Palestine Polytechnic University
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A New Approach for QOS Based "Ant Colony Optimization" Routing Protocol In MANETs (QOS-Based ACO)

Submitted By

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Dedication

To my parents.

Acknowledgment

I would like to thank my supervisor Dr. Amal Al Dweik for her support and guidance throughout the work.
I would like to thank my parents for their support and patience.

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Abstract

As the world tends to increase the use of the Mobile Ad hoc wireless Networks (MANETs), a very important challenging issue is to enhance the performance of the used routing protocols. Each of the routing protocols used has some drawbacks on the network performance. However, enhancements to these protocols are needed to increase the network performance; hence a lot of research is done.

The use of the mobile agent is one of the promising approaches for enhancing the performance of the routing protocols. When its used in the MANETs along with a traditional protocol, or if it is used in proposing a totally new routing protocol approach, it results in a good enhancement of the network performance most of the time.

This thesis proposes a new routing protocol to be used in MANETs based on the ant colony optimization (ACO) algorithm, by taking the quality of service (QOS) parameters in the network into consideration, which are the bandwidth, delay, battery level and the number of hops. The new protocol, which is called QOS based ant colony optimization routing protocol (QOS-Based-ACO), outperforms the ad hoc on demand distance vector routing protocol (AODV) and the ant based hybrid routing algorithm (AntHocNet) when considering the network throughput and average end to end delay.

Contents

Chapter 1

Introduction

In this chapter, the thesis problem statement, and the main contributions are listed. Also, this chapter introduces all of the thesis chapters.

1.1 Problem Statement

The mobile ad hoc network (MANET) is an infrastructure-less network consisting of mobile nodes with dynamic topology, which makes the information routing an important issue to search and discuss. MANETs are used in the military applications, applications in home network and in the commercial applications [14]. There are many routing protocols used in MANETs, which have some drawbacks that influence the network performance, such as a large delay [11]. For solving the main problems of using the traditional routing protocols in MANETs, researchers tend to propose agent based solutions to enhance the performance of the traditional routing protocols. Researchers assert that the performance of the ad hoc networks is increased, and most of the protocols that uses the agents in its mechanism outperforms the traditional routing protocols.

A software agent is a computational and autonomous entity, which can migrate, clone, learn and cooperate. It has two kinds:

static and mobile [2].

The average end to end delay, the network overhead, the throughput and the received packet delivery ratio are the main parameters that the researchers focus on for measuring the performance of the routing protocols in MANETs and so, these parameters are important for comparing the routing protocols with each other.

The aim of this thesis is to propose a new Ant Colony Optimization (ACO) and QOS parameters based routing protocol to be used in MANETs that can increase the network performance.

1.2 Contributions

The contributions of this thesis are as follow:

1. Survey the agent based routing protocols used in MANETs, which includes the ACO based protocols.
2. Propose a new routing protocol to be used in MANETs, based on the ACO algorithm and on the QOS parameters.
3. Implement and test the proposed routing protocol and measure its performance.
4. Implement other existing MANETs routing protocols, which are the AODV and AntHocNet, and measure their performance.
5. Compare the performance of the proposed protocol with that of the AODV and AntHoocNet.

1.3 Chapters Overview

An overview on the MANETs, a survey of the agent based routing protocols, a methodology of the proposed protocol and the protocol performance evaluation are all presented in this thesis.

The rest of this report is organized as follows:

Chapter 2

An overview on the MANETs, it's routing protocols with their advantages and disadvantages is presented in this chapter. In addition, an overview on the software agents and on the ACO algorithm is presented too.

Chapter 3

A survey on the agent based MANETs routing protocols, and a survey on the ACO based MANETs protocols is presented in this chapter.

Chapter 4

The Methodology of the proposed routing protocol is presented in this chapter.

Chapter 5

The simulation environment, results and the performance evaluation of the proposed and other two MANETs protocols, which are the AODV and AntHocNet, is presented in this chapter.

Chapter 6

This chapter includes the thesis summary, conclusion and the future work.

Chapter 2

Theoretical Background

2.1 Mobile Wireless Ad Hoc Networks

The mobile wireless ad hoc network is an infrastructure-less network, which consists of mobile nodes with a wireless interface to interact with each other. However, as there is no administrator in this kind of networks, the nodes behave as routers and take part of sending data packets from source to destination in addition to its specification as a terminal device. So, if one node wants to transmit data to other node, which is out of its transmission range, the data will pass through the intermediate nodes between them, till it reach the destination. Furthermore, as the nodes can move, the topology of the network and the specified routes between any two nodes are changed frequently, which makes it a challenge to route data.

Mobile ad hoc networks (MANETs) are used in military applications, applications in home network and in commercial applications. In order to transmit data from a node to another in MANET with its dynamic topology, routing protocols are needed. Those are divided in two main categories: the proactive and the reactive routing protocols. In addition there is the hybrid and the location aware routing protocols [14] [13]. Figure 2.1 shows an example on a MANET.

Figure 2.1: Mobile ad hoc wireless network

2.2 Ad Hoc Routing Protocols

As the topology of the network is dynamic, protocols must be used to let the nodes communicate with each other efficiently. The main kinds of the protocols used in the ad hoc networks are: the proactive, reactive and hybrid, which are described in the following subsections. Figure 2.2 shows the main MANET routing protocol types, with an example on each type.

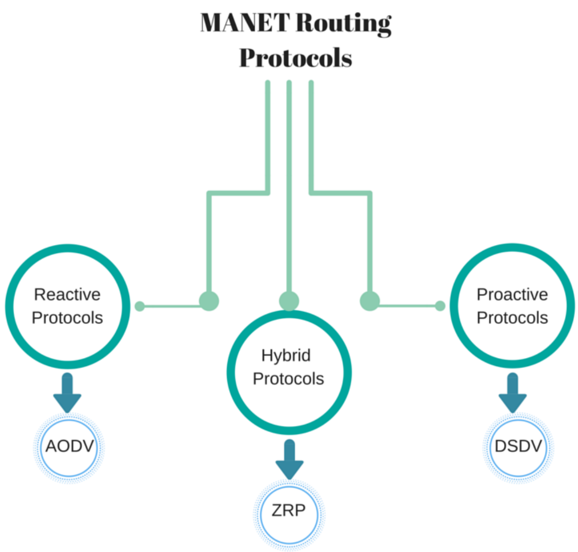

Figure 2.2: MANET routing protocols

2.2.1 The Proactive Routing Protocols

In the proactive routing protocols, each node has a routing table containing a route to each other node in the network, which is updated periodically by routing packets. The proactive protocols includes: the Destination Sequenced Distance Vector (DSDV) protocol, the Topology Dissemination Based on Reverse Path Forwarding (TBRPF) protocol and the Optimized Link State Routing (OLSR) protocol [13].

This kind of protocols is not scalable for a network with a large number of nodes, it consumes the bandwidth for the periodic updates and that results in a large overhead. On the other hand, the transmission of the data can be started by the source node without an initial delay and hence can be used for real time applications because the routes to the destinations are always available [39][11].

Destination Sequenced Distance Vector (DSDV) protocol

A loop free routing protocol that uses the distance vector shortest path algorithm to find a path to the destination from the source. Although, the overhead is still large, two kinds of packets are used in this protocol to reduce the overhead: the incremental and the full dump packets. The full dump packet is used to carry the network information that is available. On the other hand, the incremental packets, which is sent more frequently, is used to carry only the network information which is changed from the last dump [15].

2.2.2 Reactive Routing Protocols

In the reactive routing protocols, the routes between any two nodes in the network are found only when they are needed. Furthermore, they consist of two mechanisms: the route discovery, and the route maintenance. The reactive protocols includes: the Ad hoc On Demand Distance Vector (AODV) protocol, the Dynamic Source Routing (DSR) protocol, the Associatively Based Routing (ABR) protocol, the Signal Stability Routing (SSR) protocol and the Temporally Ordered Routing Algorithm (TORA) protocol [13].

This kind of protocols is scalable for a network with a larger number of nodes than that of the proactive protocols. It also results in lesser overhead and hence doesn't consume the bandwidth of the network. On the other hand, there is an initial delay before transmitting the data by the source node due to the route discovery process, so it's not suitable to be used in real time applications [39][11].

The Ad Hoc On Demand Distance Vector (AODV) protocol

Is a loop free reactive routing algorithm used in the ad hoc wireless networks, in which the routes to each node are found only when it's needed. It requires a route discovery and a route maintenance processes. The route discovery process is used when a node (source node) wants to send packets to a destination node and there is no route in its routing table towered that destination. The source will initiate a route request message (RREQ) and broadcast it to the neighbors and each neighbor will then broadcast it to its neighbors till it received by the destination node or to a node that has a route to the destination node, then the RREQ message will be converted to a route reply message (RREP) that will be sent from the destination in the reverse direction of the RREQ message back to the source node. When the source node receives the RREP packet, it will start sending the data to the destination node over the path discovered by the RREQ message. The route maintenance process is initiated when an intermediate node or the destination node is moved while the discovered route is still needed by the source node. The upstream node that discovers the movement of that node will send a route error (RERR) packet to the upstream nodes, and when it reaches the source, the source node will stop sending the data to the destination, and it will reinitiate a route discovery process to that destination [27].

2.2.3 Hybrid Protocols

The hybrid routing protocols uses both the proactive and reactive mechanisms in the network. For the nodes which are close to each other, the proactive techniques are used to communicate. On the other hand, when any node wants to send data to a far node, the reactive techniques is used to discover a route and send the data. Hybrid protocols includes: the Zone Routing Protocol (ZRP), Zone-based Hierarchal Link State (ZHLS) protocol, Scalable Location Update Routing Protocol (SLURP), Distributed Spanning Trees Based Routing Protocol (DST) and Distributed Dynamic Routing (DDR) protocol [15].

Zone Routing Protocol (ZRP)

Network nodes are distributed into zones, each with a number of hops suitable for proactively finding routes to destinations. Routes are available in the same zone, but if a node want to communicate with a destination resides outside its zone it will find a route reactively to that destination using any of the on demand routing protocols. This protocol reduces the overhead compared with the proactive protocols and reduces the delay compared with the reactive protocols [15].

2.2.4 Other MANET Protocols Types

There are also other routing protocols types used in MANETs such as the location aware protocols and the ant colony based protocols.

Location Aware Protocols

In the location aware protocols, the geographical position of each node is determined in addition to the used mechanism for routing by using for example the Global Positioning System (GPS). When any node wants to send packets to any other node, it uses the position of the existing nodes to forward the packets to the neighboring node. In this kind of protocols, the routing information doesn't needed to be stored [13].

Ant Colony Based Routing Protocols

This kind of protocols is based on the ACO algorithm, that uses software mobile agents to find the best route between a source and destination from several found paths. These protocols are introduced to overcome the limitations of the traditional MANETs protocols [35].

2.3 Ant Colony Optimization Algorithm

It describes the behavior of the ants, when the ants go out from their nest searching for food, they will take a random paths to go to the food initially. In their journey to find the food and in their way back to their nest, they will lay a chemical material on air. Other ants that sense this chemical material which is called pheromone, will follow it in their way to food or back to the nest. So, most of the ants will use the same path to find the food and to return back to their nest within time. The pheromone concentration will decrease within time, so when there is several paths to the food, the ants will finally follow the shortest path among them, because the pheromone concentration will be higher than that of a longer one and will take a longer time to disappear.

Researchers follow the behavior of ants for searching for food to find the best path from a source to destination in the mobile wireless ad hoc network.

The wireless ad hoc network can be represented as a graph G=(V, E) with $|V|$ nodes, and E links between the nodes which are in the transmission range of each other, and the ACO algorithm will be used to find the best path between a source and a destination on the graph.

In the ACO algorithm, ants travel in the network to find destinations, collect information about the network, modify the network information on the nodes and later to use this information, for deciding the best path between a source and destination. When ants choose a specific route to go to the destination through, it deposits on the links pheromone. The pheromone changed as follows [35].

$$\alpha_{(i,j)} = \alpha_{(i,j)} + \Delta\alpha \tag{2.1}$$

where $\Delta\alpha$ is an incremental amount, and $\alpha_{(i,j)}$ is the pheromone value of the link (i,j).
Within time, the pheromone concentration is decreased (evaporated) with a specific amount as given by [35].

$$\alpha_{i,j}(t+\tau) = (1-q).\alpha_{i,j}(t), q \in (0,1] \tag{2.2}$$

where q is the evaporation factor.

To determine the path to go through to the destination, and depending on the pheromone values of the nodes collected by the ants, a probability is calculated to be used by the ant to decide which is the next node to go to [35].

$$p_{i,j} = \frac{\alpha_{i,j}}{\sum_{J \in N} \alpha_{i,J}} \quad , ifj \in N_i \tag{2.3}$$

$$p_{i,j} = 0 \quad , ifj \notin N_i \tag{2.4}$$

where $p_{i,j}$ is the probability of choosing a neighbor j of node i, $\alpha_{i,j}$is the pheromone value of the link (i,j) and N_i is the set of neighbors of node i.

The software agents are used as ants in this algorithm that will deposit the pheromone, collect the network information and modify the nodes with this information. The pheromone of the visited nodes by the agents will be increased to let other agents follow the same visited path and with time the pheromone will be decreased preventing the visited nodes from reaching the optimal state [35]. Figure 2.3 shows the ants behavior.

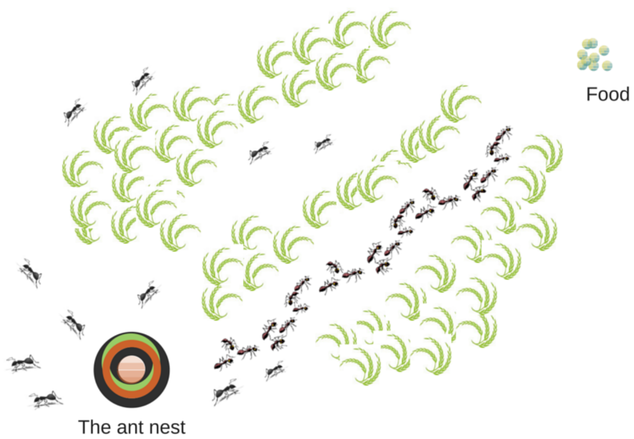

Figure 2.3: Ant colony behavior

2.4 Software Agents

Software agents are autonomous software entities that can migrate, resume its execution on different hosts, clone, learn, interact with each other and can adapt with the environment that holds them, as they can sense, think and then act accordingly.

There are two kinds of agents: the static and the mobile agents. Static agent doesn't move or migrate to other hosts. On the other hand, the mobile agent can move and migrate to other hosts, and it needs a mobility framework from the system in order to do its tasks [2][5].

Mobile agents can be used to overcome the limitations of the traditional distributed systems, as the agent, which is introduced to make certain tasks, can suspend its execution when needed and transfer from one to another computer host in a network, which can be heterogeneous, to complete its tasks intelligently, adding flexibility to the distributed systems [17].

2.5 Summary

The MANET, which is an infrastructure-less network with mobile nodes, is defined in this chapter with examples on it's routing protocols that are used to let the nodes communicate efficiently with each other. The MANET routing protocols are divided into two main types: proactive and reactive routing protocols. Each type has advantages and disadvantages that are discussed within this chapter.

Moreover, this chapter also described the ACO algorithm, which follows the ants behavior for food searching, and used for routing to find the best path between a source and destination in MANETs. In addition, the software mobile agents were defined, which are used as ants in the ACO based routing protocols, to enhance the network performance.

Chapter 3

Literature Review

Some researchers used the software mobile agents to enhance the performance of the traditional routing protocols used in MANETs. However, others proposed a new different routing protocols based on the usage of the mobile agents to get better network performance or to satisfy some of the QOS parameters as needed for certain applications or demanded services. In the following subsections, some of the agent based protocols are presented.

3.1 Mobile Agent Based Routing Protocols

3.1.1 Mobile Agent With Traditional Protocols

Bhati et al. in [26] proposed an agent based ad hoc on demand routing protocol (AB-AODV) for the mobile ad hoc networks, which is a protocol that based on the AODV protocol and uses the mobile agents, which have a unique ID to make the hosts aware of the network information and to calculate the transmission capacity for each node to choose the more efficient route from a source to a destination. Furthermore, static agents are used to update the information it take from the mobile agents on the host it resides on. The most efficient route to a destination chosen by the mobile agent depends on the transmission capacity value of each node on the path.

Rajpoot et al. in [16] made an enhancement over the Dynamic Source Routing (DSR) protocol, which is one of the reactive mobile ad hoc network protocols, by combining it with the mobile agents. In their approach, two kinds of mobile agents are created: Discovery/Reply and maintenance agents. In the discovery/reply process, a discovery mobile agent is created at the source node and broadcasted to the neighbors in its transmission range to discover the path to the destination. In the maintenance process, when a node in the discovered route between the source and the destination is failed, a mobile agent is created by the first node that notifies the failure to make the source aware of the failure in order to reinitiate a new route discovery process.

3.1.2 Mobile Agent Based Clustering Protocols

Sugar et al. in [28] used the mobile agents for clustering in the wireless ad hoc networks. Each cluster use a mobile agent called a clustering agent to take the membership decisions to clusters, or taking decisions for splitting or merging clusters. The communication is done only between the neighboring agents to reduce the overhead of the network.

Bhaumik et al. in [22] introduced a cooperative routing protocol that uses the mobile agents for sending the short messages and exchanging the network information in the ad hoc networks. When multiple sources want to send messages to the same destination, they create mobile agents which will then cooperate with each other when meeting on certain nodes called Rendezvous points, and wait at these nodes a certain amount of time called Rendezvous period. However, they will merge the messages they hold with one agent that will migrate to that destination to reduce the traffic and the overhead in the network at high load.

3.1.3 Mobile Agent Based Congestion Control

Shekhar et al. in [32] proposed a routing protocol for the congestion control to be used in the mobile ad hoc networks that uses the mobile agents in its criteria. The protocol is called a mobile agent based framework for routing and congestion control (MAFRC). It contains an agent based congestion detection, awareness and control.

Das et al. in [36] made a comparison between the AODV and a mobile agent congestion aware routing (MACAR) protocol. However, they concluded that the packet loss in the AODV is higher than that of the MACAR protocol, and the throughput in the AODV is less than that of the MACAR. The routing protocol (MACAR) that can be used with any on demand routing protocol, is a congestion awareness and control protocol that provides a ready routes to a destination.

3.1.4 Other Agent Based Protocols

Choudhury et al. in [29] produced a multi agent routing protocol for the mobile ad hoc network (MARP), which is a proactive protocol with a reduction on the overhead and delay. It allows the calculation of some parameters and take them into consideration when deciding which route to take to the destination, which increases the efficiency of using this routing protocol. These parameters are: the afinity, which is the prediction of the link span life. The stability which describes the life span of the path. The recency, which describes the newness of the information that is held by the mobile agents, and the node with the least recency value is chosen by the agents to be visited as the next hop. Time to migrate, which is an amount of time that must be passed, so the agent can migrate to another node.

Choudhury et al. in [30] proposed a multi agent protocol that makes the nodes aware of the network topology without consuming the network capacity (proactive protocol with less overhead). The network information is collected by using the mobile agents. Agents are traveling from node to node, meet other agents and interact with them to collect the information from other parts of the network. These information which is used to choose the best route, are the stability, recency and afinity.

Bandyopadhyay et al. in [31] introduced a mobile agent based routing protocol to transfer messages between a source and a destination with the off line messaging in a highly dynamic large mobile ad hoc network. The proposed protocol decreases the traffic and allows the asynchronous communication (sending emails for example). Agents are used as messengers to deliver messages from sources to destinations. They used the GPS to determine the neighboring nodes, and they used in their approach the concept of the physical and logical neighbors.

Zhou et al. in [39] Introduced a new ad hoc routing protocol called Mobile Agent Routing protocol (MAR), that uses the mobile agents which can interact with each other indirectly by leaving information about the network in every node they visit and also collect information from it. When a node has an event, it adds this event in its events table. Then, it creates a mobile agent to propagate the event through the network. The event could be any network information, for example a route information. Therefore, when a mobile agent arrives at a node, first it will update the routing table of this node with the new information it holds, after that the mobile agent will collect the information that does not have from the node's routing table. Then, it will record the node as a visited node and it will choose the unrecorded node to visit next to update the network information.

Migas et al. in [17] used static and mobile agents to determine the best route between a source and destination in the mobile ad hoc networks. The static agents can test the node's memory capacity, processing capabilities and other parameters to be used later from the mobile agents to choose the best route to a destination, and periodically updates the mobile nodes about the best paths in the network. This protocol increases the network performance by reducing the delay and losses and by providing reliable communication and scalability.

3.2 ACO Based Protocols

Marwaha et al in [33] proposed a protocol called ant-AODV, that combines the usage of the ant-like mobile agent with the AODV to overcome the shortcuts of the both. This protocol increases the node connectivity which reduces the route discovery amount and decreases the route discovery latency, end to end delay and the overall overhead. In the conventional ant like mobile agents, the routes are provided and updated depending on the mobile agents that visit the nodes in the network with the updating information. If a node wants to communicate with another node and doesn't have a fresh route to that node, it will wait with the data in its buffer till a mobile agent visits it with the route information. Ant like mobile agent doesn't provide route maintenance in a node breakage case. In the AODV, if any node wants to communicate with other node, it must first discover a route to the destination which causes a large delay before beginning communication. In the Ant-AODV, the mobile agents which work independently, provide routes to the nodes, and the nodes can change the route to a destination into a better (shorter) one due to the route update information carried by the agents all the time.

Kumar et al. in [35] produced a multi agent ant based routing protocol (MARA), which is a hybrid protocol that combines the AODV with the ant based protocol. MARA reduced the average end to end delay, the latency of the route discovery, the overload, and increases the nodes connectivity. The path from the source to the destination is chosen depending on the value of the pheromone.

Ducatelle et al. in [10] proposed a hybrid routing protocol called AntHocNet that combines the reactive and proactive techniques of the protocols used in the ad hoc wireless networks by using the ant agent based approach. At the start of each communication session, the source node sets up a route between the source and destination in a reactive way, and during this session the source uses the ant agents to search for a better alternative paths in a proactive way.

Deepalakshmi et al. in [24] proposed an on demand routing protocol called Ant Routing For Mobile Ad Hoc Networks (ARMAN) based on the ACO algorithm, and depends on the QOS parameters in MANETs as it depends on the links bandwidth and delay. These parameters are used in the probability calculation of choosing the next hop, in addition to the pheromone value of the link, and the number of hops between the source and the destination. They compared their approach with the AODV routing protocol, and concluded that ARMAN outperforms the AODV protocol.

Hussein et al. in [18] proposed a new routing protocol based on the ant colony optimization algorithm called Ant Routing Algorithm for Mobile Ad-hoc networks (ARAMA), which uses forward and backward ants to collect and modify the network information. Choosing the next hop for routing based on a probability calculation that depends in addition to the pheromone value, on the number of hops to the destination, and on the battery ratio of each node. The proposed protocol obtains fair energy distribution.

Hussein et al. in [19] enhanced the ARAMA protocol by sending a negative backward ant, when the sent forward ant goes through a loop, or when the time to live threshold is reached. Furthermore, a destination trail ant is sent by the destination node when the network becomes larger, to randomly moves in the network, collects and modifies the network information.

Chatterjee et al. in [34] made an enhancement on the DSR routing protocol by combining it with the ACO algorithm. The pheromone calculation for choosing the best path to a destination in their approach depends on the end to end path reliability, congestion and on the number of hops of the route. The packet delivery ratio of their proposed approach is higher than that of the DSR protocol. Furthermore, the overhead and the energy consumption is lower.

Singh et al. in [12] proposed an ant colony based routing protocol called ANTALG (an innovative ACO based routing algorithm) that uses the ant colony algorithm for routing in MANETs. The calculated probability for choosing the next hop depends in addition to the pheromone value, on a heuristic function, which is based on the length of the link queue between the node and its neighbor. Their approach includes in addition to the route set up process, a maintenance and route recovery techniques. The measured throughput, average end to end delay, packet drop and the average jitter for their approach are better than that of a number of existing protocols.

Persis et al. in [6] proposed a multi-objective ant based routing protocol called Multi-objective Ant Optimized Routing (MAOR) algorithm. In their approach and in addition to the pheromone calculation, they tried to optimize some important network parameters for choosing a path to a certain destination from a source. The parameters are: the hop distance, delay, the link reliability, the link cost and load. The packet delivery ratio, throughput and the average delay of the proposed protocol are better than that of the AODV routing protocol.

Sensarma et al. in [8] made an enhancement on the temporally ordered routing algorithm (TORA) by combining it with the ACO algorithm. They calculated the pheromone value and the probability of choosing the next hop to a certain destination as a function of: the minimum bandwidth of the path links from the source to the destination, the minimum energy of the path nodes, the maximum energy drain rate of the path nodes, the delay and the number of hops of the path.

Cañas et al. in [7] proposed a hybrid ant based routing protocol called Hybrid ACO Routing (HACOR) protocol. They combined in their approach the proactive and reactive routing techniques. When a node has data to be sent to a certain destination, the node sends out ants to discover a path to the destination reactively, then the node proactively sends out every some time interval ants to find out better paths to the destination. Instead of using the pheromone evaporation technique, they used an outdated route management to control the routes which are outdated. Moreover, they use the hello message to update the routes via the node's neighbors instead of using an initial pheromone value and instead of using the pheromone update technique. The packet delivery ratio, throughput and the average end to end delay of the proposed protocol is better than that of the AODV protocol.

Gupta et al. in [3] made a combination between the DYMO routing protocol and the ACO algorithm and hence proposed a new ant based routing protocol called E-DYMO (Enhanced DYMO). The simulation results of their approach showed that the E-DYMO has a better performance than the traditional DYMO when considering the throughput, average end to end delay and the packet delivery ratio. On the other hand, the traditional protocol outperforms the E-DYMO when considering the overhead.

Kumar et al. in [20] proposed an efficient ant based routing protocol for MANETs. In their approach, they added a new factor called the orientation factor, for calculating the probability of choosing the shortest path from a source to a destination. The network throughput of the proposed approach is higher than that of the AODV protocol.

Sardar et al. in [1] proposed an ant based routing protocol with QOS parameters dependency for MANETs to choose a route from a source to a destination that accomplish a best quality of service. The QOS parameters that they used are: the delay, bandwidth, available buffer and the link stability.

Tyagi et al. in [4] proposed a new routing protocol that combines the ACO based routing protocol with the OLSR routing protocol. In their approach the pheromone and the probability calculation depends on the links delay and bandwidth. The simulation results showed that the packet delivery ratio of the new approach is higher than that of the OLSR. Furthermore, the end to end delay is less than that of the OLSR routing protocol.

3.3 QOS-Based ACO Features

There are a lot of differences between the QOS-Based ACO protocol and other protocols, which is based on the ACO algorithm.

The collected information, the criteria of finding paths and using the ACO algorithm within the protocol and the probability calculation dependency are the major points that give the QOS-Based ACO protocol its features.

The QOS-Based ACO protocol should increase the MANET performance because:

1. It depends on the neighbors local information for taking routing decisions and not on the goodness of the whole path as the nodes can move and hence the routes will change accordingly.

2. The nodes broadcast forward ants periodically in addition to broadcast forward ants reactively when there is no route to a specific needed destination, in order to finds alternative routes and keeps up with the newest network information.

The above two features of the QOS-Based ACO protocol are the main difference with other protocols.

The following subsections describe the QOS-Based ACO protocol features compared with the Deepalakshmi et al. [24], Hussein et al. [18], Sardar et al. [1] and Sensarma et al. [8] approaches, which are the closest protocols among the ACO based protocols to the QOS-Based ACO.

3.3.1 The Collected Information

The collected information are just the links pheromone values of a path in the other protocols, or different QOS parameters collection than that of the collection used in the QOS-Based ACO protocol, in the QOS parameters based protocols.

Table 3.1 summarizes the differences between the QOS-Based ACO and the other protocols when considering the network collected information by the forward ant.

Table 3.1: The collected information

Deepalakshmi et al.	The pheromone, the bandwidth, the delay and the hop count.
Hussein et al.	The number of hops, the battery level and the pheromone.
Sardar et al.	The bandwidth, delay, available buffer and the link stability.
Sensarma et al.	The hop count, the bandwidth, delay, energy and the battery drain rate.
QOS-Based ACO	The pheromone, the bandwidth, the hop count, the delay, the battery level.

3.3.2 The Criteria Of Using The ACO Algorithm

The criteria of finding the paths and using the ACO algorithm in the QOS-Based ACO protocol is also differ from the other protocols that is based on the ACO algorithm. Finding paths are either reactive, hybrid as in the AntHocNet protocol or it is a combination between the ACO algorithm and one of the traditional routing protocols used in MANETs.

Table 3.2 presents a comparison between the QOS-Based ACO protocol with the others.

Table 3.2: The criteria of using the ACO algorithm.

Deepalakshmi et al.	Reactive protocol
Hussein et al.	Reactive protocol
Sardar et al.	Reactive protocol
Sensarma et al.	A combination between the ACO algorithm and TORA traditional routing protocol.
QOS-Based ACO	Reactive with broadcasting the forward ants periodically to discover the network topology and finding alternative paths.

3.3.3 Probability Calculation Dependency

The calculation of the probability of choosing the next hop during the routing process is differ in the QOS-Based ACO protocol from the other protocols. In the other protocols, the calculation depends on just the pheromone value or on the path goodness in the QOS parameters based protocols, in which each parameter used in the calculation represent the whole path parameters. So, the calculation is depends on global information, while in the QOS-Based ACO protocol, it depends on local information, as the calculation depends on parameters measured for each specific node or link, and not on the whole path nodes and links, as the network topology is dynamic and the nodes can frequently change its position.

Table 3.3 summarize the differences between the QOS-Based ACO and the other protocols based on the probability calculation dependency.

Table 3.3: Probability calculation dependency

Deepalakshmi et al.	Depends on global information.
Hussein et al.	Depends on global information.
Sardar et al.	Depends on global information.
Sensarma et al.	Depends on global information.
QOS-Based ACO	Depends on local information.

3.4 Summary

The agent based, and the ACO based MANET routing protocols were surveyed in this chapter. The network performance when using this kind of protocols is better most of the time than that when using the traditional routing protocols.

Also, the proposed protocol features, and differences between the proposed protocol and other protocols are presented in this chapter.

Chapter 4

Methodology

The QOS-based-ACO is a new routing protocol proposed to be used in MANETs based on the ant colony optimization algorithm. It takes into consideration some of the network QOS parameters in order to enhance the network performance. The proposed protocol follows the ants in their natural behavior for food searching via using the software mobile agents to behave as ants. The agents will collect the network information to discover its topology and hence find multiple paths to destinations. The network information includes in addition to the pheromone value, the bandwidth of the neighbor link, the trip time to the neighbor, number of hops from the source to the neighbor and the battery level of the node.

4.1 The Proposed Protocol Description

In the proposed QOS-Based-ACO routing protocol, each node has a neighbor, pheromone and routing tables. The neighbor table contains the neighbors, and the bandwidth of each neighbor of the node. The pheromone table contains at each row a certain destination, a neighbor to go to that destination with a corresponding pheromone value. The routing table contains in each row a certain destination, a neighbor to go to that destination with a corresponding probability value.

One of the important issues in the wireless mobile networks scenarios is discovering the neighbors of each node, those which are in the node's transmission range, in order to establish any data communication attempt. In the proposed protocol, discovering the neighbors is done by broadcasting a HELLO message. The HELLO message is consisting of $\langle type, sequence\ number, source\ address, start\ time, size\rangle$. Where the type is the type of the sent message (HELLO in this case), the sequence number is the number of the message sent from a specified node, the source address is the address of the source of the message, the start time is time of sending the message and size is the length of the HELLO message. Each node receives a HELLO message will register the source address of the message as a neighbor in the neighbor table, and then will register the bandwidth of the neighbor link also in the neighbor table after calculating it.

As the nodes are mobile, and in order to discover the network topology and hence multiple paths to destinations, each node in the network will broadcast frequently a forward ant (FANT) to randomly chosen destinations. The FANT will collect the network information in its way to the destination. It consists of $\langle type, sequence\ number, source\ address, destination\ address, start\ time, length, memory\ stack\rangle$, where the type is the type of the message (FANT in this case), the sequence number is the number of the agent sent from a specified node, the source address is the address of the node that generates the FANT, the destination address is the address of the destination of the FANT, start time is the time of sending the FANT and length is the size of the FANT. The memory stack contains the nodes ids along the path, the trip time of each node, the battery level of each node, the number of hops along the path.

When a FANT reaches a destination, a backward ant (BANT) will be created and hold the information carried by the FANT.

The BANT will follow the reverse path of the FANT to the source and update the nodes routing and pheromone tables in its way. It consists of $\langle type, sequence\,number, source$ $address, destination\ address, memory\,stack\rangle$, where the type is the type of the message (BANT in this case), the source address is the address of the destination node of the FANT, the destination address is the address of the source node of the FANT and the memory stack is the same memory stack that was carried by the FANT.

4.1.1 Detailed Description

At the beginning, all the tables will be initialized with neighbors, certain destinations and with initial pheromone and probability values. The FANT will be broadcasted from all of the network nodes to chosen destinations periodically every some time interval. The node will also broadcast a FANT, if it has data to be sent without having a route to the destination. The FANT will collect the network information from all of the nodes it visits, which are the node's id, battery level, trip time and the number of hops it passed. In its way, the FANT will check if the node it visits was visited before by it. If yes, it will remove the loop from its stack.

When receiving a FANT, every intermediate node will check if it has a route to the FANT destination. If it has, the FANT will be forwarded to the specified neighbor. Otherwise, the FANT will be deleted.

When the FANT reaches the specified destination, BANT with the same sequence number as the FANT will be generated and hold the information that was carried by the FANT, before killing it. The BANT will take the reverse path of the FANT to travel back to the source node. The tables of each node that is visited by the BANT will be updated, and when it reaches its destination, which is the source of the FANT, it will be killed after updating its tables.

In the proposed protocol, a HELLO message will frequently be broadcasted to a maximum one hop, to discover the neighbors along with the frequently network topology changes. When a node receives this message, it will check if the neighbor is already existing in its neighbor table or not, and it will calculate the bandwidth of its link with the source of the message by following equation (4.1). The neighbor table of the node will be updated if the neighbor and bandwidth is not existing in it [25].

$$band_{i,j} = \frac{hello_s}{(ct - st)} \tag{4.1}$$

Where $band_{i,j}$ is the bandwidth of the link of neighbor j of node i, $hello_s$ is the size of the HELLO message received, ct is the current time specified by the node and st is the time of sending the HELLO message.

The size of the HELLO message is constant, and the equation of calculating the bandwidth can equal to a constant amount of bits divided by the difference of the time of receiving the HELLO message from the time of sending the HELLO message.

4.1.2 Pheromone And Probability Calculation

The pheromone of the neighbors is initialized with a constant value α that is updated upon receiving the BANT according to equation (2.1).

However, the pheromone value of the rest of the neighbors, which aren't visited by the BANT, will be evaporated according to equation (2.2).

The probability values of the neighbors will be initialized with a value that depends on the node's number of neighbors by the following equation.

$$prob_{i,j} = \frac{1}{numNeighbors} \tag{4.2}$$

where $prob_{i,j}$is the probability value of choosing a neighbor j from node i, and numNeighbors is the number of neighbors of node i.

Then, and when the BANT visits the node, the probability value of the node will be updated as follow.

$$prob_{i,j} = \frac{\frac{\alpha_{i,j}+B_j+BW_{i,j}}{H_{s,j}+T_{s,j}}}{\sum_{l\in N_i}[\frac{\alpha_{i,l}+B_j+BW_{i,l}}{H_{s,l}+T_{s,l}}]} \tag{4.3}$$

Where $prob_{i,j}$ is the probability of choosing the neighbor j of node i, $\alpha_{i,j}$ is the pheromone value of the link (i,j), B_j is the battery level of neighbor j, $BW_{i,j}$ is the bandwidth of the link i,j, $H_{s,j}$ is the hop count at neighbor j from the source, $T_{s,j}$ is the trip time at neighbor j from the source and N_i is the neighbors set of node i.

The probability equation is a heuristic equation, and it is written in this way as the value of the probability of choosing any neighbor must increase if:

1. The battery level of the neighbor, the bandwidth and the pheromone value of the neighbor link is increased.

2. The hop count, and the time delay at the neighbor is decreased.

So, it can be written as a fraction that has a summation of the pheromone value, the bandwidth and the battery level at the numerator, and the summation of the hop count and the time delay at the denominator. Then the fraction will be normalized to get a positive value ≤ 1.

In equation (4.3), $\alpha_{i,j} \leq 1$, but during the simulation, it can increase to more than that. $BW_{i,j} \geq 0$. The maximum value of B_j is 100 J, and the maximum value of $H_{s,j}$ can be any number around the maximum number of nodes in the network. $T_{s,j}$ can take any value within the total simulation time. The time to live of the ant packets will make the maximum values of $H_{s,j}$ and $T_{s,j}$ to be much smaller than that.

4.1.3 Maintenance Phase

If a route broke, for example the link i,j is no longer available as the neighbor j is moved, then node i will search for another valid route to the destination. If there is no other route, the node i will drop the data packet, and broadcast an ERROR message, which consists of $\langle type, sequence\, number, destination, source\rangle$. Where type is the type of the message (ERROR in this case), sequence number is the number of the message sent from a specified node, destination is the unreached destination and source is the source of the data packets. If a node receives an ERROR message, it will check if it is the destination of this message, which is the source of the data. If it is the source, it will send a FANT to search for a path to that destination. Otherwise, the node will forward the message.

4.2 The QOS-based-ACO Algorithms

When a source node wants to communicate with any other node in the network, it will search for a route. If the route is not available, it will queue the data and broadcast a FANT to find a route. Otherwise, the data will be sent via the found path. If an intermediate node has data to be sent to a specified destination, it will also search for a route. If there is no path, the data packets will be dropped and an ERROR message will be prepared and broadcasted by the intermediate node. If the route is available, the data packets will be forwarded via the found path. Algorithm (1) describes the behavior of a node when it has data packets to be sent.

```
for every mobile node do
    search for route (next hop);
    if route is available then
        forward the packet to next hop;
    end
    if route is not available then
        if node == source then
            insert data packet in queue;
            send FANT;
        end
        if node == intermediate then
            drop(data packet);
            prepare and broadcast an ERROR massage;
            call "When Receiving An Error Message"
            algorithm;
        end
    end
end
```

Algorithm 1: When Receiving A Data Packet

If a FANT reaches a node in the network, it will check if this node was visited before. If yes, it will remove the loop from its stack. Otherwise, it will collect the node's id, battery level, trip time and will increase the number of hops it visits by one. When the FANT reaches the destination, a BANT will be prepared, and it will hold the stack of the FANT. The BANT will be forwarded to the previous visited node by the FANT, after killing the FANT. Algorithm (2) describes the behavior of both the node and the FANT, when receiving a FANT.

```
for every mobile node do
    if node == destination then
        prepare a BANT;
        kill the FANT;
        forward the BANT to the previous visited node by
        FANT;
        call “When Receiving A Backward Ant” algorithm;
    end
    if node == intermediate then
        if node is visited before then
            remove loop from stack;
        end
        else
            store the node’s id;
            store the node’s battery level;
            store the trip time;
            increase one to the number of hops;
        end
    end
end
```

Algorithm 2: When Receiving A Forward Ant

When it visits a node, the BANT will update the node's routing and pheromone tables. If the node is the destination of the BANT, the BANT will be killed and the data, if there is any, will be forwarded along the found path to the destination. If the node is an intermediate, the BANT will be forwarded to the next hop that found from the stack. Algorithm (3) describes the behavior of both the BANT and the node, when receiving a BANT.

```
for every mobile node do
    if node == destination then
        update the node's routing table;
        update the node's pheromone table;
        kill the BANT;
        forward data if any;
    end
    if node == intermediate then
        update the node's routing table;
        update the node's pheromone table;
        find next hop from stack;
        forward the BANT to next hop;
    end
end
```

Algorithm 3: When Receiving A Backward Ant

If any node receives a HELLO message, it will record the source address of the message as a neighbor, and calculate the bandwidth of the neighbor link. The neighbor table of the node will be updated with the neighbor address and bandwidth, if these information is not already existing in the table. Algorithm (4) describes the behavior of the node when receiving a HELLO message.

```
for every mobile node do
    neighbor = source of the message;
    calculate bandwidth;
    if neighbor is not already in the table then
        update the node's neighbor table;
    end
end
```

Algorithm 4: When Receiving A Hello Message

When an ERROR message is received by a source node, a FANT will be sent to discover out another path to the unreached destination. If the message is received by an intermediate node, the message will be forwarded. Algorithm (5) describes the behavior of the node when receiving an ERROR message.

```
for every mobile node do
    if node == source of data packets then
        send FANT;
    end
    if node ==intermediate then
        forward ERROR message;
    end
end
```

Algorithm 5: When Receiving An Error Message

At the beginning, every node will broadcast a hello message and a forward ant. Then a timer for sending hello messages, and a timer for sending forward ants will be started. When these timers times out, the nodes will broadcast again a hello message or a forward ant, and the algorithms for receiving these packets, which were explained before, will be called. Algorithm 6 describes the main algorithm for the proposed protocol.

for *every mobile node* **do**
    broadcast hello message;
    broadcast FANT;
    call "When Receiving A Hello Message" algorithm;
    call "When Receiving A Forward Ant" algorithm;
    start hello message timer;
    start FANT timer;
    if *hello timer end* **then**
        broadcast HELLO message;
        call "When Receiving A Hello Message" algorithm;
    end
    if *FANT timer end* **then**
        broadcast FANT;
        call "When Receiving A Forward Ant" algorithm;
    end
    if *has data* **then**
        call "When Receiving A Data Packet" algorithm;
    end
end

Algorithm 6: The Main Proposed Protocol Algorithm

4.3 Summary

This chapter described the methodology of the proposed routing protocol, which is based on the ACO algorithm and satisfies some of the network QOS parameters, to find the best path between a source and destination in the MANETs. In addition, a description on the pheromone and probability calculations used in the proposed protocol is presented, which is based on the nodes battery level, trip time, bandwidth and the number of hops. Also, the chapter presented some of the proposed protocol algorithms, which describe the behavior of the ants and nodes when receiving a certain packet or when having data to be sent. The ants collect the network information and modify the nodes tables with these information. The nodes calculate the needed equations and take the rule of finding paths, receiving and forwarding the packets.

Chapter 5

Simulation And Results

The proposed protocol (QOS-Based-ACO) is simulated with different networking scenarios, and compared with the AODV and the AntHocNet routing protocols using the ns-2.35 simulator. The routing protocol performance is measured by calculating the average throughput, end to end delay, the packet delivery ratio and the control overhead.

5.1 Network Simulator 2

The network simulator version 2 (NS2) is an event driven simulator that is introduced to study the wired and the wireless communication networks, and is used to simulate different networking protocols to evaluate their behaviors among different networking scenarios. This simulator is known with its flexibility and is used a lot in the research field. Two programming languages is used in NS2 simulation; the C++ and the OTCL (Object Oriented Tool Command Language) [38].

In order to simulate via NS2, the user will use the OTCL to build the network topology, specify when, from where and to where the data traffic will be sent. Furthermore, the event scheduler will also be initiated by the OTCL. However, the C++ in the simulator is used to program the NS2 internal objects for example the protocols. The simulation is done by linking the OTCL and the C++ objects via a linking language called TCLCL.

The output of the simulation is found in a file called the trace file (.tr), which contains all of the network communication information, and is animated via another file called the NAM trace file (.nam) [23].

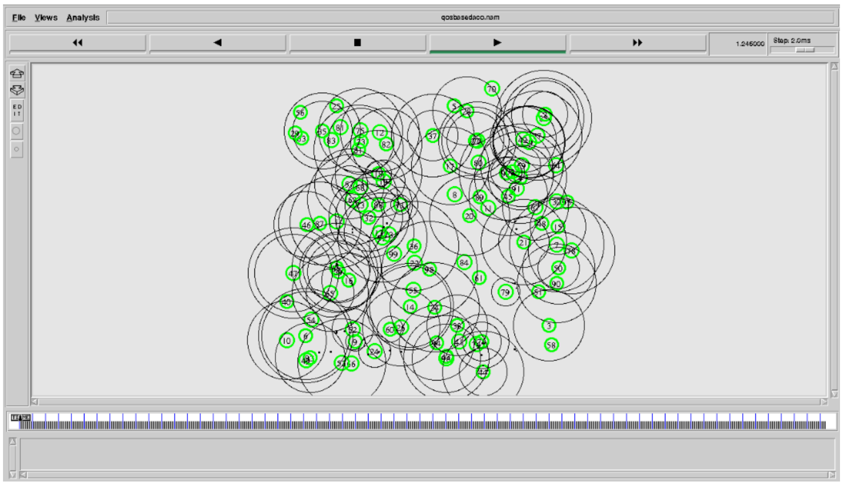

Figure 5.1: NAM trace file

5.2 The Routing Protocols Performance Measurements

The performance of the routing protocols in the wireless ad hoc networks can be measured through the average network throughput, end to end delay, packet delivery ratio and the control overhead. The network throughput is the total number of the packets received by the different destinations in the network in the total simulation time. The average end to end delay is the difference between the time of transmitting a packet from the source node and the time of receiving the packet at the destination node for all the transmitted packets divided by the number of packets transmitted. Packet delivery ratio is the number of packets received by the destination node divided by the number of packets transmitted by the source node. Overhead is the total number of the control packets over the total number of data packets received [21] [37].

5.3 Simulation Environment

The proposed protocol is simulated with an area of 1500 m x 1500 m, and by changing different networking factors for 900 s simulation time, which is equal to almost 5 hours run time on the used computer. The time interval of sending the FANT is set to be 0.03 s. The time interval of sending the HELLO message is set to be a random number product to 1.25.

The initial pheromone value $\alpha_{i,j}$ is set to be 0.1, the incremental pheromone value $\Delta\alpha$ and the pheromone evaporated factor is set as 0.05. The traffic pattern that is used is the constant bit rate (CBR), and the used transport layer protocol is the UDP protocol. However, the MAC 802.11 protocol is the data link layer protocol that is used, and the propagation model that is used is the two way ground model, with a transmission range of 250m, and with the Omni antenna as the antenna type. Moreover, the queue type that is used is the drop tail. The nodes mobility behavior follows the random way point model.

5.3.1 Random Way Point Model

In the random waypoint model, nodes move in straight lines with a constant speed from point to point called waypoints, which are distributed uniformly in a certain dominant area. Each node in the MANET will have a random initially position in a specified area, and then each node will move to a randomly chosen waypoint in the simulation area with a randomly chosen velocity in the range of (0, V_{max}) m/s, where V_{max} is a maximum specified speed. When the node reaches the specified waypoint, it will stop moving for a certain period of time called the pause time to start moving again towered another waypoint in the area. The nodes will continue moving with this criteria till the end of the simulation. The behavior of the nodes mobility is determined by the values of the pause time and the maximum velocity [9].

5.4 Simulation Results

Several experiments were performed, and the results were taken at different flow count, different maximum nodes speed, different number of network nodes and at different pause time, as the following subsections present.

5.4.1 Flow Count Variation Scenario

The average end to end delay, throughput, the packet delivery ratio and the network overhead are measured when varying the data flow count from five to twenty five flows with different number of nodes at 150 s pause time and 10 m/s maximum mobile nodes speed.

Flow Count Variation With 100 Network Nodes

By increasing the number of data flows, the throughput of the three protocols is increased as shown in figure (5.2). The throughput of the proposed protocol is much higher than that of both the AODV and AntHocNet protocols. Moreover, the increasing rate of the throughput values in the proposed protocol is small, while its higher in the AODV and much higher in the AntHocNet.

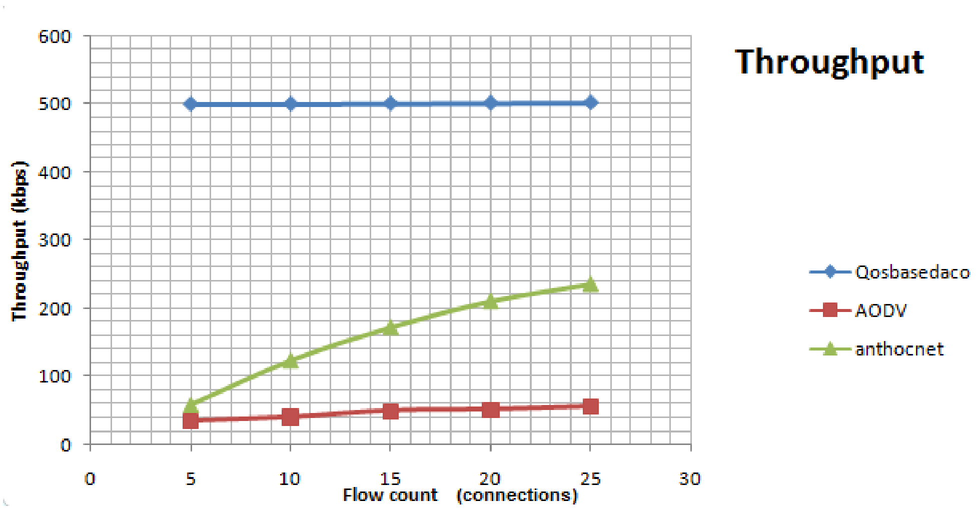

Figure 5.2: Throughput Vs Flow Count

Figure 5.3 shows that the overhead of the proposed protocol is decreasing when the number of flow connections is increased, because the number of the data packets is increased when increasing the connections and hence, the ratio to the number of data packets will decreased. The overhead of the proposed protocol is much higher than that of the other two protocols at low flow counts due to the frequently transmission of the forward ant with very small intervals. Another reason is that the proposed protocol in addition of sending the ants frequently, sends HELLO messages every some time interval to discover the nodes neighbors. However, in the AODV and the AntHocNet, discovering the nodes neighbors is done by using the link layer detection techniques instead.

When increasing the flow count, the overhead of the proposed protocol is sharply decreasing, while in the AODV and the AntHocNet, the decreasing rate of the overhead is small.

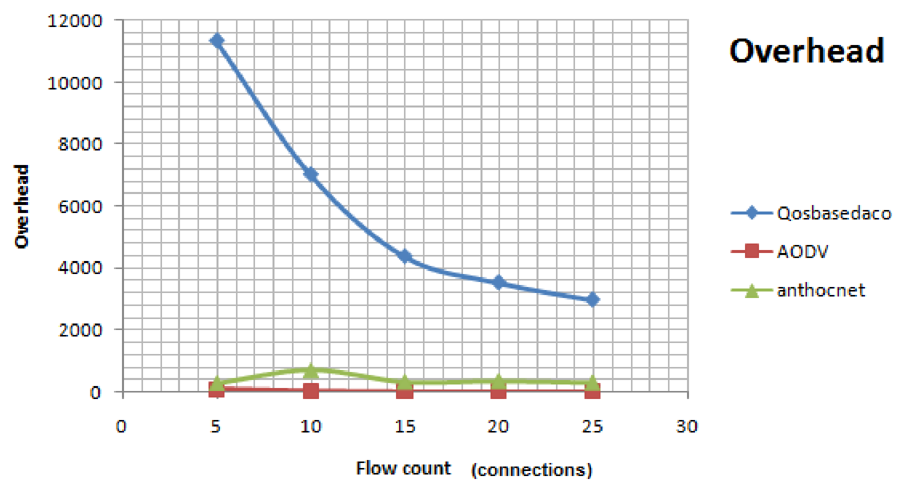

Figure 5.3: Overhead Vs Flow Count

The average end to end delay in this scenario is very small in the proposed protocol compared with the AODV and the AntHocNet routing protocols as shown in figure 5.4. When increasing the flow count, the average end to end delay is increasing in the proposed protocol with a small increasing rate. However, in the AODV the delay is decreasing while increasing the flow count till reaching twenty flows then the delay is start to increase with high increasing rate. The average end to end delay of the AntHocNet is sharply increasing when the number of flow connections is increased to ten, after that the delay is start to decrease, to increase again at twenty flows but with a less decreasing rate value than that at ten flows.

In figure 5.5, as it can be seen, the packet delivery ratio of the three protocols is increasing, when the flow count is increased, and the increasing rate in the packet delivery ratio of the proposed protocol and the AODV is very small, with higher AODV ratio values, but still close to the ratio values of the proposed protocol. On the other hand, the AntHocNet routing protocol has much higher packet delivery ratio than that of the proposed and the AODV protocols, with a higher increasing rate.

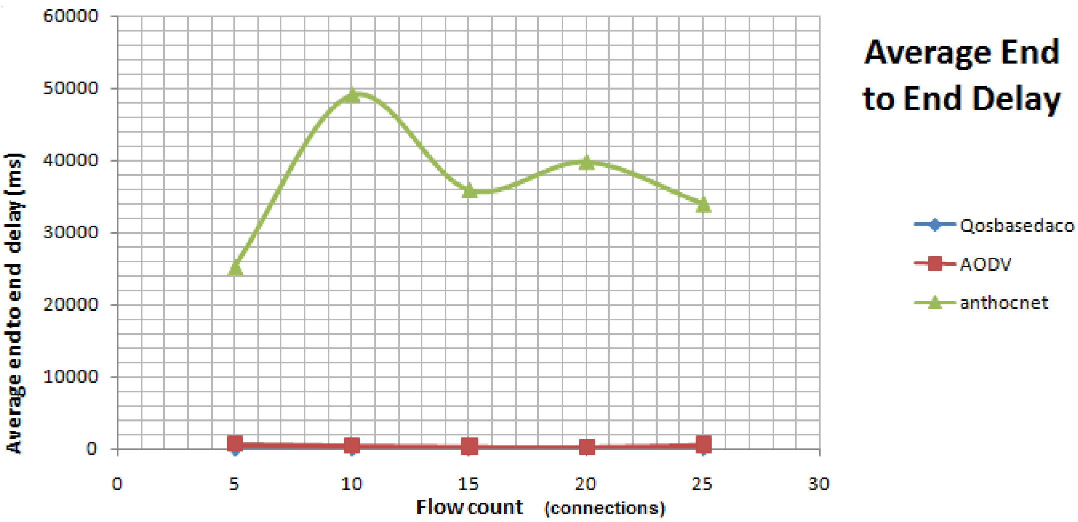

Figure 5.4: Average End to End Delay Vs Flow Count

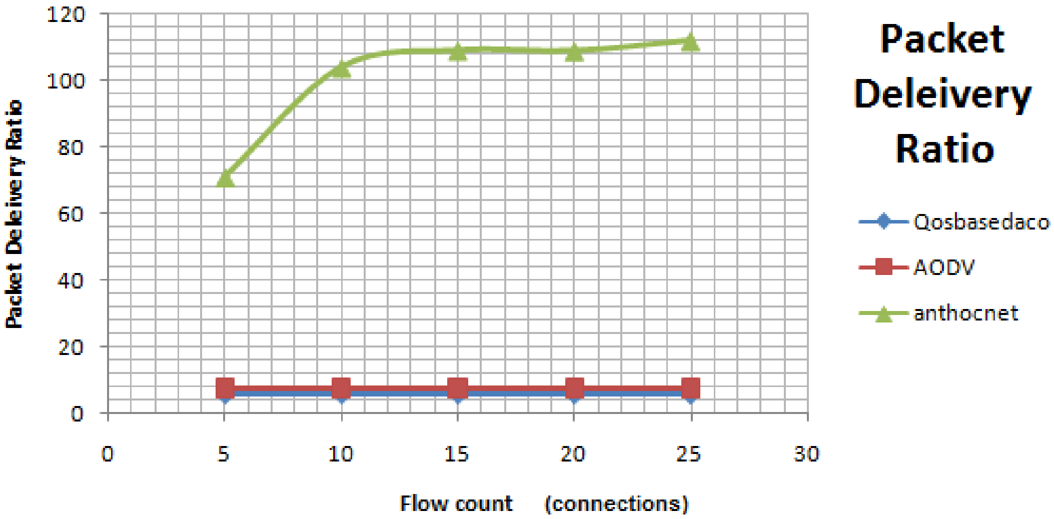

Figure 5.5: Packet Delivery Ratio Vs Flow Count

Flow Count Variation With 50 Network Nodes Scenario

The Throughput as can be seen from figure 5.6 is increasing as the flow count is increased. The throughput of the proposed protocol is higher than that of the AODV and AntHocNet protocols. The increasing rate of the throughput in the proposed and in the AODV protocols is small compared with the increasing rate of the AntHocNet. Moreover, the increasing rate at 50 nodes is smaller than that at 100 nodes for both the AntHocNet and the AODV, while its larger in the case of the proposed protocol.

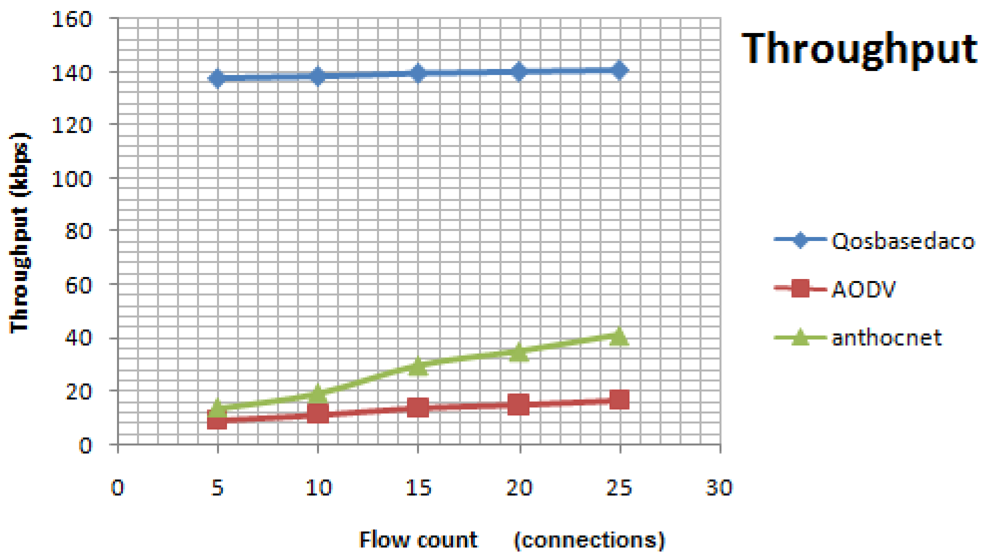

Figure 5.6: Throughput Vs Flow Count

Figure 5.7 shows that the overhead of the three protocols is decreasing when the flow count increasing. However, the overhead at 50 nodes is smaller than that at 100 nodes in the case of the three protocols, but when the flow count is five, the AODV overhead at 50 nodes is much larger than that at 100 nodes.

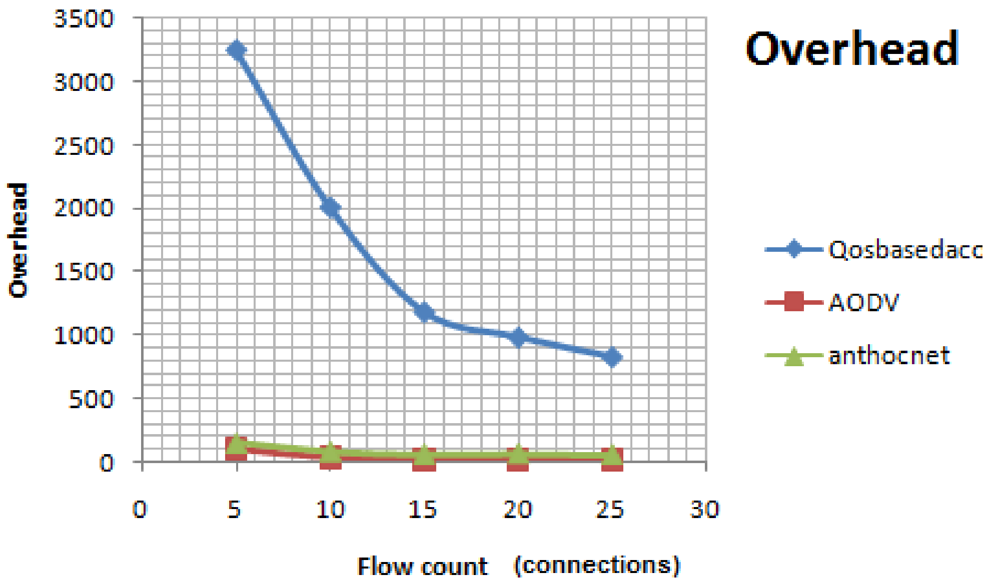

Figure 5.7: Overhead Vs Flow Count

The average end to end delay in figure 5.8 is increasing as the number of flow count is increased in the case of the proposed protocol. However, the delay of the proposed protocol is much less than that of the AODV and the AntHocNet. Moreover, the delay of the three protocols in this case is higher than that at 100 nodes.

In figure 5.9 the packet delivery ratio of the proposed protocol is increasing as the flow count is increased with a very little increasing rate. However, the ratio of the AODV and the AntHocNet is fluctuating. The packet delivery ratio of the three protocols is smaller than that at the case of 100 nodes with a large decreasing rate for the AntHocNet protocol and small decreasing rate for the AODV protocol and even smaller for the proposed protocol, and hence the ratio values of the proposed protocol get closer to the AODV ratio values at 50 nodes.

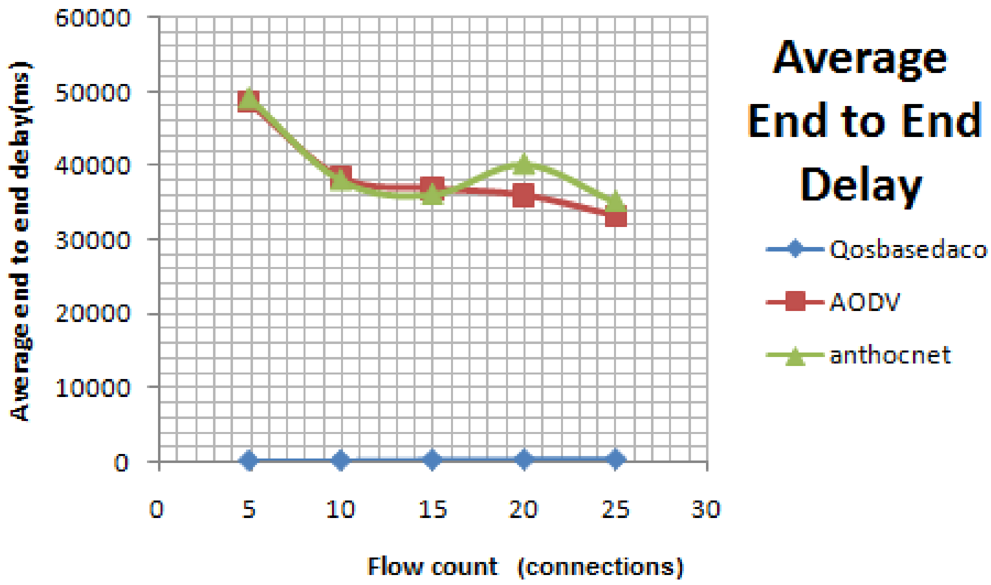

Figure 5.8: Average End to End Delay Vs Flow Count

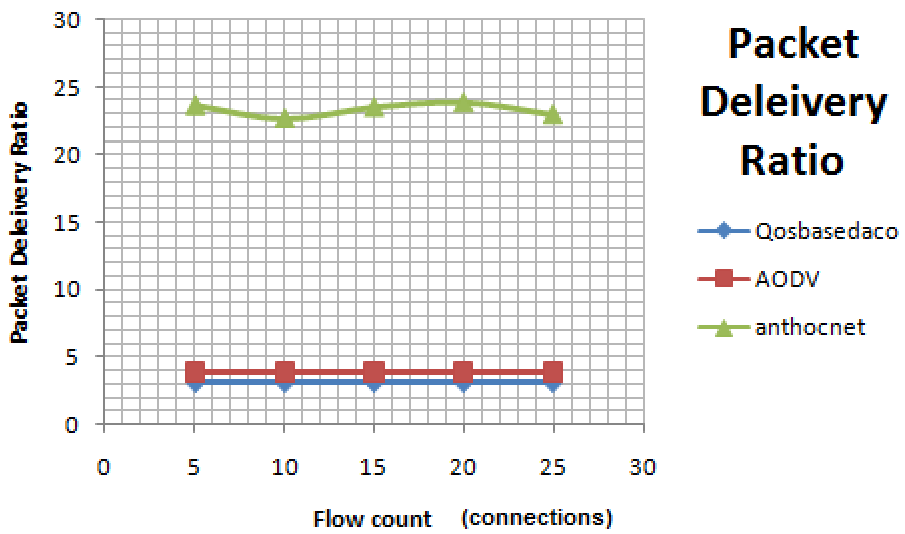

Figure 5.9: Packet Delivery Ratio Vs Flow Count

Flow Count Variation With 20 Network Nodes Scenario

It is clear from figure 5.10 that the throughput of the proposed protocol is also higher than that of the other two protocols, and that the throughput values is smaller than that at 100 nodes and at 50 nodes cases. At flow count larger than fifteen, the throughput values of the three protocols don't change as the flow count increasing.

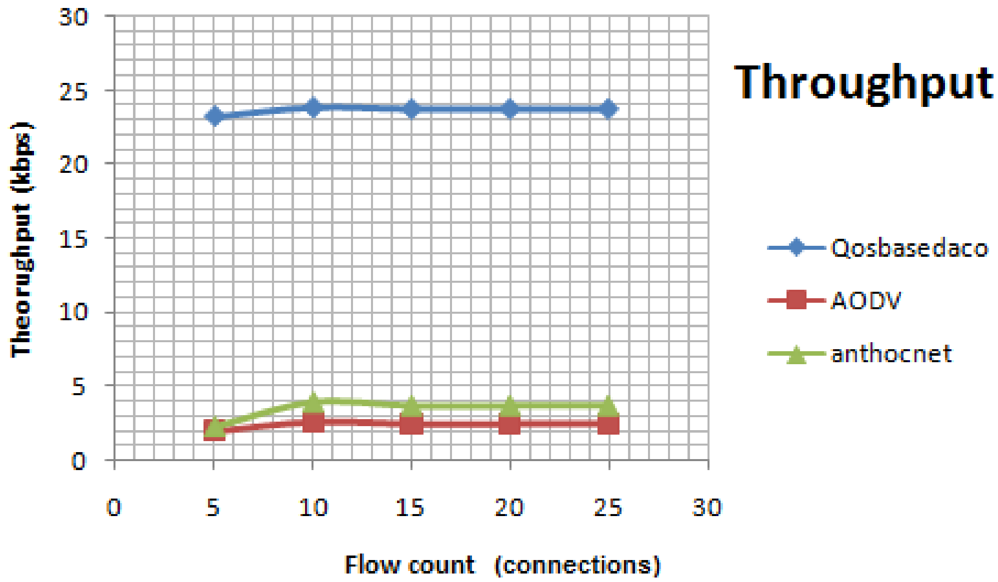

Figure 5.10: Throughput Vs Flow Count

Figure 5.11 shows that the overhead of the proposed protocol is also higher than that of the other two protocols. The overhead values of the three protocols is smaller than that at 100 nodes and at 50 nodes cases. As the number of flow connections is increased more than fifteen, the overhead values don't change.

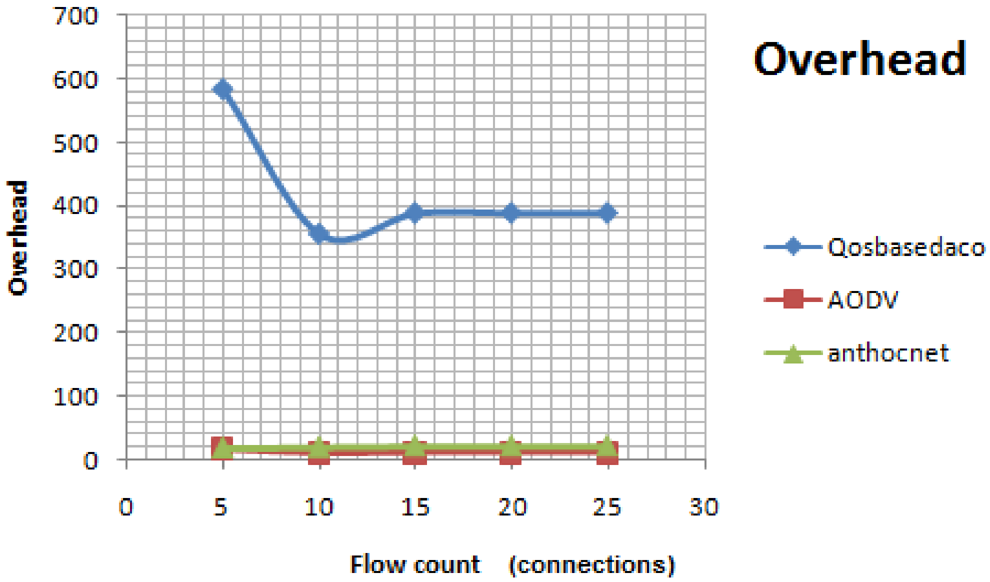

Figure 5.11: Overhead Vs Flow Count

The average end to end delay of the proposed protocol has the least values. The delay of the three protocols is higher than that at 100 nodes and at 50 nodes cases. No changes to the delay values when the flow count is increasing more than fifteen as in figure 5.12.

Figure 5.13 shows that the packet delivery ratio of the proposed protocol is getting closer to the values of the AODV than that at 100 nodes and at 50 nodes cases, and the ratio values of the AntHocNet become smaller than that at 100 and at 50 nodes cases with a large decreasing rate. However, at fifteen flows, the ratio doesn't change when increasing the flow count.

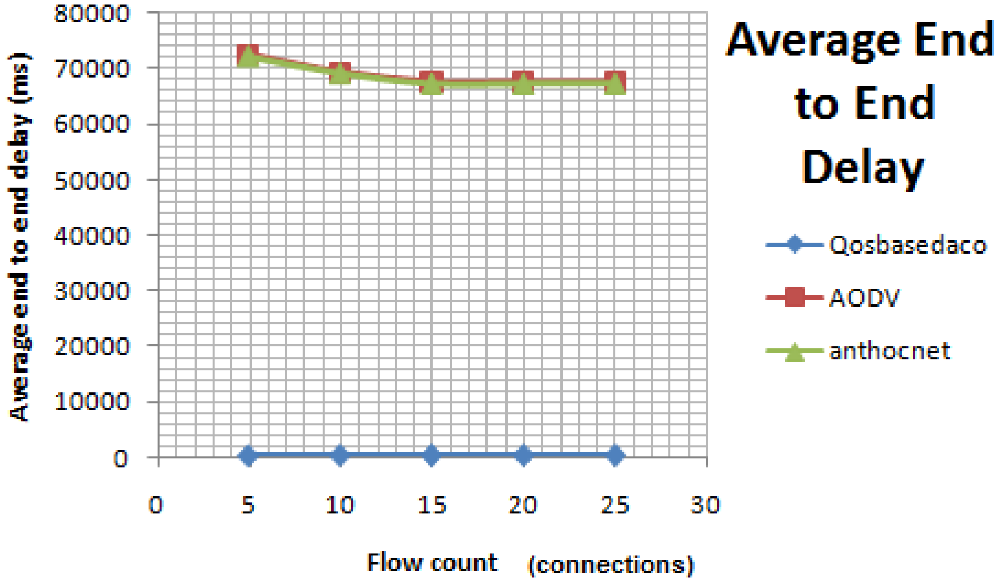

Figure 5.12: Average End to End Delay Vs Flow Count

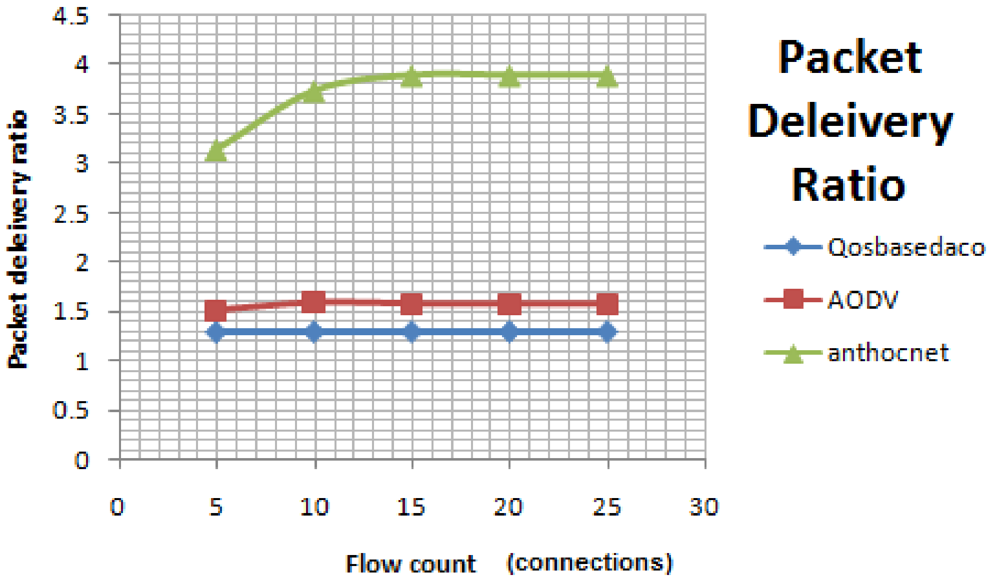

Figure 5.13: Packet Delivery Ratio Vs Flow Count

5.4.2 Maximum Node Speed Variation Scenario

Increasing the maximum nodes speed, makes fluctuating in the throughput, overhead, average end to end delay and in the packet delivery ratio values of the three protocols. This is because what is vary is the maximum node speed, and the mobility behavior of each node depends on different velocity value than the other nodes, which is chosen randomly from a range starts from zero to the maximum node speed. When the maximum node speed is increased, the range for choosing different velocities is increasing, allowing more different velocities to be chosen by the node to.

For this scenario, the pause time is set to be 150 s.

Maximum Node Speed Variation At 100 Network Nodes and 5 Flows

In general, the throughput values of the three protocols are fluctuating when increasing the nodes maximum speed as in figure 5.14. The fluctuating rate of the proposed protocol is high, and is higher in the AntHocNet protocol, while it is small in the AODV protocol.

As increasing the maximum node speed, the overhead of the AntHocNet protocol is increased. While in both the AODV and the proposed protocol, the overhead values are fluctuating as in figure 5.15.

The average end to end delay of the proposed protocol is smaller than that of the other two protocols. In general, the average end to end delay in the AntHocNet protocol is increased when increasing the maximum node speed. In the proposed protocol, the average end to end delay is fluctuating and the maximum delay value is at 60 m/s maximum node speed. Moreover, The AODV maximum delay value is at 20 m/s maximum node speed. Figure 5.16 shows the average end to end delay when varying the maximum nodes speed.

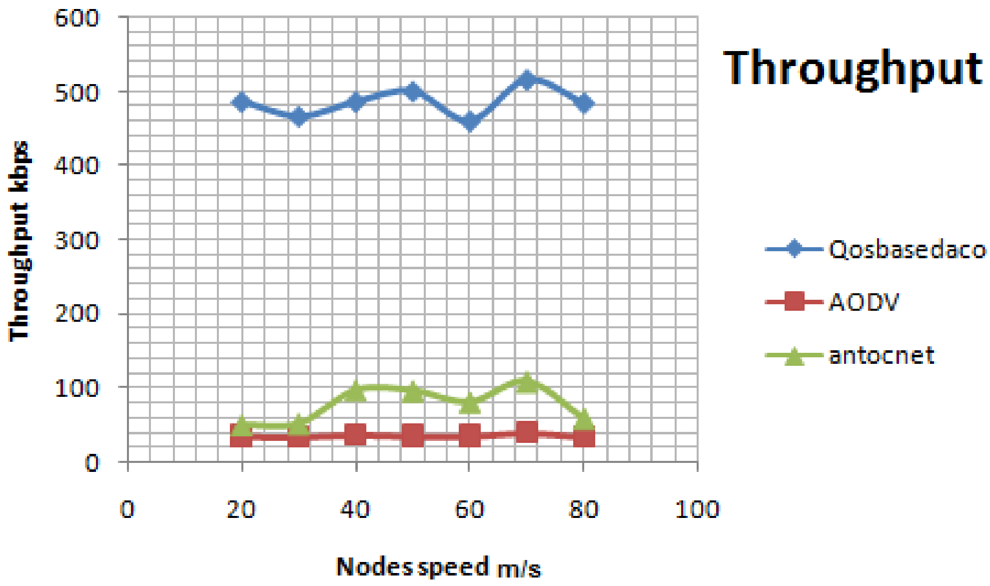

Figure 5.14: Throughput Vs Nodes Speed

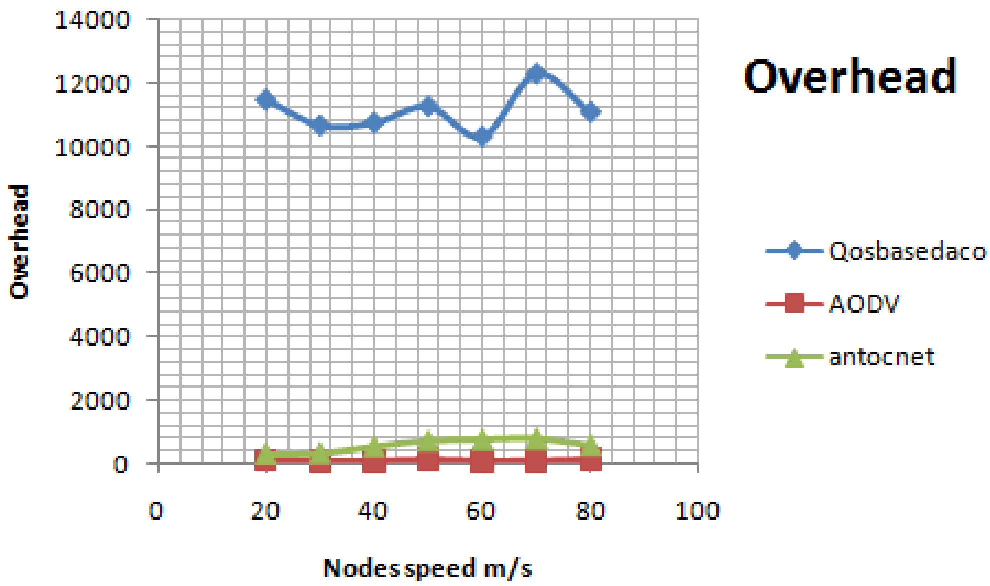

Figure 5.15: Overhead Vs Nodes Speed

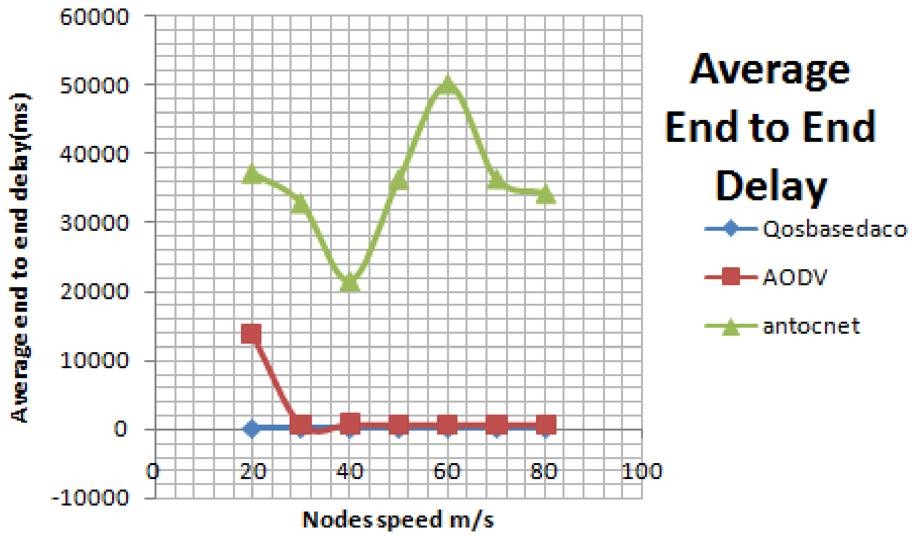

Figure 5.16: Average End to End Delay Vs Nodes Speed

The values of the packet delivery ratio of the three protocols is fluctuating, and the maximum ratio value of the three protocols is at 70 m/s maximum node speed, as can be seen from figure 5.17.

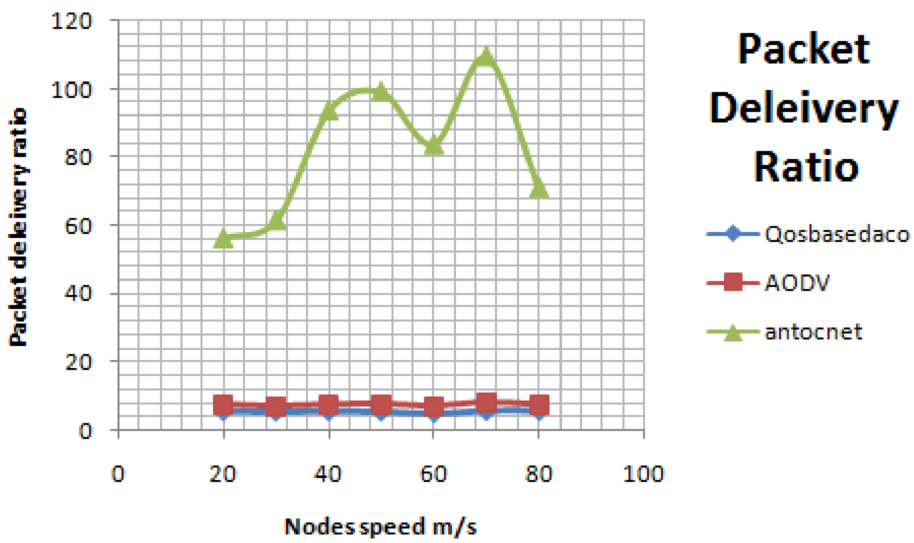

Figure 5.17: Packet Delivery Ratio Vs Nodes Speed

Maximum Node Speed Variation With 100 Nodes And 25 Flows

As figure 5.18 shows, the maximum throughput value of both the AntHocNet and the proposed protocols is at 70 m/s maximum node speed, while the maximum throughput value of the AODV is at 10 m/s maximum node speed. The throughput values of the three protocols in this case are higher than that at the 5 flows case.

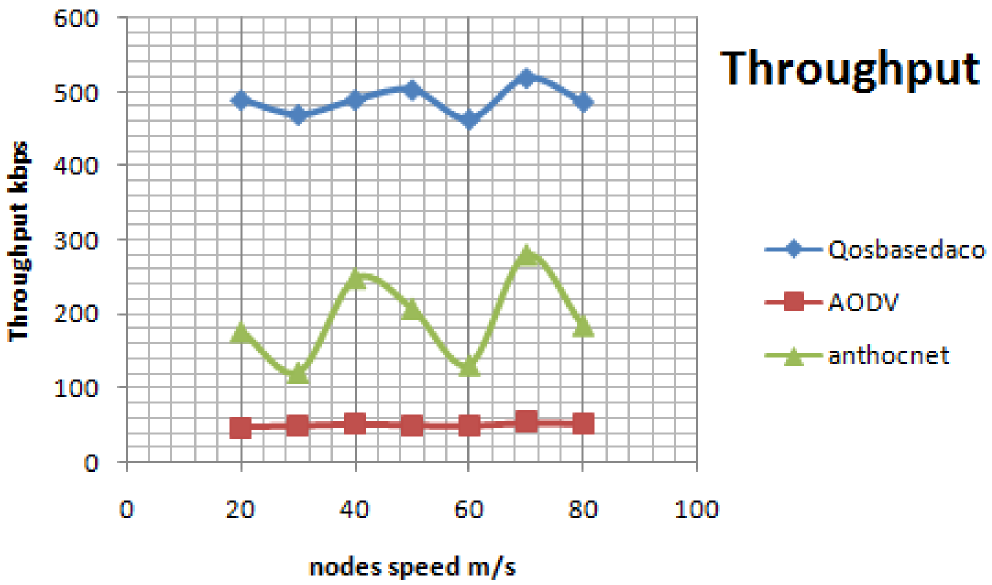

Figure 5.18: Throughput Vs Nodes Speed

As figure 5.19 shows, the least value of the overhead in both the proposed protocol and the AntHocNet protocol is at 30 m/s maximum node speed, while in the AODV the least value is at 10 m/s. The overhead of the three protocols in this case is lesser than that at the 5 flows case.

The least average end to end delay among the three protocols is of the proposed protocol. The least delay value for both the proposed and the AntHocNet protocols is at 60 m/s maximum node speed, while the least value for the AODV is at 70 m/s maximum node speed, as can be seen from figure 5.20.

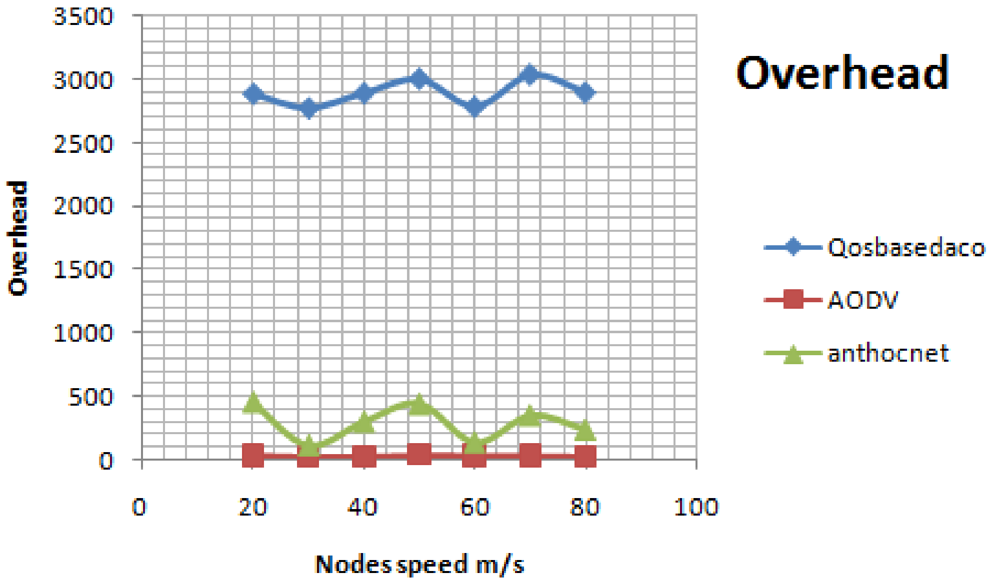

Figure 5.19: Overhead Vs Nodes Speed

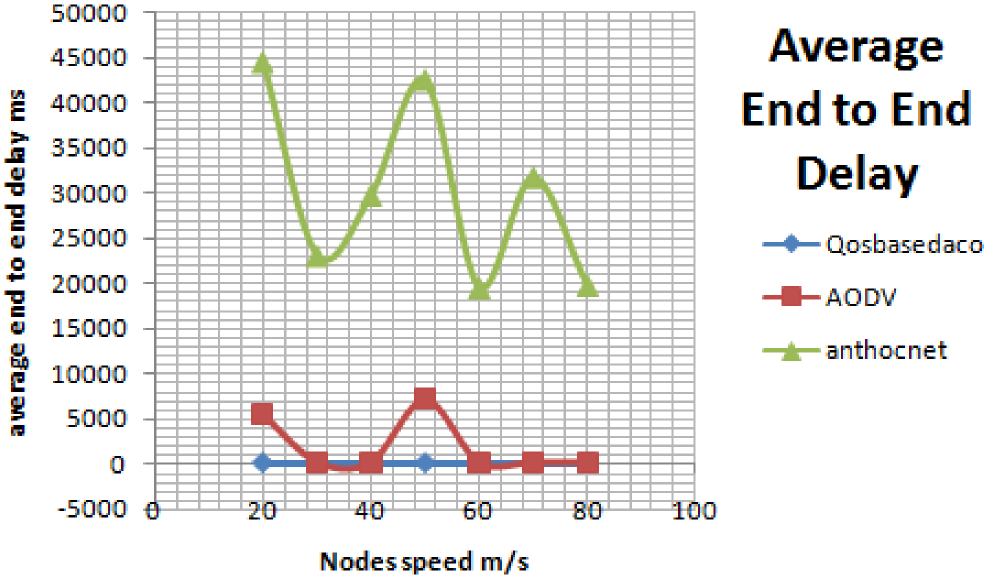

Figure 5.20: Average End to End Delay Vs Nodes Speed

The packet delivery ratio of both the AntHocNet protocol and the proposed protocol in this case is higher than that of the 5 flows case, while the ratio of the AODV protocol is lower. The maximum value of the packet delivery ratio of the three protocols is at 70 m/s maximum node speed. Figure 5.21 shows the packet delivery ratio at 25 flows.

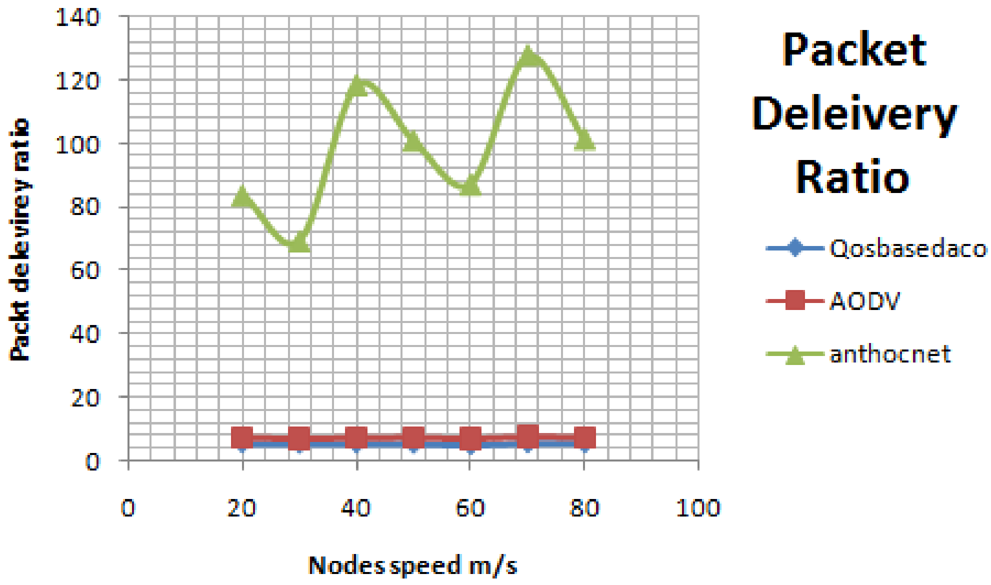

Figure 5.21: Packet Delivery Ratio Vs Nodes Speed

Maximum Node Speed Variation With 50 Nodes And 25 Flows

Figure 5.22 shows the throughput values of the three protocols, and as can be seen, the throughput of the proposed protocol is higher than that of the other two protocols with a highest value at 70 m/s maximum node speed. The throughput of the three protocols in this case is lower than that at the 100 nodes, 25 flows case.

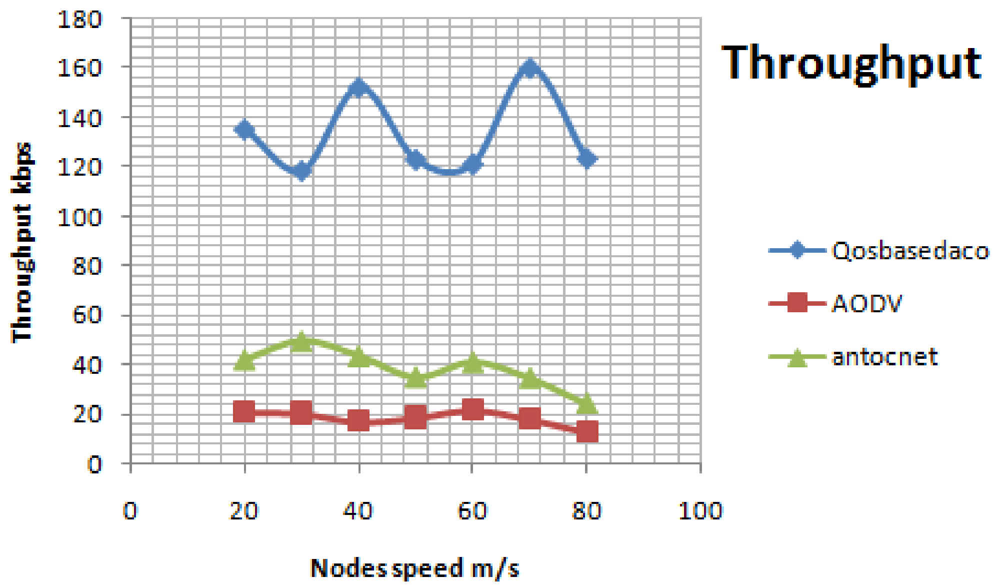

Figure 5.22: Throughput Vs Nodes Speed

The least overhead value of the proposed protocol is at 80 m/s maximum node speed, while in the AODV, the least overhead value is at 60 m/s maximum node speed, and in the AntHocNet is at 70 m/s maximum node speed as in figure 5.23.

The smallest average end to end delay value of the proposed protocol is at 30 m/s maximum node speed, and for both the AODV and the AntHocNet protocols is at 60 m/s maximum node speed. Figure 5.24 shows the average end to end delay for the three protocols in this case.

Figure 5.25 shows that the highest packet delivery ratio value of the proposed and the AODV protocols is at 70 m/s maximum node speed, while the highest value of the AntHocNet protocol is at 40m/s maximum node speed.

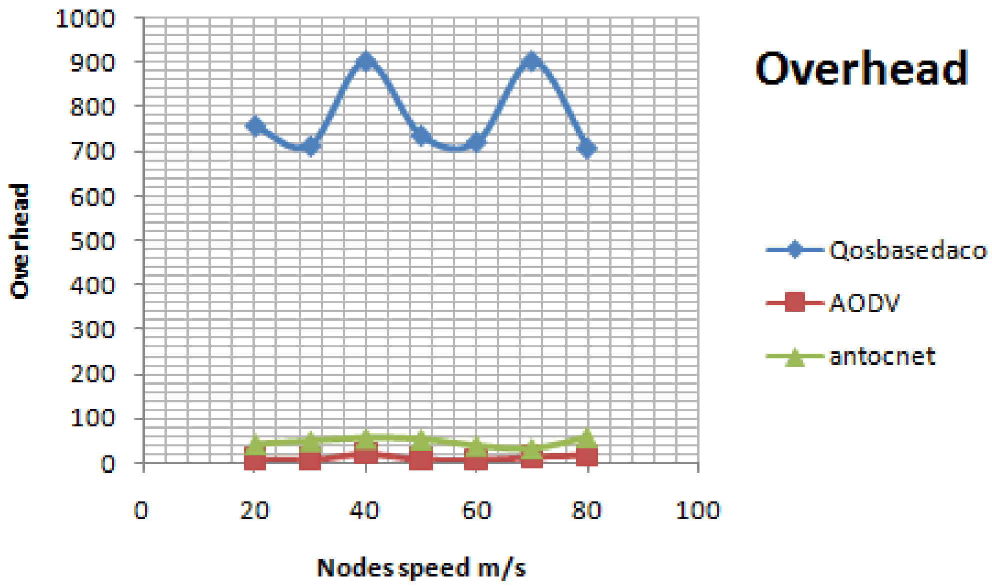

Figure 5.23: Overhead Vs Nodes Speed

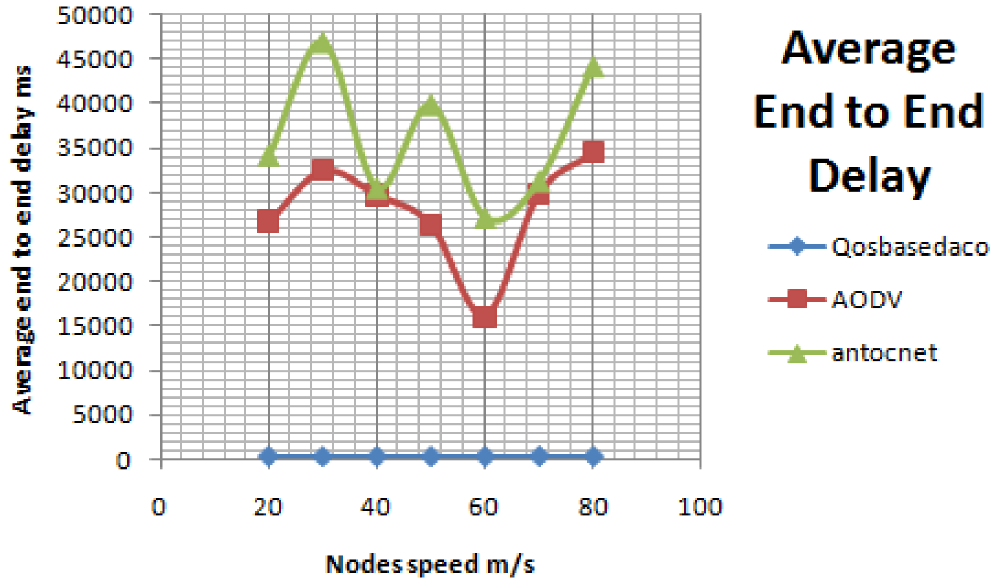

Figure 5.24: Average End to End Delay Vs Nodes Speed

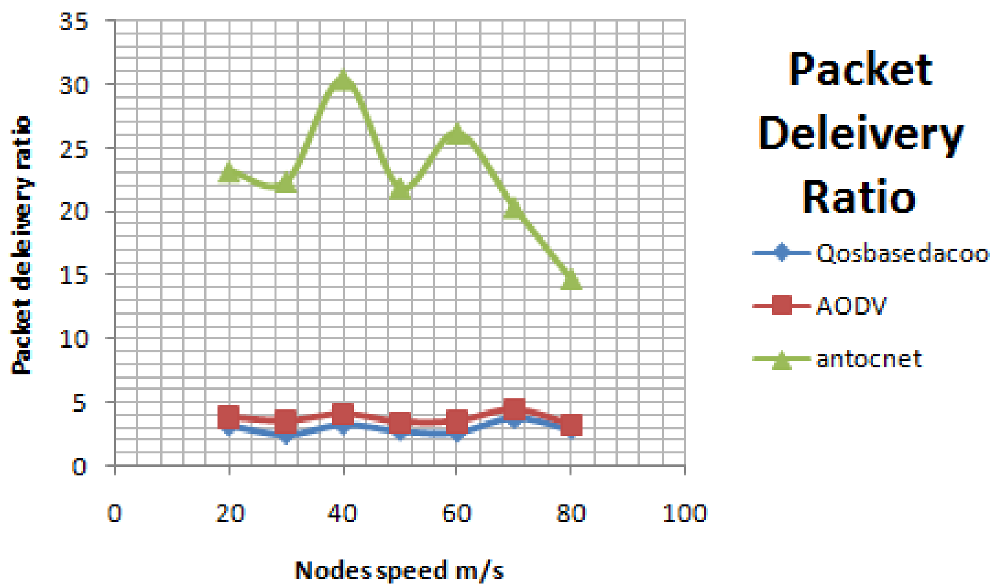

Figure 5.25: Packet Delivery Ratio Vs Nodes Speed

5.4.3 Pause time variation scenario

In this case, the maximum node speed is set to be 10 m/s, the number of nodes is set to 50 nodes, and the number of flows is set to 25 flows.

As in figure 5.26, the maximum throughput value of the proposed protocol is at 100 s pause time. In general, the throughput of the three protocols is start to increase again after some fluctuating in its values when increasing the pause time to more than 400 s.

Figure 5.27 shows the overhead at different pause time values. The least overhead value of the proposed protocol is at 400 s pause time, while in both the AODV and the AntHocNet routing protocols, the least overhead value is at 450 s pause time.

The least average end to end delay value of the proposed and the AntHocNet protocols is at 50 s pause time, while of the AODV is at 450 s pause time. Figure 5.28 shows the average end to end delay of the three protocols in this case.

The highest value of the packet delivery ratio of both the proposed and the AODV protocols is at 100 s pause time, while the highest value of the AntHocNet is at 150 s as can be seen from figure 5.29.

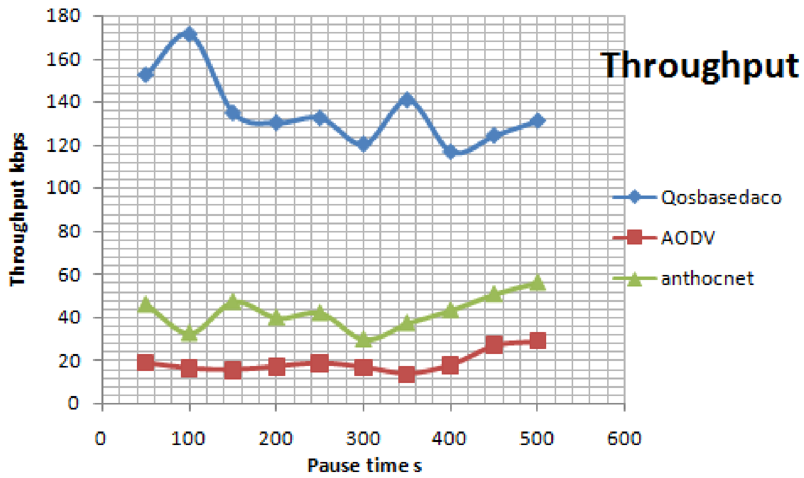

Figure 5.26: Throughput Vs Pause Time

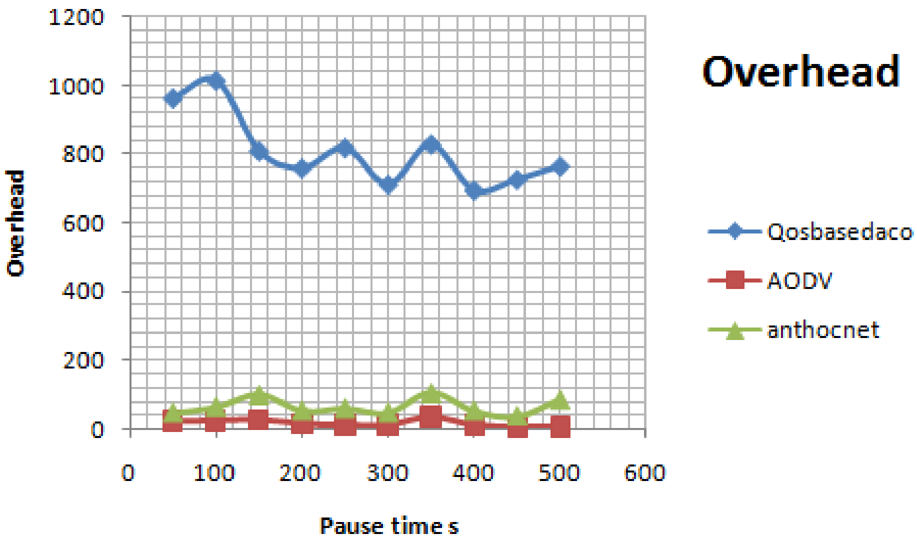

Figure 5.27: Overhead Vs Pause Time

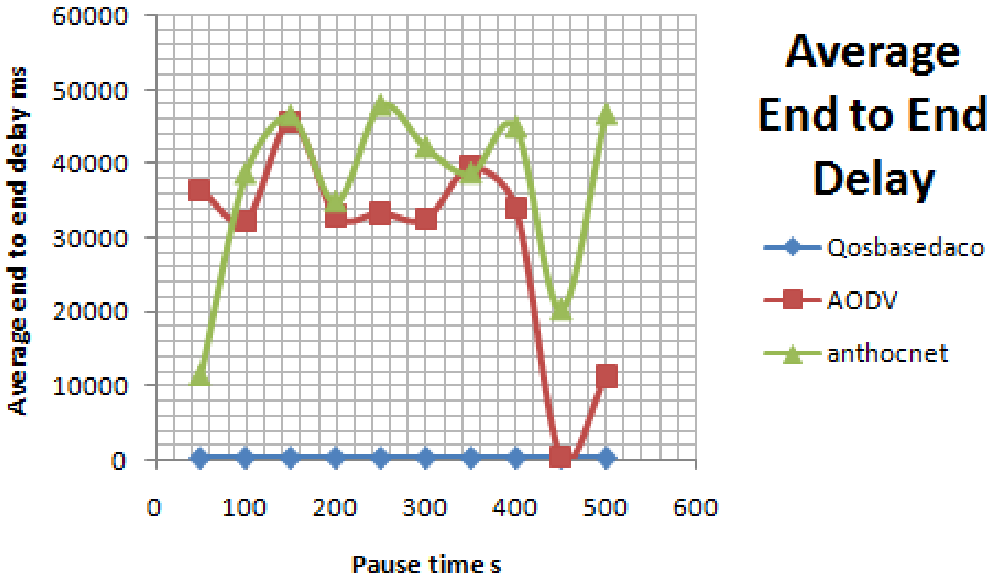

Figure 5.28: Average End to End Delay Vs Pause Time

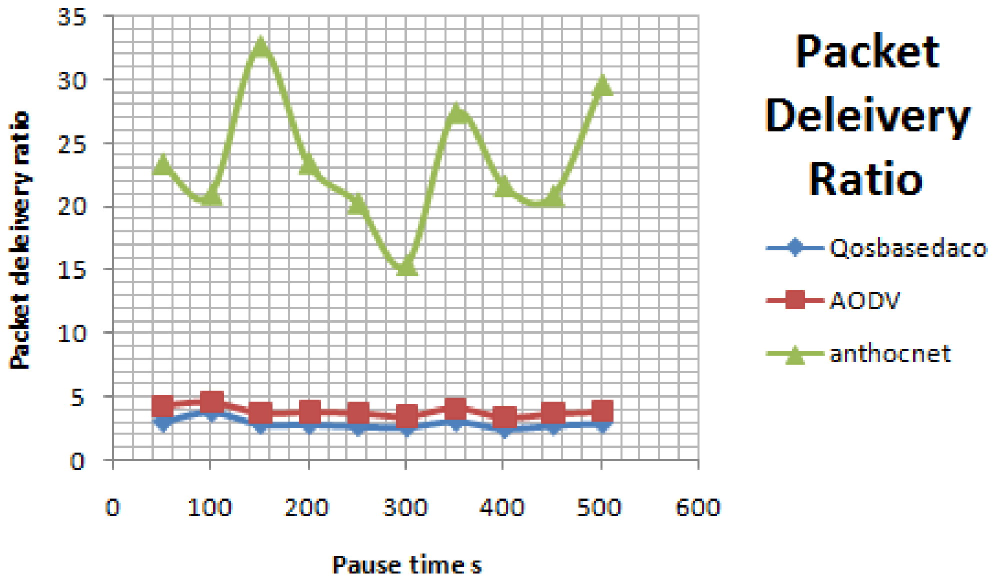

Figure 5.29: Packet Delivery Ratio Vs Pause Time

5.5 Concluding Remarks

The proposed protocol, the AODV and the AntHocNet were simulated with different networking scenarios. Their performance was measured when varying the number of flows, the maximum nodes velocity, the network pause time at different number of network nodes.

In all of the simulated networking scenarios, the proposed protocol outperforms the AODV and the AntHocNet when considering the throughput and the average end to end delay, while the AntHocNet protocol outperforms the proposed protocol and the AODV when considering the packet delivery ratio. The AODV outperforms the proposed protocol and the AntHocNet protocol when considering the overhead.

In all of the scenarios, the packet delivery ratio values of the proposed protocol are so close to that of the AODV routing protocol. Moreover, the average end to end delay values of the AntHocNet protocol are close to that of the AODV routing protocol in most of the simulated scenarios.

When the number of network nodes decreases, the throughput, overhead, packet delivery ratio of the three protocols is decreased, while the average end to end delay is increased. The decreasing rate of both the proposed protocol and the AntHocNet is large when considering the overhead, while the decreasing rate of the AODV in the overhead is small. Moreover, the increasing rate of the average end to end delay in the proposed protocol is small, while in the other two protocols is large.

At small number of network nodes, any attempt to increase the flow count will not change the values of any of the used measuring parameters of the three protocols.

Changing the maximum nodes mobility speed and the nodes pause time highly affects the network, as can be seen from the simulation results of the three protocols, because the network topology depends directly on these two parameters.

Fluctuations Causes

There are several reasons for appearing the fluctuations in the results curves summarized as follows:

1. The fluctuations in the results, which were appeared when varying the number of flows for the AntHocNet protocol when taking the average end to end delay values of the protocol, are appeared due to the AntHocNet algorithm itself, which consists of a reactive and a proactive components. In the reactive component, when a node has data to be sent and there is no route to the destination, a forward ant will be sent from the node to find a route to the specified destination. During the open session, forward ants are sent proactively to finds alternative paths, and a bootstrapping technique is used to diffuse the expected network information which is called the virtual pheromone that is used in addition to the regular pheromone in the algorithm. Furthermore, the forward ants in the AntHocNet take the same queue as the data in addition to the randomness of the topology that can make some routes to be broken and hence a local route repair or a forward ant broadcasting to find another route can take place, which in turn makes the average end to end delay to be variable with changing the number of data flows.

2. The fluctuations in the results, which were appeared when varying the maximum node speed in the three protocols are due to the randomness of the network topology, as the speed of any node in the network is in the range between zero and the maximum node speed. Each node can take different speed in the range in each time the maximum node

speed is differ, and hence the topology of the network will be random in different way in each time the maximum node speed is differ and the protocols take different behaviors.

3. The fluctuations in the results, which were appeared when varying the pause time are caused because of the dependency of the pause time on the nodes speed, and this results were taken at 10 m/s maximum nodes speed, which means that any node can take different speed in the range between zero and ten meters per seconds, and that makes the behavior of the protocols to vary in this way when the pause time is changed in the network.

Chapter 6

Conclusion

6.1 Summary

This thesis defined the MANET, which is an infrastructure-less network with a dynamic topology that is used in many applications, and also described the MANETs routing protocols that are divided into proactive and reactive, and listed their advantages and disadvantages. Moreover, a description on the software agents is presented, which are used within the routing protocols to enhance their performance, in addition to a description of the ant colony optimization algorithm, which uses the software mobile agents as ants to enhance the network performance. The thesis also presented a survey on the agent based routing protocols and on the ant colony based routing protocols used in MANETs. It is an interested field to research on by the network researchers.

Trying to enhance the MANETs performance, a new routing protocol is proposed in this thesis based on the ant colony optimization algorithm and on the QOS parameters of the network, called QOS-Based-ACO. It is described, implemented and compared to other two MANETs protocols; one is a traditional reactive MANET routing protocol, which is the AODV, and the other is based on the ant colony optimization that combines the reactive and proactive routing techniques, which is the AntHocNet routing protocol.

6.2 Conclusion

A new MANET routing protocol called QOS-Based-ACO is proposed and implemented by using the NS2 simulator. It is based on the ACO algorithm, to enhance the MANETs performance. The proposed protocol performance is measured and compared with that of the AODV and the AntHocNet protocols.

The comparison made is based on different networking scenarios: different number of nodes, different nodes speeds, different pause time and at different number of data flows. The results showed that the proposed protocol outperforms the other two protocols when considering the throughput and the average end to end delay in all of the simulated scenarios.

6.3 Future Work

As a future work, a modification can be made on the methodology of the proposed protocol to increase its packet delivery ratio and decrease its overhead. Moreover, it can be combined with one of the traditional protocols to enhance the both. Then, the proposed protocol will be simulated after the modifications, and its performance will be compared with the performance of its original version and with other existing protocols in different networking scenarios.

Appendix A

Simulation Results Tables

Table A.1: Flow Count Variation With 100 Network Nodes For QOS-Based-ACO Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Flow Count**
500.22	11339.49	5.467	49.2774	5
500.55	7014.003	5.4625	71.0641	10
501.18	4367.012	5.4584	104.06	15
501.88	3517.795	5.4617	129.982	20
502.54	2958.57	5.4596	151.082	25

Table A.2: Flow Count Variation With 100 Network Nodes For AODV Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Flow Count**
35.09	84.322	7.4601	570.965	5
40.67	42.455	7.4175	377.602	10
49.87	25.791	7.312	246.17	15
51.58	23.441	7.237	210.97	20
55.83	19.039	7.2396	461.253	25

Table A.3: Flow Count Variation With 100 Network Nodes For AntHocNet Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Flow Count**
58.16	274.171	70.7208	25209	5
123.62	691.783	103.8063	49072.6	10
172.69	320.916	108.9428	35901	15
211.24	351.666	108.7896	39794.5	20
236.48	298.704	111.8748	33964.7	25

Table A.4: Flow Count Variation With 50 Network Nodes For QOS-Based-ACO Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Flow Count**
137.61	3253.966	3.0925	80.7787	5
138.33	2011.859	3.0954	125.216	10
139.45	1184.819	3.0979	198.91	15
140.03	984.291	3.0988	245.004	20
140.57	829.566	3.0998	285.094	25

Table A.5: Flow Count Variation With 50 Network Nodes For AODV Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Flow Count**
9.3	105.711	3.8508	48508.9	5
11.26	38.014	3.8576	38442.4	10
13.77	23.324	3.8347	36995.4	15
14.88	20.178	3.8342	36099.5	20
16.44	16.715	3.8259	33348.8	25

Table A.6: Flow Count Variation With 50 Network Nodes For AntHocNet Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Flow Count**
13.79	151.411	23.6641	49171.9	5
19.34	84.576	22.6788	38072.2	10
29.8	61.638	23.5192	36146.1	15
35.06	66.581	23.8718	40259.9	20
41.12	57.168	22.9761	35187.8	25

Table A.7: Flow Count Variation With 20 Network Nodes For QOS-Based-ACO Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Flow Count**
23.26	583.049	1.2938	216.555	5
23.86	355.799	1.2969	297.348	10
23.76	388.533	1.2979	300.509	15
23.76	388.533	1.2979	300.509	20
23.76	388.533	1.2979	300.509	25

Table A.8: Flow Count Variation With 20 Network Nodes For AODV Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Flow Count**
1.99	16.589	1.5055	72490.1	5
2.63	10.321	1.5854	69377.8	10
2.5	11.339	1.5737	67634.4	15
2.5	11.339	1.5737	67634.4	20
2.5	11.339	1.5737	67634.4	25

Table A.9: Flow Count Variation With 20 Network Nodes For AntHocNet Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Flow Count**
2.26	18.467	3.1465	72319.7	5
3.94	19.833	3.7354	69260.2	10
3.7	21.161	3.8923	67346.6	15
3.7	21.161	3.8923	67346.6	20
3.7	21.161	3.8923	67346.6	25

Table A.10: Maximum Nodes Speed Variation At 100 Network Nodes and 5 Flows For QOS-Based-ACO Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Maximum Nodes Speed (m/s)**
486.55	11475.5	5.569	47.6824	20
466.53	10675.24	5.3992	46.2634	30
486.58	10760.17	5.5313	48.0148	40
500.81	11272.53	5.4331	48.8322	50
460.11	10327.45	5.0349	50.5153	60
516.67	12292.01	5.6417	46.7756	70
484.99	11094.58	5.6139	47.2894	80

Table A.11: Maximum Node Speed Variation At 100 Network Nodes and 5 Flows For AODV Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Maximum Nodes Speed (m/s)**
33.85	99.833	7.3527	13685.7	20
33.01	82.948	6.915	542.751	30
36.23	62.207	7.3252	588.227	40
33.87	163.488	7.5268	529.394	50
33.89	70.815	6.923	569.619	60
38.35	90.005	7.9689	581.067	70
33.06	160.721	7.353	556.046	80

Table A.12: Maximum Node Speed Variation At 100 Network Nodes and 5 Flows For AntHocNet Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Maximum Nodes Speed (m/s)**
49.31	312.702	56.4851	37185.8	20
51.3	337.1	61.7767	32827.9	30
96.22	543.575	93.7439	21574.1	40
95.29	716.214	99.2431	36312.8	50
80.02	752.38	83.8953	50089.8	60
107.72	782.972	109.4386	36369	70
58.15	578.915	71.2389	34265.7	80

Table A.13: Maximum Node Speed Variation At 100 Network Nodes and 25 Flows For QOS-Based-ACO Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Maximum Nodes Speed (m/s)**
489.89	2886.826	5.5697	153.417	20
469.74	2776.752	5.4033	149.603	30
490.11	2891.86	5.5351	148.292	40
503.74	3001.799	5.4343	148.402	50
463.42	2787.815	5.0387	148.077	60
519.86	3034.669	5.6422	150.356	70
487.37	2896.885	5.6086	150.307	80

Table A.14: Maximum Node Speed Variation At 100 Network Nodes and 25 Flows For AODV Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Maximum Nodes Speed (m/s)**
46.27	29.47	7.1018	5480.26	20
48.3	21.363	6.7373	169.127	30
51.57	22.038	7.046	173.738	40
49.06	30.898	7.2665	7165.35	50
47.81	26.794	6.6745	168.425	60
53.71	27.089	7.627	165.373	70
51.07	21.777	7.1369	169.06	80

Table A.15: Maximum Node Speed Variation At 100 Network Nodes and 25 Flows For AntHocNet Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Maximum Nodes Speed (m/s)**
175.53	454.963	83.7408	44538.1	20
120.74	114.803	69.4637	23161.3	30
247.31	298.702	118.3526	29849.4	40
206.69	439.331	100.9419	42563.7	50
130.67	137.86	87.2882	19591.2	60
279.06	349.588	127.612	31808	70
183.78	237.335	101.4377	19852.4	80

Table A.16: Maximum Node Speed Variation At 50 Network Nodes and 25 Flows For QOS-Based-ACO Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Maximum Nodes Speed (m/s)**
135.32	758.807	3.1714	317.895	20
118.63	713.881	2.4871	283.317	30
152.16	903.673	3.2581	285.995	40
123.12	737.441	2.7498	296.895	50
121.34	722.792	2.6529	285.716	60
159.93	904.013	3.7626	317.702	70
123.59	708.89	2.8903	304.606	80

Table A.17: Maximum Node Speed Variation At 50 Network Nodes and 25 Flows For AODV Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Maximum Nodes Speed (m/s)**
20.64	8.61	3.8574	26797.5	20
20.05	8.791	3.5604	32575.6	30
16.85	20.519	4.1091	29789.5	40
18.47	9.375	3.4795	26445.2	50
21.35	8.057	3.5502	16077.5	60
17.88	15.271	4.4464	29962.7	70
12.83	17.772	3.3069	34564.9	80

Table A.18: Maximum Node Speed Variation At 50 Network Nodes and 25 Flows For AntHocNet Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Maximum Nodes Speed (m/s)**
42.01	42.188	23.1751	34194.7	20
49.41	49.05	22.3596	46983.5	30
43.44	55.588	30.428	30496.7	40
34.85	53.188	21.8789	39936.5	50
40.94	38.114	26.2002	27162.9	60
34.49	31.583	20.3659	31281.6	70
24.26	58.075	14.7292	44262	80

Table A.19: Pause Time Variation Scenario For QOS-Based-ACO Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Pause Time (s)**
152.39	963.514	3.0391	262.197	50
171.32	1015.205	3.8292	300.536	100
134.61	809.215	2.8819	288.466	150
130.02	759.506	2.8547	301.715	200
132.23	818.761	2.7117	268.454	250
120.08	711.357	2.6439	293.151	300
140.61	829.305	3.0948	288.493	350
116.47	694.615	2.5281	290.352	400
124.14	726.064	2.7845	293.509	450
130.99	764.946	2.934	300.687	500

Table A.20: Pause Time Variation Scenario For AODV Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Pause Time (s)**
18.76	21.318	4.3073	36456.2	50
16.21	24.11	4.5721	32246	100
15.51	26.546	3.7438	45568.7	150
17.16	14.426	3.8006	32959.5	200
18.74	9.935	3.7407	33267.5	250
16.64	10.958	3.4554	32437.5	300
13.71	35.255	4.1166	39516.1	350
17.88	10.666	3.3821	34037.8	400
27.09	5.223	3.6613	458.569	450
28.89	5.23	3.8297	11220.1	500

Table A.21: Pause Time Variation Scenario For AntHocNet Routing Protocol

Throughput (kbps)	**Overhead**	**Packet Delivery Ratio**	**Average End to End Delay (ms)**	**Pause Time (s)**
45.82	46.721	23.4076	11412.5	50
32.5	63.767	21.0342	38646.8	100
47.02	99.568	32.6027	46465.2	150
39.61	52.759	23.4471	34900.4	200
41.8	59.791	20.3364	47899.1	250
29.61	47.367	15.4631	42252.1	300
37.07	104.958	27.4135	38743.9	350
43.17	52.523	21.6805	44950	400
50.57	36.721	20.8885	20329.5	450
55.93	85.257	29.6045	46673.7	500

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Publications

- Walaa shawar, Amal Al-Dweik, "A New Approach for QOS Based Ant Colony Optimization Routing Protocol In MANETs (QOS-Based ACO)", *4th Palestinian International Conference on Computer and Information Technology (PICCIT 2015), Palestine Polytechnic University* , 2015.

- Walaa shawar, Amal Al-Dweik, "A Survey: The Agent Based Routing Protocols In the Wireless Ad hoc Networks", *4th Palestinian International Conference on Computer and Information Technology (PICCIT 2015), Palestine Polytechnic University* , 2015.

Date: **December 9, 2015**

Dear **Walaa shawar, Amal Al-Dweik**

We are pleased to inform you that your paper

Paper ID: **150**

Paper Title: **A Survey: The Agent Based Routing Protocols In the Wireless Ad hoc Networks**

Authors: **Walaa shawar, Amal Al-Dweik**

Has been accepted for presentation at 4th Palestinian International Conference on Computer and Information Technology (PICCIT 2015) that will be organized by Palestine Polytechnic University on October 7-8, 2015. The decision was based on reviewers' evaluation reports.

This letter can be used for issuing Visas or Permissions to attend PICCIT2015.

The final electronic version of your paper must be submitted using the PICCIT OpenConf System at http://piccit.ppu.edu/ before September 10, 2015 in order to be presented and published in the proceedings of PICCIT2015. In preparing the final version of your paper, please refer to our web site for more information and instructions in preparing your final submission. Following this template is mandatory for publication.

Your final presentation should be emailed to piccit@ppu.edu before October 1st, 2015 using the template on the conference site.

The registration will be open on the conference days (On Desk).

Thank you for submitting a paper to PICCIT2015 and congratulations on its acceptance. We look forward to meeting you in Hebron, Palestine for a very rewarding and professionally stimulating conference.

Regards,

Dr. Radwan Tahboub,

radwant@ppu.edu

Date: **December 9, 2015**

Dear **Walaa Shawar**

We are pleased to inform you that your paper

Paper ID: **155**

Paper Title: **A New Approach for QOS Based Ant Colony Optimization Routing Protocol In MANETs (QOS-Based ACO)**

Authors: **Walaa shawar, Amal Al-Dweik**

Has been accepted for presentation at 4th Palestinian International Conference on Computer and Information Technology (PICCIT 2015) that will be organized by Palestine Polytechnic University on October 7-8, 2015. The decision was based on reviewers' evaluation reports.

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Regards,

Dr. Radwan Tahboub,

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A Survey: The Agent Based Routing Protocols In the Wireless Ad hoc Networks

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***Abstract*—Routing is a problem in the wireless ad hoc networks, many researchers tried to solve it because the usage of these networks in many applications is increasing within time. There are many routing protocols designed for the ad hoc wireless networks, but these protocols have some drawbacks that influence the network performance. To increase the performance of the ad hoc wireless networks, many modifications or new protocols have been proposed using the static agent, mobile agent or both types of agents in the network routing process. Researchers assert that the performance of the ad hoc networks is increased and the protocols that use the agents in its mechanism outperforms the traditional routing protocols. In this paper a number of agent based routing protocols used in the wireless ad hoc networks is surveyed.**

Keywords—Ad hoc wireless networks, agents, MANETS, routing protocols.

I. INTRODUCTION

The wireless ad hoc network is an infrastructure-less network, which consists of mobile nodes, each with a wireless interface to interact with each other. However, as there is no administrator in this kind of networks, the nodes behave as routers and take part of sending data packets from a source to a destination. Furthermore, as the nodes can move, the topology of the network is dynamic, which makes the routing process a problem that needs to be solved.

Mobile ad hoc networks (MANETs) are used in the military, commercial and homes networks applications [1]. There are many routing protocols used in MANETs, which have some drawbacks that influence the network performance, and can be categorized into two main kinds: the table driven and the demand driven. However, the table driven routing protocols such as the Destination Sequence Distance Vector routing protocol (DSDV), update the routing table of each node in the network periodically, so the routes to destinations are always available, and hence these protocols are suitable to be used in the real time applications. On the other hand, this kind of protocols increases the overhead in the network and is not scalable to large networks. In the demand routing protocols such as the Ad hoc On Demand Distance Vector routing protocol (AODV), the routing tables of the nodes don't need to be updated periodically with the network topology information. Instead, the nodes demand and invoke a route discovery for a path to the destination only when needed. So, there is no need for unnecessary routes exchanges between nodes, which provides less network overhead. On the other hand, these protocols produce a communication initial delay, and hence aren't suitable to be used within the real time applications [2].

To enhance the performance of the traditional routing protocols in MANETs, researchers tend to propose agent based solutions, and they assert that the performance of the ad hoc networks is increased when using these solutions.

Agents are used in many applications in the communication and networking fields, which includes security, enhancing the routing protocols in the wireless ad hoc networks and others. A software agent is a computational and autonomous entity, that can migrate, clone, learn and cooperate. It has two kinds: static, in which the agent doesn't move or migrate to another host, and mobile that can migrate, and needs a mobility framework from the system in order to do its tasks [3].

The rest of the paper is organized as follow: Section 2 presents the ad hoc agent based routing protocols. Section 3 presents a discussion, and finally, section 4 presents the conclusion and future work.

II. MOBILE AGENT BASED PROTOCOLS

Researchers used the mobile agents with the reactive, proactive and clustering protocols. However, they also use it to propose the ant colony and other protocols as presented in this section.

A. Agent Based Reactive Protocols

Bhati et al. in [4] proposed an agent based ad hoc on demand routing protocol (AB-AODV) for the mobile ad hoc networks, which is a protocol that uses mobile agents with a unique ID to make the hosts aware of the network information and to calculate the transmission capacity for each node, in order to choose the more efficient route from a source to a destination. Also, static agents are used to take the information from the mobile agents and update the information of the host it resides on. Depending on the transmission capacity value of each node of a path, the most efficient route to a destination is chosen.

Rajpoot et al. in [5] made an enhancement over the Dynamic Source Routing (DSR) protocol, which is one of the reactive mobile ad hoc network protocols, by combining it with the mobile agent. In their approach, two kinds of mobile agents are created: the Discovery/Reply and the maintenance agents. In the discovery/reply process, a discovery mobile agent is created in the source node and broadcasted to the neighbors in its transmission range to discover the path to the destination. In the maintenance process, when a node in the discovered route between the source and the destination is failed, a mobile agent is created by the first node that notice the failure to make the source aware about the failure in order to reinitiate a new route discovery process.

Jhuria et al. in [6] surveyed a research on the Dynamic Source Routing Protocol (DSR) indicates its advantages, disadvantages, and the improvements made to this protocol by the usage of the mobile agents.

B. *Ant Based Mobile Agent Protocols*

Marwaha et al in [7] proposed a protocol called ant-AODV, that combines the usage of the ant-like mobile agent and the AODV to overcome the shortcuts of the both. However, this protocol increases the node connectivity which reduces the route discovery amount and decreases the route discovery latency, end to end delay and the overall overhead. In the conventional ant like mobile agents, the routes are provided and updated depending on the mobile agents that visit the nodes in the network carrying the updating information. If a node wants to communicate with another node and doesn't have a fresh route to that node, it will wait with the data in its buffer till a mobile agent visits it carrying the route information. Ant like mobile agent doesn't provide route maintenance in a node breakage case.

In the AODV, if any node wants to communicate with another node, it must first discover a route to the destination which causes a large delay before the communication begins. In the Ant-AODV, the mobile agents which work independently, provide routes to the nodes and the nodes can change the route to a destination into a better (shorter) one due to the route update information carried by the agents all the time.

Kumar et al. in [8] produced a multi agent ant based routing protocol (MARA), which is a hybrid protocol that combines the AODV with the ant based protocols. It reduces the average end to end delay, the latency of the route discovery, the overload, and increases the nodes connectivity. The path from the source to the destination is chosen depending on the value of the pheromone.

Ducatelle et al. in [9] proposed a hybrid protocol called AntHocNet that combines the reactive and proactive techniques in the ad hoc wireless networks and uses the ant agent based approach. At the start of each communication session, the source node set up a route between the source and destination in a reactive way, and during this session the source uses the ant agents to search for a better alternative paths in a proactive way.

Lutimath et al. in [10] surveyed the use of the ant based mobile agents routing protocols used in the mobile ad hoc networks and made comparisons between them includes: the protocol type, year, number of paths to a single destination, the overhead and the latency resulted.

Kumar et al. in [11] proposed an efficient ant based routing protocol for MANETs. In their approach, they added a new factor called the orientation factor, for calculating the probability of choosing the shortest path from a source to a destination. The network throughput of the proposed approach is higher than that of the AODV protocol.

C. *Proactive Agent Based Routing Protocols*

Bandyopadhyay et al. in [12] produced a multi agent routing protocol for the mobile ad hoc networks (MARP), which is a proactive protocol that makes a reduction on the overhead and delay. It allows the calculation of some parameters and take it into consideration when deciding which route to take to the destination and that increases the efficiency of the network. However, these parameters are: The afinity, the recency and time to migrate.

Choudhury et al. in [13] proposed a multi agent protocol that makes the nodes aware of the network topology without consuming the network capacity (proactive protocol with less overhead). The network information is collected by using the mobile agents. Agents are traveling from node to node, meet other agents and interact with them to collect the information from other parts of the network. However, these information which are the stability, recency and afinity, are used to choose the best route. They also in their approach implemented the stigmergic communication.

D. Proposed Agent Based Routing Protocols

Bandyopadhyay et al. in [14] introduced a mobile agent based routing protocol to transfer messages between a source and a destination for the off line messaging in a highly dynamic large mobile ad hoc network. The proposed protocol decreases the traffic and allows the asynchronous communication (for example sending emails). Agents are used as messengers to deliver messages from sources to destinations. In their approach they used the Global Positioning System (GPS) to determine the neighboring nodes, and they used the concept of the physical and logical neighbors.

Zhou et al. in [15] proposed a new ad hoc routing protocol called Mobile Agent Routing protocol (MAR), which uses the mobile agents that can interact with each other indirectly by leaving information about the network in every node they visit and collect information from it. When a node has an event, it adds this event in its events table. Then it creates a mobile agent, which propagates the event through the network. However, the event could be any network information, for example a route information. Therefore, when a mobile agent arrives at a node, first it will update the routing table of this node with the new information it holds, after that the mobile agent will collects the information that does not has from the node's routing table. Then, it will record the node as a visited node and it will choose the unrecorded node to visit next to update the network information.

Migas et al. in [16] used static and mobile agents to determine the best route between a source and destination in the mobile ad hoc networks. The static agents can test the memory capacity, processing capabilities and other parameters to be used later by the mobile agent to choose the best route to a destination and periodically updates the mobile nodes about the best paths in the network. However, this protocol increases the network performance, reduces the delay and losses and provides reliable communication and scalability.

E. Mobile Agent Based Clustering Protocols

Sugar et al. in [17] used the mobile agent for clustering in the wireless ad hoc networks. Each cluster has a mobile agent called a clustering agent for taking membership decisions to clusters, decisions of splitting or decisions of merging clusters. The communication is done only between the neighboring agents to reduce the overhead on the network.

Bhaumik et al. in [18] proposed a cooperative routing protocol that uses the mobile agents for sending short messages and exchanging the network information in the ad hoc networks. When multiple sources want to send messages to the same destination, they create mobile agents which will then cooperate with each other on certain nodes called Rendezvous point and wait at these nodes an amount of time called Rendezvous period, then will merge the messages they hold with one agent that will migrate to that destination. However, the introduced protocol reduces the traffic and the overhead in the network at a high load.

F. Mobile Agent Based Congestion Control

Shekhar et al. in [19] proposed a routing protocol for the congestion control in the mobile ad hoc networks, which is called a Mobile Agent Based Framework For Routing And Congestion Control (MAFRC). Their protocol includes an agent based congestion detection, congestion awareness and congestion control.

Das et al. in [20] made a comparison between the AODV and an agent congestion aware routing (MACAR) protocols. However, they concluded that the packet loss in the AODV is higher than that of MACAR, and the throughput in the AODV is less than that of MACAR. However, the proposed routing protocol MACAR, which can be used with any on demand routing protocol, is a congestion awareness and control protocol that provides a ready routes to a destination.

III. DISCUSSION

Most of the protocols of the previous studies are simulated by using the NS-2 simulator. The simulations results show the advantages of each one of the protocols, and present the weaknesses of each one. Most of these protocols don't behave the same in all the simulated scenarios. For example, in the low mobility scenarios, protocols behave in different way than that in the high mobility ones. Also for example, in the large network scenarios, the protocols perform differ from that of the small networks scenarios. Table 1 summarizes the described agent based protocols. Although, there is some problems of the proposed protocols, it is still better than the conventional ones.

TABLE 1. ADVANTAGES AND DISADVANTAGES OF AGENT BASED ROUTING PROTOCOLS

Routing Protocol	Year	Delay	Overhead and Traffic	Throughput, Packet Delivery ratio, Losses	Simulation
Behati et al.(AB-ODV)	2011	Lower average end to end delay	Lower overhead		No simulation
Raipoot et al. (Agent based DSR)	2013	Lower average end to end delay		Lower packet delivery ratio, higher throughput	
Marwaha et al.(Ant-AODV)	2002	1-Lower route discovery latency 2-Lower average end to end delay	Higher overhead	Higher packet delivery ratio	
Kumar et al. (MARA)	2007	1-Lower route discovery latency 2-Lower average end to end delay	Lower overhead		High delay in low mobility
Ducatelle et al. (AntHocNet)	2005	Lower average end to end delay	Lower overhead	Higher packet delivery ratio	Overhead is high in some scenarios
Choudhury et al. (MARP)	2004	Lower average end to end delay	Lower overhead		Congestion is high in some scenarios
Bandyo-padhyay et al.	1999	Lower average end to end delay		Traffic and number of visited nodes are lower	
Zhou et al. (MAR)	2004			Packet delivery ratio is same as traditional protocols	
Migas et al.	2003			Packet losses is lower	No simulation
Sugar et al.	2001		Lower overhead		No simulation
Bhaumik et al.	2005	Lower average end to end delay	Lower overhead Lower traffic		High delay at high mobility
Shekhar et al. (MAFRC)	2006	Lower average end to end delay	Lower overhead	Higher throughput for each separate module	The three modules together aren’t simulated
Das et al. (MACAR)	2012			Packet losses is lower	
Kumar et al.	2015			Higher throughput	One simulated scenario

IV. CONCLUSION

There is a number of traditional routing protocols used in the wireless mobile ad hoc networks. They are mainly divided into two kinds: the proactive (table driven), and the reactive (on demand). These protocols have limitations when considering for example: the latency, overhead and throughput in the network. To overcome the limitations, a combination between these protocols is sufficient, and this combination is easy to be done through the usage of the software agents.

Using the agents in the wireless ad hoc routing protocols enhances the performance of these networks. In general, it decreases the average end to end delay, network overhead, average number of visited nodes and losses. Also, it increases the packet delivery ratio and throughput.

Most of the previous works use the mobile and static agents in the routing protocols. The mobile agents visit all the network nodes, collect and provide some of the network information which depend on the used protocol such as: the nodes neighbors, nodes GPS values, transmission capacity, time to arrive, pheromone value, recency value and others. The static agents reside on each node, wait for the mobile agents to take the collected information, update the nodes routing tables and choose the most efficient route as the path to the desired destination. The details and the combining way is differ from one proposed protocol to another.

In every proposed protocol, there is still some drawbacks appear in many ways. Some protocols decreases the end to end delay but the overhead is still large, some others decrease the end to end delay and overhead but don't take the number of nodes visited into consideration. Others increase the packet delivery ratio, throughput, and decrease the delay and overhead, but don't take the network congestion into consideration. In the most of the previous works the communication is considered to be reliable, without any kind of losses but in real life this can't be happen and I think that this consideration is a main weak in these protocols. However, as most of these protocols provide the same route for the agents and messages to take, a congestion may happen in the network, which in turn makes losses in the data or agents, which hence increases the delay and overhead.

Some of the research studies focused on the congestion detection and congestion control separately from the other techniques used for enhancing the routing protocols in the wireless ad hoc networks. So, it will be a good idea to combine the works of the congestion control with other works to get a better and a complete routing protocol.

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A New Approach for QOS Based Ant Colony Optimization Routing Protocol In MANETs (QOS-Based ACO)

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***Abstract*—As the world tends to increase the use of the mobile ad hoc wireless networks (MANETs), a very important challenging issue is to enhance the performance of the used routing protocols. The traditional used protocols have some drawbacks on the network performance, and the proposed ones still also have drawbacks although it is still better than the traditional ones. According to that, a research in this field is continuing to attract the researchers to enhance or propose a protocols with better network performance.**

The use of the mobile agent is one of the promising approaches for enhancing the performance of the routing protocols. However, when it's used along with the ant colony algorithm in the ad hoc wireless networks, it results in a good enhancement of the network performance most of the time.

This paper introduces a new MANETs routing protocol based on the ant colony optimization algorithm, by taking the quality of service parameters (QOS) in the network into consideration. We called the new protocol a QOS Based Ant Colony Optimization Routing Protocol in MANETs (QOS-Based ACO).

***Keywords*—Ad hoc wireless networks, agents, MANETS, ant colony optimaizaion.**

I. INTRODUCTION

The wireless mobile ad hoc network is an infrastructure-less network, which consists of mobile nodes that can interact with each other by sending the data to the neighboring nodes along a certain path till it reach the destination. So, the nodes behave as routers between the source and the destination nodes. The topology of the network is dynamic, and that may lead to data loss. Data transmission in MANETs needs routing protocols, so data can be transmitted correctly to the specified destination. However, routing protocols used in MANETs are divided in to: proactive, reactive, hybrid and location aware routing protocols [1, 2].

In the proactive routing protocols, each node has a routing table containing a route to each other node in the network, which is updated periodically. However, the proactive protocols include: the Destination Sequenced Distance Vector (DSDV) protocol, the Topology Dissemination Based on Reverse Path Forwarding (TBRPF) protocol and the Optimized Link State Routing (OLSR) protocol [2]. This kind of protocols are not scalable for a large number of nodes, it consumes the bandwidth for the periodic updates and that is results in a large overhead. On the other hand, the transmission of the data can be started by the source node without an initial delay and hence can be used in the real time applications because the routes to the destinations are always available [3][4].

In the reactive routing protocols, the routes between any two nodes in the network is found only when it's needed. Furthermore, it consists of two mechanisms: the route discovery, and the route maintenance. The reactive protocols include: the Ad hoc On Demand Distance Vector (AODV) protocol, the Dynamic Source Routing (DSR) protocol, the Associatively Based Routing (ABR) protocol, the Signal Stability Routing (SSR) protocol and the Temporally Ordered Routing Algorithm (TORA) protocol [2]. This kind of protocols are scalable for a large number of nodes, and it results in a less overhead and so don't consume the bandwidth of the network. On the other hand, there is an initial delay before transmitting the data by the source node due to the route discovery process, so it's not suitable for the real time applications [3][4].

The hybrid routing protocols uses both the proactive and reactive mechanisms in the network.

For the nodes which are close to each other, the proactive techniques are used. On the other hand, when any node want to send data to a far node, it uses the reactive techniques to discover a route and send the data. However, hybrid protocols include: the Zone Routing Protocol (ZRP), Zone-based Hierarchal Link State (ZHLS) protocol, Scalable Location Update Routing Protocol (SLURP), Distributed Spanning Trees Based Routing Protocol (DST) and Distributed Dynamic Routing (DDR) protocol [5].

In the location aware protocols, the geographical position of each node is determined in addition to the used mechanism for routing by using for example the Global Positioning System (GPS). However, when any node want to send packets to any other node it uses the position of the existing nodes to forward the packets to the neighboring one. In this kind of protocols, the routing information do not needed to be stored [2].

The mobile agent is used by many researchers for increasing the ad hoc networks performance and solving the main problems of using the traditional routing protocols.

Software agents are autonomous software quantities with two kinds: static and mobile, which have the following characteristics: can migrate, clone, learn, interact with each other and can adapt with the environment [6][7].

One of the uses of the software agents in MANETs routing is using the idea of the ant colony optimization. It is based on the behavior of the ants when searching for food, as the ants finally take the shortest path from the nest to the food by following the pheromone that the ants deposit. The pheromone concentration is decreased within time.

The rest of this paper is presented as follow, in the next section, the related work is introduced. In section three, a brief description of the ant colony optimization is presented. In section four, the description of the proposed routing protocol is presented. Section five shows the pseudo code of the proposed methodology. A major differences between the presented approach and the Deepalakshmi et al. approach are presented in section six. Section seven presents the conclusion and the future work.

II. RELATED WORK

Many researchers proposed ant based routing protocols, and the following are some of them:

Marwaha et al in [8] proposed a protocol called ant-AODV, that combines the usage of the ant-like mobile agent and the AODV to overcome the shortcuts of the both. However, this protocol increases the node connectivity which reduces the route discovery amount and decreases the route discovery latency, end to end delay and the overall overhead.

Kumar et al. in [9] produced a multi agent ant based routing protocol (MARA), which is a hybrid protocol that combines the AODV with the ant based protocols. It reduced the average end to end delay, the latency of the route discovery, the overload, and increases the nodes connectivity. The path from the source to the destination is chosen depending on the value of the pheromone.

Ducatelle et al. in [10] proposed a hybrid protocol called AntHocNet that combines the reactive and proactive techniques in the ad hoc wireless networks and uses the ant agent based approach. At the start of each communication session, the source node set up a route between the source and destination in a reactive way, and during this session the source uses the ant agents to search for a better alternative paths in a proactive way.

Deepalakshmi et al. in [11] proposed an on demand routing protocol called Ant Routing For Mobile Ad Hoc Networks (ARMAN), that based on the ant colony optimization algorithm, and depends on QOS in MANETs. In their approach, they depends on the links bandwidth and delay as the QOS, and used it in the probability calculation of choosing the next hop while routing in addition to the pheromone value of the link and the number of hops between the node and the destination. They compared their approach with the AODV routing protocol, and concluded that their approach outperforms the AODV protocol.

Hussein et al. in [12] proposed a new routing protocol based on the ant colony optimization algorithm called Ant Routing Algorithm for Mobile Ad-hoc networks (ARAMA), in which they used forward and backward ants to collect and modify the network information. Choosing the next hop for routing based on a probability calculation that depends in addition to the pheromone value on the number of hops to destination, and the battery ratio of each node. The proposed protocol obtains fair energy distribution.

Hussein et al. in [13] enhanced the previous proposed protocol by adding a negative backward ant to be sent if the sent forward ant goes through a loop or if the time to live threshold is reached. Furthermore, they added a destination trail ant to be sent by the destination node if the network become larger to randomly moves in the network, collects and modifies the network information.

Sardar et al. in [14] Proposed an ant based routing protocol with the QOS parameters dependency for MANETs to choose a route from a source to a destination that accomplish a best quality of service. The QOS parameters that they used are: the delay, bandwidth, available buffer and the link stability.

Kumar et al. in [15] proposed an efficient ant based routing protocol for MANETs. In their approach, they added a new factor called the orientation factor, for calculating the probability of choosing the shortest path from a source to a destination. The network throughput of the proposed approach is higher than that of the AODV protocol.

III. ANT COLONY OPTIMIZATION

Ant Colony Optimization algorithm describes the behavior of the ants, when the ants search for food, it will take a random paths to go to their destination initially. In their journey to find the food and in their way back to their nest, they will lay a chemical material on air. Other ants that sense this chemical material which is called pheromone, will follow it in their way back to the nest. So, most of the ants will use the same path to find the food and to return back within time. However, the pheromone concentration will decrease within time on the path, so when there is several paths to the food, the ants will finally follow the shortest path because the pheromone concentration will be higher than in the longer one.

By following the behavior of the ants for searching on food, researchers follow this behavior for finding the best path between a source and destination in MANETs.

The wireless ad hoc network can be represented as a graph G= (V, E) with |V| nodes, and E links between the nodes that are in the transmission range of each other. However, the ant colony optimization algorithm will be used to find the best path between a source and a destination on the graph.

In the ant colony optimization algorithm, ants travel in the network nodes to collect information about the network, modify the network information on the nodes and later to use this information, which is called pheromone, for deciding the best path between a source and a destination.

Depending on the pheromone value in any node, a probability is calculated to be used to decide which is the next node to go to for routing.

$$p_{??} = ?\begin{cases} \frac{?_{??}}{\Sigma_{?\in ?}\ ?_{??}} & \text{if } j \in Ni \\ 0 & \text{if } j \notin Ni \end{cases} \quad I \in [1,N] \quad \text{--- (1).}$$

where Ni are the set of neighbor nodes of node i.

When ants choose a specific route to go to the destination through, it increase the pheromone value on the routes nodes, which is changed in the form of $\partial_{??} = \partial_{??} + \Delta\partial$, with $\Delta\partial$ amount. --- (2).

With time, the pheromone concentration decreases within a specific amount:

$\partial_{??}(t + \tau) = (1 - q).\partial_{??}(t), \quad q \in (0,1]$ --- (3).

The software agents is used as ants in this algorithm that will collect the network information to choose a best route to the destination, and increasing the pheromone value of the chosen routes' nodes. However, the pheromone of any visited node will be increased to let other agents and data follow the same visited path, and with time the pheromone will be decreased preventing the visited nodes from reaching the optimal state [9].

IV. THE QOS-BASED ACO ALGORITHM DESCRIPTION

To understand the proposed algorithm, the following is a description of the algorithm and the assumptions.

Every node i in the wireless ad hoc network will broadcast every second a hello message, which contains the <source address> to the nodes in its transmission range j, and an acknowledgment which contains <address j, address i> will be sent by the neighbor to the initiator of the hello message. Then, the source node will add any new neighbor to the neighbor table with an initial probability.

Every node in the network could be a source, intermediate or a destination node, and each one has a routing table that contains the neighbors, a probability for each neighbor for going through a possible destination. Furthermore, each node will have two counters that counts the number of packets received and delivered from/for a certain neighbor in order to calculate the packet delivery ratio between any two neighbor nodes.

The routing table of a node will be filled initially by the neighbors of this node and an initial probability for going through each neighbor. Then, every node in the network will broadcast a forward ant for a possible destination to collect the network information and modify the routing tables. However, the probability of all the neighbors initially is the same and the sum of all the neighbors probabilities must always equal to one. So, when the probability of choosing a certain neighbor is increased, the probability of choosing the rest must decrease.

$\sum_{?\in ?,?} p_{??} = 1, \; j = 1, \quad ,N$ --- (4).

Also, when any source node want to communicate with a specific destination, it will generate a forward ant to the destination. If there is a route to the destination, the ant will follow the route via the nodes that have the highest probability values to the destination, and if there is no route to the destination, the source node will broadcast the forward ant towered all of its neighbors to find the destination. However, this ant holds <the source address, the destination address, the ids of the intermediate nodes>.

When the ants or packets arrive at an intermediate node, it will forwards it to the next node depending on the probability that is calculated before and exists in the routing table. The forward ants arrive at the intermediate nodes will collect the visited nodes ids from each visited node to the destination.

Each intermediate node will check if the destination is one of its neighbors, and if yes it will forward the ant toward the destination, and if not it will forward the ant to the neighbor with the highest probability. However, and while searching for the destination, if a cycle has been detected by checking if the id of the visited node is already existing in the forward ant stack, the forward ant will be killed.

At the destination node and when the forward ant arrives, the destination will take the ids of the intermediate nodes that has been visited by the forward ant and the source address. Then, the forward ant will be killed and a backward ant will be generated within the same sequence number as the forward ant and forwarded to the neighbor of the destination node, taking the reverse path from the destination to the source that the forward ant was taken to reach the destination.

The network information that will affect the probability value of a node are: The bandwidth, number of hops between the node and the specified destination, the processing delay, the length of the node queue, the nodes battery level and the packet delivery ratio between two nodes in addition to the pheromone value of a node.

The backward ant that contains <source address, destination address, nodes ids, processing delay, queue length, battery level, number of hops, bandwidth, received packets, pheromone value >, will modify the network information in each node it visits, and the pheromone value about each neighbor will be modified. Then, each node will recalculate the probability for going throw a certain path depending on this information. However, it will collect the bandwidth from the outgoing link, the processing delay, the queue length, the battery level and the number of packets received from the neighbor node in the forward direction from the last data delivery process if any.

When the backward ant reaches its destination, which is the source node, it will be killed after modifying the network information about the path. If the backward ant is not received by the source node within a certain time, it will reinitiate another forward ant with a new sequence number, and if the backward ant is received within the specified time, the source node will start sending the data to the destination.

The probability of choosing a neighbor must increase when the number of hops between the node and the specified destination and the processing time of the next node is decreased, and when the bandwidth, the battery level, the packet delivery ratio, the queue length and the pheromone of a node is increased.

The probability of choosing a neighbor to be visited by the ant or to forward the data through it to the destination could be calculated as follow:

$$X_{?,?} = \frac{??^{??} \times ??^{??} \times ??\ ^{??} \times ??^{??} \times ??^{??}}{??^{??} \times ??^{??}} \quad \text{--- (5).}$$

$$?_{?,?} = \frac{?_{?,?}}{\sum_{?\in ?} ?^{?}_{?,?}} \quad \text{--- (6).}$$

Where $P_{?,?}$ is the probability of going from node i to node j, R is the packet delivery ratio of node j from transmitting packets from node i in previous transmissions, W is the bandwidth of the link connects node i to node j, Q is the queue length of node j and B is the battery level of node j. However, a,a1,b,b1,c,c1,d,d1,e,e1,h,h1,i and i1 are all factors that control the weight of each parameter. $\partial$is the pheromone value of the neighbor node j.

The pheromone values of all neighbors initially are the same and having a constant value. When the forward ant visits a node, the pheromone value of this node will be increased by an amount $\Delta\partial$, which could be constant following equation (2).

And within time, the pheromone concentration will be decreased also by a certain amount, depending on the evaporation function following equation (3).

If a failure happens on one of the links, the node will search for another valid link to the destination, and if there is no valid link to the destination, a packet will be sent from the node to the source node to inform it about the failure, and the source node will then reinitiates a route discovery.

In order to avoid the overhead that could be caused by the information held by the backward ant, a part of the calculations could be done before leaving the node. So, the backward ant hold the result of these calculations instead of holding each single parameter, and by that less information will be held by the ant and less overhead will be caused.

The performance of this protocol will be measured by measuring the end to end packet delivery ratio, delay and throughput. Furthermore, it will be compared to Deepalakshmi et al. approach in [11, 16].

V. QOS-BASED ACO ALGORITHM’S PSEUDO CODE

The pseudo code of the algorithm can be stated as follows:

A. WHEN RECEIVING A DATA PACKET

- ✓ for every mobile node{
- ✓ search for route (next hop)
- ✓ if (route is available)
- ✓ forward the packet to next hop;
- ✓ if (route is not available and node == source)
- ✓ insert data packet in queue;
- ✓ find route via broadcasting a forward ant;
- ✓ if (route is available and node== source)
- ✓ forward the forward ant via the route for updating the network information;
- ✓ if route is not available and node == intermediate)
- ✓ drop(pkt);
- ✓ prepare and forward a route error massage ;}

B. WHEN RECEIVING A FORWARD ANT (ROUTE REQUEST)

- ✓ for every mobile node{
- ✓ if(node == destination)
- ✓ prepare a backward ant (route reply);
- ✓ forward the backward ant to the previous node;
- ✓ if(node == intermediate)
- ✓ if (node is already in the stack)
- ✓ drop (forward ant);
- ✓ if (node is not in the stack)
- ✓ store the node's ID in the stack;}

C. RECEIVING THE BACKWARD ANT (ROUTE REPLY)

- ✓ for every mobile node {
- ✓ if (node == source of forward ant)
- ✓ update the node with the network information;
- ✓ forward packets via the found best route;
- ✓ if (node == intermediate)
- ✓ update the node with the network information;
- ✓ find next hop from stack;
- ✓ forward the backward ant to next hop;}

D. RECEIVING A HELLO MESSAGE

- ✓ for every mobile node {
- ✓ the source of the message is called a neighbor
- ✓ update table with that neighbor;}

E. DETECTING A MOVEMENT OF A NEIGHBOR

- ✓ for every mobile node {
- ✓ remove the neighbor from table;}

VI. A COMPARISON BETWEEN QOS BASED ACO ALGORITHM AND DEEPALAKSHMI et al. APPROACHES

Deepalakshmi et al. in [11, 16] is differ from the proposed approach in that the network information is held by the forward ant, which is forwarded only on demand, and not by the backward ant. Furthermore, the forward ant contains: "<Source Address, Destination Address, Hop Count=1, Starting Time = Current Time, Bandwidth=available capacity of outgoing link, A stack of visited nodes> ".

The information held by the backward ant is also differ from the proposed approach which contains: "<Destination Address, Original Source address, Hop Count=Received Hop Count, Request Arrival Time, Reply Starting Time = Current Time, A stack of nodes to be visited = Received stack of visited nodes>". The hello message format also differ which contains the <source address, starting time> and the replying acknowledgment contains < source address, destination address, receiving time>.

Each node in their approach has a three tables: neighbor, preference and routing tables. The neighbor table contains each neighbor with the pheromone value and the bandwidth of the outgoing link. The preference table contains the neighbors for going to each destinations with the goodness of each neighbor as a next hop. The routing table contains each desired destination with the best next hop to go through.

In their approach, if there is a route to destination, the data will be sent through that route without sending a forward ant to collect the network information and update the probability calculation of that path.

The information collected by their approach depends on the path information from the source or the intermediate node to the destination, but the information collected by the proposed approach depends on the local information for each node.

In their approach, the probability of choosing a neighbor node j from node i for a certain destination is calculated as follow:

$$?_{???} = \frac{??_{??}^{?}\ ??_{???}^{?}\ ??_{???}^{?}\ ?B_{???}^{?}}{\sum_{?\in ?_?} [?_{??}]^{?} [?_{???}]^{?} [?_{???}]^{?} [B_{???}]^{?}} \quad \text{--- (7).}$$

$$?_{???} = \frac{?}{????? (????(??))} \quad \text{--- (8).}$$

$$?_{???} = \frac{?}{????????(????(??))} \quad \text{--- (9).}$$

$$B_{???} = ?????\ ???h????h(?, ?)? \quad \text{--- (10).}$$

$$????????h(?, ?)? = \sum_{?\in ?(?,?)} ?????(?) + \sum_{?\in ?(?,?)} ????(?) \quad \text{---(11).}$$

$$?????\ ???h????h(?, ?)? = \min_{?\in ?(??)}\{?????\ ???h(?)\} \quad \text{--- (12).}$$

$$h??????????h(?, ?)? = ???\ ??????????\ ??\ ?h?\ ???h \quad \text{--- (13).}$$

$$?_{??} = ? \begin{matrix} (1 - ?)?_{??} ??(1 - ?)?_{??} > 0.1 \\ 1\ ??(1 - ?)?_{??} \geq 1 \\ 0.1 \quad ??h???\ ??? \end{matrix} \quad \text{--- (14).}$$

Where e is a link between two nodes, n is a node, delay(n) is the processing delay of the node n, $?_{??}$ is the pheromone value and p is a factor.

VII. CONCLUSION AND FUTURE WORK

In this paper, a new methodology of an ant based colony algorithm with the QOS parameters taken into consideration is presented in details. The major differences between the new approach and Deepalakshmi et al. approach is also presented. As a future work, the probability equation of choosing the next hop neighbor of a route will be modified by determining the most demonstrating parameters of the equation on the network performance, and then determine the factors of each one. Hence, the most demonstrating parameter will have the highest factor value in order to make a better enhancement on the network performance.

Also, the new approach and Deepalakshmi et al. approach will be simulated using OMNeT++ simulator. The performance of the network will be measured within each approach, and a comparison between the two approaches will be made.

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