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An Energy-Aware Retransmission Model for Multimedia Communications over Wireless Networks

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B.S. in Computer Science, LAU 2007

Thesis submitted in partial fulfillment of the requirements for the
Degree of Master of Science in Computer Science

Department of Computer Science and Mathematics
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7/14/2010

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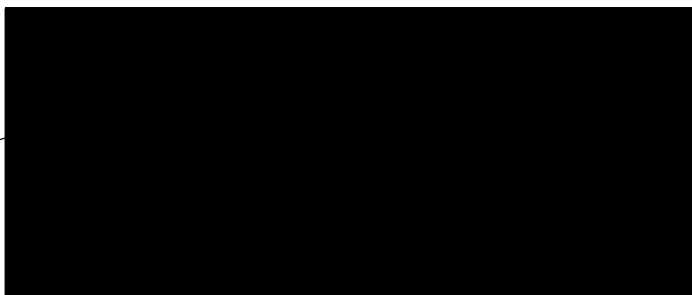


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Dedication

To my father,

I hope I made you proud. You taught me patience and love. A part of you will always be with me to enlighten my heart and way!

To my mother,

You have always been my support system. You taught me how to dream and to believe.

To my loving family,

I dedicate this work to you as a bashful notice for your love and support. Thank you for being what you are, my family!

Acknowledgement

I would like to thank Dr. Sanaa Sharafeddine for being my thesis advisor. She has been very supportive, guiding and patient throughout the entire work of my thesis. I would also like to thank Dr. Nashaat Mansour and Dr. Ramzi Haraty for giving me the honor of being part of my thesis committee. A special thanks to the President of the Lebanese American University, Dr. Joseph Jabbra along with the entire faculty of the Department of Computer Science and Mathematics at LAU.

Abstract

Traditional error recovery schemes such as automatic repeat request (ARQ) and incremental forward error correction (FEC) rely on immediate retransmissions to deal with transmission errors. Such an approach leads to substantial energy drain and notable performance degradation in case of multimedia communications over wireless networks especially when the probability of data error is high. Moreover, retransmissions negatively impact the performance of other mobile nodes due to the nature of resource sharing in wireless environments. In this thesis, an energy-aware retransmission scheme for multimedia distribution over wireless networks is designed, implemented, and evaluated in different realistic network scenarios. The proposed scheme adapts the retransmission rate based on the predicted channel conditions in a way that keeps the quality of service metrics within the desired range. Performance results using ns2 simulations demonstrate reduction of up to 50% in terms of energy consumption while maintaining the target quality constraints. Results also show that the proposed scheme outperforms the default WLAN medium access control (MAC) protocol in terms of packet delay that is an important metric for real-time multimedia applications.

Table of Contents

1 Introduction	1
2 Literature Review	6
2.1 Energy Efficiency at the Different Internet Model Layers	7
2.2 Energy Efficiency Schemes at the LLC Block	11
2.3 Energy Efficiency Schemes at the MAC Block	17
3 EARM: An Energy-Aware Retransmission Model for Multimedia Communications over Wireless Networks	26
3.1 Problem Description	26
3.2 System Model.....	27
3.3 Simulation Environment	29
4 Implementation Details of EARM.....	31
4.1 Model Workflow	32
4.2 Signal Strength Threshold	36
4.3 The Refrain Queue Size.....	38
4.4 The Refrain Counter	39
4.4 The Radio Propagation Model	42
4.5 A Simple Example	45
5 Simulation Results and Performance Analysis.....	49
5.1 Single-hop Ad hoc Network Scenarios.....	50
5.1.1 Case Scenario 1: Three Mobile Nodes	50
5.1.2 Case Scenario 2: Five Mobile Nodes	57
5.2 Multi-hop Ad hoc Network Simulations	62
5.2.1 Case Scenario 3: Eleven Nodes with Low Mobility	62
5.2.2 Case Scenario 4: Eleven Nodes with Medium Mobility	64
5.2.3 Case Scenario 5: Eleven Nodes with High Mobility	66

5.2.4 Case Scenario 6: Eleven Nodes with Mixed Mobility.....	68
5.2.5 Performance Analysis with respect to Mobility	70
5.2.6 Case Scenario 5: Multi-Source File	73
6 Conclusions and Future Work.....	76
Bibliography.....	78

List of Figures

Figure 1- Infrastructure-based wireless network architecture.....	2
Figure 2- Wireless ad hoc network architecture.....	2
Figure 3- The internet model and corresponding energy-efficient approaches	6
Figure 4- The data link layer sub-blocks	11
Figure 5- Single-hop wireless architecture	28
Figure 6- Multi-hop wireless architecture	28
Figure 7- Simulation setup.....	30
Figure 8-The workflow of EARM	35
Figure 9- Relation between dBm and mW	37
Figure 10- The refrain counter value	40
Figure 11- CCDF of packet delay for all refrain counters	42
Figure 12- Throughput results using two-ray ground and ricean factor	45
Figure 13- Model workflow, SS is the signal strength and RC is the refrain counter.....	48
Figure 14- Movement of Node N1	51
Figure 15- Signal strength versus time	52
Figure 16- Signal strength versus distance	53
Figure 17- Throughput per node using default MAC	54
Figure 18- Throughput per node using EARM	55
Figure 19- Delay per node using default MAC.....	56
Figure 20- Delay per node using EARM	56
Figure 21- Throughput per node using default MAC	59
Figure 22- Throughput per node using EARM	60
Figure 23- Delay per node using default MAC.....	61
Figure 24- Delay per node using EARM	62
Figure 25- CCDF of packet delay in low mobility scenarios.....	64
Figure 26- CCDF of packet delay in medium mobility scenarios.....	66

Figure 27- CCDF of packet delay in high mobility scenarios.....	68
Figure 28- Percentage of packet delay in mixed mobility scenarios.....	70
Figure 29- Packet delivery ratio versus mobility.....	71
Figure 30- Average throughput versus mobility	72
Figure 31- Average delay versus mobility	73
Figure 32- CCDF of packet delay with multi-source file	75

List of Tables

Table 1- System parameters.....	49
Table 2- The energy model parameters.....	50
Table 3- Energy efficiency versus mobility.....	73

Chapter 1

1 Introduction

The proliferation of mobile devices along with the invasion of wireless environments has given rise to what is so called mobile computing. In fact, the increasing trend of mobile devices triggered a shift from fixed-wireless computing to mobile-wireless computing. While fixed-wireless computing simply replaced wired communication, mobile computing was developed to support user mobility while maintaining quality of service. The reason why mobile computing has gained vast attention lies in the fact that it provides mobility through enabling people to access network services at anytime and anyplace.

Unlike wired environments that operate over infrastructure-based networks, wireless networking operates using two architectures: infrastructure-based and ad hoc-based. Infrastructure-based networks require a predetermined network architecture that utilizes a fixed dedicated station for relaying information. The latter can be used to connect the wired backbone of the network with the wireless part. Such a mode of communication is able to support a wide spectrum of users. Figure 1 depicts an infrastructure-based wireless network with an access point connected to three different users. Ad hoc networks, on the other hand; require no predetermined infrastructure. In ad hoc networks, nodes are capable of forwarding data to each other using other mobile nodes as relays. However, ad hoc networks require that mobile devices frequently exchange data in order to maintain

current routing information [2]. Figure 2 is an example of an ad hoc network in which a mobile device can act as both, an end-user and as a relay node.

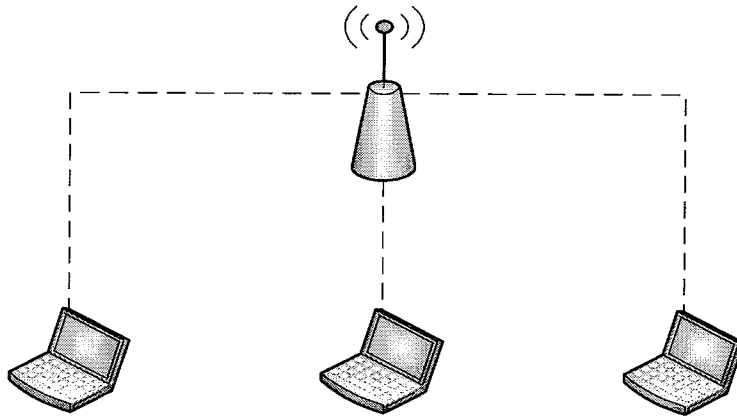


Figure 1- Infrastructure-based wireless network architecture

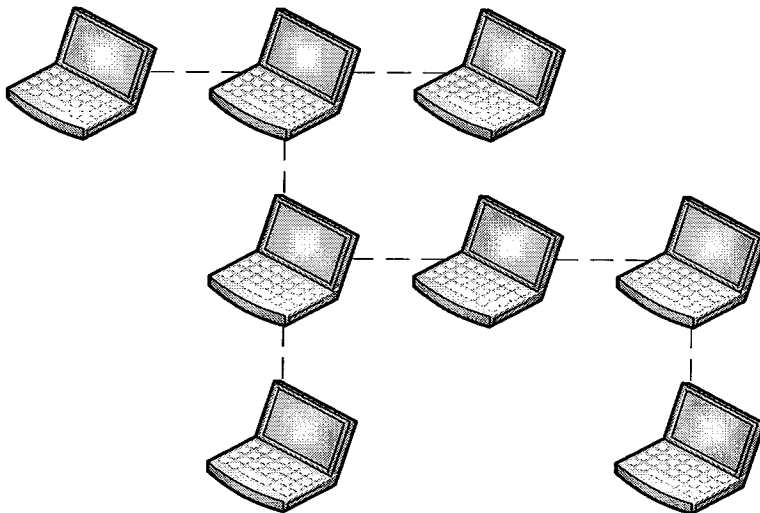


Figure 2- Wireless ad hoc network architecture

Despite its attractiveness, wireless networking suffers from more challenges than wired networking does. The first challenge is providing reliable communication and supporting quality of service regardless of the wireless factors. These factors could be

variations in physical and/or environmental conditions such as temperature, sound, vibration, pressure, obstacles, fading signals, etc. The second challenge in wireless environments is to support user mobility which is associated with the use of mobile devices. Finally, the third obstacle is to cope with energy limitations by establishing an energy-aware mechanism while maintaining quality of service. In mobile devices, the battery life is considered to be an essential resource whose energy should be preserved. Energy consumption in mobile devices can be divided into two types: communication energy and computation energy consumption. Communication energy refers to energy consumed while transmitting and receiving data and control packets. On the other hand, computation energy refers to energy consumed by the processor and main memory in order to process data. The process of compressing data is one example of computation energy that should be preserved through energy-aware compression schemes [24]. Research has found that the main drain of energy in mobile devices is attributed to the wireless network interface card (WNIC). Thus, experimental studies and research work [21], [26], [27], [28] have focused on conserving the energy of WNIC. The energy consumed by the WNIC is determined via the amount of data being sent and received in addition to the total amount of time needed to process received data.

Error/loss recovery via link layer retransmission schemes is a significant source of energy depletion in wireless environments. Error/loss recovery schemes [4], [12], [15], [16], [17], [36] are actually used to amend packet errors and packet losses in wireless networks. In fact, wireless networks suffer from high bit error rates induced by different factors such as weather conditions, urban obstacles, paths interferences, noise, etc. These

wireless factors are a major cause of packet errors and losses which are masked by retransmissions. Nonetheless, link layer retransmission schemes suffer from two main problems in wireless environments [15]. The first problem emerges from the fact that the probability of losing packets over unstable links is higher than losing them over stable links. Thus, when a packet is lost over a non-stable link due to wireless factors, retransmission will only make the condition of the link worse leading to more packet loss. Consequently, energy is wasted due to immediate retransmission. The second problem occurs with multiple retransmissions that would block the transmission of other packets destined to nodes observing good conditions. This will lead to a total degradation in the network's performance, an increase in the delay which could be fatal to real-time applications and a major waste of energy.

For the issues discussed earlier, an energy-aware retransmission model that takes into account wireless factors is proposed. The proposed model suggests checking the condition of the channel before retransmitting lost packets immediately. This is needed to determine if the packet loss was due to wireless factors or not. Bad channel conditions imply that the packet loss was due to channel errors. Therefore, immediate retransmission would only deteriorate the condition of the wireless link. This will lead to more packet loss, and thus performance degradation and useless expenditure of energy. Therefore, the suggested model proposes suspending retransmission of lost packets when the channel condition is dreadful to the next scheduled service. On the other hand, immediate retransmission can take place in good channel conditions. This means that that the wireless

errors do not exist, and retransmission will not cause any unwanted drain in energy. This scheme is implemented and tested using the network simulator (NS-2).

The rest of this thesis is organized as follows. Chapter 2 provides a detailed literature review of the different work done to reduce energy consumption at all layers of the internet model. Chapter 2 also provides a critique for the work done in literature. Chapter 3 presents the problem description, the system model and the setup of the simulation used to test the suggested model. Chapter 4 describes the proposed energy-aware retransmission model along with its implementation details. Chapter 5 provides simulation results and an assessment of these results to evaluate the efficiency of the suggested model. Chapter 6 finally concludes this thesis and proposes some future work.

Chapter 2

2 Literature Review

Energy efficiency has become a major concern in research work that tackles wireless networks. Many techniques and protocols have been suggested in literature to mitigate energy drain. The suggested techniques address energy depletion at the different layers of the protocol stack of the wireless internet model [16]. Figure 3 depicts the internet protocol stack along with the generic energy-aware approaches at every layer.

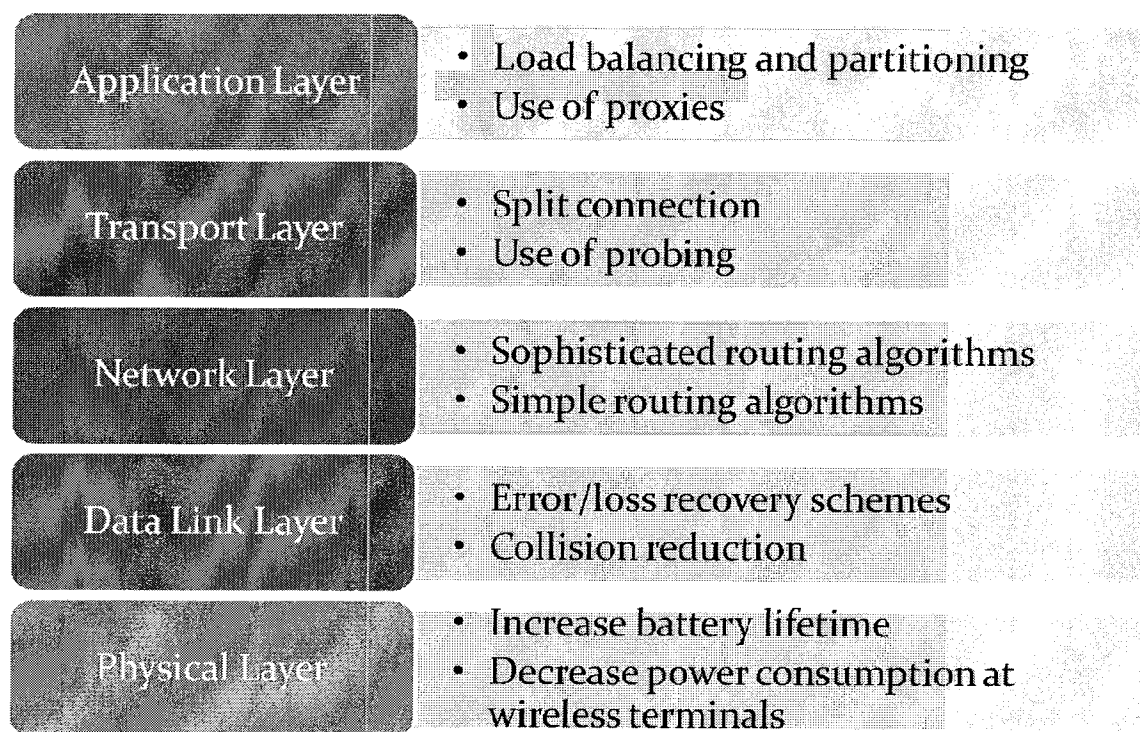


Figure 3- The internet model and corresponding energy-efficient approaches

2.1 Energy Efficiency at the Different Internet Model Layers

Starting at the physical layer, two main approaches have been studied to save energy consumption, one of which aims at increasing the battery capacity, and the other focuses on decreasing energy drain at wireless terminals [4], [16], [29]. Since increasing battery capacity requires increasing the battery size, little advancement has been made regarding the first approach. On the other hand, extensive work has been performed concerning the second approach. Applying parallel architectures and pipelining help reduce energy consumption through decreasing the amount of supply voltage. In fact, decreasing a supply voltage from 5 volts to 3.3 volts implies a 44% voltage supply reduction which is translated as a 56% energy saving. Moreover, reducing power consumption can be also achieved by controlling clock frequency. Clock frequency control can be achieved by transiting the clock into sleep mode when the processor is idle and thus saving energy drained in idle periods [29].

Climbing up the protocol stack, enhancements at the data link layer were double-fold. In fact, energy-aware techniques focused on saving energy at both the link layer control (LLC) block and the media access control (MAC) block which both constitute the data link layer. Research work at the LLC block aimed at introducing energy-aware error correction schemes. The problem with traditional error control techniques such as ARQ (Automatic Repeat Request) and incremental FEC (Forward Error Correction) is that they rely on retransmissions to mask up link errors. Such a behavior doesn't only yield unwanted massive energy drain, but also degrades the total network performance. Therefore, different error control schemes [4], [12], [15], [16], [17], [36] have been

proposed in order to adapt with bad channel conditions. The suggested schemes act accordingly with respect to channel conditions when retransmission of lost packets should take place. There are two generic methods to help assess network conditions. One of which focuses on sending probe packets to the mobile nodes until an ACK is received indicating good channel conditions. The second method focuses on getting feedback periodically from the client node itself. A positive feedback indicates good channel, and thus lost packets can be retransmitted to that node successfully. As for the MAC block, various protocols and schemes have been implemented with the aim of energy drain reduction. MAC protocols [7], [16], [21], [22], [26], [27], [30], [35] mainly focus on avoiding collisions so that to reduce the number of retransmissions. Other energy-aware MAC techniques [5], [9], [28], [31], [34] focus on transiting idle nodes into sleep mode instead. Finally, some energy-effective MAC schemes [4], [16], [18] focus on reducing the turnaround overhead in order to save energy drain and enhance network performance. A turnaround occurs when a mobile node switches from receiving mode to transmission mode and vice versa. The significant energy drain and time caused by turnarounds motivated research work to minimize turnaround periods and reduce their occurrences.

Moving up to the network layer, most of the research work laid emphasis on this layer. In fact, many routing algorithms [2], [15], [16], [19], [25], [27], [33] have been suggested in literature in order to reduce energy depletion of mobile nodes. These routing algorithms may be divided under two generic categories. The first category implements “frequent topology updates” that focuses on enhanced and sophisticated routing schemes [25], [27], [33]; meanwhile, the second category implements “infrequent topology

updates” that focuses on simple routing techniques [15] [20] . Nonetheless, both categories have drawbacks. In fact, sophisticated routing algorithms which require a lot of message transmission to update the topology ends up consuming available bandwidth. Nonetheless, they reduce energy consumption by reducing the number of losses through achieving optimal routing. As for the simple routing algorithms that aim at decreasing the number of updated messages, they reduce energy drain but cause packet losses due to ineffective routing.

At the transport layer, different variants of TCP have been proposed. Over wireless networks, TCP’s performance degrades massively causing more retransmissions that consume the energy of the mobile nodes. For that reason, many TCP versions have been suggested to cope with wireless communication. TCP PEACH [1], Freeze-TCP [13] and ATCP [20] are all examples of TCP versions that aim at working over wireless networks. These TCP variants aim at assessing the channel condition in case of packet loss. This is needed to determine whether the loss was due to wireless errors or network congestion. If it was due to congestion, normal TCP behavior would take place. Meanwhile; if it was due to wireless factors, probe packets are sent to determine the channel condition. If the channel condition is good, then the congestion window is adjusted. If the channel is observing bad conditions, it transits into a low power mode that aims at reducing energy drain when the channel is deteriorated. On the other hand, other TCP variants work by splitting the connection between wired and wireless links and act differently with the two distinct links. However, such an approach lays burden on the router that holds information about the two links and isolates the concept of end-to-end connectivity at the transport

layer. Thus, if the router crashes, all the data is lost. Examples of TCP variants that split the connection are I-TCP [6] and M-TCP [8]. Even though energy effectiveness is a key aspect of these protocols, UDP remains superior to TCP when it comes to wireless multimedia traffic in terms of energy efficiency and delay.

Finally, at the application layer, enhancements focused on dividing application loads between the mobile node and the base station with the latter having the bigger load [4], [16]. Consequently, a mobile node would only attain the basic functionalities needed for the application to run properly. Another enhancement that reduces energy drain at the application layer is utilizing proxies [18]. Proxies act as a mediator between the mobile nodes and the base station. It should be noted that proxies are assumed to attain inexhaustible power. They have a significant role in tuning the application with respect to variations in available bandwidth and battery power. For instance, suppose in a multimedia transmission, the power or bandwidth is relatively low, the proxy would then suppress transmitting video streams and transmit audio traffic instead. It should be noted that many studies combined the use of proxies at the application layer along with their suggested scheme at one of the different layers of the protocol stack.

The energy-aware retransmission model suggested in this thesis works at the data link layer mainly. For that reason, a thorough and profound analysis of the state-of-the-art energy efficiency schemes implemented at the data link layer is provided. This analysis forms the basis in comparing these approaches and the suggested model in terms of energy

effectiveness achieved and the level of QoS between. Figure 4 depicts the two blocks that constitute the data link layer along with a brief overview of their main functionalities.

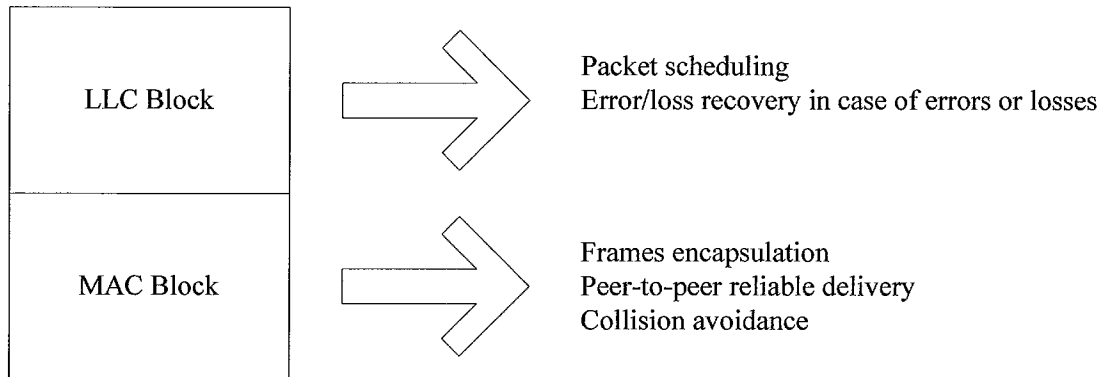


Figure 4- The data link layer sub-blocks

2.2 Energy Efficiency Schemes at the LLC Block

Traditional error recovery schemes such as ARQ and incremental FEC rely on immediate retransmissions to mask up link errors. Such an approach leads to substantial energy drain and notable degradation of performance in wireless networks.

Automatic Repeat Request (ARQ) [34] uses receivers' acknowledgements and timeouts to determine the occurrence of a packet loss. If the sender receives duplicate acknowledgements, or if it doesn't receive an acknowledgement of the sent packet and a timeout occurs, this indicates that a packet is lost and requires retransmission from the sender. Such a scheme, though effective in wired networks, suffers from two major issues in wireless environments: implosion and exposure. Implosion takes place when the sender is flooded with many duplicate acknowledgements coming from different receivers.

Exposure, on the other hand, occurs when retransmitted packets are sent to the wrong receivers i.e. those who didn't lose these packets in the first place.

Forward Error Correction (FEC) [34] is another traditional non-cooperative recovery scheme where the sender creates redundant data called parity packets out of the original packets and adds them to the messages sent to the receiving hosts. Thus, in case of error or loss, the receiver is able to reconstruct the missing packet from the received messages. However, such an approach suffers from performance degradation in wireless networks since it requires successfully transmitting the maximum number of parity packets to the receiving hosts. For example, suppose the number of original packets is 4 and the number of created parity packets is 3, then a total of 7 packets should be transmitted to the host. However, at least three of which should be successfully received to recreate the original message.

In [36], Zorzi et al. suggests an error control scheme that overcomes the problems of traditional error recovery schemes by adapting to wireless network conditions. The suggested scheme depends on probe packets to save energy. Normally, packets are transmitted to their receiving mobile nodes as scheduled until a packet loss occurs. The latter is detected when an acknowledgement (ACK) is not received. This is often referred to as a negative acknowledgement (NACK). In this case, the sender switches from normal mode to probe mode in which probe packets that contain no data are actually transmitted on a scheduled basis. When an acknowledgement of a probe packet is received, it indicates

the correct reception of the packet and better channel conditions. Thus, the sender switches back to normal mode and starts transmitting the previously lost packets.

Experimental work was conducted to evaluate the effectiveness of this approach. Results prove that this approach saves energy wasted by retransmissions through adapting the proposed error control scheme to the network conditions. Nonetheless, this leads to considerable throughput degradation since some of the allocated time slots are left empty in order to reduce the number of failed transmissions. In addition, although such an approach can save energy especially during channel deterioration, it may not be well-suited for real-time applications that are delay-sensitive especially if bad channel conditions tend to persist.

In [12], De et al. combines using probe packets with the utilization of client feedback. In fact, the sender would normally transmit packets to its receiving nodes until a NACK is received by the sender. Then, the transmitter would transit into the probe mode. In the probe mode, the transmitter would send probe packets to the receiver. Up till this point, this approach looks similar to the one suggested in [36]. Nonetheless, this approach utilizes client feedback in addition to using probe packets. With every probe packet sent to the receiver node, the latter adds to the ACK or NACK additional information about its status. This information is compared with a given threshold to assess the current and subsequent condition of the node. This assessment is needed to determine whether to retransmit lost packets or not.

Experimental work was conducted to evaluate the effectiveness of the suggested approach. Results show that this approach reduces energy consumption caused by retransmissions without degrading the throughput rate. Nevertheless, there is a trade-off between attaining good throughput and energy effectiveness on one hand and causing additional delay to the transmitted packets on the other hand.

In [17], Kim et al. proposes an energy-aware hybrid ARQ algorithm to reduce energy consumption caused by retransmissions. To do so, dividing the packet that is to be retransmitted into several sub-packets and transmitting these sub-packets consecutively is suggested. Moreover, the transmitted energy needed to transmit the packet completely is divided over these sub-packets in an energy-efficient manner. In fact, the first sub-packet is assigned a certain transmission energy value and is sent over to the receiver. If the transmitter receives an ACK, it sends the subsequent sub-packet with $1/2$ of the transmission energy needed to transmit the complete packet. Consequently, if the sender receives an ACK, it sends the third sub-packet with $1/4$ of the total transmission energy of that packet. This procedure is repeated until all sub-packets of the same packet are completely transmitted to the receiver node. The latter would then decode those sub-packets and assemble them as one packet. It should be noted that in case a NACK is received upon transmission of a sub-packet, the latter is resent until it's correctly received by the client node.

While this scheme can reduce communication energy drained during retransmissions of lost packets, it shifts this energy drain into computational energy drain

needed by the receiver node to decode the received sub-packets. Furthermore, there is a delay trade-off caused by waiting for the ACK or NACK of each sub-packet instead of having one for the entire packet.

In [34], Zhang et al. addresses the problem of error/loss recovery schemes of packets in reliable multicast applications in wireless environments. In such applications, information flows to multiple users simultaneously which requires the assurance of data delivery via effective error/loss recovery schemes. Nonetheless, conventional, non-cooperative schemes such as ARQ and FEC suffer from impeded performance when applied to multicast applications in wireless systems especially when the receiving hosts have heterogeneous probabilities of packet loss. Zhang et al propose an alternative approach that provides a cooperative error/loss recovery that makes use of the peer-to-peer architecture. An experimental study to compare the different strategies was conducted, and the results showed that cooperative error/loss recovery outperforms the existing recovery schemes.

This approach known as the cooperative retransmission strategy exploits the advantages of peer-to-peer architecture in cellular wireless data networks. In such networking models, mobile devices located in the vicinity of each other form a cluster where they can communicate directly over short multi-hop routes. This strategy utilizes a token packet that consists of a lost packet matrix (LPM) to count all missing packets that need to be retransmitted and a complete reception bit (CRB) to indicate correct reception of lost packets. It should be noted that the mobile hosts belonging to the same cluster

alternate between two roles: primary and auxiliary mobile hosts. Primary mobile hosts are responsible of retransmitting lost packets, marking their corresponding location in the LPM as 0 and passing the token packet to another primary mobile host. Auxiliary hosts; on the other hand, form the remaining mobile nodes within the cluster. They assist in completing the error recovery scheme. When an auxiliary node receives a copy of its lost packet successfully, it marks the complete reception bit by 1. The idea of the token packet is to trigger the action of the primary mobile host that receives it. When the last primary mobile device receives the token packet and finishes its retransmission, it checks the LPM to ensure that all lost packets were retransmitted and set the complete reception bit to 1 as an indication of the completion of the recovery mechanism.

Experimental work was conducted to investigate the efficiency of the suggested strategy in comparison with the other existing techniques. Results show that the cooperative retransmission strategy outperforms the other non-cooperative approaches since it has lower energy consumption. Retransmission time is less than that in the case of ARQ and FEC. Furthermore, cellular retransmission is rarely needed since the percentages of unrecoverable packets are very low. Finally, this strategy works well in case of different packet loss probabilities as well.

This approach aims at decreasing the time needed to complete retransmissions of lost packets in order to reduce the amount of energy drained during the retransmissions. Nonetheless, there is a computational overhead caused by building and updating the LPM within the token packet. It should be noted that the primary mobile hosts are responsible

for building and then updating the LPM in each cluster. Moreover, this approach divides mobile nodes into primary and auxiliary roles on a scheduled basis in order to facilitate the retransmission of packets. However, if the mobile nodes are in permanent movement, this might lead to thrashing of the mobile nodes between auxiliary and primary roles.

2.3 Energy Efficiency Schemes at the MAC Block

Different protocols and schemes have been suggested at the MAC layer. One of which is the IEEE 802.11 protocol [7], [21] that conserves energy through letting mobile nodes to switch to sleep mode instead of being idle. The base station keeps record of all the mobile nodes that are in sleep mode. Consequently, if packets were destined to the sleeping node, they are buffered at the base station and beacon packets are sent instead to monitor the state of the mobile node. When the latter is awake, the base station would transmit the buffered packets to that node. In addition, IEEE 802.11 attains a collision avoidance technique (CSMA/CA) to avoid collisions. This technique reduces the number of retransmissions and in turn lessens the amount of energy waste. Although such a protocol saves energy consumption, it doesn't account for delay-sensitive applications.

Another MAC protocol whose primary goal is to save energy is the EC-MAC [27], [30]. The latter focuses on saving energy through reducing unwanted retransmissions invoked by collisions. Thus, the aim of EC-MAC is to reduce collisions through detailed scheduling and channel reservation. In fact, EC-MAC defines a set of transmission frames with each frame being divided into multiple phases: reservation phase, new-user phase, schedule beacon phase and the data phase. The reservation phase is needed to reserve the

channel so that to avoid collisions and unwanted retransmissions. Then, each user connected to the same base station sends request to attain the connection. The base station would then schedule the data phase in which actual data is sent over to the requesting node. After that, it will broadcast that schedule to the concerning nodes through the schedule-beacon phase. It should be noted that the new-user phase allows new mobile nodes to connect to the base station and enter its area of coverage. Such an approach saves energy drained due to idle periods by allowing nodes to transit to sleep mode while taking into consideration QoS. In fact, with the use of scheduled frames, nodes are able to know when the occurrence of the second frame will take place, and thus allowing it to sleep in idle periods to save energy. Although EC-MAC works well for infrastructure-based networks, it doesn't cope well for ad-hoc networks.

In [26], a power-aware multi-access protocol with signaling called PAMAS was proposed. This protocol solved the problem of EC-MAC and presented an energy-aware scheme for ad-hoc networks. PAMAS suggested using two different channels, one of which is to be used to send control packets and the other is used for data packets. Consequently, a mobile node can send RTS/CTS control frames to insure they can send and receive packets without causing packet collisions. And if it was allowed to send data packets, it uses the data channel for that purpose. On the other hand, if it wasn't granted permission to receive packets, it should transit into sleep mode because one of its neighbors is actually using the channel. The node remains in sleep mode until the transmission time of its neighboring node expires. Moreover, if the node's transmit-queue is empty, then it should also power off by transiting into sleep mode. Not only does this

approach saves energy drained during idle periods, but it also saves energy by avoiding collisions through the use of RTS/CTS frames along with the utilization of two different channels for control frames and data frames respectively. The only trade-off is that it consumes channel resources instead since it requires two different channels for each type of communication. Furthermore, there is an overhead caused by the RTS/CTS frames that are needed to be utilized in order to avoid collisions.

Aside from the various suggested MAC protocols, different scheduling techniques were also implemented to enhance the energy efficiency at the MAC block. In [18], Li et al. propose an energy-aware scheduling mechanism that copes with multiple source wireless video streaming environments. In multi-source WLANs, peer nodes are subject to failure due to degradation in their power that is consumed by their wireless network interface card (WNIC). The energy of their WNIC is determined via the amount of data that is being sent and received along with their total activation periods. Normally, there are three modes in which a WNIC can exist: receive, transmit and idle. In these three modes, the amount of energy consumed is relatively high.

The motivation behind the proposed scheme thus is to preserve energy by setting the WNIC into a sleep mode when it is idle. However, such an approach gives rise to controversial issue regarding the duration of time that the WNIC stays in the sleep mode. A long “sleep” duration leads to loss in the packets that should be delivered. A short “sleep” duration doesn’t achieve optimal energy saving. The suggested scheme solves this problem by making use of the underlying architecture of the multi-source WLANs.

In fact, the proxy associates an asynchronous clock to each participating peer node in the WLAN. When a client sends a request to the server for a certain video, the proxy selects a peer node in the network and sets its associated clock to wake up at specific intervals of time. Once the clock wakes up, the proxy sends a data unit request from that peer to be then transmitted over to the requesting node (client). It should be noted that the peer selection and the duration in which the peer's associated clock wakes up is not done arbitrary. In fact, in order to decrease energy consumption, this problem is modeled as a joint rate/energy distortion optimization problem whose goal is to minimize the overall distortion of the data units transmitted by peer nodes. Consequently, the proxy checks the link quality and the energy level of the peer sender before setting its clock. Moreover, the proxy keeps record of the transmission history and transmission decision for each data unit sent in order to ensure that the current data units arrive correctly. In addition, the proxy removes those peer nodes whose energy level drops below a certain threshold and stops sending them requests. Such an approach reacts rapidly to network conditions mainly dying peer connection and can thus achieve better performance. Simulations using the network simulator (ns2) were conducted over two network strategies: with power saving as proposed and without power saving. Results show that the proposed mechanism achieves better performance through reducing energy consumption while maintaining good video quality.

This approach requires that the proxy attains all necessary information about the network conditions from the peer nodes so that it could act accordingly. While this approach may save energy wasted during idle periods of the mobile nodes, it requires

extensive messaging between the mobile nodes and the proxy in order for the latter to be always updated about the channel condition.

In [9], Kim et al. describes the challenges that are faced in wireless environments. The first challenge is to maintain a stable link for data transmission regardless of all the wireless factors. The second challenge is to establish an energy-aware scheme of operation while maintaining quality of service. Kim et al. further explains the different types of energy consumption in wireless networks: communication energy and computation energy. The first type refers to the energy expenditure during the sending and receiving of data, while the latter refers to energy expenditure during the processing of received data.

In this paper, Kim et al. focuses on reducing the communication energy expenditure. Kim et al. propose an energy-aware scheme that takes into account the two obstacles described earlier for MPEG-4 FGS streaming in wireless networks. The proposed scheme is based on receiving feedback from the client about its battery lifetime. As a matter of fact, the client sends the server its decoding aptitude which is identified as the total amount of data that its decoder can decode at a given period of time. The server would then determine the data rate at which it should send the packets to the client. It should be noted that Kim et al. utilizes an AC-powered server whose energy is inexhaustible. Thus, the focus is on preserving the energy of the client's battery while maintaining an acceptable QoS level. For this purpose, Kim et al. use the fine granularity service (FGS) coding scheme which is built in MPEG-4 since FGS provides a graceful degradation in of QoS.

FGS plays an essential role in this scheme since it adapts to changes within the channel capacity that is subject to various wireless factors. In fact, if the decoding aptitude is less than the data rate at a given point in time, there exists energy waste. On the other hand, if the decoding aptitude is greater than the data rate, then there is no energy waste. Yet, the video quality is confined by the value of the data rate. Finally, if the data rate and the decoding aptitude are equal, then there is no energy waste and the video quality is determined according to the value of the data rate or the decoding aptitude. Therefore, the goal is that when the client changes its decoding aptitude, it sends feedback to the server which in turn adjusts its data rate accordingly in order to avoid energy waste. Mathematical proof along with simulation experiments were conducted to show the efficiency of the suggested scheme, and the results show a 20% reduction in communication energy expenditure.

The problem with this approach is that it affects the QoS metrics since it limits the video quality by the data rate at which the client can operate. In addition, although that this approach can save energy when the client sends negative feedback, useless energy is wasted by the exchange of messages especially when the client is reporting positive feedback.

In [31], Wei et al. proposes a statistical prediction-based scheme to help reduce energy consumption of mobile devices in wireless environments. Research work has shown that energy consumption in mobile devices is mainly affected by the wireless network interface card (WNIC). In fact, WNIC consumes up to 50% of a PDA's energy

and 10% of a laptop's energy as experiments have shown. For this purpose, approaches to reduce energy consumption in mobile devices have focused mainly on WNIC. One approach is to optimize existing network protocol in such a way that unnecessary retransmissions of packets are diminished. Although this scheme reduces total consumed energy via reducing traffic in the network, it has little effect on the entire client energy consumption. An alternative to enhance this approach is to manipulate the state of WNIC itself. In fact, when the WNIC is idle i.e. there is no transmission of data, it can be programmed to enter a sleep state which affects energy consumption significantly. When packets are being received again, WNIC is put back into a live, active state.

This paper proposes a different approach to ensure energy conservation of mobile devices in wireless networks. The mechanism suggested is called a linear-prediction-based approach. It takes into account the silent periods between consecutive data bursts where there are no packets in transit. Such an interval changes dynamically with every data burst, yet it is affected with certain wireless factors. The latter characteristic makes it easy to statistically correlate previous silent periods with current ones to predict future silent intervals. Such an interval is needed to determine the optimal period during which WNIC is put in a sleep mode. The statistical prediction model is defined as follows:

$x'(n) = \sum a_i * x(n - i)$, where $x'(n)$ is the estimated no-data interval, $x(n - i)$ corresponds to previous estimated silent interval and a_i is the predictor coefficient. It should be noted that the client has a proxy that is responsible for putting WNIC into a sleep mode when the client enters the no-data interval.

An experimental procedure was conducted to measure the efficiency of this predictor model and its effect in reducing energy consumption. To this end, two performance metrics were taken into account: energy and drop rate. The energy metric measures the amount of energy saved and the amount of energy spent on the amount of data received. Drop rate measures the amount of data dropped i.e. lost due to longer expansion of the no-data interval. Results show that the statistical linear prediction-based approach yields a reduction in energy consumption and a low data drop rate.

However, the experimental work turns attention into a significant factor that should be taken into consideration when calculating the estimated prediction model of the silent interval. In fact, a negative bias should be added to the estimated silent interval. This is critically needed since long silent interval periods could set the WNIC in longer sleep states which may result in some packets being dropped. Moreover, this bias should not be very large; otherwise energy saving will not be efficiently achieved. Consequently, there is a trade-off between reducing energy consumption and reducing the drop rate when choosing the bias value.

In conclusion, most energy-aware techniques focus on saving energy drained during communication (transmission, reception and idle). While they save communication energy, they shift energy consumption to computational energy needed to implement their suggested schemes. For that matter, some of the proposed work assume that senders are AC-powered i.e. they attain inexhaustible power. Others suggest using a proxy that acts as a mediator between the sender and the receiver nodes. Moreover, these proxies are

assigned to carry the burden of most computational energy with the aim to reduce energy consumption of the mobile nodes.

Another aspect that could be concluded from this chapter concerns energy drained by retransmissions. In wireless networks, retransmissions are inevitable due to bit errors and mobility of nodes. Therefore, research work has tried to come up with energy-aware retransmission schemes through implementing collision avoidance techniques to reduce the number of lost packets, and consequently the needed number of retransmissions. Other techniques focused on limiting the transmission energy needed to retransmit packets. Finally, some techniques focused on limiting time periods allocated for retransmissions for the purpose of saving energy drained by these retransmissions.

The various suggested techniques in literature could save energy consumption, but their techniques increased computational complexity and in turn affected the QoS support as explained earlier. Some techniques had lower throughput rates as a result of their energy-aware schemes. Others produced additional delay which is considered fatal to delay-sensitive applications. In addition, some caused an increase in the number of lost packets. On the other hand, the energy-aware retransmission model for multimedia communications for wireless networks that is suggested in this thesis reduces energy consumption while maintaining QoS.

Chapter 3

3 EARM: An Energy-Aware Retransmission Model for Multimedia Communications over Wireless Networks

In this chapter, a description of the problem is first provided. Then, this chapter illustrates the system model to which the suggested scheme is applied. Finally, the simulation environment used in building the model is also explained.

3.1 Problem Description

The problem with wireless networks is that the probability of channel errors is relatively high due to wireless factors such as fading signal, obstacles, node mobility, etc. Such errors lead to frequent packet losses and packet errors that are masked by the link layer through instant retransmissions. Retransmitting a lost packet repeatedly takes place until the packet is successfully received or the retransmission limit count is reached [7]. While retransmission can be effective in wired networks, it yields performance degradation in wireless environments. The logic behind this claim is that sending packets to a node with bad channel condition will only make the channel worse and induce more packet losses. Consequently, this would not only affect the throughput of the node concerned, but also that of other nodes connected to the same channel. Unwanted delay which is fatal to delay-sensitive applications would be also induced [15]. In addition, such a behavior would produce unwanted energy drain consumed by unsuccessful retransmissions.

This thesis suggests an energy-aware retransmission model for multimedia communications over wireless networks. The objective of the suggested approach is to save up energy drained by unsuccessful retransmissions by simply reducing the number of these non-successful retransmissions. In addition, this model aims at maintaining quality of service (QoS) in terms of delay, throughput and packet delivery ratio which are a priority for multimedia traffic. The suggested model tries to assess the condition of a receiving node before attempting to retransmit lost packets. If the receiver node observes good channel conditions, then retransmission can take place immediately as in the normal flow of the MAC protocol. However, if the receiver node suffers from bad conditions, then retransmission is postponed until the channel condition improves. It should be noted that retransmission takes place only during the time service allocated for that particular node. The importance of retransmitting lost packets only during the service scheduled for the receiver node was derived from the work proposed by [15]. Such a technique doesn't require modification to be done for the packet scheduler and doesn't induce undesired shift in the resource allocation to nodes. Changes in resource allocation such as bandwidth can be unfair to other nodes leading in a decrease in their throughput rate and incurring unwanted additional delay.

3.2 System Model

The energy-aware retransmission model was applied to multimedia traffic transmitted over wireless channels. The underlying transport protocol used is UDP that provides constant bit rate (CBR) services over the wireless network. CBR provides a deterministic transmission capability with low delay. Therefore, it is well suited for real-

time applications such as audio and video streaming. Moreover, the mobile nodes communicate with each other over a Wi-Fi (802.11b) connection. Different mobility scenarios are assessed: low, medium, high and mixed. First the model was applied to single-hop ad hoc networks with a single source node. Figure 5 depicts single-hop ad hoc network architecture. Then, it was extended to cope with multi-hop ad hoc environments as depicted in figure 6. Finally, it was applied to multi-hop ad hoc networks with multiple sources instead of a single source node.

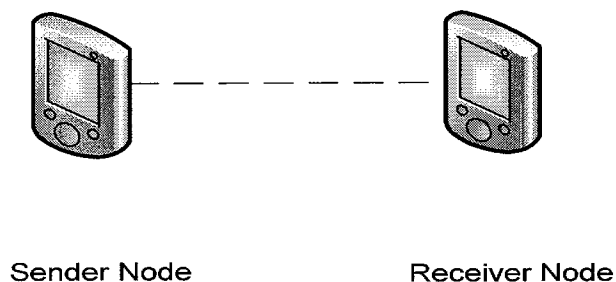


Figure 5- Single-hop wireless architecture

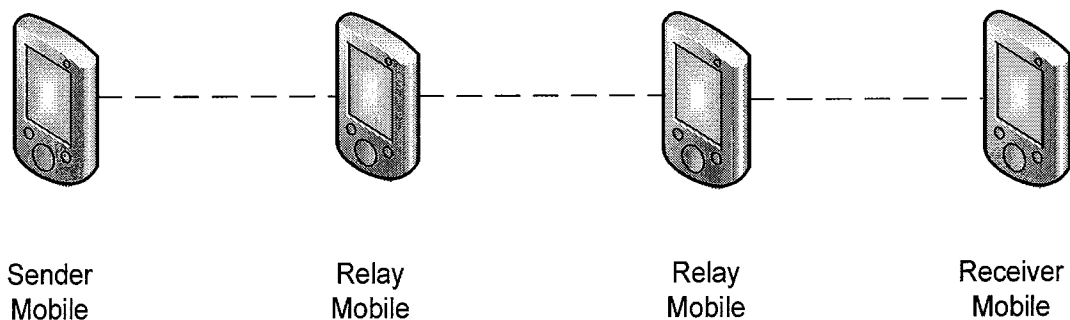


Figure 6- Multi-hop wireless architecture

3.3 Simulation Environment

The network simulator (NS-2) [11], [14] was used to implement the proposed energy-aware retransmission model over wireless networks. NS-2 is an object-oriented simulator that uses two languages, C++ and TCL. All the protocols (transport protocols, routing protocols, MAC protocols, etc.) along with all the aspects of the communication networks (nodes, links, packets, etc.) are written in C++. TCL, on the other hand, is used to build simulations by using the pre-defined aspects in C++ (type of routing protocol, number of nodes, etc.). Therefore, the proposed model in this thesis was written in C++ as part of the MAC block, mainly MAC 802.11 that is defined in NS-2. To assess the effectiveness of this scheme, experimental work was conducted through building simulations written in TCL. Nam is a utility provided by NS-2 in order to visualize the built simulations. Moreover, the X-graph utility is also used to view results of throughput, delay and loss in 2-D planar graphs. Finally, AWK is another utility used to properly and neatly extract information from trace files produced by the simulations.

Figure 7 shows the workflow followed in building the simulation setup of the suggested model. First, the retransmission model was written in C++ and added as a part of the predefined MAC protocol (802.11b). Then, simulation scripts were written in TCL. These scripts form different scenarios that are used to assess the effectiveness of the suggested model. After running a simulation script, the NAM utility was used to visualize such a simulation. The AWK utility was used to extract important information from the trace files produced by running the simulations in order to calculate throughput, packet

delivery ratio, delay, and energy consumption. Finally, the X-graph utility was used to visualize the previous parameters in 2-D graphs.

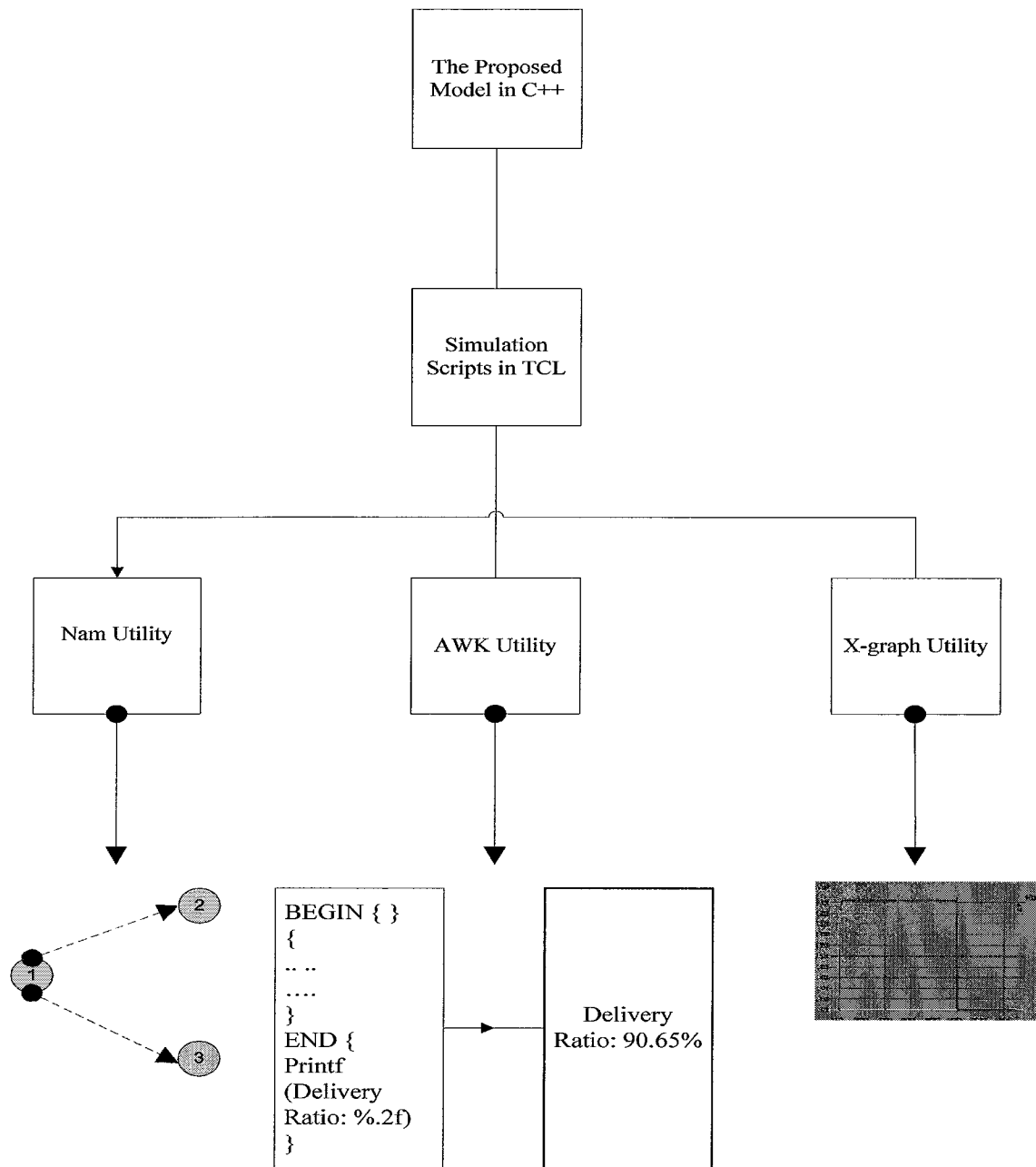


Figure 7- Simulation setup

Chapter 4

4 Implementation Details of EARM

The proposed energy-aware retransmission model (EARM) for wireless multimedia suggests checking the condition of the receiver node before attempting to retransmit lost packets. The motivation behind such an approach is to determine whether packet loss was due to wireless factors associated with that node or due to congestion in the network. If loss was due to congestion, immediate retransmission would take place as in normal behavior. On the other hand, if loss was due to wireless factors, the proposed model checks if these wireless factors persist before retransmitting the lost packets. If they do not persist, then retransmission would also take place immediately. However, if the wireless factors associated with that receiver node continue to exist, the packet is saved in a separate refrain queue, allocated to hold lost packets that are refrained from being transmitted, for each receiver node within the network. To accurately assess the condition of the node before transmitting or retransmitting a packet, two check points are utilized. Signal strength is the first check point and the refrain counter is the second check point. Signal strength primarily depends on the location of the receiver node and is affected by its movement. The refrain counter, on the other hand, corresponds to the number of positive/negative acknowledgements (ACK/NACK) per each node at the MAC layer. For every ACK received, the refrain counter is decremented by 1, and for every NACK, the refrain counter is incremented by 1. The utilization of the refrain counter is further explained in section 4.4. Initially, the refrain counter is set to zero for all nodes.

4.1 Model Workflow

When a packet is scheduled to be transmitted to its destination node, the MAC layer would check the signal strength. If the latter is above a certain threshold indicating a strong signal and the refrain queue of that receiver node is empty, then this packet is immediately sent to its destination. If the refrained queue is not empty, this packet and the packets stored in the refrained queue of the receiver node are transmitted. On the other hand, if the signal strength is below the predefined threshold indicating a weak signal, the refrain counter of the receiver node is checked. The latter corresponds to the number of negative acknowledgements per each receiver node at the MAC layer. For example, a value of one indicates that one packet has not been successfully received by a particular node. Hence, if the refrain counter is greater than zero indicating that one packet or more was not successfully received, the scheduled packet is refrained from being sent and stored in the refrain queue of its receiver node instead. The refrain counter is then decremented by 1 every time the packet is enqueued instead of being transmitted. Conversely, when the refrain counter is equal to zero, this either indicates that no unsuccessful transmissions have occurred yet or that the number of packets to be refrained has been reached. Either case, when the refrain counter is equal to zero, the refrained queue of the receiver node is checked. If it is empty, then the packet is sent directly despite the weak signal. Alternatively, if the queue is not empty indicating that there are refrained packets, then the new packet is enqueued in the refrain queue, and the first refrained packet in the queue is dequeued and transmitted instead. It should be noted that weak signal strength doesn't indicate that a packet will never be received successfully, but rather that the probability of

receiving it successfully is low. Moreover, every time a packet is received successfully, the refrain counter of the corresponding receiver node is decremented. It should be also noted that the minimum refrain counter is equal to zero while its maximum value is equal to 4. In addition, the refrain counter only affects the transmission of packets when the signal strength is weak. Therefore, if the signal strength is strong, packet transmission is not affected by the value of the refrain counter.

In case of packet loss and retransmission, a similar behavior is followed as proposed above in the case of packet transmission. When a packet is successfully received, no retransmission is required, and the refrain counter is decremented by 1 as stated earlier due to the reception of a positive acknowledgement. On the contrary, if it was not successfully received, the refrain counter is incremented by 1. Then, the signal strength and the refrain counter are once again checked before any retransmission attempt. If the signal is weak and the refrain counter is greater than zero, the packet is enqueued in the refrain buffer of the receiver node instead of being immediately retransmitted. The logic behind such an approach is that it is more likely to have a packet lost when it is sent while the signal is weak. Moreover, a lost packet would normally incur instant retransmission until it is successfully received or the retransmission count is achieved. Such a procedure will only deteriorate the channel condition and affect other nodes that have strong signal strength. Hence, refraining from instant retransmission when the node condition is bad protects the performance of other nodes sharing the same source and postpones retransmitting of lost packets until the condition of that receiver node enhances. Consequently, retransmitting lost packets when the node condition enhances increases the probability of successful

reception. On the other hand, if the signal is strong or the refrain counter is equal to zero, the refrain counter is incremented by one due to the unsuccessful reception, and the packet is immediately retransmitted.

The direct advantages of such an approach lie in the fact that it is very suitable for wireless multimedia traffic. This approach protects nodes with good conditions from having performance deterioration because of other nodes with bad conditions. As a matter of fact, channel errors in WLANs are more likely to be location-dependent for each node. When a set of nodes share the same source, some of them may suffer from errors and other nodes may observe good conditions. In such a case, the node observing location-dependent errors is highly prone to continuous packet losses. This would invoke link layer retransmissions which would block packets destined to other nodes with good channel conditions. Furthermore, sending packets to links with bad conditions will only increase the probability of losing these packets and causing performance degradation [15]. Therefore, the suggested model tries to amend the situation of the node with bad conditions until it attains back good conditions. As a result, the suggested model would eventually decrease unwanted energy drain caused by unsuccessful retransmissions. Figure 8 depicts the workflow of the suggested model.

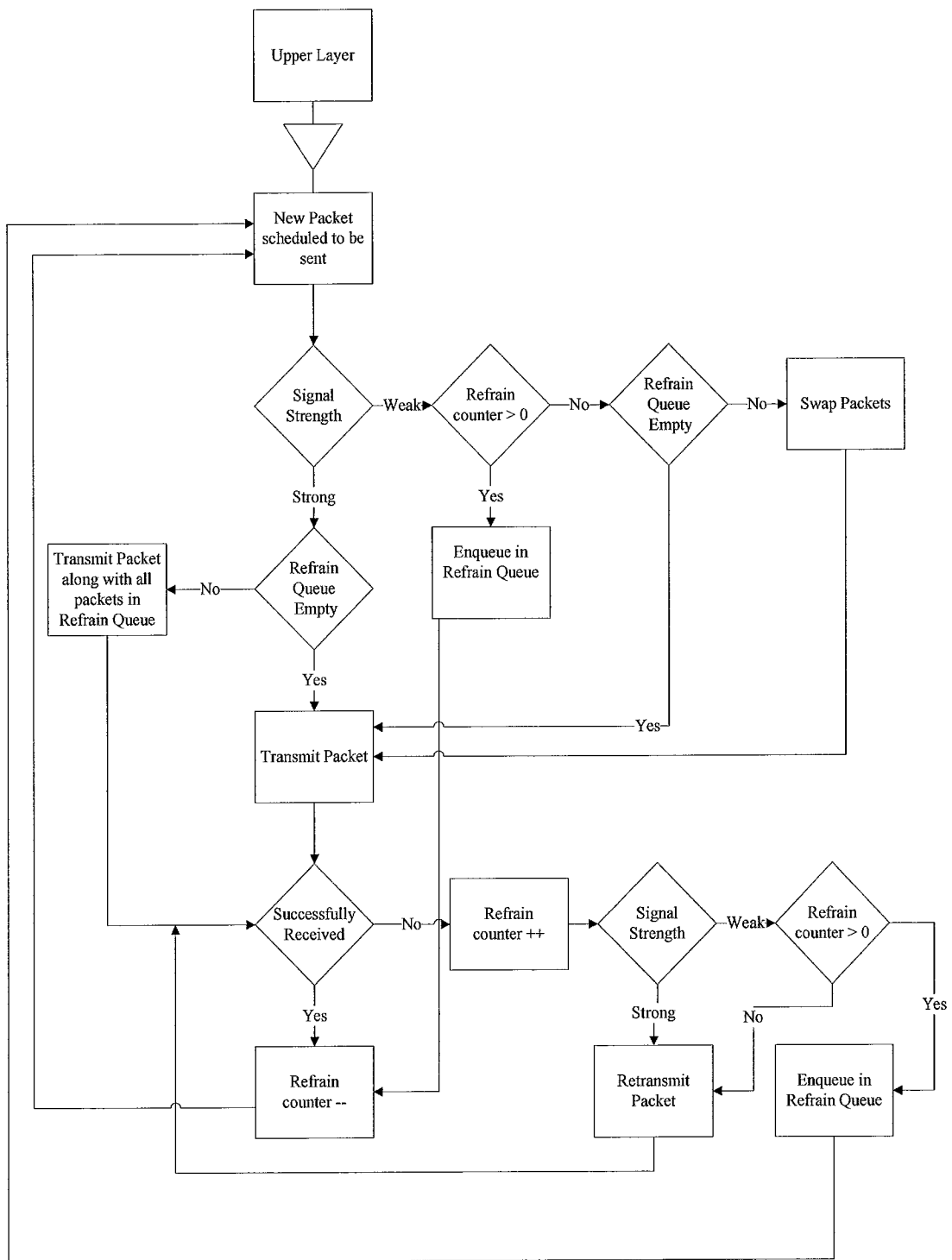


Figure 8-The workflow of EARM

The key aspect of the suggested model is that it takes into account two factors to evaluate the condition of a certain node. The use of signal strength along with the refrain counter provides a better assessment of the condition of a particular receiving node. Furthermore, using a dynamic refrain counter that copes with number of negative/positive acknowledgements makes the suggested model more adaptive to changes to each mobile node within the wireless network without affecting the performance of other nodes.

Four main concerns should be further discussed to correctly implement this model. One of which is the signal threshold that separates a weak signal from a strong one. The second issue discusses choosing the refrain queue size. The third issue concerns the maximum refrain counter value. Finally, the fourth issue discusses the radio propagation model that should be used.

4.2 Signal Strength Threshold

Signal Strength can be measured in mW, dBm or RSSI. MW measures the amount of energy present, dBm provides a logarithmic measurement of signal strength and RSSI (Receiver Signal Strength indicator) measures the amount of radio energy available in the channel. Conversion from/to RSSI is usually a specification set by the network card vendor. However, RSSI increases and decreases in integer steps regardless of the WNIC since it is an integer value, it. Thus it tends to lose accuracy when it is used to measure energy levels. While there is a clear formula to convert signal from mW to dBm and the other way around, conversions tend to lose accuracy at certain values. Figure 9 shows that at a value greater than or equal to 5 mW, signal does not change significantly in dBm.

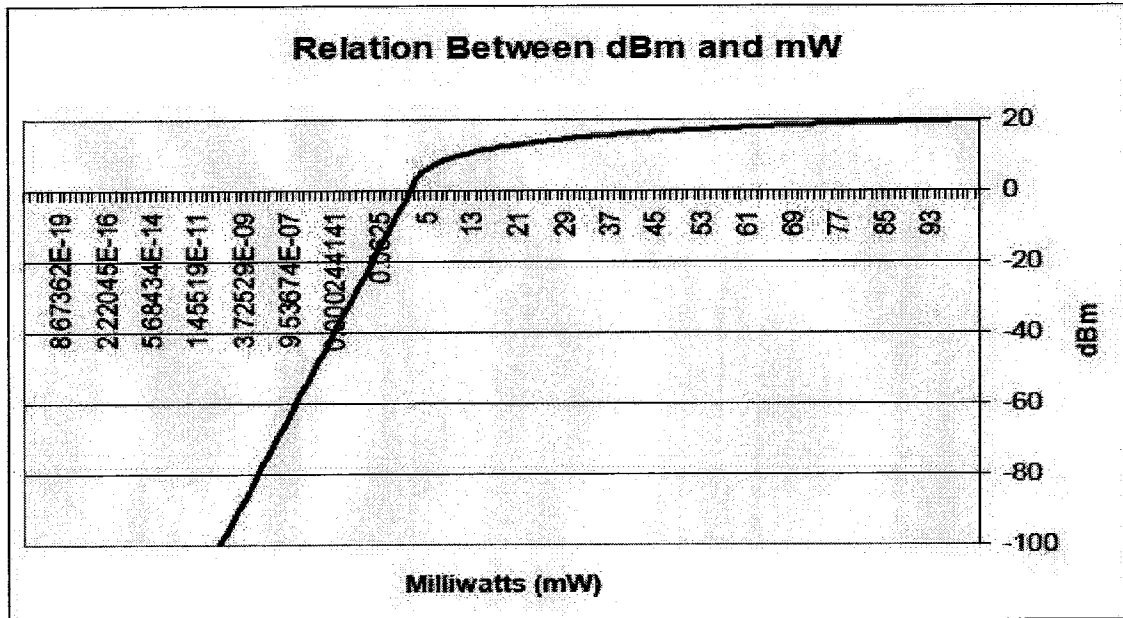


Figure 9- Relation between dBm and mW [32]

For that purpose, [32] suggests using a percentage metric for measuring signal strength. This metric provides a more reliable and more generic measurement of signal strength than does mw, dbm and RSSI. Moreover, [32] provides a map for accurately converting signal strength in one of the previously stated metrics to a percentage value and the other way around without losing precision.

In my work, the MAC protocol used within all experiments is IEEE 802.11b. The latter has a data rate of 11Mb/sec as its maximum rate value. This implies that when the MAC is operating at its maximum rate, the signal strength would be equal to 100%. When the MAC 802.11b rate drops to 5.5Mb/sec, this indicates the existence of wireless errors which would manifest itself in the corrosion of the signal strength. As the wireless errors increase due to node mobility or other wireless factors, the data rate would continue to

decrease to 2Mb/sec and even to 1Mb/sec. A rate value below 1Mb/sec indicates that the channel can no longer differentiate data signal from noise. The study done by [32] shows that as long as the measured signal strength remains above 30%, there should be sufficient signal for normal 802.11b operations. Accordingly, this percentage was used in my work as the threshold value that separates strong signal from a weak one. A 30% value for the signal strength corresponds to a value of -82dbm according to the conversion table provided by [32].

4.3 The Refrain Queue Size

The suggested approach requires attaining a separate queue for every mobile node to store lost packets. The aim behind such an approach is to separate the occurrence of retransmissions of the same packet to the next scheduled service instead of repeatedly retransmitting a lost packet. This was explained earlier as immediate retransmissions would cause performance degradation and unwanted energy drain in wireless networks. The idea of using a queue was derived from the work proposed by [15]. In [15], using a buffer was used to hold lost packets instead of retransmitting them immediately. The buffer size should not be too large or too small. A small queue will induce more packet loss since packets would be dropped frequently and replaced by new refrained packets especially if the weak signal persists. Consequently, a very small queue would lead to an unwanted decrease in the packet delivery ratio. On the other hand, if the queue is too large, the packet delivery ratio would definitely increase. Nonetheless, most of the packets would violate the delay limit of real-time applications. Therefore, a very large queue would simply be useless to delay-sensitive applications. As a result, in this thesis, the refrain

queue size is set to 10 as suggested by [15]. It should be noted that a queue size of 10 indicates that a packet can only be retransmitted four times at most before being dropped. This is highly important since the retry count limit is normally set to 4. Thus, the idea of using this queue is to separate the occurrences of these packet retransmissions by postponing them to the next scheduled service instead of repeatedly retransmitting and affecting the network performance.

4.4 The Refrain Counter

The refrain counter corresponds to the number of positive/negative acknowledgements taking place at the MAC layer. Each receiver node attains a separate value of the refrain counter for that purpose. For example, if the refrain counter for node1 is set to one, this means that one packet was not received successfully by node1 resulting in a negative acknowledgement. Consequently, one packet will be refrained from transmission and stored in the refrain queue instead. Initially, the refrain counter for each receiver node is set to zero since there are no unsuccessful transmissions yet. For every positive acknowledgement, the refrain counter is decreased by one, and with every negative acknowledgement, the refrain counter is increased by one. It should be noted that the minimum value for the refrain counter is zero. Thus, if the refrain counter is set to zero, and a packet was successfully acknowledged, the refrain counter remains zero since dropping it to -1 is meaningless. On the other hand, for every negative acknowledgement, the refrain counter is increased by one. Thus, a refrain counter of value 2 means that during a weak signal two packets should be refrained from transmission. After refraining two packets, it would be time to transmit from the refrain queue if weak signal persists. In case

of another loss, the packet is again enqueued in the refrain queue and the refrain counter would be set to 3 instead indicating that three packets should be refrained if weak signal persists.

An important issue that should be taken into account is the maximum value of the refrain counter. This thesis suggests that the maximum refrain counter value should be equal to 4. The reason behind this value is explained later in this subsection. Figure 9 shows the changes in the refrain counter value with respect to the number of ACKs and NACKs. With every NACK, the refrain counter is incremented by 1 until the number of NACKs exceeds 4, where the refrain counter value remains four. On the other hand, with every ACK, the refrain counter is decremented by 1 until it reaches a value equals to zero at which it remains the same even if the number of ACKs is increasing.

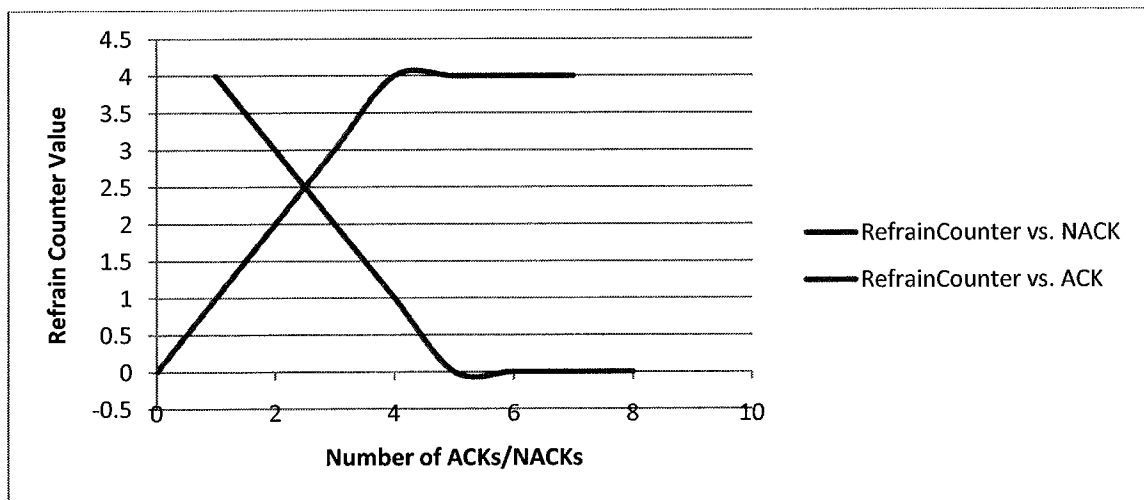


Figure 10- The refrain counter value

The maximum value for the refrain counter was chosen to be 4 after thorough investigation. A very small number would be worthless in terms of increasing packet

delivery ratio. Therefore, refraining more packets during bad channel conditions and transmitting the refrained packets when the channel condition enhances, is undoubtedly effective in terms of packet delivery ratio. Therefore, the first maximum refrain counter chosen was actually ten which corresponds to the queue size. However, this value caused unwanted additional delay. Therefore, the maximum value for the refrain counter was dropped by one each time until a value of four was reached. A maximum refrain counter equals to 4 did not only beat the other refrain counters in terms of delay as figure 11 shows, but also outperformed the default MAC in terms of delay, energy efficiency and packet delivery ratio as shown later in chapter 5. Figure 10 shows the complementary cumulative distribution function (CCDF) of packet delay associated with a maximum refrain counter value. It displays the probability (in percentage) of packet delay meeting or exceeding a certain value. Same scenario files were run with a different maximum refrain counter in order to determine the best value to be chosen. As the graph shows, a maximum value of 4 outperforms the other values. In case of a refrain counter 10, the percentage of packet delay that violated the time limit of real-time applications (150 milliseconds) is almost 20%, while in the case of a refrain counter 4; it is less than 3%. It should be noted that the percentage of energy saved and the percentage of packet delivery ratio was slightly higher as the maximum refrain counter value increased. However, since delay could be fatal for real-time applications, the refrain counter with the least percentage of packet delay was chosen. In this case, refrain counter of maximum value of 4 was utilized in this thesis.

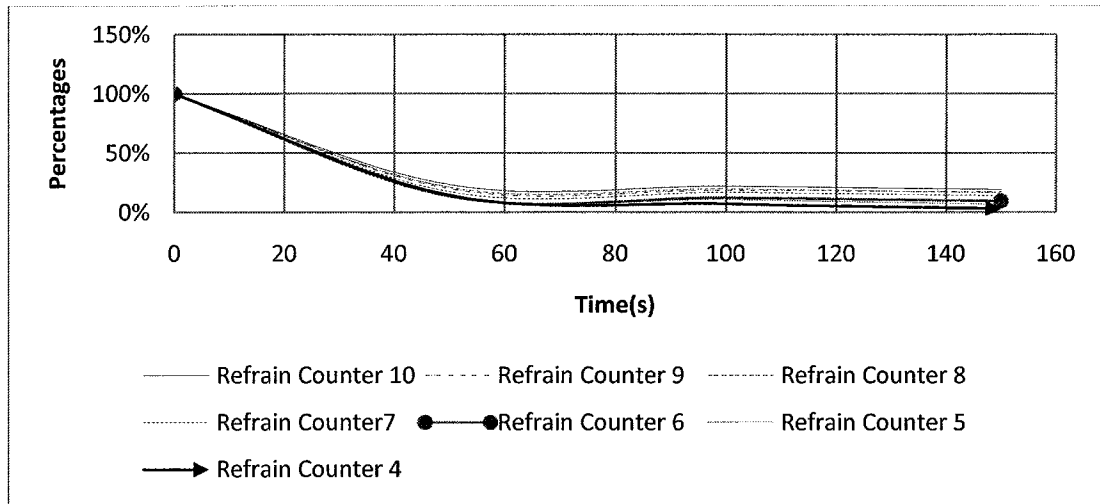


Figure 11- CCDF of packet delay for all refrain counters

4.4 The Radio Propagation Model

Radio propagation models are an important aspect that should be taken into account in wireless networking. A propagation model is responsible for determining the signal strength of the received packets. Therefore, it should account for the wireless factors involved in wireless networking. These factors include the distance that separates the sender from its receiver, the transmit power of the packet, the gain and height of the antenna and the scale fading of the packet. The latter is induced by mobile movement in wireless networks. All these factors should be considered by the propagation model in order to accurately determine the packet's receiving signal [7].

In fact, when a node receives a packet, the physical layer sends this packet to the propagation model for a calculation of the packet's signal strength. Then, this packet is handed over again to the physical layer which attains a receiving threshold. If the received packet has a receiving power below the receiving threshold, it would be dropped by the

MAC layer. Unlike, the previous NS-2 propagation models used (free space and two-ray ground), the rician fading model accounts for all these wireless factors. Free space considers a single line of sight between the sender and the receiver, and is hence considered to be an idealistic model. Two-ray ground, on the other hand; does account for ground reflection path when calculating the packet's receiving power. Nonetheless, it fails to take into consideration mobile movement which is a key aspect in wireless environments [35].

Consequently, I have adopted the rician model instead of the two-ray ground model in my work since rician is more suited to wireless networks that involve mobile node movement. While in the case of the two-ray ground, throughput remains the same at all times during a simulation as long as the node concerned is within the transmission range, the rician model accounts for the position of the mobile node and the number of mobile nodes connected to the same network. In fact as a mobile node moves further away from its sender, its throughput would degrade gradually until it becomes null when it is no longer within the transmission range. On the other hand, if the mobile node moves closer to its sender its throughput should increase reaching its ultimate allowed rate.

Figure 12 shows the throughput of a mobile node moving gradually away from its sender. Two experiments were executed, one of which used the two-ray ground model, while the second used the rician factor. The two experiments leading to the two different results are exactly the same. In fact, there are two mobile nodes in each of the two experiments (N0 and N1). When the simulation starts, N0 sends CBR traffic over an

802.11b MAC network to N1 until the simulation stops at time 150 seconds. All the network parameters are set to be identical in both experiments except for the propagation model. Experiment1 is using the two-ray ground model; whereas, experiment2 is using the ricean model. The results of the two experiments show that the ricean model is more suitable for wireless networks that include mobile movement than two-ray ground. This is due to the fact that the ricean model takes into consideration the position of the mobile node, its movement and its speed throughout the entire simulation.

Figure 12 shows a steady throughput for N1 when using the two-ray ground as a propagation model as long as it is within the transmission range of N0 and drops suddenly to null when it's no longer within that range. On the other hand, Figure 12 shows that the throughput of N1 starts having spikes and then degrades gradually as N1 moves away from its sender i.e. N0 upon using the ricean Factor Model. At time 100 seconds, N1's throughput becomes null indicating that N1 is no longer within the transmission range of N0. Consequently, N1 is no longer able to receive data packets from N0. The experiments show that the ricean model relates more to real-world wireless scenarios than does the two-ray ground model. For that matter, the ricean model was adopted in this study since it accounts for signal strength variation of each packet as the distance between the mobile nodes varies.

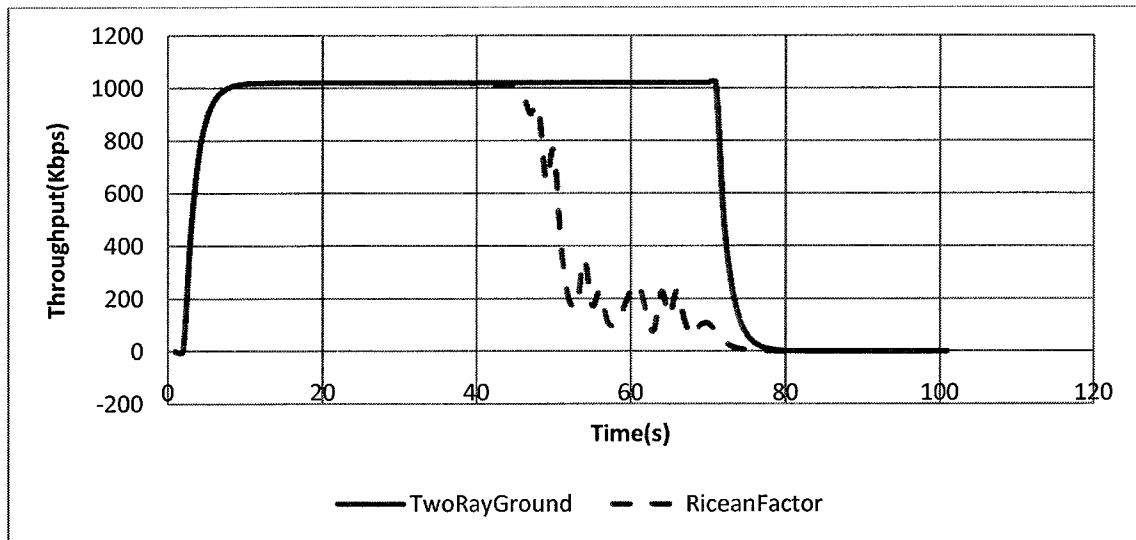


Figure 12- Throughput results using two-ray ground and ricean factor

4.5 A Simple Example

A simple example of how the suggested energy-aware retransmission model for wireless multimedia operates is provided to better understand the workflow of this model. Suppose there is a network with three mobile nodes (A, B and C) with A being the sender node, and B and C being the receiver nodes. The packet scheduler works as a round-robin i.e. it schedules a packet for B and another one for C, then B again and further on. Figure 13 displays the workflow of the suggested energy-aware retransmission model in this simple example. In addition, the original interface queue that contains packets destined to both B and C along with the refrain queues of B and C are shown in figure 13. Moreover, the changes in the refrain counters (RC) of B and C and the variations of B's and C's signal strength (SS) are also depicted.

Initially, the refrain counters of B and that of C are both set to zero, and refrain queue of each of these receiving nodes are empty. B observes bad channel condition until the end of the connection where it enhances; meanwhile C observes good channel conditions until the end of the connection where it becomes bad. B1 is scheduled to be sent to B. The model would check the refrain counter and since it is equal to zero, the packet will be transmitted normally despite the weak signal. Now, suppose the packet was not successfully received. The refrain counter is thus incremented by 1. The signal strength and the refrain counter are checked once again. As a result, B1 is enqueued in B's refrain queue because the weak signal persists, and refrain counter is greater than zero. C1 is then scheduled to be transmitted to node C and is successfully received. B2 is then scheduled to be sent to node B. Because the refrain counter is greater than zero, this packet will be refrained from being sent and thus enqueued in B's refrain queue. The refrain counter of B would then be decremented by 1. Packets destined to node C are received successfully during their allocated service until the last two packets. B3 is scheduled to be transmitted to node B. At this point, B's refrain queue is not empty, but its refrain counter is set to zero. This indicates that it is time to swap packets and transmit from B's refrain queue. As a result, B3 will be queued in B's refrain queue and B1 will be transmitted instead. Suppose that B1 was not received successfully this time either. It will be enqueued once again in B's refrain queue and the refrain counter this time would be set to 2 indicating two unsuccessful transmissions during a persistent weak signal. This also means that two packets should be refrained from transmission if B continues to observe weak signal strength.

The two nodes keep observing the same patterns as above until C4 is destined to node C. Suppose that this packet was not successfully transmitted despite the strong signal. Before retransmission attempt, the signal strength along with the refrain counter would be checked. At this point, the refrain counter is set to 1 due to a negative acknowledgement, but the signal is still strong. This means that the loss was due to congestion in the channel rather than to wireless factors. Consequently, C4 would be directly retransmitted. Suppose it was successfully received, then the refrain counter of node C would be decremented and is set back to zero.

At this point, the signal strength of node B enhances and becomes strong. In such a case, the refrain queue of node B is checked and since it is not empty, the new arriving packet B5 along with all the packets in B's refrain queue (B1, B2, B3 and B4) would be transmitted. Suppose, they were successfully received, the refrain counter would be reset back to zero. Finally, C5 is scheduled to be sent to Node C. Suppose that C observes weak signal strength and C5 is not received successfully. At this point, C5 would be enqueued in C's refrain queue since the weak signal persists and the refrain counter is greater than zero.

At this point, Node A has no more packets to be sent to B or C. However, C's refrain queue contains one packet which was refrained from retransmission (C5). Consequently, the suggested model proposes to have all refrain queues checked before attempting to close the connection. If any of these queues contain any packets, then these packets are flushed i.e. transmitted to their destination node regardless of the signal strength and the value of the refrain counter. In case of transmission failure, then these

packets would be simply dropped and not retransmitted again. C5 is retransmitted and is received successfully in this example.

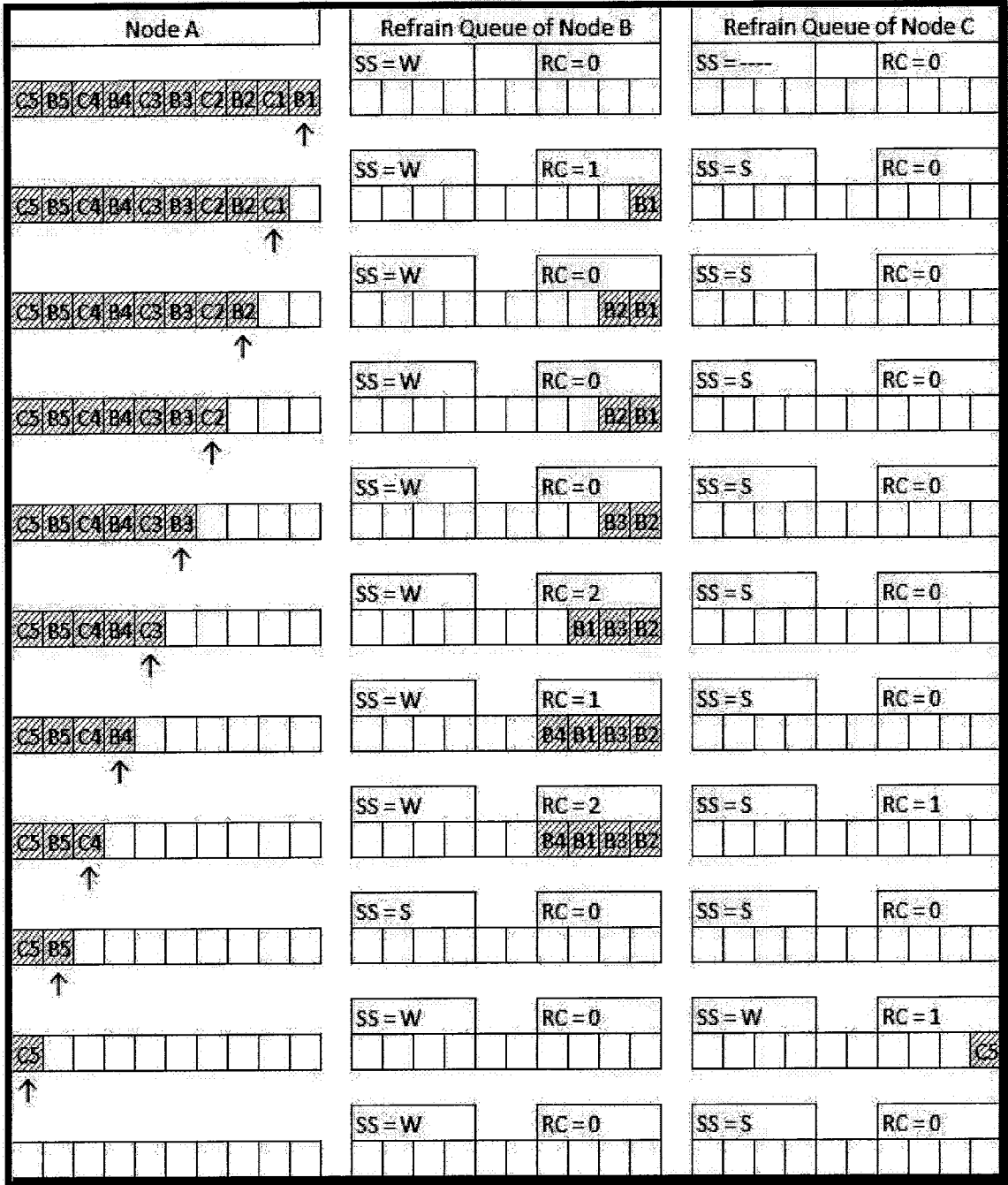


Figure 13- Model workflow, SS is the signal strength and RC is the refrain counter

Chapter 5

5 Simulation Results and Performance Analysis

Different scenarios have been simulated to assess the effectiveness of the suggested retransmission model and compare it to the default case of the MAC 802.11b protocol. In each experiment, two runs were performed, one to show the normal behavior of the MAC protocol and the second run to show the behavior of the proposed energy-aware retransmission model. In all scenarios, the number of retransmissions, percentage of energy drain by these retransmissions, throughput, delay and packet delivery ratio is recorded for thorough evaluation of the adopted model. Table 1 summarizes the network parameters used in all simulations.

Radio Propagation Model	Ricean Factor
Transmission Power	0.2818 (watt) = 24.5 (db)
Transport Protocol	UDP
Routing Protocol	DSDV
MAC protocol	802.11b
Interface Queue Length	100 packets
Refrain Queue Length	10 packets
Topology	400 meters, 400 meters
Traffic	CBR

Table 1- System parameters

Table 2 shows the default energy model built in NS-2. This model was also applied to all nodes involved within the simulations performed in this thesis.

Initial Energy	100 (joules)
Transmission Energy	0.6 (watts)
Receive Energy	0.3 (watts)
Idle Energy	0.1 (watts)

Table 2- The energy model parameters

5.1 Single-hop Ad hoc Network Scenarios

5.1.1 Case Scenario 1: Three Mobile Nodes

In this scenario, three mobile nodes (N0, N1 and N2) communicate with each other. N0 is the sole sender, meanwhile; N1 and N2 are the receivers. At the beginning of the simulation, all nodes are in proximity with each other. At time equals to 1.0 seconds, N0 starts sending CBR traffic to N1 and N2. As the simulation proceeds, N1 observes random mobility. At some point, it moves away from N0 and another time, it moves toward N0. N2 on the other hand, remains in its initial position near the sender N0. The CBR rate and the packet size are set to 1000 kbps and 1000 bytes respectively. The simulation runs for 150 simulated seconds.

Node Movement

Figure 14 displays the node movement for N1 since N1 is the only node observing mobility in this case scenario. At the beginning of the simulation, N1 is in proximity with N0. Then, as the simulation proceeds, N1 moves further away from N0 until it goes out of

the transmission range. After that, it moves closer to N0, then away from N1. Finally, it moves toward N0 once again and remains close to N0 until the simulation ends.

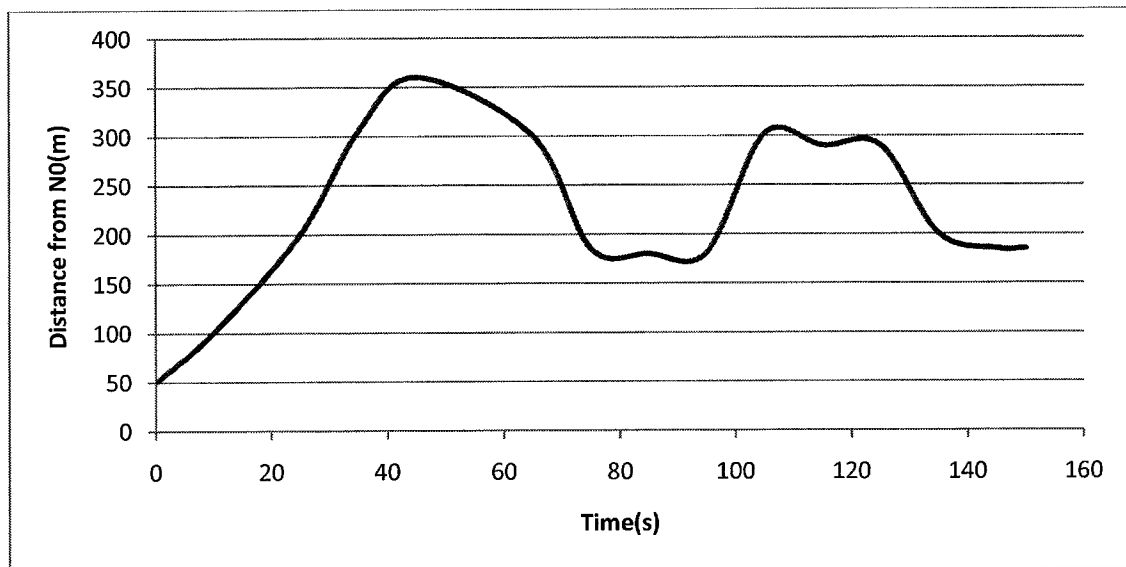


Figure 14- Movement of Node N1

Signal Strength

Figure 15 and figure 16 display the signal strength fluctuation with respect to N1. Figure 15 displays signal strength of N1 versus time, while Figure 16 shows the signal strength of N1 versus its distance from the sender N0. The urge behind showing these two figures is to explain the importance of signal strength since it has been used as a key aspect in implementing the suggested energy-aware retransmission model. In this case scenario, N1 is the only node observing movement, its signal strength was thus recorded to show how wireless factors; primarily mobility can affect a certain node. It should be noted that figure 15 captures the essence of N1's movement. At the beginning of the simulation, N1 is near its sender and therefore, it attains strong signal strength. Then, this signal begins to

diminish and become weaker as N1 moves away from N0. At time 35 seconds, N1 attains a signal strength equals to -82 dBm which is the threshold value chosen in the proposed model to separate a strong signal from a weak one. Then, at time 40 seconds, the signal reaches a value less than -96 dBm. A signal value less than or equal to -96 dBm in networking means the same since it indicates that the concerned node is no longer within the transmission range of the sender. At time 70 seconds, N1 is back in the transmission range of N0 and thus attains a better signal as it moves closer to the sender N0. Then, N1 moves again away from N0 and its signal strength drops below the threshold until it moves back near the sender and its signal strength enhances.

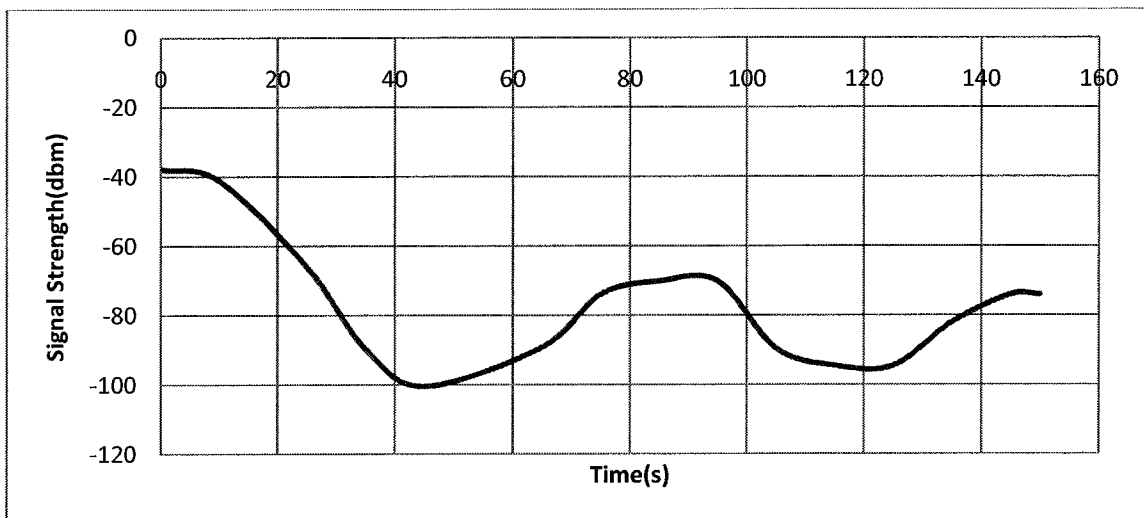


Figure 15- Signal strength versus time

Figure 16 confines with figure 14 and figure 15. This figure shows how the signal strength of N1 drops as it moves away from its sender N0. It should be noted that at a position greater than 200 meters, N1's signal strength becomes less than the signal threshold value suggested in this thesis i.e. -82dBm. At a position greater than 300 meters

from the sender, N1 is no longer within the transmission range of its sender N0 since its signal strength drops to -96 dBm and less as shown.

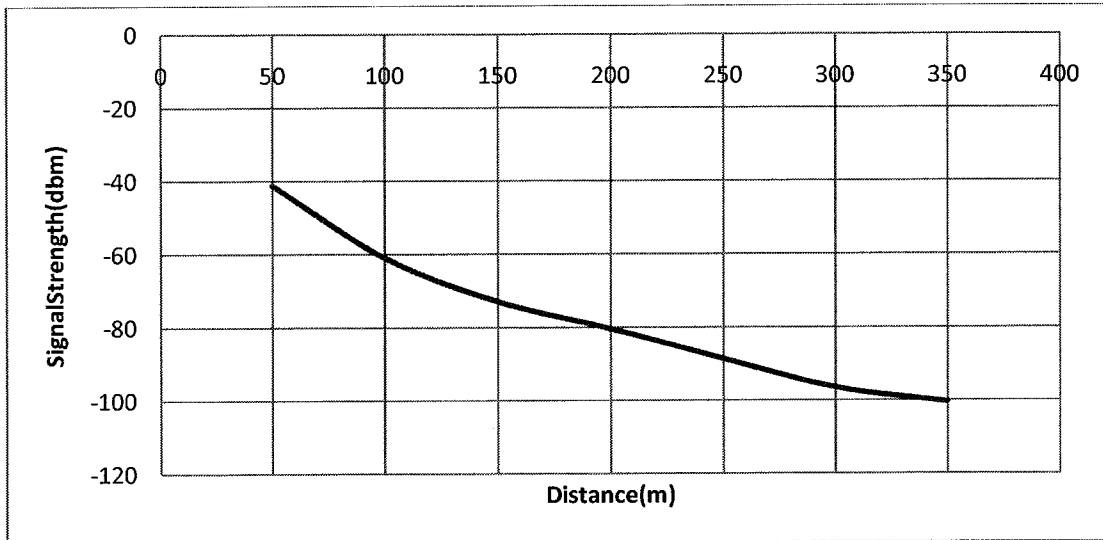


Figure 16- Signal strength versus distance

Packet Delivery Ratio

The packet delivery ratio is calculated as the value of the number of packets received successfully by their destination nodes over the number of packets transmitted by the sender node. The results of the packet delivery ratio of the default MAC and the suggested retransmission model were very similar with a slight improvement for the suggested model. EARM resulted in 86.49% packet delivery, while the default MAC scored 78.15% packet delivery.

Throughput

Figure 17 displays the throughput of N1 and N2 using the default MAC protocol. As N1 moves away from N0, its throughput would decrease. As it moves closer to N0, its

throughput would increase again till it reaches its maximum rate. It should be noted that the throughput graph conforms with that of the signal strength. Consequently, whenever the signal is strong, N1 attains good throughput values, and as N1's signal strength weakens due to wireless factors, its throughput is also degraded. An important observation that should be made is that with the weakening of N1's signal, not only N1's throughput is degraded, but also that of N2 which is also connected to the same sender N0. Thus, in the default MAC protocol, if one node is observing some wireless problems, all other nodes connected to the same source are also affected negatively. This problem is amended with the suggested energy-aware retransmission model.

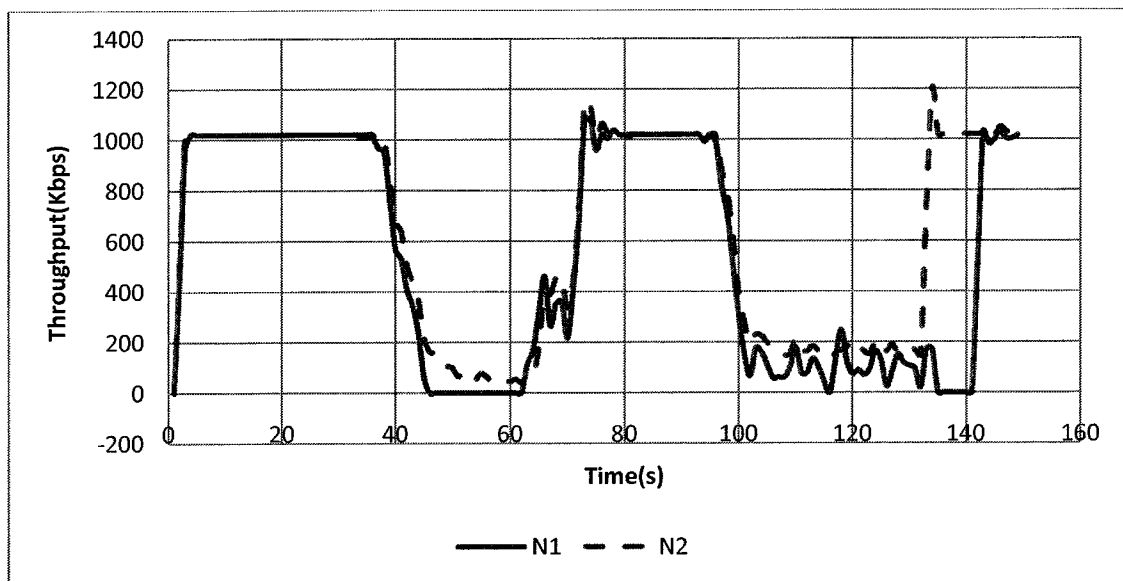


Figure 17- Throughput per node using default MAC

Figure 18 displays the throughput of N1 and N2 upon the utilization of suggested energy-aware retransmission model. It can be concluded that with the proposed model, only nodes that suffer from wireless factors leading to weak signal strength have their

throughput affected, meanwhile; other nodes sharing the same source with strong signal have their throughput left intact. Therefore, the suggested model removes the negative effect of the MAC protocol on the performance of other nodes with good conditions.

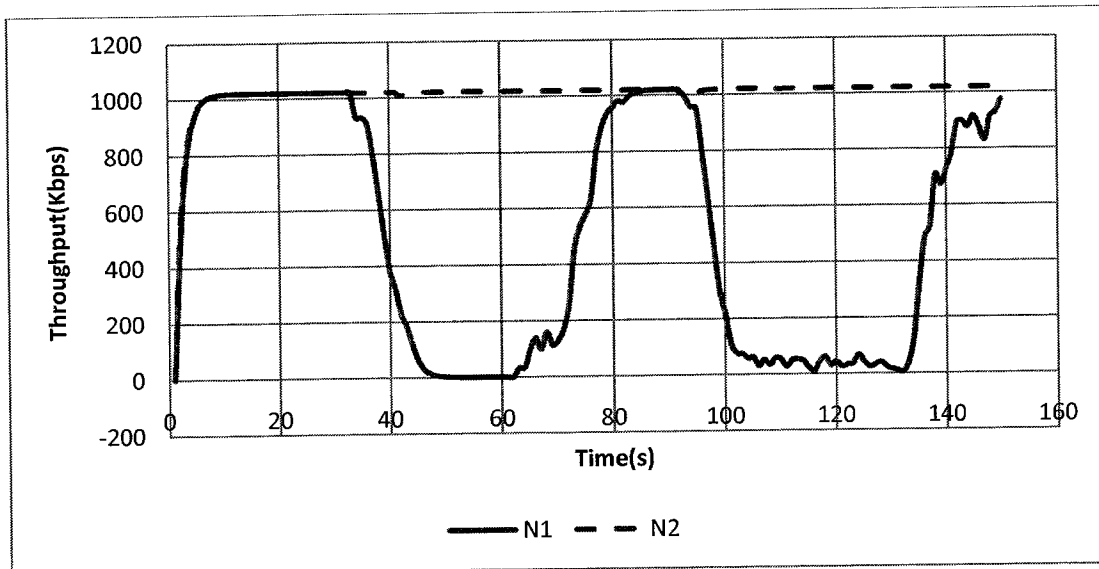


Figure 18- Throughput per node using EARM

Delay

Figure 19 shows the delay for N1 and N2 in the case of the default MAC protocol. When N1 has a weak signal, its packets are affected and consequently they suffer from delay. Moreover, with the default MAC, N2 whose signal is strong throughout the entire connection, is also affected by N1's weak signal. N2 thus suffers from delay as N1 moves away from its sender even though N2 is near N0 and didn't change its position. This problem is very crucial in the case of delay-sensitive applications and is also amended by the suggested model.

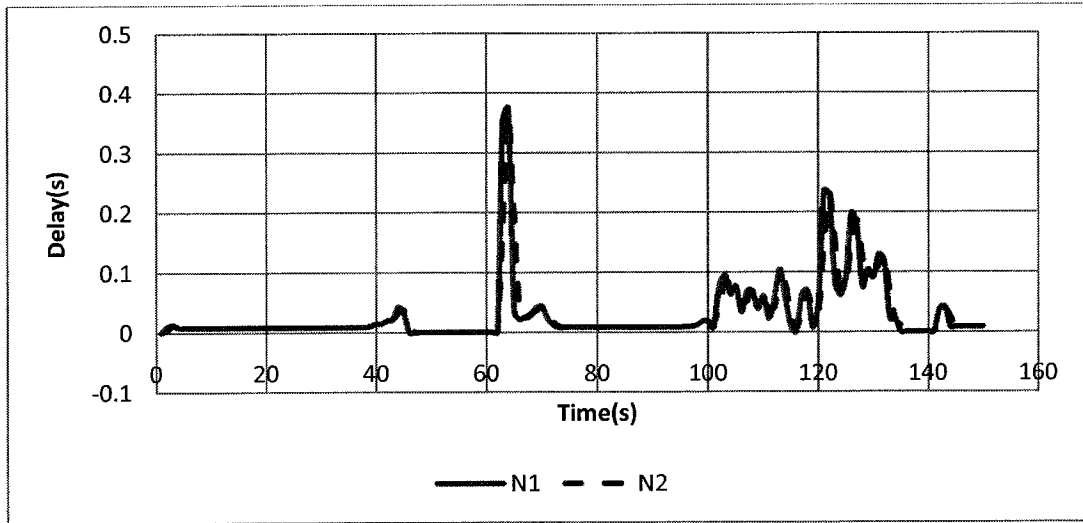


Figure 19- Delay per node using default MAC

Figure 20 displays the end-to-end delay for nodes N1 and N2 upon using the proposed model. It is shown that only nodes that are observing wireless factors are subject to packet delay. On the other hand, nodes with good signal are not affected by other bad nodes and thus their packets are not subject to additional undesired delay.

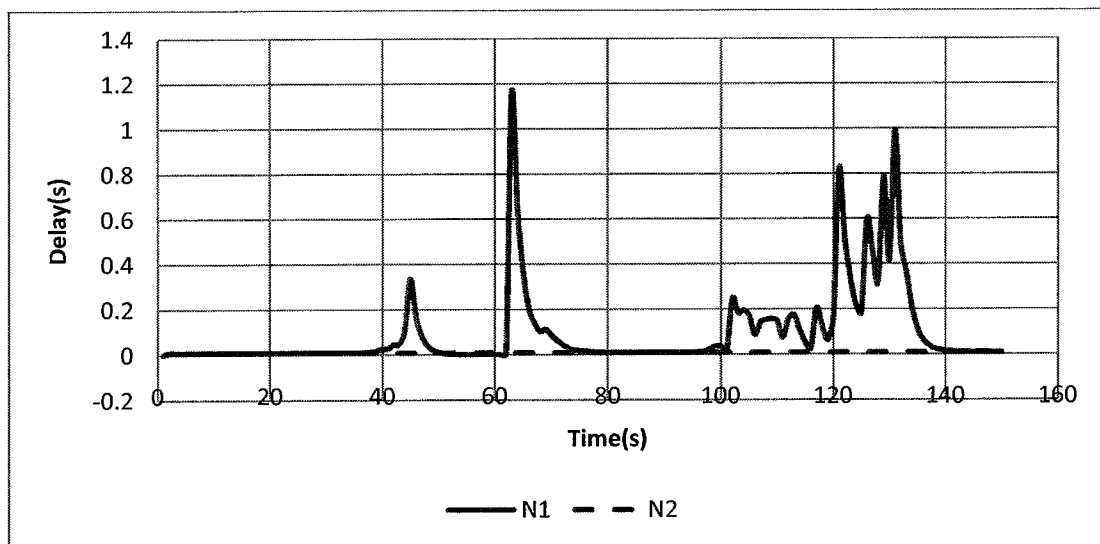


Figure 20- Delay per node using EARM

Energy Efficiency

Energy Efficiency is generally defined as the amount of energy consumed in useful work and not drained as useless power. In terms of this thesis, energy efficiency can be determined by the number of successful transmission attempts per energy unit and not wasted by non-successful useless transmission attempts. Since this thesis proposes an energy-aware retransmission model, energy efficiency is thus achieved by diminishing the number of non-successful retransmissions. In addition, since energy consumption per each transmission is constant as established earlier in the energy model used in this thesis, energy efficiency was calculated as the difference between the number of non-successful retransmissions in the case of the default MAC protocol and the suggested energy-aware retransmission model.

The number of non-successful retransmissions that took place in this experiment when using the default MAC protocol was 10732. On the other hand, this number dropped down to 8659 upon the utilization of the suggested energy-aware retransmission model. Consequently, the percentage of energy saved on retransmissions by the suggested model on this experiment is equal to $100 \times (10732 - 8659) / 10732 = 19.31\%$.

5.1.2 Case Scenario 2: Five Mobile Nodes

In this scenario, there are five mobile nodes (N0, N1, N2, N3 and N4) communicating with each other. N0 is the sole sender, meanwhile; N1, N2, N3 and N4 are the receivers. At the beginning of the simulation, all nodes are in proximity with each other. At time equals to 1.0 second, N0 starts sending CBR traffic to N1, N2, N3 and N4. As the simulation proceeds, N1 starts moving away from the sender. The CBR rate and the

packet size are set to 1000 kbps and 1000 bytes respectively. The simulation runs for 150 simulated seconds. The motivation behind this case scenario is to evaluate the effectiveness of the suggested model when a node persists having bad conditions till the end of the simulation.

Packet Delivery Ratio

The default MAC protocol scored a packet delivery ratio equal to 95.22% in this case scenario. On the other hand, the packet delivery ratio increased to a value equal to 98.86% upon using the EARM.

Throughput

Figure 21 shows the throughput for N1, N2, N3 and N4 throughout the entire simulation. At time equals to 1.0 second, N0 starts sending CBR traffic over the channel to N1, N2, N3 and N4, and thus their throughput begins to increase until it reaches 1.0 Mbps i.e. the set CBR rate. All nodes continue to receive data at the maximum rate until time equals to 50 seconds where N1 is moving further away from N0 till it becomes 200 meters away from N0. At this point of the simulation, all nodes start having spikes until time equals to 65 seconds when N1 is 300 meters away from N0. It's at the border of the transmission range i.e. it is still accepting, but the throughput drops severely for all nodes with N1's throughput degradation being even greater. At time greater than 70 seconds, the throughput of all nodes becomes null. It should be noted that even though only N1 becomes outside the transmission range of N0, the throughput of the other nodes is also severely affected for quite some time. At time equals to 80 seconds, N2, N3 and N4 attain

their normal throughput and continue receiving packets at its maximum CBR rate. On the other hand, N1 remains away from the sender N0 with a weak signal.

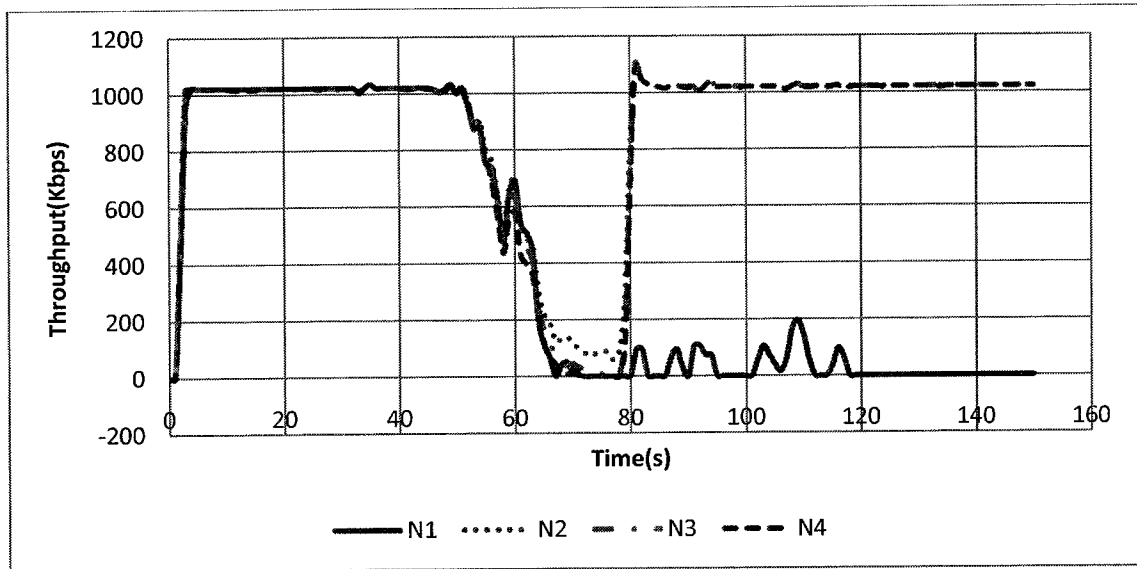


Figure 21- Throughput per node using default MAC

Figure 21 displays the throughput of N1, N2, N3 and N4 upon the utilization of suggested energy-aware retransmission model. It can be concluded that with the proposed model, only nodes that suffer wireless factors leading to weak signal have their throughput affected, meanwhile; other nodes sharing the same source with strong signal have their throughput left intact.

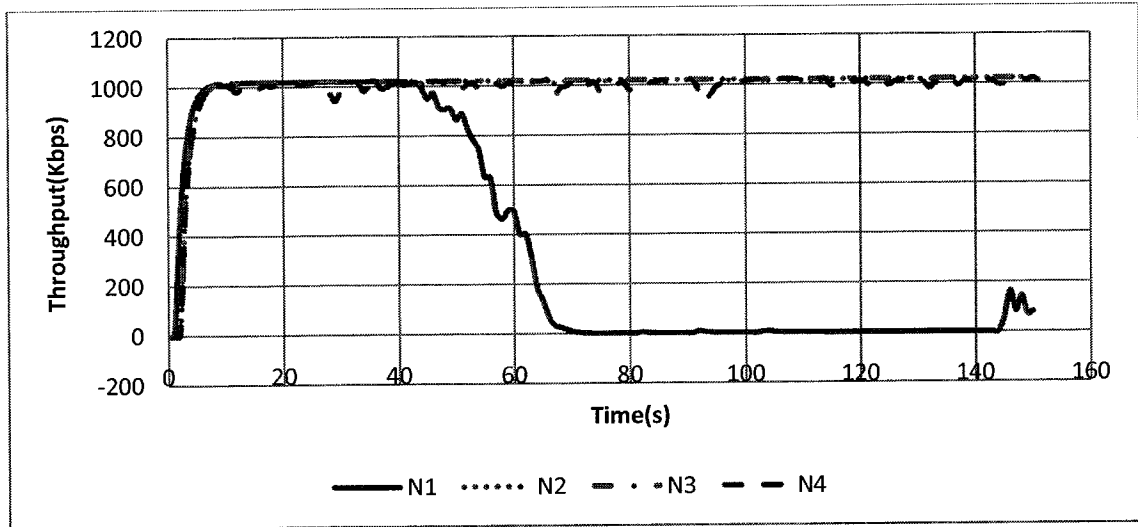


Figure 22- Throughput per node using EARM

Delay

Figure 23 shows the end-to-end delay for N1, N2, N3 and N4. Delay is null for all mobile nodes until time equals to 60 seconds where N1 is 300 meters away from N0. It should be stressed out that the movement of N1 doesn't only cause its packets to be delayed, but also the packets destined to another nodes. In fact, the default MAC protocol induces delay to N2, N3 and N4 even though they attain good signal and are set near their sender N0. This problem is attributed to the continuous packet loss associated with immediate retransmissions to mask these losses.

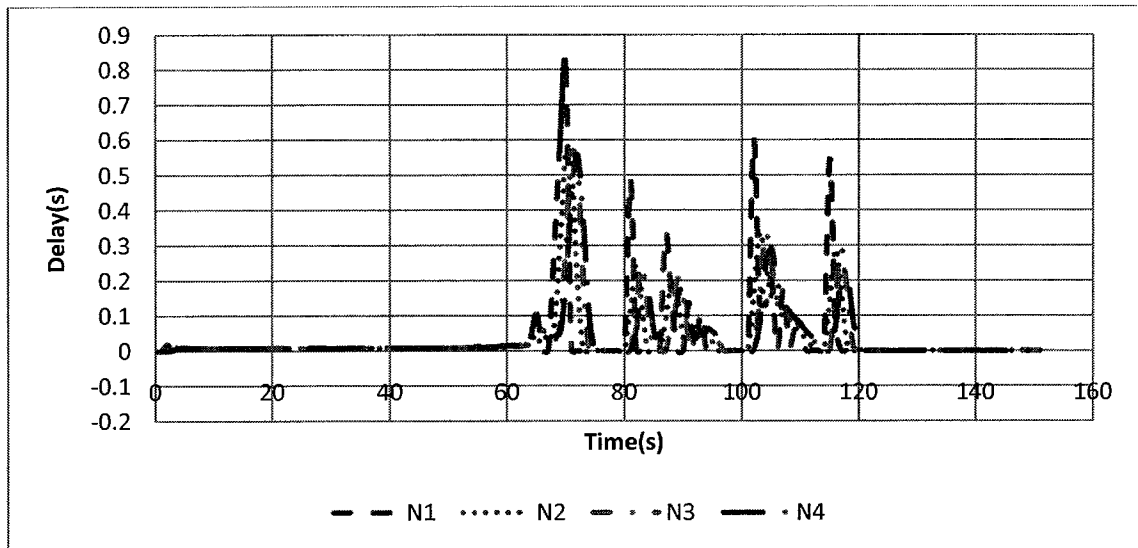


Figure 23- Delay per node using default MAC

Figure 24 displays the end-to-end delay for nodes N1, N2, N3 and N4 upon using the proposed model. It is shown that only nodes that are observing wireless factors are subject to packet delay. On the other hand, nodes with good signal are not affected by other bad nodes and thus their packets are not subject to additional undesired delay.

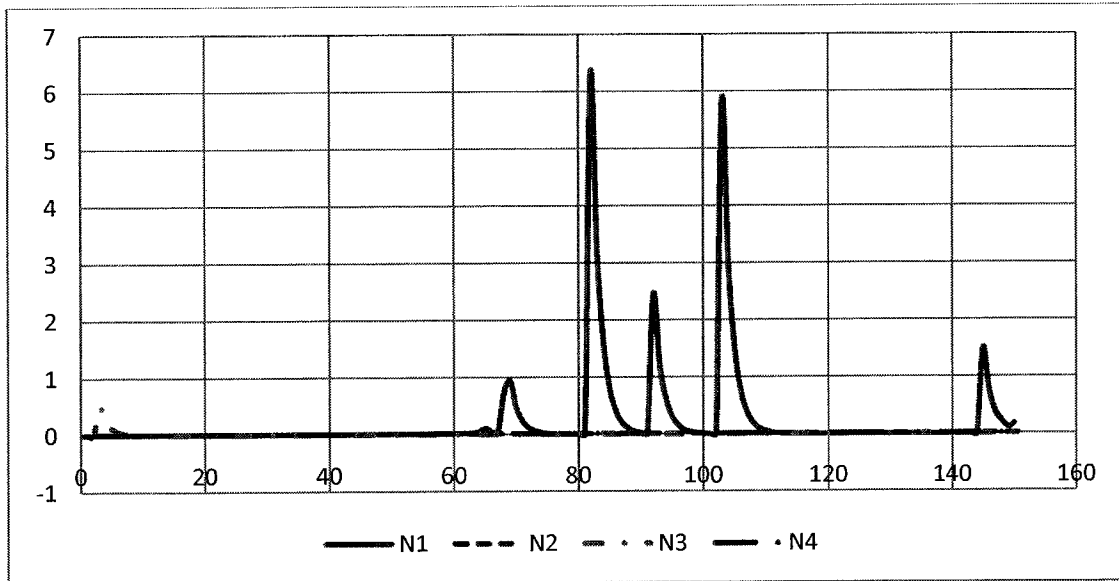


Figure 24- Delay per node using EARM

Energy Efficiency

The number of non-successful retransmissions that took place in this experiment when using the default MAC protocol was 5799. On the other hand, this number dropped down to 1457 upon the utilization of the suggested energy-aware retransmission model. Consequently, the percentage of energy saved on retransmissions by the suggested model on this experiment is equal to $100 * (5799 - 1457) / 5799 = 74.87\%$.

5.2 Multi-hop Ad hoc Network Simulations

5.2.1 Case Scenario 3: Eleven Nodes with Low Mobility

In this scenario, there are eleven mobile nodes. N0 is the only sender and the other mobile nodes are the receivers. In this scenario, all nodes observe low mobility. At time equals to 1.0 second, N0 starts sending CBR traffic to all receiver nodes. As the simulation

proceeds, N1 starts moving away from the sender. The CBR rate and the packet size are set to 200 kbps and 512 bytes respectively. The simulation runs for 100 simulated seconds.

Packet Delivery Ratio

The results of the packet delivery ratio of the default MAC and the suggested retransmission model were very close. EARM resulted in a 99.54% packet delivery, while the default MAC scored 99.51% packet delivery.

Average Throughput

The results of the average throughput of the default MAC and the suggested retransmission model were very close. EARM resulted in a 99.96% as an average throughput, while the default MAC scored 99.91% on average.

Percentage of Packet Delay

Figure 25 displays the CCDF of packet delay in the case of the default MAC and EARM. It shows similar results for both. The percentage of the packets which suffer from a delay greater than 20 milliseconds almost becomes null for the default MAC and the suggested model. This is due to the fact that the default MAC 802.11 protocol is originally designed for low mobility environments.

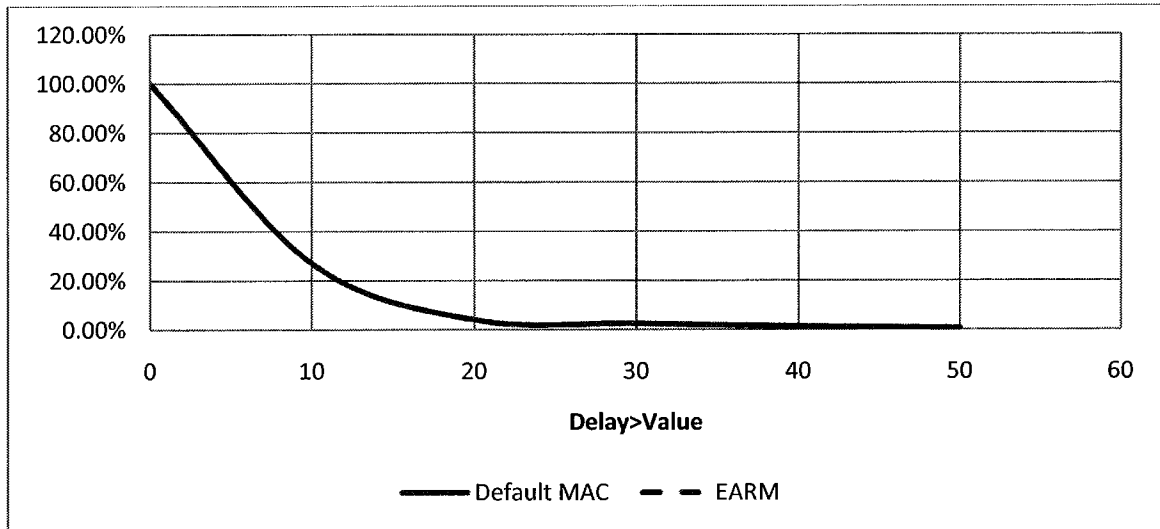


Figure 25- CCDF of packet delay in low mobility scenarios

Energy Efficiency

The number of non-successful retransmissions that took place in this experiment when using the default MAC protocol was 898. On the other hand, this number dropped down to 486 upon the utilization of the suggested energy-aware retransmission model. Consequently, the percentage of energy saved on retransmissions by the suggested model on this experiment is equal to $100 * (898 - 486) / 898 = 45.87\%$.

5.2.2 Case Scenario 4: Eleven Nodes with Medium Mobility

Case Scenario 3 is repeated, but with nodes moving at medium mobility. The parameters are all set the same as in the previous scenario.

Packet Delivery Ratio

The results of the packet delivery ratio of the default MAC and the suggested retransmission model were very similar. EARM resulted in a 97.06% packet delivery, while the default MAC scored 95.82% packet delivery.

Average Throughput

The results of the average throughput of the default MAC and the suggested retransmission model were very close. EARM resulted in a 98.03% as an average throughput, while the default MAC scored 97.47% on average.

Percentage of Packet Delay

Figure 26 displays the percentage of packet delay for the default MAC and the suggested retransmission model. The latter outperforms the default MAC when the nodes are moving with medium mobility. This is a key aspect that distinguishes the suggested model over the default MAC. In fact, since real-time applications are delay sensitive, it is of high importance to decrease the delay value that packets are subject too. The graph shows that the percentage of packets which suffer from a delay greater than 50 milliseconds is equal to less than 5% in the case of the suggested retransmission model, while it reaches a value of almost 20% in the case of the default MAC. Thus, it is shown that the suggested model beats the default MAC protocol in a major aspect, packet delay.

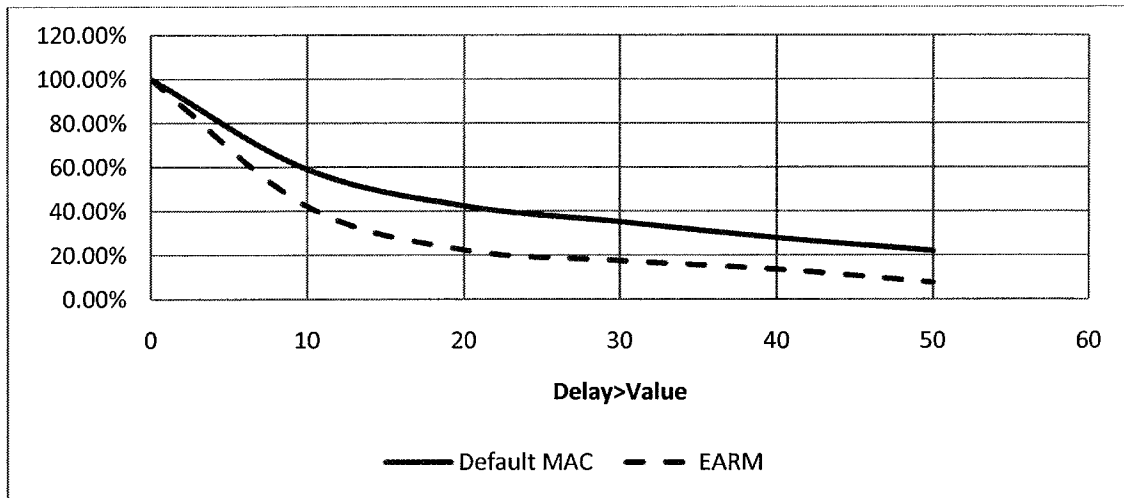


Figure 26- CCDF of packet delay in medium mobility scenarios

Energy Efficiency

The number of non-successful retransmissions that took place in this experiment when using the default MAC protocol was 4360. On the other hand, this number dropped down to 2100 upon the utilization of the suggested energy-aware retransmission model. Consequently, the percentage of energy saved on retransmissions by the suggested model on this experiment is equal to $100 \times (4360 - 2100) / 4360 = 50.78\%$.

5.2.3 Case Scenario 5: Eleven Nodes with High Mobility

In this case scenario, nodes are moving at high mobility. All parameters are set the same as in the previous two case scenarios

Packet Delivery Ratio

The results of the packet delivery ratio of the default MAC and the suggested retransmission model were very similar with a slight improvement for the suggested

model. EARM resulted in a 96.65% packet delivery, while the default MAC scored 94.55% packet delivery.

5.5.2 Average Throughput

The results of the average throughput of the default MAC and the suggested retransmission model were very similar with a slight improvement for the suggested model. EARM resulted in a 96.15% as an average throughput, while the default MAC scored 95.5% on average.

5.5.3 Percentage of Packet Delay

Figure 27 displays the percentage of packet delay for the default MAC and the suggested retransmission model. The latter outperforms the default MAC when the nodes are moving with high mobility. Figure 27 shows that the percentage of packets which suffer from a delay greater than 50 milliseconds is equal to less than 5% in the case of the suggested retransmission model, while it reaches a value of almost 30% in the case of the default MAC.

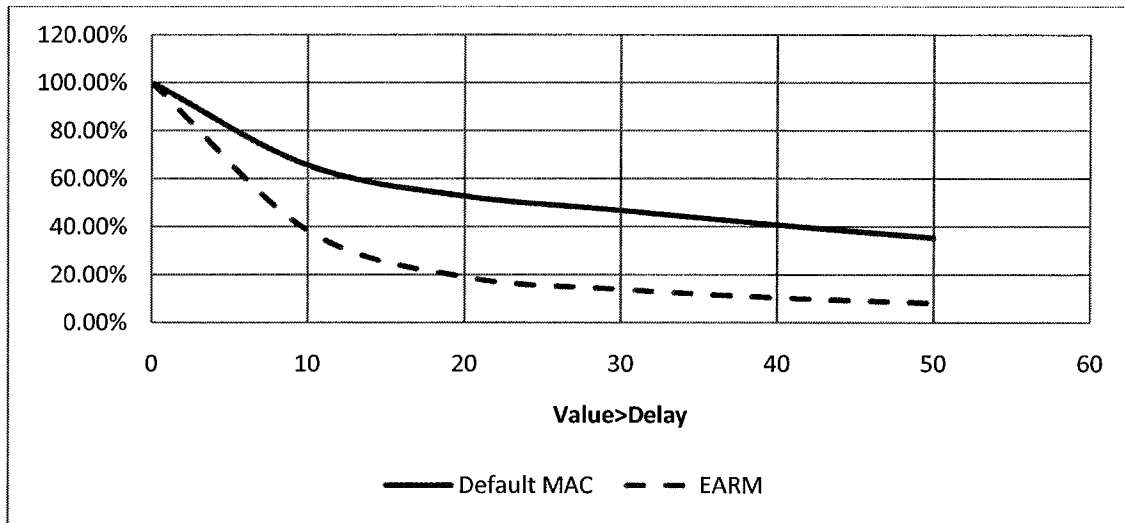


Figure 27- CCDF of packet delay in high mobility scenarios

Energy Efficiency

The number of non-successful retransmissions that took place in this experiment when using the default MAC protocol was 5331. On the other hand, this number dropped down to 2199 upon the utilization of the suggested energy-aware retransmission model. Consequently, the percentage of energy saved by the suggested model on this experiment is equal to $100 \times (5331 - 2199) / 5331 = 58.75\%$.

5.2.4 Case Scenario 6: Eleven Nodes with Mixed Mobility

In this experiment, the topology is quite large and provides a mixed network. 60% of the nodes observe low mobility, 30% observe medium mobility and 10% observe high mobility. The simulation runs for 100 simulated seconds.

Packet Delivery Ratio

The results of the packet delivery ratio of the default MAC and the suggested retransmission model were close. EARM resulted in a 99.65% packet delivery, while the default MAC scored 98.58% packet delivery.

Average Throughput

The results of the average throughput of the default MAC and the suggested retransmission model were close. EARM resulted in a 98.91% as an average throughput, while the default MAC scored 96.28% on average.

Percentage of Packet Delay

Figure 28 displays the percentage of packet delay for the default MAC and the suggested retransmission model. The latter outperforms the default MAC. Figure 28 shows that the percentage of packets which suffer from a delay greater than 50 milliseconds is equal to less than 3% in the case of the suggested retransmission model, while it reaches a value of almost 10% in the case of the default MAC.

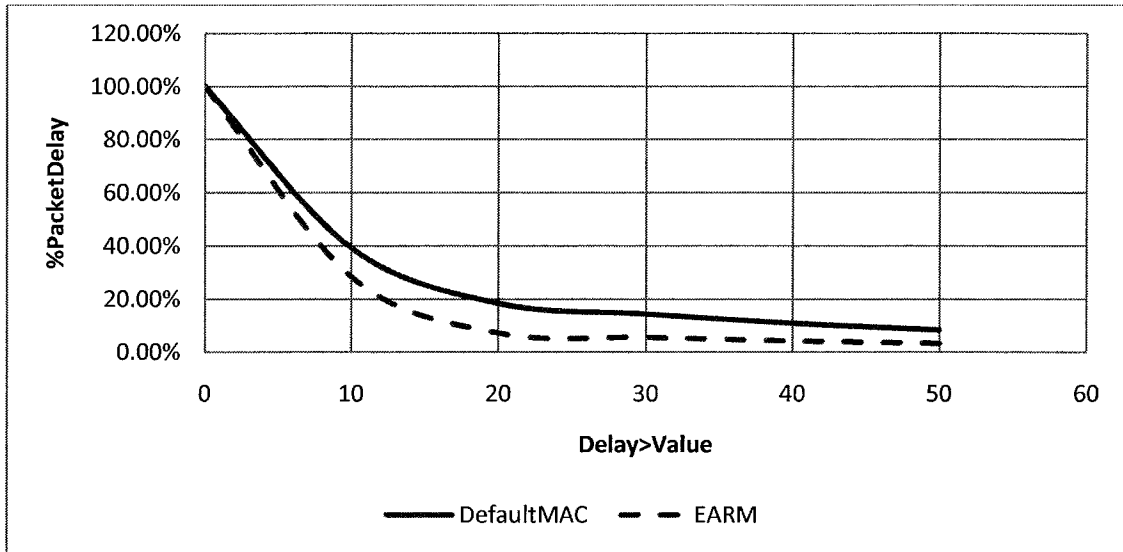


Figure 28- Percentage of packet delay in mixed mobility scenarios

Energy Efficiency

The number of non-successful retransmissions that took place in this experiment when using the default MAC protocol was 2243. On the other hand, this number dropped down to 809 upon the utilization of the suggested energy-aware retransmission model. Consequently, the percentage of energy saved by the suggested model on this experiment is equal to $100 \times (2243 - 809) / 2243 = 63.93\%$.

5.2.5 Performance Analysis with respect to Mobility

Analysis of the experimental work performed proves that the suggested energy-aware retransmission model outperforms the default MAC protocol in terms of packet delivery ratio, average throughput, average delay and energy effectiveness. Figure 29 summarizes the packet delivery results of case scenarios 3, 4, 5 and 6. It is noticed that as the nodes' movement tend to increase, the performance of the default MAC protocol is deteriorated in terms of packet delivery. On the other hand, since the suggested model

cope with mobility, it proved to have better packet delivery ratios. The best packet delivery ratio results were obtained in high mobility scenarios, then medium mobility and finally mixed mobility.

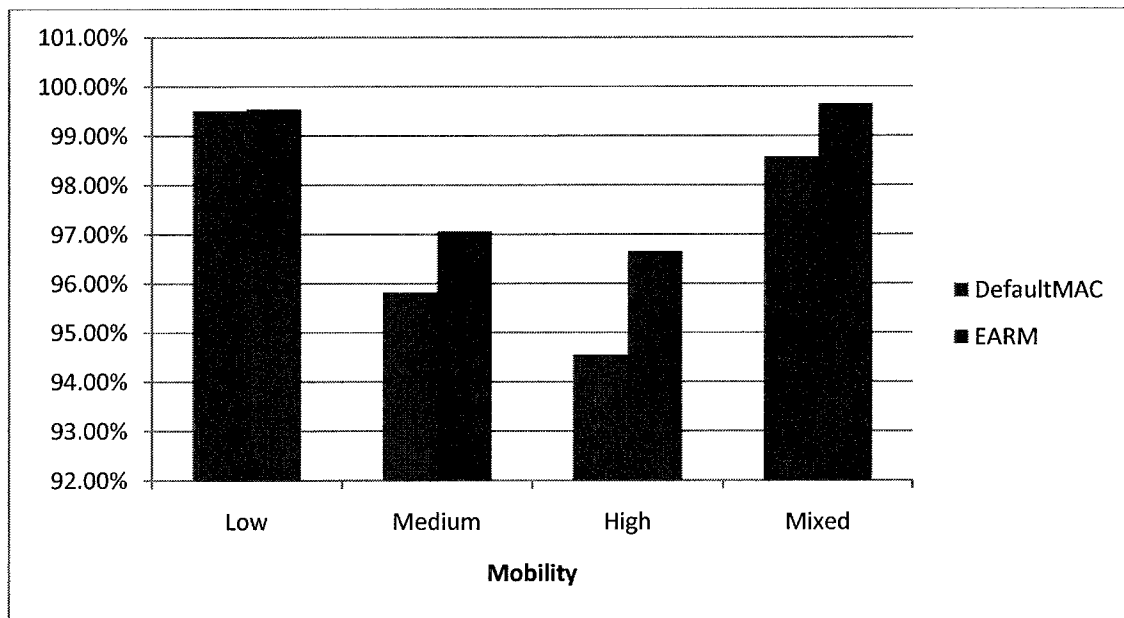


Figure 29- Packet delivery ratio versus mobility

Figure 30 summarizes the obtained throughput results versus mobility. As the nodes' movement tends to increase, throughput performance tends to degrade in the case of the default MAC. The logic behind this result is that it is enough to have one node observing bad channel conditions to affect the throughput results of all other nodes connected to the same source. The suggested model solves this problem and thus outperforms the default MAC protocol in terms of throughput. Best results are obtained during medium mobility, high mobility and mixed mobility scenarios.

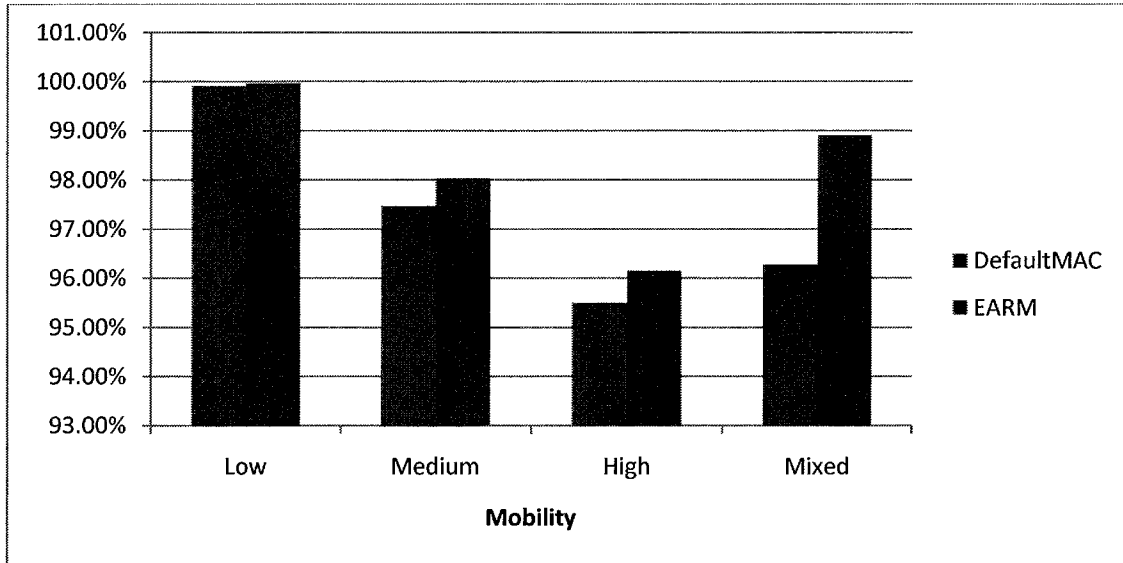


Figure 30- Average throughput versus mobility

Figure 31 summarizes the obtained average delay results versus mobility. As the nodes' movement tends to increase, average delay tends also to increase in the case of the default MAC. On the other hand, the suggested model solves this problem and thus outperforms the default MAC protocol in terms of delay which could be fatal to real-time applications. Best results are achieved during medium mobility, high mobility and mixed mobility scenarios.

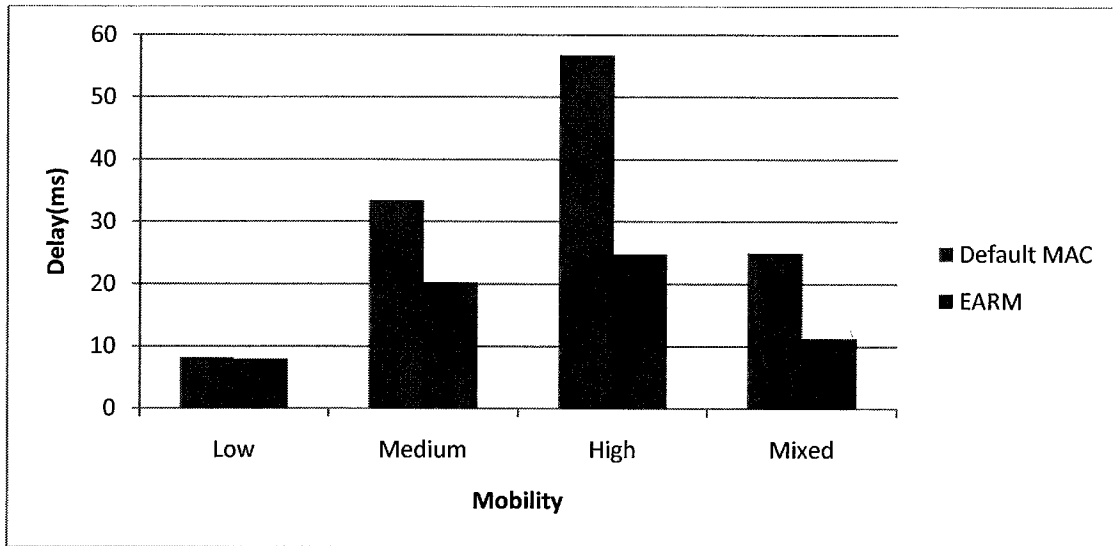


Figure 31- Average delay versus mobility

Table 4 displays the results of energy-efficiency achieved by the suggested energy-aware retransmission model. Table 4 shows that the best results are obtained in high mobility and mixed mobility scenarios.

Mobility	Percentage of Energy Efficiency
Low	45.87%.
Medium	50.78%.
High	58.75%.
Mixed	63.93%.

Table 3- Energy efficiency versus mobility

5.2.6 Case Scenario 5: Multi-Source File

In this scenario, the topology is quite large and provides a mixed mobility network as in experiment 6. Moreover, this experiment contains multiple senders instead of one

sender as in the previous experiments. Moreover, the packet size and packet rate vary from one connection to the other. The motivation behind this case scenario is to evaluate the effectiveness of the suggested model in case of heavy load and random environments. The simulation runs for 100 simulated seconds.

Packet Delivery Ratio

The results of the packet delivery ratio of the default MAC and the suggested retransmission model were very similar. EARM resulted in a 96.12% packet delivery, while the default MAC scored 96% packet delivery.

Average Throughput

The results of the average throughput of the default MAC and the suggested retransmission model were very similar with a slight improvement for the suggested model. EARM resulted in 87.071% as an average throughput, while the default MAC scored 84.03% on average.

Percentage of Packet Delay

Figure 32 displays the percentage of packet delay for the default MAC and the suggested retransmission model. The latter slightly outperforms the default MAC. Figure 32 shows that the percentage of packets which suffer from a delay greater than 50 milliseconds is equal to 0.8% in the case of the suggested retransmission model, while it reaches a value of almost 1.5% in the case of the default MAC.

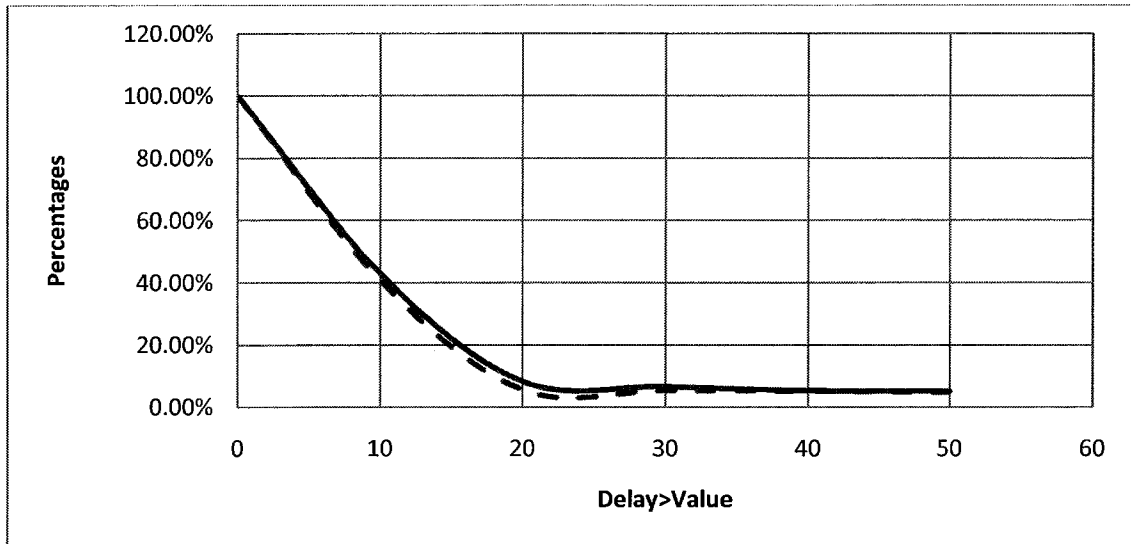


Figure 32- CCDF of packet delay with multi-source file

Energy Efficiency

The number of non-successful retransmissions that took place in this experiment when using the default MAC protocol was 6737. On the other hand, this number dropped down to 5701 upon the utilization of the suggested energy-aware retransmission model. Consequently, the percentage of energy saved by the suggested model on this experiment = $100 \times (6737 - 5701) / 6737$ is equal to 15.37%.

Chapter 6

6 Conclusions and Future Work

Research work have focused recently on solving the problems of wireless networking as the utilization of handheld devices and the supremacy of wireless networks have increased. Research mainly focused on two issues, one of which is providing quality of service over wireless communication despite the wireless factors. These factors include fading signal, mobility and obstacles that could affect wireless connection and cause performance degradation. Another related issue is energy conservation especially that handheld devices and smart phones are battery-fed and thus have limited energy source. Many protocols and schemes have been suggested in literature to provide energy optimization of wireless networks. These approaches focused on reducing communication energy (transmission, reception and idle energy). Nonetheless, they shifted the burden from communication energy to computation energy by demanding large matrices, sophisticated routing protocols or even massive feedback messaging from the client. Moreover, most of the suggested approaches resulted in a minor deterioration in terms of quality of services which is an essential priority of wireless multimedia traffic.

In this thesis, an energy-aware retransmission model for wireless multimedia was proposed. The suggested model saves energy consumption wasted due to unsuccessful retransmissions. It also proves to outperform the MAC protocol in terms of throughput, packet delivery ratio and most importantly delay which is fatal to real-time applications.

The suggested model works through monitoring the condition of each connected node. If the latter is observing wireless factors which manifests itself in weak signal strength, then retransmission of lost packets would be postponed until the condition of that node enhances. On the other hand, if the node is observing good condition, then retransmission of lost packets can take place immediately.

This thesis exploited the effectiveness of the suggested model on CBR traffic. As a future work, the effect of this model could be examined on VBR traffic. In addition, energy efficiency in this thesis was determined in terms of reducing the number of non-successful retransmissions. The effect of the proposed model on the occurrences of collisions can be further evaluated. Finally, this model was tested over networks that run over Wi-Fi. Thus, this work can be extended to assess the effectiveness of the proposed model in networks running over Wi-MAX.

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