BANDWIDTH PROVISIONING SCHEME FOR CLUSTERED WIRELESS SENSOR NETWORK

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COMMITTEE DECISION

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DEDICATION

I dedicate this thesis to my beloved parents Mr. Abd Al-Jabbar Mizher and Mrs. Muntaha Yahya, who gave me an appreciation of learning and taught me the value of perseverance and resolve.

I also dedicate this work to my maternal uncle Dr. Abdel Fatah Yahya, dean of IT college in Al-Zaytoonah University for his unlimited support throughout my entire academic route. I further dedicate this study to my brothers (Ahmad, Hosam and Deaa) and sisters (Manar, Marwa, and Duaa) for their unfaltering support and understanding while I was working on this thesis.

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LIST OF ABBREVIATIONS

1G	Mobile First Generation
2D	Mobile Second Generation
3D	Mobile Third Generation
3D-DBBS	Three-Dimensional Dynamic Rate-Based Borrowing Scheme
4G	Mobile Fourth Generation
A3D-DBBS	Adaptive Three-Dimensional Dynamic Rate-Based Borrowing Scheme
ABB	Actual Borrow able Bandwidth of the call
AES	the Advanced Encryption Standard
BC	Blind Cone
BER	Bit Error Rate
BLT	Bandwidth Lose Tolerance
BP	Blocking Probability
bps	bit per second
BS	Blind Spot
BW	Bandwidth
BWU	Bandwidth utilization
CDMA	Code Division Multiple Access
CDP	Connection Dropping Probability
CR	Connection Rate
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
CWN	Cellular Wireless Network
DBBS	Dynamic-Based Borrowing Scheme
DCA	Dynamic Channel Allocation
DP	Dropping Probability
DRBBS	Dynamic Rate-Based Borrowing Scheme
DSSS	Direct Sequence Spread Spectrum
DVB	Digital Video Broadcasting
FDMA	Frequency Division Multiple Access
FTP	File Transfer Protocol
GSM	the Global System for Mobile Communication
IEEE	the Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IS-95	Interim Standard-95
MAC	Medium Access Control
MANET	Mobile Ad-hoc NETworks
MEX	Minimum Expected Bandwidth
MMS	Multimedia Messaging Service
MSC	Mobile Switching Center
NADC	North American Digital Cellular

nBS	No Blind Spot
NP	Nondeterministic Polynomial
P2P	Peer to Peer
QoS	Quality of Service
RBBS	Rate-Based Borrowing Scheme
RF	Radio Frequency
SAP	Sensor Access Point
SBBS	Static-Based Borrowing Scheme
SBS	Statistical Borrowing Scheme
SLA	Service Level Agreement
SON	Service Overlay Network
SUI	Sensor Usage Index
TDMA	Time Division Multiple Access
U.S	United State
wBS	Without Blind Spot
WMSN	Wireless Multimedia Sensor Network
WSN	Wireless Sensor Network

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ABSTRACT

Bandwidth (BW) resources are scarce and valuable in Wireless Sensor NETworks (WSNs). This scarcity is resulted from WSN's compliance to 802.15.4 standard which can be distinguished by: low data rate, low power consumption, and low cost. Therefore, managing this scarcity in BW is a key challenge in WSN's environments.

Achieving high BW Utilization (BWU) will rise the Quality of Service (QoS) that network can guarantee, without the omission of the importance of concurring BWU, with the minimizing of connection blocking and dropping probabilities.

Most of previous studies considered QoS in WSNs form sensors lacked the energy aspect. On the other hand, our study considers attaining high QoS from point of BW scheduling whether WSNs is designed in two or three dimensions, also our scheme studys the effect of existence or the absence of base station blind spot.

Therefore, we have entered many concepts and metrics in QoS in WSNs, such as: Handoff, Static-Based Borrowing Scheme (SBBS), Dynamic-Based Borrowing Scheme (DBBS), Connection Blocking Probability (CBP), and Connection Dropping Probability (CDP). We have tested WSN under sixteen different cases, which comprised: Two Dimension structure (2D), 3D structure, Indoor Space, Outdoor Space, with Blind Spot (wBS), using Dynamic borrowing mechanism, using Static borrowing mechanism, and finally, without Blind Spot (nBS).

The results revealed that Dynamic borrowing mechanism outperformed the Static borrowing mechanism by 7% on average for BWU even when taking the base station into consideration. Result of simulation showed that 3D is less than 2D by 1.3% on average for BWU. Outdoor networks have better BWU by 0.2% than Indoor, bearing in mind that Blind Spot (BS) will decrease BWU by 1.2%. When network has connection rate (CR) equal to 200 connections per a round, it will increase BWU by 2.7% than having 50 CR.

On the other hand, blocking and dropping probabilities vary under different cases. Dynamic mechanism has 6% less, and 5.8% less for CBP and CDP, respectively, compared with Static one. While, 3D has 4.9% less for CBP and 5.7% less for CDP than 2D on average. Outdoor decreases CBP by 1.29% and by 3.7% when using Static and

Dynamic, respectively, and decreases CDP by 0.2% for Static and by 2.99% for Dynamic comparing with Indoor. Also, simulation results showed that neglecting existence of BS will decrease CBP by 0.85% and by 9.99% for Static and Dynamic, respectively ,and decrease CDP by 0.23% and by 3.25% (for Static and Dynamic, respectively) on average. As expected, network with CR equal 50 reduced CBP by 6.26% and CDP by 5.7% comparing with 200 CR. It is worth mentioning that previous results are processed from repetition each situation 2500 times, which make these results high strict and reliable.

As a result, considering network with using Dynamic borrowing scheme and with rate up to 50 CR will have better QoS guarantees. Moreover, we can summarize that 3D space outperforms 2D space in general view. Finally, not considering BS and building network Outdoor will have better QoS guarantee in general.

1. Introduction

This Study presents a new scheme which combines concepts from WSNs and Cellular Wireless Networks (CWNs). Before talking about our new scheme, we should be aware of important topics which are closely related to this study, these topics are : WSNs, ZigBee wireless standard, mobile phone generations, QoS, handoff in CWNs, and antenna frequency coverage range.

1.1. Wireless sensor networks

A wireless sensor network is a network which consists of devices called sensors. These sensors cooperate with each other to monitor physical or environmental conditions, for instance, temperature, vibration, sound, pressure, pollutants, etc. WSN was developed for military applications such as battlefield surveillance. Nowadays WSNs are used in many civilian application fields, such as: healthcare applications, traffic control, environment and habitat monitoring, and home automation (R¨omer and Mattern, 2004).

Node in a WSN is typically supplied with a radio transceiver, or other wireless communications device, a small microcontroller, and battery which are usually the energy source. Single sensor node size varies from big size as shoebox nodes down to sensors of small size as grain of dust. But, until now there is not any functioning sensor with motes size, perhaps it will be created in future. Sensor nodes costs are similarly variable, ranging between hundreds of dollars and few cents, depending on two factors: size of the sensor network, and complexity required for each individual sensor node. Size and cost constraints on sensor nodes result is harmonize with constraints on resources such as energy, memory, computational speed and BW (R¨omer and Mattern, 2004).

A sensor network normally forms a wireless ad-hoc network, which means that each sensor supports a multi-hop routing algorithm, so several nodes may forward data packets to the base station. Exclusive properties of a WSN include (Tjensvold, 2007):

a) Limited power they can yield or store.

b) Ability to resist harsh environmental conditions.

c) Ability to defeat with node failures.

d) Mobility of nodes.

e) Dynamic network topology.

f) Communication failures.

g) Heterogeneity of nodes.

h) Large scale of deployment.

i) Neglected operation.

1.2. ZigBee wireless standard

Many standards of wireless networks appeared last years (Tjensvold, 2007), each has its own features, applications fields, and constraints. Differences between them are shown in Table 1.1.

Table 1.1: Comparison between different wireless standards (Tjensvold, 2007)

Standard	ZigBee® 802.15.4	Wi-Fi™ 802.11b	Bluetooth™ 802.15.1
Transmission Range (meters)	1 – 100	1 - 100	1 – 10
Battery Life (days)	100 – 1,000	0.5 – 5.0	1 – 7
Network Size (# of nodes)	> 64,000	32	7
Application	Monitoring & Control	Web, Email, Video	Cable Replacement
Stack Size (KB)	4 – 32	1,000	250
Throughput (kb/s)	20 – 250	11,000	720

As shown in Table 1.1, ZigBee is one of wireless standards, which is a technology developed as an open global standard to address the unique needs of low-cost, low-power, wireless sensor networks. The standard takes full advantage of the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 physical radio specification, and operates in unlicensed bands worldwide at the following frequencies: 2.400–2.484 GHz, 902-928 MHz and 868.0–868.6 MHz (See Figure 1.1). There are sixteen channels between 2.4 and 2.4835GHz, ten channels between 902.0 and 928.0MHz, and only one single channel between 868 and 868.6MHz (Ergen, 2004).

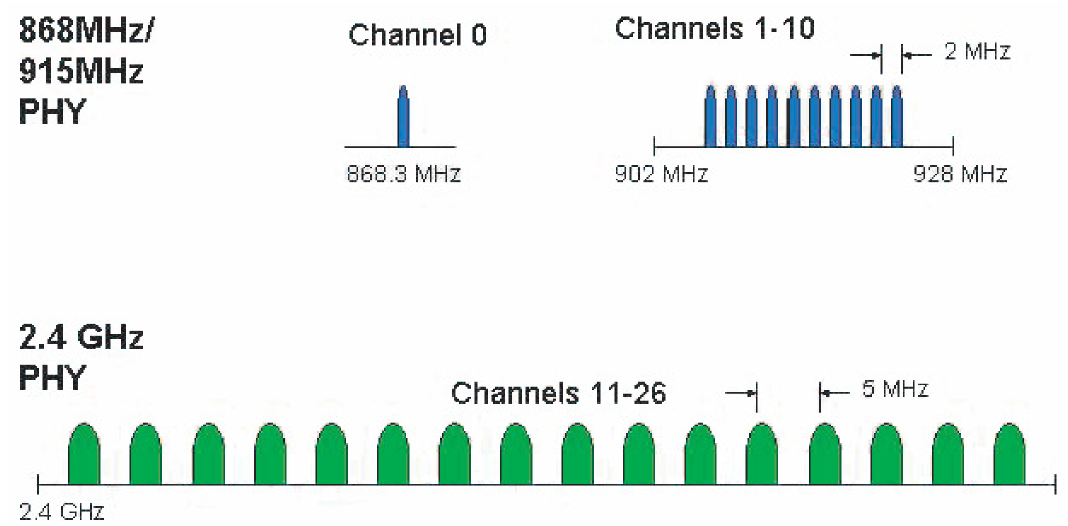

Figure 1.1: ZigBee operating frequency bands (Ergen, 2004)

The task of the ZigBee is establishing an open industry specifications for unlicensed, unrestricted peripheral, control and entertainment devices, which require the lowest cost and lowest power depletion communications between obedient devices anywhere in and around the home (Palowireless, 2009). ZigBee protocol has many good properties. We can summarize them here as follows (Ergen, 2004):

1. Low duty cycle which attains long battery life.

2. Low latency.

3. Support for multiple network topologies.

4. Direct Sequence Spread Spectrum (DSSS).
5. Up to 65,000 nodes on a network.
6. 128-bit the Advanced Encryption Standard (AES) which attains safe connections between devices.
7. Collision avoidance.
8. Link quality allusion.
9. Clear channel assessment.
10. Retrials and acknowledgements.
11. Support for warranted time slots and packet freshness.
12. Attains a security toolbox approach guaranteeing reliable and secure networks.
13. Enables broad-based deployment of wireless networks with low-cost, low-power solutions.
14. Attains the ability to run for years on inexpensive batteries for a big group of monitoring applications.

1.3. Mobile phone generations

Due to the similarity between Mobile Phone NETworks structure and our study, we have to present mobile phone phases or generations throughout years. Until now, there are four generations (Miki, et al.,2005), which are summarized below:

1.3.1 First generation (1G)

It uses frequency division multiple access (FDMA) which is an analog technology, FDMA delivers a radio-based voice channel to a mobile telephone user.

Shortcomings in this technology are: poor quality, limited coverage, and less than adequate system capacity.

1.3.2 Second generation (2G)

In the late 1980s, digital technologies were used to deployed systems. The first United State (U.S.) system used North American Digital Cellular (NADC), or which is Known as time division multiple access (TDMA). In the early 1990s, TDMA technology was used to introduce the Global System for Mobile Communication (GSM) to Europe. In the mid 1990s, code division multiple access (CDMA) came to be the second type of digital 2G system (Observe Figure 1.2), with the U.S. entrance of Interim Standard-95 (IS-95). All of the 2G systems outperform previous system by providing an enhancement of quality and better capacity. Also, Roaming was introduced as a part of the service offerings and coverage continued to improve.

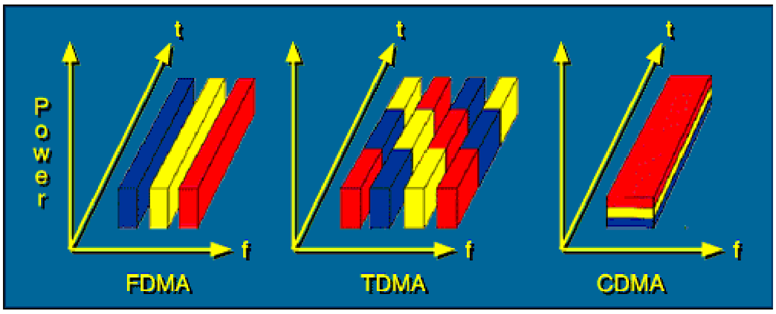

Figure 1.2: Comparison of FDMA, TDMA, and CDMA (Celusion, 2009)

1.3.3 Third generation (3G)

In this generation, Systems promised to provide better voice capacity, higher speed mobile data connectivity, and multimedia applications.

1.3.4 Fourth generation (4G)

Fourth-Generation is being grown to suit the QoS and rate requirements set by imminent applications like wireless broadband access, Multimedia Messaging Service (MMS), video chat, mobile television, Digital Video Broadcasting (DVB), minimal

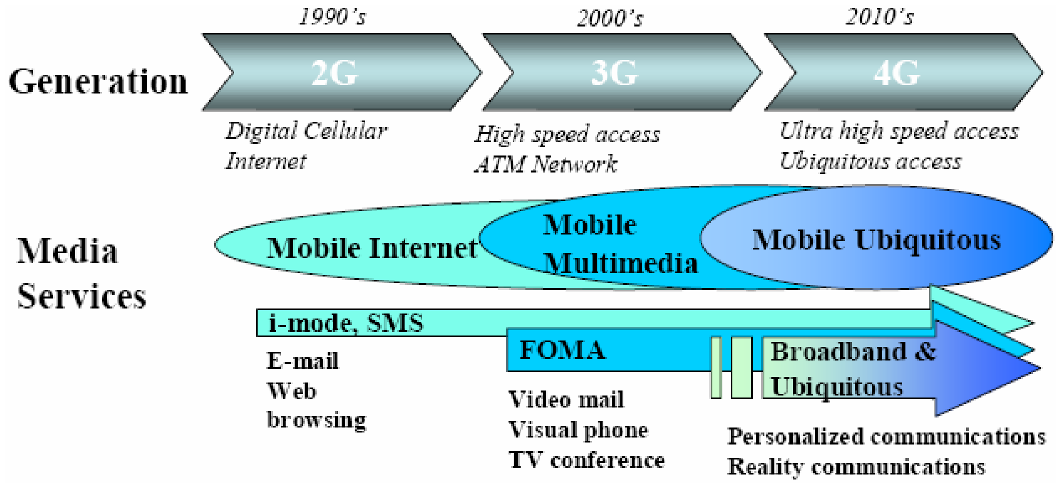

Figure 1.3 : Evolution of the mobile communications systems (Miki, et al.,2005)

service like voice and data, and other streaming services for "anytime-anywhere", as shown in Figure 1.3. The 4G has many objectives (Rouffet, et al.,2005), such as:

1. A spectrally efficient system (in bits/s/Hz and bits/s/Hz/site).

2. High network capacity which means the ability to serve more simultaneous users per cell.

3. An insignificant data rate of 100 Mbit/s when the client physically moves at high speeds relative to the station, and 1 Gbit/s when client and station are in relatively fixed positions.

4. Having data rate of at least 100 Mbit/s between any two points in the world.

5. Smooth handoff across heterogeneous networks.

6. Seamless connectivity and global roaming across multiple networks.

7. High QoS for next generation multimedia support (real time audio, high speed data, mobile television, etc).

8. Ability to Incorporate with existing wireless standards.

1.4. Quality of services

The term QoS, in computer networking and packet-switched telecommunication networks fields, refers to resource reservation control mechanisms rather than the achieved service quality. And QoS provides different priority to different users, data flow, or applications, or to guarantee a level of performance to a data flow. For example, delay, jitter, packet dropping probability, bit rate and/or bit error rate (BER) may be guaranteed.

When the network capacity is insufficient the QoS guarantees are important, especially for real-time streaming multimedia application such as voice over Internet Protocol (IP) address, IP-television and online games, since these often are delay sensitive, and require fixed bit rate, and in network where the capacity is a limited resource, for example in cellular data communication. But if network does not have congestion QoS mechanisms are not required (Guimaraes, et al. ,2008) and (Hoes, et al.,2009).

1.4.1 Quality of services in cellular networks

Here we present abbreviated necessary information about CWNs which is significantly related to our work. Nowadays, CWNs become a desired medium for real-time multimedia traffic. These networks must supply their users with QoS warranties. To have QoS in desired range, many challenges should be exceeded, such as: mobility of hosts, scarcity of BW, and channel fading. To overcome these challenges, many CWNs parameters must be taken into consideration (El-Kadi, 2002), these parameters are:

1. Bandwidth utilization.
2. End-to-end delay.
3. Jitter.

4. Blocking probability(BP).

5. Dropping probability(DP).

1.5. Handoff in cellular networks

The term handoff in cellular telecommunications refers to the process of transferring data session, or an ongoing call from one channel connected to the core network to another.

There may be different causes why a handoff (handover) might be leaded (Zeng and Agrawal, 2001):

1. To avoid call termination when the phone gets outside the range of the first cell, the call is transferred to the second cell. This happens when the phone is moving away from the area covered by one cell and entering the area covered by another.

2. When a new user has ability to connect with only one cell, but capacity of this cell has been used up, and one of an existing or new call in that cell can be transferred to an overlapped cell with its cell, then transferring will be done to free up some capacity for that user.

3. When the channel used by the phone in non-CDMA networks is interfered by another phone using the same channel in a different cell, the call is transferred to a different channel in another cell, or to a different channel in the same cell to avoid the interference.

4. When the user behavior changes in non-CDMA networks caused by his fast-traveling, connected to a large, umbrella-type of cell stops, then the call may be transferred to a smaller macro cell or even to a micro cell in order to reduce the

potential interference to other cells or users ,and to free capacity on the umbrella cell for other fast-traveling users (on another case when the call can be transferred to a larger umbrella-type of cell to minimize the frequency of the handoffs, due to a user is detected to be moving faster than a certain threshold).

5. In CDMA networks the interference to a smaller neighboring cell due to the "near-far" effect, even when the phone still has an excellent connection to its current cell, may be reduced by using a soft handoff .

Handoff is classified to inter-cell handoff, and intra-cell handoff, another classification is: hard handoff, and soft handoff.

1.6. Antenna frequency coverage range

The IEEE defines BW as "The range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard.", In other words, BW depends on the overall effectiveness of the antenna through a range of frequencies, so all of these parameters must be understood to fully characterize the BW capabilities of an antenna. One of these characters is antenna blind cone (BC), which can be defined as the volume of space, usually approximately conical with its vertex at the antenna, that cannot be scanned by an antenna because of limitations of the antenna radiation pattern and mount (IEEE Std, 1993).

In BC the signal power is almost zero (See Figure 1.4). As a result, any connection exists in this spot can not receive any signal, so it will be dropped by the Handling Mobile Switching Center (MSC). Therefore, BC should be considered as an effective factor in BWU (Al-Sharaeh, 2008).

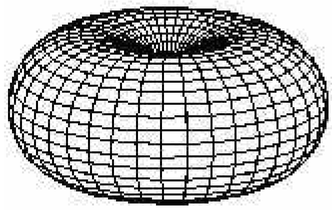

Figure 1.4: Antenna blind cone (IEEE Std,1993)

1.7. Problem statement

In recent years, almost all research works in routing protocol at WSNs were interested in energy efficiency factor because energy is rare and should not be scattered. But, when imaging and video sensors have been used, and when growing in demand certain end-to-end performance guarantees another factor was appeared, this factor is QoS. In Mobile Ad-hoc Networks (MANETs), several new protocols have been proposed for QoS routing while, at the same time, taking the dynamic nature of the network into consideration. On the other hand, there is little research done in QoS for WSNs.

As mentioned before, WSNs are similar to CWNs in a lot of properties, so sensor networks have the same QoS issues as general wireless networks, in addition to its unique QoS issues which are yielded from its unique characteristics. When designing WSNs, there are some considerations that should be observed for handling QoS traffic (Younis, 2004), these considerations are:

6. Bandwidth limitation
7. Removal of redundancy
8. Energy and delay trade-off
9. Buffer size limitation
10. Support of multiple traffic types

It is clear that one of the key challenges in WSNs environment is the limited BW, so this work comes to test WSNs under various cases and unprecedented structures, to find the best BW provisioning scheme for clustered WSN.

In our study, we improve QoS by developing a new scheme for WSN technology with new concepts for measuring BWU in this environment, such as: Handoff, CBP, and CDP.

1.8. Thesis organization

The rest of this thesis is organized as follows: In Chapter 2 related works will be presented, our work will be introduced in Chapter 3. Simulation environment and the related results taken from the simulation will be presented and analyzed in Chapter 4. Chapter 5 provides the conclusions and suggests the future work.

2. Literature review

2.1. Introduction

As mentioned previously, many researchers proposed different mechanisms for routing QoS constrained multimedia data in MANET. These mechanisms cannot be directly applied to WSNs due to its inherent characteristics, especially BW limitation. In this chapter, we will present a brief literature review for QoS research that has been presented for WSNs, MANET, and CWNs.

The majority of research in QoS for WSNs considered energy efficiency as the main objective, but lots of efforts are considered QoS from other different sides. Here we will summarize most recent research in this area. In (Sangeon, et al., 2008), the authors proposed an energy efficient medium access control (MAC) layer protocol that delivers multimedia contents with certain degree of QoS. They developed and analyzed this sensory MAC protocol which classifies the wireless traffic into different categories, and adaptively satisfies application-specific QoS requirements, like delay and throughput. The protocol also attempts to save the energy consumption without immolation the QoS-constraints, also (Aslam, et al. , 2006) paid their attention to MAC in WSNs for applications with different QoS priorities in a clustered WSN environment. Their protocol combined CDMA, TDMA, and contention based access mechanisms.

Authors in (Latré, et al. ,2006) considered delay and throughput of un-slotted IEEE 802.15.4. While in (Boukerche , and Martirosyan, 2007) , the task of providing QoS is obtained by selecting the route with the least cost for high-priority event notification message. Furthermore, QoS is extended to take into account the availability of multiple sinks monitoring the WSN. In (KUI, et al.,2005), a new algorithm was proposed to turn off redundant sensors without using accurate location information. The result was reducing network energy consumption and providing desired QoS requirements. Another view for QoS was presented in (Huang, and Fang, 2008). Their goal was to supply soft-QoS to different packets since the path information is not readily available in WSNs. So they based on local link state information, which helped them to utilize the multiple paths between the source and the sink pairs for QoS provisioning. Another work (Politis, et al. , 2008) achieved QoS requirements by proposing a power efficient mutipath video packet scheduling scheme for reducing distortion transmission over wireless multimedia sensor networks (WMSNs).

Selecting a network path with sufficient resources was offered in (Ouferhat, and Mellouck, 2006) to satisfy a certain delay requirement in a dynamic environment. This way depends on distributing QoS routing to achieve QoS requirements and to have optimal routing path cost. QoS for data relaying in hierarchal WSNs is the title of (Benkoczi, et al., 2005). The route(s) in this work are chosen to satisfy QoS, which are expressed by the maximum delay incurred by data from the moment they are captured by sensors to the moment they reach the base station. In (Cheng, et al.,2006), the QoS provisioning and resource allocation are driven by the service level agreement (SLA). Another paper (Boukerche, et al.,2007) presented a novel routing protocol which aimed to keep the QoS as required with regarding latency, delivery rate, packet lost rate, energy aware, and fault tolerant. Homecare e-Health applications need control of the energy consumption and need to have an acceptable level of QoS. So, (Pantazis, et al., 2008) came to satisfy these applications needs. In (Tsang-Ling , and Yi-Jen, 2006), authors also considered minimizing the transmission power and maximization the link quality under the constraint, such as an end-to-end frame error probability, so authors developed two cost function to meet their objectives. Meanwhile, Sensor Usage Index (SUI) is another function, which is presented in (Yang, and Heinzelman, 2008) to increase network lifetime with QoS support. QoS in stateful information filters is an effort presented by (Fischer, and Kossmann, 2006). An important issue in QoS area is the issue in the Service Overlay Networks (SON) where SON undergoes from problem of bandwidth provisioning, so (Duan , et al.,2003) devoted to study this problem, and put new equations to solve it. In (Song, and Hatzinakos, 2007) QoS knob is found to control the tradeoff between the tracking error and the network energy consumption.

Architectural and operational challenges of handling QoS traffic in sensor networks were presented in (Younis, et al.,2004). A survey on QoS support in WSNs was done by Chen and Varshney (Dazhi , and Varshney, 2004), while (Hoes, et al.,2007) and (Hoes, et al., 2008) analyzed QoS trade-off in WSNs.

Dynamic Channel Allocation (DCA) was the proposed algorithm in (Chowdhury, et al.,2009). It was put to solve the problem of channel assignment with minimum interference. In (Dash, et al.,2005), a mechanism for constraining BW allocation was suggested for Multi-Sensor information fusion, Also, (Hull, et al.,2003) was interested in BW management and reservation, its interest included three main components: a semantic priority system to handle BW allocation, hop-by-hop flow control to mitigate congestion, and a sensor access point (SAP) selection metric for load balancing. Anther work (Allard, et al.,2004) is also interested in BW reservation in multi-hop wireless networks, and how link interferences in such networks make selecting a path satisfying BW requirements a nondeterministic polynomial (NP)-complete problem. Maximum data rate and base station capacity were the objects of (Shi, and Hou, 2008). QoS management, but with mobile sink, was a new idea presented by (Hoes, et al.,2009), Real-Time QoS in WSNs was surveyed in (Li, et al.,2008). Fast Hand-Off was the pivot for (Waharte, et al.,2005) and (Waharte, et al.,2008). WMSN was presented as a survey in (Akyildiz, et al.,2006), while (Akan, et al.,2008) concerned with WMSN in side of its special issues.

Recently, we mentioned published works in QoS of WSNs, and here we will pass quickly through QoS for MANET, and CWNs. QoS and BW reservation take an abundant portion of efforts that put in MANET research. In (Capone, and Stavrakakis, 1999), authors focused on determining the call admission region and scheduling policies for a TDMA, while in (Lakshmanan, et al.,2009) a new model was presented to associate Multi-gateway in wireless mesh networks. The purpose of this model was to have high throughput range comparing with single association model. In (Guimaraes, et al. ,2008), a QoS reservation mechanism for multi-rate was proposed. This mechanism enabled nodes to select the highest possible transmission rate for exchange data independently for each neighbor. While in (Rubin, and Zhang, 2009), authors introduced the robust throughput measure as a new performance metric. Another work done for QoS was (Noubir, et al.,2009), in which the consideration was in experimentation-oriented platform. This platform developed and evaluated MANET cross-layer protocols by providing a network virtualization above the physical/link layers.

Cellular networks also have a portion in QoS studies. In (Oliveira, et al.,1998), a new scheme was presented, it was for adaptive BW reservation for high speed wireless multimedia networks. The purpose of this scheme was achieved by allocating BW to a connection in the cell where the connection request originates and reserves BW in all neighboring cells. On the other hand, (Fodor, et al.,2003) provided QoS in always best connected networks. The term of always best connected refers to a concept which means a set of access selection criteria, and mechanisms that allow users to get connected to various services in a nearly optimal manner.

2.2. Related works

2.2.1 A Rate-Based Borrowing Scheme

El-Kadi, et al. (2002) proposed a Rate-Based Borrowing Scheme (RBBS) in which the size of the reserved pool is fixed at a certain percentage of the total amount of available BW in the cell, in contrary to previous work, where the size of pool is determined by requests from neighboring cells. In this scheme, the gain was having same low CDP but with cancellation of the overhead of communication between neighboring base stations to request and release reservations.

Borrowing strategy in RBBS divides BW for each node as shown in Figure 2.1, where:

M: maximum bandwidth needed by a call (desired bandwidth).

m: minimum bandwidth needed by a call.

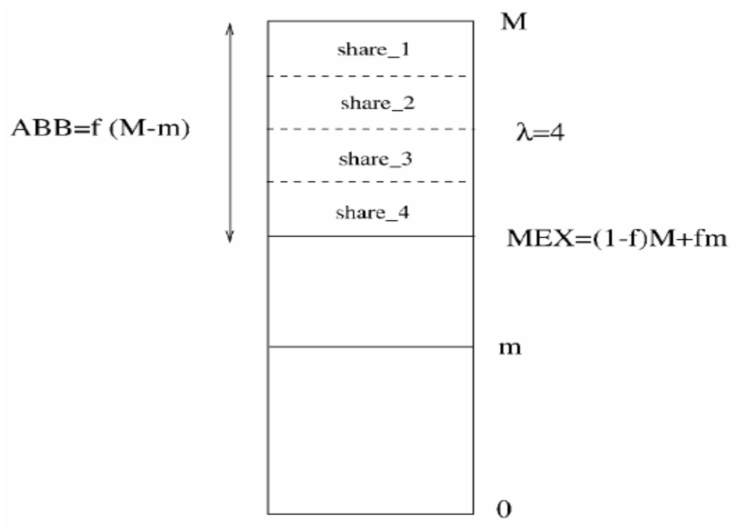

Figure 2.1: Main call parameters (El-Kadi, et al., 2002)

BLT: bandwidth lose tolerance, where: BLT= M-m.

f: the fraction of BLT that a call may have to give up in the worst case. Where: $f\,(0 \leq f \leq 1)$

ABB: actual borrowable bandwidth of the call.

MEX: minimum expected bandwidth that the call is guaranteed to receive during its stay in its starting cell.

λ: number of shares.

In RBBS, the primary drawback is that there is pre-allocation of resources, which will cause the BW reservation for future calls, or handoffs to increase CBP and CDP, and will definitely lead to waste BW.

2.2.2 Dynamic Rate-Based Borrowing Scheme

Dynamic Rate-Based Borrowing Scheme (DRBBS) has been designed in CWNs (Al-Sharaeh, 2006), and has been introduced to obtain the main purpose which is keeping the CBP and CDP low, while at the same time maximizing BWU. DRBBS is one of algorithms that achieved superior results for this purpose comparing with all previous algorithms. Thus, in this work, we will focus our efforts to apply DRBBS principles, but in WSNs rather than CWNs.

Dynamic Rate-Based Borrowing Protocol is a modification to RBBS scheme, where the concept of borrowing BW from existing connections, to accept both new and handoffs connections, is proposed. Unlike RBBS and Statistical Borrowing Scheme (SBS), DRBBS exploits the positive feature of fair borrowing BW and avoids pre-allocation of resources. Fair borrowing from ongoing connections shows a decrease in the rate of CDPs and a decrease in the CBPs, while avoiding pre-allocation of resources offers a significant improvement in the BWU.

The DRBBS was tested in a simulation that considered a 2D cellular network. Coverage area in simulator was partitioned into seven cells, as shown in Figure 2.2. In

DRBBS, author assumed that the mobile users move along the cell areas that are adjacent in boundaries. He also assumed the movement follows a Poisson distribution.

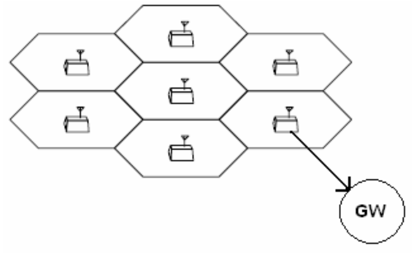

Figure 2.2: Two-dimensional cellular network (Gerald.W, 1995)

2.2.3 Three-Dimensional Dynamic Rate-Based Borrowing Scheme

Concept of 3D was introduced to QoS for CWNs in (Al-Sharaeh, et al. ,2008). In this paper, authors adopted the DBBS as in (Al-Sharaeh, 2006) but yet they took into consideration the antenna properties, such as: 3D propagation for radio frequency signal, and the existence of BS in an area close to the base station base, go back to Figure 1.2.

The importance of considering BS that any node exists in this spot is unable to receive any signal, so the connection of this node will be blocked or dropped even if there is enough BW. Consequently, the CBP and CDP will be increased and the BWU will be decreased comparing without considering BS.

As we mentioned earlier, the 2D CWNs structure consists of seven hexagonal cells. While in Three-Dimensional Dynamic Rate-Based Borrowing Scheme (3D-DBBS), the CWN has nine cells (See Figure 2.3).

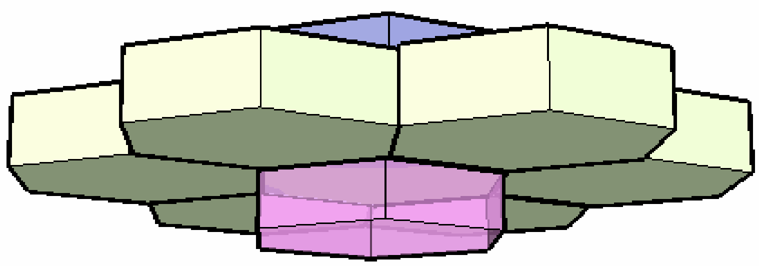

Figure 2.3: Cellular network in 3D-DBBS

Simulation results in 3D-DBBS showed that CDP increased by 2% on average when they moved to 3D instead of 2D. Also BWU increased 2.3% due to the increase of coverage area. Another result was inferred that the BWU gets decreased by 0.2% with the existence of BS in the 3D space.

3. Bandwidth provisioning scheme for clustered wireless sensor network

3.1. Overview

In this chapter, we explore in details our proposed scheme which we called an Adaptive Three-Dimensional Dynamic Rate-Based Borrowing Scheme (A3D-DBBS). Our scheme aims to increase the BWU in WSNs, and to decrease CBPs and CDPs. Also, we study WSN under new cases which give us a vision about performance of this type of network and how it submits to these new conditions. Hence, we did this scheme to improve QoS, that WSNs can guarantee, and to find best structure for this type of networks.

Al-Sharaeh, et al. (2008) designed 3D-DBBS scheme for CWNs, while our scheme is designed for WSNs. Also, 3D-DBBS has nine cells in its 3D structure while on the contrary our 3D structure has 21 cells. On the other hand, there are many similarities between 3D-DBBS and our scheme, such as: borrowing mechanisms, BWU, BS, CBP, and CDP.

Our scheme concentrates on total BW scheduling, on available BW distributing on current connections, and on QoS guaranteeing which is required by each connection. To be more efficient, many factors will be considered in designing this scheme, like: CBP, CDP, Handoff connections, new connections, coverage area space whether 2D or 3D, Indoor environment, Outdoor environment, existence or absence of BS, and most importantly the borrowing mechanism.

Blocking and dropping probabilities, and BWU ratio are critical metrics in any BW provisioning scheme. This is because they will affect the whole utilization of the network BW. So the previous metrics will be used in measuring the performance of our scheme.

Connections will be assigned values, such as: Maximum desired BW- symbolized by M, and minimum acceptable BW- symbolized by m , and their connection admission by base station will be accepted or rejected depending on these values. These values will play a significant role in borrowing mechanism as will be shown in the next sections.

3.2. Some features of the proposed scheme

Like 3D-DBBS, our scheme is tested under 3D environment, but unlike 3D-DBBS, our scheme is applied for WSNs instead of CWNs. Also our scheme increases coverage area space by dividing network area into twenty one cells in place of nine cells as in 3D-DBBS.

Sensors move in 3D environment, so each region - excepting outer regions of network- has twenty neighboring regions. To imagine the network architecture, let's suppose area X , where X has two neighbor regions, one is above it and the other is below it (two vertical neighbors). Also X is surrounded by six regions (six Horizontal neighbors), each region of them has region above it and another one below it. So X has also (twelve diagonal neighbors), hence any interior region has twenty neighbors. Our conception for 3D WSN is shown in Figure 3.1.

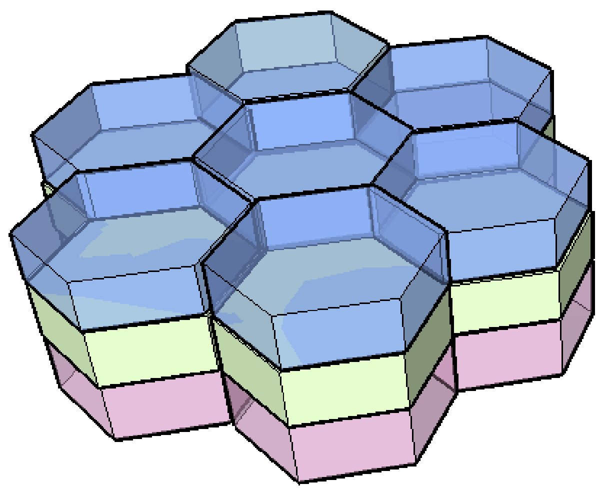

Figure 3.1 Wireless sensor network in A3D-DBBS

The network area is divided into hexagonal cells, these cells are overlapped with each other, where overlapping areas are shadowed in Figure 3.2. When a connection moves from one cell to another one, this moving is known by handoff, so the area of overlapping is the area of handoff connections.

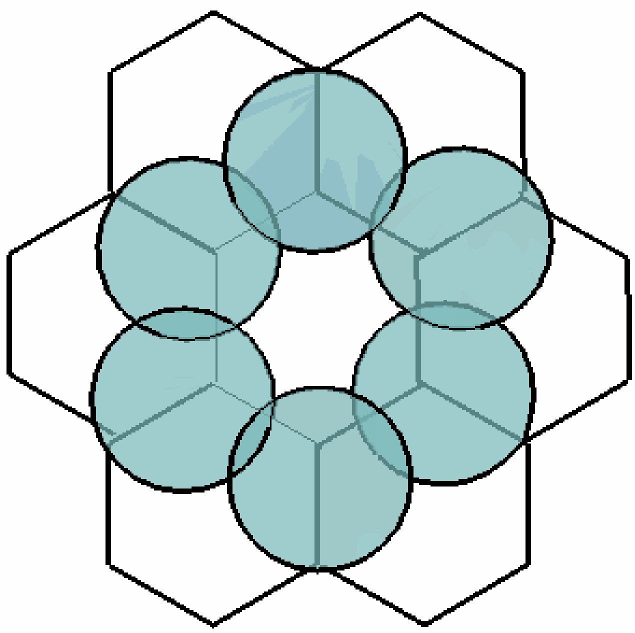

Figure 3.2 Overlap areas between cells

To ensure that our scheme is suitable for WSNs, we modified values that measure base station capacity and that measure desired BW for each connection depending on special needs for sensor.

Every cell has one base station which can supply connections with 4000 Kbps, where we determined this value by:

1. Choosing ZigBee standard with 2.4 GHz band.
2. This band has sixteen channels.
3. Each channel of them has data rate equal to 250 Kbps.
4. So, sixteen channels will have 16 * 250 Kbps= 4000 Kbps.

Connections may be originated in Base station cell space (called new connection) or come from neighbor cells (called handoff connection). Base station is responsible for scheduling BW between connections to have maximum BWU as possible.

3.3. Assumptions

Our study concerns about sensor wireless networks with these assumptions:

- Sensors are mobile, and we will not be concerned about routing algorithm inside the cell, clustering mechanism, and energy consuming. On the other hand, we will focus only on Handoff operation between different cells, dropping and blocking probabilities, and BWU during roaming.
- Each cell has one fixed base station which is responsible to collect data from sensors in its cell, and is responsible to transmit collected data to Gateway through other cells, and also it is responsible to schedule BW for its sensors and any sensor entering its cell. Our scheme will concern only with last mentioned job.
- All regions have equal probability of receiving new and handoff connections.
- Use concept of borrowing BW from existing connections to accept both new and handoffs connections.
- This idea is useful in environment that needs to be sensed in 3D and with real time multimedia vision.
- Our scheme will use IEEE 802.15.4 or ZigBee standard for Radio Frequency (RF) to transmit data.

In next section, we will explain how we determined our scheme characteristics, and how we adapted our simulator to imitate actual WSNs by choosing realistic values.

3.4. Determining the proposed scheme characteristics

3.4.1 Determining wireless band

At first, we choose ZigBee standard to manage communication between sensors due to its specification (ZigBee Alliance, 2008), such as:

- ZigBee supports one to one communication, one to multi-points of communication, Multi-hop communications, and peer to peer (P2P) mesh networking.

- ZigBee has Global common band of 2405 - 2480MHz with sixteen channels in 5MHz interval, this universality is because its physical layer is Specified by IEEE 802.15.4, also ZigBee has Better signal quality, simpler circuit, lower power, and Data rate Equal to 250 Kbps.

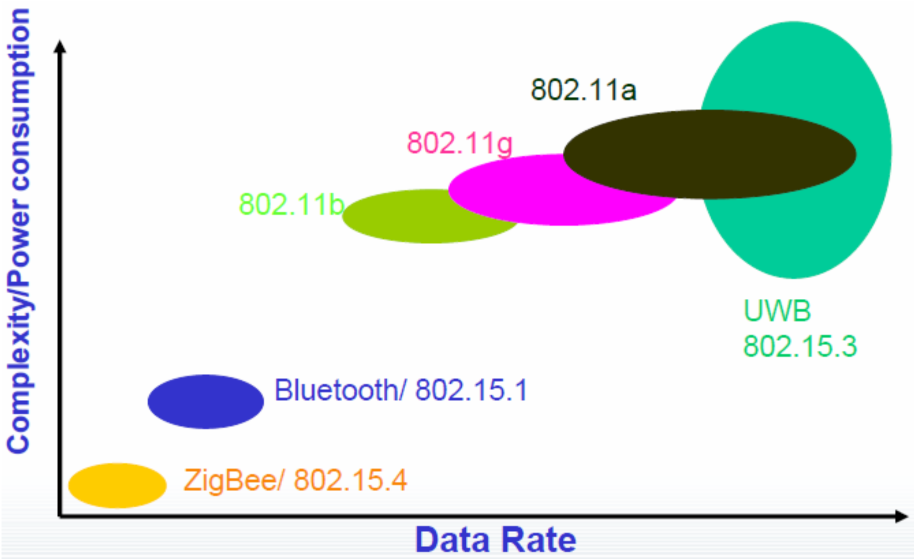

Figure 3.3 Differences between wireless standards (Tjensvold, 2007)

- ZigBee standard applies Carrier Sense Multiple Access with Collision Avoidance mechanism (CSMA-CA). Figure 3.3 displays the main differences between ZigBee and other wireless standards.

As we mentioned so far, ZigBee has three frequency bands, and because our work is done for multimedia data packets, we preferred to choose the wider band with highest data rate which is equal 2.4 GHz.

After determining which standard and which band we will use, we searched for realistic hardware products to simulate it in our study. We found that crossbow products are the most suitable for our study, so we decided to imitate one of them for our base station, this hardware is called MICAz (See Figure 3.4).

Figure 3.4: MICAz mote (Crossbow, 2009)

We dropped MICAz specifications into our imitation base station with the following properties (Crossbow, 2009):

- Compatibility with IEEE 802.15.4 and ZigBee with band 2.4 GHz.
- Designed Specifically for Sensor Networks.
- Having high Data Rate Radio equal to 250 kbps.
- Capability to act as a router with every node for Wireless Communications.
- The MICAz (MPR2400CA) has two good properties: high speed (250 kbps), and hardware security (AES-128).
- The MICAz is applied for many applications such as: Indoor building monitoring

and security, acoustic, video, vibration and other high speed sensor data, etc.

- MICAz has ability to Avoid RF Interference Between WiFi and ZigBee, but this needs to be properly configured for MICAz, then the issue of RF interference and lost data can be avoided. Figure 3.5 shows the difference between ZigBee and WiFi waves.

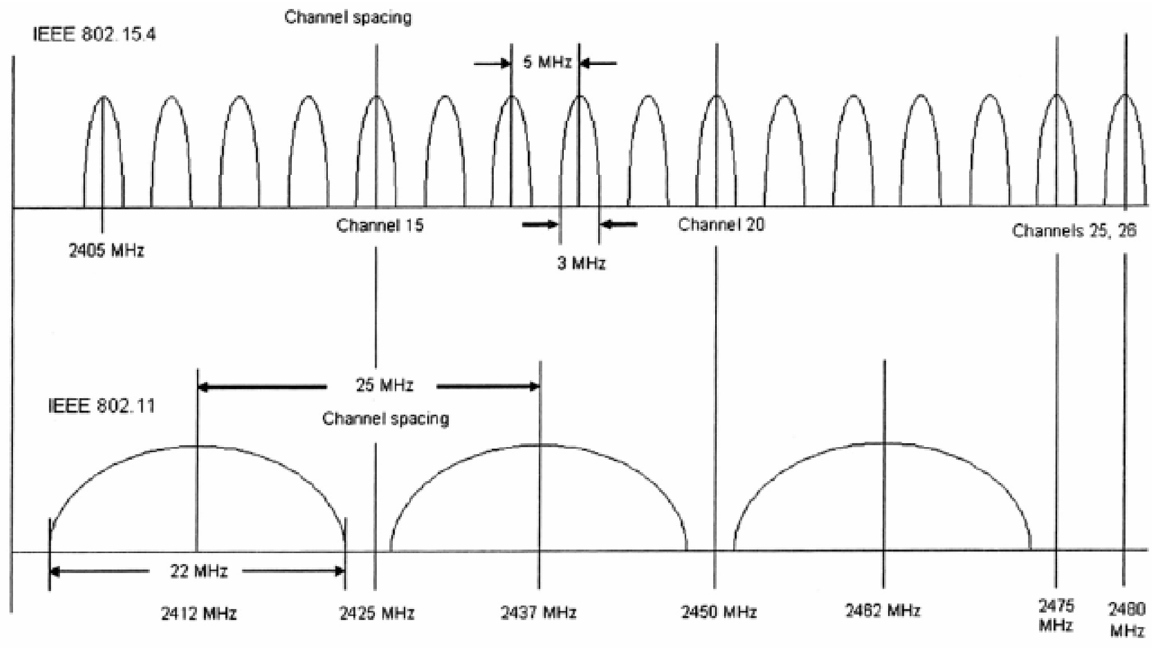

Figure 3.5 Frequencies in ZigBee and WiFi (Kumar.S.P, 2005)

3.4.2 Bandwidth scheduling and borrowing mechanism

We use two mechanisms for borrowing BW. The first one is the Static borrowing mechanism which was explored previously in Section 2.2.1. The other is the Dynamic borrowing mechanism which was presented in Section 2.2.2. Also, we classify connections in WSNs, the same classification for CWNs in (Al-Sharaeh, 2006), where connections are divided into two classes:

1. Class I connections that include real-time multimedia connection, such as interactive voice and video applications.

2. Class II connections (non-real-time data connection) such as e-mail or File Transfer Protocol (FTP).

So, any sensor should provide three parameters when it requests a new connection in a given cell, these parameters are:

1. the desired class of connection (either I or II).

2. the desired amount of BW for the connection.

3. the minimum acceptable amount of BW.

Here, we will focus on how Dynamic borrowing mechanism work During a handoff, a connection of class I is dropped if base station can not provide it with its minimum BW requirements, unless BW can be borrowed from existing connections without violating their minimum requirement (See Figure 3.6). while connection of class II will not be dropped at same case since are no minimum BW requirements.

At setup time, every connection should supply its origin cell with two values for its need of BW, first value is called maximum desired BW (M), and the second one is the minimum acceptable BW (m).

Loss tolerance of the connection could be defined as the difference between M and m. Also each connection has a local parameter called f, f $(0 \leq f \leq 1)$, this parameter represents the fraction of the BLT that a connection may have to give up in the worst case. Back to Figure 2.1

Accepting a new connection means that the cell is able to supply this connection with its need of BW and it will not fall below a certain level that is called MEX. By definition, MEX = $M - fx(M\text{-}m)$.

Another cell parameter, Lambda λ, is used. The BLT is divided into shares. Each share is equal to *fx(M-m)/λ*. Lambda represents the number of steps for degradation in BW from maximum to minimum during borrowing operation.

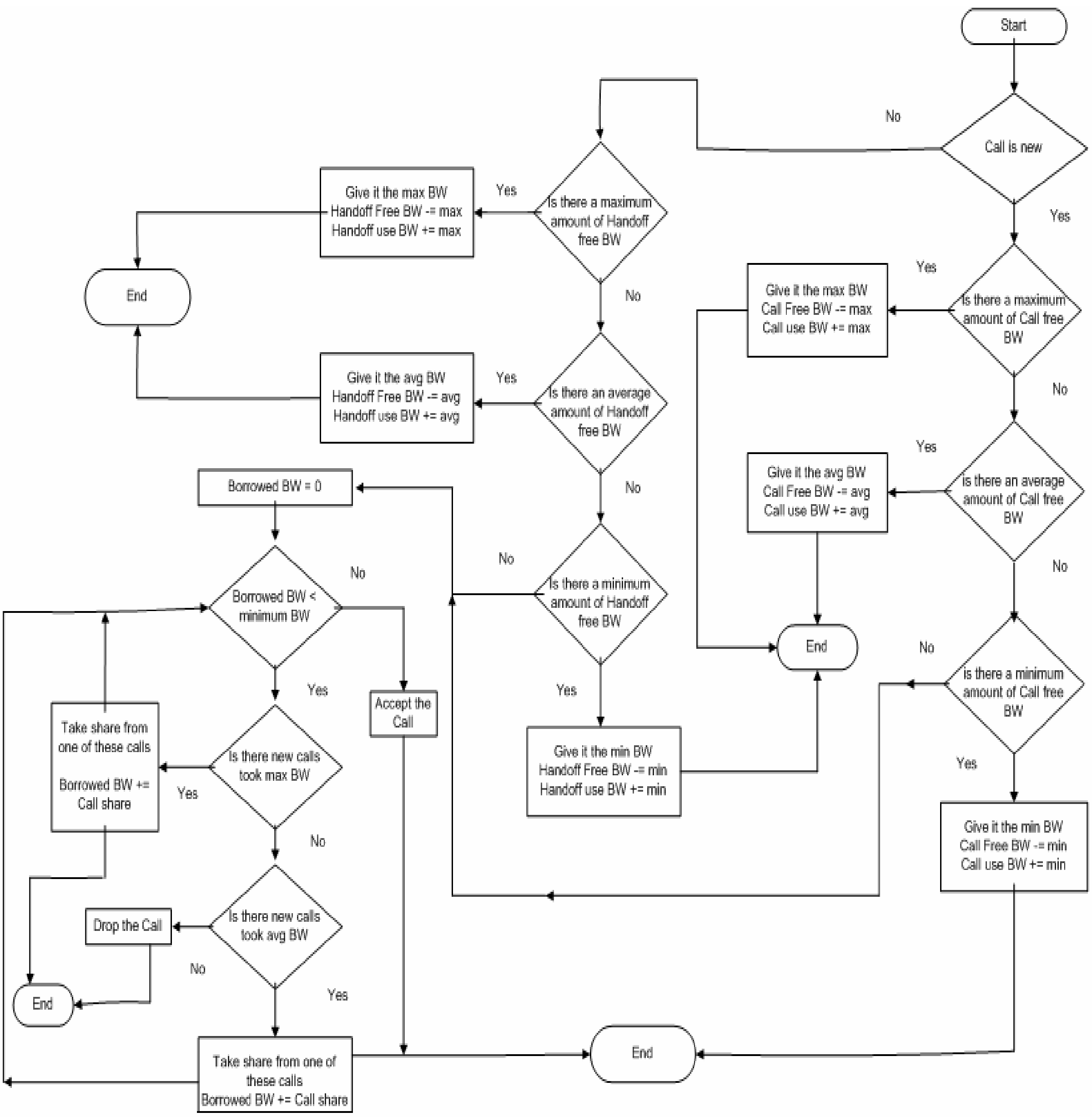

Figure 3.6 Borrowing scheme in AD-DBBS (Al-Sharaeh, et al. ,2008)

3.5. Simulation parameters selection

It is possible to wisely transfer audio and video media across a ZigBee infrastructure although ZigBee is not a high-data-rate protocol. This can be carried out using two processors. First one is used to compress media at the source ZigBee node and another processor is used at the destination ZigBee node to decompress the media.

Most multimedia data transferring are associated with real-time concept, so the media processor must perform its operations, like: encoding and decoding within acceptable user-defined time constraints.

Low-bit-rate ZigBee networks suffer from challenges in video encoding. The theoretical rate of the underlying IEEE 802.15.4 standard is 250 kbps. Because of the CSMA/CA technique, the realistic maximum is on the order of half the theoretical rate. In practice, it is possible to achieve upwards of 60 kbps with large packet sizes in a low configuration and without considering security. Implementing an advanced codec can yield higher compression ratio which leads to increase the frame-rate while transmitting images over ZigBee (EDN, 2007).

From what we said so far, we found that the proper value for Maximum desired BW (M) in WSNs could be equal 60 Kbps, the average BW could be equal 30 Kbps, and the minimum BW (m) could be equal 10 Kbps. Also, we assigned different values to Lambda to find the most suitable one.

3.6. Neglecting bit error rate

Brambley, et al. (2005) said that BW is defined as the width of a particular frequency band. Nyquist theorem is one of the famous theorems that handle relation between BW and data rate. According to this theorem the maximum data rate in bits per second (bps) that can be achieved in a noiseless transmission system of bandwidth B is 2B. Surely, practical applications when considering signal noise show that the signal-to-noise ratio limits the actually achievable data rate to a value less than that determined by the Nyquist theorem.

Depending on this fact, we decided to neglect the effect of the signal-to-noise ratio which gives our study pure results of our metrics effects, which will be mentioned in details on next chapter.

3.7. Determining suitable transmission rate

Many methods were represented to determine the proper bit rate (transmission rate) for a network, for example: standard rate control method. These methods are important for:

a) Achieving desired QoS.

b) Avoid congestion on network when sensors are using improvised higher bit rate.

c) Finding the ideal set of network users' bit rates.

In our study, we examined network under various transmission rates to reflect the behavior of network under heavy and light connections. Connection rate varied between zero to two hundred connections per one simulation round.

3.8. Calculating blind spot area

Commonly, antenna has in maximally a BS area equal to one tenth of its coverage area; and since every connection is considered as a point, it is obligatory that it will have two coordinates (x_2 ,y_2). These coordinates are signs to determine if connection is in or out of BS area. The judgment is done by calculating the distance between connection and base station (*d*). The distances in 2D and in 3D are calculated by Euclidean distance equation since it is always a straight line distance between two points (See Equation 3.1).

$$d = \sqrt{(\Delta x)^2 + (\Delta y)^2} \quad \textbf{(3.1)}$$

Where: (x_1 ,y_1) are the coordinates of BS,

$\Delta x = x_2 - x_1$,

$\Delta y = y_2 - y_1.$

Similarly, connection and base station have three coordinates for each one (x_1, y_1, z_1) and (x_2, y_2, z_2) in 3D space, the distance between them is shown in Equation 3.2.

$$d = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2} \quad \textbf{(3.2)}$$

Where: $\Delta x = x_2 - x_1,$

$\Delta y = y_2 - y_1,$

$\Delta z = z_2 - z_1.$

As shown in Figure 3.7, the connection has coordinates (x_2,y_2) and base station has (x_1,y_1). So by calculating the distance (*d*) between these two points, the result will show that connection is out of BS area, and it is able to be accepted if the base station can provide it with its need of BW.

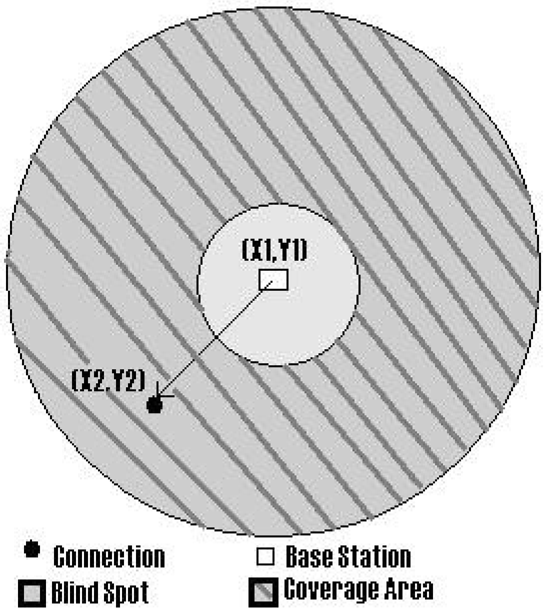

Figure 3.7 Blind spot in 2D networks

3.9. Simulation cases

Our scheme study QoS in WSNs under sixteen different cases, which are summarized in Figure 3.8.

Here are some assumptions that we considered while building our scheme:

1) The data rate of the radio does not differ whether the mote is transmitting Outdoor or Indoor. The radio will keep on sending; the problem is whether or not any other nodes will receive the data packets.

2) Applying different connection rates up to two hundred, although we recommend only up to fifty motes per one base station. Anything greater than that will be congestion within the network. Up to fifty nodes that are all trying to send data at any given time will cause data packets to be dropped.

3) Neglecting the fact that said : "The difference in radio range has to do more with the environment. Indoors there is more RF interference i.e. wireless routers, cube walls etc. Outdoors is a bit better especially if the nodes are line of sight". So, in our scheme the only difference between Indoor and Outdoor cases is the radius of cell. We supposed the radius of Indoor cell is equal to thirty meters, while it is equal one hundred meters in Outdoor cases. These are realistic values taken from MICAz base station that is produced by Crossbow company.

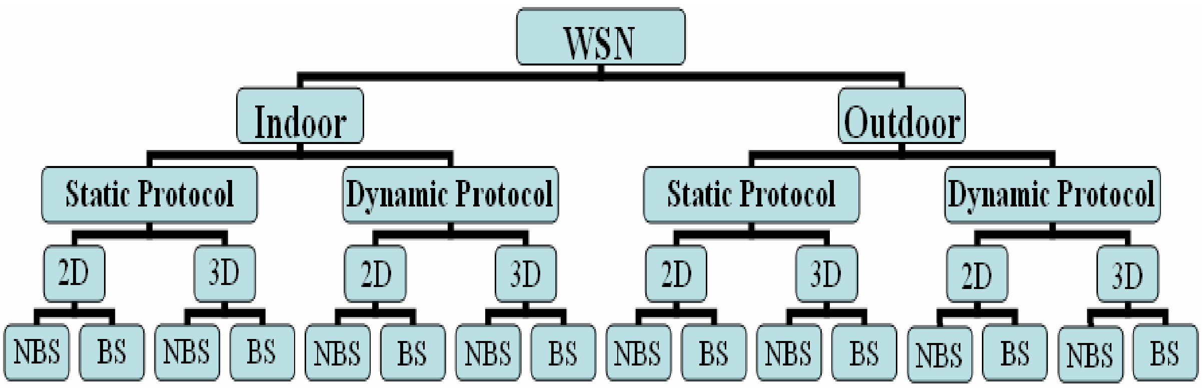

Figure 3.8 A3D-DBBS scheme cases

4. Simulation results and evaluation

4.1. Introduction

This chapter presents in details the simulation results and their evaluation. To start with, an overview of the network simulator used in our experiments is given. Next, different scenarios are discussed along with their simulation setup parameters. To check the performance of our method, certain metrics should be chosen to give us the right indication about our goals, these metrics are explored. Finally, simulation results along with their evaluation are given.

4.2. Network simulator

Our scheme has been simulated using special simulator which we built it exclusively for our work.

Our simulator is designed in Java language; it can simulate networks with up to thousand homogeneous nodes. The aim of this simulator is to examine WSN under different cases while taking in consideration BW availability, and disregarding the effect of BER.

Our work takes only the difference in frequency range between Indoor and Outdoor. Further information about the simulator can be found in Appendix A.

We ran the simulator on a machine having the following capabilities, Intel® Pentium® M Processor 1.60GHz, 512 MB of Random Access Memory, and 40 GB Hard Disk.

4.3. Scenarios and simulation setup parameters

We divided the simulation study samples into two groups; this helped us to trace different scenarios and conditions. The first group of simulations done for Indoor network structure, the other group tested Outdoor networks. Inside each group we divided the simulations depending on borrowing mechanism whether Dynamic or Static. In every mechanism we tested 2D and 3D spaces. Finally, each space of them, was tested in two cases: wBS, and nBS . Figure 3.8 summarizes the simulation study cases.

For A3D-DBBS, we use similar simulation setup parameters for all simulation study cases, including: total BW in base station, maximum desired BW for one connection, average BW for one connection, minimum acceptable BW for one connection, lambda λ, fair factor f, Indoor cell radius, Outdoor cell radius, and finally maximum CR. Also, we use different simulation setup parameters for each simulation study case. We will clarify these parameters individually. Tables 4.1 and 4.2 show the simulation study parameters for all cases.

Table 4.1: Simulation setup parameters for all cases

Parameter	Value
Total Bandwidth	4000 Kbps
Maximum Bandwidth	60 Kbps
Average Bandwidth	30 Kbps
Minimum Bandwidth	10 Kbps
Maximum connection rate CR	200

Table 4.2: Variant simulation setup parameters for different cases

Parameter	Value
Indoor cell radius	30 m
Outdoor cell radius	100 m
Reserved BW for handoff connections in Static mechanism	1330 Kbps
Reserved BW for handoff connections in Dynamic mechanism	0 Kbps
Number of cells in 2D structure	7 cells
Number of cells in 3D structure	21 cells

In order to get consistent results, we used same connection rates for each simulation study case. The connection rate value varied between zero to two hundred . This is because the effect of network engaged is a serious factor in all study cases.

The type of connection whether new or handoff was randomly hosen . Also, cell election for generating a new or handoff connection was chosen in a random way. Our simulator works as follows: at beginning of simulation, the number of connections starts with zero, with time the number increases till two hundred; some of these connections are new and the others are handoff. They are generated and roam in cells in a random manner. When a cell has a connection, its base station must determine whether or not it can admit the connection. During simulation BWU, CBP, and CDP are calculated.

4.4. Performance metrics

In this section, we will show the performance metrics we used in our simulation, to compare the performance of WSN under different cases. The choice of performance metrics considers the goal which we aim to achieve. Next subsections will give a brief description of each metric and the purpose of using it.

4.4.1 The number of connections

This metric measures the number of connections that exist in the network, the purpose of this metric is to show how much network is engaged, and to show the effect of low and heavy load in BWU, CBP, and CDP.

4.4.2 The value of Lambda

Value of Lambda determines the size of connection share portion. We used this metric to yield different sizes of connection share, and to study its effect on the BWU,CBP, and CDP.

4.4.3 The value of fair factor

Fair factor f determines the amount of BW that can be borrowed by other connections, so we expect that when f is larger , then the blocking and dropping will be decreased, while BWU will be increased.

4.4.4 The size of blind spot

While BW availability is our main interest, but also the existence of BS and its size will affect CBP ,CDP, and BWU. So, in our simulator we diversify the size from 0% to 10 % of whole area or volume of cells to emphasize its role.

4.5. Results and discussion

Comparing between two cases (A, B) is calculated by finding the percentage difference which has the following equation, but it should be notable that case A always presents the case with higher average (See Equation 4.1).

$$pDiff = ([avg(A) - avg(B)] / avg(A)) * 100 \% \quad \textbf{(4.1)}$$

Where: avg (A) >= avg (B),

pDiff: the percentage difference,

avg(A): the average of Case A,

avg(B): the average of Case B.

It is worth mentioning that each situation in our simulator was repeated 2500 times, making our results highly trustworthy. Also, Al-Sharaeh, in his work on 3D-DBBS (Al-Sharaeh, et al. ,2008), had results with percentages very close to ours. This convergence gives a sign that our simulator results could be considered as contribution.

4.5.1 Indoor simulation

We start by testing Indoor 2D-WSN with absence of BS, this case has two sub-cases: one is using Static borrowing scheme, and the other is using Dynamic borrowing scheme.

Figure 4.1 indicates that Dynamic mechanism is better than Static in Indoor 2D architecture with nBS. Figure 4.1 (a) shows that Dynamic achieves 97% on average for BWU, while Static has 91% on average. Also, Figure 4.1 (b) displays that Dynamic has 14% while Static has 23% for CBP. Moreover, Dynamic obtains 19% on average, but Static obtains 25% on average for CDP.

Dynamic has better outcomes because it exploits the positive feature of fair borrowing BW (borrowing from existing connections to accept both new and handoff connections), and avoids pre-allocation of resources. Fair borrowing yield decreasing in the rate of CDPs and decreasing in the CBPs, while avoiding pre-allocation of resources offers a significant improvement in the BWU.

Furthermore, Figure 4.1 (c) designates that Dynamic loses supremacy for keeping CDP at least when CR is up to 50. This is caused since there is no reserved pool of BW for handoff connections in Dynamic, while there is in Static. Reserved pool gives handoff connections more opportunity to find its BW requirements without competition with new connections specially when networks have heavy load. Hence, CDP (probability of drooping handoff connections) series intersects when CR is 50, then the series of Static has fixed property until 200 CR, while Dynamic series continue increasing. The intersection shows that Static is more efficient in heavy-load networks, since Static reserved pool of BW for handoff connections.

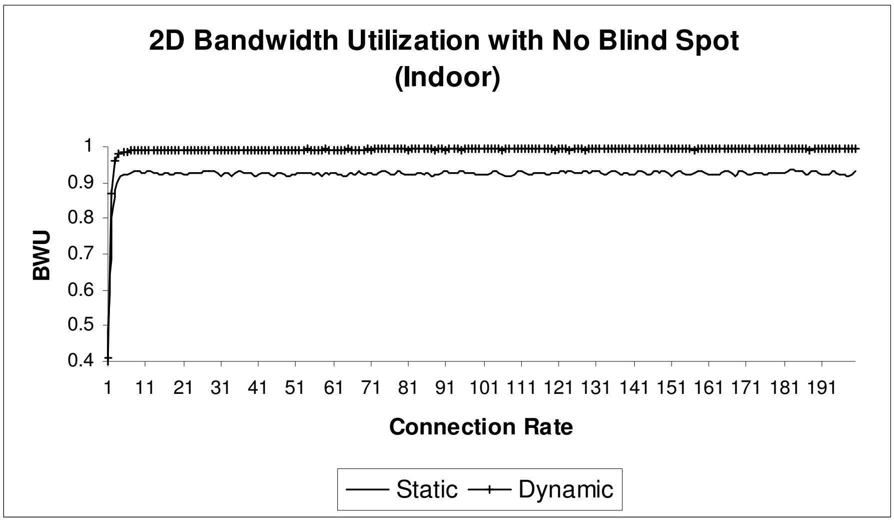

Figure 4.1 (a): BWU

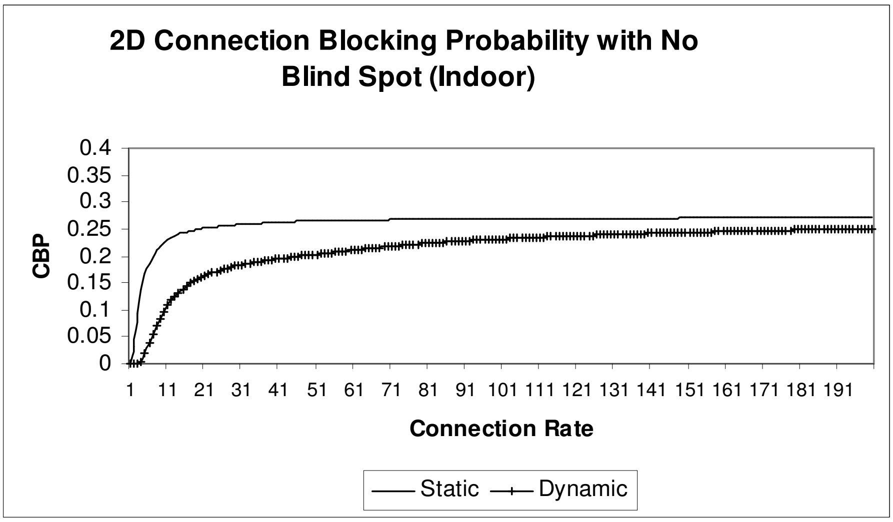

Figure 4.1 (b): CBP

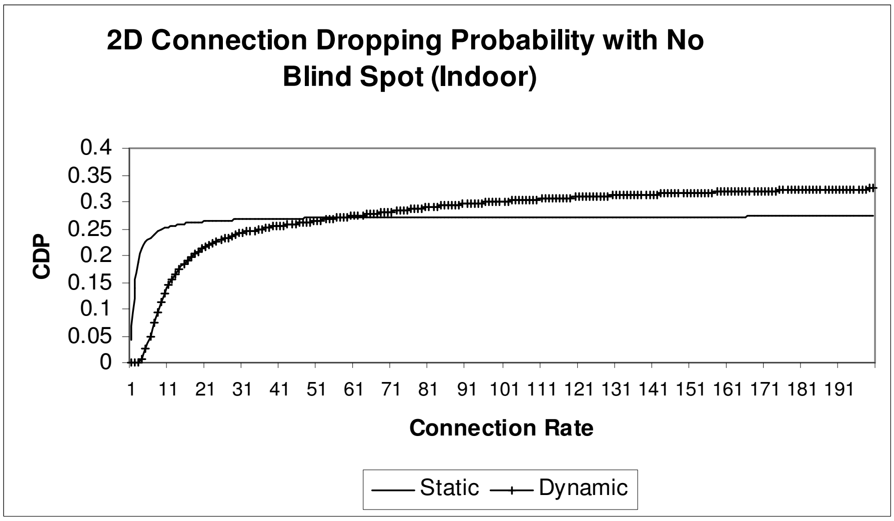

Figure 4.1 (c): CDP

Figure 4.1: The effects of borrowing mechanisms on 2D-nBS (Indoor)

Figure 4.2 shows that Dynamic and Static have similar behaviors as those found in Figure 4.1, but bearing in mind that BWU is upper in nBS, and probabilites for CBP and CDP are lower with two mechanisms when neglecting existence of BS. Also, the intersection point in CDP is 75 in wBS instead of 50 in nBS, as shown in Figure 4.2 (c). These differences can be ascribed to decrease in coverage area with the existance of BS where there is no RF. So any connection presence in this area will be dropped or blocked although there is enough BW in base station.

Figure 4.1 shows results of Indoor 2D-nBS cases. These results revealed that Static mechanism achieved 6.5% BWU less than Dynamic mechanism. Also, CBP and CDP in average are better in Dynamic than Static by 8.6% and 5.8%, respectively.

Similar behavior can be noticed when the simulation takes in consideration the BS presence (See Figure 4.2). Results show that Dynamic surpassed Static by 9.1% for BWU, and by 5.7% for decreasing CBP , and by 4.9% for decreasing CDP. We notice that the existence of BS increases the difference between two mechanisms in BWU and decreases it in CBP and CDP. So, we can infer that Static mechanism is more effected negatively by existence of BS.

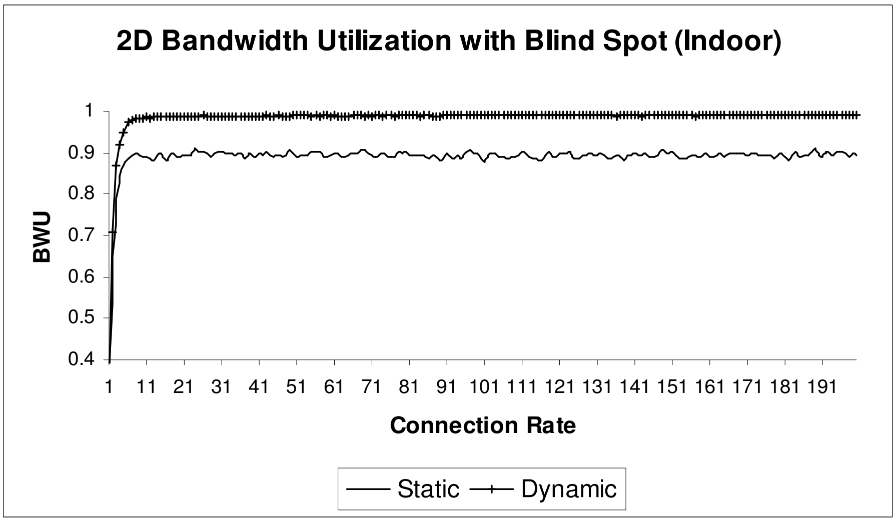

Figure 4.2 (a): BWU

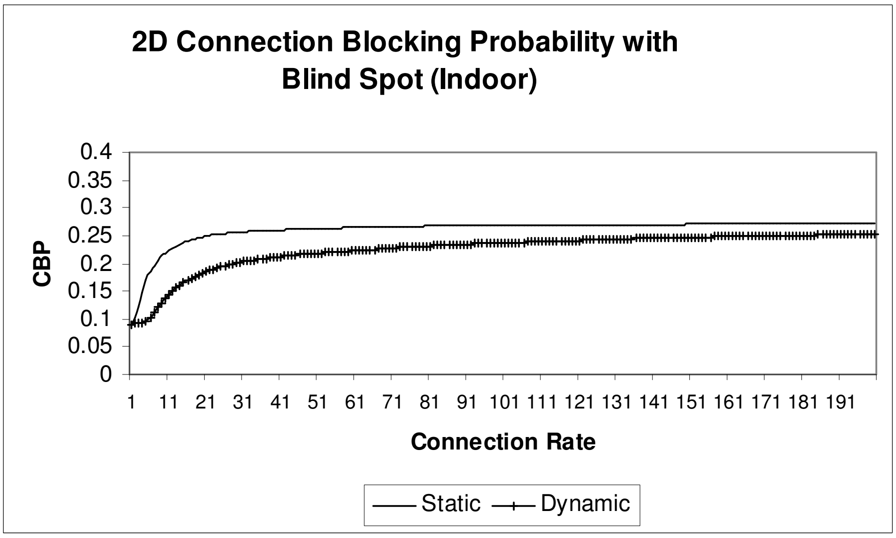

Figure 4.2 (b): CBP

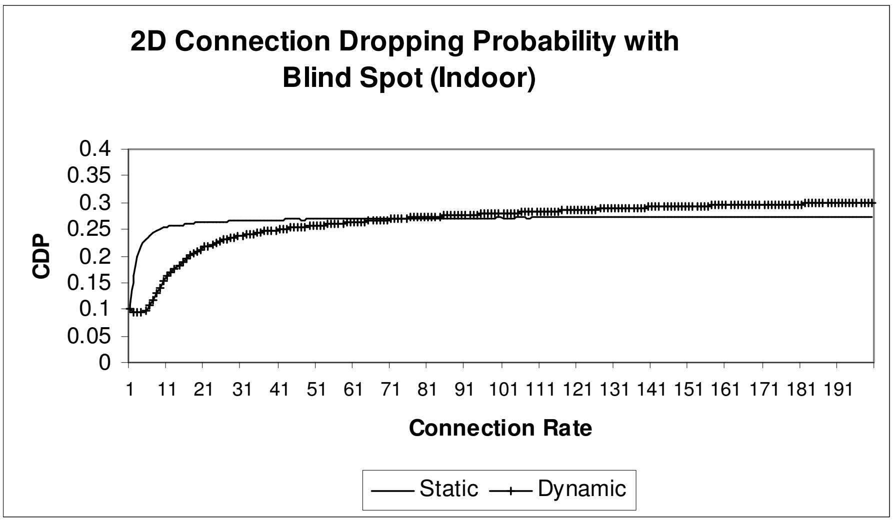

Figure 4.2 (c): CDP

Figure 4.2: The effects of borrowing mechanisms on 2D-wBS (Indoor)

Simulation test for cases mentioned earlier (Indoor 2D-nBS, and Indoor 2D-wBS) were repeated, but this time for 3D environment. These simulation results are shown in Figures 4.3 and 4.4.

In Indoor 3D structure with no BS, Dynamic still surpasses Static in: increasing BWU, and decreasing both CBP and CDP, as shown in Figure 4.3. More details about results percentages will be mentioned in Section 4.6.

In contrary to the case shown in Figure 4.1 (c), Dynamic in 3D structure overcomes Static all the time by having less CDP (See Figure 4.3 (c)). The reason behind this conversion in Dynamic behavior is the nature of our 3D architecture. Our 3D structure has 21 cells while 2D has 7 cells. This inequality means that coverage area is larger, then same number of connections (whether network is 2D or 3D) is distributed in 21 cells rather than 7. So, cell opportunity to have connection is less in 3D. Hence, connection in 3D becomes more fortunate to have its requirements of BW and not to drop or block. Figure 4.3 presents that 3D with Dynamic borrowing mechanism is preferred when looking for high QoS.

Similar to pervious cases BWU is also in the interest of Dynamic (explanation is the same as in previous cases) when network is 3D-Indoor with existence of BS (See Figure 4.4 (a)). More information is presented in Section 4.6. Figure 4.4 (b) shows that Static has a little chance to surpass Dynamic by having less CBP till CR equal to 10. In agreement to the result at Figure 4.4 (b), the result in Figure 4.4 (c) presents that Static has highest probability in CDP because of the pre-reservation of resources in Static mechanism.

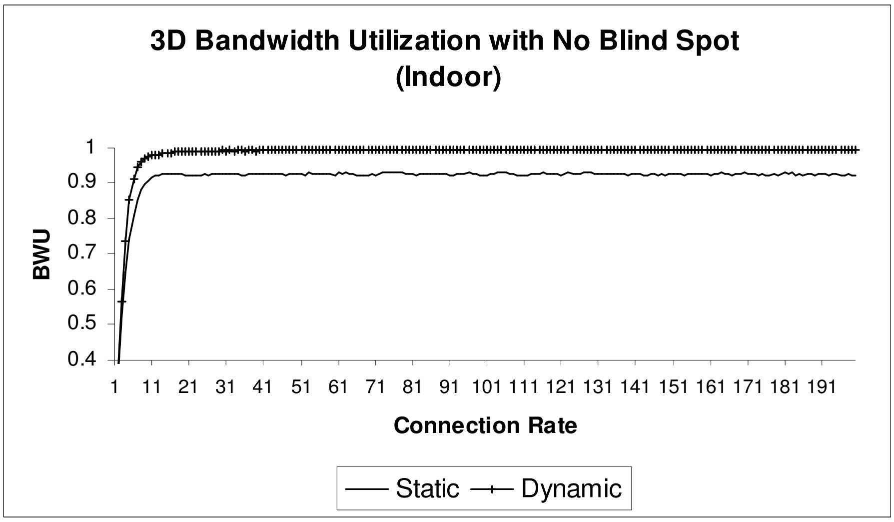

Figure 4.3 (a): BWU

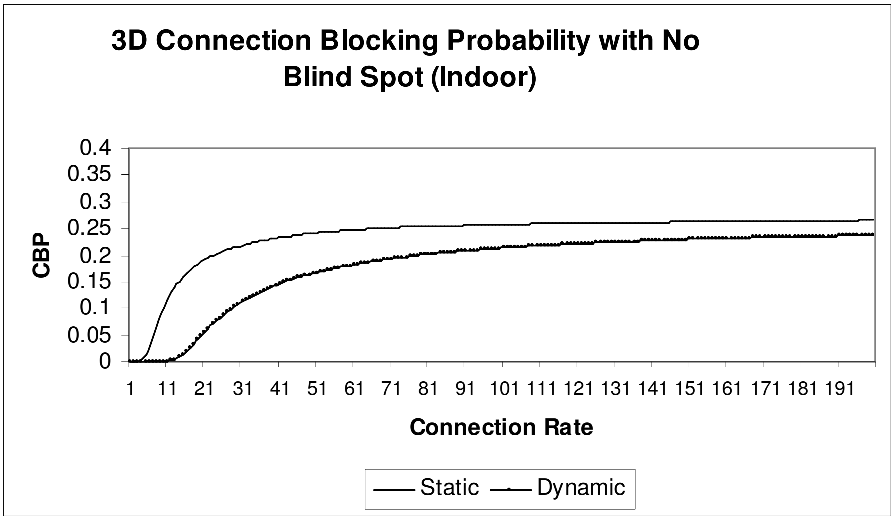

Figure 4.3 (b): CBP

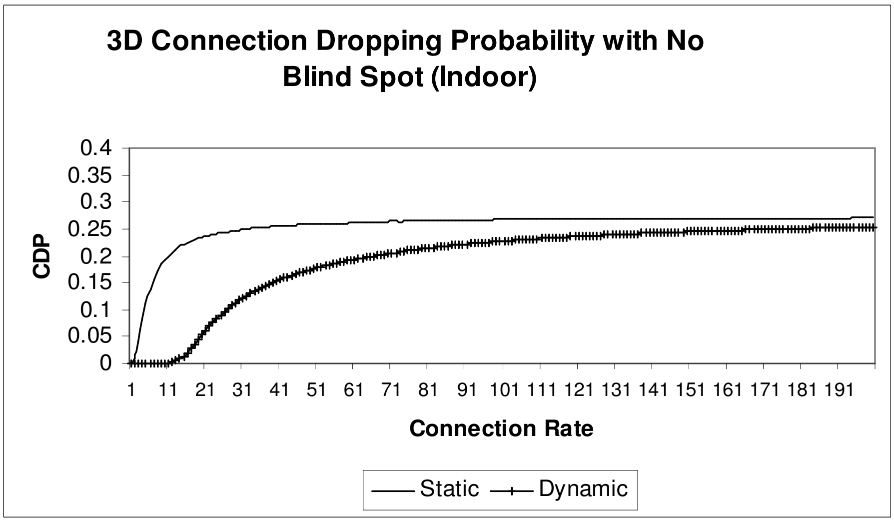

Figure 4.3 (c): CDP

Figure 4.3: The effects of borrowing mechanisms on 3D-nBS (Indoor)

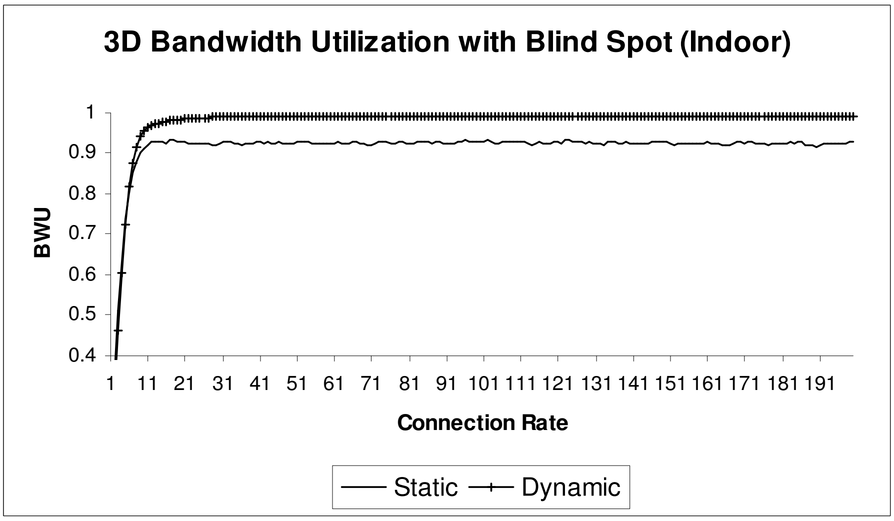

Figure 4.4 (a): BWU

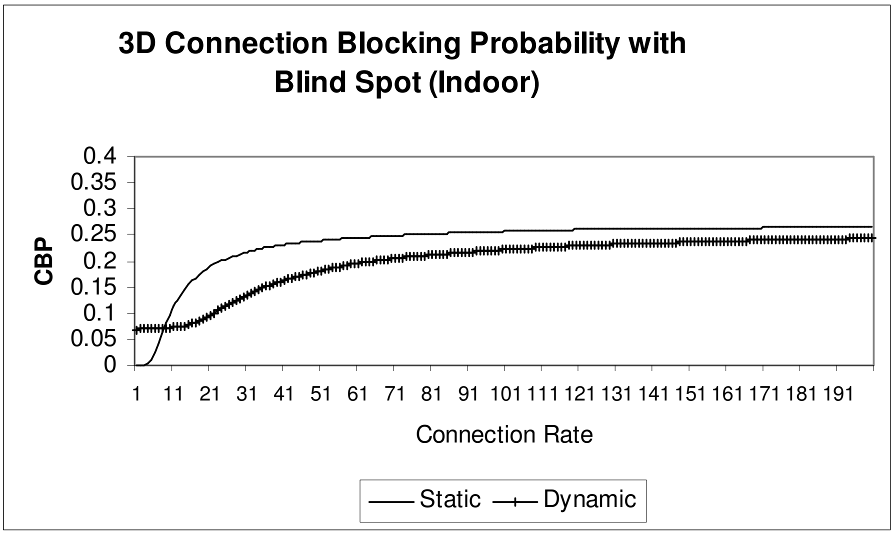

Figure 4.4 (b): CBP

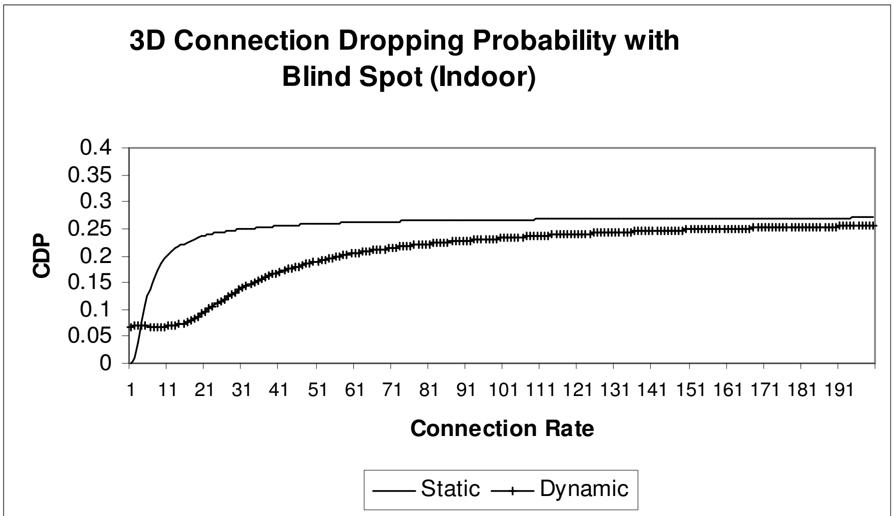

Figure 4.4 (c): CDP

Figure 4.4: The effects of borrowing mechanisms on 3D-wBS (Indoor)

In few words, last four figures show that the space of network whether it is 2D or 3D has an observable effects. Simulation without considering BS shown that Dynamic scheme outperformed Static by 6.6% for BWU on average, also Dynamic decreased CBP by 9.4%, and CDP by 1.3% comparing with Static. On the other hand, simulation results with considering BS show that Dynamic scheme has better utilization for BW by 4.9% , and has less probabilities for connections Blocking and dropping by 5.2% and 9.7% respectively.

4.5.2 Outdoor simulation

Second group of our simulator is done for Outdoor networks. Simulation results for this group are very closely to results for Indoor simulation results. This is because we only consider radius as a difference between two networks, and we neglect RF interference which is more in Indoors. Interferences yield from some factors like: wireless routers, cube walls etc. Outdoors is a bit better especially if the nodes are line of sight.

4.6. Detailing comparison results

In this section, we view detailing comparison result between all cases of our simulation runs. We use our own synopses to express all cases (Observe Table 4.3).

Table 4.3: Legend keys

I	O	S	D	NB	B	2	3	200	50
Indoor	Outdoor	Static	Dynamic	No Blind Spot	With Blind Spot	2D	3D	CR=200	CR=50

Table 4.3 can help us to symbolize and to give each case of our sixteen cases its own abbreviation. For instances:

- OD3-200 means Outdoor-Dynamic-3D with maximum 200 connection rate.

- IS2-50 means Indoor-Static-2D with maximum 50 connection rate.

4.6.1 Bandwidth utilization

In this subsection, we study BWU in more details under all cases by fixing two metrics each time, then comparing and deducing effects of these metrics on BW. Figure 4.5 shows that network utilizes BW more efficiently at most cases when not considering existence of BS by 1.2% on average. As we mentioned, BS has an efficient role that can decrease BWU depending on the size or area of BS. Also, Figure 4.5 shows that 2D structure is more negatively affected by existence of BS, this is due to having small network space. Small network space means small range for connections to be distributed in. Hence, connections in 2D have higher opportunity to fall down in BS than connections in 3D.

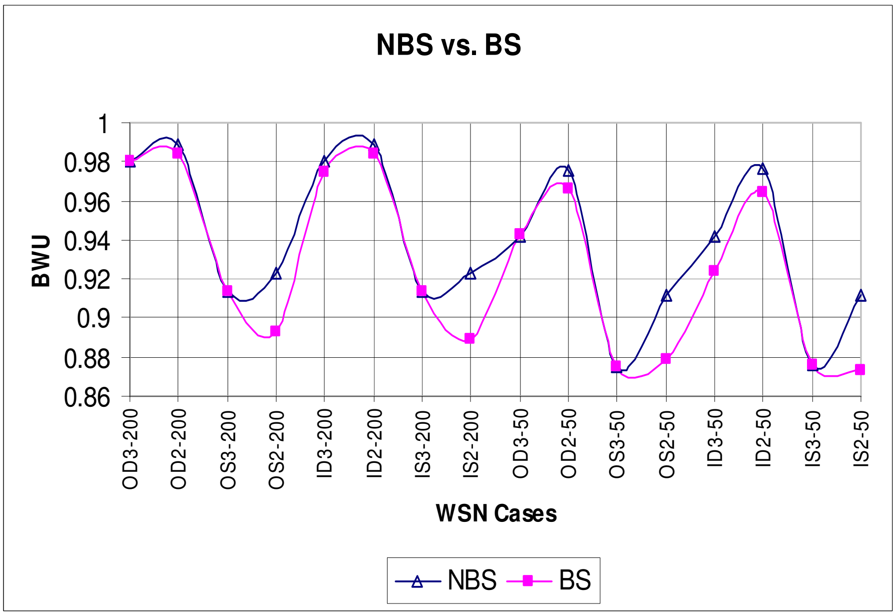

Figure 4.5: Difference between nBS and wBS for BWU

Also, as shown in Figure 4.6 network more utilizes BW definitely when using Dynamic mechanism instead of Static one, the difference equal 7% on average. Explanation of this point was explored in details in Sections 4.5.1 and 4.5.2. Moreover,

Figure 4.6 reveals that Dynamic borrowing mechanisms is the suitable technique for busy networks.

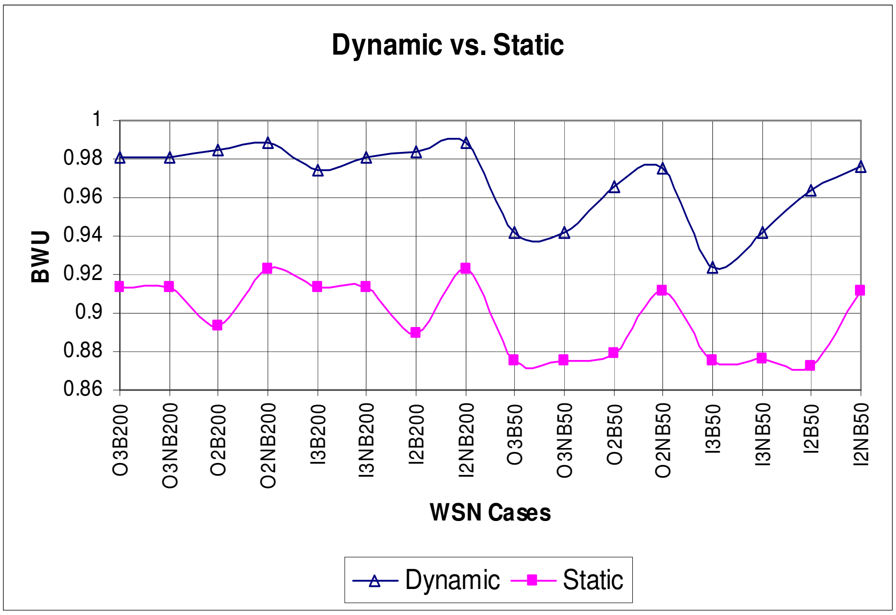

Figure 4.6: Difference between Dynamic and Static for BWU

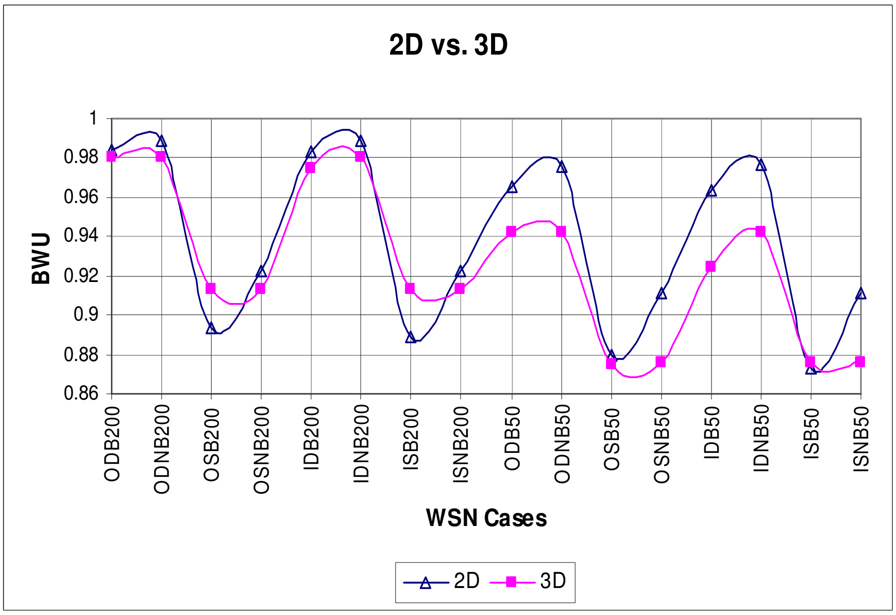

Figure 4.7: Difference between 2D and 3D for BWU

Figure 4.7 shows an unexpected result which is 2D space is more efficient than 3D space by 1.3% . In contrary to previous study (Al-Sharaeh, et al.,2008) which showed that 3D is more efficient due to increase of size of cell. But our explanation emphasizes our simulation results. The explanation is : Figure 4.6 shows that 3D structure on average is less by 3.5% comparing with 2D, This is because each round in simulator will be finished only when reaching the desired CR which is equal to 50 C/Round or equal to 200 C/Round, and due to having same number of connections distributed over 21 cells rather than 7 cells, which means that each cell portion from connections is less. Also, as Equation 4.2 presents, the used BW for each cell depends entirely on numbers of connections it has. Therefore, the outcome of BW utilization for 50 connections will be the same whether the structure is 2D or 3D, (See Equations 4.3 and 4.4), since the number of connections is fixed in 2D and 3D, and the number of cells in 3D is more than it in 2D. Also the whole network bandwidth in 3D is more than that in 2D, so the denominator in 3D case is always larger than in 2D. Accordingly, the fraction (BWU) will be less for 3D.

$$uBW(C) = uBW\_nw\ (C) + uBW\_h(C) \qquad \textbf{(4.2)}$$

$$TuBW += uBW(C) \qquad \textbf{(4.3)}$$

$$BWuti = TuBW / (Cs * CBW) \qquad \textbf{(4.4)}$$

Where: $1 \leq C \leq$ number of cells,

uBW(C) : used BW for a cell,

uBW_nw (C) : BW used by new connections for cell C,

uBW_h(C) : BW used by handoff connections for cell C,

TuBW : Total used BW,

BWuti : BW utilization,

Cs : number of cells,

CBW : cell BW.

Figure 4.8 depicts the difference of BWU when using variant network loads. As we can see, network with heavy load has more efficient BWU since it is more busy than low loaded network, and due to having more connection to be served. The simulation showed that having 200 CR is better by 2.7% than having 50 CR.

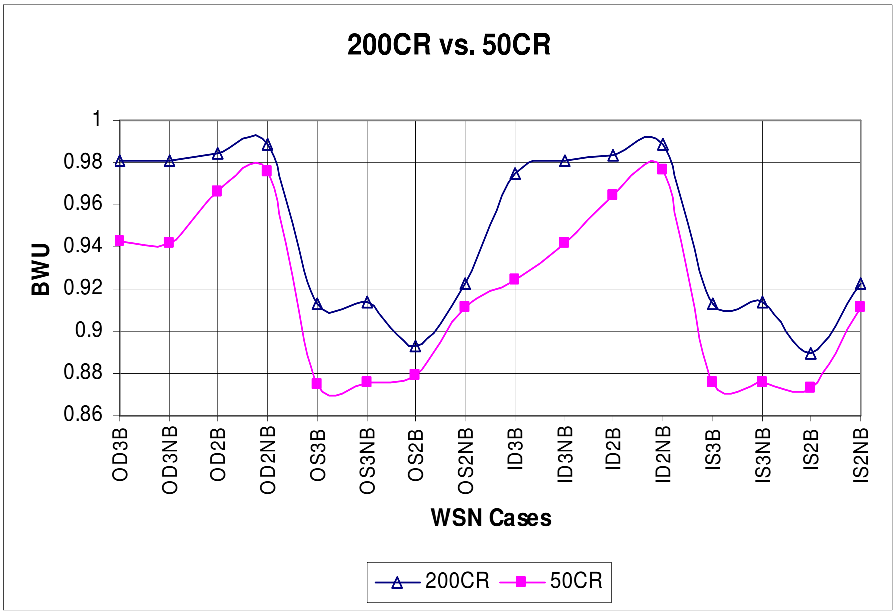

Figure 4.8: Difference between 200 CR and 50 CR for BWU

Table 4.4 presents the difference between Indoor and Outdoor environments. The difference in BWU between them is very low which equals 0.2% in favor of Outdoor on average, because we take in consideration only radius factor and neglect other factors, such as: RF interference in Indoor environment. Difference between Indoor and Outdoor appears clearly in D3B50 case.

Table 4.4: Difference between Indoor and Outdoor for BWU

Study Case	BWU/Indoor	BWU/Outdoor	Difference	To the advantage of
S2NB50	0.91130	0.91134	**0.00345**	Outdoor
S2B50	0.87278	0.87919	**0.72816**	Outdoor
S3NB50	0.87590	0.87540	**0.05773**	Indoor
S3B50	0.87562	0.87509	**0.06066**	Indoor
D2NB50	0.97651	0.97548	**0.10486**	Indoor
D2B50	0.96405	0.96586	**0.18812**	Outdoor
D3NB50	0.94186	0.94180	**0.00626**	Indoor
D3B50	0.92422	0.94228	**1.91610**	Outdoor
S2NB200	0.92283	0.92256	**0.02963**	Indoor
S2B200	0.88917	0.89322	**0.45272**	Outdoor
S3NB200	0.91356	0.91351	**0.00549**	Indoor
S3B200	0.91344	0.91318	**0.02932**	Indoor
D2NB200	0.98899	0.98872	**0.02771**	Indoor
D2B200	0.98362	0.98437	**0.07538**	Outdoor
D3NB200	0.98062	0.98062	**0.00031**	Outdoor
D3B200	0.97464	0.98071	**0.61904**	Outdoor
Average	**0.93182**	**0.93396**	**0.20%**	**Outdoor**

4.6.2 Connection blocking probabilities

In this subsection, we focus on CBP. Table 4.5 shows the difference in CBP when considering existence or absence of BS. The simulation showed that absence of BS is better by 1% than existence of BS on average. Table 4.5 (a) indicates that network with no BS and with Static mechanism has less CBP by 0.85% comparing with similar network, but with existence of BS, while Table 4.5 (b) shows that using Dynamic mechanism will improve performance (mentioned previously) by decreasing CBP by 9.99%.

Table 4.5: Difference between nBS and wBS for CBP

Table 4.5 (a): Static schemes

Study Case	CBP/No BS	CBP/with BS	Difference	percentage	To the advantage of
IS2-50	0.23400	0.23500	0.42553	**0.43%**	With BS
IS3-50	0.17200	0.16972	1.32781	**1.33%**	No BS
OS2-50	0.23029	0.23681	2.75559	**2.76%**	With BS
OS3-50	0.16502	0.17145	3.74747	**3.75%**	With BS
IS2-200	0.26697	0.26730	0.12590	**0.13%**	With BS
IS3-200	0.23700	0.23585	0.48392	**0.48%**	No BS
OS2-200	0.25950	0.26093	0.54505	**0.55**	With BS
OS3-200	0.23359	0.23679	1.35149	**1.35%**	With BS
Average	**0.22480**	**0.22673**	**0.85343**	**0.85%**	**With BS**

Table 4.5 (a): Dynamic schemes

Study Case	CBP/No BS	CBP/with BS	Difference	percentage	To the advantage of
ID2-50	0.14735	0.17819	17.30449	**17.30%**	With BS
ID3-50	0.07791	0.11729	33.57433	**33.57%**	With BS
OD2-50	0.14828	0.17608	15.78911	**15.79%**	With BS
OD3-50	0.07891	0.08106	2.64742	**2.65%**	With BS
ID2-200	0.21305	0.22493	5.27989	**5.28%**	With BS
ID3-200	0.18206	0.19834	8.20926	**8.21%**	With BS
OD2-200	0.21484	0.22391	4.05295	**4.05%**	With BS
OD3-200	0.18281	0.18363	0.44600	**0.45%**	With BS
Average	**0.15565**	**0.17293**	**9.99110**	**9.99%**	**With BS**

Table 4.6 presents the difference in CBP between Indoor and Outdoor, as we can see, Indoor has more probability to blocking connections than Outdoor, this probability equals 1.29% on average when using Static mechanism, and equals 3.7% when using

Dynamic one. We explained before why the difference in simulation is very low while it is in nature a bit larger. The reason is that we do not consider BER which effects Indoor more than Outdoor networks.

Table 4.6: Difference between Indoor and Outdoor for CBP

Table 4.6 (a): Static schemes

Study Case	CBP/Indoor	CBP/Outdoor	Difference	percentage	To the advantage of
S2NB50	0.234	0.23029	1.58675	**1.59%**	Indoor
S2B50	0.235	0.23681	0.7654	**0.77%**	Outdoor
S3NB50	0.172	0.16502	4.05698	**4.06%**	Indoor
S3B50	0.16972	0.17145	1.0095	**1.01%**	Outdoor
S2NB200	0.26697	0.2595	2.79551	**2.80%**	Indoor
S2B200	0.2673	0.26093	2.38585	**2.39%**	Indoor
S3NB200	0.237	0.23359	1.4384	**1.44%**	Indoor
S3B200	0.23585	0.23679	0.39617	**0.40%**	Outdoor
Average	**0.22723**	**0.224298**	**1.29054**	**1.29%**	**Indoor**

Table 4.6 (b): Dynamic schemes

Study Case	CBP/Indoor	CBP/Outdoor	Difference	Percentage	To the advantage of
D2NB50	0.14735	0.14828	0.62384	**0.62%**	Outdoor
D2B50	0.17819	0.17608	1.18304	**1.18%**	Indoor
D3NB50	0.07791	0.07891	1.26974	**1.27%**	Outdoor
D3B50	0.11729	0.08106	30.89043	**30.89%**	Indoor
D2NB200	0.21305	0.21484	0.82994	**0.83%**	Outdoor
D2B200	0.22493	0.22391	0.45259	**0.45%**	Indoor
D3NB200	0.18206	0.18281	0.41463	**0.41%**	Outdoor
D3B200	0.19834	0.18363	7.41415	**7.41%**	Indoor
Average	**0.16739**	**0.16119**	**3.70392**	**3.70%**	**Indoor**

Here, in Figure 4.9 we can see the outperforming of Dynamic mechanism over Static one on reducing the probability of blocking connections, where Dynamic has less probability by 6%, this is due to reserving a pool of BW for handoff connections by Static schemes.

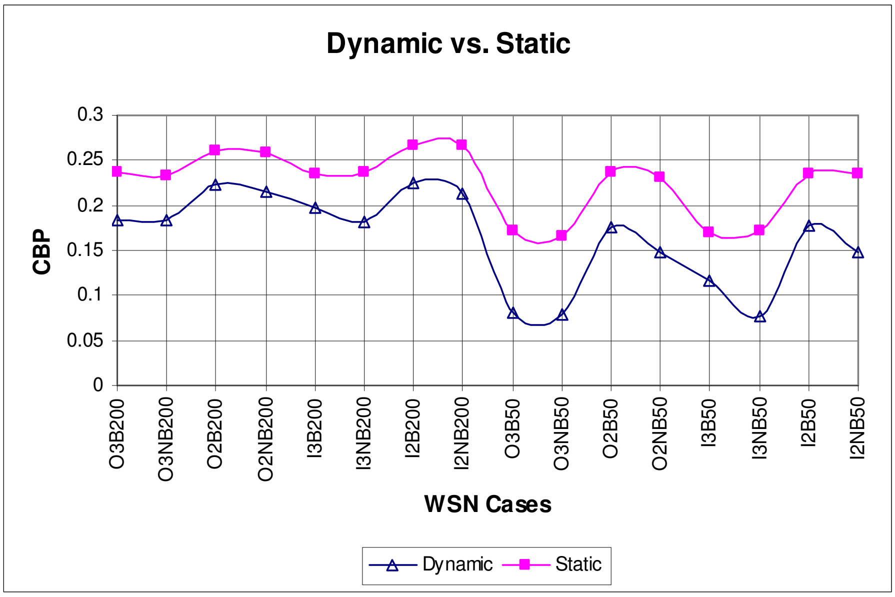

Figure 4.9: Difference between Dynamic and Static for CBP

Figure 4.10 depicts that 2D space is subjected to have more CBP than 3D by 4.9% on average (back to page 42 for explanation). On the other hand, 6.2% is the difference between high CR and moderate CR (See Figure 4.11).

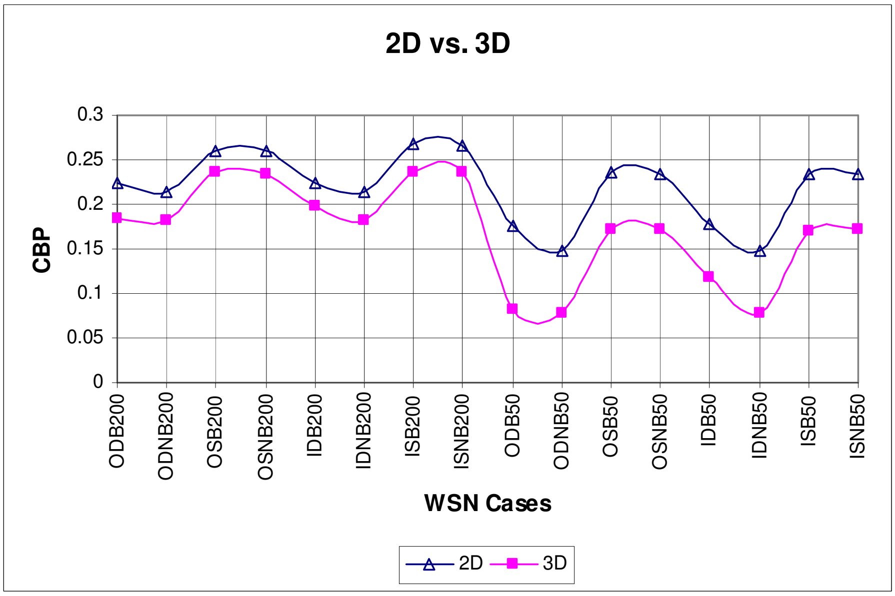

Figure 4.10: Difference between 2D and 3D for CBP

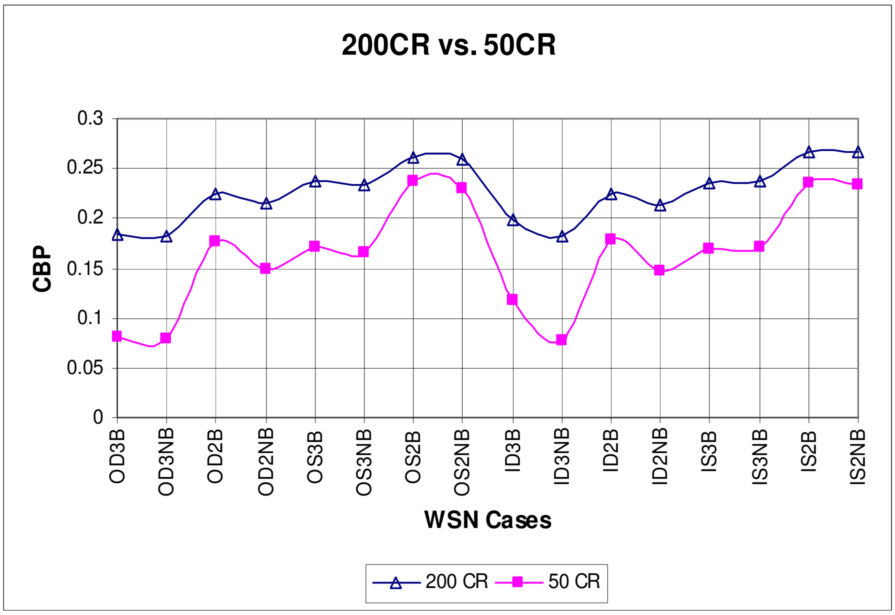

Figure 4.11: Difference between 200 CR and 50 CR for CBP

4.6.3 Connection dropping probabilities

Here, simulation results show that WSN without BS has less probabilities for connection dropping, where the difference percentage between nBS and wBS is 0.23% for Static schemes and 3.25% for Dynamic schemes (See Table 4.7 for more details). As we can see, the variation between two percentages is due to the use of two different borrowing mechanisms. As we mentioned, existence of BS decreases coverage area which, in turn, yields increasing in dropping.

Table 4.7: Difference between nBS and wBS for CDP

Table 4.7 (a): Static schemes

Study Case	CDP/No BS	CDP/With BS	Difference	Percentage	To the advantage of
IS2-50	0.25241	0.25454	0.83649	**0.84%**	With BS
IS3-50	0.21622	0.21644	0.10165	**0.10%**	With BS
OS2-50	0.25382	0.25469	0.34506	**0.35%**	With BS
OS3-50	0.21700	0.21736	0.1653	**0.17%**	With BS
IS2-200	0.26697	0.2673	0.1259	**0.13%**	With BS
IS3-200	0.25478	0.25457	0.08305	**0.08%**	No BS
OS2-200	0.26665	0.26827	0.60256	**0.60%**	With BS
OS3-200	0.25500	0.25434	0.25833	**0.26%**	No BS
Average	**0.247856**	**0.248439**	**0.23446**	**0.23%**	**With BS**

Table 4.7 (b): Dynamic schemes

Study Case	CDP/No BS	CDP/With BS	Difference	Percentage	To the advantage of
ID2-50	0.19397	0.20548	5.60301	**5.60%**	With BS
ID3-50	0.08367	0.11948	29.97631	**29.98%**	With BS
OD2-50	0.19209	0.20339	5.55577	**5.56%**	With BS
OD3-50	0.08341	0.086	3.01963	**3.02%**	With BS
ID2-200	0.27723	0.26483	4.47284	**4.47%**	No BS
ID3-200	0.19449	0.20727	6.16596	**6.17%**	With BS
OD2-200	0.27888	0.26554	4.78419	**4.78%**	No BS
OD3-200	0.19444	0.19651	1.05391	**1.05%**	With BS
Average	**0.187273**	**0.193563**	**3.24960**	**3.25%**	**With BS**

Table 4.8 shows that dropping probability for Outdoor is more than Indoor by 0.2% on average for Static schemes (See Table 4.8 (a)), while Indoor network with Dynamic schemes achieves 2.99% increasing in CDP, as shown in Table 4.8 (b). Two cases (Indoor and Outdoor) are differing from each other only by their radiuses, so we can see that the differences in most situations are very slight.

Table 4.8: Difference between Indoor and Outdoor for CDP

Table 4.8 (a): Static schemes

Study Case	CDP/Indoor	CDP/Outdoor	Difference	Percentage	To the advantage of
S2NB50	0.25241	0.25382	0.55442	**0.55%**	Outdoor
S2B50	0.25454	0.25469	0.06159	**0.06%**	Outdoor
S3NB50	0.21622	0.217	0.36142	**0.36%**	Outdoor
S3B50	0.21644	0.21736	0.4249	**0.42%**	Outdoor
S2NB200	0.26697	0.26665	0.11877	**0.12%**	Indoor
S2B200	0.2673	0.26827	0.35892	**0.36%**	Outdoor
S3NB200	0.25478	0.255	0.08749	**0.09%**	Outdoor
S3B200	0.25457	0.25434	0.08801	**0.09%**	Indoor
Average	**0.247904**	**0.248391**	**0.19626**	**0.20%**	**Outdoor**

Table 4.8 (b): Dynamic schemes

Study Case	CDP/Indoor	CDP/Outdoor	Difference	Percentage	To the advantage of
D2NB50	0.19397	0.19209	0.96615	**0.97%**	Indoor
D2B50	0.20548	0.20339	1.01568	**1.02%**	Indoor
D3NB50	0.08367	0.08341	0.30837	**0.31%**	Indoor
D3B50	0.11948	0.086	28.01868	**28.02%**	Indoor
D2NB200	0.27723	0.27888	0.59094	**0.59%**	Outdoor
D2B200	0.26483	0.26554	0.26588	**0.27%**	Outdoor
D3NB200	0.19449	0.19444	0.02674	**0.03%**	Indoor
D3B200	0.20727	0.19651	5.19185	**5.19%**	Indoor
Average	**0.193303**	**0.187533**	**2.98495**	**2.99%**	**Indoor**

Dynamic mechanism is more efficient in CDP resistance especially in 3D cases, this is because our 3D scheme has more neighbors, which give handoff connection more opportunity to roam and to be admitted by new base station. Figure 4.12 shows that Dynamic has less CDP than Static by 5.8% on average.

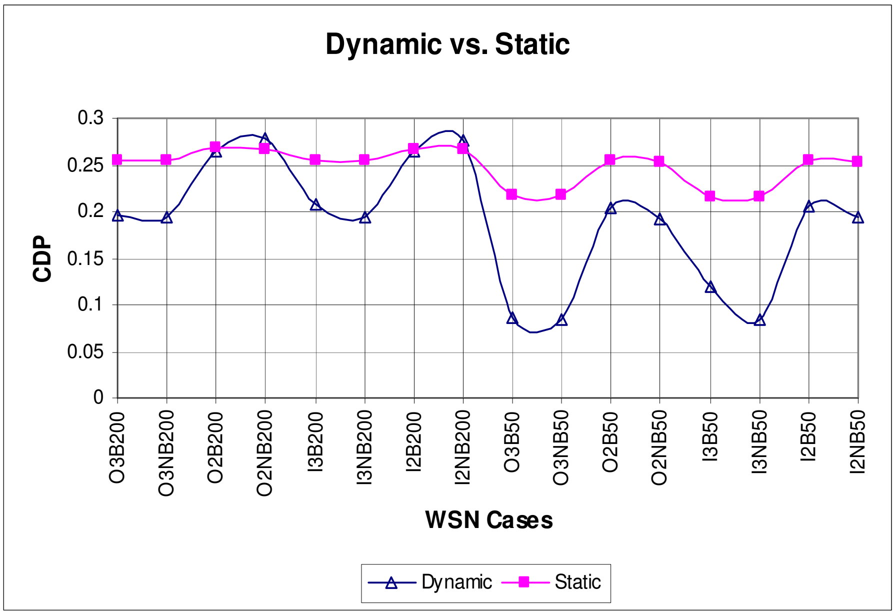

Figure 4.12: Difference between Dynamic and Static for CDP

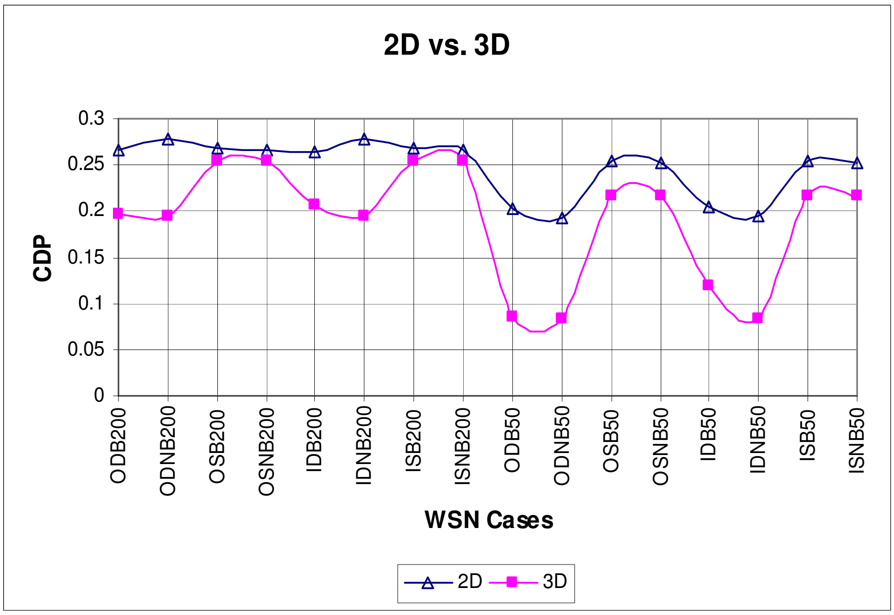

Figure 4.13: Difference between 2D and 3D for CDP

Difference between 2D and 3D is presented in Figure 4.13, as we can see, CDP is less in all cases for 3D, best less probabilities can be achieved on four cases that have Dynamic mechanisms with CR equal to 50 regardless whether these cases are with or without BS and Indoor or Outdoor. These cases are the best due to the use of Dynamic mechanisms and due to having light-load networks which equal to 50.

Dropping has least probabilities when using Dynamic mechanism in 3D spaces with CR equal 50 while using high CR will increase dropping in Dynamic in noticeable percentage. This appears clearly in Figure 4.14. On the other hand, this figure shows that Static is more stable under two CRs but with high probabilities. the reason behind stability is that Static retains a pool of BW for handoff connections. The difference in CDP between network with 200 CR and network with 50 CR is 5.7% on average.

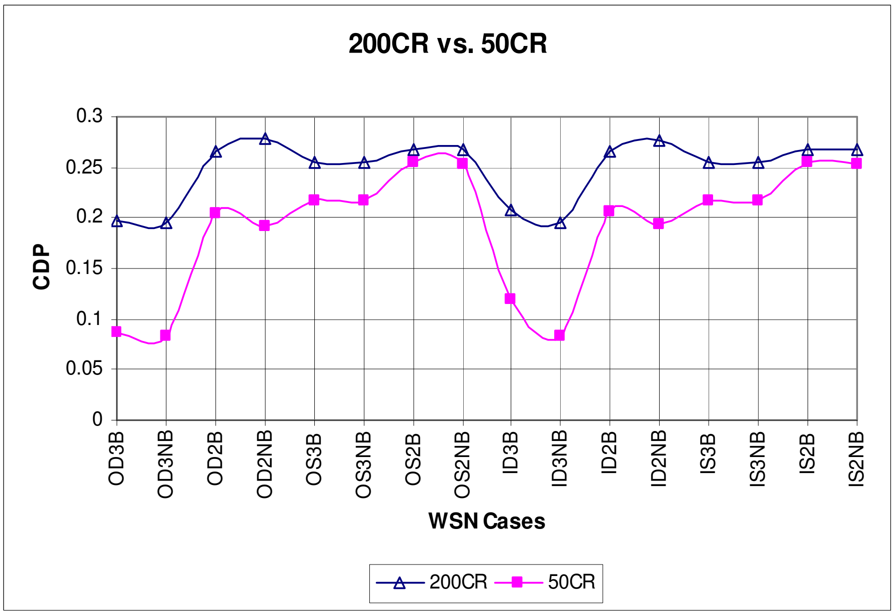

Figure 4.14: Difference between 200 CR and 50 CR for CDP

4.6.4 Variant Lambda effects

In this subsection, we will study Lambda effects on BWU,CBP, and CDP under all our study cases to find the suitable value for Lambda. To show the effect of Lambda, we ran simulation for different values of Lambda. Figure 4.15 depicts the results, as we can see when Lambda ranges between (5 to 7.5), the BWU is in its highest utilization. Lambda equals the number of shares that can be borrowed from one connection, since Lambda and value of one share are contrary. If we have large lambda, then the share becomes small. So when a base station has no enough BW, and borrows from current connections, this borrowing needs a lot of shares to achieve the minimum BW for one connection, which is not efficient. In contrary, if we have small Lambda and large share (with one share value is larger than minimum BW), then borrowing one share from a connection will degrade QoS in lender connection, Moreover, borrower connection will have more than its minimum BW and this is not effective and not fair beside being useless in BWU.

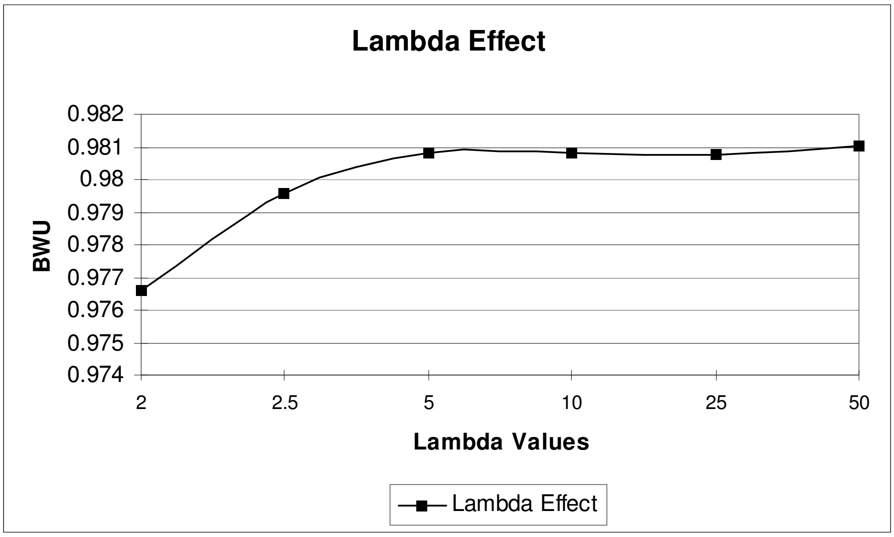

Figure 4.15: Lambda effect on BWU

Figures 4.16 and 4.17 assert our inference about best value of Lambda, this because CBP and CDP have their least values when Lambda value is within range [5 to 7.5].

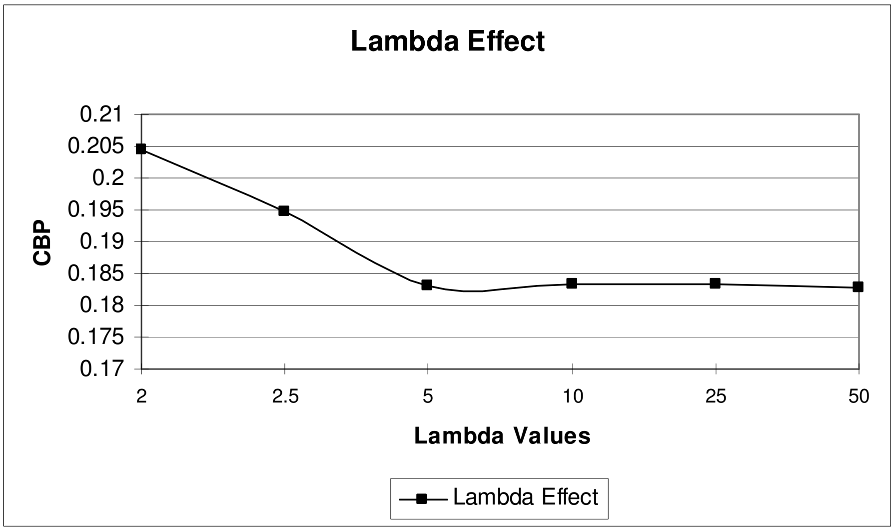

Figure 4.16: Lambda effect on CBP

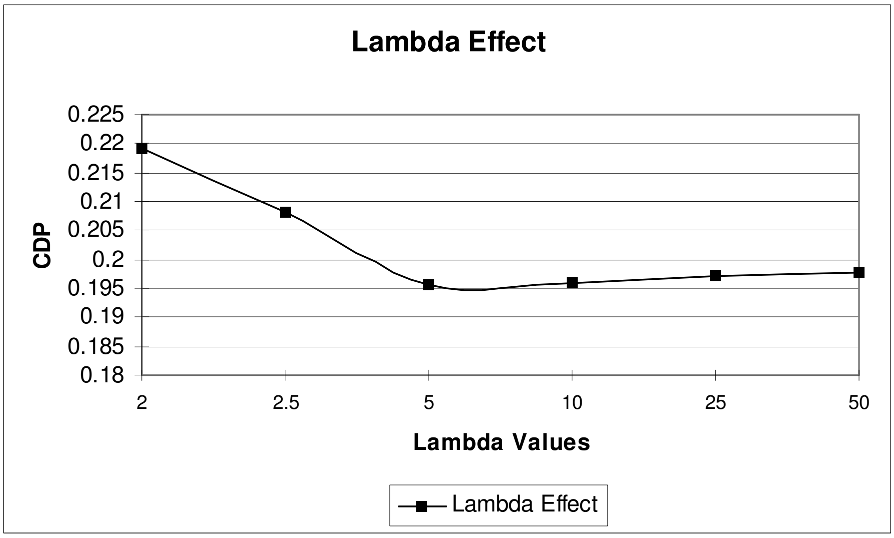

Figure 4.17: Lambda effect on CDP

4.6.5 Variant fair factor effects

Due to the fact that fair factor *f* will determine borrowed BW for cells, so if *f* is small, then the amount of BW will be small, and as a result having higher connections rate means more blocking and dropping, which yields less BWU (Figures 4.18, 4.19, and 4.20).

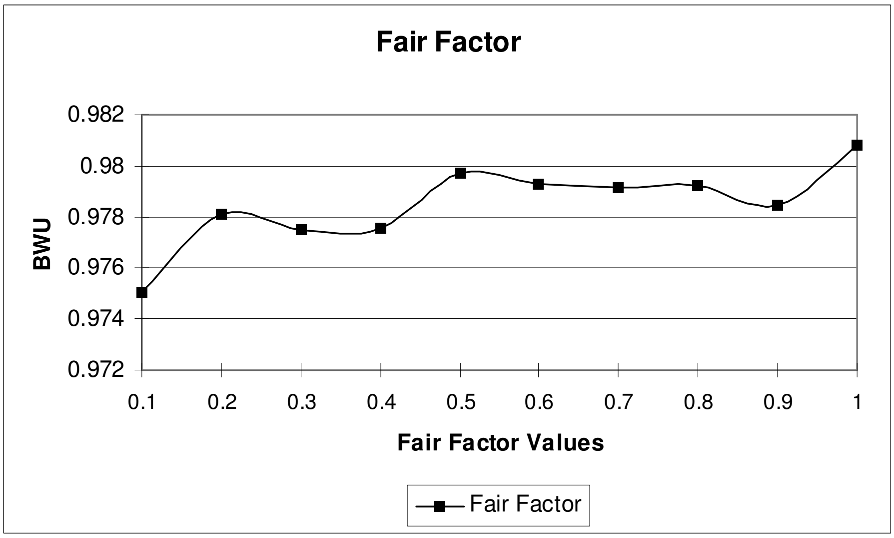

Figure 4.18: Fair factor effect on BWU

Figure 4.18 shows that the best value for *f* is 1, which means that the connection tolerates with the maximum difference BW (between maximum and minimum) to be borrowed. Figures 4.19 and 4.20 present that the best value of *f* is when it equals one in point of CBP and CDP.

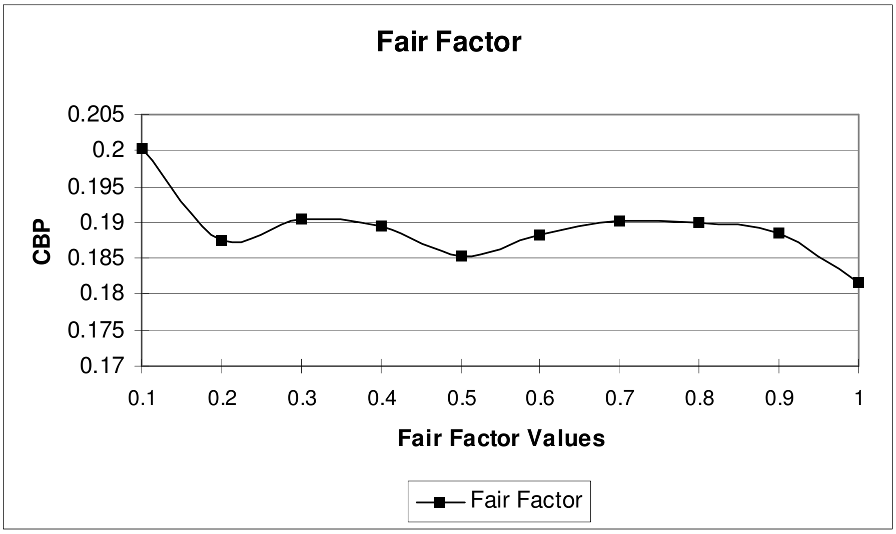

Figure 4.19: Fair factor effect on CBP

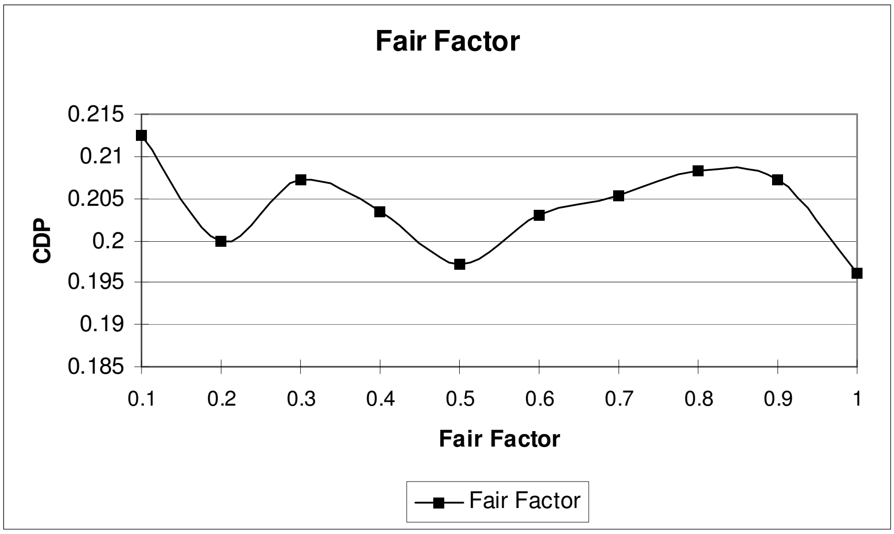

Figure 4.20: Fair factor effect on CDP

We can conclude that suitable value for *f* is one, and this is congruous with (Al-Sharaeh, et al.,2008).

4.6.6 Variant blind spot effects

Blind spot is an important factor in QoS, because large BS means high probability for connection to be originated or to move into this spot. Therefore, there is a direct proportion between the size of BS and non-admission of connections. Figure 4.21 shows how BWU drops when BS becomes larger, this is because of having larger BS which means having more connections lie in BS area. Thus, it yields higher inadmissible connections by base station in spite of availability of BW. Moreover, CBP and CDP arise when BS is larger (See Figures 4.22 and 4.23).

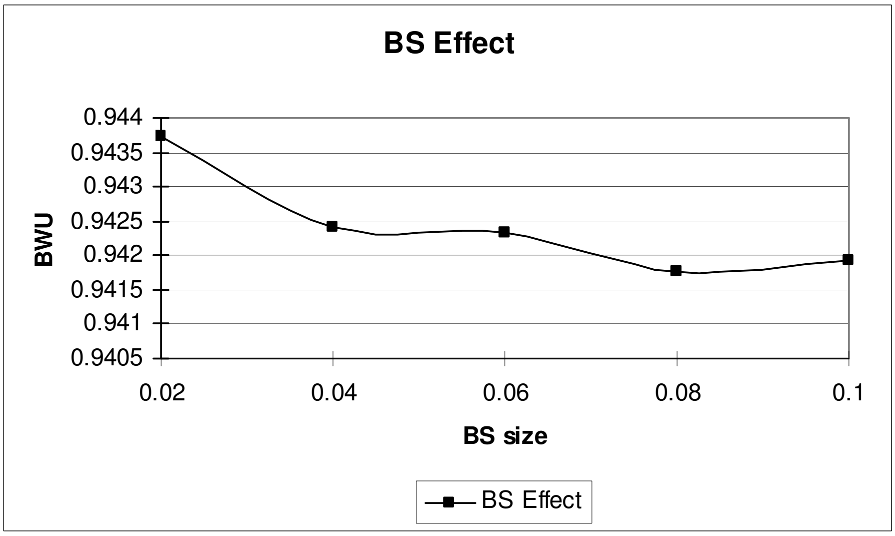

Figure 4.21: BS size effect on BWU

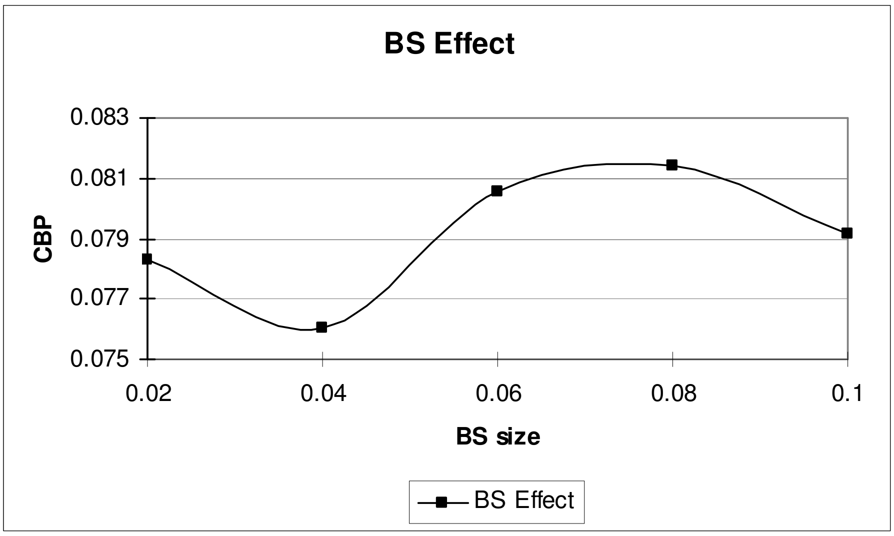

Figure 4.22: BS size effect on CBP

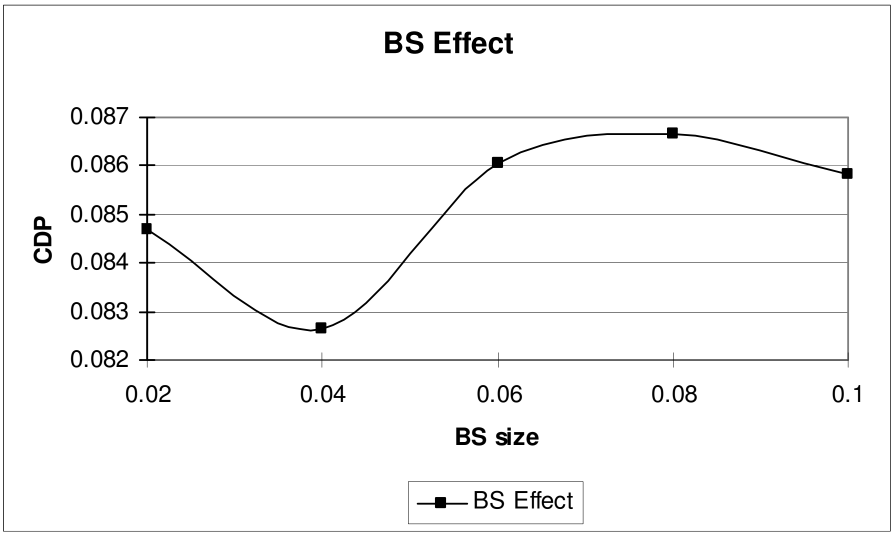

Figure 4.23: BS size effect on CDP

5. Conclusions and future works

5.1. Conclusions

In this study, we have proposed a new scheme (A3D-DBBS) where we aim to find: best structure, space, and mechanism for WSNs to have high QoS guarantees. Having a WSN with high guarantees requires three conditions: achieving high BWU, and at same time decreasing CBP and CDP.

To achieve this goal, we considered sixteen different study cases, by applying two borrowing mechanisms (Static and Dynamic). Static mechanism reserves a pool of BW in base station for handoff connections. Resource reservation decreases BWU, and increases CBP and CDP. Hence, Dynamic is more efficient since it does not have any kind of resource reservation.

We also tested network when it is designed whether Indoor or Outdoor. Our study revealed that Outdoor network is a bit better in QoS guarantees. We entered new concept (3D space which has 3 layers with seven cells at each one) to WSNs , and we studied its effects on QoS comparing with 2D.

Here, we mention in brief our major simulation findings. The simulation results revealed that Dynamic borrowing mechanism outperformed the Static borrowing mechanism by 7% on average for BWU and by decreasing CBP by 6% and decreasing CDP by 5.8%. Also results showed that 3D is less than 2D by 1.3% on average for BWU but at the same time 3D has 9% less for CBP and 5.7% less for CDP than 2D on average. Outdoor networks have better BWU by 0.2% than Indoor, and in addition Outdoor networks decreased CBP by 1.29% and by 3.7% when using Static and Dynamic respectively, and decreased CDP by 0.2% with Static and by 2.99% with Dynamic comparing with Indoor. BS decreased BWU by 1.2%, decreased CBP by 0.85% and by

9.99% when using Static and Dynamic, consecutively. Also BS decreased CDP by 0.23% and by 3.25% (when using Static and Dynamic, successively) on average. When network has connection CR equal to 200, it increased BWU by 2.7% than having 50 CR, while CDP and CBP are less for networks with 50 CR by 6.26% and 5.7%, respectively. All previous results are yielded from the repetition of each status 2500 times, which make these results high strict and reliable.

We can conclude, based on the above, that using Dynamic borrowing mechanism is better than using Static one. Also, 3D is more suitable when thinking of QoS. And existence of BS will decrease the QoS that network can warrant. Finally, when looking for better QoS in general, network with connection rate up to 50 is more preferred than the one with 200 CR.

5.2 Future works

In this study, we constrained on homogenous sensors in network, which simplified determining the maximum, average , and minimum BW for all sensors. Also, imitating network with homogenous sensors is easier than the one with heterogeneous sensors. Homogeneity facilitated calculating borrowed shares and scheduling BW. So, we suggest studying heterogeneous WSNs.

We also considered the radius as the only different factor between Indoor and Outdoor cases, while it is more realistic to consider BER as another factor which yields from RF interference in Indoor environment. This factor will decrease BWU, and increase CBP and CDP in Indoor cases. So we suggest adding this factor to this study metrics and studying its effect on QoS.

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Appendix A: About simulator

Our study considered with sixteen different cases, we have our own simulator to simulate these cases. Each case of them was represented by two Java files: mainframe.java, and cell_Definition.java.

In mainframe.java file, the structure of network is built, each instance of this file was modified to be suitable for presenting one case of our study. Here, we display some sections from mainframe.java code:

1) Assigning different values to BW:

```
Max_bw = 60;
Average_bw = 30;
Min_bw = 10;
total_bw = 4000;
reserved_for_hand = 1330;
```

Note: the variable reserved_for_hand is used only in cases where the borrowing mechanism is Static.

2) Network creation:

In 2D structure:

```
Static_Based [] cellArray = {c0, cell1, cell2, cell3 , cell4, cell5, cell6};
```

In 3D structure:

```
Static_Based [] cellArray = {c0, cell1, cell2, cell3 , cell4,
cell5,cell6,cell7,cell8,cell9,cell10,cell11,cell12,cell13,cell14,cell15,
cell16,cell17,cell18,cell19,cell20};
```

Note: c0 represents central cell in the network, and other cells are the neighbours.

3) Generating new connection / Handoff connection randomly:

Ex: In 3D structure

```
New connection: rand_Cell = (int)((Math.random()*20)%20) + 1;
                c0.generate_New_Call(cellArray, rand_Cell);

Handoff connection: rand_Cell = (int)((Math.random()*20)%20) + 1;
                    c0.generate_Handoff(cellArray, rand_Cell);
```

4) Terminating new connection / Handoff connection randomly:

Ex: In 2D structure

```
New connection: rand_Cell = (int)((Math.random()*10)%6) + 1;
                c0.Terminate_Call(cellArray, rand_Cell);

Handoff connection: rand_Cell = (int)((Math.random()*10)%6) + 1;
                    c0.Terminate_Handoff(cellArray, rand_Cell);
```

5) Calculating Three values (CBP,CDP, and BWU):

```
blockingProbability = (TotalBlocked / CallAttempts);
droppingProbability = (TotalDropped / HandoffAttempts);
bandwidthUtilization = TotalBwUsed / (total_bw * 6);
```

Note: total_bw is divided on 6 when structure is 2D and divided on 20 when it is 3D.

Now, we display some sections from cell_Definition.java code:

1) generate_New_Call Procedure:

This procedure is responsible of checking available amount of BW in base station, then determining the BW that base station can provide for this new connection whether (maximum BW, average BW, or minimum BW).

```
if(Max_bw <= cellArray[r].free_new)
{   .....
cellArray[r].used_bw_new += Max_bw;
cellArray[r].free_new = total_bw - reserved_for_hand -
                                cellArray[r].used_bw_new;
.....} else if (Average_bw <= cellArray[r].free_new){.....}.....
```

Note: using variable reserved_for_hand shows that this network uses Static borrowing mechanism.

2) generate_Handoff Procedure:

This procedure works in similar way as generate_New_Call Procedure.

3) Terminate_Call and Terminate_Handoff Procedures:

These two Procedures terminate a New connection or a Handoff connection randomly from a cell which means free some of this cell base station BW.

4) Calculating Blind Spot in cases that consider it:

In 2D structure:

The procedure generate_New_Call / generate_Handoff at first check if new connection / Handoff connection is in or out BS, if it is in the BS then the connection will be not admitted whether there is or not enough BW.

new_radius = Math.sqrt(x*x + y*y);

In 3D structure:

new_radius = Math.sqrt(x*x + y*y + z*z);

Finally, we should mention that we used "**JAVA™ 2 SOFTWARE DEVELOPMENT KIT (J2SDK), STANDARD EDITION, VERSION 1.4.2_X**".

Note: This part is taken from (http://java.sun.com/j2se/1.4.2/docs/index.html)

This version of Java has these contents:

Development Tools

(In the `bin` subdirectory.) Tools and utilities that will help you develop, execute, debug, and document programs written in the Java programming language.

Runtime Environment

(In the `jre` subdirectory.) An implementation of the Java 2 runtime environment for use by the SDK. The runtime environment includes a Java virtual machine, class libraries, and other files that support the execution of programs written in the Java programming language.

Additional Libraries

(In the `lib` subdirectory.) Additional class libraries and support files required by the development tools.

Demo Applets and Applications

(In the `demo` subdirectory.) Examples, with source code, of programming for the Java platform. These include examples that use Swing and other Java Foundation Classes, and the Java Platform Debugger Architecture.

C header Files

(In the `include` subdirectory.) Header files that support native-code programming using the Java Native Interface, the Java Virtual Machine Debugger Interface, the Java Virtual Machine Profiler Interface and other functionality of the Java 2 Platform.

Source Code

(In `src.zip`.) Java programming language source files for all classes that make up the Java 2 core API (that is, sources files for the java.*, javax.* and some org.* packages, but not for com.sun.* packages). This source code is provided for informational purposes only, to help developers learn and use the Java programming language. These files do not include platform-specific implementation code and cannot be used to rebuild the class libraries. To extract these file, use any common zip utility. Or, you may use the Jar utility in the Java 2 SDK's `bin` directory:

```
jar xvf src.zip
```

Appendix B: Selected simulation results

Our simulator produces five text files, these files are: BandWidth_Utilization, Blocking_Probability, Dropping_Probability, Intermediate_File, and Tracing_File. More details are available in this appendix.

Table B.1: BandWidth_Utilization.txt (Indoor\Dynamic\2D\wBS\CR_200\ experiment no. 1)

CR	BWU
1	0.36625
2	0.793083
3	0.924458
4	0.969708
5	0.971917
6	0.979417
7	0.979792
8	0.983375
9	0.9865
10	0.988083
11	0.986
12	0.990833
13	0.987458
14	0.9875
15	0.990083
16	0.9865
17	0.979833
18	0.991375
19	0.986792
20	0.98225
21	0.984458
22	0.986167
23	0.982292
24	0.987375
25	0.9885
26	0.987792
27	0.988417
28	0.987208
29	0.991
30	0.987167
31	0.989417
32	0.991292
33	0.989292
34	0.989125
35	0.989667
36	0.988167
37	0.9885
38	0.986417
39	0.987
40	0.988958

CR	BWU
41	0.985458
42	0.98775
43	0.989
44	0.987417
45	0.986875
46	0.990417
47	0.989625
48	0.986375
49	0.99025
50	0.991208
51	0.989125
52	0.990083
53	0.988333
54	0.989958
55	0.988417
56	0.989792
57	0.988583
58	0.990125
59	0.990625
60	0.988375
61	0.98925
62	0.989125
63	0.990167
64	0.98875
65	0.988167
66	0.989
67	0.988333
68	0.992083
69	0.988458
70	0.988667
71	0.99025
72	0.98675
73	0.992208
74	0.987583
75	0.991958
76	0.989958
77	0.990125
78	0.990833
79	0.991708
80	0.989542
81	0.991208
82	0.990875
83	0.991
84	0.991458
85	0.991208
86	0.985583
87	0.99
88	0.990667
89	0.9855
90	0.98925
91	0.991292

CR	BWU
92	0.989417
93	0.9895
94	0.991375
95	0.991
96	0.991875
97	0.993417
98	0.988167
99	0.991292
100	0.991417
101	0.98775
102	0.989875
103	0.991833
104	0.98875
105	0.990125
106	0.992583
107	0.992708
108	0.989958
109	0.99175
110	0.99325
111	0.9895
112	0.989625
113	0.990208
114	0.988042
115	0.992833
116	0.98725
117	0.990292
118	0.991
119	0.990833
120	0.99
121	0.992583
122	0.987833
123	0.991
124	0.992167
125	0.99025
126	0.992125
127	0.992792
128	0.992625
129	0.986417
130	0.988208
131	0.988708
132	0.990458
133	0.990625
134	0.991458
135	0.98975
136	0.986833
137	0.989375
138	0.990333
139	0.991833
140	0.992417
141	0.991125
142	0.992042

CR	BWU
143	0.991667
144	0.989875
145	0.99075
146	0.990417
147	0.992125
148	0.990375
149	0.99225
150	0.988833
151	0.993292
152	0.9915
153	0.991333
154	0.990875
155	0.991
156	0.991333
157	0.98825
158	0.991833
159	0.991833
160	0.987125
161	0.990625
162	0.989333
163	0.984375
164	0.989042
165	0.990458
166	0.989292
167	0.992583
168	0.9915
169	0.992125
170	0.989875
171	0.992583
172	0.991708
173	0.991583
174	0.993833
175	0.989042
176	0.990458
177	0.990625
178	0.991375
179	0.989417
180	0.989458
181	0.990792
182	0.989667
183	0.989625
184	0.991708
185	0.990417
186	0.990542
187	0.987167
188	0.991667
189	0.991292
190	0.991125
191	0.990917
192	0.991875
193	0.990375

CR	BWU
194	0.992292
195	0.990417
196	0.993083
197	0.992542
198	0.991833
199	0.990958
200	0.993042

Table B.2: Blocking_Probability.txt (Indoor\Dynamic\2D\wBS\CR_200\ experiment no. 1)

CR	CBP
1	0.085035
2	0.083388
3	0.088076
4	0.088708
5	0.088471
6	0.09144
7	0.10221
8	0.113786
9	0.122895
10	0.133449
11	0.145341
12	0.152111
13	0.154473
14	0.158742
15	0.162682
16	0.165783
17	0.169867
18	0.17297
19	0.177503
20	0.179546
21	0.18141
22	0.183764
23	0.185579
24	0.186479
25	0.188545
26	0.189167
27	0.190194
28	0.191213
29	0.191862
30	0.19428
31	0.196257
32	0.198015
33	0.199068
34	0.201336
35	0.202549
36	0.204947
37	0.206406
38	0.207547
39	0.208245

CR	CBP
40	0.208639
41	0.208752
42	0.20829
43	0.208971
44	0.209221
45	0.20955
46	0.210158
47	0.21066
48	0.21185
49	0.211945
50	0.21236
51	0.212861
52	0.213882
53	0.214406
54	0.21487
55	0.215561
56	0.215957
57	0.21641
58	0.216465
59	0.216861
60	0.217736
61	0.219117
62	0.220084
63	0.220594
64	0.220527
65	0.2207
66	0.220936
67	0.221157
68	0.221519
69	0.222559
70	0.222931
71	0.223849
72	0.224975
73	0.225424
74	0.225827
75	0.226562
76	0.227654
77	0.228432
78	0.228734
79	0.229507
80	0.229989
81	0.230395
82	0.230718
83	0.230969
84	0.231488
85	0.231858
86	0.232421
87	0.232636
88	0.232779
89	0.233097
90	0.233339

CR	CBP
91	0.233671
92	0.234236
93	0.23477
94	0.234818
95	0.235224
96	0.235395
97	0.235716
98	0.23631
99	0.236968
100	0.237243
101	0.237701
102	0.237725
103	0.237921
104	0.238025
105	0.23819
106	0.238409
107	0.238542
108	0.238777
109	0.239195
110	0.239979
111	0.24064
112	0.240978
113	0.240972
114	0.2413
115	0.241436
116	0.241749
117	0.241718
118	0.241769
119	0.242019
120	0.242415
121	0.242748
122	0.242956
123	0.243137
124	0.243215
125	0.243595
126	0.243774
127	0.244146
128	0.244433
129	0.244932
130	0.244877
131	0.244918
132	0.244927
133	0.245398
134	0.245728
135	0.245764
136	0.246052
137	0.245974
138	0.24583
139	0.245853
140	0.246104
141	0.246186

CR	CBP
142	0.246456
143	0.246771
144	0.247093
145	0.247187
146	0.247163
147	0.247255
148	0.24753
149	0.247723
150	0.247726
151	0.247813
152	0.248041
153	0.248154
154	0.248325
155	0.24869
156	0.249116
157	0.249499
158	0.249663
159	0.249655
160	0.249734
161	0.249797
162	0.250043
163	0.250164
164	0.250041
165	0.249914
166	0.249881
167	0.249911
168	0.250239
169	0.250428
170	0.250465
171	0.250477
172	0.250823
173	0.250908
174	0.25112
175	0.251241
176	0.251144
177	0.251133
178	0.25111
179	0.251075
180	0.251229
181	0.251264
182	0.251472
183	0.251599
184	0.251777
185	0.252171
186	0.252407
187	0.252428
188	0.252342
189	0.25241
190	0.252462
191	0.252663
192	0.252749

CR	CBP
193	0.252978
194	0.253148
195	0.253213
196	0.253135
197	0.253166
198	0.253489
199	0.253764
200	0.254255

Table B.3: Dropping_Probability.txt (Indoor\Dynamic\2D\wBS\CR_200\ experiment no. 1)

CR	CDP
1	0.079473
2	0.076369
3	0.077479
4	0.084742
5	0.088492
6	0.09558
7	0.107228
8	0.119126
9	0.135952
10	0.150602
11	0.164867
12	0.171374
13	0.177472
14	0.183262
15	0.18851
16	0.19468
17	0.200952
18	0.205284
19	0.210825
20	0.21472
21	0.217294
22	0.221265
23	0.223723
24	0.225182
25	0.2273
26	0.229301
27	0.231191
28	0.23298
29	0.23424
30	0.236498
31	0.23757
32	0.239155
33	0.240814
34	0.241797
35	0.243287
36	0.245511
37	0.246591
38	0.24755
39	0.249178

CR	CDP
40	0.249956
41	0.250572
42	0.250936
43	0.251943
44	0.251858
45	0.252015
46	0.253342
47	0.253467
48	0.25408
49	0.253939
50	0.254357
51	0.255107
52	0.255463
53	0.256099
54	0.256962
55	0.25767
56	0.258198
57	0.258821
58	0.259378
59	0.259881
60	0.260305
61	0.261056
62	0.261127
63	0.261705
64	0.262202
65	0.262555
66	0.262888
67	0.263244
68	0.263816
69	0.26443
70	0.264925
71	0.265557
72	0.266296
73	0.2668
74	0.267699
75	0.269388
76	0.270494
77	0.271449
78	0.271988
79	0.272848
80	0.273165
81	0.273986
82	0.274614
83	0.27542
84	0.276229
85	0.276808
86	0.27689
87	0.276903
88	0.277107
89	0.277376
90	0.277483

CR	CDP
91	0.277524
92	0.277951
93	0.278714
94	0.278971
95	0.279163
96	0.279464
97	0.279487
98	0.280219
99	0.2808
100	0.280819
101	0.280818
102	0.280678
103	0.280877
104	0.281363
105	0.281665
106	0.282181
107	0.282587
108	0.283292
109	0.283688
110	0.28475
111	0.285292
112	0.285713
113	0.285746
114	0.286346
115	0.286534
116	0.286859
117	0.287085
118	0.287176
119	0.287421
120	0.287932
121	0.288408
122	0.288911
123	0.289001
124	0.289006
125	0.289354
126	0.289546
127	0.290152
128	0.290649
129	0.291111
130	0.291267
131	0.291339
132	0.291257
133	0.291463
134	0.29146
135	0.291767
136	0.291852
137	0.291956
138	0.29196
139	0.292081
140	0.292296
141	0.29265

CR	CDP
142	0.293022
143	0.293672
144	0.294124
145	0.294463
146	0.294896
147	0.295383
148	0.295791
149	0.29612
150	0.296197
151	0.296555
152	0.296864
153	0.297104
154	0.297552
155	0.298213
156	0.298675
157	0.299161
158	0.29938
159	0.299493
160	0.299503
161	0.299359
162	0.299316
163	0.299443
164	0.299229
165	0.298843
166	0.298589
167	0.298598
168	0.298762
169	0.299003
170	0.299245
171	0.299272
172	0.299544
173	0.299836
174	0.299905
175	0.299852
176	0.299831
177	0.299964
178	0.300207
179	0.300402
180	0.300629
181	0.300692
182	0.300966
183	0.301247
184	0.301547
185	0.301953
186	0.302146
187	0.302177
188	0.302148
189	0.30224
190	0.302109
191	0.302258
192	0.302297

CR	CDP
193	0.302482
194	0.302454
195	0.302424
196	0.302394
197	0.302591
198	0.302883
199	0.303019
200	0.30334

Table B.4: Intermediate_File.txt (Indoor\Dynamic\2D\wBS\CR_200\ experiment no. 1)

Cell #	call type	BW	Free_bw
….	….	….	….
4	New Call	Max: 60	150
2	Hand off	Max: 60	110
4	Hand off	Max: 60	90
3	New Call	Ave: 30	10
1	New Call	Ave: 30	20
3	Hand off	Min: 10	0
2	Hand off	Max: 60	50
2	Hand off	Ave: 30	20
4	New Call	Max: 60	90
4	New Call	Max: 60	30
5	Hand off	Max: 60	130
2	Hand off	Ave: 30	0
1	Hand off	Min: 10	10
3	New Call	Bor 10	0
2	New Call	Bor 10	0
1	Hand off	Min: 10	10
1	New Call	Min: 10	0
3	New Call	Min: 10	10
2	New Call	Bor 10	0
1	Hand off	Bor 10	0
2	New Call	Max: 60	60
5	New Call	Max: 60	70
3	Hand off	Min: 10	0
2	New Call	Max: 60	30
4	New Call	Max: 60	30
1	Hand off	Bor 10	0
5	Hand off	Max: 60	70
2	New Call	Max: 60	30
5	New Call	Max: 60	10
2	Hand off	Ave: 30	0
5	New Call	Min: 10	0
1	New Call	Max: 60	0
4	New Call	Max: 60	90
1	New Call	Min: 10	0
5	New Call	Bor 10	0
6	Hand off	Max: 60	140
2	New Call	Max: 60	0
2	Hand off	Bor 10	0

Cell #	call type	BW	Free_bw
4	Hand off	Max: 60	90
5	New Call	Bor 10	0
4	New Call	Max: 60	30
2	Hand off	Max: 60	0
1	New Call	Ave: 30	10
1	Hand off	Min: 10	0
1	Hand off	Bor 10	0
2	New Call	Bor 10	0
5	New Call	Min: 10	0
3	Hand off	Max: 60	10
1	Hand off	Min: 10	0
5	Hand off	Bor 10	0
1	New Call	Ave: 30	20
4	Hand off	Max: 60	30
6	Hand off	Max: 60	100
3	New Call	Ave: 30	10
3	Hand off	Min: 10	0
5	Hand off	Bor 10	0
4	Hand off	Ave: 30	0
6	New Call	Max: 60	40
3	Hand off	Bor 10	0
2	Hand off	Min: 10	0
2	Hand off	Bor 10	0
3	New Call	Bor 10	0
1	New Call	Max: 60	90
1	Hand off	Max: 60	30
2	Hand off	Max: 60	40
6	Hand off	Max: 60	40
4	Hand off	Max: 60	120
1	Hand off	Ave: 30	0
6	New Call	Max: 60	40
6	New Call	Ave: 30	10
6	Hand off	Min: 10	0
3	Hand off	Max: 60	0
1	New Call	Ave: 30	0
1	New Call	Bor 10	0
5	Hand off	Bor 10	0
4	New Call	Max: 60	240
5	Hand off	Bor 10	0
6	Hand off	Max: 60	0
1	New Call	Bor 10	0
1	New Call	Bor 10	0
1	Hand off	Bor 10	0
1	New Call	Min: 10	10
3	New Call	Min: 10	0
1	Hand off	Min: 10	0
6	New Call	Max: 60	10
4	New Call	Max: 60	300
2	Hand off	Max: 60	60
1	New Call	Max: 60	70
2	New Call	Max: 60	0

Cell #	call type	BW	Free_bw
1	Hand off	Max: 60	10
3	New Call	Min: 10	0
1	New Call	Min: 10	10
2	New Call	Bor 10	0
6	New Call	Min: 10	0
2	Hand off	Min: 10	0
6	Hand off	Bor 10	0
1	New Call	Min: 10	0
4	New Call	Max: 60	420
4	Hand off	Max: 60	360
2	New Call	Max: 60	110
3	Hand off	Max: 60	10
6	Hand off	Min: 10	0
3	Hand off	Min: 10	0
4	New Call	Max: 60	360
6	New Call	Ave: 30	20
6	Hand off	Min: 10	10
4	New Call	Max: 60	300
6	Hand off	Min: 10	0
3	New Call	Max: 60	0
2	New Call	Max: 60	140
3	Hand off	Bor 10	0
1	Hand off	Ave: 30	0
6	Hand off	Max: 60	0
2	New Call	Max: 60	150
4	New Call	Max: 60	300
6	Hand off	Bor 10	0
6	Hand off	Bor 10	0
3	Hand off	Max: 60	60
3	New Call	Max: 60	0
1	New Call	Max: 60	90
4	New Call	Max: 60	240
4	Hand off	Max: 60	180
3	New Call	Bor 10	0
3	New Call	Bor 10	0
2	Hand off	Max: 60	90
3	Hand off	Bor 10	0
4	New Call	Max: 60	240
4	New Call	Max: 60	180
1	New Call	Max: 60	90
1	Hand off	Max: 60	30
3	Hand off	Bor 10	0
6	New Call	Max: 60	10
4	New Call	Max: 60	120
4	Hand off	Max: 60	60
4	Hand off	Max: 60	0
3	New Call	Ave: 30	20
4	New Call	Bor 10	0
1	Hand off	Max: 60	60
2	Hand off	Max: 60	150
5	Hand off	Max: 60	10

Cell #	call type	BW	Free_bw
6	New Call	Min: 10	0
1	New Call	Max: 60	0
4	Hand off	Ave: 30	20
6	New Call	Bor 10	0
3	New Call	Ave: 30	20
2	New Call	Max: 60	150
6	Hand off	Bor 10	0
1	Hand off	Bor 10	0
3	New Call	Min: 10	10
5	Hand off	Min: 10	0
2	Hand off	Max: 60	90
6	New Call	Ave: 30	10
2	New Call	Max: 60	30
1	New Call	Max: 60	60
4	Hand off	Max: 60	260
4	Hand off	Max: 60	200
3	Hand off	Max: 60	20
6	New Call	Min: 10	0
2	Hand off	Ave: 30	0
3	Hand off	Ave: 30	20
4	New Call	Max: 60	200
1	New Call	Max: 60	10
4	New Call	Max: 60	140
1	Hand off	Min: 10	0
5	Hand off	Bor 10	0
2	New Call	Bor 10	0
1	New Call	Bor 10	0
3	Hand off	Ave: 30	0
2	Hand off	Bor 10	0
1	New Call	Ave: 30	20
1	Hand off	Min: 10	10
3	New Call	Ave: 30	10
5	New Call	Bor 10	0
3	Hand off	Min: 10	0
2	Hand off	Max: 60	60
4	New Call	Max: 60	260
4	New Call	Max: 60	200
5	Hand off	Ave: 30	10
6	Hand off	Max: 60	0
2	New Call	Max: 60	50
4	New Call	Max: 60	140
3	Hand off	Max: 60	0
1	Hand off	Max: 60	80
2	Hand off	Max: 60	50
5	New Call	Ave: 30	20
3	New Call	Min: 10	0
1	Hand off	Max: 60	30
2	Hand off	Ave: 30	20
6	New Call	Max: 60	0
4	New Call	Max: 60	200
2	Hand off	Max: 60	10

Cell #	call type	BW	Free_bw
6	Hand off	Bor 10	0
5	Hand off	Min: 10	10
5	New Call	Min: 10	0
4	New Call	Max: 60	320
2	Hand off	Min: 10	10
6	Hand off	Bor 10	0
4	New Call	Max: 60	260
3	New Call	Min: 10	0
1	Hand off	Max: 60	10
3	New Call	Min: 10	10
2	New Call	Min: 10	0
1	Hand off	Min: 10	0
6	Hand off	Min: 10	0
1	Hand off	Bor 10	0
2	New Call	Min: 10	0
4	New Call	Max: 60	320
1	Hand off	Bor 10	0
2	New Call	Ave: 30	0
5	Hand off	Ave: 30	10
3	New Call	Min: 10	10
6	Hand off	Max: 60	0
1	New Call	Ave: 30	10
3	New Call	Min: 10	0
4	Hand off	Max: 60	320
4	Hand off	Max: 60	260
4	New Call	Max: 60	320
3	Hand off	Ave: 30	10
6	New Call	Max: 60	60
5	Hand off	Min: 10	0
3	Hand off	Min: 10	0
1	New Call	Max: 60	70
6	Hand off	Max: 60	0
2	Hand off	Max: 60	0
2	Hand off	Bor 10	0
2	New Call	Min: 10	0
4	New Call	Max: 60	260
4	Hand off	Max: 60	200
1	New Call	Max: 60	10
6	New Call	Bor 10	0
2	New Call	Bor 10	0
3	Hand off	Min: 10	10
2	Hand off	Bor 10	0
3	New Call	Min: 10	10
6	New Call	Max: 60	0
1	New Call	Ave: 30	10
2	Hand off	Max: 60	30
5	Hand off	Ave: 30	20
4	New Call	Max: 60	240
6	New Call	Bor 10	0
3	New Call	Ave: 30	0
3	New Call	Ave: 30	0

Cell #	call type	BW	Free_bw
4	Hand off	Max: 60	180
1	New Call	Max: 60	10
4	Hand off	Max: 60	190
2	Hand off	Ave: 30	10
5	New Call	Max: 60	70
....	....	....	....

Table B.5: Tracing_File.txt (Indoor\Dynamic\2D\wBS\CR_200\ experiment no. 1)

Cell #	call type	Used BW	Free_bw
5	New Call	60	3940
1	New Call	60	3940
4	Hand off	60	3940
1	New Call	120	3880
2	New Call	60	3940
2	Hand off	120	3880
2	Hand off	180	3820
1	New Call *T*	60	3940
4	Hand off *T*	0	4000
2	New Call	240	3760
1	Hand off	120	3880
2	Hand off *T*	180	3820
3	New Call	60	3940
6	New Call	60	3940
6	Hand off	120	3880
6	New Call *T*	60	3940
6	New Call *T*	60	3940
1	New Call	180	3820
4	New Call	60	3940
5	Hand off	120	3880
3	Hand off	120	3880
5	Hand off	180	3820
4	New Call *T*	0	4000
1	Hand off *T*	120	3880
1	Hand off	120	3880
6	New Call	120	3880
3	Hand off *T*	60	3940
5	Hand off *T*	120	3880
5	Hand off	180	3820
4	New Call	120	3880
5	Hand off	240	3760
4	New Call *T*	120	3880
3	New Call *T*	180	3820
5	Hand off *T*	180	3820
5	Hand off	240	3760
2	Hand off	360	3640
6	New Call *T*	120	3880
3	Hand off *T*	180	3820
1	New Call	180	3820
5	Hand off	300	3700
1	New Call *T*	120	3880

Cell #	call type	Used BW	Free_bw
4	Hand off *T*	60	3940
3	New Call	240	3760
2	Hand off	420	3580
5	Hand off	360	3640
1	Hand off	180	3820
1	Hand off *T*	120	3880
3	New Call	300	3700
....	....	....	....

مخطط لتوفير سعة نطاق الشبكة في شبكات المجسات اللاسلكية عنقودية التركيب

إعداد
منال عبد الجبار أحمد مزهر

المشرف
الدكتور صالح حسني الشرايعة

ملخص

إن الاحتياط المتوافر لسعة نطاق الشبكة قليل و ثمين في شبكات المجسات اللاسلكية، هذه القلة تنتج عن أن شبكات المجسات اللاسلكية تخضع للمقياس 802.15.4 الذي يتصف بالآتي: معدل منخفض لنقل البيانات، ومعدل منخفض في صرف الطاقة، و قلة التكلفة، و بهذا فإن إدارة هذه القلة في سعة نطاق الشبكة تعد من التحديات الرئيسة في بيئة شبكات المجسات اللاسلكية.

كما أن تحقيق استغلال أعلى لسعة نطاق الشبكة سوف يرفع نوعية الخدمة المقدمة التي تستطيع أن تضمنها الشبكة، و لكن دون إغفال أهمية أن يتزامن الاستغلال الأعلى لسعة النطاق مع تقليل نسب احتماليات منع و إسقاط الاتصال.

ويجدر بالذكر أن معظم الدراسات السابقة اهتمت بموضوع نوعية الخدمة في شبكات المجسات اللاسلكية من ناحية ندرة الطاقة، من ناحية أخرى، دراستنا تهتم بتحقيق أعلى نوعية خدمة من ناحية جدولة سعة نطاق الشبكة سواء كانت شبكة المجسات اللاسلكية ذات بعد ثنائي أو ثلاثي، كذلك فإن مخططنا يدرس أثر وجود البقعة العمياء أو عدم وجودها في هوائي القاعدة الأساسية. و هكذا، فقد قمنا بإدخال مصطلحات و وحدات قياس متعددة في مجال شبكات المجسات اللاسلكية، مثل: الانتقال من قاعدة أساسية لأخرى، و تقنية الاستعارة الثابتة، و تقنية الاستعارة الفعالة، و احتمالية منع الاتصال، و احتمالية اسقاط الاتصال.

كذلك قمنا بفحص شبكة المجسات اللاسلكية تحت ست عشرة حالة دراسية مختلفة، و هذه الحالات تشمل: تركيبة البعد الثنائي، و تركيبة البعد الثلاثي، و الشبكة الموجودة في حيز داخلي، و الشبكة الموجودة في حيز خارجي، و وجود البقعة العمياء، و أخيرا عدم وجود البقع العمياء.

و بذلك فإن النتائج تظهر أن تقنية الاستعارة الفعالة تفوقت على تقنية الاستعارة الثابتة بمعدل 7% حتى عند الأخذ بعين الاعتبار وجود البقعة العمياء. كذلك أثبتت نتائج المحاكاة أن الشبكة ثلاثية البعد أقل استغلالا لنطاق الشبكة بمعدل 1.3% من الشبكة ثنائية البعد. كما أن الشبكات الموجودة في حيز خارجي تحقق استغلالا أفضل لسعة نطاق الشبكة بمعدل 0.2% من الشبكات الداخلية، كذلك اعتبار البقعة العمياء سوف يقلل استغلال سعة النطاق بمعدل 1.2%. كذلك فإنه عند امتلاك الشبكة لمعدل اتصال مرتفع و يساوي 200 اتصال هذا سوف يزيد من استغلال نطاق الشبكة بمعدل 2.7 % مقارنة مع امتلاكها لمعدل اتصال يساوي 50.

من جانب آخر، نسب احتماليات المنع والاسقاط تختلف بوقوعها تحت حالات مختلفة للشبكة، مثلا: تقنية الاستعارة الفعالة حققت أقل من 6% و 5.8 % في نسب احتماليات منع الاتصال واسقاطه على التوالي مقارنة مع تقنية الاستعارة الثابتة، بينما الشبكة ثلاثية البعد حققت أقل من 4.9% في المعدل بنسبة احتمالية منع الاتصال وأقل من 5.7% في المعدل بنسبة احتمالية اسقاط الاتصال مقارنة مع الشبكة ثنائية البعد. أما الشبكات الخارجية قللت احتمالية منع الاتصال بمعدل 1.29% و بمعدل 3.7% عند استخدام تقنيتي الاستعارة الثابتة والفعالة على التوالي، كما قللت أيضا من احتمالية اسقاط الاتصال بمعدل 0.2% للتقنية الثابتة و بمعدل 2.99% للتقنية الفعالة مقارنة مع الشبكات الداخلية، كذلك نتائج المحاكاة أظهرت أن اهمال وجود البقعة العمياء سوف يقلل من احتمالية منع الاتصال بمعدل 0.85% و بمعدل 9.99% عند استخدام تقنيتي الاستعارة الثابتة والفعالة على التوالي و يقلل أيضا من احتمالية اسقاط الاتصال بمعدل 0.23% للتقنية الثابتة و 3.25% للتقنية الفعالة. و كما هو متوقع فإن الشبكة ذات معدل الاتصال المساوي ل 50 اتصال هي أفضل بالمعدل ب 6.36% في تقليل احتمالية منع الاتصال و أفضل بالمعدل ب 5.7% في تقليل احتمالية اسقاط الاتصال مقارنة مع الشبكة ذات معدل اتصال مساوي ل 200 اتصال.

نتيجة لذلك يمكننا اعتبار أن شبكة ذات تقنية استعارة فعالة ومعدل اتصال لا يزيد عن 50 اتصال سوف تحقق أعلى وأفضل ضمان لنوعية الخدمة، كذلك يمكننا أن نخلص إلى أن الشبكة ثلاثية البعد تتفوق على الشبكة ثنائية البعد بشكل عام، و أخيرا، عدم اعتبار البقعة العمياء و بناء الشبكة في حيز خارجي سوف يحقق نوعية خدمة أعلى بشكل عام.