Development and Performance Analysis of a Probabilistic Flooding Algorithm in Noisy Mobile Ad Hoc Networks

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Abbreviations

ADR	Average Duplicate Reception.
AODV	Ad-Hoc On Demand Distance Vector.
D	Destination Node.
DSDV	Destination Sequential Distance Vector.
DSR	Dynamic Source Routing.
GPS	Global Positioning System.
IEEE	Institute of Electrical and Electronics Engineers.
IETF	Internet Engineering Task Force.
LAR	Location Aided Routing.
MANET	Mobile Ad-hoc Network.
PDF	Probability Distribution Function.
PDU	Protocol Data Unit
RCH	Reachability.
RERR	Route Error.
RET	Number of Retransmission.
RREP	Route Reply.
RREQ	Route Request.
RTS/CTS	Request To Send/Clear To Send.
S	Source Node.
TTL	Time To Live.
WLAN	Wireless Local Area Network
WAP	Wireless Access Point.
ZRP	Zone Routing Protocol.

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Abstract

Many research studies have been carried out to analyze the performance of the probabilistic flooding optimization algorithm in a noise free environment, but in reality communication channels are unreliable due to many types of impairments, such as: signal attenuation, free space loss, noise, atmospheric absorption, etc. All of these impairments may cause an error in reception and are represented by a generic name, noise. In addition, in MANETs, error in reception may occur due to rapidly changing topologies that are caused by nodes movement.

The main objective of this work is to develop an algorithm that can be used to investigate the effect of the noise level on the performance of the probabilistic flooding optimization algorithm that is widely used for route discovery in a number of dynamic routing protocols for MANETs (e.g., DSR, AODV, ZPR, etc.).

The noisy environment is described by introducing a probability distribution function, namely, the probability of reception function or simply the probability of reception (p_c), which means that a wireless signal survives of being lost, and the carried data is successfully delivered to destination. The probability of reception could be a constant value or a function of certain distribution.

In order to evaluate the performance of the new algorithm, a number of scenarios are simulated using a locally developed simulator. In these simulations, the researcher investigates the effect of a number of network parameters (e.g., node density (n_d), node average speed (u), radio transmission range (R), and retransmission probability (p_t), reception probability (p_t)) on some computed parameters (e.g., number of retransmission (RET), average duplicate reception (ADR), and reachability (RCH)).

The results obtained show that the computed parameters (RET, ADR, and RCH) are decreasing as p_c decreases, i.e., the noise level increases. The reduction in RET and ADR is considered as an advantage while the reduction in RCH is a drawback. The results obtained are discussed and presented in tables and graphs. Finally, conclusions are drawn and recommendations for future works are pointed out.

تطوير وتحليل أداء لوغارثمية الفيضان الاحتمالي في الشبكات اللاسلكية المبعثرة شديدة الضجيج

اعداد

يوسف محمد جرادات

اشراف

الدكتور حسين البهادلي

الملخص

Arabic Summary

البث ألفيضاني هو خاصية فعالة لآلية بث البيانات في الشبكات اللاسلكية المبعثرة المتحركة، حيث يتميز بميزات ايجابية متعددة، إلا انه له تأثير سلبي يؤثر على فعالية وكفاءة الشبكات، يعرف هدا التأثير باسم مشكلة البث العاصف (Broadcast Storm Problem). طريقة الفيضان الاحتمالي (Probabilistic Flooding) تستخدم بشكل واسع لحل هذه المشكلة.

قامت عدة دراسات بحثية بتحليل أداء الفيضان الاحتمالي في بيئة خالية من الضجيج (Noise)، لكن في الواقع فان قنوات الاتصال لا يمكن الوثوق بها بسبب عدة أنواع من الأخطاء وحالات الضعف التي تحدث فيها مثل ضعف الإشارة، فقدانها، أو امتصاصها، الخ. هذه الأخطاء وحالات الضعف (Impairments) تؤدي الى خطأ في استقبال الإشارة، حيث يعبر عن هذه الأخطاء باسم عام و هو الضجيج، كما تسمى البيئة بالبيئة شديدة الضجيج.

هدف الرسالة هو تطوير طريقة لبحث تأثير الضجيج على أداء الفيضان الاحتمالي في عملية كشف المسار والتي تستخدم في البروتوكولات الديناميكية في الشبكات اللاسلكية المبعثرة. البيئة شديدة الضجيج يعبر عنها باستخدام اقتران توزيع احتمالي، والذي يعني أن الإشارة تصل الى المستقبل ولا تضيع، وهذا الاقتران إما يكون ثابت أو اقتران بتوزيع معين.

من أجل حساب وتقدير أداء الطريقة الجديدة قام الباحث بإجراء عدد من تجارب المحاكاة باستخدام برنامج محاكاة صمم خلال البحث في جامعة عمان العربية (MANSim). في هذه السلسلة من تجارب

المحاكاة قام الباحث بفحص والتحقق من تأثير عدد من العوامل والتي تضـمنت كثافة النقاط (Nodes Density، معدل سرعتها (Node Speed) ، واحتمالية إعادة البث (p_t) ، واحتمالية إسـتقبال البث (p_c) ، لمعرفة مـدى تـأثيرهـا على بعض العوامـل تحـت الـدراســة وهي عـامـل إعـادة البـث (Number of Retransmission-RET)، ومـعـدل الوصـــول المتكرر (Average Duplicate Reception-ADR) ، والوصولية (Reachability-RCH).

أظهرت النتائج أن العوامل تحت الدراسـة (RET, ADR, RCH) ، تنقص عند زيادة معدل الضـجيج في الشبكة، وبالطبع يعتبر الانخفاض في (RET, ADR) مسألة إيجابية، أما الانخفاض في (RCH) فهو مسألة سـلبية. إن النتائج التي تم اسـتخراجها قد تم مناقشـتها وعرضـها في جداول ورسـومات توضيحية، وأخيرا" فقد تم استخراج النتائج، ووضع التوصيات وبعض المقترحات المناسبة للعمل مستقبلا.

Chapter 1
Introduction

1.1. Wireless Networks

Wireless networks usually consist of a number of communication devices (e.g., computers, microprocessor-based devices, personal digital adapters (PDAs), mobile phones, or any digital devices with compatible communication capabilities) that are connected without using wires [1, 2, 3]. Instead they are utilizing radio waves to enable communication between devices in a limited coverage area. This allows communicated devices (also called nodes) to move around within the broad radio coverage area and still be connected to the network [4, 5].

Wireless networks that use the IEEE 802.11 wireless local area network (WLAN) protocol, can be configured to operate in two modes [6, 7]:

i. Infrastructure (Access Point) mode: In this mode nodes communicate with each other through a base station that works as a centralized controller, which is also referred to as access point (AP).
ii. Infrastructureless (Ad Hoc) mode: In this mode, nodes communicate with each other directly without relying on any infrastructure or centralized controller. Such networks are also referred to as ad hoc networks.

In the first configuration, a wireless access point (WAP), which is a device that connects wireless devices together to form a wireless network, is used as a centralized controller as shown in Figure (1.1). The WAP is usually connected to other wired networks to relay data between wired and wireless networks. Due to the nature of the radio links, nodes are allowed to be mobile within the WAP coverage area.

Several WAPs can be linked together to form a larger network, similar to cellular mobile phone networks [8, 9], that allow the exchange of data between devices connected to different base stations. As the node of one WAP travels into the range of another, a "hand off" occurs from the old WAP to the new one and the node is able to continue communication seamlessly throughout the network. Typical applications of this type of network include office WLANs [6, 10].

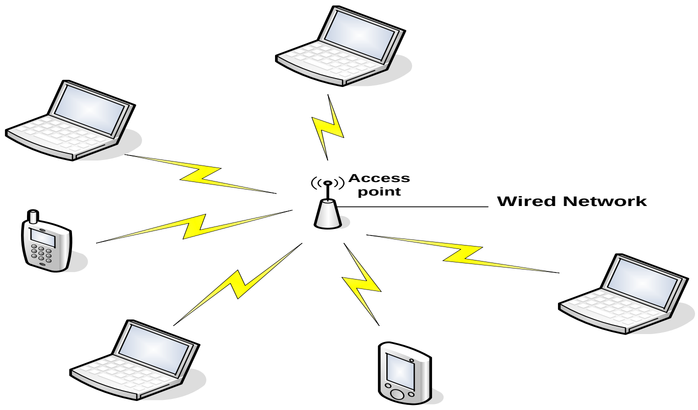


Figure (1.1) – An infrastructure (access point) network.

In contrast to the centralized control WAP networks, in the other type of wireless networks configuration, nodes manage themselves without the need for any WAP or centralized controller, therefore, they are called ad hoc wireless networks as shown in Figure (1.2). Once again, due to the nature of the radio links that connect nodes, nodes are allowed to move around, and therefore, such networks are also called mobile ad hoc networks (MANETs) [11].

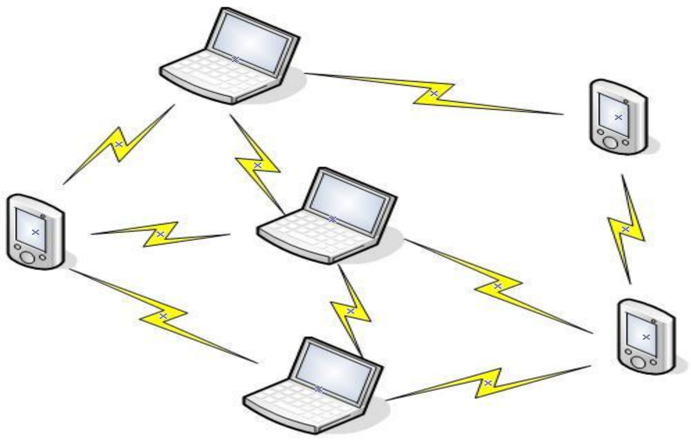


Figure (1.2) – An infrastructureless (Ad Hoc) networks.

However, in this thesis the researcher is concerned with the second wireless networks configuration, namely, the MANETs.

1.2. Mobile Ad Hoc Networks (MANETs)

Mobile Ad hoc Networks (MANETs) consist of a set of low-power, wireless, mobile nodes, which communicate with one another without relying on any pre-existing infrastructure or centralized control in the network, as shown in Figure (1.2) [1, 2].

In such environment, due to the limited radio transmission range of each mobile node, it may be necessary for one mobile node to enlist the aid of other nodes in forwarding data packets to their destination. Thus, each mobile node operates not only as a host but also as a router using a specific routing mechanism (routing protocol) to efficiently and reliably forward data packets for other mobile nodes within the network, which may not be within the transmission range of the source node [12].

A routing protocol is defined as the algorithms by which a route is created to enable source and destination nodes to exchange data efficiently, reliably and errors free [13]. The efficiency of the routing protocol can dramatically affect the performance of the entire network in terms of bandwidth utilization, delay, and battery power consumption. Therefore, the process of route establishment should be done with a minimum complexity, overhead, and power consumption [4, 14].

In MANET, nodes mobility results in a continuous change in network topology and thereafter routes connecting nodes within the network are continuously changed, as shown in Figure (1.3). This requires even more efficient routing algorithms for determining and maintaining new routes [15, 16].

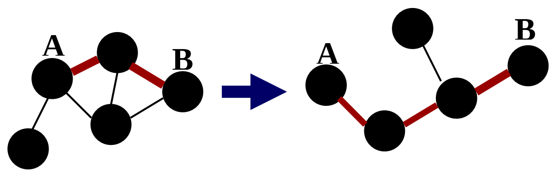


Figure (1.3) - Change in network topology.

1.3. MANETs Applications

MANETs have many advantages over infrastructure (access point) wireless networks and wired networks, such as [17, 18]:

1. Rapid and ease of deployment.
2. Improved flexibility.
3. Reduced costs.
4. No backbone infrastructure is needed
5. Self-configure networks (no centralized administration)
6. Useful when the infrastructure is absent, destroyed or impractical

However, since their emergence in the 1970s, in general, wireless networks have become increasingly popular and widely used in many civilian, military, industrial, environmental, and commercial applications. This is particularly true within the past decade when wireless networks were developed to enable node mobility [7].

MANETs are widely used, especially, in the absence of network infrastructure. Examples of such circumstances include: military tactical operations which are still the main application of MANETs today. For example, military units (e.g., soldiers, tanks, etc.) equipped with wireless communication devices could form a MANET to connect all units within the battlefield, and roam to connect other units outside the battlefield. Ship-to-ship mobile communication is also desirable since it provides alternate communication paths without reliance on ground-base or space-base communication infrastructure [13].

A MANETs can also be used for emergency services, law enforcement, and rescue missions. Since a MANETs can be deployed rapidly with relatively low cost, it becomes an attractive option for commercial and industrial uses such as environmental sensor networks, collecting data from measuring devices in factories, university campuses, classrooms, etc [1, 19].

1.4. Wireless LAN Requirements

A wireless local area network (WLAN) must meet the same sort of requirements typical of any LAN, including high capacity, ability to cover short distances, full connectivity among attached stations, and broadcast capability. In addition, there are a number of requirements specific to the WLAN environment. The following are among the most important requirements for WLANs [7]:

- Throughput: The medium access control (MAC) protocol should make as efficient use as possible of the wireless medium to maximize bandwidth capacity.

- Scalability: A WLAN may need to support expandable number of nodes across the network.

- Handoff and roaming: The MAC protocol used in the WLAN should enable mobile stations to move from one cell to another.

- Connection to backbone LAN: In most cases, interconnection with stations on a wired backbone local area network (LAN) is required. For infrastructure WLANs, this can be easily accomplished through the use of control modules that connect to both types of LANs. There is also a need to interconnect infrastructureless ad hoc networks with wired backbone LAN.

- Battery power consumption: Mobile users use battery-powered nodes that need to have a long battery life when used with wireless adapter. Typically, WLAN implementations have features to reduce power consumption while not using the network, such as a sleep mode.

- Transmission robustness and security: Unless properly designed, a WLAN may be interference prone and easily eavesdropped. The design of WLAN must permit reliable transmission even in a noisy environment and should provide some level of security from eavesdropping.

- Collocated network operation: As WLANs become more popular, it is quite likely for two or more WLANs to operate in the same area or in some area where interference between the LANs is possible. Such interference may thwart the normal operation of the network algorithms and may allow unauthorized access to a particular LAN.

- License-free operation: Users would prefer to buy and operate WLAN products without having to secure a license for the frequency band used by the LAN.

- Dynamic configuration: The network addressing and network management aspects of the LAN should permit dynamic and automated addition, deletion, and relocation of end systems without disruption to other users.

1.5. MANETs Challenges and Limitations

Development of efficient, reliable, flexible routing protocols is considered as one of the most important limitations and challenges that are facing the wide use of MANETs. Other main limitations and challenges that are facing MANETs include [1, 4, 14]:

i. Data loss due to transmission errors especially in noisy environment, variable capacity links, frequent disconnections, limited communication bandwidth and broadcast nature of the communications.

ii. Dynamically changing topologies/routes due to node mobility, and lack of mobility awareness by system/applications.

iii. Limited mobile battery lifetime due to relatively high power consumptions and limited battery capacities.

iv. Vulnerability to security attacks (e.g., passive eavesdropping over wireless channel, denial of service attacks by malicious nodes, and attacks from compromised entities or stolen devices).

1.6.Characteristics of MANETs

In this section, a brief introduction to the characteristics of MANETs is presented, in order to develop a solid background for the research.

i. Wireless links

Data packets are modulated on radio frequency (RF) at the sender side. Then, the radio signal is transmitted on the air. While the signal travels on the air, its strength decreases. Therefore, if the receiver is too far from the sender, or signal is blocked or abnormal absorption occurs, the signal may not reach or correctly interpreted at the receiver. At the receiver, the received signal is demodulated to recover the original data packet. Because only radio signal that is strong enough can be sensed and correctly interrupted at the receiver side, the nodes far from the sender cannot correctly receive the signal from the sender. Therefore, only nodes inside the communication range of the sender can correctly receive the packet from the sender.

The transmission range of each node is determined by the transmission power level. The transmission range is larger when higher transmission power is used. However, if a single channel is used for the entire network; higher transmission power may result in blockage of transmissions among other nodes in the neighborhood.

To reduce interference among transmissions, the use of directional antenna (one-to-one model) [20] has been proposed. Comparing with omni-directional antenna (one-to-all model), directional antenna can focus transmission energy along a specific direction. Directional antenna, however, has not been widely used yet. Therefore, the omni-directional antenna is considered in this thesis.

ii. Shared communication channel

The Media Access Control (MAC) sublayer, which forms the lower part of the data link layer (DLL) of the OSI model, thereafter it is referred to as MAC layer, adopts protocols that focus on efficiently using the shared channel among multiple nodes. IEEE 802.11 standard proposes MAC sublayer architecture that includes two coordination functions, these are:

a. Distributed Coordination Function (DCF) for infrastructureless networks

b. Point Coordination Function (PCF) for infrastructure networks.

A coordination function is a logical function that determines when a node is permitted to transmit and may be able to receive protocol data units (PDU) via the wireless medium. The challenges at the MAC sublayer are:

a. Hidden terminal problem.

b. Exposed terminal problem.

c. Distribution control problem.

As shown in Figure (1.4), when node **A** transmits data to node **B**, node **C** is not aware of the transmission due to the distance separating these two nodes. If node **C** transmits a packet to **B** simultaneously, a collision will occur at node **B**. This problem is called the hidden terminal problem.

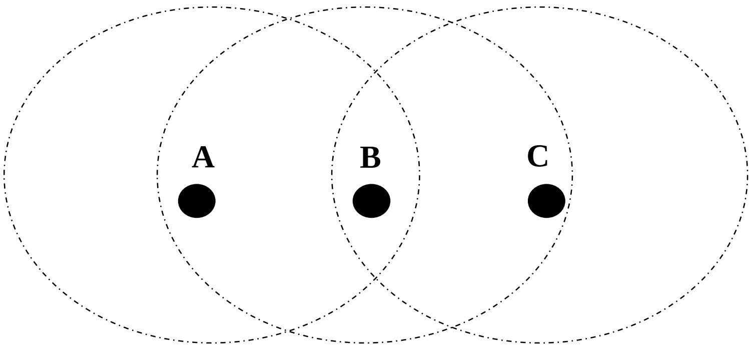


Figure (1.4) Hidden terminal problem in MANETs.

In Figure (1.5), when node **B** transmits data to node **A**, node **C** is blocked from sending data to node **D** since the channel at **C** is also receiving the signal from **B**. However, transmission from node **C** to node **D** does not actually collide with the **B-A** transmission. Therefore, the blockage is unnecessary. This problem is called the exposed terminal problem.

The WLAN protocol, namely, the IEEE 802.11 standard protocol is designed to solve these problems at the MAC sublayer and the physical layer. In a MANET, the IEEE 802.11 uses CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) protocol as its DCF. Before transmitting a packet, a node always senses the channel. It transmits the packet only after the channel is idle for a specific time interval.

In addition, using the RTS (Request to Send)/CTS (Clear to Send) hand-shaking scheme can avoid some collision problems, such as the hidden terminal problem, by using a handshaking notification process between the sender and the receiver. The MAC layer protocol should also treat each node equally, assigning each host similar chance to access the channel.

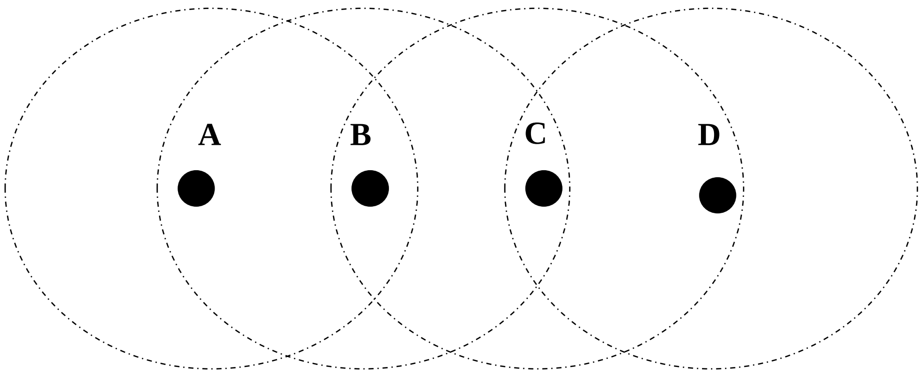


Figure (1.5) - Exposed terminal problem in MANETs.

iii. Dynamic network topology

Nodes in a MANET are free to move randomly. This feature makes the network topology changes often. Even though the network topology varies, connectivity in the network should be maintained to allow applications and services to operate without disruption. In particular, this characteristic will affect the design of routing protocols. In addition, a network user will require access to a fixed network, such as the internet, even if nodes are mobile. This needs mobility management functions allowing network access for devices located several radio hops away from the source [10].

v. Efficiency, scalability, and Quality of Service (QoS) in MANETs

Because of the bandwidth and battery life limitation, it's preferred to use as lower energy as possible to transmit packets from source to destination. Energy consumption is measured for path setup and maintenance, as well as the consumption for packet transmission along the path. The latter is based on the number of hops along the path (path length). Route discovery and maintenance is the key concern for efficiency. For scalability, the sustainable size of the network should be considered. As the number of node increases, both transmission and computation costs increase. Therefore, an efficient routing protocol that can deal with large number of nodes is needed. Qos is needed to support application, such as, multimedia applications, in an environment prone to link breakage, frequent disconnections and reconnections, multiple path, collisions and contentions.

iv. Decentralized network control

The decentralized nature of network control in MANETs supports extra robustness against the single points of failure of more centralized approaches [15, 21].

vi. Limited physical security

Mobile wireless networks are generally more prone to physical security threats than are fixed cable nets. The increased possibility of eavesdropping, spoofing, and denial-of-service (DoS) attacks should be carefully considered. Existing link security techniques are often applied within wireless networks to reduce security threats. As a benefit, the decentralized nature of network control in MANETs provides additional robustness against the single points of failure of more centralized approaches.

1.7. Wireless Routing protocols

A routing protocol is a part of the network layer software that is responsible for deciding which output path a packet should be transmitted on. Many routing protocols have been proposed for MANETs. These algorithms differ in the approach used for searching a new route and/or modifying a known route, when nodes move. The major challenges that face a routing protocol for MANETs are mobility, bandwidth constraint, resource constraints, error-prone and shared channel. Various approaches are proposed to solve these various challenges [22, 23, 24, 25, 26, 27].

Thus, there is a large number of routing algorithms that have been developed for MANETs. Each of them has its own unique characteristic strengths and weaknesses. A detailed description of all these protocols is beyond the scope of this thesis. However, the researcher describes protocols that are relevant to this work. Different algorithms may have benefits in different topologies, motion scenarios, and different application scales. For example, one protocol may work very well for 10 nodes in a small area but may work imperfectly (cause excessive delay or fail to deliver or drop most packets) for 1000 nodes in a large area or in certain mobility conditions [16, 28].

As it has been mentioned earlier, in MANETs, each node must act as a router since routes are mostly multi-hop [16]. If only two nodes, located closely together, are involved in the network, no real routing protocol or routing decisions are necessary. Practically, two nodes that want to communicate may not be within wireless transmission range of each other [29], but still they could communicate if other nodes between them are willing to forward packets for them.

For example, in the network illustrated in Figure (1.6), mobile node C is not within the range of node A's wireless transmitter (indicated by the circle around A) and node A is not within the range of node C's wireless transmitter. If A and C wish to exchange packets, they may in this case enlist the services of node B to forward packets for them, since B is within the overlap between A's range and C's range. Indeed, the routing problem may be more complicated than this simple example suggests, due to the possibility that any or all of the nodes involved may move at any time [12, 29].

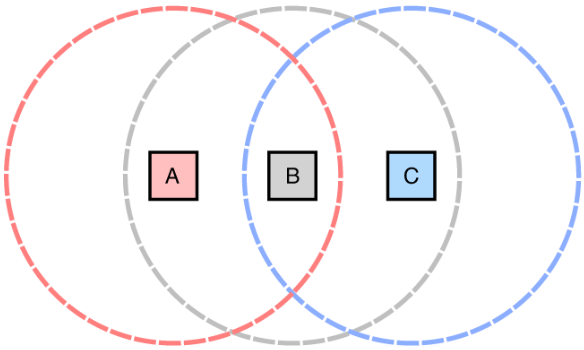


Figure (1.6) - Nodes radio transmission range.

1.7.1 Requirements of MANETs routing protocols

The design of network protocols for MANETs is a complex issue. These networks need efficient distributed algorithms to determine network organization (connectivity), link scheduling, and routing. An efficient approach is to consider routing algorithms in which network connectivity is determined in the process of establishing routes. The major requirements of a routing protocol in MANETs can be summarized as follows [30]:

1. Minimum route acquisition delay.
2. Quick route reconfiguration.
3. Loop-free routing.
4. Distributed routing approach.
5. Minimum control overhead.
6. Scalability.
7. Provisioning of quality of service (QoS).
8. Support for time-sensitive traffic.
9. Minimum energy consumption.
10. Security and privacy.

Following is a brief description for each of them:

1. **Minimum route acquisition delay:** The route acquisition delay for a node that does not have a route to a particular destination node should be as minimal as possible. This delay may be varying with the size of the network and the network load.

2. **Quick route reconfiguration:** The unpredictable changes in the topology of the network require that the routing protocol be able to quickly perform route reconfiguration in order to handle path breaks and subsequent packet losses.

3. **Loop-free routing:** This is a fundamental requirement of any routing protocol to avoid unnecessary wastage of network bandwidth. In MANETs, due to the random movement of nodes, transient routing loops may form in the route. A routing protocol should detect such transient routing loops and take corrective actions.

4. **Distributed routing approach:** MANET is a fully distributed wireless network and the use of centralized routing approaches in such a network may consume a large amount of bandwidth.

5. **Minimum control overhead:** The control packets exchanged for finding a new route and maintaining existing routes should be kept as minimal as possible. The control packets consume precious bandwidth and can cause collisions with data packets, thereby reducing network throughput.

6. **Scalability:** Scalability is the ability of the routing protocol to perform efficiently in a network with a large number of nodes. This requires minimization of control overhead and adaptation of the routing protocol to the network size.

7. **Provisioning of quality of service (QoS):** The routing protocol should be able to provide a certain level of QoS as demanded by the nodes or the category of calls. The QoS parameters can be bandwidth, delay, jitter, and packet delivery ratio. Supporting differentiated classes of service may be of importance in tactical operations.

8. **Support for time-sensitive traffic:** Tactical communications and similar applications require support for time-sensitive traffic. The routing protocol should be able to provide support for time-sensitive traffic.

9. **Minimum energy consumption:** This aims to maximize the system lifetime of MANET.

10. **Security and privacy:** The routing protocol in MANETs must be resilient to threats and vulnerabilities. It must have inbuilt capability to avoid resource consumption, denial-of-service (DoS), impersonation and similar attacks possible against an MANET.

1.7.2 Classification of routing protocols

Routing protocols can be classified into different categories according to their properties and applications. Classification of routing protocols into different categories is an important issue that needs to be carefully considered, since it helps researchers to understand distinctive characteristics of a routing protocol and find its fundamental relationship with each others.

There are different approaches that can be used in classifying MANET routing protocols, which are based on diverse criteria and from specific perspectives. However, routing protocols can be broadly classified into four categories [13]:

i. Routing information update mechanism.
ii. Temporal information.
iii. Topology information.
iv. Specific resources utilization.

The most widely used mechanism is that based on routing information update mechanism**.** Based on the routing information update mechanism, MANETs routing protocols can be classified into three major categories these are [27]:

i. Proactive or table-driven routing protocols.
ii. Reactive or on-demand routing protocols.
iii. Hybrid routing protocols.

i. Proactive or table-driven routing protocols

In table-driven routing protocols, every node maintains the network topology information in the form of routing tables, by periodically exchanging routing information that is usually flooded in the whole network. Some of the popular proactive routing protocols are:

- Destination-Sequenced Distance-Vector Routing (DSDV) [31].
- The Wireless Routing Protocol (WRP) [17].
- Global State Routing (GSR) [32]
- Fisheye State Routing (FSR) [33].
- Hierarchical State Routing (HSR) [33].
- Zone-Based Hierarchical Link State Routing (ZHSL) [34].
- Cluster Head Gateway Switch Routing Protocol (CGSR) [35].

ii. Reactive or on-demand routing protocols

Protocols that fall under this category do not maintain the network topology information. They obtain the necessary path when it is required, by using a connection establishment process. Hence these protocols do not exchange routing information periodically [40]. In fact, when a source wants to communicate with a particular destination, it invokes the route discovery mechanisms to find the path to the destination. The route remains valid till the destination is reachable or until the route is no longer needed. Some of the popular reactive routing protocols are:

- Ad Hoc On-Demand Distance Vector (AODV) Routing [18, 27].
- Dynamic Source Routing (DSR) [36, 37].
- Associated-Based Routing (ABR) [38, 39].
- Signal Stability Routing (SSR) [22].
- Cluster-Based Routing Protocol (CBRP) [23]
- Temporally Ordered Routing Algorithm (TORA) [26].

- Location-Aided Routing (LAR) [14, 40, 41, 42, 43].

iii. Hybrid routing protocols

Protocols belonging to this category combine the best features of the above two categories in a unique and meaningful way. In this category, nodes within a certain distance from a specific node or within a particular geographical region are said to be within the routing zone of the given node. For routing within this zone a table driven approach is used. For nodes that are located beyond this zone, an on-demand approach is used [13].

An example of a hybrid routing protocol is the Zone Routing Protocol (ZRP) [44, 45]. It uses the proactive approach with intra-zone routing (it maintain routes to all nodes within the source node's own zone). Then, it uses the reactive approach with inter-zone routing to determine routes to nodes outside the zone [4].

In this work the researcher will focus on the reactive category of the routing protocols where the optimization protocols belong.

1.7.3 On-demand routing protocols phases

A different approach from the table-driven routing is a source-initiated on-demand routing, or simply known as on-demand routing. This type of routing creates routes only when desired by the source node. When a node requires a route to a destination, and it does not have a valid route, then it initiates a route discovery process within the network. This process is completed once a route is found or all possible route permutations have been examined. Once a route has been established, some form of route maintenance procedure maintains it, either until the destination becomes inaccessible along every path from the source or until the route is no longer desired [13, 46].

Reactive or on-demand routing protocols normally consist of two main phases, these are:

- Route discovery
- Route maintenance.

In the route discovery phase, when a source node desires to send a message to some destination node and does not already have a valid route to that destination, it initiates a route discovery process to locate the other node. It broadcasts a route request (RREQ) packet to its neighbors, which then forward the request to their neighbors, and so on, until either the destination itself or a node that have a fresh route to the destination is located which then responds with a route reply (RREP) packet back to the node from which it first received the RREQ.

Route maintenance is the process of maintaining the existing route from initiating source node to the target destination node, against link failure due to dynamic network topology, or noise factors or both. The process is done using the route error (RERR) packets to inform the source node of the link failure, more details will be introduced in chapter three.

Flooding broadcast mechanism is typically used for route discovery in MANETs, especially in highly mobile networks. Due to the nature of the flooding broadcast mechanism, the time required to find the optimum route connecting two nodes (i.e., source and destination) is normally more than the time required for data packet transmission.

1.8. The Broadcasting Technique in MANETs

Network-wide broadcasting is used extensively in MANETs [11] for the process of route discovery, address resolution, and other network layer tasks. The dynamic nature of MANETs, however, requires the routing protocols to refresh the routing tables frequently, which could generate a large number of broadcast packets at different nodes. Since a node in a MANET cannot directly communicate with the nodes outside its communication range, a broadcast packet may have to be rebroadcast several times at intermediate nodes to do relaying in order to guarantee that the packet can reach all nodes as shown in Figure (1.7). Consequently, an inefficient broadcast approach may generate many redundant rebroadcast packets.

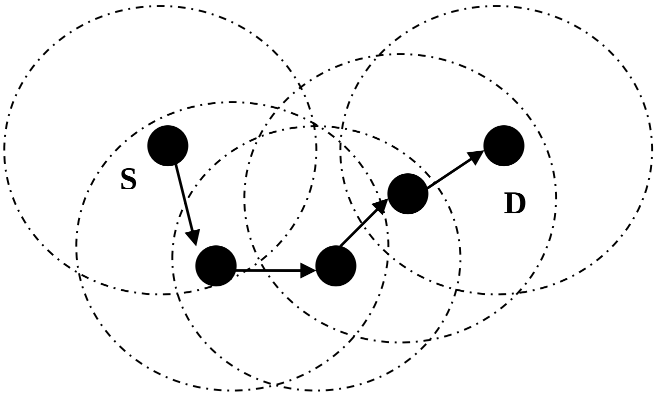


Figure (1.7) - Relaying (Multi-hopping) in MANETs.

The effectiveness of broadcasting is critical for the performance of MANET due to the following reasons [47]:

1. The wireless channel in a MANET is shared by neighboring nodes. Although CSMA/CA [IEEE 97] algorithm is generally effective for collision avoidance, the contention among the broadcast/rebroadcast nodes for the channel could substantially reduce the overall transmission rate.

2. Wireless bandwidth is typically lower than its wired counterpart. Therefore, a poor broadcast approach can result in extremely low available bandwidth for actual data traffic.

3. Nodes in MANETs are constrained resources; they are limited in their processing power, memory, battery capacity, and transmission range.

There are many schemes proposed for broadcasting in MANETs. The simplest one is flooding [4]. In this approach, each node rebroadcasts received broadcast packets if they have not been received before except for the source and destination nodes. Packets that have already been recorded are discarded.

Since every node rebroadcasts a packet for (and only for) the first-time it receives, it is easy to see that the total number of rebroadcasts is equal to n-2 [48], where n is the total number of nodes in the MANET. In most cases, however, many such rebroadcast packets are redundant and simply waste the channel bandwidth and the nodes power.

In addition, a straightforward implementation of flooding broadcast in wireless networks, using the IEEE 802.11 protocols, results in number of serious drawbacks, such as duplicate reception, contentions, and collisions. Because of the deficiency of this mechanism, the lack of RTS/CTS dialogue, and the absence of collision detection, collisions are more likely to occur and cause more damage [4, 14].

More sophisticated solutions including:

- Probabilistic (gossip-based) flooding [4, 49].
- Counter-based flooding [4].
- Distance-based flooding [4, 5].
- Location-based flooding [4, 5].
- Neighbor-knowledge-based flooding [5].

are proposed, to reduce flooding overhead by reducing the number of retransmission; thereafter, duplicate reception, contentions, and collisions in MANETs.

For the purpose of the research the researcher will focus on probabilistic algorithms for optimizing flooding in MANETs. Probabilistic algorithms are based on probability theory to minimize flooding overhead during route discovery in reactive routing. A node rebroadcasts packets according to a certain probability (p_t) and with probability (1 - p_t) it inhibits transmission. More details will be introduced in chapter three.

1.9. Noise in MANETs

In any communication system, the received signal will differ from the transmitted signal; for that, channels are lossy since the received power signal is less than the transmitted signal due to various transmission impairments. These impairments are due to many factors regarding the environment (buildings, mountains, hills, electrical equipments, etc), electronics circuits (transceiver' circuits), shared channel (fog, rain, lights, etc), and mobility. All of these impairments will try to inhibit the receiver from receiving a signal, detailed information is provided through chapter 3.

In MANETs, all of these factors are applied. For the purpose of this research all of these factors are represented by a generic name, Noise. The environment is called noisy environment, which is described by introducing a probability distribution function, namely, the probability of reception function (p_c). In this scheme, when a broadcast request is transmitted, a node received the request from its neighbors with a predetermined probability (p_c) and with probability ($1 - p_c$) the signal is discarded, because of the error in reception due to noise.

1.10. Statement of the Problem

Current flooding optimization algorithm are concerned with noise free environment, therefore the purpose of this study is to develop, analyze, and test a more realistic network environment, in which a new probabilistic factor is introduced, namely, the probability of reception (p_c).

In this scheme, when a broadcast request is transmitted, a node received the request from its neighbors with a predetermined reception probability (p_c) and with probability ($1 - p_c$) the signal is discarded, because of the error in reception due to noise.

The noise will be applied to a well-known flooding optimization scheme, which is the probabilistic scheme, and the effects of noise will be studied on a number of network computed parameters (reachability, average duplicate reception, and retransmission).

1.11 Organization of the Thesis

The rest of the thesis is organized as follows. Chapter 2 presents some of the previous works that are related to flooding optimization algorithms, in particular, works that are mainly concerned with probabilistic algorithm. It provides the development steps in this algorithm. In Chapter 3, a detailed description is given for how pure flooding mechanism, probabilistic algorithm, may be used for route discovery in MANETs. Chapter 4 describes our newly developed probabilistic flooding optimization algorithm in noisy environment. In this chapter, the methodology that is used in developing this algorithm, network model, mobility model, and the computational model, that are used in the network simulator MANSim, are presented. In addition, in chapter 4, definitions for a number of computed network parameters are given.

Chapter 5 presents simulation results, using MANSim, and performance analysis for the probabilistic scheme in noisy environment, for two types of networks conditions, namely, ideal and realistic network conditions. In these simulations, the researcher investigates the effect of a number of network parameters (e.g., node density, node average speed, retransmission probability, reception probability, etc.) on some computed parameters (e.g., number of retransmission, average duplicate reception, and reachability). In this chapter, the results obtained are discussed and presented in tables and graphs.

Finally, in Chapter 6, conclusions based on the results obtained from the different simulations, are drawn, and suggestions and recommendations for future work and further development are pointed out.

Chapter Two
Literature Review

2.1. Introduction

Flooding is a fundamental broadcast mechanism that has been used for route discovery in mobile ad hoc networks (MANETs) routing protocols. In flooding, every node in the network retransmits the route request (RREQ) packet (message) to its neighbors upon receiving it for the first time, and typically every node is allowed to retransmit the same RREQ packet only once. Although flooding is extremely simple and easy to implement, it can be very costly and may lead to a serious problem known as “broadcast storm problem”. This problem is characterized by redundant packet retransmissions, network bandwidth contention, and collision.

A number of mechanisms have been developed throughout the years to alleviate the flooding broadcast storm problem by inhibiting some nodes from rebroadcast to reduce the number of retransmission, contention, and collision. These mechanisms include: probabilistic schemes [1, 2, 3, 4, 5, 50, 51, 52, 53, 54, 55], location-based schemes [14, 19, 28, 40, 41, 42, 43, 44, 56], multipoint relaying schemes [48, 57], counter-based schemes [4, 14, 24], distance based schemes [4, 13, 27], cluster-based schemes [23, 25, 30, 58].

In the next section, the researcher presents some of the work that is related to the probabilistic flooding optimization algorithm. Reviews of other flooding optimization algorithms can be found in their related literatures.

2.2. Probabilistic algorithm

A. Al-Thaher [59] propose, evaluate, and compare the performance of a new flooding optimization algorithm, namely, the location-aided routing-probabilistic (LAR-1P) protocol.

The proposed algorithm utilizes two well-known flooding optimization algorithms, the location-aided routing scheme 1 (LAR-1), and the probabilistic algorithms. In this algorithm, when receiving a broadcast request message (i.e., RREQ message), a node within the requested zone rebroadcasts the request message with a pre-defined retransmission probability (p_t), and each node is allowed to rebroadcast the received request message only once. The results obtained show that the computed parameters (e.g., the number of retransmission (RET), average duplicate reception (ADR), and network reachability (RCH)) are decreasing as p_t is decreased.

M. Bani Yassein et al. [1] analyzed the performance of probabilistic flooding in a MANET environment using extensive ns-2 simulations. They investigated the effect of node speed, pause time, traffic load, and node density in a typical MANET. Their results reveal that most of these parameters have a critical impact on the reachability and the number of saved rebroadcast message achieved by probabilistic flooding. Their study highlights the great need for a new broadcasting strategy that can dynamically adjust the broadcast probability to take into account the current state of the node in two hops in order to ensure a certain level of control over rebroadcasting, and thus helps to improve reachability and saved rebroadcasts.

A. Jamal et al. [60] analyzed the performance of ad hoc on-demand distance vector (AODV) routing protocol over a range of possible forwarding probabilities (retransmission probabilities). Their studies focused on the route discovery part of the routing algorithm, they modified the AODV routing protocol implementation to incorporate the forwarding probability; the RREQ packets are forwarded in accordance with a predetermined forwarding probability. Results obtained have shown that setting efficient forwarding probability for AODV routing discovery has a significant effect on the general performance of the routing protocol. The results have also revealed that the optimal forwarding probability for efficient performance of the routing protocol is affected by the prevailing network conditions such as traffic load, node density, and node mobility. During their study they observed that the optimal forwarding probability is around 0.5 in the presence of heavy network (dense network) conditions and around 0.6 for light and moderate network conditions.

M. Bani Yassein et al. [51] proposed a dynamic probabilistic flooding algorithm in MANETs to improve performance metrics (reachability and saved rebroadcast). The algorithm determines the rebroadcast probability by considering the network density and node movement. This is done based on locally available information and without requiring any assistance of distance measurements or exact location determination devices. The algorithm works as follows: When receiving a broadcast message for the first time, a node rebroadcasts the message with a pre-determined probability so that every node has the same probability to rebroadcast the message, regardless of its number of neighbors. In dense networks, multiple nodes share similar transmission range. Therefore, these probabilities control the frequency of rebroadcasts and thus might save network resources without affecting delivery ratios.

It should be noticed that in sparse networks there is much less shared coverage; thus some nodes will not receive all the broadcast packets unless the probability parameter is high. So if the retransmission probability is set to a far small value, the reachability will be poor. On the other hand, if the retransmission probability is set far large, many redundant rebroadcasts will be generated. In order to achieve both high saved rebroadcast and high reachability in MANETs where network topology changes frequently, the rebroadcast probability at every host must be dynamically adjusted. The rebroadcast probability should be set high at the hosts in sparser areas and low at the hosts in denser areas.

The algorithm is a combination of probabilistic and knowledge-based approaches. It dynamically adjusts the retransmission probability at each mobile host according to the value of the local number of neighbors. The value of the retransmission probability changes when the host moves to a different neighborhood. They showed that using their improved algorithm a saved rebroadcast of 50% is achieved compared to simple flooding and flooding with fixed probability.

M. Bani-Yassein et al. [52] investigated the effect of density with different speeds on the behavior of probabilistic flooding in mobile ad hoc networks (MANETs). This investigation was conducted through extensive simulation on a network of size 25 to 100 nodes.

The results they obtained reveal that the effect of node density with different speeds has a critical impact on the levels of rebroadcast and reachability achieved by probabilistic flooding. In this study, they used the random waypoint model applied to the probabilistic flooding approach. Through simulation, they had shown that there was a substantial effect of node density and mobility on the reachability and saved rebroadcast ratios.

Q. Zhang D. P. Agrawal [47, 55] presented a probabilistic solution that is appropriate to solving flooding broadcast problems in dense mobile networks. They proposed a routing protocol that dynamically adjusted itself, to the local network topology, in order to provide reliable and efficient interaction between nodes in an ad hoc network, also referred to as gossip protocol. Their approach can prevent broadcast storms during flooding in dense networks and can enhance comprehensive delivery in sparse networks. The dynamic gossip protocol utilizes a relay ping method to give a local awareness of the density of the network. This information is used to locally and instantly adjust the node retransmission probability.

J. S. Kim et al. [61] introduced a dynamic probabilistic broadcasting approach with coverage area and neighbours confirmation for MANETs. Their scheme combines probabilistic approach with the area-based approach. A mobile host can dynamically adjust the value of the rebroadcast probability according to its additional coverage in its neighbourhood. The additional coverage is estimated by the distance from the sender. Their scheme combines neighbour confirmation concept to prevent early die-out of rebroadcast. The simulation results show this approach generates fewer rebroadcasts than flooding approach. It also incurs lower broadcast collision without sacrificing high reachability.

Scott D. and Yasinsac A. [2] presented a probabilistic solution that is appropriate to solving broadcast storm problems in dense mobile networks. They proposed a routing protocol that dynamically adjusted itself, to the local network topology, in order to provide reliable and efficient interaction between nodes in an ad hoc network, also referred to as gossip protocol. Their approach can prevent broadcast storms during flooding in dense networks and can enhance comprehensive delivery in sparse networks.

The dynamic gossip protocol utilizes a relay ping method to give a local awareness of the density of the network. This information is used to locally and instantly adjust the node retransmission probability.they also showed that they can control the number of retransmission in any overlap area between two nodes and distribute the retransmission probability (p_t) as the originator start transmission for the 1-hop neighbors

J. Cartigny and D. Simplot [62] proposed some improvements to the flooding protocols that aim to efficiently broadcast given information through the network. These improvements are based on probabilistic approach and decrease the number of emitted packets and hence, the medium occupation. Indeed, it is more interesting to privilege the retransmission by nodes that are located at the radio border of the sender. They observed that the distance between two nodes with full duplex communication can be approximated by comparing their neighbor lists. This leads to broadcasting schemes that do not require position or signal strength information of nodes. Moreover, proposed broadcast protocols require only knowledge of one hop neighborhood and thus need only short hello message. Such protocols are more able to support high mobility networks than protocols that need knowledge of two or more hops neighborhood and then need longer hello messages. They compared their new schemes with variable density and experiments show that the probabilistic approach is efficient.

Haas et al. [49] proposed a gossip-based ad hoc route discovery approach. They use a predefined probability value (p_t) to decide whether or not to forward the packets, their algorithm works as follows: A source node sends the RREQ with probability 1. When a node first receives a RREQ, with probability p_t it broadcasts the request to its neighbors and with probability $(1-p_t)$ it discards the request; if the node receives the same RREQ again, it is discarded. Thus, a node broadcasts a given RREQ at most once. This simple protocol is called GOSSIP1, but GOSSIP1 has a slight problem with initial conditions. If the source has relatively few neighbors, there is a chance that none of them will gossip, and the gossip will die. To make sure this does not happen, they gossip with a retransmission probability equal to 1 for the first k hops before continuing to gossip with retransmission probability less than 1.

They call this modified protocol GOSSIP1 (p_t, k). Clearly, GOSSIP1 (1, 1) is equivalent to pure flooding. Their results show that, by using appropriate heuristics, they can save up to 35% message overhead compared to pure flooding. Furthermore, adding gossiping to a protocol such as AODV and ZRP not only gives improvements in the number of messages sent, but also results in improved network performance in terms of end-to-end latency and throughput.

Sasson et al. [3] explored the phase transition phenomenon observed in percolation theory and random graphs as a basis for defining probabilistic flooding algorithms. They considered ideal and realistic models. They simulated ideal network conditions to provide best-case results that can be used for comparisons with more realistic network conditions. They studied a purely probabilistic approach to flooding attempting to exploit the phase transition phenomenon. Their results showed a major difference between the behaviour obtained in ideal situations inspired from random graphs and percolation theory and simulations undertaken in MANETs prone to packet collisions. For the latter, the success rate did not exhibit a bimodal behaviour as percolation theory and random graphs would suggest. The success rate tends to become linear for MANETs of low average node degree, and resembles a bell curve of high average node degree. Although phase transition is not observed, probabilistic flooding nonetheless greatly enhances the successful delivery of packets in dense networks.

Sasson et al. also suggested exploring algorithms in which nodes would dynamically adjust their retransmission probability based on local topology information. Because in their work they made the assumption that all nodes possess the same transmission range, they suggested another potential area for study which is to understand within probabilistic flooding the combined effects on MANETs performance of modifying the nodes transmission range with regard to retransmission probability.

Y.C. Tseng et al. [4] Investigated the performance of the probabilistic flooding as a function of the network density in a noise-free environment. They presented results for three network parameters, namely, reachability, saved rebroadcast, and average latency, as a function of retransmission probability and network density.

B. Williams and T. Camp [5] provided comprehensive comparative analysis by classifying existing broadcasting schemes into categories and simulating a subset of each category, thus supplying a condensed but comprehensive side by side comparison. The simulations were designed to pinpoint, in each category, specific failures to network conditions that are relevant to MANETs, e.g., bandwidth congestion and dynamic topologies. In addition, protocol extensions using adaptive responses to network conditions were proposed, implemented and analyzed for one broadcasting scheme that performs well in the comparative study.

Ni et al. [63] studied the flooding protocol analytically and experimentally. The obtained results indicate that rebroadcast can provide at most 61% additional coverage and only 41% additional coverage in average over that already covered by the previous.

Therefore, rebroadcasts are very costly and should be used with caution. They also classified flooding broadcast optimization schemes into five categories to reduce redundancy, contention, and collision. These categories are probabilistic, counter-based, distance-based, location-based and cluster-based.

In probabilistic scheme, a mobile host rebroadcasts packets according to a certain probability (p_t). In counter-based scheme, a node determines whether to rebroadcast a packet or not by counting how many identical packets it received during a random delay. Counter-based scheme assumes that the expected additional coverage is so small that rebroadcast would be ineffective when the number of recipient broadcasting packets exceed a certain threshold value.

The distance-based scheme uses the relative distance between a mobile node and previous sender to make the decision whether to rebroadcast a packet or not. In the location-based scheme, the additional coverage concept is used to decide whether to rebroadcast a packet. Additional coverage is acquired by the locations of broadcasting hosts using the geographical information of a MANET.

The cluster-based scheme divides the MANET into a number of clusters or sub-sets of mobile hosts. Each cluster has one cluster head and several gateways. Cluster head is a representative of the cluster whose rebroadcast can cover all hosts in that cluster. Only gateways can communicate with other clusters and have responsibilities to propagate the broadcast message to other clusters.

The results for the probabilistic scheme shows that in a small map (geometric area) which implies dense host distribution, a small probability (p_t) is sufficient to achieve high reachability, but a larger p_t is needed if the host distribution is sparse. The amount of saving decreases, roughly proportionally to ($1-p_t$), as (p_t) increases.

For the latency part, the results showed that for MANETs with sparser hosts tends to complete broadcasting more quickly than one with denser hosts. This is due to the heavier contention on the channel in denser network.

Chapter 3
Flooding Optimization Algorithms in MANETs

3.1. Introduction

Mobile ad hoc networks (MANETs) consist of wireless mobile nodes that communicate with each other, in the absence of a fixed infrastructure or centralized control [1, 2]. Routes between any two nodes in a MANET may consist of hops through other nodes in the network; therefore, in practice more than one path may exist to forward a message (data packet or packet) between a source and destination nodes [64]. Thus, an efficient methodology should be developed to find the optimum route, which can be used to bypass data packets between a source and destination nodes. A route may be optimized with regards to a number of parameters, such as: number of hops, elapsed time, security issues, cost, politics, etc.

A static routing approach is not valid for MANETs, and the only possible routing approach that can be used is a dynamic routing that searches for a new route when nodes move or link failure detected, because nodes mobility can cause frequent unpredictable topology changes and link failure. The task of finding and maintaining routes in MANETs is nontrivial and costly. Many routing protocols have been proposed for MANETs, with the goal of achieving efficient routing in terms of bandwidth utilization, delay, algorithm complexity, and reliability. These algorithms differ in the approach they use for searching a new route and/or maintaining a known route, when nodes move and link failure is detected [13].

Section 3.2 explains the route establishment in dynamic routing protocols, while section 3.3 gives an example of route discovery in the DSR protocol. Section 3.4 shows what type of an environment a MANETs networks can exist in, Pure flooding is discussed in section 3.5, and in section 3.6 flooding optimization algorithms are explained, section 3.7 explains the probabilistic flooding in noiseless MANET environment, and finally the chapter closed with section 3.8 which explains how to determine the retransmission probability for route discovery in the probabilistic algorithm.

3.2 Route Establishment in Dynamic Routing Protocols

Dynamic (reactive) routing protocols are the only efficient and reliable routing protocols for MANETs. Examples of such type of protocols include: dynamic source routing (DSR) protocol [23, 43], ad hoc on-demand distance vector (AODV) routing protocol [65].

Dynamic routing protocols usually consist of two major phases; these are [13]:

1. **Route discovery.** It is the mechanism by which a source node S obtains a source route to a destination node D. Route discovery is used only when S attempts to send a data packet to D and does not already know a route to D.

2. **Route maintenance**. It is the mechanism by which node S is able to detect, while using a source route to D, if the network topology has changed such that it can no longer use its route to D because a link along the route no longer works. When route maintenance indicates a source route is broken, S can attempt to use any other route it happens to know to D, or can invoke route discovery again to find a new route. Route maintenance is used only when S is actually sending data packets to D.

Route discovery and route maintenance each operate entirely on demand. To initiate the route discovery, the source node transmits a route request (RREQ) packet as a single local broadcast packet, which is received by (approximately) all nodes currently within wireless transmission range of the source node. Each RREQ packet identifies the source (initiator) and the destination (target) of the route discovery, and also contains a unique request sequence number or identification number (ID), determined by the source of the request. Each RREQ also contains a record listing the address of each intermediate node through which this particular copy of the RREQ packet has been forwarded. This route record is initialized to an empty list by the source of the route discovery.

In addition, the header of the RREQ packet contains information on the lifetime of the request. This is expressed in terms of the maximum number of intermediate nodes (hops count) that are allowed to forward the data packet from the source node to the destination node. During the route discovery phase, each intermediate node (any node along the path that retransmits the RREQ packet which is neither the source nor the destination) reduces the hop count by 1. If at a particular intermediate node, the hops count approaches 0 before the RREQ reaches its destination, an error is detected and this is considered as an unsuccessful route discovery process. Then, this last node sends back a unicast route error (RERR) packet to the source. Upon receiving it, the source node initiates a new RREQ with different sequence number.

If the destination node is located and successfully receives the RREQ, the destination node sends back a unicast route reply (RREP) packet to the source node; otherwise, if the destination node is not located, then this is considered as an unsuccessful route discovery process and the source node should initiate a new RREQ with different sequence number.

The RREP packet usually follows the same route followed by the first RREQ that has reached the destination, but in reverse order [13]. This is because; the destination node may receive the same RREQ more than once through different valid routes. However, relying on the fastest route is not the only way that can be used to select the optimum route, different protocols may use different methodologies.

Flooding broadcast mechanism is widely used for route discovery in MANETs, especially in highly mobile networks [1, 2, 3], and at this stage, it must be clearly emphasized that due to the nature of the flooding broadcast mechanism, the time required to find the optimum route connecting two nodes (i.e., route discovery between a source and destination nodes) is normally more than the time required for data packet transmission [3]. This is especially true in a noisy and highly mobile MANET environment, since in this case a lot of links failure may occur.

During the process of forwarding the RREQ packet, different routing protocols using different methodologies to efficiently establish a reliable and an efficient active data packet forward route between a source and destination nodes. In this work, the researcher is not concerned with how an optimum route is being established between a source and a destination in dynamic routing protocols. However, in this thesis, the researcher is mainly concerned in developing an efficient and reliable flooding route discovery mechanism between two nodes in a noisy MANET environment. In order to clarify the complete route discovery process, in the next section, a brief description of a simplified methodology for route discovery similar in a widely used dynamic routing protocol, namely, the DSR protocol is provided.

3.3. Route Discovery in the DSR Protocol

This section illustrates how flooding being used in the route discovery phase of the DSR protocol. In this phase, when a source node S needs to find a route to a destination node D, node S broadcasts a RREQ packet to all its neighbors. A node, says X, on receiving a RREQ packet, compares the desired destination identifier with its own identifier. If there is a match, it means that X is the destination. Otherwise, node X rebroadcasts the request to its neighbors – to avoid redundant transmissions of RREQs, a node X is allowed to broadcast a particular RREQ only once, and if it receives the same RREQ later, it just discarded it (repeated reception of a RREQ is detected using its sequence numbers) [13].

In Figure (3.1) node S needs to determine a route to node D. In this case, node S broadcasts a RREQ to its neighbors. When nodes A, B and C receive the RREQ, they forward it to all their neighbors. When node F receives the RREQ from B, it forwards the request to its neighbors. However, when node F receives the same RREQ from C, node F simply discards the RREQ. As the RREQ is propagated to various nodes, the path followed by the request is included in the RREQ packet payload.

Using the above flooding algorithm, provided that the intended destination is reachable from the source and the environment is error-free, the destination should eventually receive a RREQ packet. On receiving the RREQ, the destination responds by sending back a RREP packet to the sender – the RREP packet follows a path that is obtained by reversing the path followed by the first RREQ received by node D (the RREQ packet includes the path traversed by the request).

It is possible that the destination will not receive a RREQ packet (for instance, when it is unreachable from the source node, or RREQs are lost due to transmission errors, especially in noisy and highly mobile environment). In such cases, the source node needs to be able to reinitiate a route discovery process by broadcasting a new RREQ with different sequence number [13].

To avoid such lost packet problem, when a source initiates route discovery, it sets a timeout. If during the timeout interval, a RREP is not received, then a new route discovery is initiated (the RREQ packets for this route discovery will use a different sequence number than the previous route discovery – recall that sequence numbers are useful to detect multiple receptions of the same RREQ). Timeout may occur if the destination does not receive a RREQ, or if the RREP packet from the destination is lost, due to noise interference or node mobility.

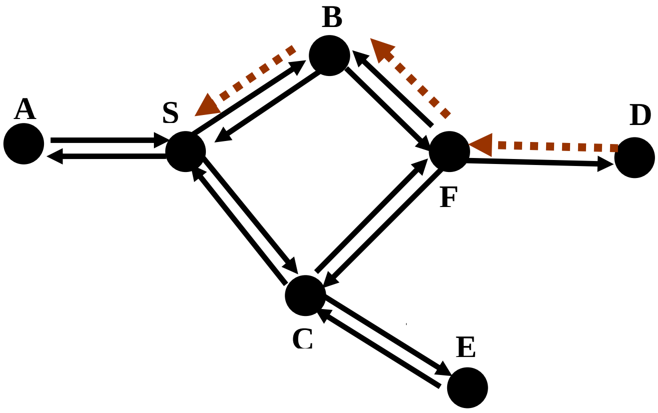


Figure (3.1) - Illustration of flooding.

(Route reply ▪▪▪▶ , Route request⟶)

As it was mentioned in the previous section, each RREQ packet has a specific lifetime that is expressed in number of hops. Each intermediate node that retransmits the RREQ packet reduces the hops count by 1. If the hops count of the request approaches 0 at a particular node before it reaches the destination, the last intermediate node sends back a unicast RERR packet to the source node. Upon receiving this RERR packet, the source node reinitiates a route discovery process with different sequence number.

Route discovery is usually initiated either when the source node detects that a previously determined route to the destination node is broken, or if the source node does not know a route to the destination. In this implementation, it is assumed that the source node can know that the route is broken only if it fails to use the route. When the source node sends a data packet along a particular route, a node along that path returns a RERR packet, if the next hop on the route is broken. When the source node receives the RERR packet, it initiates route discovery for the destination node.

3.4 Network Environment

The network environment can be categorized into two types of environments, these are:

- Noiseless (error-free) environment
- Noisy (error-prone) environment

3.4.1 Noiseless environment

Noiseless environment (also called error-free environment) can be characterized by the following axioms or assumptions, which are still part of many MANET simulation studies, despite the increasing awareness of the need to represent noisy features [66]:

i. The world is flat

ii. All radios have equal range, and their transmission range is circular

iii. Communication link symmetry

iv. Perfect link

v. Signal strength is a simple function of distance.

Following is a brief description for each of them. Further description can be found in related literatures [66].

i. The world is flat

Common stochastic radio propagation models assume a flat earth, and yet clearly the Earth is not flat. We need no data to "disprove" this axiom. Even at the short distances considered by most MANET research, hills and buildings present obstacles that dramatically affect wireless signal propagation. Furthermore, the wireless nodes themselves are not always at ground level; indeed, Gaertnerand Cahill noticed a significant change in link quality between ground-level and waist-level nodes. Furthermore, it is not uncommon to see two nodes in a multi-story building deployed at the same *(x,y)* location, but on different floors.

ii. All radios have equal range, and their transmission range is circular

The signal coverage area of a radio is far from simple. Not only is it neither circular nor convex, it often is non-contiguous. So the success of a transmission from one radio to another depends only on the distance between radios.

iii. Communication link symmetry

If an unacknowledged message from A to B succeeds, an immediate reply from B to A succeeds. This wording adds a sense of time, since it is clearly impossible (in most MANET technologies) for A and B to transmit at the same time and result in a successful message. Since A and B may be moving, it is important to consider symmetry over a brief time period.

iv. Perfect link

The reception probability distribution over distance exhibits a sharp cliff; that is, under some threshold distance (transmission range) the reception probability is 1 and beyond that threshold the reception probability is 0. But in reality the reception probability does indeed fade with the distance between sender and receiver rather than remaining near 1 out to some clearly defined range and then dropping to zero. There is no visible “cliff.”

v. Signal strength is a simple function of distance.

It has been noted that the average signal strength should fade with distance according to a power-law model. While this is true, one should not underestimate the variations in a real environment caused by obstruction, reflection, refraction, and scattering.

3.4.2 Noisy environment

In a noisy environment (also called error-prone environment) for any communication system, the received signal will differ from the transmitted signal, due to various transmission impairments. These impairments include [7]:

i. Wireless signal attenuation

ii. Free space loss

iii. Thermal noise

iv. Atmospheric absorption

v. Multipath effect

vi. Refraction

following is a brief description for each of them. Further description can be found in related literatures.

i. Wireless signal attenuation (p_{att})

The strength of an electromagnetic (wireless) signal falls off with distance over any transmission medium. For the wireless media, attenuation is a more complex function of distance and the makeup of the atmosphere. Attenuation introduces three factors for the transmission engineer to carefully consider, these are:

- A received electromagnetic signal must have sufficient strength so that the electronic circuitry in the receiver can detect and interpret the signal.
- The signal must maintain a level sufficiently higher than noise to be detected and received without errors.
- Attenuation is greater at higher frequencies, causing distortion.

The first and second factors are dealt with by attention to signal strength ratio and the use of amplifiers or repeaters. The signal strength of the transmitter must be strong enough to be received intelligibly, but not so strong as to overload the circuitry of the transmitter or receiver, which would cause distortion. The third factor is known as attenuation distortion. Because the attenuation varies as a function of frequency, at high frequencies, the received signal is distorted, reducing intelligibility. Assuming the probability of a wireless signal, carrying the RREQ packet, surviving a loss due to wireless signal attenuation, and successfully delivered to the receiver, is p_{att}.

ii. Free space loss (p_{free})

For any type of wireless communication, the signal disperses with distance. Therefore, an antenna with a fixed area will receive less signal power the farther it is from the transmitting antenna. This form of attenuation is known as free space loss, which can be express in terms of the radiated power P_t to the received power P_r by the antenna as:

$$\frac{P_t}{P_r} = \left(\frac{4\pi\, d}{\lambda}\right)^2 = \left(\frac{4\pi f d}{c}\right)^2 \qquad (3.1)$$

where P_t and Pr are the signal power at the transmitting and receiving antennas, respectively; λ and f are the carrier wavelength and frequency; D is the propagation distance between the transmitting and receiving antennas; and finally, c is the speed of light (3×10^8 m/s). Assuming the probability of a wireless signal, carrying the RREQ packet, surviving a loss due to free space loss, and successfully delivered to the receiver, is p_{free}.

iii. Thermal noise (p_{therm})

For any data transmission event, the received electromagnetic signal will consist of the transmitted signal, modified by the various distortions imposed by the transmission system, plus additional unwanted signals that are inserted somewhere between transmission and reception antennas. These unwanted signals are referred to as noise. Noise is the major limitation factor in communication system performance.

One type of noise is the thermal noise, which is due to thermal agitation of electrons. It is present in all electronic devices and transmission media and is a function of temperature. Thermal noise is uniformly distributed across the frequency spectrum and hence is often referred to as white noise. Thermal noise cannot be eliminated and therefore places an upper bound on communication system performance. Assuming the probability of a wireless signal, carrying the RREQ packet, surviving a loss due to thermal noise, and successfully delivered to the receiver, is p_{therm}.

iv. Atmospheric absorption (p_{atm})

An additional loss between the transmitting and receiving antennas is atmospheric absorption. Water vapor and oxygen contribute most to this type of attenuation. Rain and fog (suspended water droplets) causes scattering of radio waves that result in attenuation. This can be a major cause of signal loss. Assuming the probability of a wireless signal, carrying the RREQ packet, surviving a loss due to atmospheric absorption, and successfully delivered to the receiver, is p_{atm}.

v. Multipath effect (p_{mult})

For wireless facilities where there are obstacles in abundance. The signal can be reflected by such obstacles so that multiple copies of the signal with varying delays can be received. In fact, in extreme cases, the receiver may capture only reflected signals and not the direct signal. Depending on the differences in the path lengths of the direct and reflected waves, the composite signal can be either larger or smaller than the direct signal. Assuming the probability of a wireless signal, carrying the RREQ packet, surviving a loss due to multipath effect, and successfully delivered to the receiver, is p_{mult}.

vi. Refraction (p_{ref})

Radio waves are refracted (or bent) when they propagate through the atmosphere. The refraction is caused by changes in the speed of the signal with altitude or by other spatial changes in the atmospheric conditions. This may result in a situation in which only a fraction or no part of the line-of-sight wave reaches the receiving antenna.

Assuming the probability of a wireless signal, carrying the RREQ packet, surviving a loss due to refraction, and successfully delivered to the receiver, is p_{ref}.

Real environment exposed to these impairments, in addition to nodes motion, which will result in topology changes. All of these factors could prohibit some nodes from receiving RREQ signals, even though, a node could be within the transmission range of the transmitting or relay node, or their controlling parameters such as, Time To Live (TTL) or hop count fields are non-zero, and that will drop down the route discovery process, as a result, the network performance will be compromised.

All of these factors are represented by a generic name, ***Noise***. The environment is called ***noisy environment***. The ***noisy environment*** is described by introducing another probability function, namely, the probability of reception function (p_c) or simply the probability of reception (p_c), which means that a wireless signal survives being lost, and is successfully delivered to a destination node, due to any of the above impairments mentioned above. Thus (p_c) can be expressed as:

$$p_c = p_{att} \cdot p_{free} \cdot p_{therm} \cdot p_{atm} \cdot p_{mult} \cdot p_{ref} \cdots \quad (3.2)$$

This equation can be applied to any flooding optimization scheme, but for the purpose of this research it will be applied and studied only under the probabilistic scheme. This probability could be a constant value or a function of certain distribution.

3.5. Pure Flooding

One of the earliest and simplest route discovery broadcast mechanism that is proposed in the literature is called "simple" or "blind" flooding [67], it is also known as "pure" flooding, in which each node rebroadcasts the RREQ to its neighbors upon receiving it for the first time starting at the source node. However, nodes are allowed to rebroadcast the same packet only once. Packets are identified through their sequence number, i.e., when a node receives a RREQ packet, it first checks its sequence number to see if it has retransmitted it or not. If it finds that it has retransmitted this RREQ, and then it just discarded it, it rebroadcast the RREQ after loading it with its IP address. Figure (3.2) outlines the pure flooding broadcast algorithm [1, 3].

Pure flooding broadcast algorithm.

On receiving a broadcast request at node i, do the following:

```
IRec(i)++ {Update the node reception index IRec(i)}
If  IRet(i) = 0 Then {The node has not retransmit the request before (IRet(i) = 0}
        Retransmit request
        IRet(i) = 1 {Update the node retransmission index IRet(i) by equating it to 1}
End if
```

Figure (3.2) - Pure flooding broadcast algorithm.

It can be easily observed that using pure flooding in error-free (noise-free) environment, the RREQ would reach every node that is reachable from source node (potentially, all nodes in the network). Pure flooding generates vast numbers of duplicate packets, in fact, an infinite number unless some measures are taken to damp the process. One such measure is to have a hop counter contained in the header of each packet, which is decremented at each hop, with the packet being discarded when the counter reaches zero. Ideally, the hop counter should be initialized to the length of the path from source to destination. If the source does not know how long the path is, it can initialize the counter to the worst case, namely, the full diameter of the subnet or the maximum possible size.

It is obvious from the above discussion that the main advantages of pure flooding are its simplicity and reliability. But, despite the measures considered above of allowing nodes to retransmit RREQ packet only once and using hop counter, pure flooding still suffers from many drawbacks due to the large number of redundant rebroadcasts. This is because, in pure flooding, all nodes upon receiving the RREQ packet will be allowed to rebroadcast it, so that in a network of n reachable nodes, the number of rebroadcast is n-2.

A straightforward flooding broadcast in wireless networks, using the IEEE 802.11 protocols results in the following serious drawbacks [41, 63]:

i. Duplicate reception: When a node decides to rebroadcast a RREQ packet to its neighbors, all its neighbors already may have the packet.

ii. Contentions: After a node broadcasts a RREQ, if many of its neighbors decide to rebroadcast the packet, these transmissions (which are all from nearby nodes) may severely contend with each other.

iii. Collisions: Because of the deficiency of this mechanism, due to the lack of RTS/CTS dialogue, and the absence of collision detection mechanism, collisions are more likely to occur and cause more damage.

In 802.11 specifications, for route discovery, the only requirement made for broadcasting nodes is that they assess a clear channel before broadcasting, using the carrier sense multiple access (CSMA) protocol [6, 7]. However, in congested networks, still a significant amount of collisions occur leading to many dropped packets due to the following reasons:

i. Clear channel assessment does not prevent collisions from hidden nodes.

ii. No resource is provided for collision avoidance when two neighbors assess a clear channel and transmit simultaneously.

iii. Lack of RTS/CTS dialogue, a node has no way of knowing whether a packet was successfully delivered to its neighbors, i.e., lack of acknowledgment (ACK).

Thus, effective and efficient broadcasting protocols always try to limit the probability of collisions and contention by limiting the number of rebroadcasts in the network.

3.6 Flooding Optimization Algorithms

There are several algorithms that have been proposed throughout the years to reduce the number of retransmission (redundant rebroadcasts); thereafter, duplicate reception, contentions, and collisions in MANETs. These include:

i. Probabilistic scheme [1, 2, 3, 4, 28, 50]

In this scheme when a node receives a RREQ packet for the first time, it will retransmit it with a certain retransmission probability, either a pre-determined probability p_t that is set for all nodes within the network, or dynamically evaluate by each node according to the actual number of neighboring nodes using a particular analytical formula. Pure flooding is the same as probabilistic flooding with p_t=1. Further details on this scheme will be given in subsequent sections and chapters.

ii. Location based scheme [14, 28, 41, 43, 44]

In this scheme a node forwards a RREQ packet depending on the location of the nodes that it has received the packet from. Location information can be used to reduce propagation of RREQ packets, to perform controlled flooding, to maintain valid routes in mobility conditions and to make simplified packet forwarding decisions. The basic advantage of using location information for wireless routing is to improve network scalability by reducing overall routing overhead. The routing protocols that are based on location information are called location-aided routing (LAR) protocols.

In these protocols, it is assumed that each node may calculate its current location either precisely or approximately using a Global Positioning System (GPS) [68]. Basically, there are two types of LAR, namely LAR scheme 1 (LAR-1) and LAR scheme 2 (LAR-2).

iii. Multipoint relaying [48]

This technique restricts the number of retransmitters to a small set of neighbors nodes, instead of all neighbors. This small subset of neighbors is called multipoint relays (MPRs) of a given node.

iv. Cluster based scheme [44, 62]

This scheme partitions the network into clusters (set of nodes), each cluster has a cluster head and cluster members, a cluster member can be a gateway cluster (the one that can communicate with nodes in other clusters). In a cluster, the heads rebroadcast can cover all other nodes in that cluster. Only cluster heads and cluster gateways may rebroadcast a RREQ.

v. Hybrid schemes [50]

In such schemes combinations of the above flooding optimization schemes may be used to develop a single efficient flooding algorithm. Recently, a new flooding optimization algorithm (LAR-1P) is developed [50]. It utilizes two well-known flooding optimization algorithms, namely, the LAR-1 algorithm and the probabilistic algorithm. In this algorithm, when receiving a broadcast message, a node within the requested zone rebroadcasts the message with a certain retransmission probability, and each node is allowed to rebroadcast received message only once.

In this work, the researcher is mainly concerned with probabilistic flooding, therefore further details will given in the rest of this thesis, while further description of other flooding algorithms can be found on their related literatures.

3.7 Probabilistic Flooding in Noiseless MANET Environment

Probabilistic retransmission scheme is one of the alternative approaches that aim at reducing number of RREQ packet retransmission, in the route discovery phase of reactive routing protocols, in an attempt to alleviate the flooding broadcast problem in

MANETs [1, 2, 3, 41, 45, 50]. In this scheme, when receiving a broadcast RREQ packet, a node retransmits the packet with a particular retransmission probability (p_t) and with probability ($1 - p_t$) it discards the packet. If the node receives the same packet again, it just discards it, since each node is allowed to retransmit a given RREQ packet only once. Nodes usually can identify the RREQ packet through its sequence number.

The actual value of the retransmission probability for intermediate nodes (all nodes except the source and the destination nodes) is either statically or dynamically set. Determination of the retransmission probability for intermediate nodes is presented in detail in the next section. In the simulation, the source and the destination nodes retransmission probability is always set to 1 to enable these two nodes to initialize the route discovery and the route reply course of actions, respectively.

As it has been mentioned above, in probabilistic flooding, a node is allowed to retransmit a given RREQ packet only once. In this sense, the researcher proposes two schemes that can be used to implement the probabilistic retransmission algorithm; these are:

Probabilistic Flooding Algorithm in a Noiseless MANET Environment Based on the Single-Trial Scheme.

```
If IRange = 1 Then {The receiving node within the transmission range of the sender, in a noiseless
                   environment this guarantees request reception by the receiver. IRange = 0
                   means the receiver is not within the transmission range of the sender}
      IRec(i)++ {Update the node reception index IRec(i)}

      If IRet(i) = 0 Then {The node has not retransmitted the request before (IRet(i) = 0)}
        If ITry(i) = 0 Then {The node has not tried to retransmit the request before (ITry(i) = 0)}
           ξ = rnd() {ξ some random number between 0 and 1}
           ITry(i) = 1 {To indicate that the node has tried to retransmit the request}
           If ξ <= p_t Then
               Retransmit request
               IRet(i) = 1 {Update the node retransmission index IRet(i) by equating it to 1}
           End if
        End if
      End if
End if
```

Figure (3.3) - Probabilistic flooding broadcast algorithm in a noiseless MANET environment based on the single-trial scheme.

i. Single-trial retransmission probabilistic scheme

In this scheme, upon successfully receiving a RREQ packet, an intermediate node reties only once to retransmit the RREQ, if it fails then each time it receives the same RREQ from other neighbouring nodes, it just discards it.

ii. Multi-trials retransmission probabilistic scheme

In this scheme, an intermediate node continuously tries to retransmit the RREQ each time it receives it from its neighbours. Since each node is allowed to retransmit the RREQ only once, if the intermediate node succeeds to retransmit the RREQ in any of the trials, it will stop trying to retransmit the request and discard all other duplicate receptions.

Figures (3.3) above, and (3.4) outline the probabilistic flooding algorithms in noiseless MANET environment that are based on the single-trial and the multiple-trials schemes, respectively.

Probabilistic Flooding Algorithm in a Noiseless MANET Environment Based on the Multiple-Trials Scheme.

```
If IRange = 1 Then {The receiving node within the transmission range of the sender, in a noiseless
                    environment this guarantees request reception by the receiver. IRange = 0
                    means the receiver is not within the transmission range of the sender}
     IRec(i)++ {Update the node reception index IRec(i)}
     If IRet(i) = 0 Then {The node has not retransmitted the request before (IRet(i) = 0}
          ξ = rnd() {ξ some random number between 0 and 1}
          If ξ <= p_t Then
               Retransmit request
               IRet(i) = 1 {Update the node retransmission index IRet(i) by equating it to 1}
          End if
     End if
End if
```

Figure (3.4) - Probabilistic flooding algorithm in a noiseless MANET environment based on the multiple-trials scheme.

3.8.Determination of the Retransmission Probability (p_t)

There are basically two approaches that can be used to set a satisfactory retransmission probability (p_t) for each intermediate node within the network, these are:

i. Static approach

In this approach a pre-determined (pre-adjusted) retransmission probability is set for each or all nodes. It can be implemented in two different ways

- The same pre-determined retransmission probability is set for all nodes within the network. All nodes keep this probability unchanged regardless of the variation in the network topology (e.g., due to node mobility) or network noise level (e.g., due to noise interference). This retransmission probability could be determined by the network manager and broadcast to all nodes within the network during the registration or the authentication progression.
- Each node within the network is triggered externally or configured by the network manager or its user to determine a satisfactory retransmission probability for itself, according to the number of neighboring nodes and network noise level, and keep this probability unchanged regardless of the variation in the network topology or network noise level, until a node is triggered or configured again.

ii. Dynamic approach

In this approach a dynamically determined (adjusted) retransmission probability is set for each or all intermediate nodes within the network. This approach can be implemented in two different ways:

- The source node determines a satisfactory retransmission probability and broadcasts it with the RREQ packet to all nodes within the network for them to use to probabilistically determine whether to retransmit the RREQ packet or not. The node should use this retransmission probability regardless of its local position or the network noise level.
- Each node locally determines its retransmission probability according the number of neighboring nodes and the network noise level.

However, still in all cases above, an intermediate node is allowed to retransmit a given RREQ packet only once. All of the above retransmission probability determination approaches and retransmission strategies are implemented by our MANET simulator (MANSim).

Chapter 4
Probabilistic Flooding in Noisy Environment

4.1 Introduction

Recent advances in wireless communication technology and portable devices have generated a lot of interest in MANETs. A MANET is a collection of wireless devices moving in seemingly random directions and communicating with one another without the aid of an established infrastructure. So the communication protocols for MANETs are designed to work in peer-to-peer networking mode. To extend the reachability of a node in a MANET, the other nodes in the network act as routers to forward data or control (e.g., RREQ, RREP, RERR, etc.) packets. Thus, the communication may be via multiple intermediate nodes from source to destination.

Noise level and node mobility may frequently break the communication links between neighboring nodes; therefore, designing a MANET that provides sustained network performance, in such randomly behaving environment, is a challenging problem. There are a couple of technical challenges that must be addressed to make such networks usable in practice. First, to handle continually changing topology, a dynamic routing protocol must be employed to maintain routes between a pair of source-destination nodes. Second, the noise level and the access to the shared wireless medium by the competing nodes must be reasonable, efficient, and fair. The development of efficient and reliable dynamic routing protocols is well discussed in Chapters 1 and 3, therefore in what follows a brief discussion of the second challenge is introduced.

The nature of the wireless medium makes the medium access control problem nontrivial. For example, the received power and the signal-to-noise ratio (SNR) fall rapidly with increase in the distance between receiving and the transmitting nodes. Thus, it is difficult for a transmitting node to sense the carrier or detect packet collision at the receiver. To minimize transmission collisions during data packet transmission, short control packets, denoted RTS (Request-To-Send) and CTS (Clear-To-Send), are used to reserve the channel by the sender and receiver of a transmission.

As was mentioned in Chapter 3, during route discovery, IEEE 802.11 protocol allows for carrier sense and the use of short packets, but it does not allow for RTS/CTS dialogue between nodes. This, and other reasons that are discussed in Section 3.4, could highly increase the probability of collisions and increase the noise level at the receiver and across the network area. Thus, in this thesis, our focus is primarily on investigating the impact of the noise level on the network performance as seen by applications running on the mobile nodes. In particular, the researcher investigates the impact of the noise level on the performance of the flooding optimization algorithm, namely, the probabilistic flooding algorithm, which is used by many dynamic routing algorithms for route discovery. Route discovery is considered as one of the major factors that affect the overall performance of the network.

In our simulation model, the researcher considers a general random connection model where each pair of nodes, which lies within the transmission range of each other, can be connected according to some probabilistic function, which the researcher refers to as the probability of reception (p_c). For example, the probability of reception of a particular receiver decreases as the transmitter-receiver nodes get farther away according to a certain distribution function. However, at this stage, for simplicity, the researcher uses a constant function with a pre-determined value for the probability of reception.

Section 4.2 provides a detailed description of the probabilistic flooding optimization algorithm in a noisy environment for single and multiple trial schemes. Section 4.3 summarizes the conditions necessary for the simulation study. In section 4.4 a description of a mobile ad hoc network simulator (MANSim) is presented, which is especially developed to evaluate and analyze the performance of flooding optimization algorithms for MANETs. A definition to the computed network parameters is given in Section 4.5. The types of network conditions that are simulated in MANSim are presented in Section 4.6. An analytical derivation for a number of computed network parameters in an ideal network condition is presented in Section 4.7. In Section 4.8, in order to validate the accuracy of MANSim, a number of simulation scenarios for ideal network conditions are performed. The simulations show a 100% agreement between the analytical and simulation results using MANSim.

4.2.Probabilistic Flooding in a Noisy Environment

During route discovery, link failure between two neighboring nodes could take place due to noise interference (noisy environment) or due to node mobility. In this work, in order to investigate the effect of noise interference on the performance of probabilistic flooding optimization algorithm that is used by many dynamic routing algorithms for route discovery, the noisy environment is described by introducing a probability function, namely, the probability of reception (p_c). This noise interference could be either due to radio transmission problems (electromagnetic interference, collisions, obstacles, accessing a share channel, etc.) or because of dynamic environment with rapidly changing topologies.

The description of the probabilistic flooding algorithm in a noisy environment is straightforward. It is simply, when the receiving node is within the radio transmission range of the transmitter, a random test is performed to decide whether the request is successfully delivered to the receiver or being lost due to error. The random test is performed as follows: a random number ξ ($0 \leq \xi < 1$) is generated and compared with p_c, if ξ is less than or equal to p_c, then successful delivery occurs; otherwise, the request is not successfully delivered or being lost. The value of p_c is either predetermined or instantly computed using a certain probability distribution function. When receiving a request packet, a node rebroadcasts the packet with a retransmission probability (p_t), and each node is allowed to rebroadcast the received packet only once. This, of course, reduces the number of retransmissions and node average duplicate reception, thereafter the number of collisions and contentions. Once again, the value of p_t is either predetermined or instantly computed using a certain probability distribution function as discussed in Chapter 3.

This is at the cost of reducing the network reachability, because if the number of intermediate nodes is small and some of them will not rebroadcast the request packet, which may result in a failure of delivery of the request to the destination, so that the source has to reinitiate a new request. On the other hand, the noise introduces another problem that will reduce the network reachibility, since when a request is transmitted, a neighbouring node receives the request with a probability p_c and with a probability $1-p_c$ the request is lost. When p_c=1, this scheme models the probabilistic flooding in noiseless environment.

Figure (4.1) outlines the probabilistic flooding optimization algorithm for a noisy environment based on a single-trial scheme, while Figure (4.2) outlines the probabilistic flooding optimization algorithm for a noisy environment based on a multiple-trial scheme.

In both schemes for a noisy environment a random test must be performed to find out whether a successful delivery occurs or not.

Probabilistic Flooding Algorithm in a Noisy MANET Environment Based on the Single-Trial Scheme.

If IRange = 1 **Then** {The receiving node within the transmission range of the sender, in a noiseless environment guarantees request reception by the receiver, while in a noisy environment a random test must be performed to find out whether a successful delivery occurs or not. IRange = 0 means the receiver is not within the transmission range of the sender}

ξ_1=rnd() {ξ_1 some random number between 0 and 1}

If $\xi_1 <= p_c$ **Then** {Reception random test}

IRec(i)++ {Update the node reception index IRec(i)}

If IRet(i)=0 **Then** {The node has not retransmitted the request before (IRet(i) = 0)}

If ITry(i)=0 **Then** {The node has not tried to retransmit the request before (ITry(i) = 0)}

ξ_2=rnd() {ξ_2 some random number between 0 and 1}

ITry(i) = 1 {To indicate that the node has tried to retransmit the request}

If $\xi_2 <= p_t$ **Then**

Retransmit request

IRet(i) = 1 {Update the node retransmission index IRet(i) by equating it to 1}

End if

End if

End if

End if

End if

Figure (4.1) - Probabilistic flooding broadcast algorithm in a noisy MANET environment based on the single-trial scheme.

Probabilistic Flooding Algorithm in a Noisy MANET Environment Based on the Multiple-Trials Scheme.

```
If IRange = 1 Then {The receiving node within the transmission range of the sender, in a noiseless
                    environment guarantees request reception by the receiver, while in a noisy
                    environment a random test must be performed to find out whether a successful
                    delivery occurs or not. IRange = 0 means the receiver is not within the
                    transmission range of the sender}
   ξ1=rnd()  {ξ1 some random number between 0 and 1}

   If ξ1 <=pc Then {Perform reception random test}
      IRec(i)++ {Update the node reception index IRec(i)}

      If IRet(i) = 0 Then {The node has not retransmitted the request before (IRet(i) = 0}
         ξ2 = rnd() {ξ2 some random number between 0 and 1}

         If ξ2 <= pt Then
            Retransmit request
            IRet(i) = 1 {Update the node retransmission index IRet(i) by equating it to 1}
         End if
      End if
   End if
End if
```

Figure (4.2) - Probabilistic flooding algorithm in a noisy MANET environment based on the multiple-trials scheme.

4.3. Network Simulation

It is generally unfeasible to implement all wireless ad hoc algorithms before valid tests are being performed to evaluate their performance. It is clear that testing such implementations with real hardware is quite hard, in terms of the manpower, time, and resources required to validate the algorithm, and measure its characteristics in desired mobility scenarios. External conditions also can affect the measured performance characteristics. The preferred alternative is to model these algorithms in a detailed simulator and then perform various scenarios to measure their performance for various patterns of node densities, node mobility, radio transmission range, radio environment, size of traffic, etc.

There are a number of simulators that have been developed during the past decade for wireless networks such as OPNET [70], ns-2 [71], GloMoSim [72], etc. However, the number of simulators is still growing, and 16 out of 63 papers (25.4%) used a self-developed or custom simulator [69].

The main challenge to simulation is to model the process as close as possible to reality; otherwise it could produce entirely different performance characteristics from the ones discovered during actual use. In addition, the simulation study must carefully consider four major factors while conducting credible simulation for MANET research. The simulation study must be [69]:

i. Repeatable

ii. Unbiased, the results must not be specific to the scenario used in the experiment.

iii. Realistic: The scenarios and conditions used to test the experiment must be of a realistic nature.

iv. Statistically sound: The execution and analysis of the experiment must be based on mathematical principles.

4.4. The MANET Simulator (MANSim)

MANSim is a mobile ad hoc network simulator especially developed to simulate and evaluate the performance of a number of flooding optimization algorithms for MANETs [50]. It is written in C++ language, and it consists of four major modules:

i. Network module

ii. Mobility module

iii. Computational module

iv. Algorithm module

Following is a description of each of the above modules.

4.4.1 Network module (Geometrical configuration)

The network module is concerned with the geometrical configuration or nodes distribution within the network area. MANSim simulates two geometrical network configurations of different nodes distribution within the network area. These are:

i. Regular-grid node distribution

ii. Random node distribution.

For the two configurations, a geometrical area of size X×Y m is simulated [3].

i. Regular-grid node distribution configuration

In a regular-grid node distribution configuration, the network is considered as a regular-grid where nodes are placed at each intersection of the grid as illustrated in Figures (4.3) and (4.4). For this configuration, two node degrees are considered, namely 4-node degree and 8-node degree. In a 4-node degree (Figure (4.3)), each node is allowed to communicate directly with its vertical and horizontal neighbors, and the radio transmission range of the node covers one-hop neighbor in each direction. In an 8-node degree (Figure (4.4)), nodes are also allowed to communicate with the diagonal neighbors.

The regular-grid configuration is quite simplistic but it is useful for calculating benchmark analytical results for some computed network parameters for a specific network condition. These benchmark analytical results can be used to validate the simulation results.

However, a more realistic configuration is required, that may consider random (non-regular) node distribution and produce variable node degrees.

ii. Random node distribution configuration

In a random node distribution configuration, the nodes are randomly placed on the X×Y network area as illustrated in Figure (4.5). They are placed according to a particular probability distribution function (PDF), such as linear distribution, Poisson's distribution, etc. In our simulations, the *x* and *y* positions of the nodes are calculated according to a linear PDF, such as:

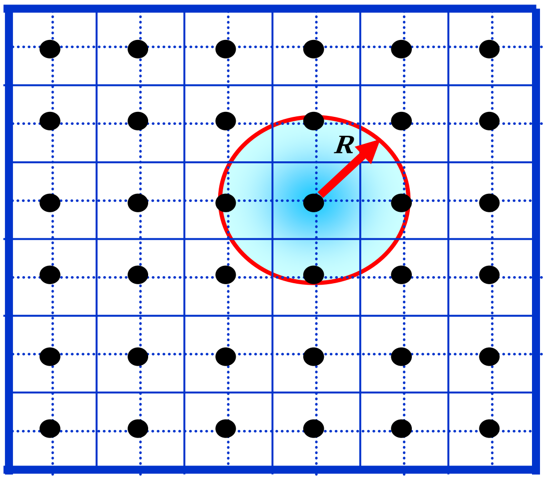
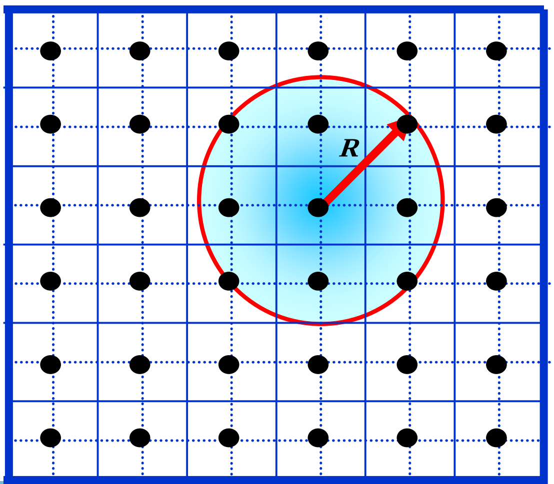


Figure (4.3) - Regular-grid nodes distribution (4-node



degree).

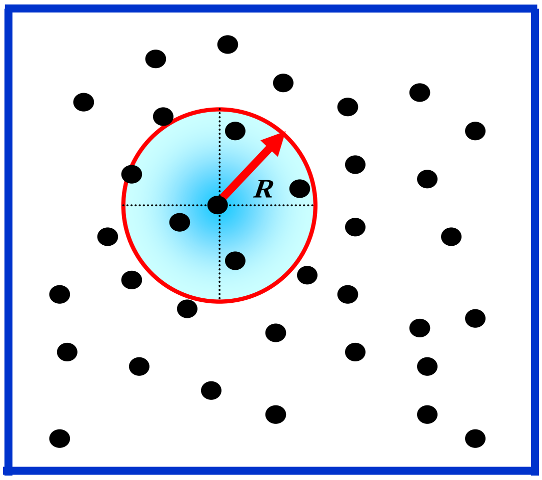
Figure (4.4) - Regular-grid nodes distribution (8-node degree)

Figure (4.5) - Random node distribution

$$x = X \cdot \xi \qquad (4.1)$$

$$y = Y \cdot \xi \qquad (4.2)$$

Where X and Y are the length and width of the network area, and ξ is a random number uniformly selected between 0 and 1 ($0 \leq \xi < 1$). Two nodes i and j are considered to be connected or neighbors if the Euclidean distance between these two nodes (r) is less than or equal to radio transmission range of the node (R), where r is given by:



$$r = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \qquad (4.3)$$

One important point that must be carefully considered using random node distribution is to make sure that initially each node within the network should have at least one neighboring node.

4.4.2 Mobility module

One of the main characteristics of MANETs is the mobility of their nodes. In the random walk mobility pattern, the direction of movement for a mobile node is randomly chosen from an appropriate PDF. In most applications, a node is allowed to move with equal probability in any direction within the geographical area of interest, i.e., the direction is sampled randomly from a uniform PDF.

In MANSim, the node mobility is simulated as follows: each node is allowed to move around randomly within the network area during the simulation. The movement pattern of a node is simulated by generating a direction (θ), a speed (u), and a time interval (τ), which is also referred to as a pause time. The direction is sampled from a uniformly distributed function between 0 to 2π, thus

$$\theta = 2\pi\xi \tag{4.4}$$

Nodes are either allowed to move with a pre-assigned average speed (u_{av}), i.e., $u=u_{av}$, a pre-assigned maximum speed (u_{max}), i.e., $u=u_{max}$, or a node speed is sampled randomly between 0 and u_{max} (i.e., $u=\xi u_{max}$).

In order to consider node mobility, a simulation time (T_{sim}) must be setup; it is divided into a number of time intervals (*nIntv*) that allows the pause time to be calculated as:

$$\tau = T_{sim}/nIntv \tag{4.5}$$

The distance traveled by the node is calculated as

$$d = u\tau \tag{4.6}$$

Then, a new node location at time $t+\tau$ is calculated by:

$$x(t+\tau) = x(t) + d\,Cos(\theta) \tag{4.7}$$

$$y(t+\tau) = y(t) + d\,Sin(\theta) \tag{4.8}$$

Where $x(t)$, $y(t)$ and $x(t+\tau)$, $y(t+\tau)$ are the old and new locations of the node, respectively. This new node location must be checked to be within the network area, if it is not (i.e., the node leaves the network area), there are different ways to bring the node back to the network. In this model the researcher uses a reduced weight approach to ensure that the node remains within the network area.

In the reduced weight appreach the node is kept moving in the same direction, but the distance traveled (d) is reduced by multiplying it by descending weight until the new location be within the network area (i.e., $d = d \bullet \omega$). The weight ω is given by:

$$\omega = \frac{(I_{\max} - k)}{I_{\max}} \quad (4.9)$$

An appropriate value for I_{max} is between 2 to 10, and k is set to zero and is incremented by 1 each time the node travels outside the network area.

4.4.3 Computational module

Many computational models start a simulation from a single source node positioned at the center of the network area, or from a single source node randomly selected within the network area. The simulation is repeated for S times, i.e., the source node is assumed to transmit S request messages. The results obtained from these simulations are averaged to give average values for the computed parameters. The results obtained reflect the average behavior with regards to this particular source node, but they may not well reflect the average behavior of other nodes within the network.

But, a major feature of MANSim computational module is that it does not randomly pick a node and use it as a fixed source node. Instead, a loop is performed using all nodes within the network as a source node, then the computation for the network parameters is performed sequentially over all nodes, except the source node, as destination nodes. The computed parameters for each source node are averaged over (n-1), and then these averaged values are averaged again over (n). In other words, the computed parameters are averaged over (n(n-1)). In this case, the computed parameters may well represent the average behavior of any of the nodes within the network.

Due to the probabilistic approach, in order to enhance the accuracy of the solution, the computation is repeated, in an inner loop, for each source and destination nodes for a number of runs, i.e., each source is allowed to initiate S requested messages. Once again, the computed parameters are averaged over S. However, it has been found that with small number of runs the solution is converged to a more stable solution, and for networks having no probabilistic behavior, i.e., p_t=1, S has no effect on the computed parameters and can be set to 1.

As it has been mentioned earlier, in order to consider node mobility, a simulation time is set. It is divided into a number of time intervals (*nIntv*) that yields a time interval or pause time $\tau = T_{sim}/nIntv.$, where T_{sim} is the total simulation time. The calculation is repeated, in an outer loop, for *nIntv*, and the results obtained for the computed parameters are averaged over *nIntv*. In general, it has been found that to obtain an adequate network performance, the pause time must be carefully chosen so that the distance traveled by the node, during location update interval, is less than the radio transmission range of the source node. For non-mobile nodes (fixed nodes) *nIntv* has no effect on the computed parameters and can be set to 1.

4.4.4 Algorithm module

In this module, the flooding optimization algorithm is implemented. For example the flooding optimization algorithm discussed in Section 4.2 is implemented here.

This module consists of a number of procedures to calculate the computed network parameters. In particular, it has procedures to calculate

i. Nodes that receive the request message. This occurs if the receiving node is within the radio transmission range of the transmitting node, and no error occurs during data transmission due to noise interference. Each time a node I successfully receives a request, an index iRec(i) is incremented by 1, where i represents the node ID. This index is used to calculate the network parameters such as: the average duplicate reception (ADR) and the reachability (RCH).

ii. Nodes that succeed to retransmit the request message. A node index iRet(i) is set to 1 if the node i retransmits the received request. This index is used to calculate the number of retransmission (RET) within the network.

Figure (4.5) outlines the algorithm and the computational modules for the probabilistic flooding optimization algorithm.

Computational Module of the Probabilistic Flooding Algorithm.

Loop over the number of intervals (*nIntv*)
{
    Loop over the number of nodes as source nodes (i=1, *n*)
    {
        Loop over the number of nodes as destination nodes (j=1, *n*), except for i=j
        {
            Loop over the number of transmitted request message (k=1, S)
            {
                Compute IRec() and IRet()
            }
            Compute the average values of the computed parameters (over S) for source node i and destination node j.
        }
        Compute the average values of the computed parameters (over *n*-1) for source node i and *n*-1 destination nodes.
    }
    Compute the average values of the computed parameters (over *n*) for *n* source nodes and *n*-1 destination nodes.
}
Compute the average values of the computed network parameters (over *nIntv*).

Figure (4.6) - Computational module of the probabilistic flooding algorithm.

4.5 Computed Parameters

Using the network simulator MANSim, a variety of network parameters are computed to evaluate, analyze, and compare the performance of the probabilistic algorithm. These parameters are recommended by the IETF to judge the performance of the flooding optimization algorithms. These parameters include: number of retransmissions (RET), average duplicate reception (ADR), reachability (RCH), saved rebroadcast (SRB), average hop counts (AHC), and disconnectivity (DIS). However, in this work the researcher shall only consider the following computed network parameters:

i. Number of retransmissions (RET). The average number of retransmissions or request messages, normalized to the total number of nodes within the network (*n*).

ii. Average Duplicate Receptions (ADR). The average number of request messages that is received by each node.

iii. Reachability (RCH). The average number of reachable nodes by any node normalized to the total number of nodes within the network (n).

In addition, MANSim can be used to investigate the effect of a number of input network parameters on the above computed parameters, such as: node density, node mobility, retransmission probability, probability of error in reception (reception probability), pause time, and simulation time.

In this work the researcher is mainly concerned with studying the effect of the following input parameters on the computed results:

i. Node density (n_d). The number of nodes per unit area ($n_d=n/A$), where A is the network area ($A=X\times Y$).

ii. Node mobility or node speed (u). Nodes are assumed to move with either an average speed (u_{av}), maximum speed (u_{max}), or a randomly selected speed.

iii. Node transmission radius (R), which represents the area that can be covered by a certain node.

iv. Retransmission probability (p_t). The probability of retransmitting a successfully received request message.

v. Reception probability (p_c). The probability of a request message being successfully received by a destination node that is located within the transmission range of the source node.

4.6. Network Conditions

In general, network condition or simulation environment can be classified into:

i. Ideal network condition.

ii. Realistic (non-ideal) network condition.

Although, ideal network condition does not exist in practice, but still it is very useful to provide best-case results with which to compare the performance of the newly developed algorithm. In addition, for such ideal network condition, an analytical solution can be derived to calculate the computed network parameters.

These analytically computed parameters are very useful to validate the accuracy of the algorithm and the simulation model. Features of an ideal network include the following:

i. Regular-grid node distribution

ii. The retransmission probability is 1 or pure flooding (p_t=1).

iii. No-error in reception or noise-free environment (p_c=1).

iv. The radio transmission range is extended to cover one node in each direction.

v. Fixed node or no node mobility (u=0).

If any of the parameters above is set to a different value, then this is considered as a non-ideal (realistic) network condition.

4.7.Analytical Solution

The main problem that is facing researchers is how they can evaluate or validate the accuracy of their simulation models, since there are no analytical solutions or experimental results that can be used to compare with. However, in order to validate the accuracy of the new simulation model analytical formulas are derived to calculate some network parameters, such as RET and ADR for an ideal network condition.

In this case, the computed parameters RET and RCH are n-2 and 1, respectively. Values of RET and RCH are the same for both 4-node and 8-node degrees. The ADR for 4-node and 8-node degrees are given by the following derived formulae [50]:

$$ADR_4 = \sum_{i=1}^{n} \sum_{j=1, j \neq i}^{n} \frac{8 + 6(n_x - 2) + 6(n_y - 2) + 4(n_x - 2)(n_y - 2) - G_4}{n^2(n-1)} \quad (4.10)$$

$$ADR_8 = \sum_{i=1}^{n} \sum_{j=1, j \neq i}^{n} \frac{12 + 10(n_x - 2) + 10(n_y - 2) + 8(n_x - 2)(n_y - 2) - G_8}{n^2(n-1)} \quad (4.11)$$

Where n_x and n_y are the edge-size in the x and y axis, or the number of nodes in the x and y direction, respectively, thus $n=n_x n_y$. Both n_x and n_y must be greater than 1. Values of G_4 and G_8 for corresponding node numbers (ID) are given in Table (4.1).

Table (4.1) Values of G_4 and G_8.				
#	G_4	G_8	Description	Node numbers
1	2	3	For nodes at the corner of the network area.	i=1 and j=1 i=n_x and j=1 i=1 and j=n_y i=n_x and j=n_y
2	3	5	For nodes at the edge of the network area (except the corners).	i=1 and j=2 to n_y-1 i=n_x and j=2, n_y-1 i=2 to n_x-1 and j=1 i=2 to n_x-1 and j=n_y
3	4	8	For nodes inside the network area.	i=2 to n_x-1 and j=2 to n_y-1

4.8 MANSim Validation

In order to validate the accuracy of MANSim and to ensure an accurate implementation for the new probabilistic algorithm, MANSim is used to simulate a number of ideal network condition scenarios. The input data for these scenarios are given in Table (4.2).

The results obtained for these simulations are given in Table (4.3). The results show a 100% agreement between the analytical and MANSim simulation results, for different node densities and different radio transmission range. These simulations validate the accuracy of MANSim and can be reliably used to solve realistic network conditions, and any variations in the values of computed network parameters may occur is due to the accuracy and efficiency of the algorithm or due to statistical errors.

Table (4.2) Input parameters for MANSim validation scenarios.	
Parameters	Values
Geometrical model	Regular-grid node distribution

Node degree	4-node and 8-node degrees
Network area	1000x1000 m
Number of nodes (*n*)	49 (7x7), 100 (10x10), 144 (12x12) nodes.
Transmission radius (*R*)	For 4-node degree *R*=150, 100, and 90 for 49, 100, and 144 nodes, respectively. For 8-node degree *R*=220, 150, and 130 for 49, 100, and 144 nodes, respectively.
Average node speed (*u*)	0 m/sec (Fixed node)
Retransmission probability (p_t)	1 (Pure flooding)
Reception probability (p_c)	1 (Ideal environment)
Number of intervals (*nIntv*)	1
Pause time (τ)	Insignificant
Number of request messages (S)	1

Table (4.3)

Analytical and MANSim solutions for an ideal network condition.

Parameters	Node degree	49 nodes	100 nodes	144 nodes
RET	4-Node	0.959	0.980	0.986
	8-Node	0.959	0.980	0.986
ADR	4-Node	3.359	3.564	3.641
	8-Node	6.237	6.772	6.979
RCH	4-Node	1.000	1.000	1.000
	8-Node	1.000	1.000	1.000

Chapter 5
Simulations and Performance Analysis

5.1. Introduction

In order to evaluate and analyze the performance of the probabilistic algorithm for more realistic network conditions, MANSim is used to simulate a number of different scenarios. These scenarios investigate the effect of a number of input network parameters, such as: (i) retransmission probability (p_t), (ii) reception probability (p_c), (iii) node density (n_d), (iv) node mobility or node speed (u), and (v) radio transmission range (R), on a number of computed network parameters, such as: (i) number of retransmission (RET), (ii) average duplicate receptions (ADR), and (iii) reachability (RCH). Definitions of those input and computed network parameters are given in Chapter 4.

The main objectives of these scenarios can be summarized as follows:

1. Scenario 1: Investigate the effects of p_t and p_c.
2. Scenario 2: Investigate the effect of n_d.
3. Scenario 3: Investigate the effect of u.
4. Scenario 4: Investigate the effect of R.

The results obtained for the above four scenarios are presented in tables and graphs in Sections 5.2 to 5.5, respectively. Finally, in this chapter, the results obtained are discussed and summarized.

5.2. Scenario 1: Investigate the effects of (pt) and (pc).

The first scenario investigates the effect of p_t and p_c on RET, ADR, and RCH. The results obtained are used to evaluate the effect of both p_t and p_c on the main computed parameters. The input parameters for this scenario are given in Table (5.1). The result obtained for RET, ADR, and RCH are shown in Figures (5.1) to (5.3), respectively.

Table (5.1) Input parameters for Scenario 1.	
Parameters	**Values**
Geometrical model	Random node distribution
Network area	1000x1000 m
Number of nodes (*n*)	100 nodes
Transmission radius (*R*)	200 m
Average node speed (*u*)	5 m/sec
Retransmission probability (p_t)	0.5 to 1.0 in step of 0.1
Reception probability (p_c)	0.5 to 1.0 in step of 0.1
Simulation time (T_{sim})	900 sec
Number of intervals (*nIntv*)	60
Pause time (τ)	15 sec
Number of transmitted requests per node (*S*)	10

As it can be seen from Figures (5.1, 5.2, and 5.3), when the retransmission probability p_t increases, the computed parameters (RET, ADR, and RCH) increase. In practice it's considered that the increase in RCH is an advantage, while the increase in RET and ADR is a drawback. Reachability improves with higher p_t, since more nodes will try to retransmit the received route request (RREQ) packet.

On the other hand, the noise factor has an opposite effect on the studied parameters, as more noise is introduced to the network environment, a reduction in the computed parameters is expected, since noise will inhibit some nodes from receiving an intelligible RREQ packet, and as a result these nodes will not participate in the retransmission process. In this case the reduction in RET and ADR is an advantage, while the reduction in RCH is a drawback.

The reduction in the computed parameters is caused by the environment itself, because of the noise factor at one end, and the ever changing network topology due to nodes mobility at the other end, or both, and not by the optimized flooding scheme used which is the probabilistic scheme used in this thesis.

In Figure (5.3) when applying the probabilistic flooding in a noise-free environment (p_c=1) for (p_t = 0.9), the RCH is 86%. A reduction of 16% in RCH is observed when (p_c=0.8), and more reduction is observed when more noise is introduced to the environment, it reaches 28% when (p_c=0.5).

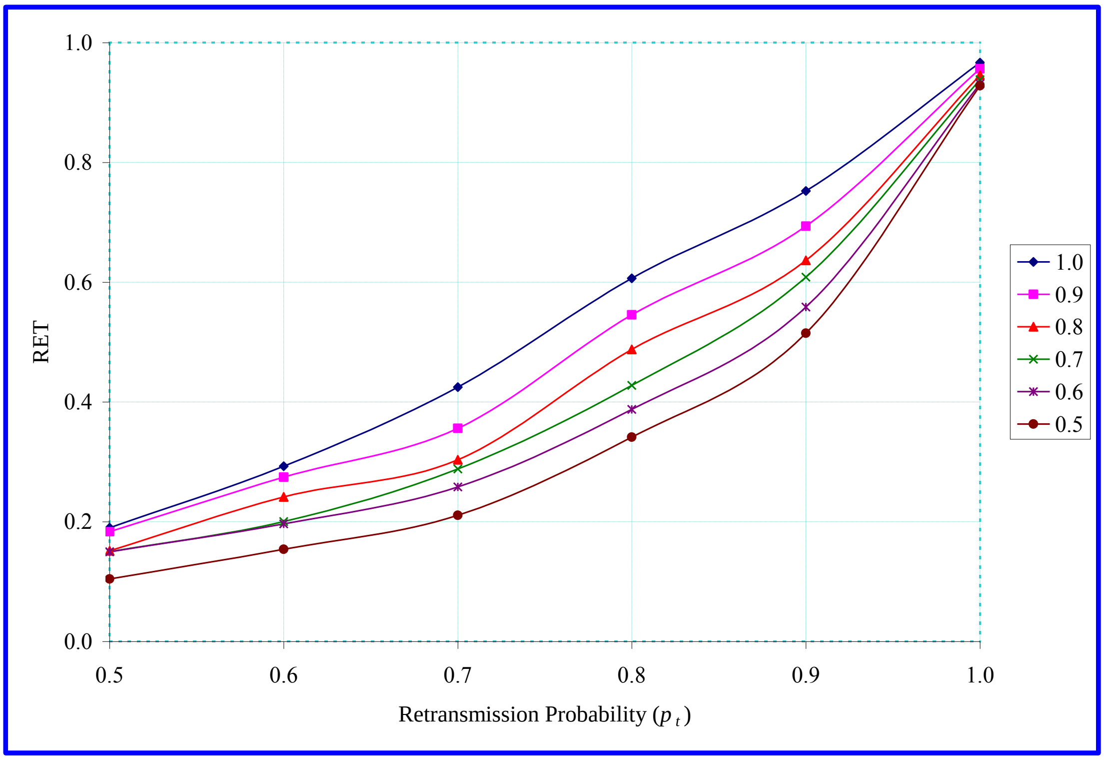


Figure (5.1) - Variation of RET with p_t for various p_c (Legend: p_c).
(n=100 and u=5 m/sec, R=200 m).

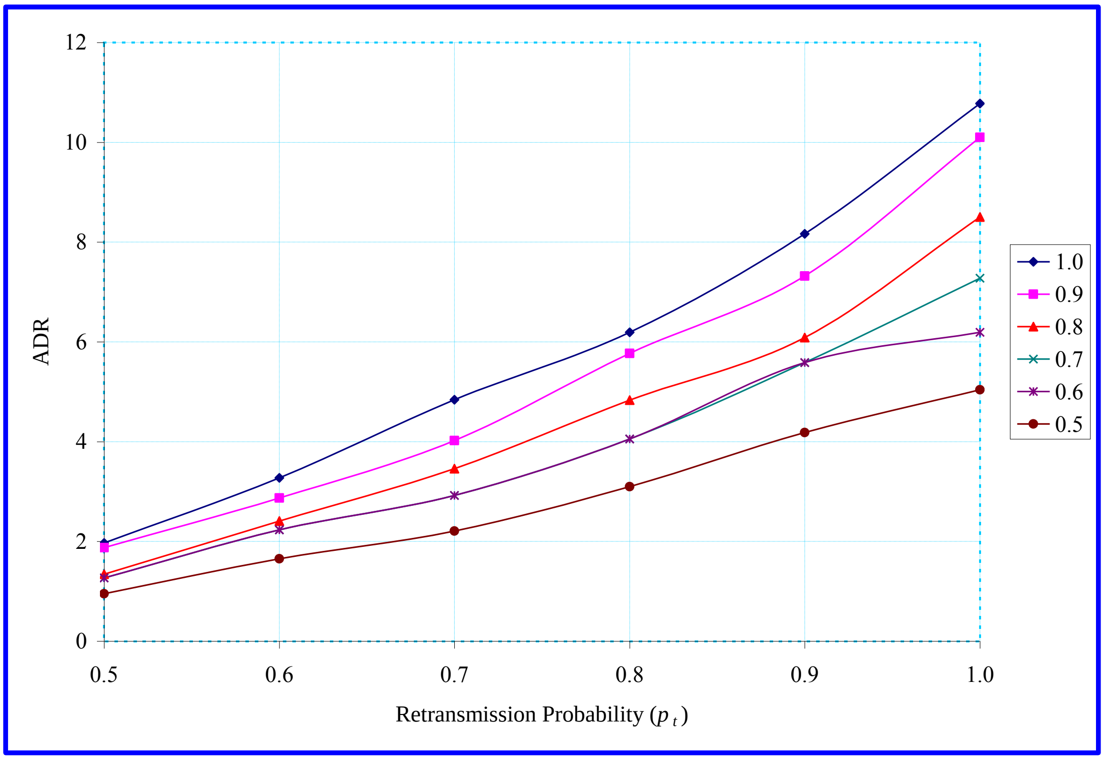


Figure (5.2) - Variation of ADR with p_t for various p_c (Legend: p_c).

(n=100 and u=5 m/sec, R=200 m).

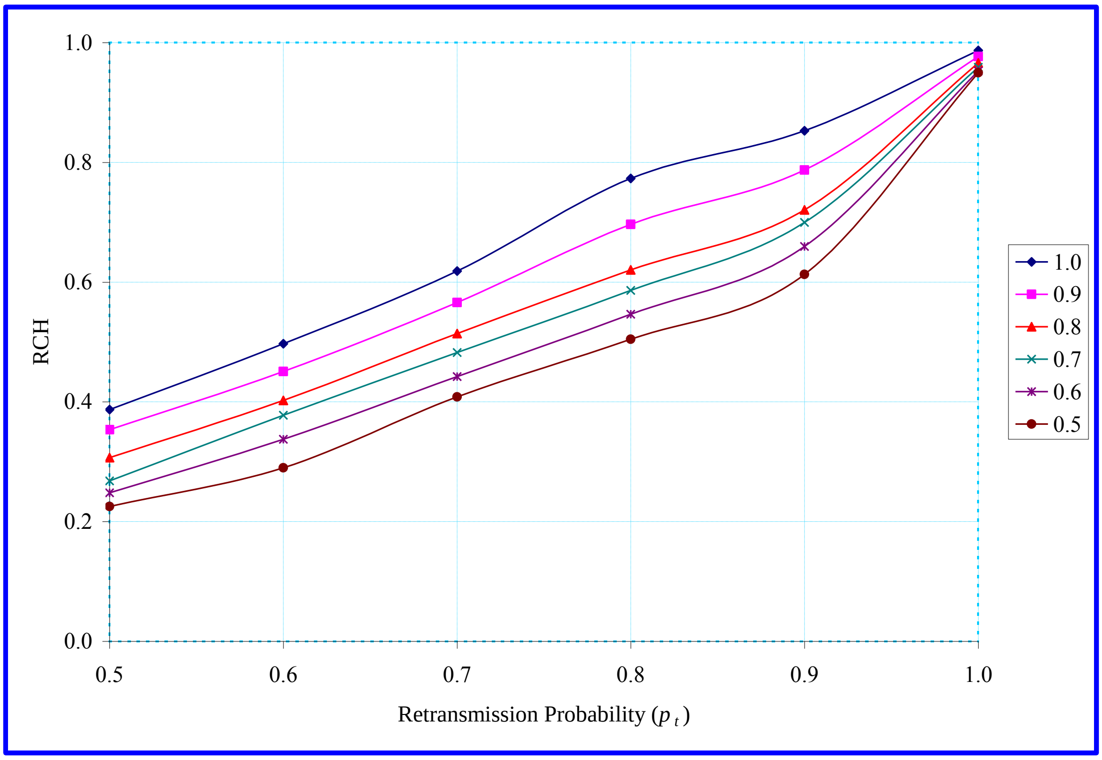


Figure (5.3) - Variation of RCH with p_t for various p_c (Legend: p_c).

(n=100 and u=5 m/sec, R=200 m).

5.3. Scenario 2: Investigating the Effect of Node Density

The second scenario investigates the effect of the node density (n_d) on RET, ADR, and RCH for various p_t and p_c. The nodes are assumed to move with an average of 5 m/sec. The input parameters for this scenario are given in Table (5.2).

The results obtained for this scenario for RET, ADR, RCH are shown in Figures (5.4), (5.5), (5.6), (5.7), (5.8) and (5.9), respectively, for two types of environments, noise-free environment (p_c=1), and noise-prone environment (p_c=0.8).

Table (5.2)
Input parameters for Scenario 2.

Parameters	Values
Geometrical model	Random node distribution
Network area	1000x1000 m
Number of nodes (n)	50, 100, 150 nodes.
Transmission radius (R)	200 m
Average node speed (u)	5 m/sec
Retransmission probability (p_t)	0.5 to 1.0 in step of 0.1
Reception probabilities (p_c)	0.8 and 1.0
Simulation time (T_{sim})	900 sec
Number of intervals (*nIntv*)	60
Pause time (τ)	15 sec
Number of transmitted requests per node (S)	10

Many conclusions may come out of these figures, and that depends on the way of looking at them. However, there are no surprises in the results where all parameters, as expected, are decreasing as p_t decreases for all node densities. Reachability improves with higher density and slower nodes for the following reason. As the density of the nodes increases, the number of nodes covering a particular area also increases.

As the probability of re-broadcast is adjustable for every node, this implies that there are more candidates for transmission in each ‘‘coverage’’ area. Hence, there is a greater chance that a broadcast re-transmission occurs, resulting in increased reachability.

Moreover, for a given transmission range, as density increases the connectivity of the network increases. As a result, a small broadcasting probability, p_t, is sufficient to achieve high reachability. However, a larger p_t is required if the node distribution is sparse, the amount of reachability increases, proportionally to p_t, as p_t increases.

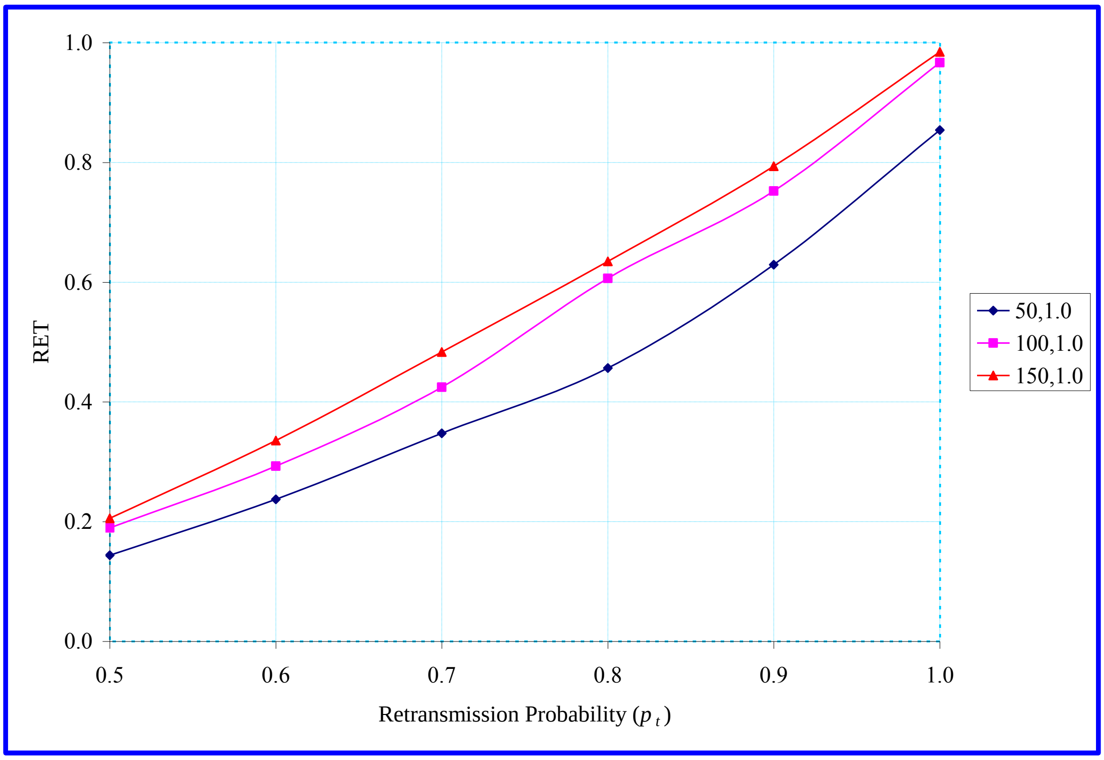


Figure (5.4) - Variation of RET with p_t for various n_d and p_c (Legend: n, p_c).

(u=5 m/sec, R=200 m).

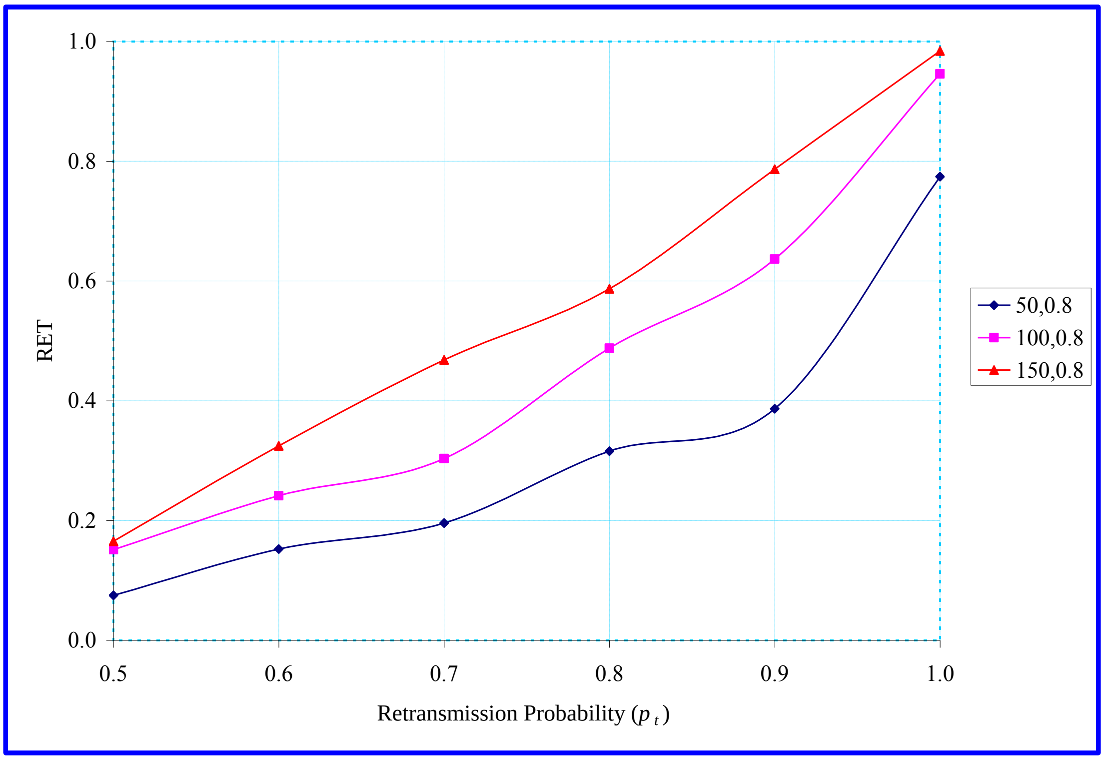


Figure (5.5) - Variation of RET with p_t for various n_d and p_c (Legend: n, p_c).

(u=5 m/sec, R=200 m).

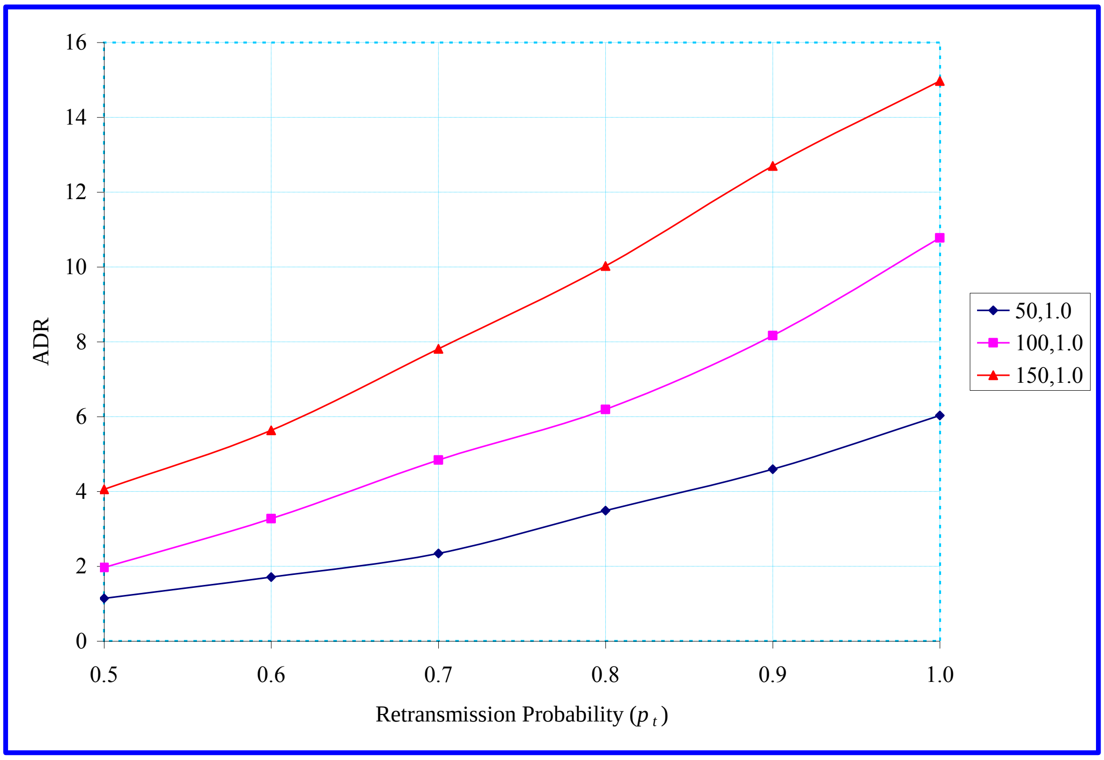


Figure (5.6) - Variation of ADR with p_t for various n_d and p_c (Legend: n, p_c).

(*u*=5 m/sec, *R*=200 m).

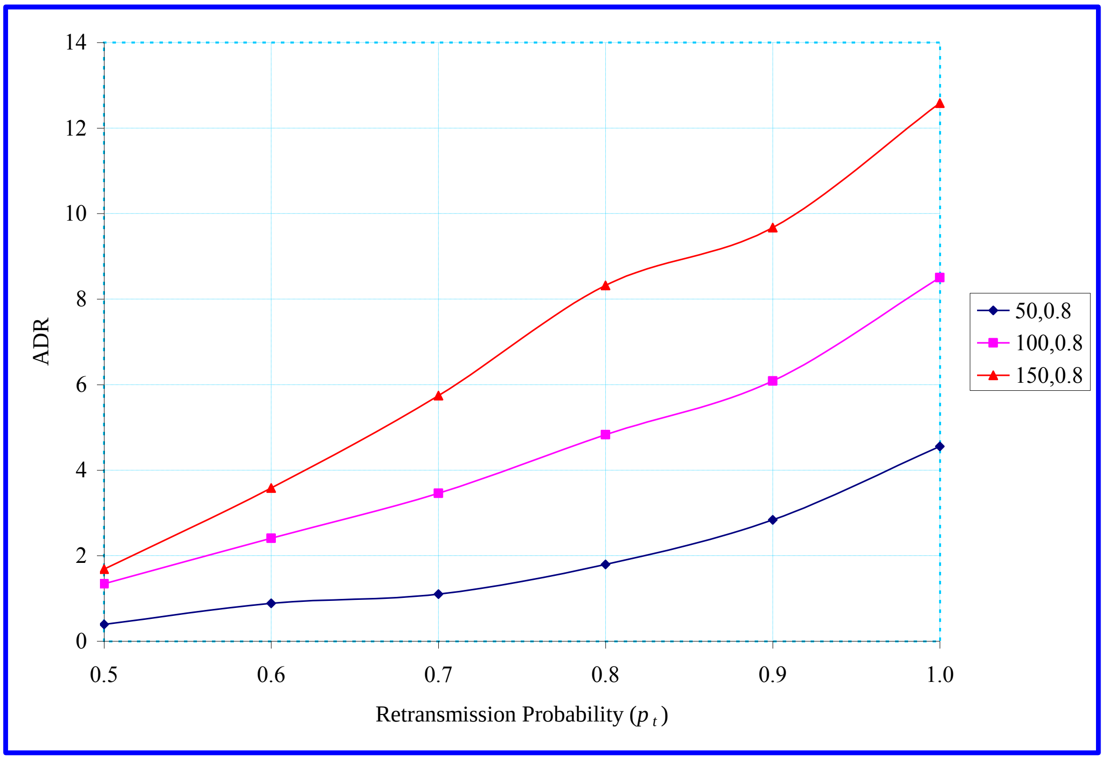


Figure (5.7) - Variation of ADR with p_t for various n_d and p_c (Legend: *n*, p_c).

(*u*=5 m/sec, *R*=200 m).

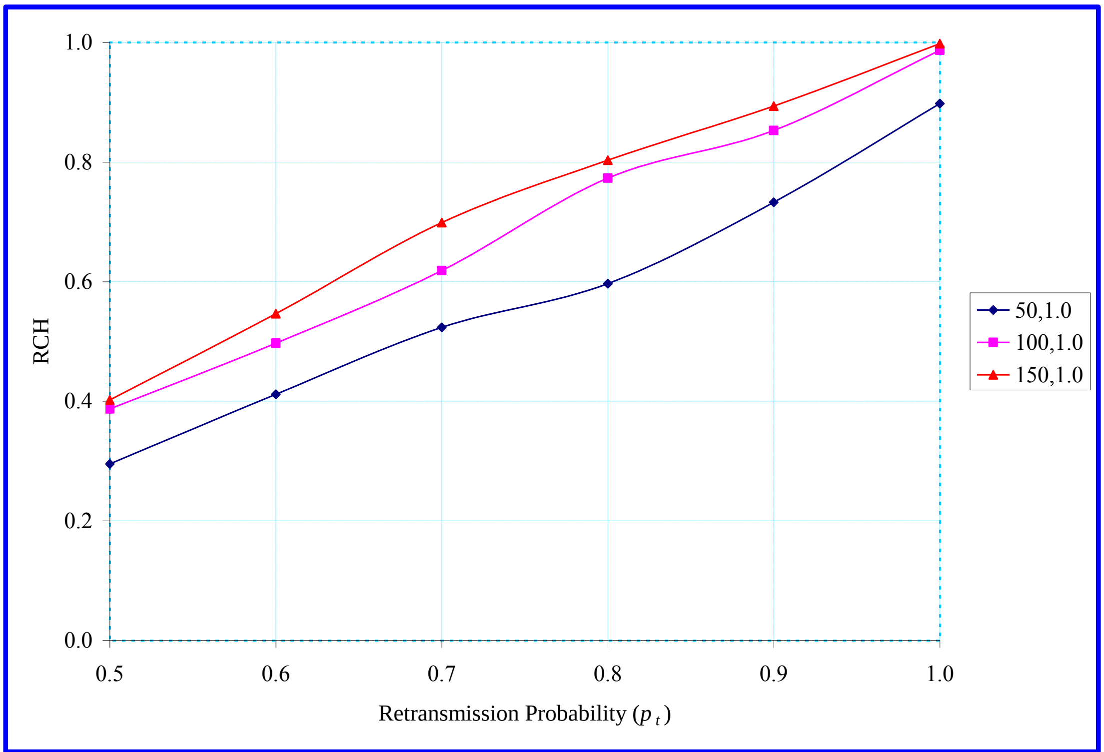


Figure (5.8) - Variation of RCH with p_t for various n_d and p_c (Legend: *n*, p_c).

(*u*=5 m/sec, *R*=200 m).

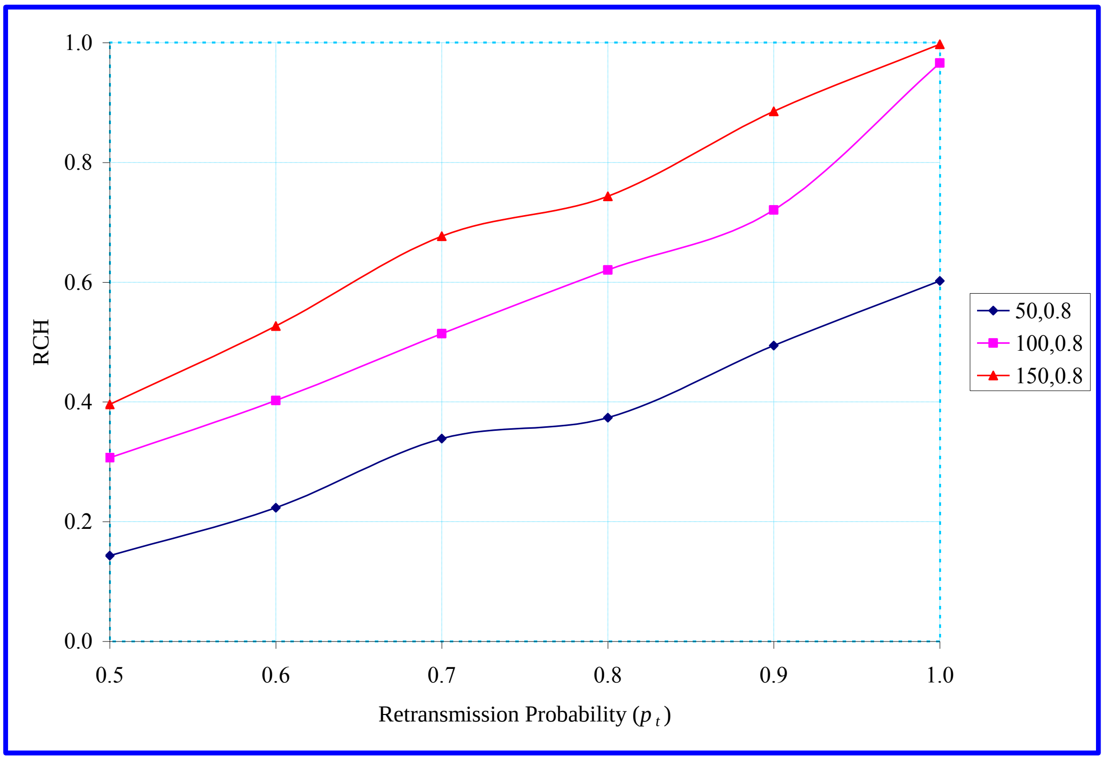


Figure (5.9) - Variation of RCH with p_t for various n_d and p_c (Legend: *n*, p_c).

(*u*=5 m/sec, *R*=200 m).

Noise, as stated previously has an opposite effect on the computed parameters; it will try to reduce the values of these parameters. This effect will be very small for dense networks, since more nodes exist that share a common coverage area, but in sparse network the noise effect will be more. For example in Figures (5.8, and 5.9), in a noise-free environment (p_c=1), (p_t = 0.9), and (n_d = 150) the RCH is 90%. A reduction of 0.8% is observed when (p_c=0.8), and this will increase as more noise is introduced in the environment. While when (n_d = 50) the corresponding reduction is almost 33%, which is huge compared to 0.8%. Table (5.3) presents a comparison between three flooding algorithms, pure, and probabilistic (with p_t=0.9 and 0.8, p_c =1.0) flooding algorithms. This table can be used to demonstrate and analyze the performance of the probabilistic algorithm in a realistic MANET with various input network parameters.

Table (5.3)

Values of RET, ADR, and RCH for various values of p_t, p_c, and n.

(u=5 m/sec, R=200 m).

p_t	n	p_c=1.0 (Noiseless)			p_c=0.8 (Noisy)		
		RET	**ADR**	**RCH**	**RET**	**ADR**	**RCH**
1.0	50	0.854	6.032	0.898	0.774	4.555	0.602
0.9		0.629	4.593	0.733	0.387	2.837	0.494
0.8		0.457	3.488	0.596	0.316	1.797	0.374
1.0	100	0.967	10.780	0.987	0.946	8.501	0.966
0.9		0.752	8.166	0.853	0.636	6.087	0.721
0.8		0.606	6.192	0.773	0.488	4.831	0.621
1.0	150	0.985	14.972	0.998	0.984	12.584	0.998
0.9		0.794	12.699	0.893	0.787	9.672	0.885
0.8		0.635	10.023	0.803	0.587	8.321	0.744

Table (5.3) shows that the flooding algorithm has the best performance in reachability, reaching nearly 1.0 for dense networks. The results show also the impact of noise on reachability, which decreases as more noise is introduced to the network environment. The percentage of reduction (**P_r**) between noise-free and noise-prone environments is given by:

$$P_r = \frac{V_i - V_n}{V_i} \times 100 \qquad (5.1)$$

Where **V_i** and **V_n** are the values of the computed parameter for a specific optimization scheme in ideal and noisy environment, respectively. Table (5.4) shows the difference between these environments.

Table (5.4) Variation of RET, ADR, and RCH as p_c changed from 1.0 to 0.8. (u=5 m/sec, R=200 m).				
p_t	n	Reduction (%)		
		RET	ADR	RCH
1.0	50	9.33	24.48	32.94
0.9		38.55	38.23	32.55
0.8		30.85	48.48	37.34
1.0	100	2.15	21.13	2.12
0.9		15.41	25.46	15.50
0.8		19.60	21.98	19.76
1.0	150	0.06	16.00	0.06
0.9		0.91	23.83	0.90
0.8		7.54	16.98	7.41

As it can be seen from table (5.4), there is a reduction in all the computed parameters, due to noise, and that reduction is very huge regarding the reachability, especially in networks with small number of nodes for the reasons mentioned earlier.

5.4. Scenario 3: Investigating the Effect of Nodes Mobility

The third scenario investigates the effect of the node average speed (u) on RET, ADR, and RCH for various values of p_t and p_c. The input parameters for this scenario are given in Table (5.5). The results obtained for RET, ADR, and RCH are shown in Figures (5.10), (5.11), (5.12), (5.13), (5.14), and (5.15) respectively.

Table (5.5) Input parameters for Scenario 3.	
Parameters	**Values**
Geometrical model	Random node distribution
Network area	1000x1000 m
Number of nodes (*n*)	100 nodes.
Transmission radius (*R*)	200 m
Average node speed (*u*)	2, 5, 10 m/sec
Retransmission probability (p_t)	0.5 to 1.0 in step of 0.1
Reception probabilities (p_c)	0.8 and 1.0
Simulation time (T_{sim})	900 sec
Number of intervals (*nIntv*)	30, 60, and 90 for 2, 5, 10 m/sec average nodes speed
Pause time (τ)	30, 15, 10 sec for 2, 5, 10 m/sec average nodes speed
Number of transmitted requests per node (*S*)	10

As it can be seen from these figures, the computed parameters behave randomly, and this is because of the mobility model used, which is the reduced weight model. In this model, the behavior of nodes cannot be predicted due to the fact that there are two random factors (direction, and speed) that also cannot be predicted, but one sure thing is that noise will reduce these parameters for the two types of flooding (pure, and probabilistic).

The insignificant fluctuation in the results is due to statistical errors, especially for small number of nodes or low nodes densities. However, as the number of nodes increases, the results vary almost smoothly and linearly. This is because, in MANSim computational model, the results are averaged over $n(n-1)$.

In addition, the mobility outer loop size, which is a function of the simulation time and the pause time ($nIntv=T_{sim}/\tau$) has a significant effect on the computed parameters and stability of the solution, and as *nIntv* increases a more stable and a reliable solution can be obtained.

Table (5.6) shows the results of computed parameters for different nodes speeds, for two types of environments, noise-free (p_c=1.0) and noise-prone (,p_c =0.8), as it can be seen, and as mentioned earlier the behavior of nodes cannot be predicted due to the fact that there are two random factors (direction, and speed)

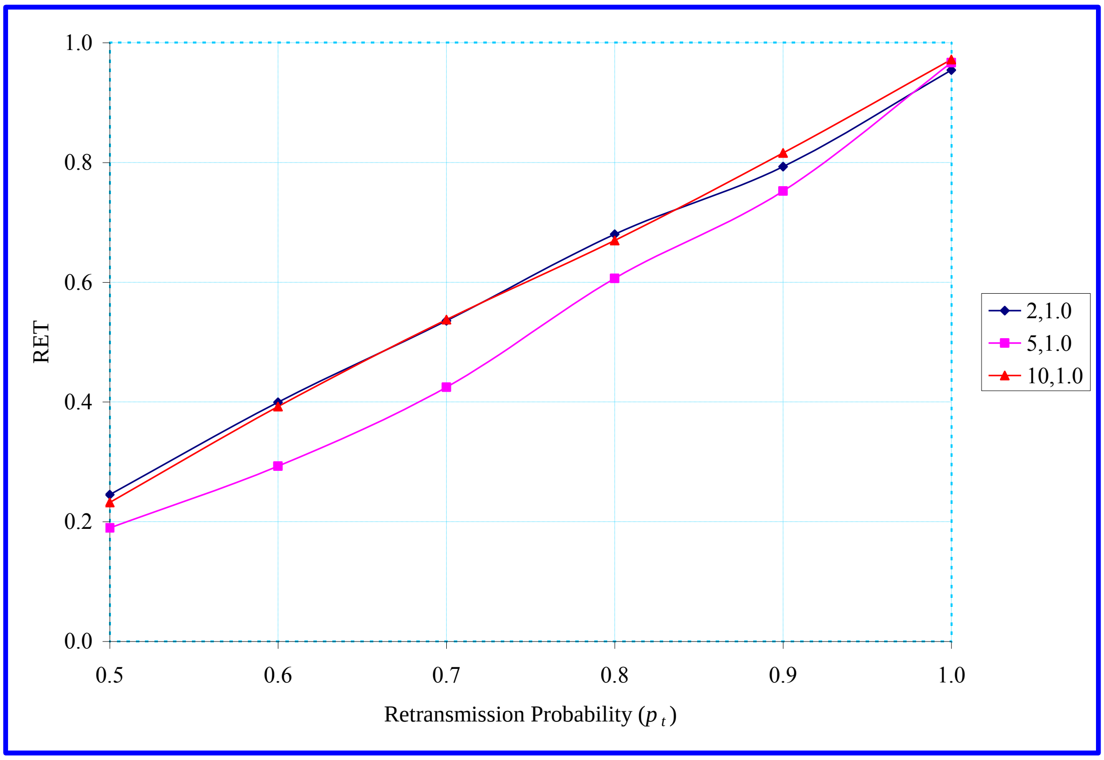


Figure (5.10) - Variation of RET with pt for various *u* and p_c (Legend: *u*, p_c).

(*n*=100 nodes, *R*=200 m).

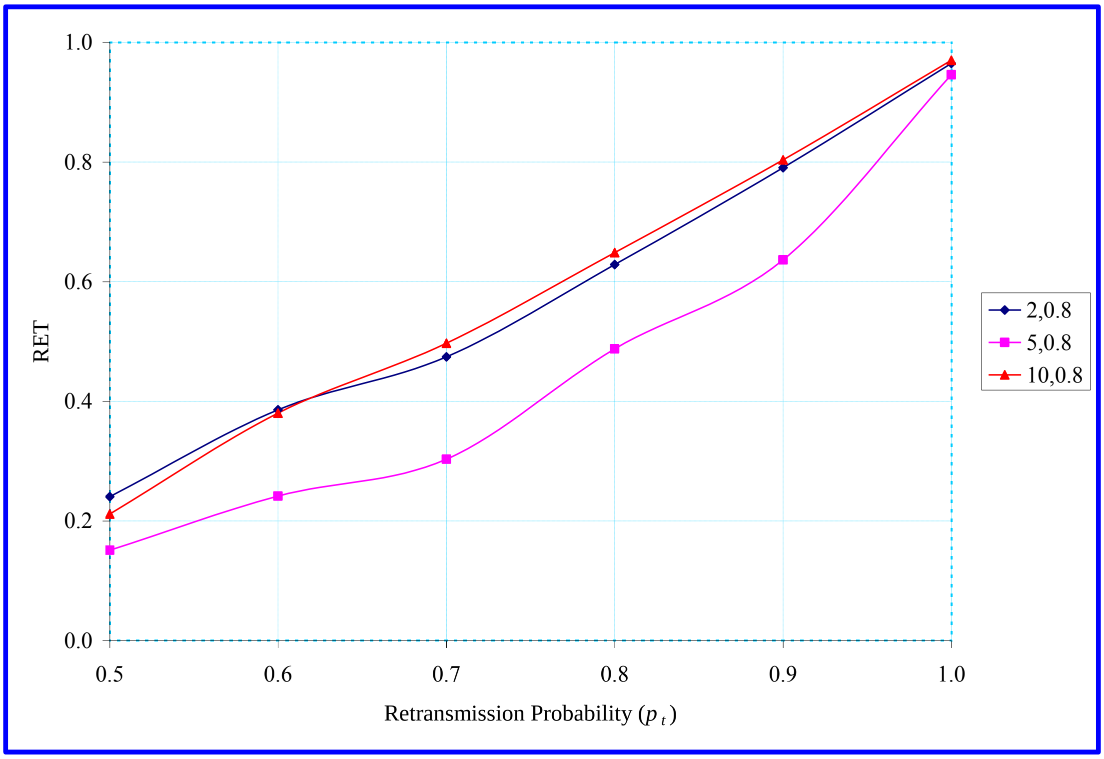


Figure (5.11) - Variation of RET with p_t for various u and p_c (Legend: u, p_c).

(n=100 nodes, R=200 m).

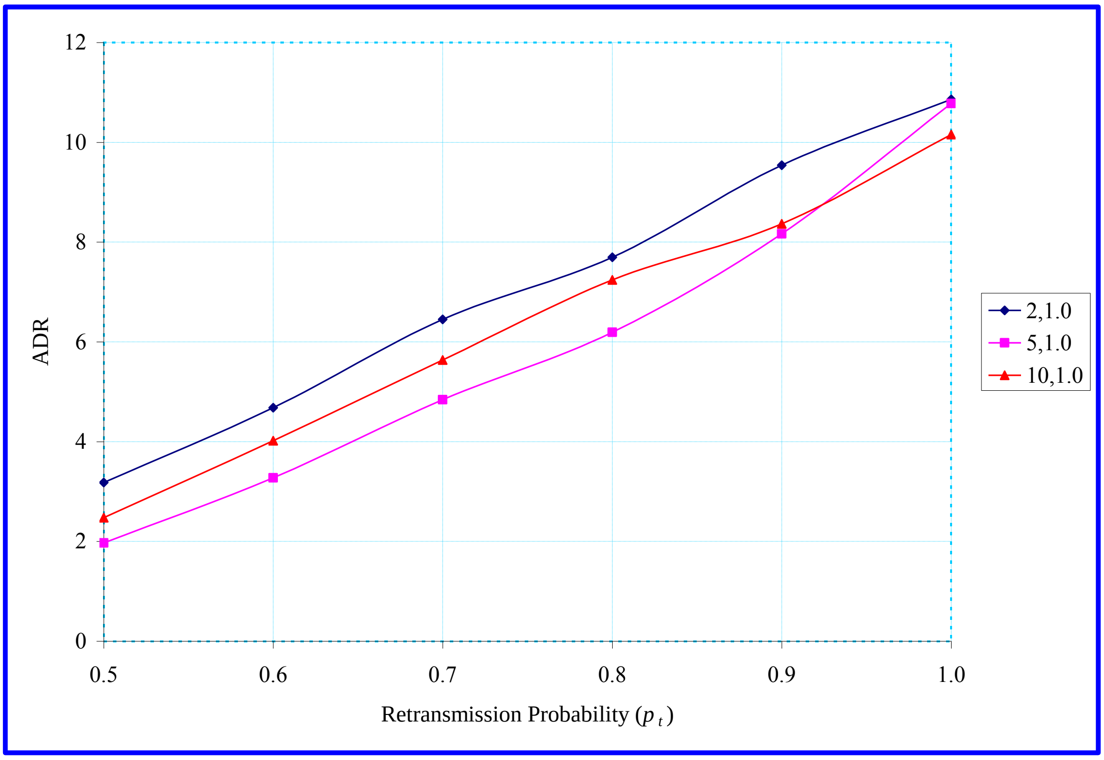


Figure (5.12) - Variation of ADR with p_t for various u and p_c (Legend: u, p_c).

(n=100 nodes, R=200 m).

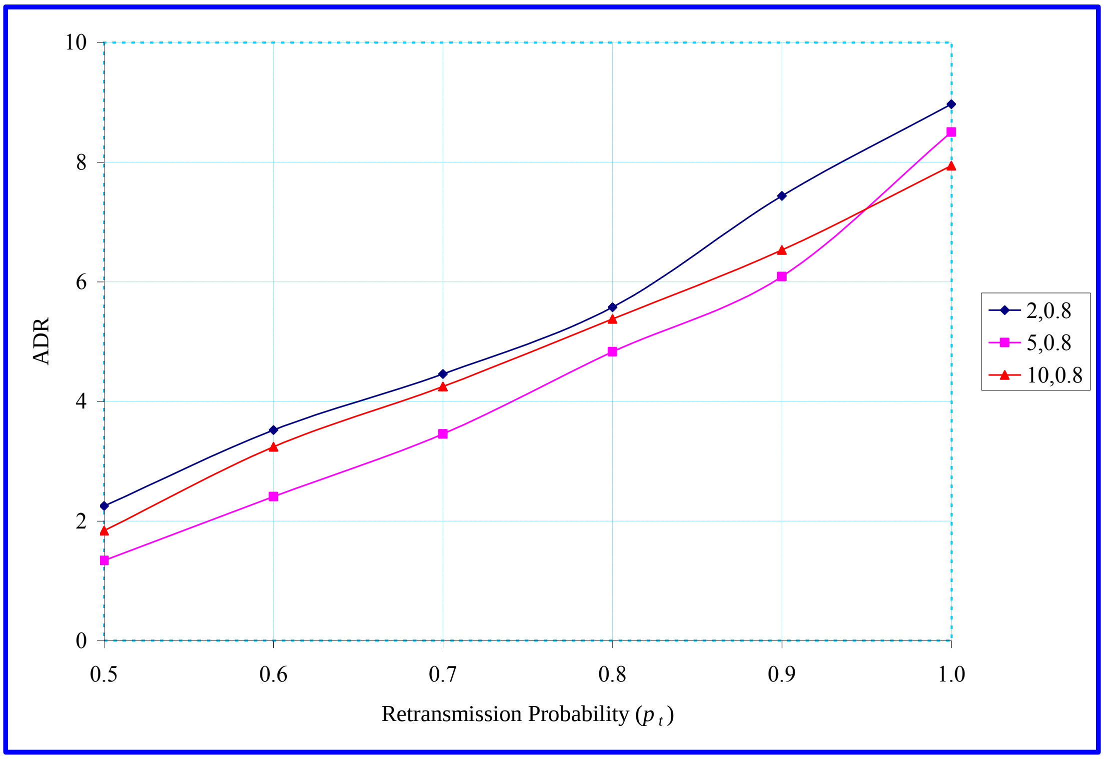


Figure (5.13) - Variation of ADR with p_t for various u and p_c (Legend: u, p_c).

(n=100 nodes, R=200 m).

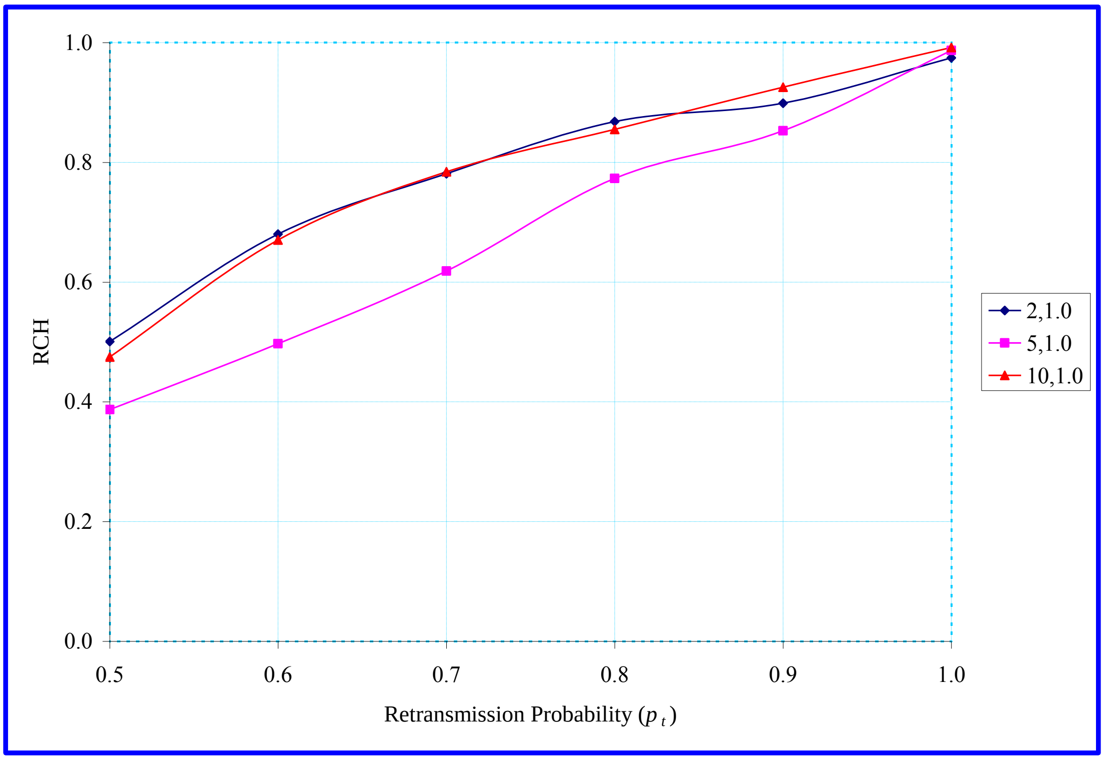


Figure (5.14) - Variation of RCH with p_t for various u and p_c (Legend: u, p_c). (n=100 nodes, R=200 m).

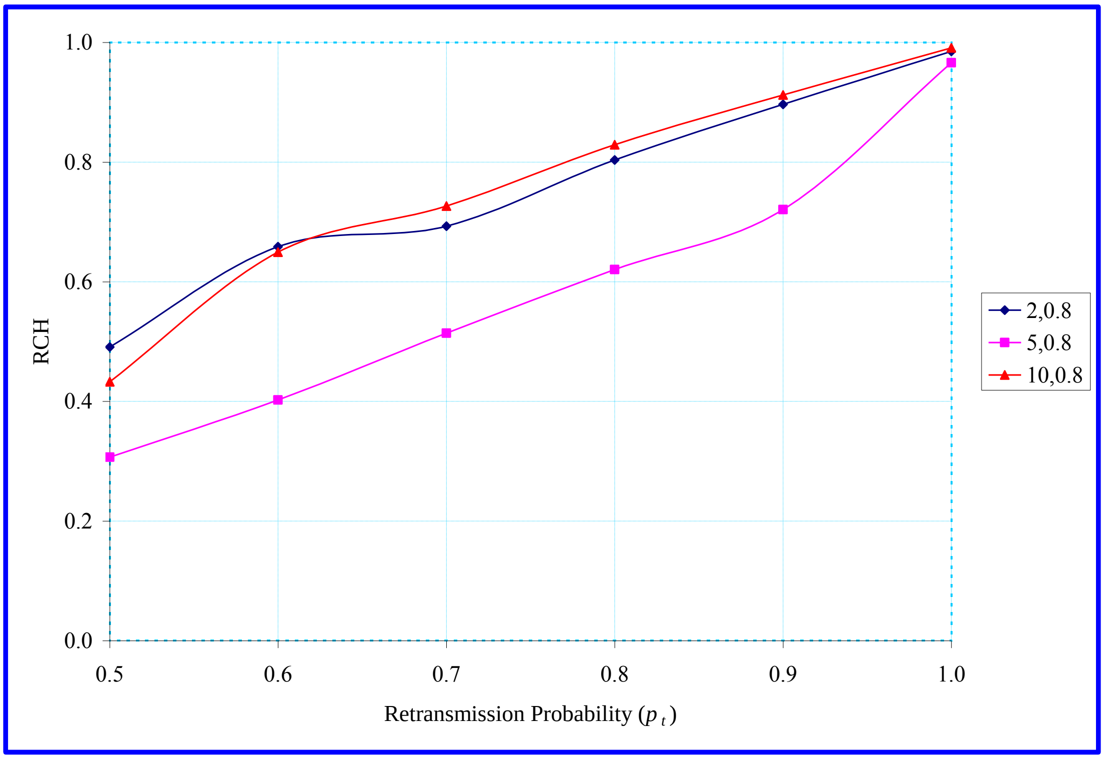


Figure (5.15) - Variation of RCH with p_t for various u and p_c (Legend: u, p_c). (n=100 nodes, R=200 m).

As it can be seen from table (5.7), there is a reduction in all the computed parameters, due to noise, and that reduction is very huge regarding the ADR, while a small reduction is observed regarding RCH for low and high speed (2 m/s, and 10 m/s).

Table (5.6)

Values of RET, ADR, and RCH for various values of p_t, p_c, and u.

(n=100 nodes, R=200 m).

p_t	u	p_c=1.0 (Noiseless)			p_c=0.8 (Noisy)		
		RET	ADR	RCH	RET	ADR	RCH
1.0	2	0.954	10.860	0.975	0.965	8.968	0.965
0.9		0.793	9.542	0.899	0.790	7.435	0.897
0.8		0.680	7.694	0.868	0.629	5.575	0.803
1.0	5	0.947	10.780	0.987	0.946	8.501	0.966
0.9		0.752	8.166	0.853	0.636	6.087	0.720
0.8		0.606	6.192	0.773	0.488	4.831	0.620
1.0	10	0.972	10.157	0.992	0.970	7.942	0.991
0.9		0.816	8.364	0.926	0.803	6.530	0.912
0.8		0.670	7.242	0.855	0.649	5.379	0.829

Table (5.7) Variation of RET, ADR, and RCH as p_c changed from 1.0 to 0.8. (n=100 nodes, R=200 m).				
p_t	n	Reduction (%)		
		RET	ADR	RCH
1.0	2	1.01	17.41	0.98
0.9		0.35	22.08	0.25
0.8		7.54	27.54	7.40
1.0	5	2.15	21.14	2.12
0.9		15.41	25.47	15.50
0.8		19.60	21.98	19.76
1.0	10	0.18	21.81	0.11
0.9		1.52	21.92	1.45
0.8		3.18	25.72	3.05

5.5 Scenario 4: Investigating the Effect of Radio Transmission Range

The fourth scenario investigates the variation of the computed parameters RET, ADR, and RCH with p_t for various values of R and p_c. The values of n and u are 100 nodes and 5 m/sec, respectively. The input parameters for this scenario are given in Table (5.8).

Table (5.8) Input parameters for Scenario 4.	
Parameters	**Values**
Geometrical model	Random node distribution
Network area	1000x1000 m
Number of nodes (*n*)	100 nodes.
Transmission radius (*R*)	150, 200, 250 m
Average node speed (*u*)	5 m/sec
Retransmission probability (p_t)	0.5 to 1.0 in step of 0.1
Reception probabilities (p_c)	0.8 and 1.0
Simulation time (T_{sim})	900 sec
Number of intervals (*nIntv*)	60
Pause time (τ)	15 sec
Number of transmitted request per node (*S*)	10

The results obtained for this scenario for RET, ADR, RCH are shown in Figures (5.16), (5.17), (5.18), (5.19), (5.20) and (5.21), respectively.

The simulation results show that as node's *R* increases, the computed parameters increase. This is obvious, since as *R* increases more intermediate nodes can be reached in a single hop, and thus, there will be more request messages retransmissions. Thereafter, request messages are likely to be successfully delivered to the requested destination nodes.

However, the slight fluctuation that can be seen in the figures can be due to nodes mobility or statistical errors. However, the researcher believes it is mainly due to nodes mobility; especially in practice, a relatively high average node speed of 5 m/sec (18 Km/hr) is applied, and the statistical errors are insignificant due to the large number of request messages that are simulated.

In addition, for large radio transmission range, the variation is almost linear, because of the 5 m/sec average node speed and 15 sec pause time, the node is allowed to move 75 m in any direction, before an update to its new location is performed. For example, if the node moves away from the source node, in the worst case, it can travel 75 m compared to 250 m radio transmission range, i.e. 33% of the range. Thus, it is highly likely to remain within the coverage area of the source node.

As it can be seen from Figure (5.20), the reachability for 250 m radio transmission range is around 83% with a retransmission probability of 0.7. This result suggests that probabilistic algorithm is very efficient and reliable in a network that has nodes with a high mobility and a large coverage area.

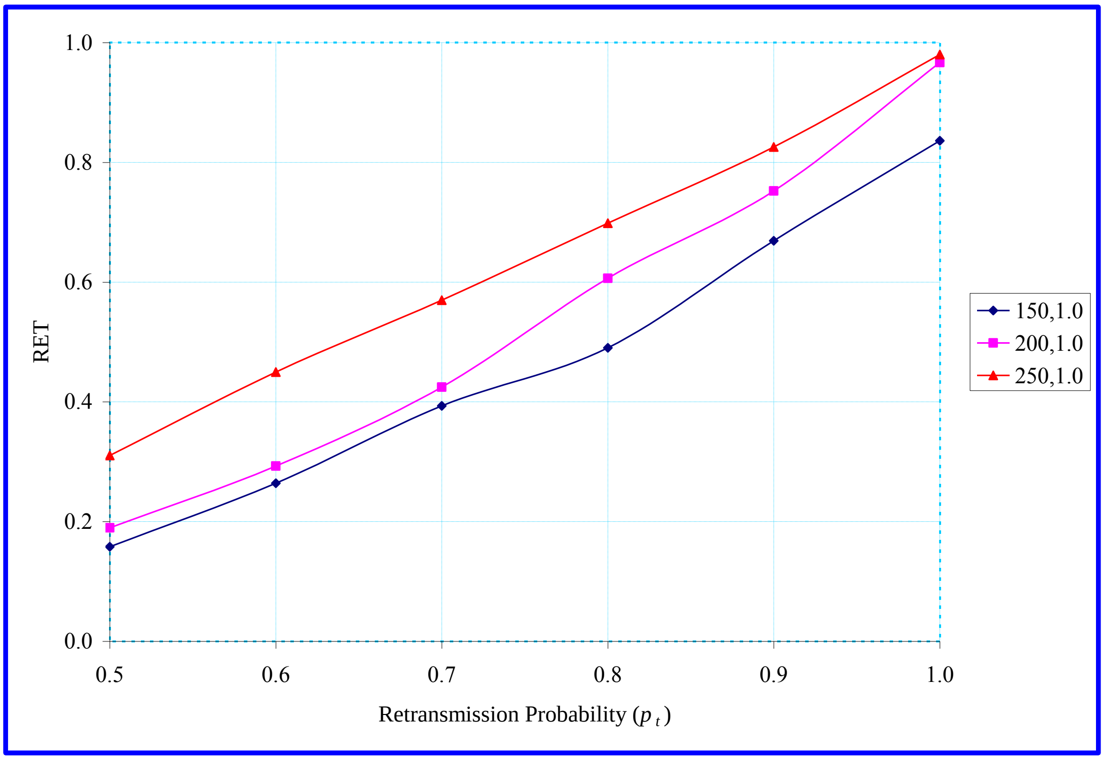


Figure (5.16) - Variation of RET with p_t for various R and p_c (Legend: R, p_c).
(n=100 nodes, u=5 m/sec).

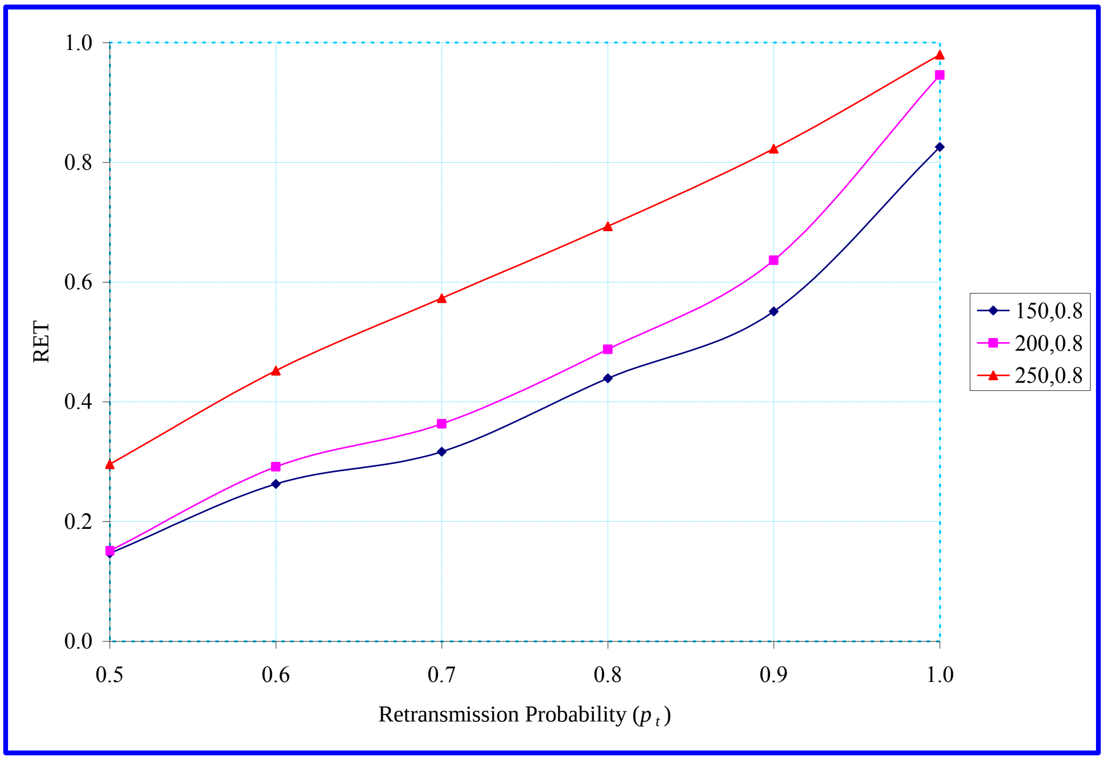


Figure (5.17) - Variation of RET with p_t for various R and p_c (Legend: R, p_c).

(n=100 nodes, u=5 m/sec).

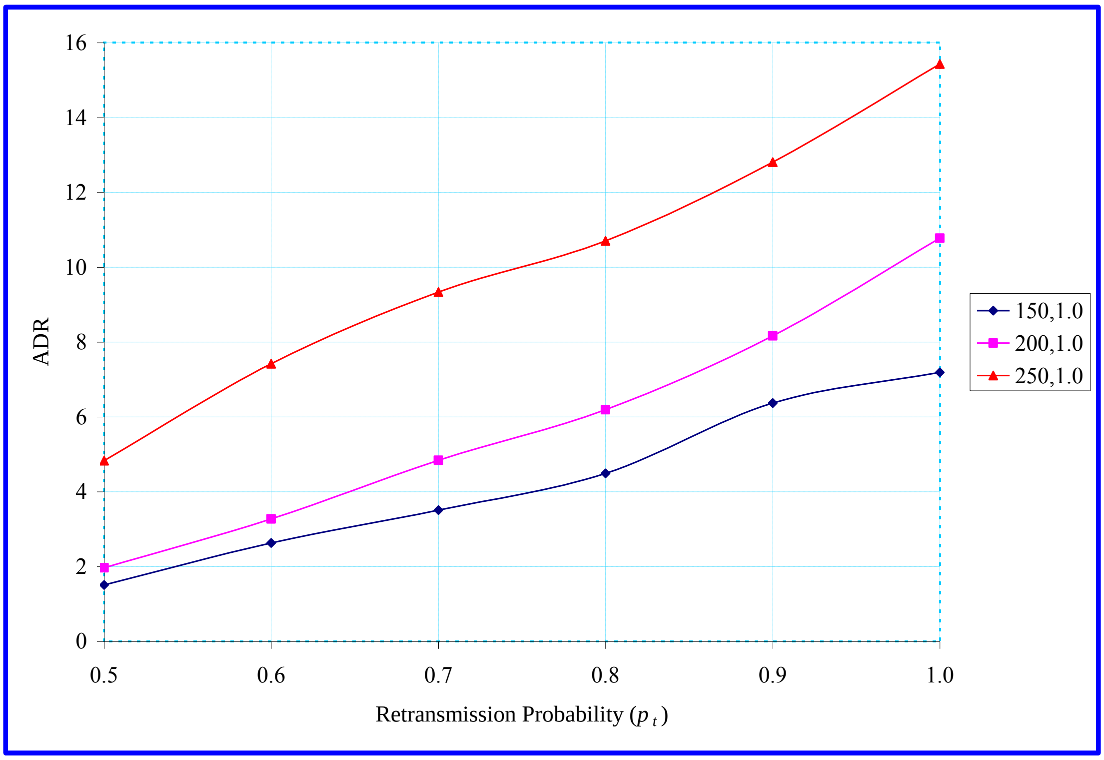


Figure (5.18) - Variation of ADR with p_t for various R and p_c (Legend: R, p_c).

(n=100, u=5 m/sec).

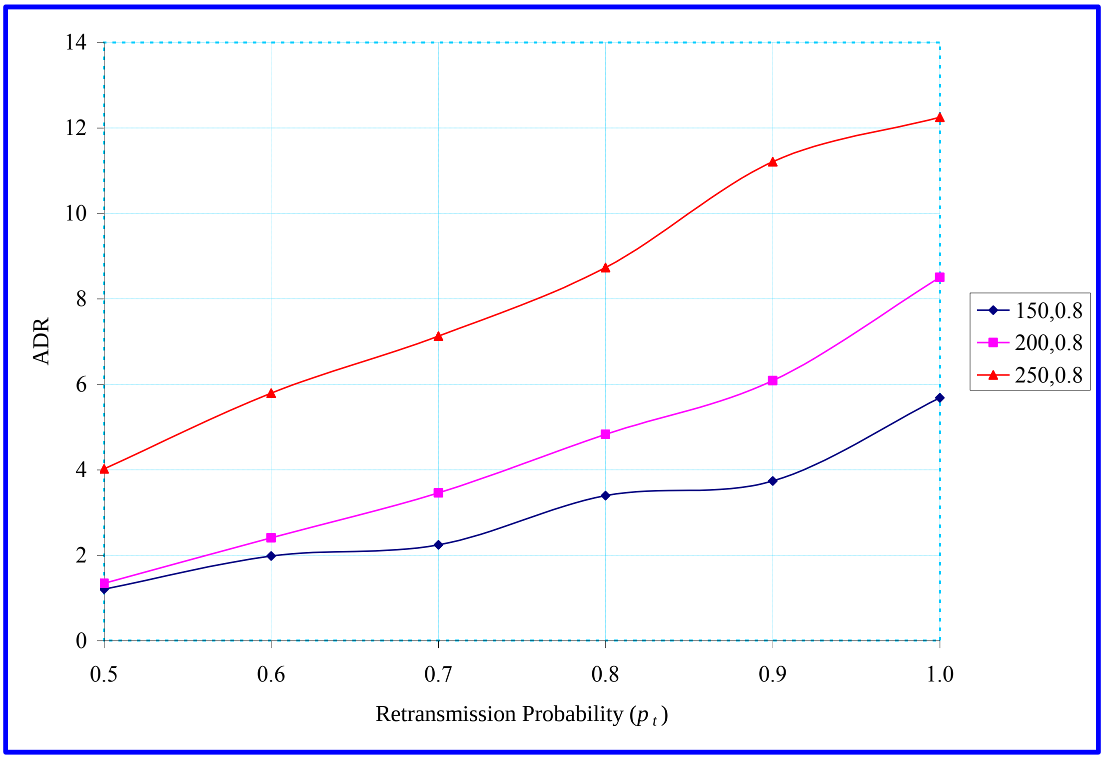


Figure (5.19) - Variation of ADR with p_t for various R and p_c (Legend: R, p_c).

(n=100, u=5 m/sec).

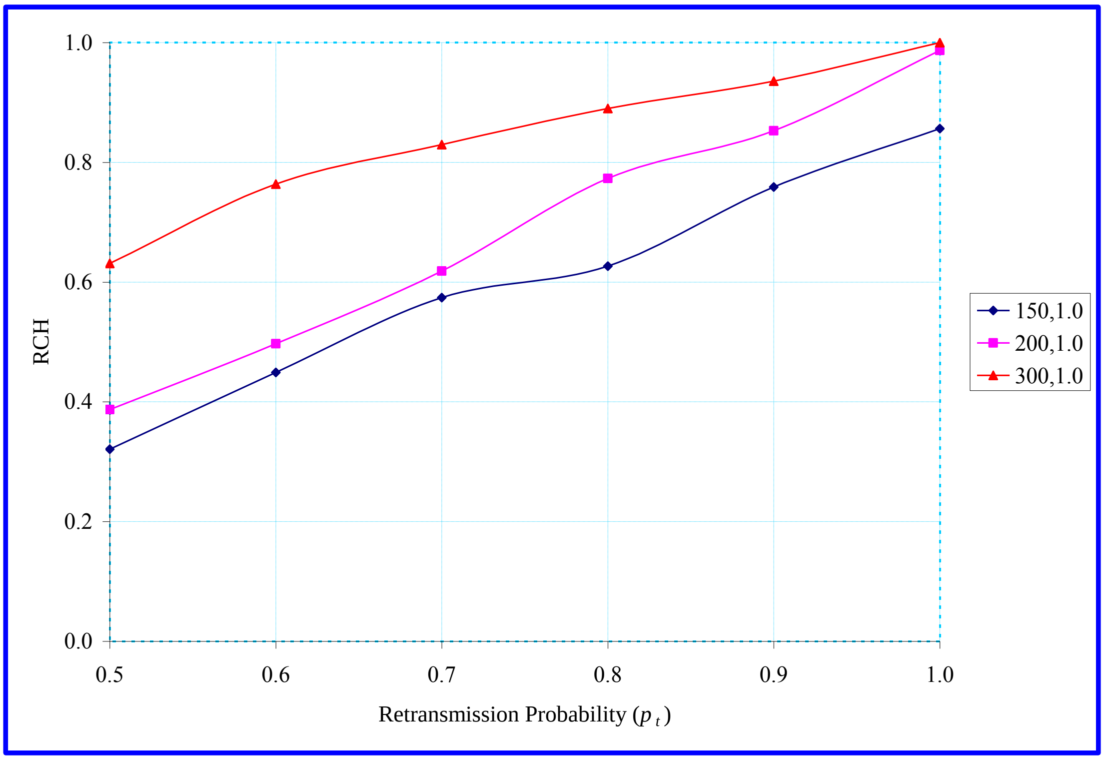


Figure (5.20) - Variation of RCH with p_t for various R and p_c (Legend: R, p_c) (n=100, u=5 m/sec).

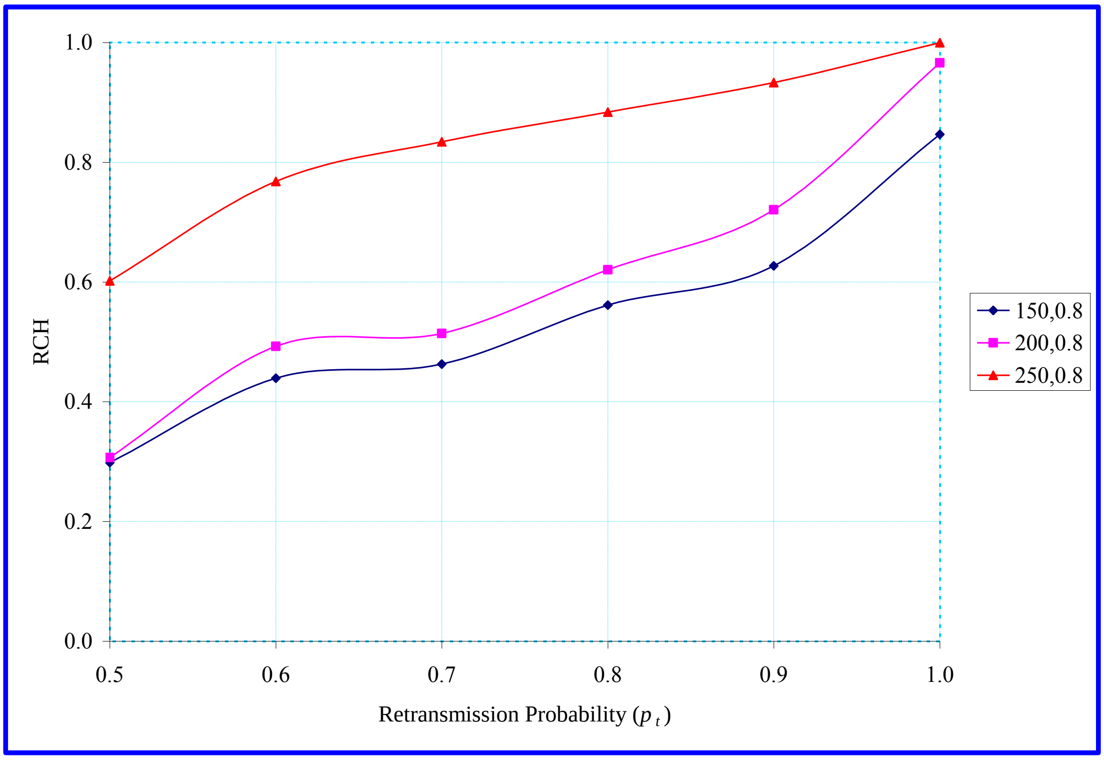


Figure (5.21) - Variation of RCH with p_t for various R and p_c (Legend: R, p_c) (n=100, u=5 m/sec).

Table (5.9) shows the results of computed parameters for different nodes transmission radius R, for two types of environments, noise-free (p_c=1.0) and noise-prone (p_c =0.8).

Once again, by introducing noise to the environment all of the computed parameters (RET, ADR, and RCH) are reduced with a varied percentage, the low variation can be seen when R is large, while high variation is observed with small R as can be seen in table (5.10). For example the reduction in RCH when R is 250 m is almost negligible, it's almost 0% when p_t = 1.0, 0.3% when p_t =0.9, while the reduction in RCH when R is 150 is 1.12% when p_t =1.0; and 17.4% when p_t =0.9.

Table (5.9) Values of RET, ADR, and RCH for various values of p_t, p_c, and R. (n=100, u=5 m/sec).							
p_t	R	p_c=1.0 (Noiseless)			p_c=0.8 (Noisy)		
		RET	ADR	RCH	RET	ADR	RCH
1.0	150	0.836	7.188	0.856	0.826	5.683	0.847
0.9		0.669	6.373	0.759	0.551	3.736	0.627
0.8		0.490	4.493	0.627	0.439	3.395	0.561
1.0	200	0.967	10.779	0.987	0.946	8.501	0.966
0.9		0.752	8.166	0.853	0.636	6.087	0.721
0.8		0.606	6.192	0.773	0.488	4.831	0.621
1.0	250	0.980	15.432	1.000	0.980	12.250	1.000
0.9		0.826	12.807	0.936	0.823	11.208	0.933
0.8		0.698	10.703	0.890	0.693	8.730	0.884

Table (5.10) Variation of RET, ADR, and RCH as p_c changed from 1.0 to 0.8. (n=100, u=5 m/sec).				
p_t	***R***	**Reduction (%)**		
		RET	**ADR**	**RCH**
1.0	150	1.28	20.93	1.12
0.9		17.68	41.38	17.40
0.8		10.39	24.42	10.45
1.0	200	2.15	21.13	2.12
0.9		15.41	25.46	15.49
0.8		19.59	21.98	19.76
1.0	250	0.03	20.62	0.00
0.9		0.33	12.49	0.30
0.8		0.75	18.44	0.71

As a conclusion of the above results and discussion, the researcher can state the following: The results demonstrate that the probabilistic flooding reduced redundancy, in terms of reducing the number of retransmissions and average duplicate reception, without significantly affecting the network reachability. This is especially true for high density networks and for networks that have nodes with large coverage area (large radio transmission range), regardless of the nodes average speed, and that noise has a reducing effect regarding the computed network parameters, since it will inhibit some nodes from receiving a rebroadcast message.

Chapter 6
Conclusions and Recommendations for Future Works

6.1. Conclusions

The main conclusions of this work can be summarized as follows:

1. A noise factor is introduced in a MANET environment; this could be either due to radio transmission problems (EMI, collisions, obstacles, etc) or because of dynamic environment with rapidly changing topologies. The noisy environment is described by introducing a probability factor, namely, the probability of reception (p_c).

2. For this algorithm, a mathematical model is developed and implemented using a mobile ad hoc network simulator MANSim. This simulator is dedicated to simulate, evaluate, and analyze the performance of various flooding optimization algorithms.

3. The simulator handles two types of network conditions, namely, ideal network condition and realistic network condition. The main features of an ideal network are regular-grid node distribution, retransmission probability is set to 1 (pure flooding), no-error in reception, i.e., noise-free environment, radio transmission range is extended to cover one node in each direction, and no node mobility (fixed node). If any of the parameters above is set to a different value, then this is considered as a non-ideal (realistic) network condition.

4. Analytical formulas are derived to calculate some of the computed network parameters (e.g., number of retransmission (RET), average duplicate reception (ADR), and reachability (RCH)) in an ideal network condition.

5. The simulation results obtained from MANSim are validated by comparing them with analytical results for an ideal network condition. The simulation tests show that the simulation and analytical results are in 100% agreement for different node densities. Although these simulations are for ideal network condition, the computation procedures examine all modules of the simulator.

6. In order to evaluate the performance of probabilistic flooding, a number of simulations are performed using MANSim for realistic network condition. In these simulations, the researcher investigates the effect of a number of network parameters (e.g., node density, node average speed, radio transmission range, retransmission probability, and reception probability, etc.) on RET, ADR, and RCH.

7. The results obtained have shown that as p_t decreases, the computed parameters (RET, ADR, and RCH) decrease. The reduction in RET and ADR is considered as an advantage, since the number of collisions and contentions are thus reduced, thereafter, a better bandwidth utilization is achieved. However, the reduction in RCH is considered as a drawback.

8. The results obtained have shown that noise has a clear effect on the computed parameters, it will tend to reduce these parameters, in general as more noise is added to the environment more reduction in the computed parameters is observed, i.e. as p_c increases, the computed parameters (RET, ADR, and RCH) decrease. The reduction of the computed parameters is obvious in sparse networks, and in networks with nodes of small transmission radii.

6.2.Recommendations for Future Works

The following recommendations are suggested for future works.

1. Investigating the effect of a dynamic retransmission probability determination approach on the computed parameters, for example, the retransmission probability is calculated as a function of the number of nodes within its coverage range. This may enhance the performance of the algorithm in terms of improving the network reachability. In addition, the retransmission probability may also depend on other factors such as noise level in noise-prone network.

2. Studying each type of noise alone, and seeing how each type of noise will affect the studied parameters (RET, ADR, and RCH), and how the optimized flooding scheme will respond if a different number of noise sources exists.

3. Current probabilistic model implements a multiple trails model, therefore, it is recommended to investigate the single trail retransmission model and compare the performance for identical scenarios.

4. A potential area of interest, in terms of power consumption in mobile nodes, would be to analyze the performance of MANETs if nodes are allowed to transmit with variable transmission range, and if that range can be adjusted dynamically according to the networks conditions.

5. Finally, another potential area of interest would be to analyze the performance of MANETs if nodes are allowed to move with variable speeds within a specific range.

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