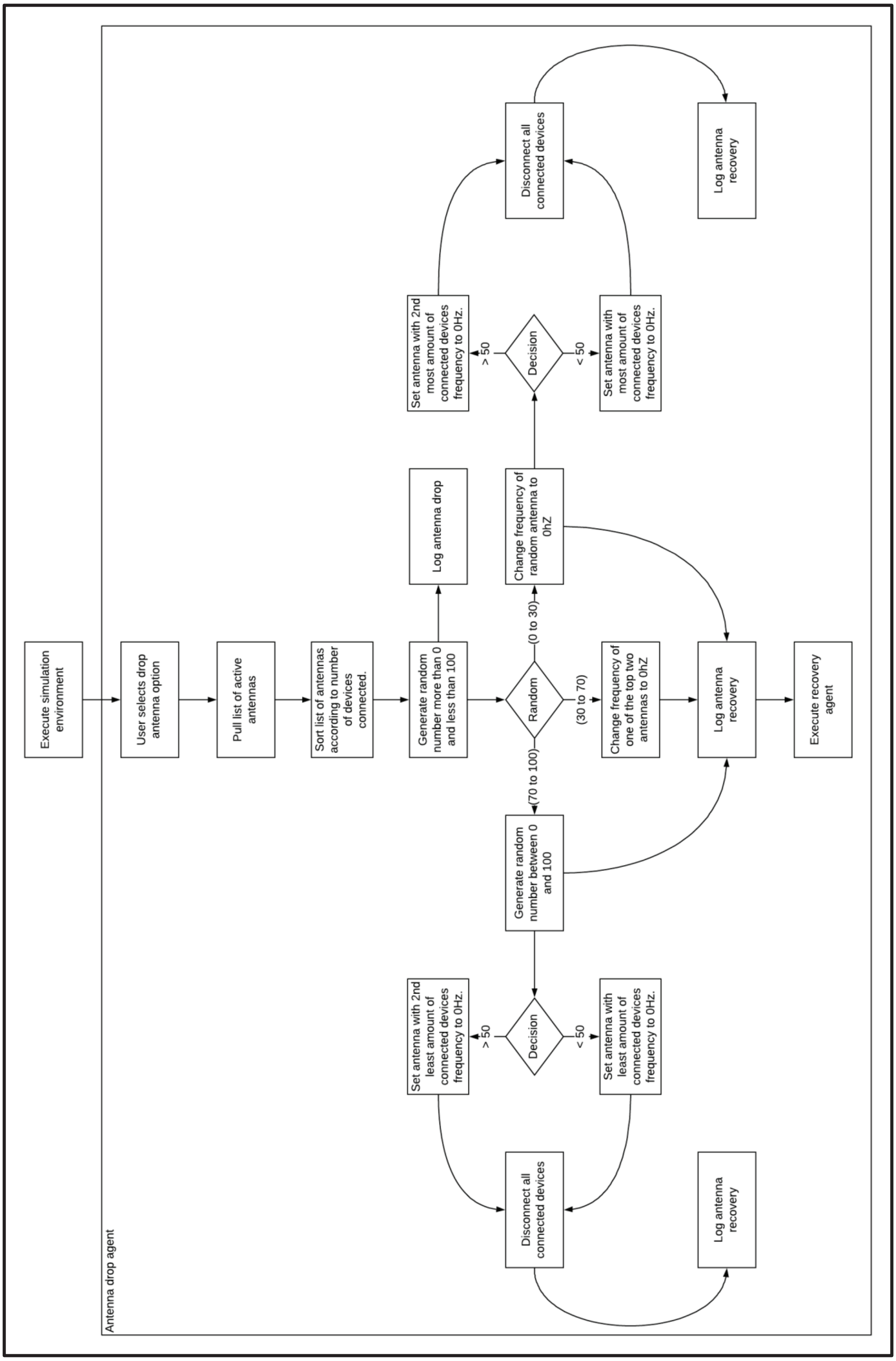


Figure 11.8: Antenna drop agent

11.6 Environment Analysis Agent

The Environment Analysis Agent (EAA) has the responsibility of informing other agents in the simulation environment that a rule has been broken and that action needs to be taken. The actions taken by the agent is demonstrated in chapter 8. The EAA makes use of several different helper agents that allows it to operate as intended.

11.6.1 Information Logger Agent

The information logger agent determines if an action in the simulation environment needs to be logged and then logs it if required. The information logger agent also ensures that information gets placed in the correct tables. The logged actions are used by the Frequency Management Agent and the Service Switching Agent.

11.6.2 Information Cleansing Agent

The information logged by the information logger is not always in the best format for other agents to utilise meaning that there are some irrelevant information logged. The information cleansing agent works with the information logger agent to clean logged information up by ensuring that information is in the format that the FMA and the SSA is expecting.

11.6.3 Communication Agent

Once the EAA determines that action is required in the environment, it will need to communicate with the relevant agent what the problem is and that action is necessary. The communication agent is an agent embedded in the EAA that communicates with the other agents in the environment, and that expects communication from other agents.

11.7 Service Switching Agent

The Service Switching Agent (SSA) is responsible for managing devices that communicate with an antenna as well as moving devices to another antenna when the load on an antenna is too high. The internal overview of the SSA is discussed in chapter 9 of this dissertation. The SSA makes use of a set of helper agents that helps the SSA to operate as intended.

11.7.1 Information Logger Agent

The information logger agent is responsible for saving actions that were performed by the SSA and data that was generated by the SSA. The FMA and the EMA also make use of the Information Logger Agent. The information logger agent is also responsible for accessing logged messages from the environment.

11.7.2 Communication Agent

The communication agent is a simple agent that takes important information that was generated by the environment or by action and communicates it to other agents that operate the environment. The communication agent also receives communication from other agents and determines if the communication can be used.

11.8 Frequency Management Agent

The Frequency Management Agent is responsible for managing frequencies in the smart antenna grid environment to ensure that all antennas in the environment have a frequency assigned that does not conflict with other antennas. The internal structure of the FMA is discussed in chapter 10 of this dissertation. Apart from the internal operation of the FMA, two helper agents are used.

11.8.1 Information Logger Agent

The information logger agent has the primary responsibility of logging actions that were performed by the FMA. The agent is also responsible for accessing logged messaged and actions.

11.8.2 Communication Agent

The communication agent is responsible for communicating messages with other agents that are operating in the smart antenna grid as well as receiving communication from other agents in the smart antenna grid.

Having discussed the different helper agents that operates in the smart antenna prototype the FMA, EAA and the SSA require a communication agent and an information logger agent. Figure 11.9 shows the internal operation of the information logger agent.

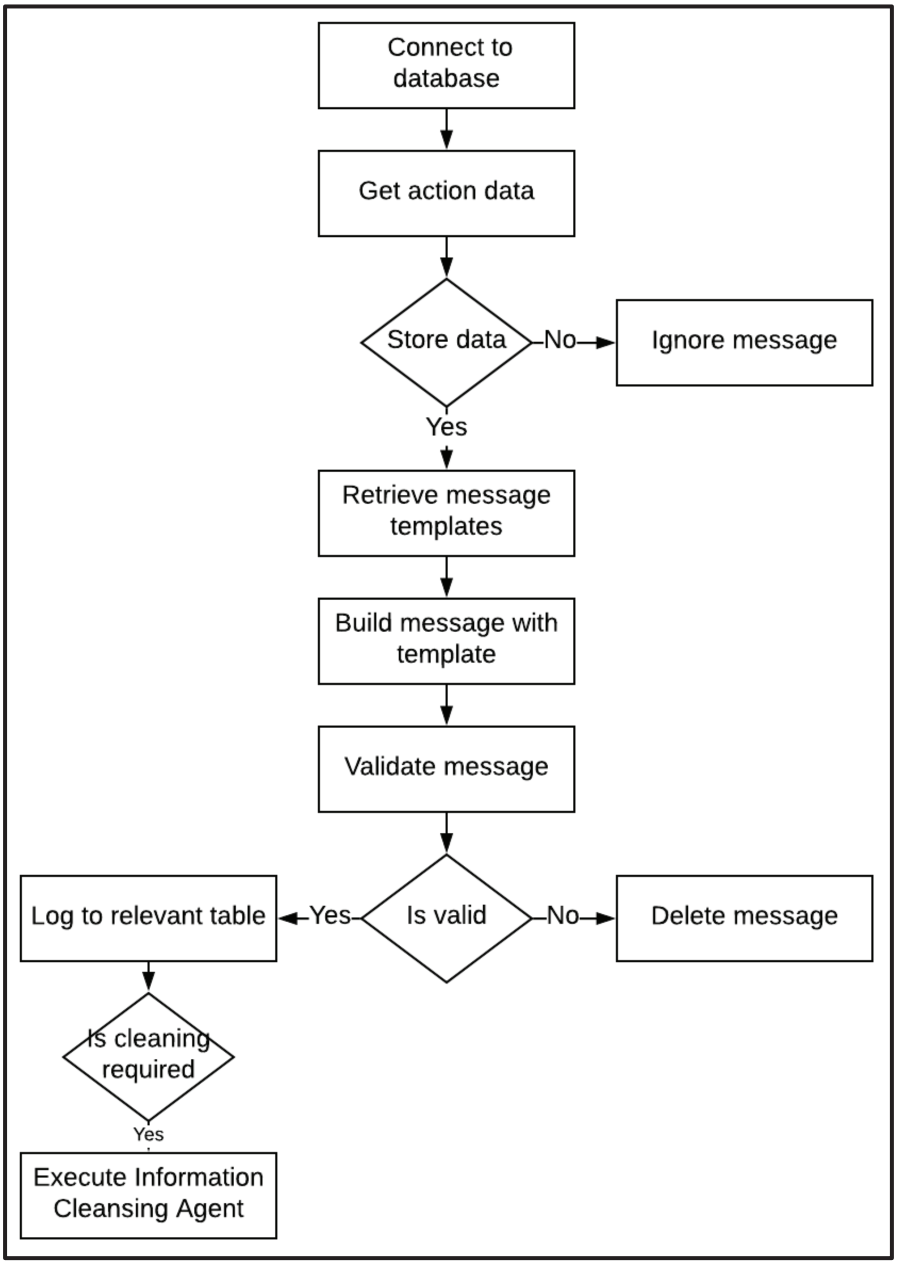


Figure 11.9: Information Logger Agent operation

11.9 Data integration and analysis

At any time in the simulation, a substantial amount of information is collected from the simulation environment that can be used to perform analysis, determine the status of the system, and many other features. Not all the data that is generated by the prototype is usable by the different agents.

Every time an action is performed in the smart antenna simulation, generated data can be used by the environment or other antennas in the environment to determine whenever the smart antenna system is under pressure. The information exchanged between the different components in the multi-agent system can also show whether an antenna is down, or if there are different frequencies in the smart antenna system. The data generated by the simulation is examined in the sections that follow.

11.9.1 Device movement agent

The device movement agent is one of the node agents that utilises and generates data that enables the workability:

Data generated:

- Device connectivity state;
- Device location that can explain the movement patterns; and
- Active communication states.

Data used:

- The antenna that the device is connected to, which can help pick up patterns;
- Antenna frequency to know which frequency to communicate with; and
- The physical location, which can help with movement predictions.

11.9.2 Device connectivity agent

The device connectivity agent generates data and makes use of some important aspects such as:

- Connectivity state to show when a device is connected;
- Connectivity status to indicate the connectivity signal to an antenna; and
- Connected time to determine connection duration.

Data used

- Antenna availability data to see if the device exists; and
- Antenna load, as it could indicate for how long a device can be connected.

11.9.3 Antenna availability agent

The antenna availability agent generates and consumes some data related to antenna availability.

Data generated:

- Number of connected devices (load);
- Antenna frequency;
- Antenna coverage map; and
- Antenna drop log for when an agent drops an antenna.

Data used:

- Device connection state to determine the stability of an antenna;
- Current antenna load status, as the load is a crucial factor to determine if an antenna can accept new devices connection requests; and
- The frequency of the antenna, because with no frequency the antenna will not have a connection available for other antennas.

As can be seen from the usable data that is generated by the antenna availability agent mentioned above there are many agents in the multi-agent system that require the same data to complete their jobs efficiently. Because of this, the information that is generated is shared among the different agents.

11.10 How is data used in the multi-agent system?

For the multi-agent system to obtain its goal of ensuring that the smart antenna system is stable while keeping many devices connected to respective antennas, the multi-agent should have access to environmental data. The following sections discuss the information that is used by the multi-agent network.

11.10.1 Environmental awareness

With a significant amount of information shared between different nodes on the smart antenna system, there is a substantial focus on communication between different node. Communication between different nodes means that the nodes can identify different patterns, which can include an increased load on the smart antenna network, or device movement between different antennas.

11.10.2 Network data

The agents in the smart antenna system must communicate information with each other. The shared information is stored for historical reasons. The logs can be used by an agent to determine the best operating parameters for an agent.

11.10.3 Predication

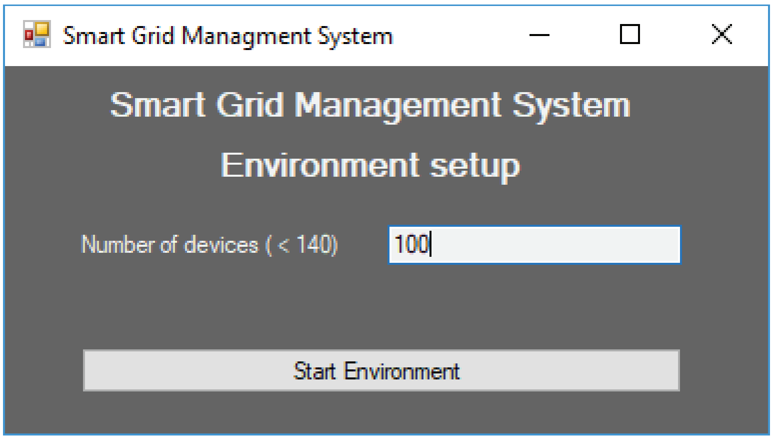
The information that is logged is valuable, as it can be used to make predictions in the smart grid system. Forecasts in the multi-agent system are made using patterns. A pattern is an indication of an event in the smart antenna system that is triggered by an action every time the action is executed. Using patterns to make decisions can have a negative or a positive influence on the simulation grid.

11.11 Interface

So far in this chapter, the discussion has focused on the simulated environment. The user must still be able to interface with the prototype, and the user must have a visual representation to see what is happening in the prototype. The visual representation is performed by using graphs and graphics. The next section focuses on the user interface component of the smart grid management system.

11.11.1 Setup stage

The setup stage is the first interface for the user in the smart grid management system representation. In this stage, the user will be asked to enter the initial number of devices that should operate in the environment. The user interface can be seen in Figure 11.10.



Smart Grid Management System

Environment setup

Number of devices (< 140) 100

Figure 11.10: Simulation start-up page

The simulation environment takes the information provided by the user and passes it through to the agents to set up the initial environment. The setup includes generating new devices and new antennas. The frequencies that are assigned to the smart antennas are randomly selected from a list of predefined frequencies. The random frequencies will cause conflicts, but that is part of the setup.

When the prototype executes it must generate a set of devices, and the device agent must generate a random starting position for the agent in the prototype. The starting position acts as a base position that will never be changed. Once an arbitrary starting position is generated, between two and six different movement sets are generated per device. The device movement agent makes use of the movement set created to move devices in the environment.

Once the user has provided the information required to start the simulation environment, the visual implementation of the environment is opened. When the visual representation is running, all the nodes are loaded, and navigation buttons are activated. The visual implementation of the environment is shown in Figure 11.11.

Once all the simulation aspects are loaded a distributed database gets created and information is stored in the database. The environment is paused until the user gives the command to start the simulation environment.

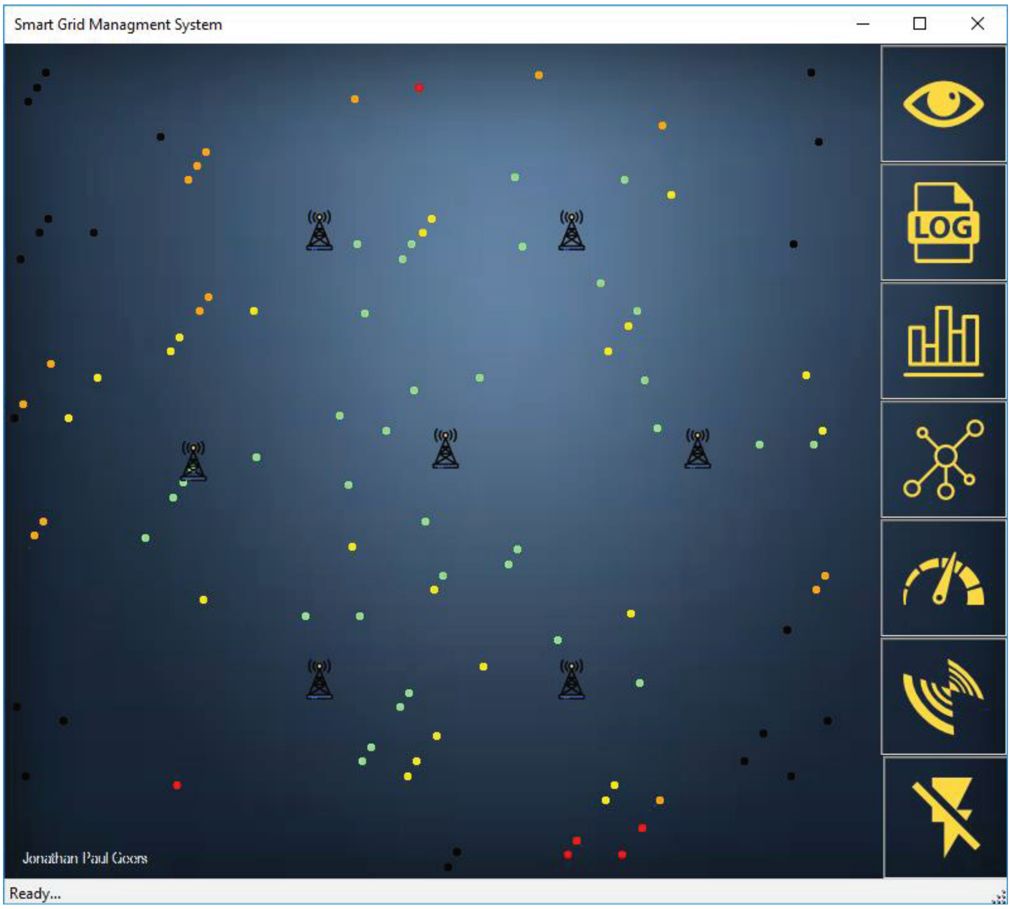


Figure 11.11: Simulation environment visual representation

The simulation environment also has a visual representation of the antenna coverage concerning the area. Figure 11.12 shows the antenna coverage in the simulation environment. The figure also shows where to access the antenna coverage.

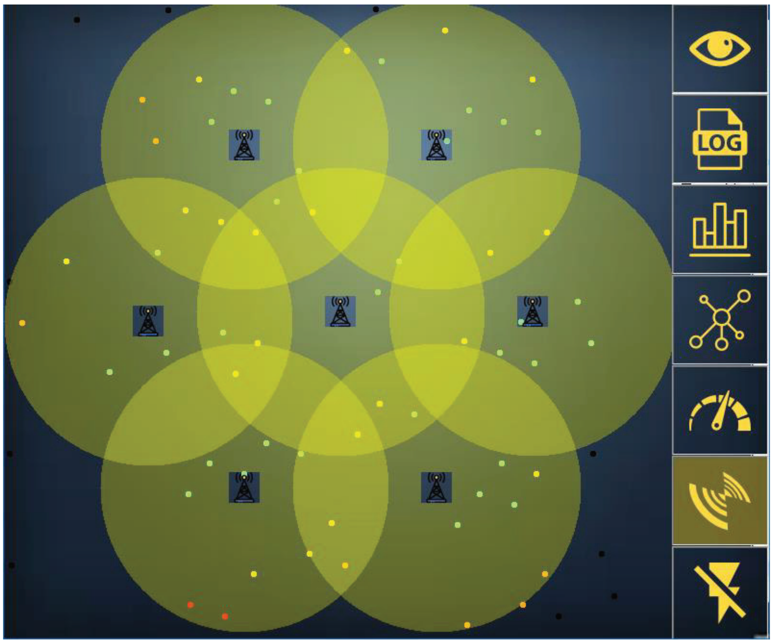


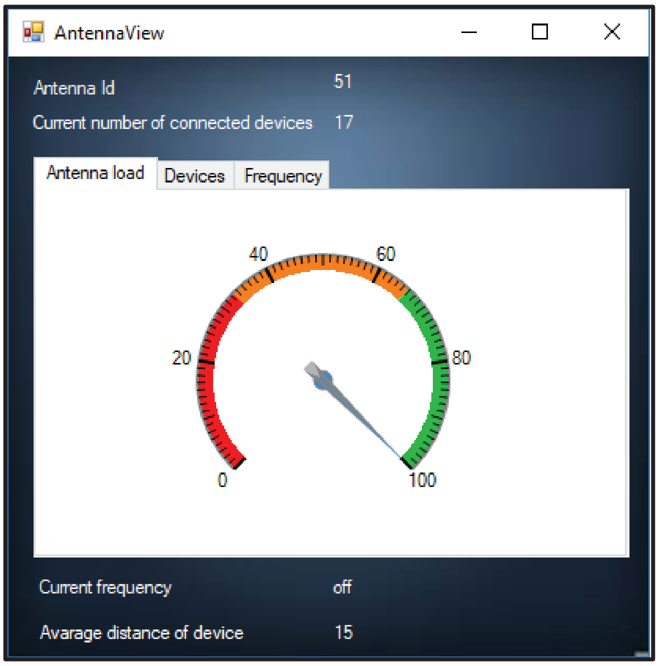
Figure 11.12: Antenna coverage area

11.11.2 Initiating the agents

Once the environment-specific information is set up by the user by selecting the number of devices, the different agent sets are initiated. The environment management agent is not the first agent deployed. In order to set up the antenna location and frequencies, the antenna placement agent is executed first.

After the antennas have been set up, the device movement agent is executed to set up the movement logs. After the nodes are all set up in the smart grid management system, the user interface is updated with links and node information. Figure 11.12 showed the user interface after the setup had been completed. In Figure 11.13 a visual representation of the different antennas shows the status of a node. The visual representation uses the information in Table 11.1 to determine its stability.

Once the user interface has been set up, the environment analysis agent is deployed. The deployment of this agent requests the service switching agent and frequency management agent to be deployed in the environment. The other agents that operate in the environment, including the antenna drop agent, are executed when the user clicks on a button.


AntennaView

Antenna Id 51

Current number of connected devices 17

Current frequency off

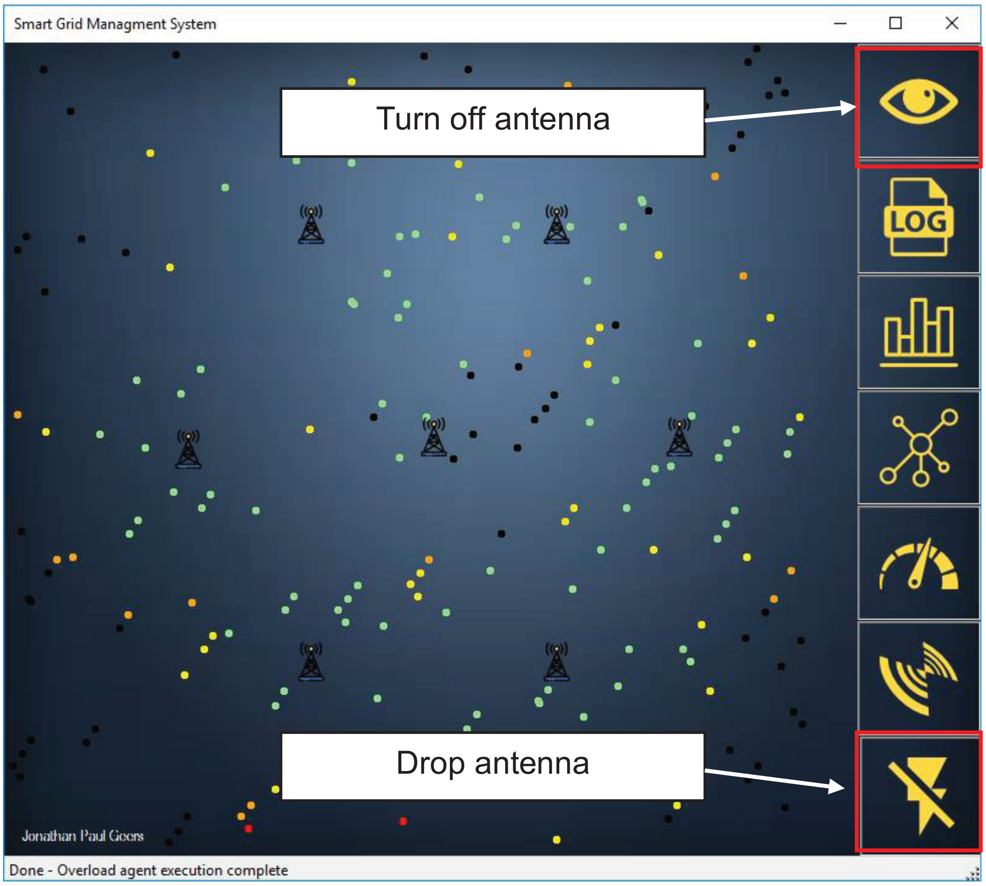
Avarage distance of device 15

Figure 11.13: Device representation

11.11.3 Initialising recalling / shutting down of antennas

Recalling the frequency allows the user to request that the antenna availability agent is called. The antenna availability agent has the responsibility of taking down an antenna that is causing a conflict of frequencies between different antennas.

The user of the SGMS can request the antenna availability antenna to execute, by clicking a button. There are two button setups to run the agent. One is to cause frequency disruptions, and the other turns off an antenna. Figure 11.14 shows the button that can execute the agent.

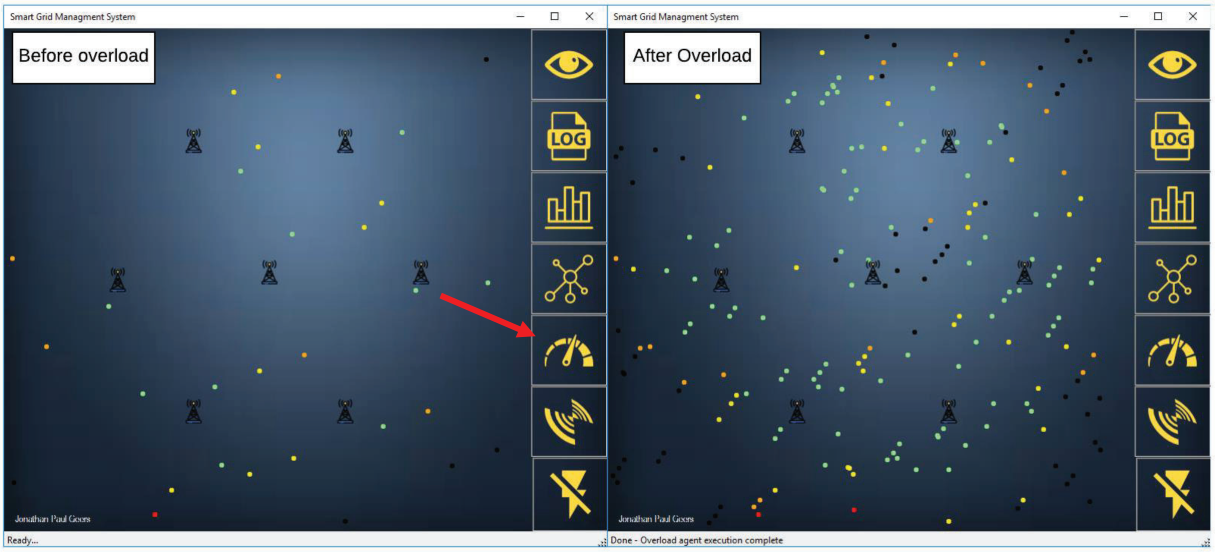


Done - Overload agent execution complete

Figure 11.14: Antenna frequency drop agent access from UI

11.11.4 Initialising device overload

The process of causing a large number of devices to enter the smart grid management system is triggered by clicking on a button on the user interface. Once the button has been clicked to overload the environment, the user interface is updated to show all the new devices that are part of the SGMS. Figure 11.15 shows the visual representation before and after the environment is overloaded.



Ready...

Done - Overload agent execution complete

Figure 11.15: Simulation overload agent executed

11.12 SGMS Prototype Class layout

This chapter of the dissertation shows that simulating the environment requires many different agents. The agents which include the antenna drop agent, the device movement agent, the communication agents that generate a lot of information about device, antennas and environmental health that gets used by the EAA, SSA and FMA that operates in the model.

Figure 11.16 shows a class diagram demonstrating all the classes that form part of the prototype. The class diagram shows that many agents that are responsible for the simulation environment operate from the SmartGridManagementSystemBase class. This class is also responsible for most of the user interface. Figure 11.16 shows that the device movement agent has its class and that the device movement agent makes use of a set of helper classes to achieve its goal of moving devices in the simulation environment.

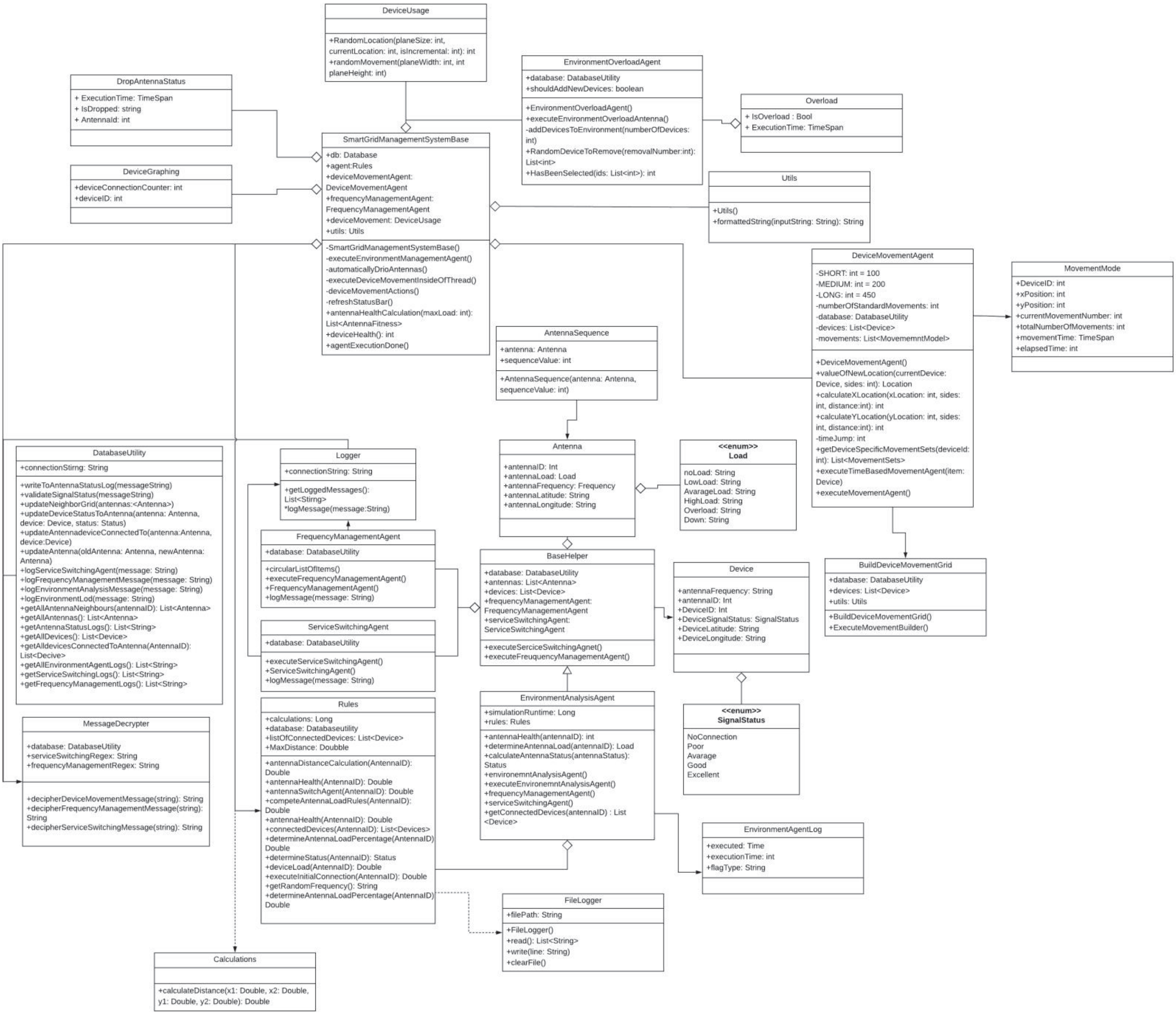


Figure 11.16: Prototype class diagram

11.13 Prototype Deployment Activity Diagram

In the deployment of the prototype environment has many different activities to complete. Figure 11:17 shows a short activity diagram that demonstrates the deployment the different agents.

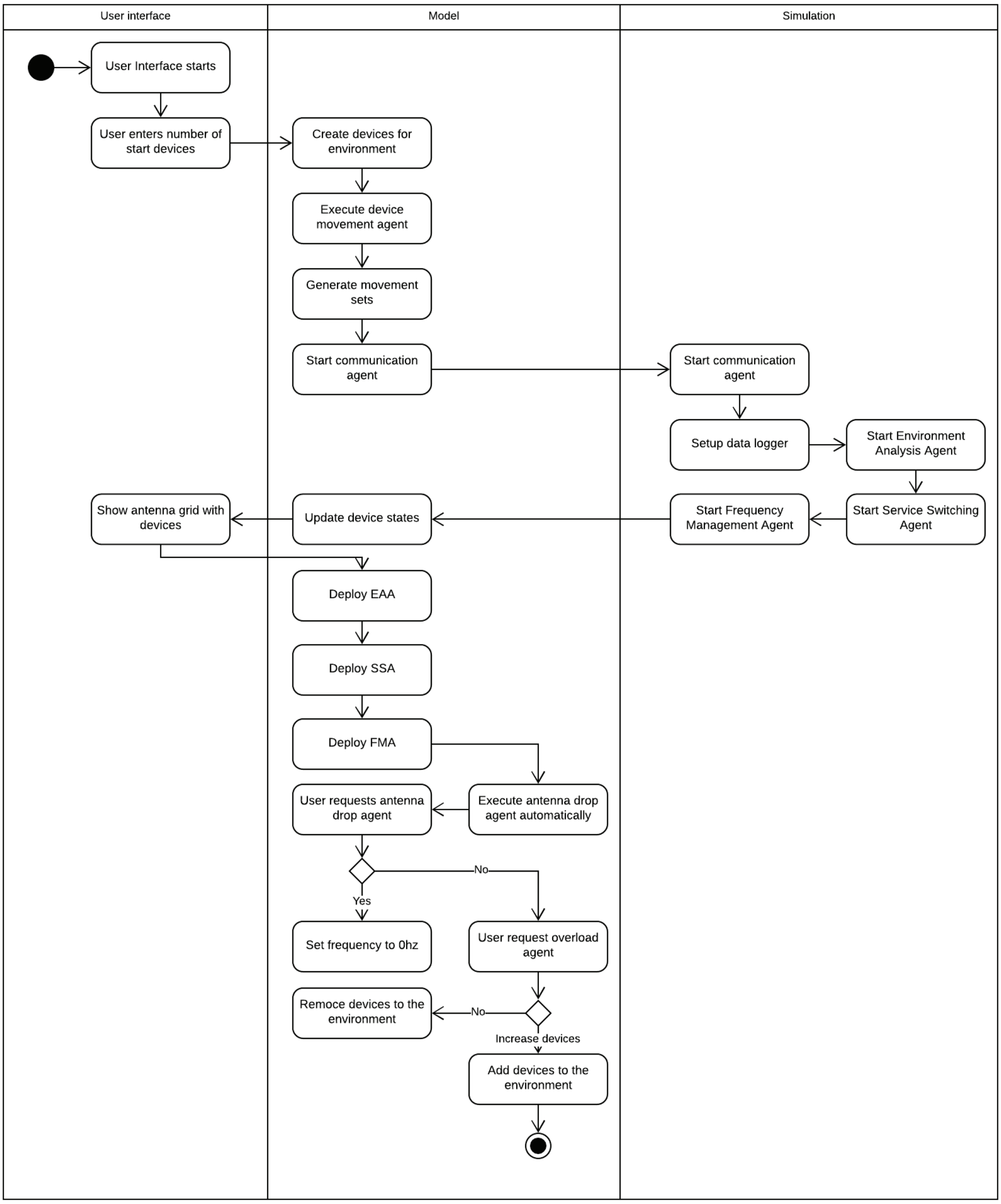


Figure 11.17: Prototype deployment activity diagram

11.14 Conclusion

The Smart Grid Management Agent model is made up of different layers. The graphical layer is what is shown to the user. The graphics layer includes analysis graphs and the simulation environment. The multi-agent system layer is responsible for handling the three agents that are responsible for managing the resources of the management system. The simulation layer is responsible for setting up the smart grid to perform experiments on, and on which to build the multi-agent system.

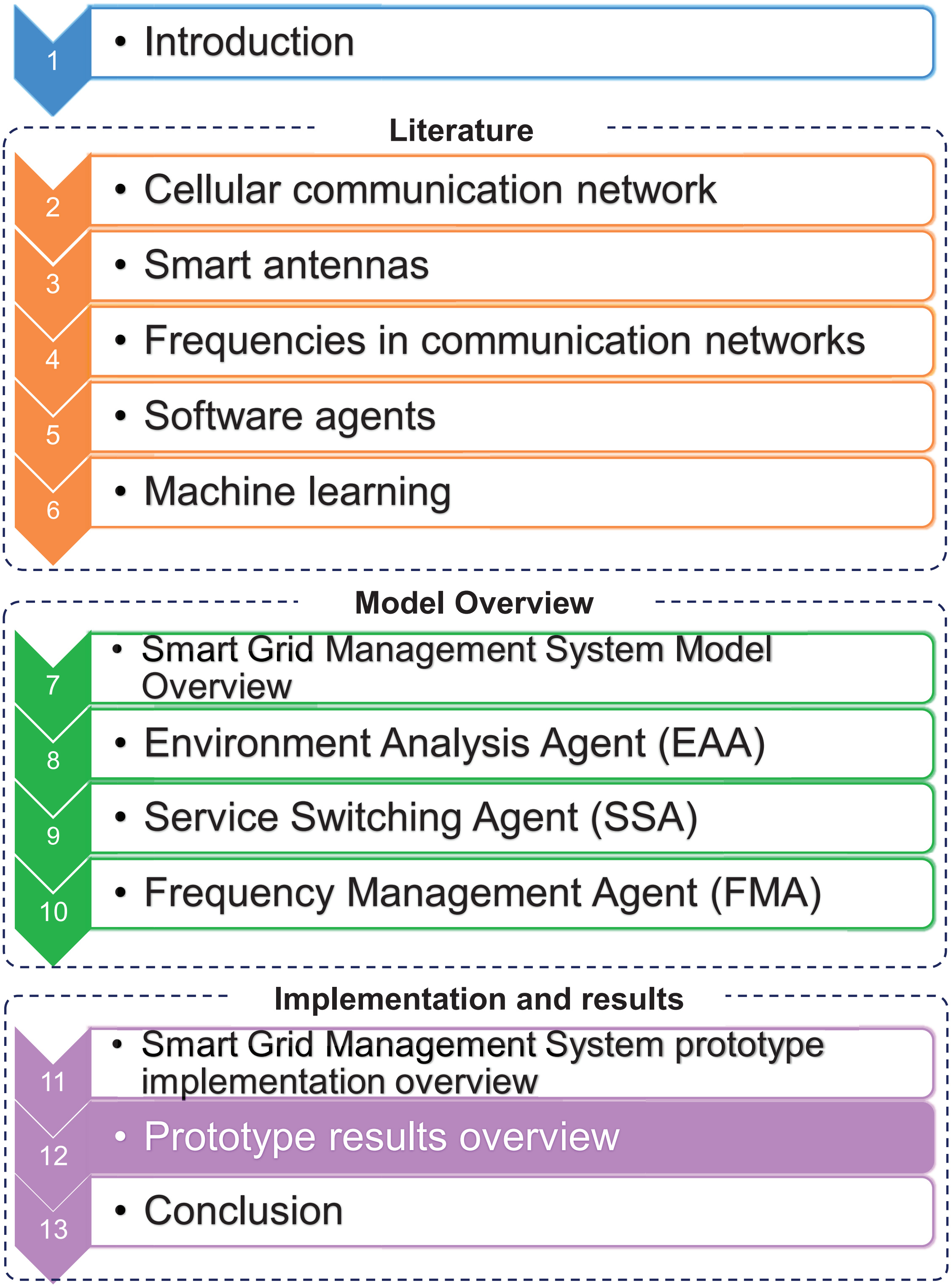
The SGMS also contains the simulation agent layer that does not include the SSA, the EAA or the FMA. It consists of the different agents that make the simulation environment operate in the same fashion as the real environment. All the agents in the SGMS share the responsibility of ensuring the environment is accurate and that the required goal is achieved.

The agents responsible for ensuring the simulation environment operates as expected, include an agent that operates on all the devices in the environment, with the responsibility of enabling device movements in the smart antenna grid systems. The antenna communication agent and device communication agent both manage communication between different nodes in the environment.

Chapter 11 has answered the research question: *How can a multi-agent system be integrated into a smart grid system?* The chapter shows the different components that form part of the model. The multi-agent system requires the simulation environment to operate and perform experiments. Understanding how the simulation environment operates helps to show the functions of the different agents that form part of the simulation environment. The chapter achieves part of one of the research objectives by detailing the implementation of the simulation environment.

Chapter 12 of the dissertation focuses on the different scenarios that were performed on the simulation environment as well as the results of the different simulation scenarios. The chapter focuses on achieving the research objective of determining the simulation environment results, and on answering the research question: *Is resource management improved by using a multi-agent system prototype level?*

Chapter 12 - Prototype results overview



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12.1 Introduction

This chapter focuses on the results of 10 scenarios that were executed in the smart grid management system in order to determine the actions of the different agents, and whether a multi-agent system could manage the resources of a smart grid.

A smart grid requires scenarios that test the operations of the different components that operate in a simulation. The scenarios should be able to test the influence of the smart grid management system on the various elements, and whether the prototype implementation could manage the resources.

Running experiments on the prototype system provides valuable information relating to how the prototype would perform in a real environment, and if the prototype was a viable solution to the problem. To determine this, some scenarios needed to be created and tested in the simulation environment. The aim of creating these scenarios was for them to demonstrate that a prototype implementation would provide valuable information regarding the simulation environment and the prototype implementation. Information generated by such simulations can be numeric or in the form of graphical representations of the quantitative information.

12.2 Simulation Scenarios

The prototype was executed in the simulation environment with different scenarios in mind. The reason for this simulation execution style was to ensure that ten different scenarios were covered and that in each case the agents executed as desired. All scenarios made use of the various agents to manage resources.

Table 12.1: Scenario parameters

Number of antennas	7
Number of devices	70 (50% environment load)
Antenna coverage	> 85% area coverage
Available frequencies	5

In each of the ten scenarios, the environment made use of the execution parameters defined in Table 12.1.

12.1.1 Initial start-up statistics

Figure 12.1 shows what the execution environment looked like when one of the simulation environments was started. All the devices in the execution environment were colour coded, with the black dots being the devices with no connection. Figure 12.1 also shows the seven antennas that formed part of the smart grid system, where the smart antennas shown in the user interface covered more than 85% of the environment.

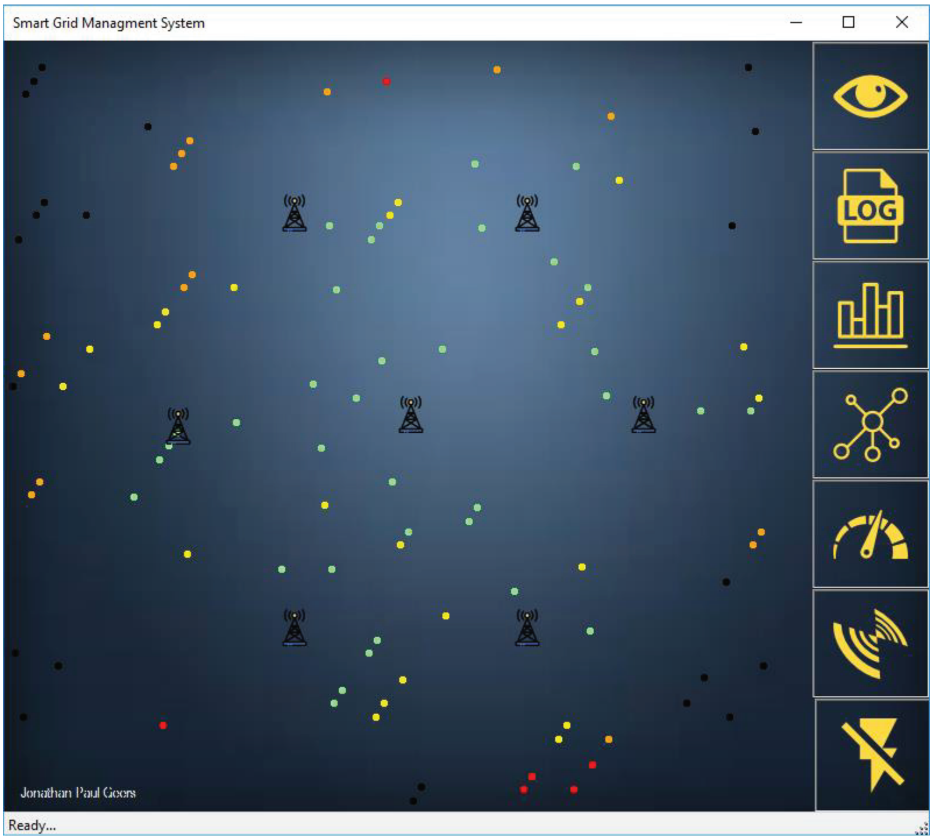


Figure 12.1: Simulation start-up

Figure 12.2 shows the health of the environment on the start-up of the scenarios. The figure shows that the environmental health was relatively good. The frequency health indicator shows that the frequency distribution fell under the well-functioning state, meaning that the provided frequency band was used and that no antenna's used the same frequency.

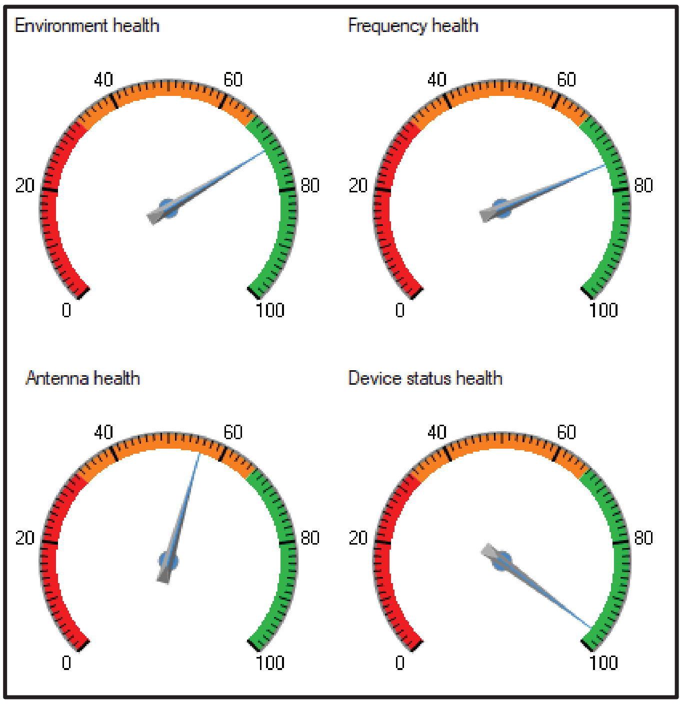


Figure 12.2: Environment health at start-up

Figure 12.2 also shows that the antenna health was in a risky state. When the antenna health is in a risky state, it means that the antennas are operational, but the antennas have many connected devices to handle. The device health status was excellent since all the antennas that were in the range of an antenna had an active communication link. Overall, the health of the environment was well-functioning.

The pie chart in Figure 12.3 shows that many devices had no connection, but that the device health indicator was well-functioning. The analytics took into account devices that were outside the antennas' range; it formatted that out for more accurate statistics.

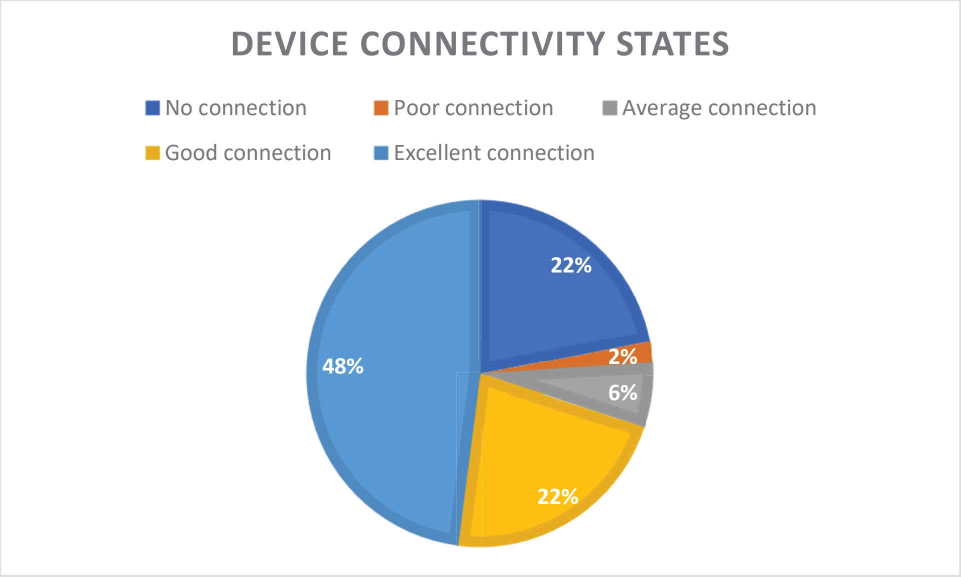


Figure 12.3: Device states at start-up

The frequency health indicator will never be 100% because not all the frequencies are used. Some frequencies are reused but never cause conflicts. The following section focuses on the ten scenarios and the results that were found after the scenarios had executed.

12.1.2 Scenario One

Scenario one is intended to get a baseline with no antenna shutdowns, no Service Switching Agent executions, no Environment Management Agent executions, no Frequency Management Agent executions and with the automatic antenna drop agent shutdown. The first scenario ran three times for ten minutes each to obtain an average value without user interaction. The next section of chapter 12 describes the results after the first scenario executed.

The first scenario did not have to respond to any antenna drop request, antenna shutdowns or environment overloads since the agents that are responsible for running such situations where shut down. After the three simulation runs, the environmental health indicators showed that the health is in a good state with little to no resource problems as is shown in Figure 12.4.

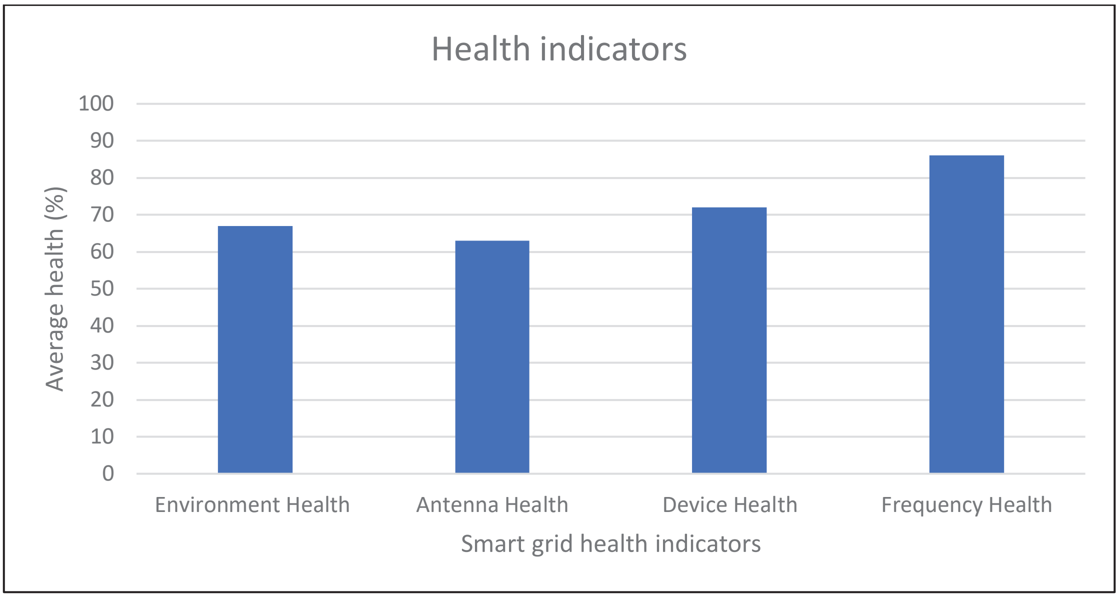


Figure 12.4: Environment health indicators scenario one

The device connection states in figure 12.5 shows that 24% of the devices in the first scenario did not have a connection to an antenna whereas the remainder of devices have mostly good to excellent connections to antennas.

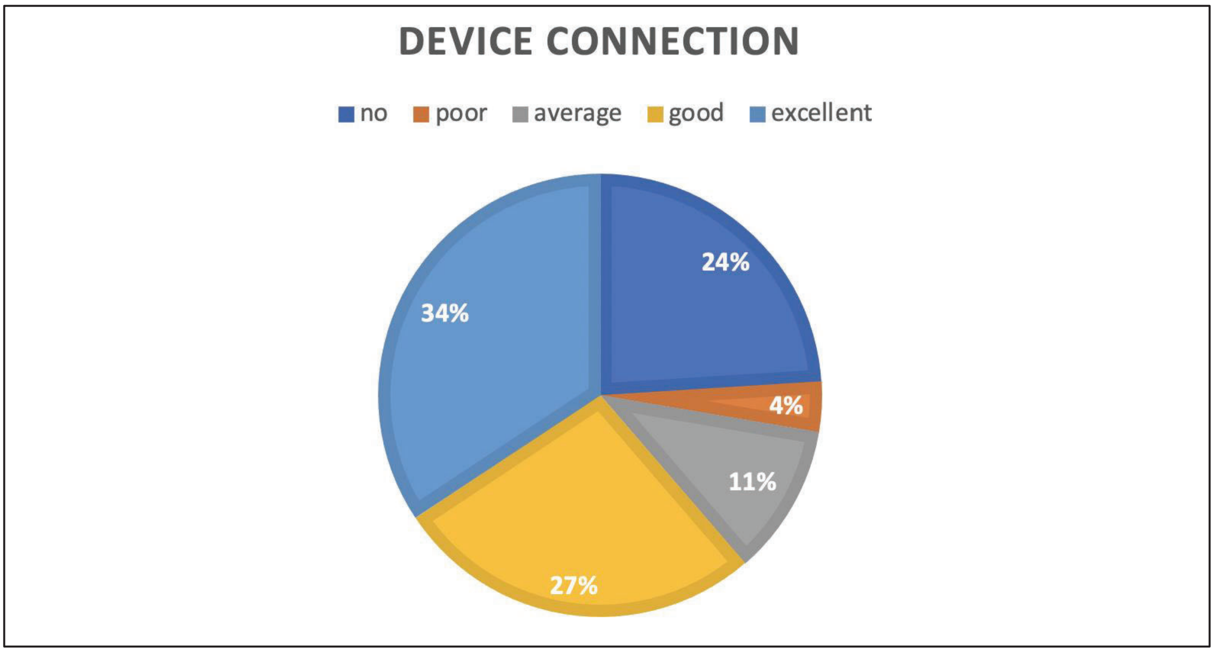


Figure 12.5: Device health indicators scenario one

There are 24% of devices without a connection due to the devices being out of range of antennas. Figure 12.6 shows two devices that are outside of antenna range.

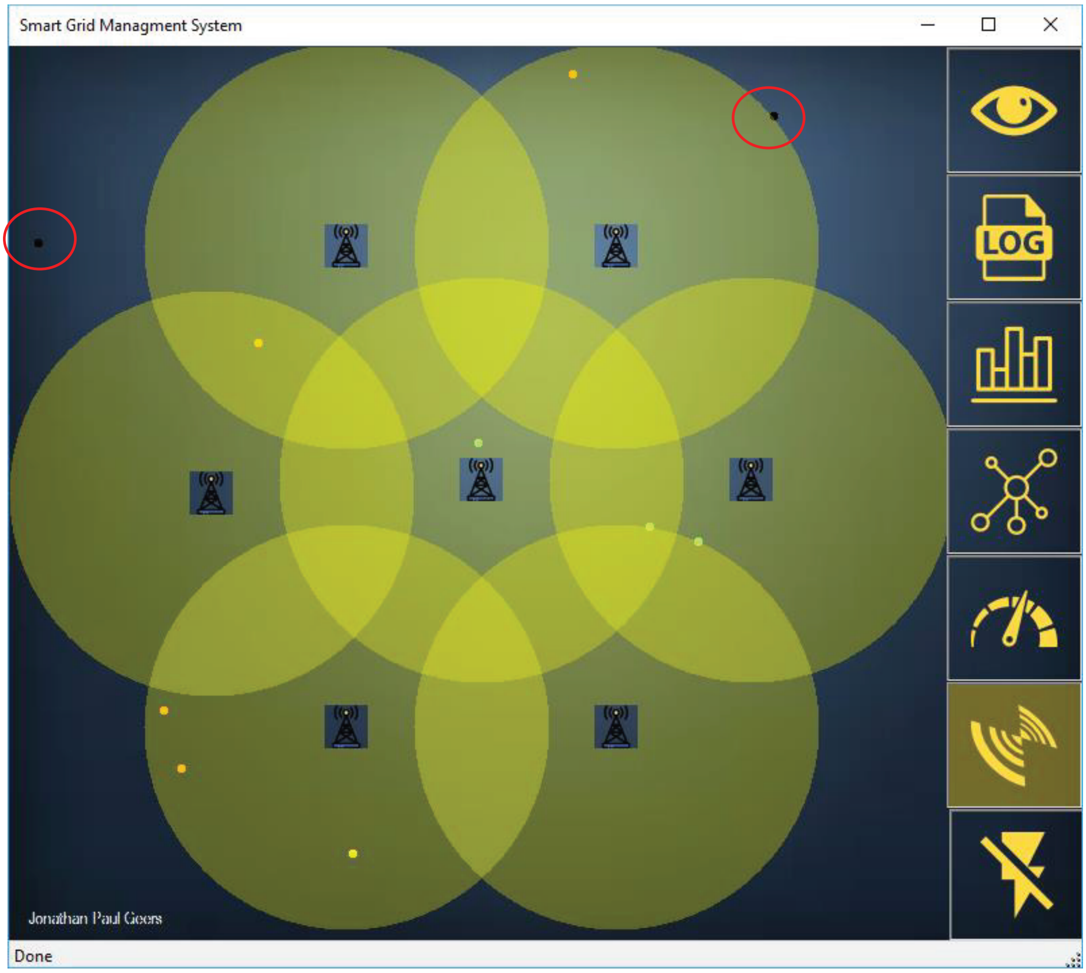


Figure 12.6: Device coverage

12.1.3 Scenario Two

The second scenario ran three times for ten minutes without any resource management agents in operation to achieve a baseline. Where the first scenario executed with only 70 devices, the second scenario executed with 168 devices to place the smart grid environment under high load. The next section of chapter 12 describes the results after the second scenario executed. The devices' health were in a good state since the majority of devices had a connection. The antenna and environment health indicators in scenario two were in the risky state as can be seen in figure 12.7

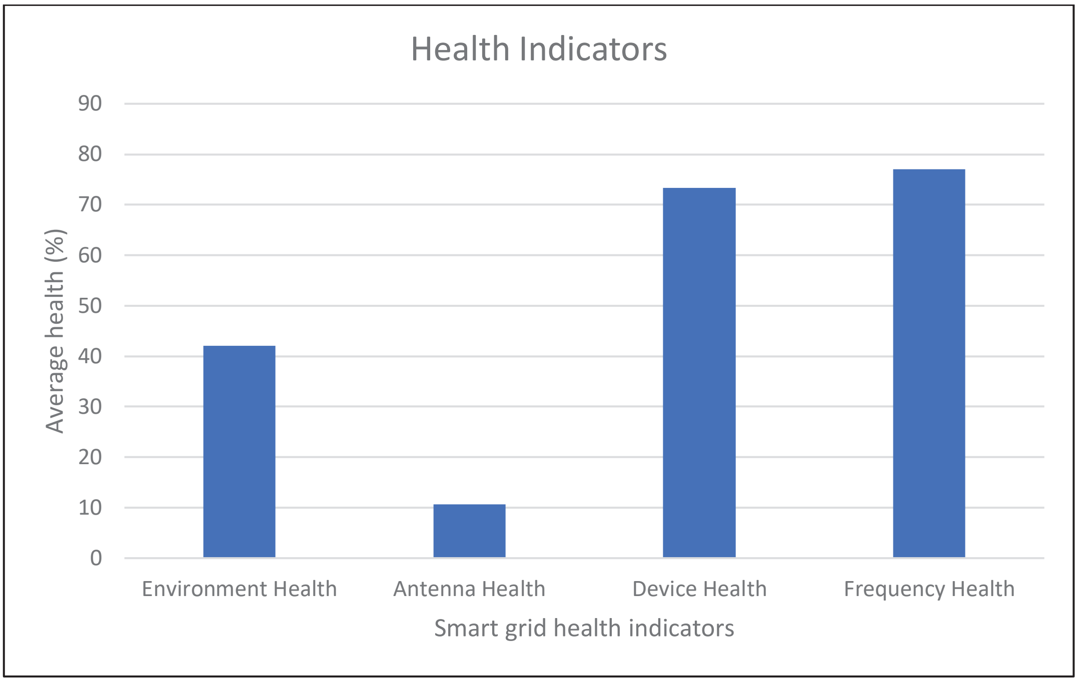


Figure 12.7: Environment health scenario two

The device connection states in figure 12.8 show that only 24% of the devices did not have any connection to an antenna and 41% of the devices had an excellent connection to an antenna in the second scenario.

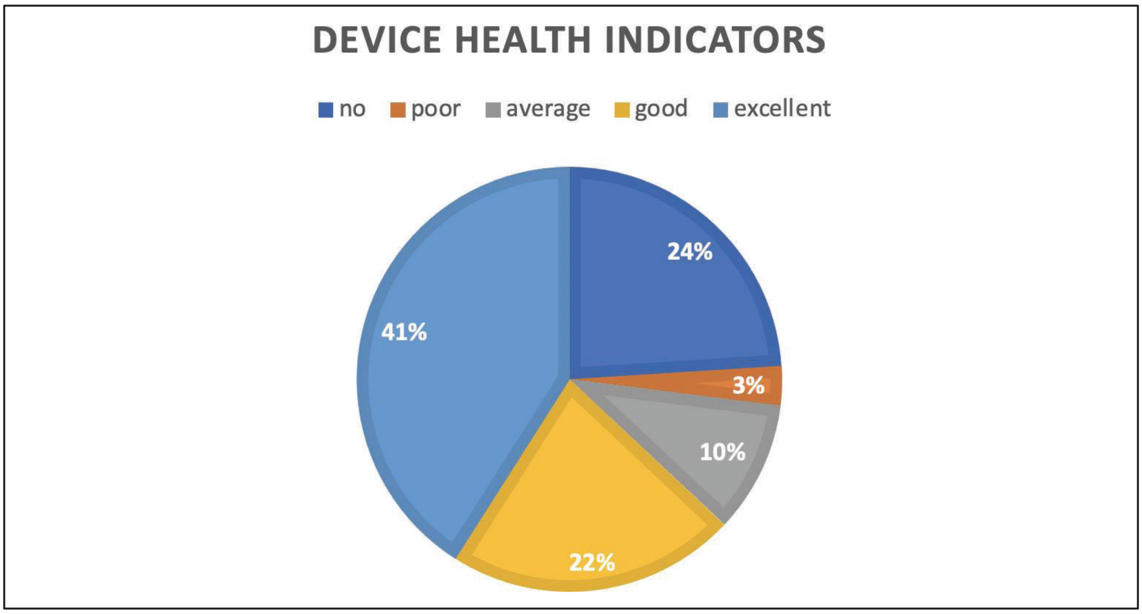


Figure 12.8: Device health states scenario two

The antenna health indicator in figure 12.7 showed that the health of the antennas was drastically low. The low health indication is due to the antennas in the environment being under high load. Figure 12.9 shows that three out of the seven antennas in scenario two are overloaded.

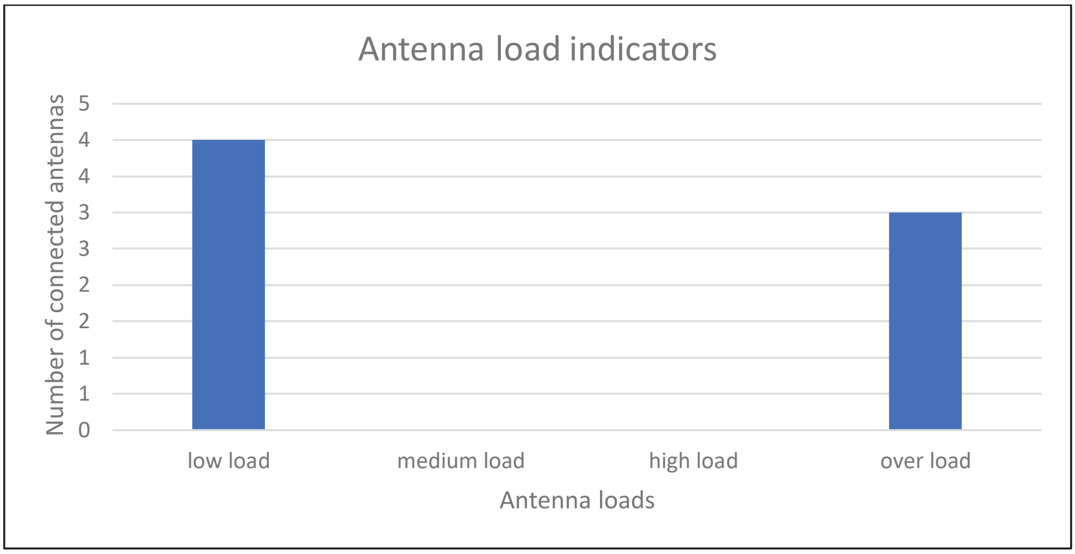


Figure 12.9: Antenna loads scenario two

12.1.4 Scenario three

In scenario three, one of the antennas is shut down for the full duration of the scenario without any agent active. The third scenario ran three times for ten minutes as was done in scenario one. The next section of chapter 12 describes the results after the third scenario executed.

After the three rounds, the environmental health indicators in Figure 12.10 showed that the health of the environment was in a good state with the health of the devices in a risky state. The antenna and frequency health was in a good state.

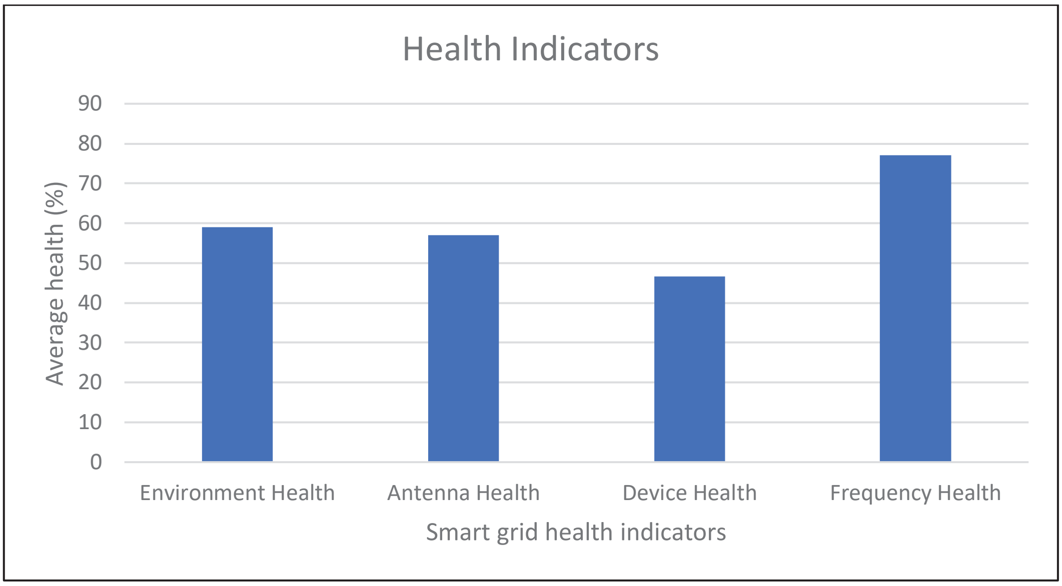


Figure 12.10: Environment health scenario three

Table 12.2 shows that 37% of the devices did not have connection contributing to the risky state of the devices.

Table 12.2: Antenna loads scenario three

Connection	**Run 1 (%)**	**Run 2 (%)**	**Run 3 (%)**	**Average (%)**
no	37	40	33	37
poor	4	4	8	5
average	10	12	9	10
good	12	10	17	13
excellent	37	33	33	34

Table 12.2 shows that 37% of the devices did not have a connection to an antenna meaning that in the third scenario there were 15% more devices without a connection to an antenna in comparison to scenario one. Figure 12.11 shows that the increase of devices without connection is due to the antenna that is shut down.

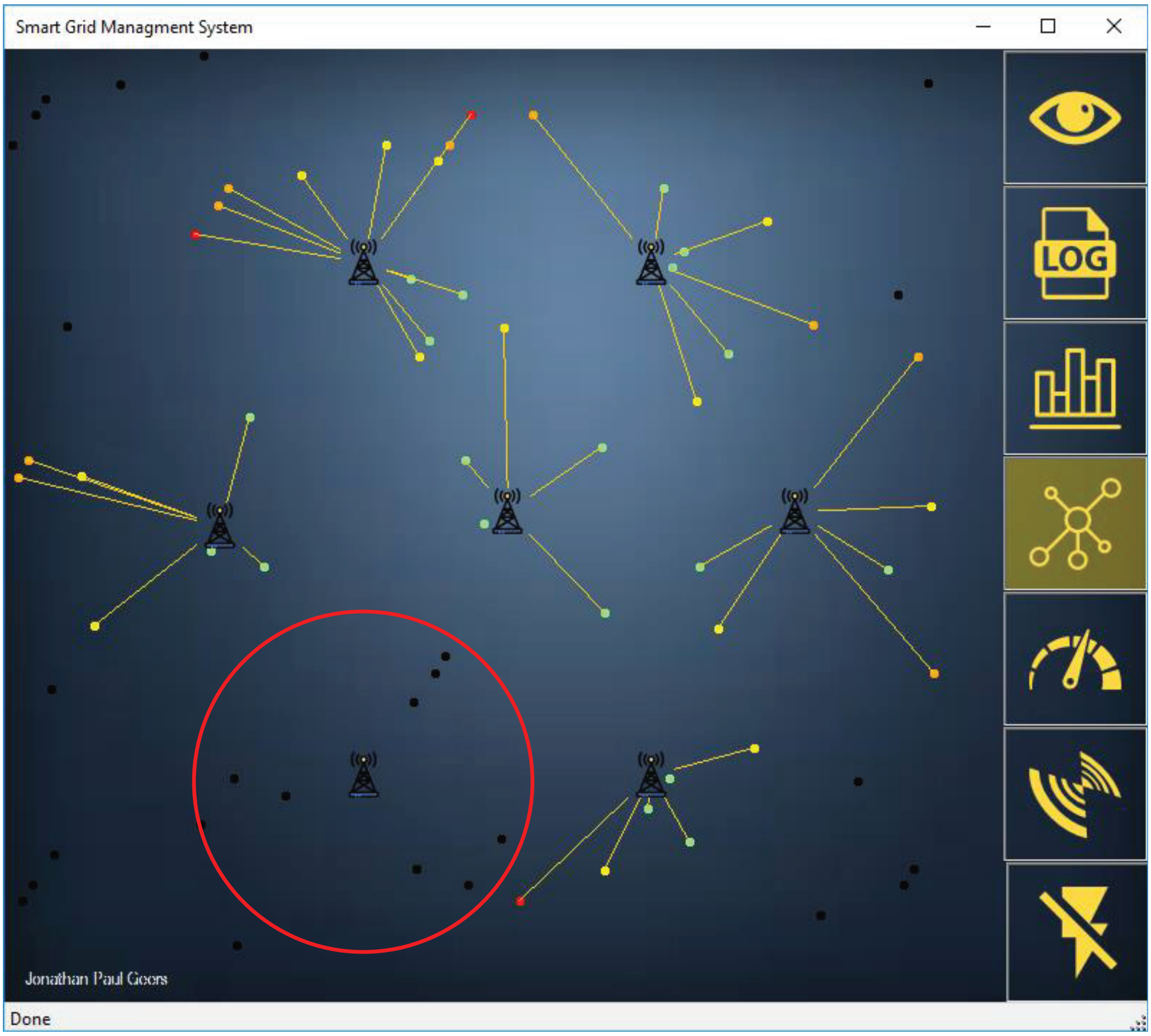


Figure 12.11: No connection to antenna

12.1.5 Scenario Four

Scenario four extends from the third scenario by switching off one antenna and overloading the prototype by 140%. The fourth scenario ran three times for ten minutes. The next section of chapter 12 describes the results after the fourth scenario executed.

After the fourth scenarios execution completed the health indicators showed that the overall health of the environment was in a risky state with the antenna health being in a dangerous state. Figure 12.12 shows that the antenna health has a score of only 10% because of the antenna that was shut down.

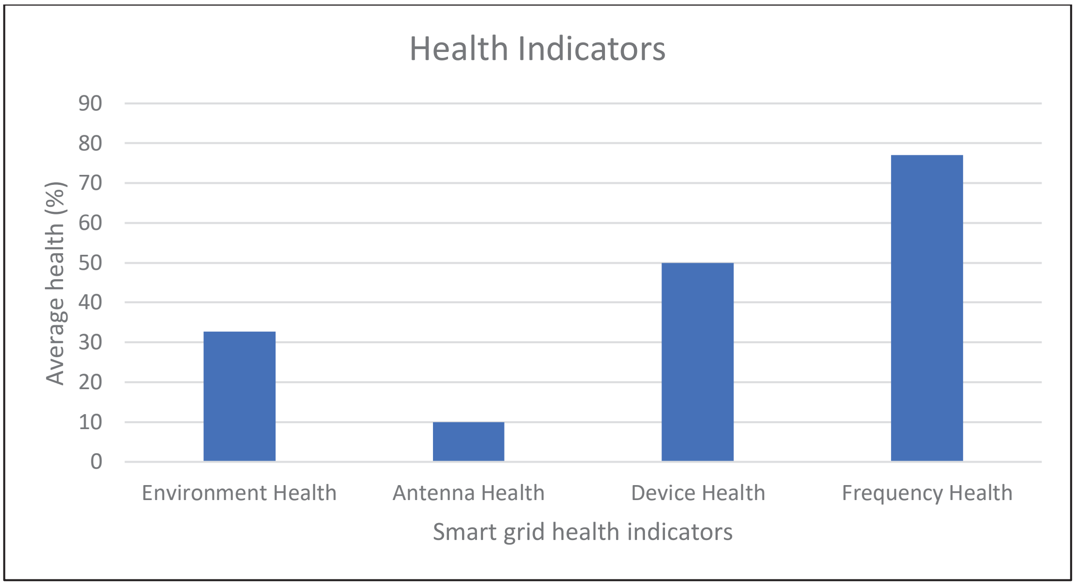


Figure 12.12: Health Indicators scenario four

In comparison to scenario three, the device connection states were roughly the same due to an antenna that was shut down. Figure 12.13 shows that in contrast to scenario two, scenario four has significantly more devices with no connection contributing to worse connection states.

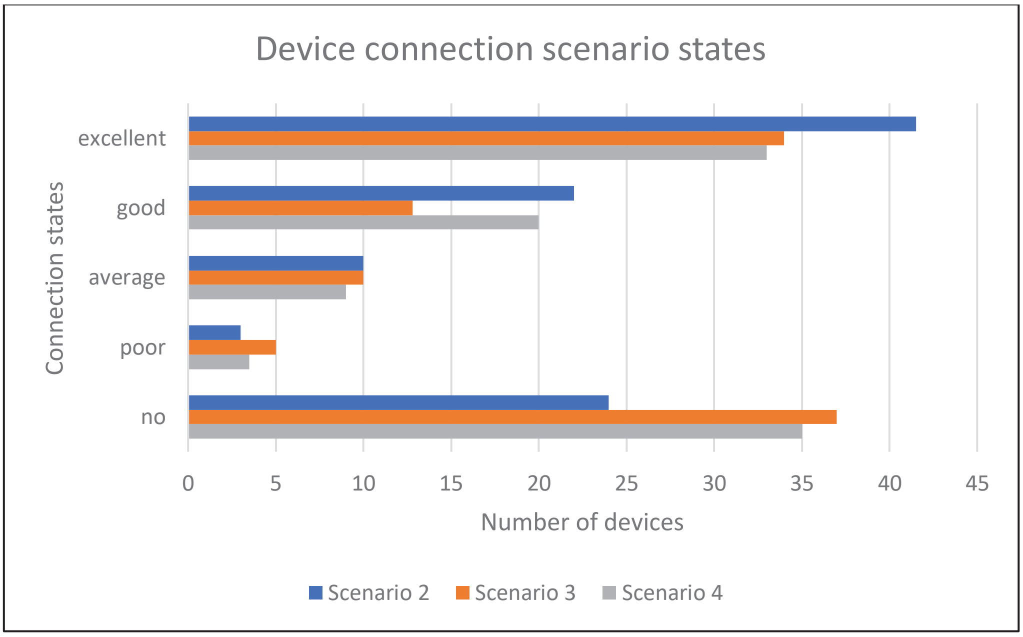


Figure 12.13: Connection stats scenario four

12.1.6 Scenario Five

Scenario five extends upon scenario three with no Service Switching Agent, Environment Analysis Agent. Scenario five executes the automatic drop antenna agent every ten to thirty seconds by changing a selected antennas frequency to 0Hz. The fifth scenario is intended to test if the Frequency Management Agent responds to a dropped antenna. Scenario five ran three times for ten minutes. The next section of chapter 12 describes the results after the fifth scenario executed.

After the prototype executed, the health of the environment was in a risky state with the health hovered at the 50% mark as can be seen in Figure 12.14.

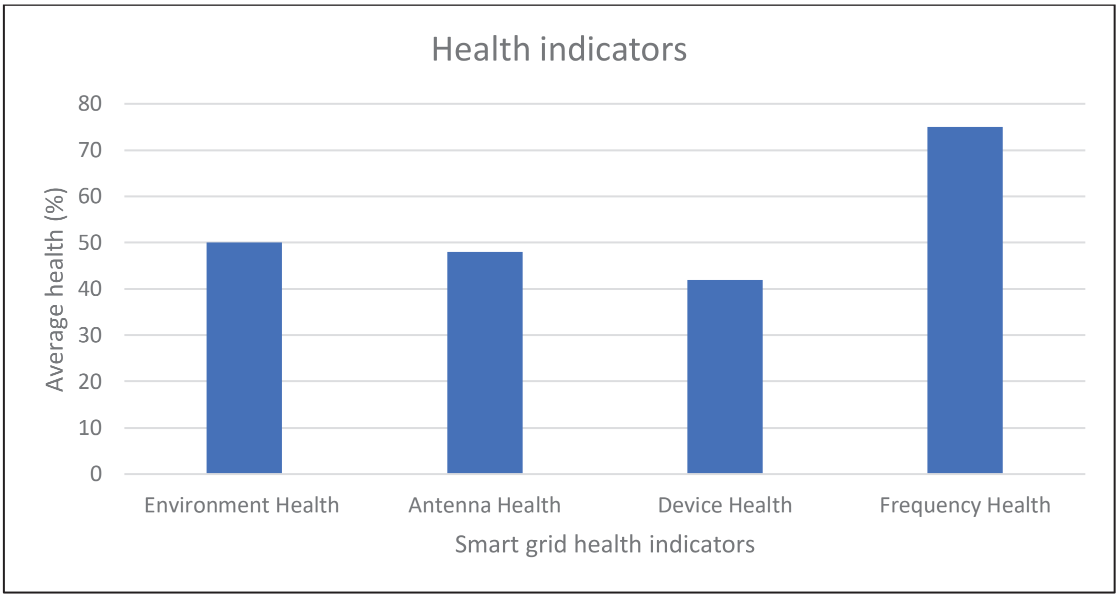


Figure 12.14: Environment health indicators scenario five

The risky health of the environment is due to a large number of devices that do not have a connection to an antenna due to the antenna drop agent disconnecting all of the devices from an antenna once it drops it.

The antenna drop agent is responsible for shutting down an antenna by assigning a frequency of 0Hz to the antenna. In the fifth scenario, 34% of the devices did not have a connection to an antenna due to an antenna that is shut down.

In scenario four, the antenna was permanently shut down by a user. In scenario five the antenna drop agent disconnected the antenna and waited for the FMA to bring the antenna back online. The Antenna Drop Agent executed an average of 21 times, and the EAA requested the FMA 21 times on average. Figure 12.15 shows one of the antennas had more frequency drop request than others.

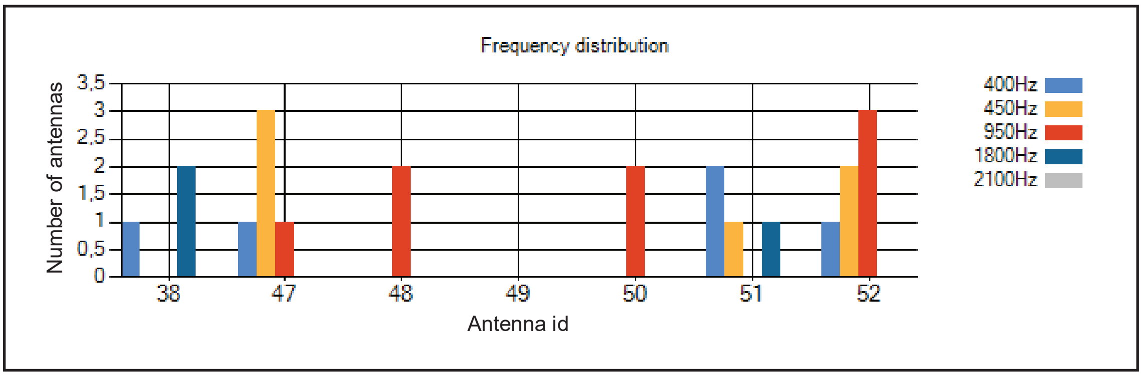


Figure 12.15: Antenna frequency distributions scenario five

The environment's health decreases when the Antenna Drop Agent drops one of the antennas. The decrease of health is because the connected devices disconnect after the antenna is shut down. After a short period, the health of the environment moves back to a good state which indicates that the FMA was able to bring the dropped antenna back up for devices to reconnect to the antenna meaning that the FMA operates as expected.

12.1.7 Scenario Six

In scenario six the automatic drop antenna agent executes every ten to thirty seconds, and the environment gets overloaded. The sixth scenario is intended to test if the FMA can operate under high load. Scenario six ran three times for ten minutes. The next section of chapter 12 describes the results after the sixth scenario executed.

One of the only notable differences between scenario five and six is the number of disconnected devices. Scenario six has more devices that are disconnected partly due to the Frequency Management Agent not reassigning an antenna drop fast enough and partly to the large number of connected devices. Figure 12.16 shows a comparison between the two scenarios.

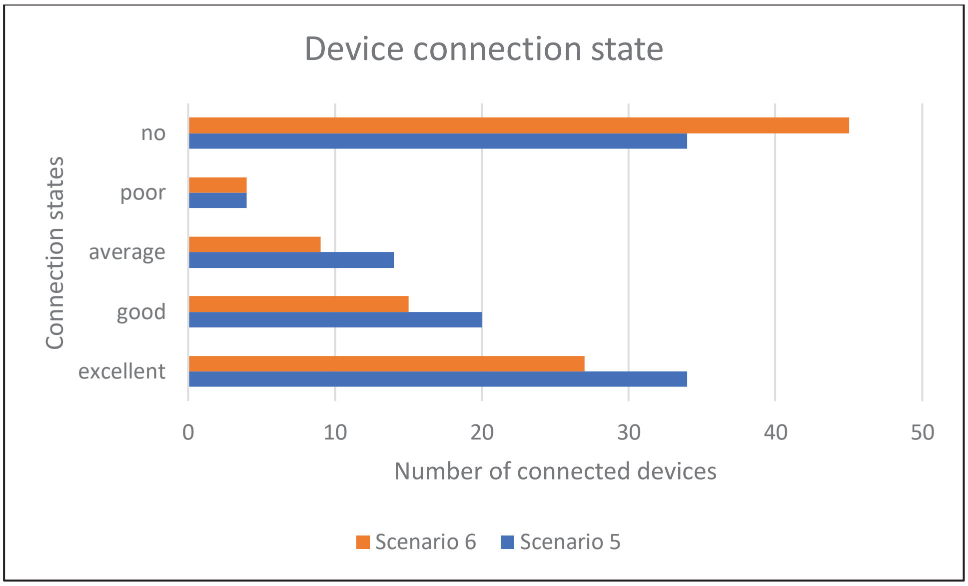


Figure 12.16: Device connection state

In the sixth scenario, the FMA was able to bring the dropped antennas back up allowing devices to reconnect to antennas as was expected. If the FMA did not execute in the sixth scenario, there would have been no devices connected to an antenna.

12.1.8 Scenario Seven

Scenario seven extends from scenario one, and two with the automatic antenna dropping agent switched off. The seventh scenario is intended to test if the Service Switching Agent executes as intended. Scenario Seven ran three times for twenty minutes. The next section of chapter 12 describes the results after the seventh scenario executed.

In the seventh scenario, the prototype ran with no load placed on the environment for the first ten minutes and with a high load for the last ten minutes. When the environment was under high load the health of the environment was dangerously low as can be seen in figure 12.17.

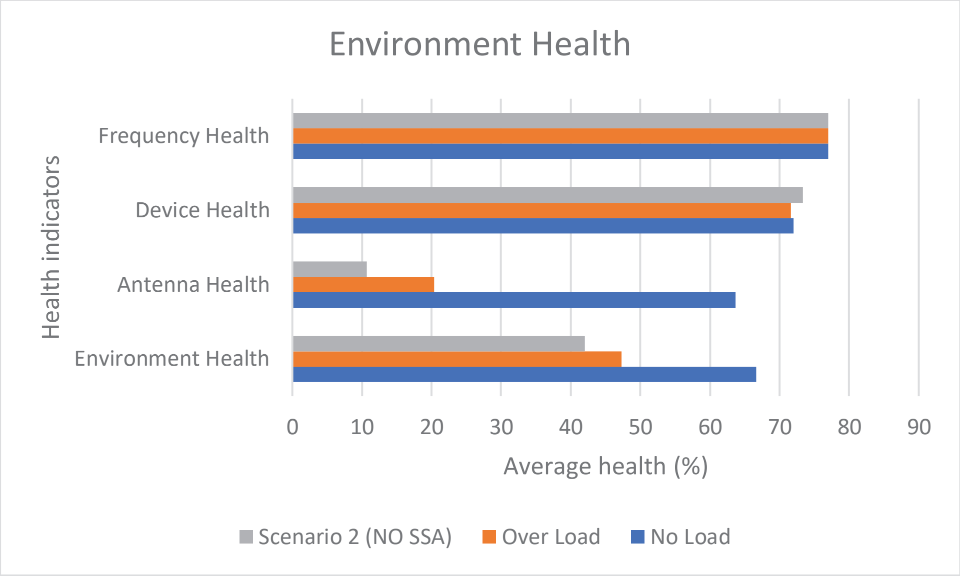


Figure 12.17: Load indicators scenario seven

In scenario two the environment was overloaded, but the SSA was shut down. The SSA executed an average of 65 times indicating that the SSA had a slight effect on the health of the environment as can be seen in Figure 12:17. The device health was slightly worse in the seventh scenario due to the SSA agent moving a small number of devices that had a good signal to different antennas that were in range forcing some of the devices to have a slightly worse signal.

12.1.9 Scenario Eight

Scenario eight is extended from scenario three and four. The eighth scenario is intended to test if the Service Switching Agent operates as planned with an antenna switched off. Scenario Eight ran three times for twenty minutes in each session. The next section of chapter 12 describes the results after the eighth scenario executed.

In the eighth scenario, the prototype ran with low load placed on the environment for the first ten minutes and with a high load of devices in the last ten minutes. When the environment was under high load the health of the environment was dangerously low but not as low as it was in scenario four. Figure 12.18 shows the health of the environment after the eighth scenario executed.

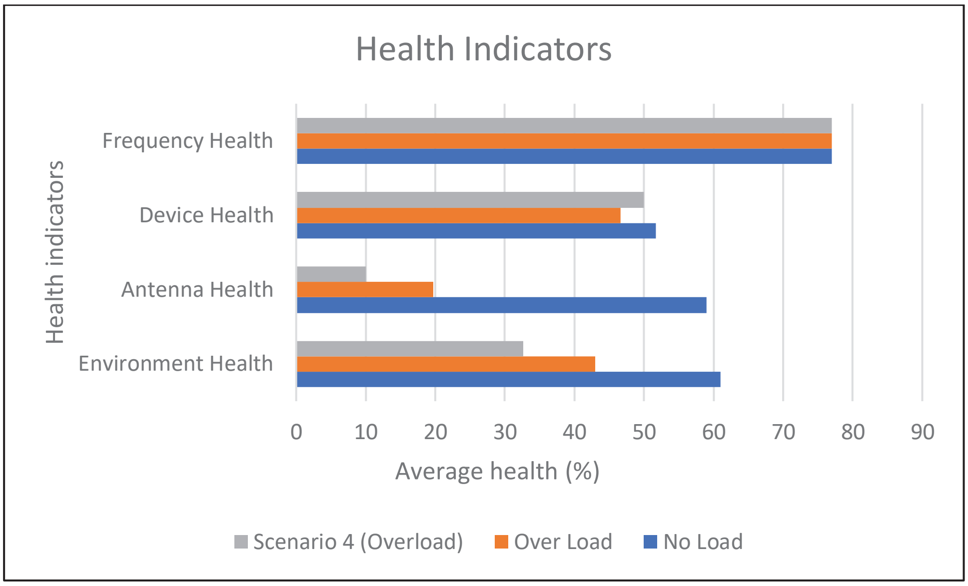


Figure 12.18: Health indicators scenario eight

As was seen in scenario seven, the health of the environment is significantly improved when the SSA ran in comparison to when the SSA did not run. The SSA executed an average of 24 times when the environment was overloaded in the eighth scenario.

12.1.10 Scenario Nine

The ninth scenario was run for one hour. One of the significant differences between the first five scenarios and the ninth scenario is that the ninth scenario had more human intervention concerning shutting down an antenna that a user selected.

The ninth scenario was neither to test the agents that cause conflicts of frequencies between antennas, nor was it about seeing how the agents reacted to that scenario. It was to determine how an agent responds when an antenna is shut down. Table 12.3 shows all the execution parameters in the ninth scenario.

Table 12.3: Scenario nine parameters

Number of antenna shutdowns	3
Time antenna was shut down	Shut down for 5 minutes on every ten-minute interval

In this experiment, the logs of the antenna before and after each of the antenna shutdown requests are reviewed.

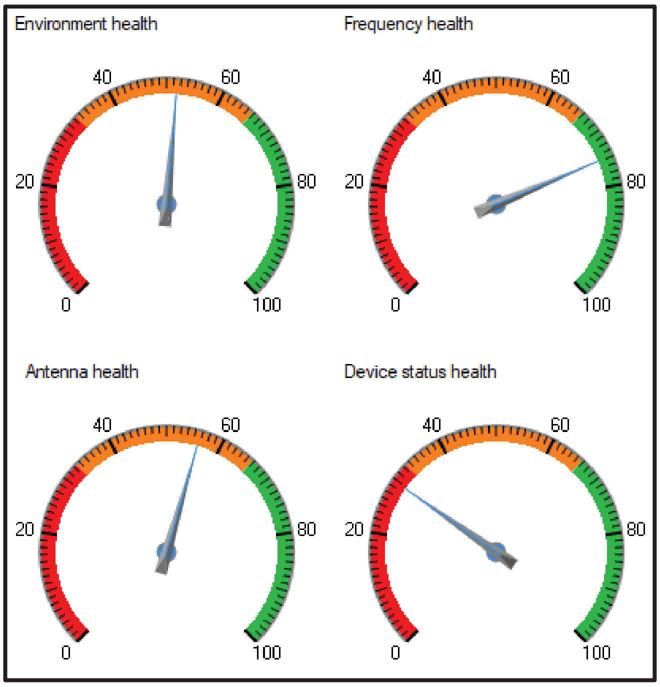


Figure 12.19: After antenna shutdown scenario nine

Figure 12.19 shows the health of the environment during one of the shutdown requests. The figure shows that the health of the environment drastically decreased further into the risky zone. The decrease was caused by device health and antenna health degrading. The device health degraded due to an antenna going down while many devices were not connected.

In comparison to the eighth scenario, the antenna health degraded heavily due to the environment losing one of the seven antennas. When one antenna is shut down the other antennas in the environment are placed under high pressure, degrading their health into a risky state.

Figure 12.20 shows that during a shutdown request there were many devices with no connectivity due to antennas not having a frequency band available for devices to use. Once an antenna was shut down, the large number of devices connected to the antennas had to search for new antennas to connect to, if they were in the range of a different antenna.

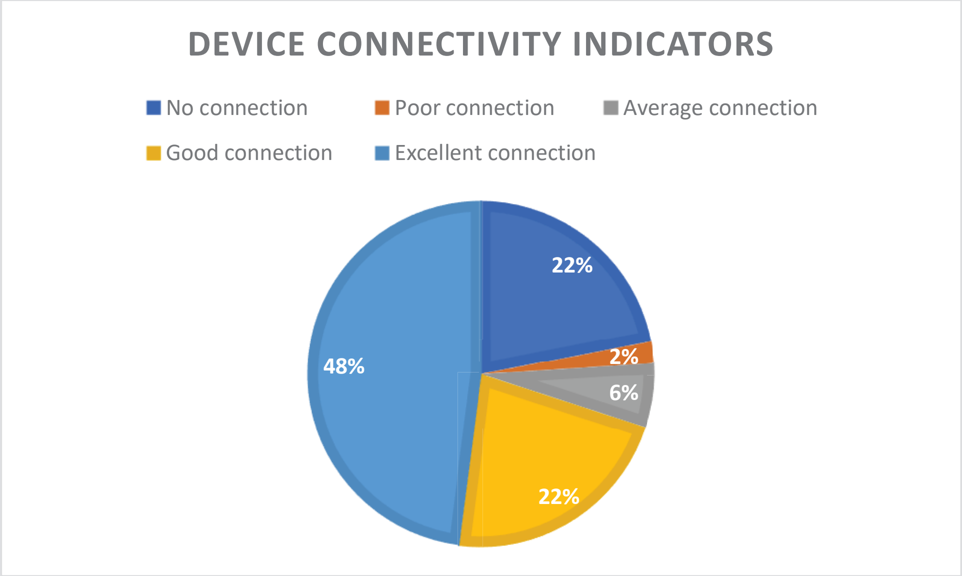


Figure 12.20: Device states while antenna was shut down, scenario nine

The disconnected devices had a profound influence on the health of the environment and the smart antenna system. Looking at the logs, some of the devices in the smart antenna network could have connected to a new antenna that was in range. Other devices were out of range of the antennas, so there was no way for them to communicate with an antenna.

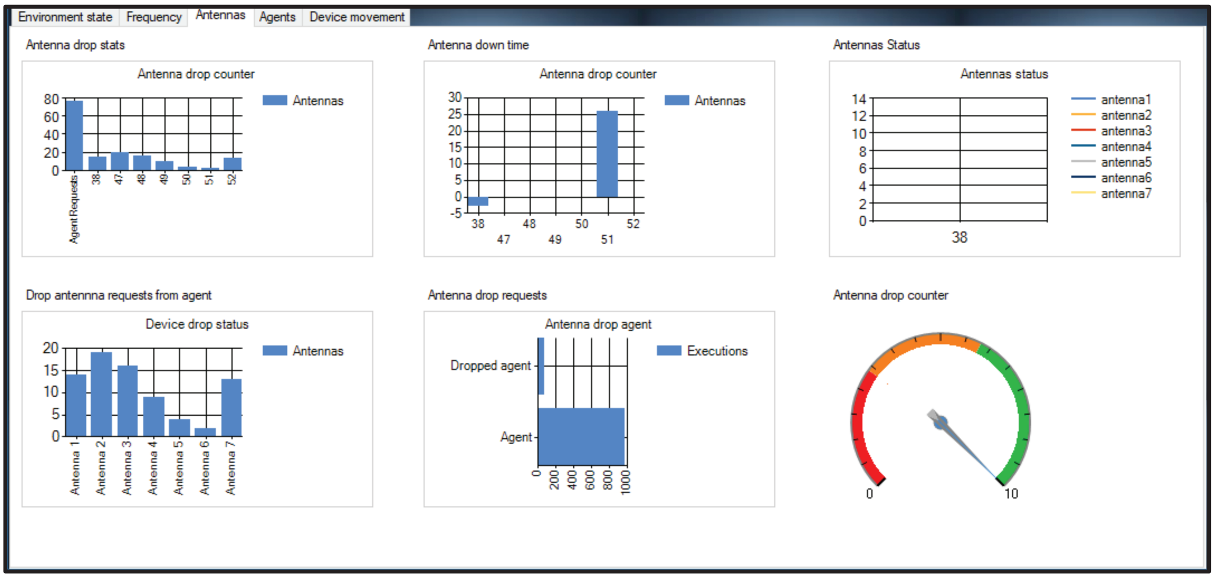


Figure 12.21: Antenna states after scenario nine

Figure 12.21 shows the antennas' states after the experiment had been completed. Since scenario nine built upon the sixth scenario, the antenna drop agent still executed more than 70 times, as regularly as Figure 12.21 demonstrates. The antenna drop counter shows a total downtime of around 25 minutes during the one-hour experiment.

Figure 12.22 shows that after the one-hour execution of the scenario, the environmental health returned to a good state, indicating that the disconnected devices had been reconnected. This was caused by the FMA bringing antennas back to an operational state.

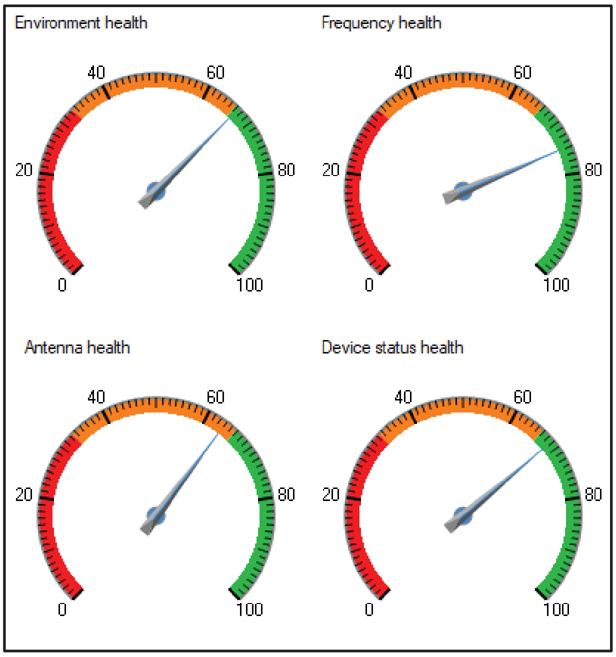


Figure 12.22: Environment health after scenario nine

Figure 12.23 shows that the only agents that executed in the experiment were the frequency management agent, the environment analysis agent, and the antenna drop agent. The figure also shows that the device status changed. In comparison to Figure 12.20 where one of the seven antennas was shut down, most of the devices in scenario nine had a connection agent. In the one-hour experiment, one of the seven antennas were under load, as shown in the antenna loads diagram, but the Service Switching Agent did not need to execute.

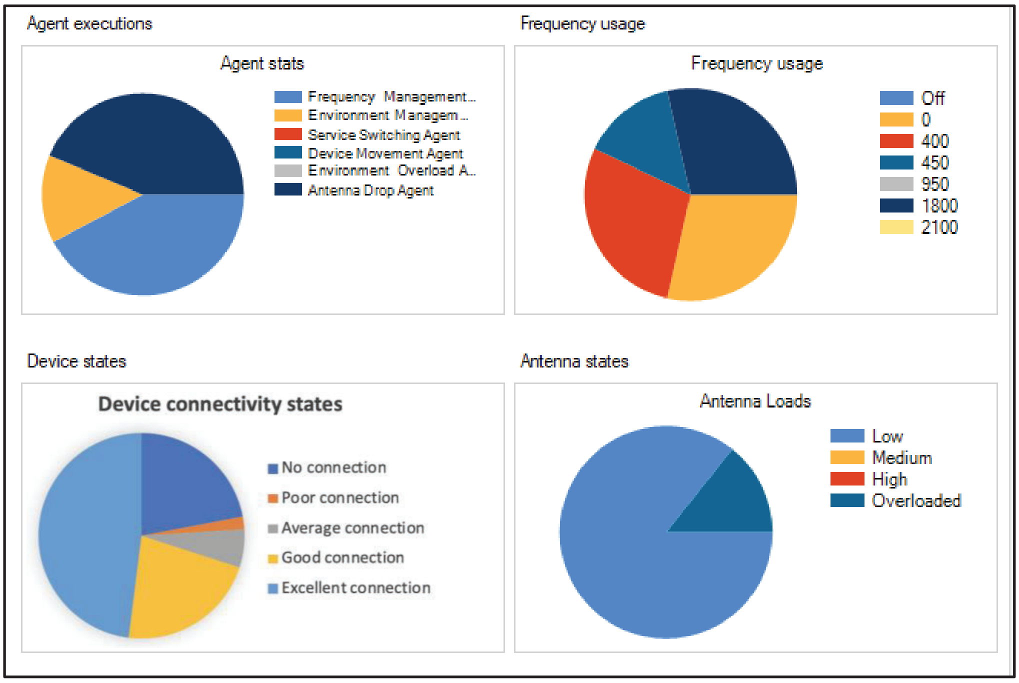
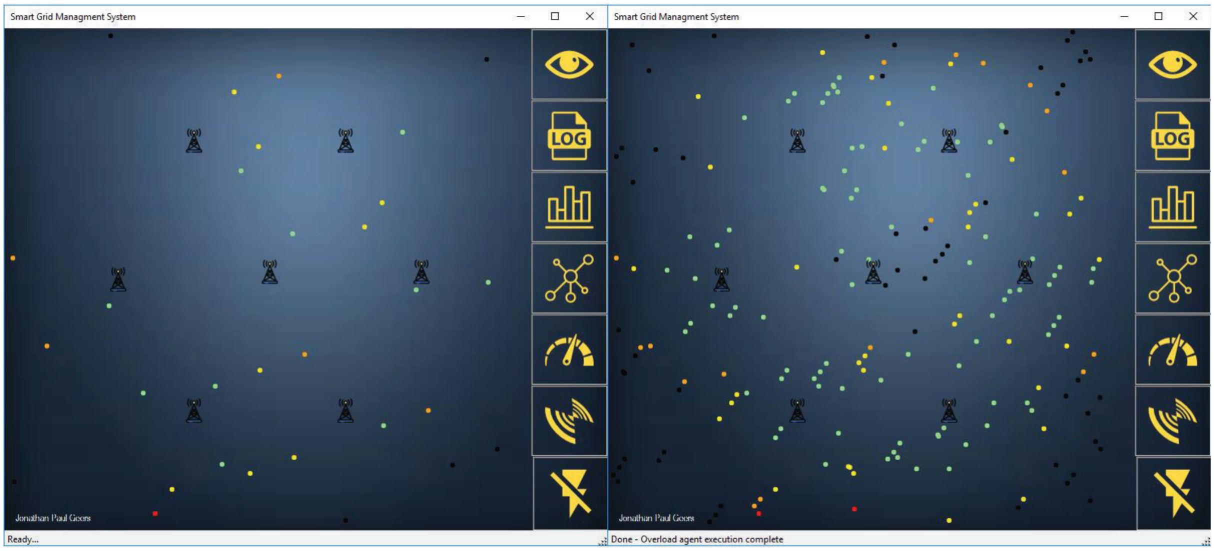


Figure 12.23: Environment state after scenario nine

In the execution of scenario nine, the environment was in a risky state when one of the antennas was switched off; however, the environment was able to recover to a normal operating state after the antennas were switched on again. In the execution, the devices that were in the range of an antenna with available space connected to the antenna.

12.1.11 Scenario Ten

Scenario ten is the final scenario executed in the smart antenna system. This scenario was designed to test all the different agents to their limits, and to observe how the different agent reacted. The tenth scenario executed for one hour, with some human interaction required. In scenario ten the environment's load was increased to over 120% by pushing the number of devices up to 168 devices.



Ready...

Done - Overload agent execution complete

Figure 12.24: Environment state before and after overload, scenario ten

Figure 12.24 shows the simulation environment before and after the environment was overloaded. The figure shows that the number of devices that operated in the environment doubled in comparison to when the environment started.

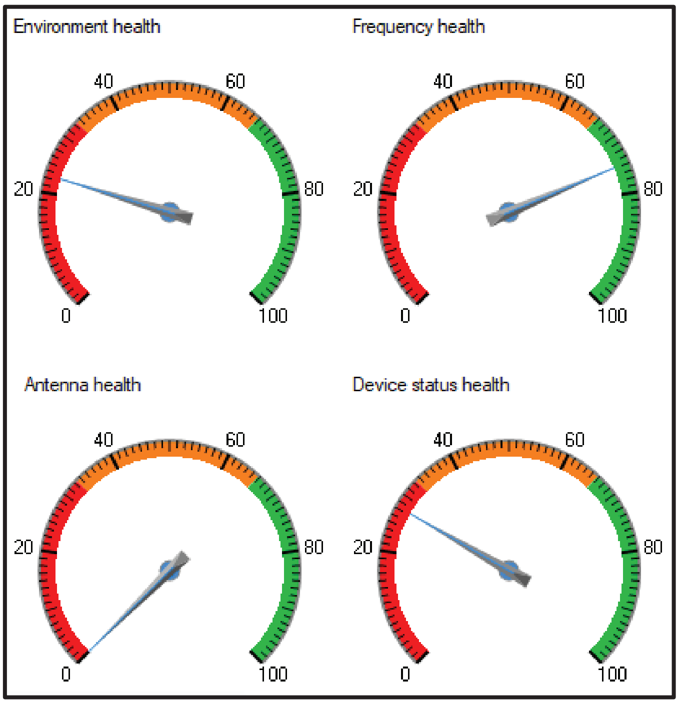


Figure 12.25: Environment state after scenario ten

Figure 12.25 shows the environment health status after the environment executed. The figure shows that the environmental health was in the dangerous area. The reason for the environmental health being low was due to the device health being low and the antenna health being very low.

Figure 12.26 shows that the frequency management agent executed 34% of the time, while the service switching agent was responsible for 20% of the executions. The environment overload agent was executed 3% of the time to test the patterns of executions. The antenna drop agent was very active in this scenario.

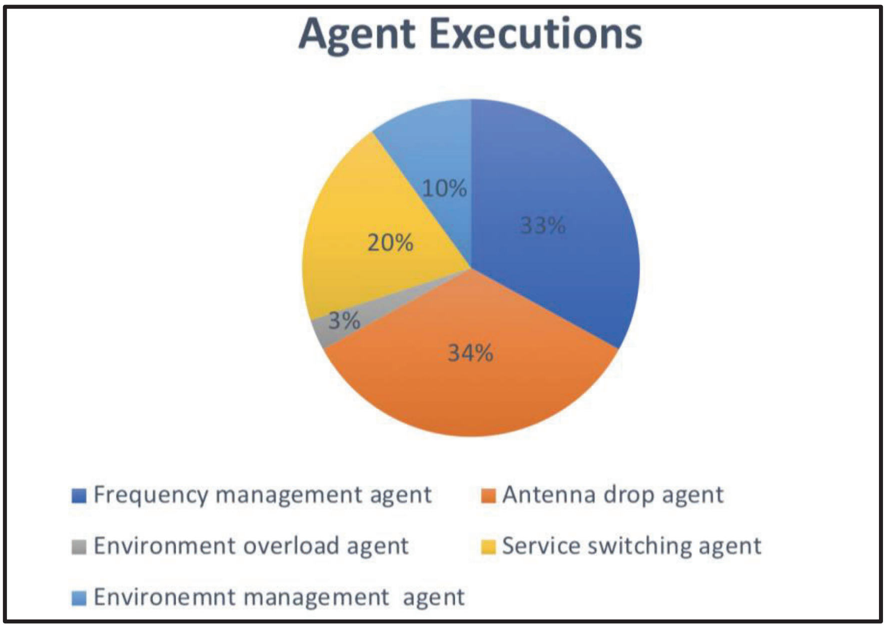


Figure 12.26: Agent executions in scenario ten

After monitoring the execution of scenario ten, the environment had some stages where the stability of the environment dropped to a low standard. The environment's health was very low in the scenario because two of the antennas were shut down for an average of 25 minutes, as can be seen in Figure 12.27.

The switched off agents forced many devices to disconnect, and forced the antennas' health to degrade. Seventy-three per cent of the devices were forced to disconnect due to an antenna shut down. After the antennas were brought back up, the health improved by moving into the risky zone.

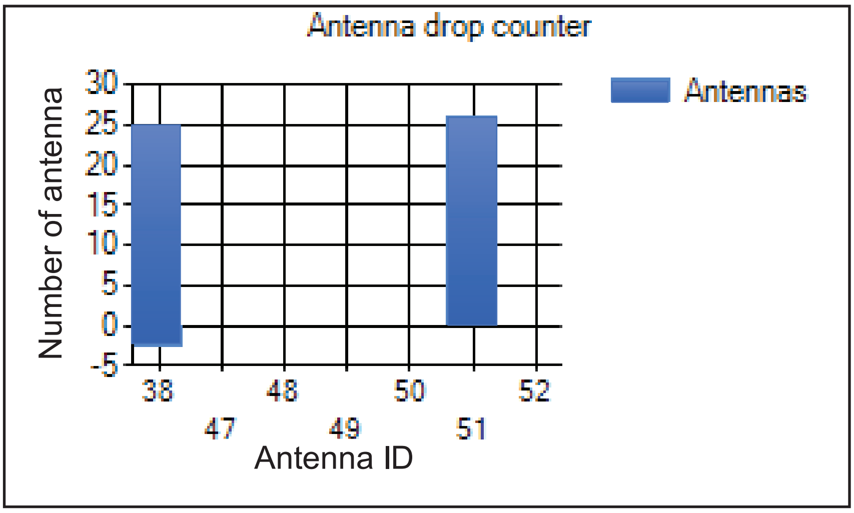


Figure 12.27: Antenna drop counter

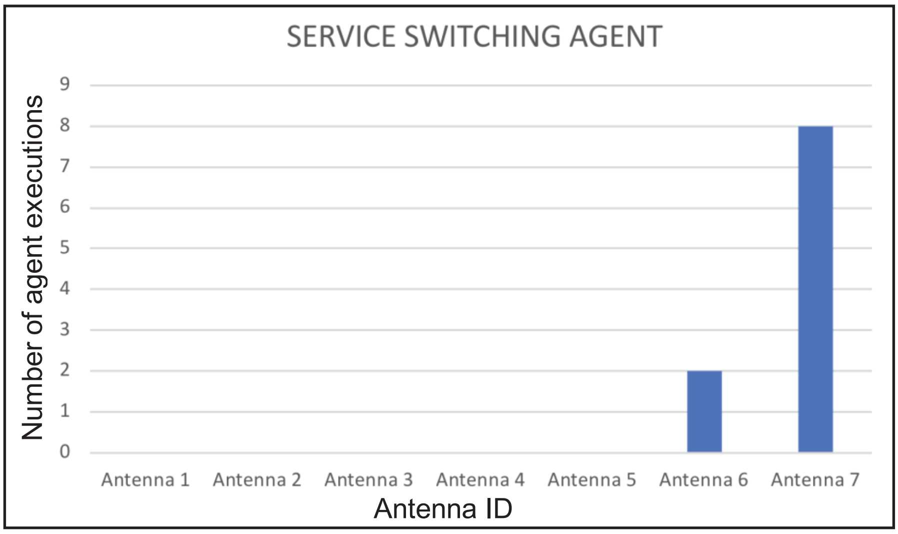


Figure 12.28: Service Switching Agent execution

Figure 12.28 shows the antenna on which the Service Switching Agent executed. As can be seen, it ran on more than one antenna several times. The figure shows that antenna 7 was under the most significant amount of load, where the agent needed to execute eight times. The agent executed multiple times on the same antenna because the majority of the load was in that one location.

Alongside the device movement agent, the pressure on the environment shifted around a bit. After the service switching agent executed on overloaded antennas, the environment saw a small improvement in health. The slight improvement showed that the SSA was able to move some devices to different antennas to improve the load on the environment.

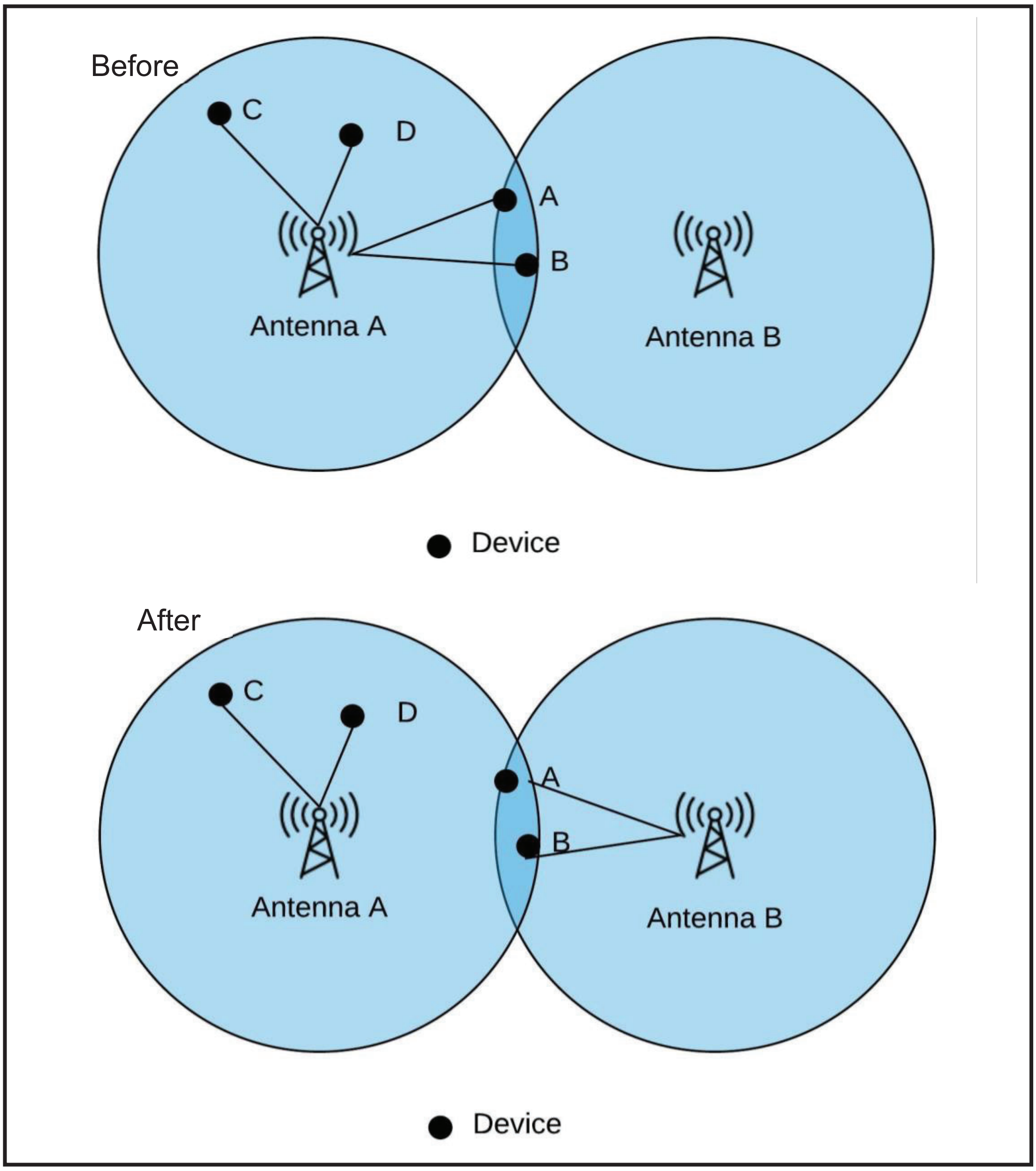


Figure 12.29: Service Switching Agent Execution Plan

Figure 12.29 shows what happened to devices in the environment before the service switching agent executed. As can be seen in the graph, device A and device B are on an intersection of two different antennas. Both devices were initially connected to the same antenna. At the same time, device C and device D are both connected to the same antenna, but not on the edge. After antenna B was overloaded, devices C and D were not able to reconnect to a new device, and there was a small possibility that the devices would disconnect. To solve this, device A and B connected to antenna B, because it had the least amount of load. The two antennas shared the responsibility of ensuring that the devices had connectivity and were as stable as possible. This means that the SSA operates as expected by moving devices to an available antenna as discussed.

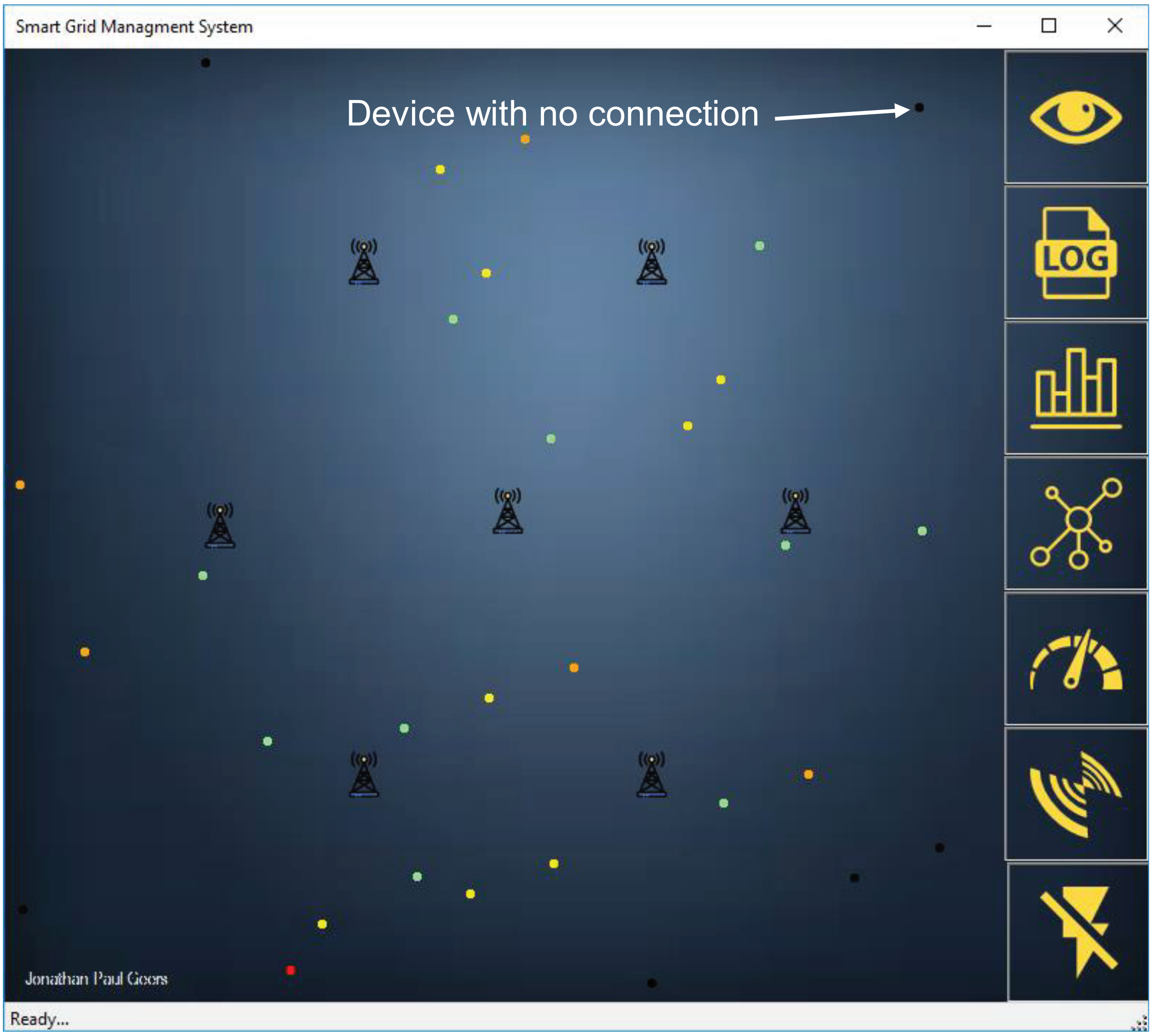


Figure 12.30: Disconnected device

In most scenarios, there are devices in the environment with no connection. These are devices that are out of range of all the antennas in the simulation environment, or devices that disconnected from an antenna due to high load or inactivity in the environment. Figure 12.30 shows the indicator of a device with no connection.

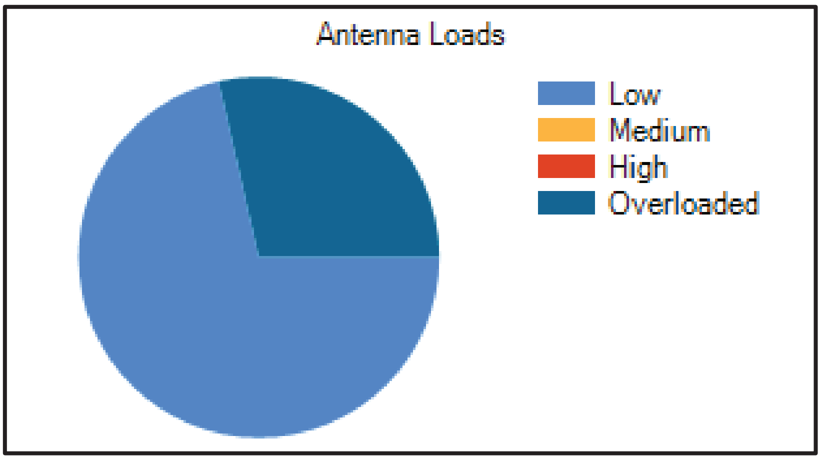


Figure 12.31: Antenna loads after scenario ten

Figure 12.31 shows antennas that are under high load. What this means in the system is that there might be some device disconnection to the antenna. The service switching agent only drops non-active users in the environment.

12.2 Results Observations

After running the tests, a few observations were made concerning agent executions. In total there were more than 300 agent executions in scenario ten. One of the main problems found when looking at the data was that agents took a while to execute, as they relied on other agents to execute.

In the tenth scenario, the antenna overload agent was executed three times. In all three of the instances, the agent was left to execute for more than three minutes at a time. It executed as expected, where two out of seven antennas were overloaded most of the time. The overload agent was not only responsible for adding more, but was responsible for returning the environment to a low load point.

The service switching agent was executed ten times in scenario ten. When reviewing the execution of the SSA, it was found that it could connect a device to another, neighbouring antenna. The agent moved devices to antennas with a lower load to improve the health of the environment.

12.3 Conclusion

When executing the simulation environment without overloading the environment or switching off any antennas, the environment operated in a well-functioning state. When running the simulation environment with antennas that were shut down for maintenance, the health of the environment deteriorated to a risky state, but this state was not permanent, as it normalised to well-functioning when all the antennas were switched back on.

When pushing the simulation environment to have too many devices the different agents that operated on the environment managed the resources by moving devices to neighbouring antennas that were in the devices range. The execution of the agents caused an improvement in environmental health. The only instances where the environment moved into a dangerous state was when the environment became overloaded, and when a set of antennas were shut down for maintenance.

The second scenario focused on the frequency management aspect in the smart grid environment. Scenario two forced the FMA to execute. Scenario ten was the last of the test scenario and had the sole responsibility of forcing the simulation environment to overload. This caused the frequency management agent to execute.

Each of the scenarios shared the objective of determining the simulation environment results. The simulations showed that there was an improvement over scenario one when the agent executed to manage resources. The second scenario could manage conflicting frequencies. It showed that frequencies were assigned to antennas that were shut down. Scenario ten indicated that the SSA made a slight improvement on antenna load by moving devices to different antennas that were in the line of sight.

Chapter 12 has focused on answering the research question: *Is resource management improved by using a multi-agent system prototype level?* To answer the research question, a selection of ten scenarios were tested. Each of the scenarios set out in the chapter focused on attempting to demonstrate the results reached by the agents in the prototype implementing the SGMS model. To compare the scenario results, scenario one acted as the initial baseline scenario.

Chapter 13, the final chapter, focuses on presenting the conclusions made in the dissertation. The chapter focuses on the research questions that were set out in Chapter 1. The final chapter also provides some critique of this research dissertation.

Chapter 13 - Conclusion

1. Introduction

Literature

2. Cellular communication network
3. Smart antennas
4. Frequencies in communication networks
5. Software agents
6. Machine learning

Model Overview

7. Smart Grid Management System Model Overview
8. Environment Analysis Agent (EAA)
9. Service Switching Agent (SSA)
10. Frequency Management Agent (FMA)

Implementation and results

11. Smart Grid Management System prototype implementation overview
12. Prototype results overview
13. Conclusion

13.1 Introduction

Research objectives are set out to reach a result. One way in which research objectives can be achieved is by setting up a research question that can be broken down into various sub-research questions that have the primary aim of meeting the research objectives. The research question is the single most crucial keystone in a research paper.

In this dissertation, different chapters were intended to answer the research questions set out in Chapter 1, and aided in reaching the research objectives. Each chapter answered a section of one of the sub-research questions, or it aided in solving a research question section.

Throughout the dissertation, the focus was on the implementation of the current communication network, the nature of smart antennas, how frequencies are managed on the different communication networks, the nature of agents, and where the various agents can be used. Much focus was placed on a prototype that manages resources in a smart grid, known as the Smart Grid Management System.

The aim of this final chapter is to answer the primary research question as well as the sub-research questions. To answer the research question, Chapter 13 defines the chapters that covered the sub-research questions, and the manner in which the chapters answered the research questions.

13.2 Research questions

Chapter 1 of the dissertation presented the main research question: *Can smart grid system stability and improved resource management be achieved by using a multi-agent system?* The question was broken down into sub-research questions. By answering the sub-research questions, the primary research question was answered.

13.2.1 How do smart antennas operate in a mobile network?

In order to answer the above research question, the question was broken down into different items. The first item called for understanding the nature of a smart antenna and all the various components that make up a smart antenna.

Chapter 2 focused on the implementation of a cellular communication network, what the cellular network needs to operate, and how the system operates. The chapter also discussed the shortcomings of cellular networks and the different types of antennas that can be used. The different kinds of cellular networks that can provide communication to smart antennas were enumerated. Smart antennas were covered in Chapter 3, which gave a description of a smart antenna, how a smart antenna operates, and the different types of smart antennas.

Chapter 4 focused on the frequencies in mobile networks, helping to understand how frequency management agents operate. The chapter gave details on the different frequencies and where they fit in. Frequency usage in mobile networks was mentioned, mainly focusing on frequency usage and the differences between the networks. The chapter looked at 1G, 2G, 3G, 4G and 5G, and the different ways a frequency can be reused.

The above three chapters described how the different smart antennas operate in the environment. The three chapters also aided in building a smart grid simulation environment on which to perform experiments.

13.2.2 How can a multi-agent system be integrated into a smart grid system?

Answering the above research question required breaking the question down into different sections for research. This particular research question was broken down into defining an agent and a multi-agent system, and how it can be integrated into a smart grid.

Chapter 5 focused on the nature of an agent, and on the different kinds of agents. One of the main focuses was on intelligent agents and the different types of intelligent agents. Understanding the different types of agents helped to define which agents could be used in a multi-agent system that manages a smart gird. A multi-agent system was described as a system that is a combination of different agents that communicate with each other to complete a task.

Chapter 6 focused on machine learning. It described the different kinds of machine learning, which helped to understand where machine learning can be used and the different types of machine learning. Because machine learning forms part of the multi-agent system that manages resources of a smart grid, it helps to understand how a multi-agent system can be integrated.

Chapter 7 focused on the different components that make up the smart grid system. It described the various agents that are used to manage resources and where in the smart grid the various agents are used, as well as the different components that make up the Smart Grid Management System.

Chapter 8 focused on the environment analysis agent concerning when the agents are deployed, their primary task in the agent's smart grid management system, and their different components.

Chapter 9 focused on the service switching agent concerning where the agent operates in the smart grid management system, and some of the parts that help with the agent's operations.

Chapter 10 focused on the frequency management agent concerning where it fits into the smart grid management system, and on the different components that help it to function. Chapters 8, 9, and 10 helped to understand how an agent can be integrated into a multi-agent system.

Chapters 11 and 7 played an essential role in answering the question: *How can a multi-agent system be integrated into a smart grid system?* The chapters described how the different agents are integrated into the smart grid management system. Chapter 11 focused more on the different helper agents that enable the smart grid system to manage resources, whereas Chapter 7 focused on how the three core managing agents are integrated into the system.

13.2.3 Is resource management improved by using a multi-agent system prototype level?

Answering the above research question required a simulation software system on which to implement a prototype, to determine if the multi-agent system was an improvement on the resource management aspect. No simulation environments utilised smart antennas in communication systems. Some simulation environments did focus on the communication network, which was not optimal, because the simulation environment was built to perform experiments.

Chapter 11 focused on the model's implementation in the prototype and the different agents that formed part of the prototype and getting the prototype to operate as expected. The chapter also focused on the tasks of the different agents in the prototype. The chapter also focused on the user interface of the prototype, which enables users to perform experiments.

Chapter 12 was the most critical chapter in answering the research question: *Is resource management improved by using a multi-agent system?* The chapter focused on the results obtained from the model. A number of scenarios were applied to the smart grid management system to determine the effectiveness of the multi-agent system.

The results were shown in Chapter 12 after ten scenarios had been executed. In the first four scenarios, the SGMS Model was turned off forcing the agents that are responsible for managing resource not to run. The four scenarios set a baseline that was used by other scenarios with the SGMS model active.

In the first scenario, the environment was executed under low load with all antennas operational for the duration of the experiment. The second scenario was executed under high load with all antennas operational for the duration. Scenario three was executed under low load with one antenna shut down for the duration of the simulation environment. The fourth scenario was executed under high load with one of the antennas shut down in the environment.

Scenario five to ten tested the SGMS model by comparing the results that were found in the first four scenarios. The fifth scenario was designed to test if the FMA can bring antennas back up that was dropped by the antenna drop agent when the environment was under low load. As was the case in the fifth scenario, scenario six was designed to test the FMA with the environment under high load. The FMA operated as intended in the fifth and sixth scenario by bringing antennas back up that were dropped and by moving the environment health back to what was seen in scenarios one and two.

The seventh scenario was designed to test the SSA in an environment that is placed under high and low load. Scenario seven shows that the health of the environment under low load was the same as what was seen in scenario two. When the environment was placed under high load in the seventh scenario, the health of the environment was improved compared to scenario two. The improved health is due to the SSA moving devices to other antennas that are in range and under low load.

Scenario eight was designed to test an environment that is placed under high and low loads with one antenna shutdown for the duration of the simulation. Compared to scenario three, scenario seven shows that the health of the environment when it was under low load was similar. Compared to the fourth scenario, the eighth scenario showed that the health of the environment improved due to the SSA executing.

The ninth scenario focused on shutting down antennas so as to resemble maintenance in progress. The results gathered from the first scenario showed that the environment was in a risky state, with many users disconnected from an antenna. Only the devices that bordered on other antennas could reconnect to them. Once the antennas were switched on again, the health of the environment returned to a well-functioning state.

The Tenth scenario was designed to test the multi-agent system. In this scenario, the environment was placed under load by adding multiple devices to operate in the environment at the same time. Antennas were shut down in the environment while it was under pressure. The SSA was able to move devices to antennas that were in range, lessening the load and aiding in improving the health of the environment by 5%, by ensuring that there are more devices with active connections in the system. When an antenna is down, and the environment is under load the environment is in a dangerous state.

The improvement on the health of the environment showed that a multi-agent system can improve upon the resource management concerning frequency distribution, ensuring that as many devices as possible are connected to an antenna by removing inactive devices and connecting new devices.

13.3 Dissertation critique

In the simulation environment, one of the main problems was finding a simulation environment that simulated a smart antenna communication system. There are not any viable existing simulation environments that show a smart antenna cellular network to perform experiments.

Throughout the research into the simulation environment, some simulation environments were focused on the traditional cellular network that makes use of the hexagon layout. These simulation environments are not what was required to perform experiments, as the results would not have been valid or useful in any way.

The requirement of a simulation environment for experiments meant that a simulation environment had to be built for the smart antenna system. The built simulation environment was not a perfect match for a smart antenna network, but it was a very close match. Because the simulation environment must contain agents to simulate movements and connections, there was not a great deal of real-time computation.

It was difficult to judge what the different agents would do in the actual environment, in comparison to the simulation environment. In each simulation run, the agents performed well.

13.4 Conclusion

The dissertation has provided information relating to cellular networks and how cellular networks work. Several chapters covered aspects of a smart antenna network similar to the antennas that make up the network, the frequency usages, and the coverage area of smart antenna networks.

The physical implementation of a simulation environment to implement several of the agents was discussed. At the end of the day, all the agents in the simulation environment had the same objective: to improve the resource management of the smart antenna network under most scenarios. The agents all had their tasks to carry out, and their unique techniques to do so.

The main research question asked if smart grid system resource management can be achieved by using a multi-agent system. When looking at the simulation environment implementation, the data shows that by focusing on environment load and the frequencies utilised in the environment, a multi-agent system can indeed be used to manage resources in a smart grid system.

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