CROSS-LAYER ANALYSIS OF ROUTE DISCOVERY PROCESS IN SATURATED AD HOC NETWORK

A Thesis by

Hardik Dinendra Shah

Bachelor of Engineering, Vir Narmad South Gujarat University, 2005

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Electrical Engineering.

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Ravi Pendse, Committee Chair

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Janet Twomey, Committee Member

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John Watkins, Committee Member

DEDICATION

To my Parents, Grand Father and my friends

ACKNOWLEDGMENTS

At the outset, I would like to thank my parents and family for their unconditional love and belief in me, which helped me reach this point in my career. I would also express my sincere gratitude to my advisor Dr. Ravi Pendse for his timely advice, motivation and support, which were much needed to produce this work. Next, I thank my committee members Dr. Janet Twomey and Dr. John Watkins for taking time out of their busy schedules and providing valuable inputs in producing a quality research work. I also thank Mr. Murali Krishna Kadiyala, because of the exceptional work he produced in the field motivated me do research in this field. Last, but not least, I would like to thank my friends for being there whenever I needed them.

ABSTRACT

This thesis presents a detailed analysis of the route discovery process in saturated ad hoc networks. The causes and consequences of this process are described in terms of medium access control (MAC) delays and routing delays. The analysis shows that an increase in MAC layer delays can increase the time spent in the route discovery process (route discovery time), which in-turn increases the packet service-time and the packet end-to-end delay. The simulations performed in the network simulator-2 (ns-2) support the theoretical analysis.

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LIST OF ABBREVATIONS

MAC	Medium Access Control
DCF	Distributed Co ordination Function
RTS	Request To Send
DSR	Dynamic Source Routing
CTS	Clear To Send
AODV	Ad hoc On Demand Distance Vector
MANET	Mobile Ad Hoc Network
RREQ	Route Request
RREP	Route Reply
QOS	Quality of Service
DIFS	Distributes Inter-Frame Space
SIFS	Short Inter-Frame Space
CT	Cross Transmission
CBR	Constant Bit Rate
DSSS	Direct Sequence Spread Spectrum
SID	Sample ID for reading

LIST OF ABBREVATIONS (Cont.)

T_CT	Time Spent in Cross Transmission
T_RTS	Transmission Delay for RTS
T_RD	Time Spent in Route Discovery
T_Total	Total Service-time for Packet
BO	Time Spent in Back-off
CT	Time Spent in Cross-transmission
IEEE	Institute of Electrical and Electronics Engineering

CHAPTER 1

INTRODUCTION

Route discovery process is a mechanism used by the nodes in the ad hoc networks to discover path to a specific destination. In this process, the source node sends a broadcast Route Request (RREQ) packet which is received by all nodes in the transmission range. The receiving node responds to the RREQ with a route reply if it has route to the destination. If the node does not know the path to the destination, it floods the RREQ packets. Finally, when the source has the route to the destination the data transmissions are initiated. This entire process increases the service-time of the packets subsequently forwarded by the source node of the route discovery process. Therefore, it is very important to study the causes of the route discovery process along with its consequences.

This thesis analyzes the causes and consequences of the route discovery process in terms of medium access control (MAC) delays and routing delays. The impact of medium access delays on the route discovery process is presented. Simulation results indicate that the medium access layer has an affect on the route discovery process. An increase in MAC delays increases the route discovery time and subsequently the packet service time.

The thesis is organized as follows. Chapter II discusses related work, Chapter III discusses the analytical model, Chapter IV discusses simulations and their results, and Chapter V discusses the conclusion.

CHAPTER 2

LITERATURE REVIEW

2.1 Related Work

This section presents related work associated with medium access control (MAC) and the routing mechanism in ad hoc networks, along with the MAC packet service-time analysis. Kadiyala and Pendse [1] modeled the route discovery process and its impact on packet end-to-end delay in wireless ad hoc network. The authors analyzed the effect of medium access control (MAC) and the route discovery process on packet end-to-end delay. The analysis shows that the medium access control (MAC) layer influences the route discovery process in ad hoc networks, which in turn affects the end-to-end delay.

Kadiyala [2] et al. analyzed the impact of medium access delays on packet service-time in stationary ad hoc networks. The effect of collisions and cross-transmissions on medium access delays was quantitatively discussed and was extended to present their impact on packet service-time.

Seangul and Keavets [3] designed the routing protocol called bypass routing to restrict broadcasts generated by AODV protocol. In this protocol, the authors proposed to store two routes in cache, so that if the first route is not available, then the backup route can be used. If both routes are not available, then it initiates a route request broadcast, which asks the directly connected neighbor for the route to the destination. This protocol restricts the route discovery broadcast to within a single hop, reducing the time spent in route discovery.

Tran and Raghavendra [4] designed the routing protocol called Congestion Adaptive Routing Protocol (CRP) to minimize packet loss caused by congestion. In this research, the authors proposed that the congested node informs its previous hop node to forward traffic on, the alternate path, which is already available. The previous node sends traffic to both the next hop in such a way that it reduces the congestion impact on the bottleneck node.

Wu and Harms [5] address the routing issues in an ad hoc network by devising the location based proactive flow handoff method. The authors proposed the routing protocol in which route failure is predicted in advance through the link lifetime mechanism. To find the new route in advance, it uses location information to get the route for the destination, which reduces route query flooding and maintains the end-to-end route once flow is established.

Tipper [6] et al. devises the performance modeling technique for mobile ad hoc networks. The authors designed the model for mobility of nodes with an adjacent metric and queuing model, using fluid-flow based differential equations which are solved using numerical methods.

Bianchi [7] modeled the throughput performance of the Institute of Electrical and Electronics Engineering (IEEE) 802.11 Distributed Coordination Function (DCF) with the assumption of a finite number of nodes and an idle channel condition in the ad hoc network. The author has used two dimensional Markov Chain Processes to design the model. The proposed analysis is applied to both DCF methods: basic access and RTS/CTS mechanism.

Kadiyala and Pendse [8] analyzed the two-dimensional Markov Chain proposed to reduce the complexity of the Markov chain.

Abdrabou and Zhuang [9] proposed that packet service-time memory is less in single hop ad hoc networks. The authors observed that the packet transmission rate follows the poison distribution process, while packet service-time follows a geometric distribution.

S.G Sitharaman [10] presented the idea that the presence of hidden node packet service-time follows an exponential pattern at MAC queues. An exponential pattern was observed for distribution of inter arrival time at the next-hop nodes. Wu and Sakurai [11] modeled access-delay in DCF networks with numerical transform inversion. The simulation results and the numerical methods closely match.

Tickoo and Sikdar [12] modeled the queuing delay at the node in IEEE 802.11 networks. The authors modeled service time, which includes the queuing delay and the channel access delay. The model can be used to provide a probabilistic quality of service for a number of nodes to satisfy the given delay constrain. The authors [13] improved the previous model, which accounts for the effect of the finite load on the collision rates and the queue utilization and provides the more accurate model for the service time distribution. The model accounts for the collision avoidance and exponential back off mechanism of IEEE 802.11, and the delays in the channel access occur due to other nodes' transmission and collisions.

Tickoo and Sikdar [14] developed the analytical model for packet inter arrival time in 802.11 MAC. Inter arrival time in 802.11 MAC is characterized by multimodal distribution. It is proven that the traffic pattern on the individual node is the same as on the wired network, but aggregate traffic has a different pattern, which is modeled with multimodal distribution.

The traditional ad hoc routing protocol is unidirectional, as the source is only responsible for route discovery. R. Bai and M. Singhal [15] proposed a bidirectional route discovery, where the destination also actively participates in the route discovery process along with the source node, which in turn reduces the control overhead by 50% less than the unidirectional routing protocol.

J. Abdulai [16] et al. proposed a probabilistic broadcast of route discovery messages. In this probabilistic method, the intermediate node re-broadcasts the RREQ packet with probability less than 1 to reduce broadcast storm caused by the blind flooding of the RREQ packets in traditional on-demand routing protocol. That results in reduction of overhead such as contention, collision and broadcast storm.

J. Gomez [17] et al. suggested the neighbor route discovery mechanism to reduce the traditional blind flooding. In this method, the source node does route discovery only in the limited area. The source nodes not only try to find the destination node, but also look for the past neighbors of the destination node, which reduces the overhead caused by blind flooding.

S. Moh [18] observed that the throughput of the networks is increased by 70% when the route discovery is done using QOS aware routing. In this process, the route is selected based on the highest link quality by comparing the signal to noise ratio among multiple received RREQ packets. The routing updates include the traditional metric and also the SNR of the path.

Y. Hu [19] et al. proposed the improvement of the route discovery process by including the second nodes information in the RREQ packet along with the source nodes information. The intermediate nodes update their routing table for both the source and the second node, which reduces the end to end delay and routing load as compared to the traditional AODV protocol.

2.2 DCF, AODV and DSR protocols

This section discusses the IEEE 802.11 Distributed Coordinate Function (DCF) MAC protocol, Ad-hoc On-demand Distance Vector (AODV) routing protocol and Dynamic Source Routing (DSR) protocol as follows.

The Distributed Coordination Function (DCF) is the commonly used protocol standard while a node is operating in the wireless medium. This protocol defines the rules to be followed when communicating in the wireless scenario. It implements the Carrier sense multiple access / collision avoidance (CSMA/CA) technique. In this technique, the node has to make sure the medium is idle before it sends the packet. If the medium is not idle, the node has to backoff for a random period based on the binary back off mechanism. If two nodes transmit data at the same time, then it would result in a collision, and the transmitting nodes will backoff randomly, depending on the backoff mechanism. There are 2 access mechanisms in IEEE 802.11 DCF protocol: the basic access mechanism and the RTS/CTS mechanism. In the basic access mechanism, the transmitting node will send the data directly without any prior handshake signal, so, the disadvantage of this mechanism is that if the data collides with the transmitting node, it has to retransmit the entire DATA packet, which is not efficient. In the RTS/CTS mechanism the transmitting node and receiving node will exchange smaller size packets like the RTS and CTS before the DATA packet is transmitted. Finally, the transmission is concluded when the transmitting node receives the ACK packet.

The Ad-hoc On-demand Distance Vector (AODV) is a routing protocol for the ad hoc networks. The AODV finds a path to the destination only if the node has a packet to deliver for an unknown destination, hence AODV belongs to the on demand routing protocol category. The destination sequence numbers are deciding factor in knowing the freshness of the route. The AODV offers fast network congestion with lesser processing and network overhead. It also determines unicast routes to destinations within the ad hoc network. On each node, the AODV maintains a routing table for each active destination, which contains six entries: destination, next-hop, Destination Sequence Number, Route Timeout, List of Neighbors who need me as next hop to destination, and hop Count.

AODV uses the request-response mechanism to establish the route to the destination. Each RREQ contains a broadcast-id, a source, a destination, a source-sequence-no, a destination-sequence-no, and a hop count (incremented as the RREQ is propagated). The node sends out the broadcast RREQ packet for establishing a path to the destination, and receiving the neighbor rebroadcast RREQ if the destination is unknown to it. Each intermediate node stores reverse-route to the requesting node, which is used to forward the route reply to the route requesting node. The RREQ packet is rebroadcasted until it reaches to a node which has a valid route with a higher sequence number then one presented in the RREQ packet. If the node receives the same route request, then it just discards it.

As the RREP propagates back to the source, the nodes add that route in the routing table. After adding the route to the destination, the nodes can forward the packet to the destination through the corresponding next hop. If the latter the source node receives the RREP message with the higher sequence number or lesser hop count, then it is considered to be the better route and stores it in the routing table, which can be used for further data transmission to the destination. The node keeps the route in the routing table as long as it is active. A route is considered active as if there are packets to send for the corresponding destination. Once the source stops sending data packets, after a certain time, it removes it from the routing table.

Dynamic Source Routing (DSR) is another on-demand routing for ad hoc networks. In this protocol, the route through which the packet will traverse from the source to the destination is included with the packet. Therefore, this protocol does not depend on the intermediate node's routing table.

Source nodes use the route discovery process to gather all the intermediate node addresses and cache it. Thus, every packet sent from the source includes the address of each device through which it will traverse to reach the destination. In this process, the routing overhead is increased when the path is too long or when the address likes IPV6.

Nodes broadcast a route request when it has to send the packet to an unknown destination and thus constructs the route to reach the destination.

To avoid asymmetric routing issues, the destination node sends the route reply with the source path information available in its routing table; otherwise, it uses the source path information present in the route request.

If a route failure occurs on the path to the destination, the intermediate node sends a route error packet to the source. The source node removes all paths passing through the erroneous hop and re-initiates route discovery.

From the above discussion, it can be seen be that the impact of medium access delay on the route discovery time in saturated mobile ad hoc networks was not investigated before. This thesis analyzes the impact of MAC delays on route discovery time and that of route discovery time on the packet service-time saturated mobile network.

CHAPTER 3

ANALYTICAL MODEL

This chapter analyzes the route discovery process and the time spent by an ad hoc node in this process: (known as route discovery time), and the impact of route discovery time on the packet service time. When a node has a route to the destination, the time spent by the node for the medium access is given by the following equation [2]:

= [(- 1)*] + (1)

= (- 1)(+ +)

+ [+ + + + 4* + 3*]

+ (2)

s the average number of transmissions required for successful delivery of the packet. is the time spent in a collision. is time taken for a successful RTS transmission. is the average back off time for packet transmission attempt, and is the average cross transmission time for each packet transmission. is time spent for distributed inter-frame spacing. , , , and are transmission time for RTS, CTS, DATA and ACK packets, respectively. is the propagation delay for each frame. is the short inter-frame spacing waiting time between each control packets.

A node initiates the route discovery process when it has a packet for an unknown destination. The route discovery time is an essential component of the routing delays in an ad hoc network, and it is given as

$$= \quad + \tag{3}$$

In the above equation, represents time taken for one route discovery attempt. is the time to send route request and is the route reply timeout.

If is the average number of route discovery attempt required to obtain a route to the destination, then the total route discovery time is given by:

$$= \quad * \tag{4}$$

For stationary networks, the packet service-time is equal to T_M, whereas the packet service-time in mobile ad hoc networks is given by:

$$= \quad + \tag{5}$$

Here is the total service-time in a mobile ad hoc network

As the time spent in collisions, backoff, and cross-transmissions at the MAC layer increases, the route discovery time also increases.

CHAPTER 4

SIMULATIONS AND RESULTS

The simulations required for analyzing the medium access delays, route discovery time, and its effect on the packet service time and packet end-to-end delay in mobile ad hoc network were carried out in NS2 v2.37. Variations in the route discovery time and packet service-time were studied by varying the network size. Results were tabulated for three different network sizes 10, 30, and 50, which are respectively named as scenario 1, 2, and 3. It is observed that the node movement and an increase in the network size increase the route failures and MAC contention, thereby increasing the route discovery time and therefore increasing the packet service-time. The default values used in the simulation are shown in table 1.

TABLE 1

DEFAULT VALUES USED FOR SIMULATIONS

PARAMETER	VALUE
Physical Layer Standard	FHSS
CW_{min}	31
CW_{max}	1023
RTS	44 bytes
CTS	38 bytes
DATA	500 kb
ACK	38 bytes
Slot-time	20 µs
DIFS	50 µs
SIFS	10 µs
Data Rate	100 kbps
Routing Protocol	AODV
Node Transmission Range	250 mts
Terrain area	1000 mts x 1000 mts
Simulation time	90s

Nodes were spread across a terrain area of 1000 x 1000 meters, where each node was placed 150 meters apart. Nodes were strategically placed such that a node could reach its immediate neighbors only as shown in figure 1. In all scenarios a source node could reach a destination node through an intermediate node, which created a multi-hop scenario. In scenario 1, nine nodes send data to node 10. In scenario 2, twenty nine nodes send data to node 30, and, likewise, in scenario 3, forty nine nodes send data to node 50.

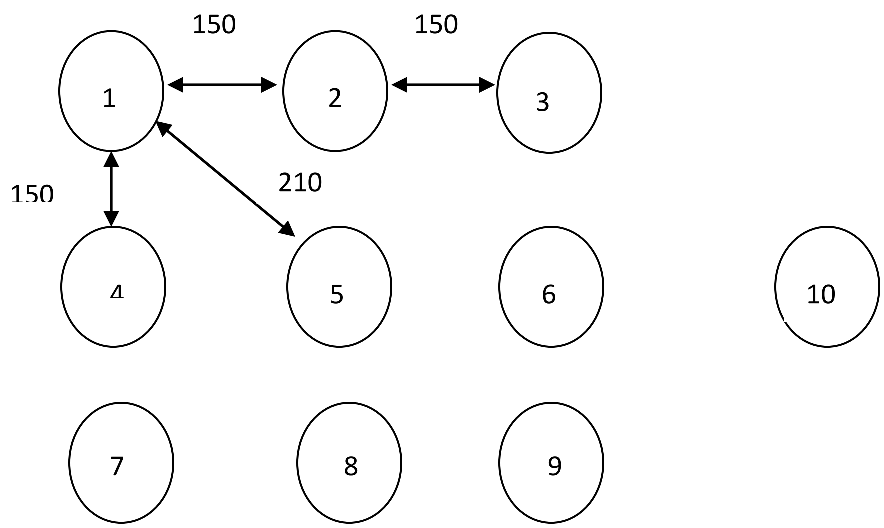

FIGURE 1

TOPOLOGY DIAGRAM FOR SCENARIO 1

The next hop node for the source nodes was made unreachable by moving the next hop node out of the source's transmission range. The source node sent 7 RTSs (for which CTS won't be received) to the next hop. After that it determines the route is invalid and initiates the route discovery process. Once the route discovery process is completed the source node resumes the packet transmission process by sending the RTS to the new next hop node.

In stationary networks, the route discovery process is initiated only once, which is when the source node starts the packet transmissions. After the initial route discoveries, the packet service-time only depends on the medium access delay. Also, the availability of the route always lowers the queuing delay significantly. In stationary networks, an increase in node density increases medium access delay, which in turn, increases packet service-time.

In mobile scenarios, routing information is dynamic, so the node initiates the route discovery process whenever the route is unreachable due to the motion of nodes. Until the route discovery process is completed, packets are accumulated in a routing queue that adds a significant queuing delay. In a mobile scenario the packet service-time depends on the route discovery time, the queuing delay and the medium access delay.

Tables 2, 3, 4, 5, 6, and 7 presents packet-service times with the route discovery process for the mobile ad hoc network, where SID represents sample ID, T_CT represents the total time spent in cross transmission for a particular back off stage, T_RD represents time spent in route discovery and T_Tot represents the total service time for packet, which includes the route discovery time as well.

The time spent in unsuccessful packet transmission, excluding DIFS, cross-transmissions and backoff-interval, is given by:

$$\begin{aligned} uRTS &= RTS + \mu \\ &= 0.000352 + 0.000001 \\ &= 0.000353 \end{aligned} \tag{6}$$

As a consequence, the node drops all the subsequent packets required to be forwarded to the same next hope node and initiates the route discovery process to identify a route to the destination.

After a route is discovered, the node forwards the next packet to its next hope node. Tables 3, 5, and 7 present fifteen samples for the successful packet deliveries followed by the route discovery process.

The total time spent in the route discovery process includes the medium access delays, such as cross transmission delays. The time spent in unsuccessful packet transmission, excluding DIFS, cross-transmissions and backoff-intervals, is given by:

$$
\begin{aligned}
sRTS &= RTS + CTS + DATA + ACK + 3SIFS + 4\mu \\
&= 0.000352 + 0.000304062 + 0.004624 + 0.000304062 + 0.000030 + 0.000004 \\
&= 0.005618124 \qquad (7)
\end{aligned}
$$

Theoretical values for successful and unsuccessful packet transmission in equation (6) and (7) matched with the practical value of simulation. Practical values for successful and unsuccessful transmissions are 0.000352 and 0.005620, which indicates that the difference between practical and theoretical value is less than 1 microsecond.

4.1 MAC Delay:

Tables 2, 4, and 6 present unsuccessful packet deliveries and Table 3, 5, and 7 represents successful packet deliveries. Here, the next hop node was moved to cause route failure. The transmitting node sends seven RTS packets to its next hop, and as it did not get the CTS it declares route failure and initiates another route discovery. After getting the route reply, the node transmits the packet to the destination. Table 2, shows the packet service-time for scenario 1, where the unsuccessful packet transmission times were 0.585394s, 0.390872s, 0.458291s, 0.422674s, and 0.398986s. In scenario 2 the packet service time for unsuccessful attempts were 0.565324s, 1.017846s, 0.616701s, 0.284274s, and 0.462014s. In scenario 3, the packet service times for unsuccessful transmission attempts were 2.154829s, 0.100465s, 0.182055s, 0.089555s, and 1.728958s. It is observed that with contention time taken for unsuccessful transmission also increases. The node initiates route discovery process after above mention event, results taken after similar route failure events are discussed in next sub section.

TABLE 2

PACKET SERVICE-TIME SAMPLES FOR SCENARIO 1 FOR UNSUCCESSFUL PACKET TRANSMISSION

SID	T_CT(s)	T_RTS(s)	T_RD(s)	T_Tot(s)
1	0.371460	0.000352	0.000000	0.371812
	0.006210	0.000352	0.000000	0.006562
	0.003350	0.000352	0.000000	0.003702
	0.003410	0.000352	0.000000	0.003762
	0.003020	0.000352	0.000000	0.003372
	0.190190	0.000352	0.000000	0.190542
	0.005290	0.000352	0.000000	0.005642
				0.585394
2	0.319871	0.000352	0.000000	0.320223
	0.001714	0.000352	0.000000	0.002066
	0.004001	0.000352	0.000000	0.004353
	0.002914	0.000352	0.000000	0.003266
	0.000000	0.000352	0.000000	0.000352
	0.059908	0.000352	0.000000	0.060261
	0.000000	0.000352	0.000000	0.000352
				0.390872
3	0.384149	0.000352	0.000000	0.384501
	0.002254	0.000352	0.000000	0.002606
	0.000000	0.000352	0.000000	0.000352
	0.002521	0.000352	0.000000	0.002873
	0.046144	0.000352	0.000000	0.046496
	0.000000	0.000352	0.000000	0.000352
	0.020760	0.000352	0.000000	0.021112
				0.458291
4	0.305800	0.000352	0.000000	0.306152
	0.002030	0.000352	0.000000	0.002382
	0.003210	0.000352	0.000000	0.003562
	0.044720	0.000352	0.000000	0.045072
	0.020250	0.000352	0.000000	0.020602
	0.040350	0.000352	0.000000	0.040702
	0.003850	0.000352	0.000000	0.004202
				0.422674

TABLE 2 CONTINUED

SID	T_CT(s)	T_RTS(s)	T_RD(s)	T_Tot(s)
5	0.328937	0.000352	0.000000	0.329289
	0.030554	0.000352	0.000000	0.030906
	0.014121	0.000352	0.000000	0.014473
	0.000000	0.000352	0.000000	0.000352
	0.000000	0.000352	0.000000	0.000352
	0.000000	0.000352	0.000000	0.000352
	0.022910	0.000352	0.000000	0.023262
				0.398986

TABLE 3

PACKET SERVICE-TIME SAMPLES FOR SCENARIO 1 FOR SUCCESSFUL PACKET TRANSMISSION WITH ROUTE DISCOVERY

SID	T_CT	T_RST	T_RD	T_Total
1	0.008950	0.005620	0.002370	0.016940
2	0.171311	0.005620	0.013804	0.190735
3	0.000421	0.005620	0.207872	0.213912
4	0.000431	0.005620	0.248531	0.254582
5	0.006333	0.005620	0.370308	0.382261
6	0.002458	0.005620	0.383998	0.392076
7	0.003958	0.005620	0.385367	0.394945
8	0.003958	0.005620	0.385367	0.394945
9	0.004526	0.005620	0.406025	0.416171
10	0.000591	0.005620	0.427154	0.433364
11	0.001226	0.005620	0.433502	0.440347
12	0.000531	0.005620	0.438977	0.445127
13	0.000630	0.005620	0.455690	0.461940
14	0.017018	0.005620	0.456357	0.478995
15	0.001297	0.005620	0.466115	0.473032

TABLE 4

PACKET SERVICE-TIME SAMPLES FOR SCENARIO 2 FOR UNSUCCESSFUL PACKET TRANSMISSION

SID	T_CT(s)	T_RTS(s)	T_RD(s)	T_Tot(s)
1	0.050640	0.000352	0.000000	0.050992
	0.065890	0.000352	0.000000	0.066242
	0.071500	0.000352	0.000000	0.071852
	0.003860	0.000352	0.000000	0.004212
	0.000980	0.000352	0.000000	0.001332
	0.037030	0.000352	0.000000	0.037382
	0.332960	0.000352	0.000000	0.333312
				0.565324
2	0.366987	0.000352	0.000000	0.367339
	0.003054	0.000352	0.000000	0.003406
	0.000000	0.000352	0.000000	0.000352
	0.000000	0.000352	0.000000	0.000352
	0.035820	0.000352	0.000000	0.036172
	0.040754	0.000352	0.000000	0.041106
	0.066511	0.000352	0.000000	0.066863
				1.017846
3	0.171144	0.000352	0.000000	0.171496
	0.165438	0.000352	0.000000	0.165790
	0.000000	0.000352	0.000000	0.000352
	0.000000	0.000352	0.000000	0.000352
	0.117349	0.000352	0.000000	0.117701
	0.016878	0.000352	0.000000	0.017230
	0.143429	0.000352	0.000000	0.143781
				0.616701
4	0.001840	0.000352	0.000000	0.002192
	0.001360	0.000352	0.000000	0.001712
	0.001920	0.000352	0.000000	0.002272
	0.002000	0.000352	0.000000	0.002352
	0.140820	0.000352	0.000000	0.141172
	0.133200	0.000352	0.000000	0.133552
	0.000670	0.000352	0.000000	0.001022
				0.284274

TABLE 4 CONTINUED

SID	T_CT(s)	T_RTS(s)	T_RD(s)	T_Tot(s)
5	0.152950	0.000352	0.000000	0.153302
	0.013780	0.000352	0.000000	0.014132
	0.001100	0.000352	0.000000	0.001452
	0.005270	0.000352	0.000000	0.005622
	0.003520	0.000352	0.000000	0.003872
	0.003880	0.000352	0.000000	0.004232
	0.279050	0.000352	0.000000	0.279402
				0.462014

TABLE 5

PACKET SERVICE-TIME SAMPLES FOR SCENARIO 2 FOR SUCCESSFUL PACKET TRANSMISSION WITH ROUTE DISCOVERY

SID	T_CT	T_RST	T_RD	T_Total
1	0.189474	0.005620	0.127530	0.322623
2	0.000680	0.005620	0.143243	0.149543
3	0.001373	0.005620	0.147542	0.154534
4	0.095710	0.005620	0.183775	0.285105
5	0.000540	0.005620	0.190475	0.196635
6	0.001380	0.005620	0.268524	0.275524
7	0.006774	0.005620	0.295625	0.308019
8	0.129434	0.005620	0.317372	0.452426
9	0.192388	0.005620	0.381756	0.579764
10	0.042270	0.005620	0.410546	0.458436
11	0.000085	0.005620	0.427542	0.433247
12	0.029496	0.005620	0.559115	0.594231
13	0.003207	0.005620	0.851956	0.860784
14	0.005812	0.005620	0.940818	0.952249
15	0.002353	0.005620	1.337302	1.345275

TABLE 6

PACKET SERVICE-TIME SAMPLES FOR SCENARIO 3 FOR UNSUCCESSFUL PACKET TRANSMISSION

SID	T_CT(s)	T_RTS(s)	T_RD(s)	T_Tot(s)
1	1.705074	0.000352	0.000000	1.705426
	0.000000	0.000352	0.000000	0.000352
	0.000000	0.000352	0.000000	0.000352
	0.018181	0.000352	0.000000	0.018534
	0.000000	0.000352	0.000000	0.000352
	0.110671	0.000352	0.000000	0.111024
	0.318437	0.000352	0.000000	0.318789
				2.154829
2	0.002700	0.000352	0.000000	0.003052
	0.004070	0.000352	0.000000	0.004422
	0.003620	0.000352	0.000000	0.003972
	0.002190	0.000352	0.000000	0.002542
	0.003520	0.000352	0.000000	0.003872
	0.070500	0.000352	0.000000	0.070852
	0.011400	0.000352	0.000000	0.011752
				0.100465
3	0.001060	0.000352	0.000000	0.001412
	0.002680	0.000352	0.000000	0.003032
	0.000820	0.000352	0.000000	0.001172
	0.003920	0.000352	0.000000	0.004272
	0.115790	0.000352	0.000000	0.116142
	0.054650	0.000352	0.000000	0.055002
	0.000670	0.000352	0.000000	0.001022
				0.182055
4	0.006130	0.000352	0.000000	0.006482
	0.001860	0.000352	0.000000	0.002212
	0.000880	0.000352	0.000000	0.001232
	0.004640	0.000352	0.000000	0.004992
	0.003080	0.000352	0.000000	0.003432
	0.053500	0.000352	0.000000	0.053852
	0.017000	0.000352	0.000000	0.017352
				0.089555

TABLE 6 CONTINUED

SID	T_CT(s)	T_RTS(s)	T_RD(s)	T_Tot(s)
5	1.497450	0.000352	0.000000	1.497802
	0.004244	0.000352	0.000000	0.004596
	0.003941	0.000352	0.000000	0.004294
	0.081215	0.000352	0.000000	0.081567
	0.031246	0.000352	0.000000	0.031598
	0.065684	0.000352	0.000000	0.066036
	0.042714	0.000352	0.000000	0.043066
				1.728958

TABLE 7

PACKET SERVICE-TIME SAMPLES FOR SCENARIO 3 FOR SUCCESSFUL PACKET TRANSMISSION WITH ROUTE DISCOVERY

SID	T_CT(s)	T_RST(s)	T_RD(s)	T_Tot(s)
1	0.202562	0.005620	0.189588	0.397769
2	0.000910	0.005620	0.396720	0.403250
3	0.051638	0.005620	0.473107	0.530364
4	0.000126	0.005620	1.354432	1.360178
5	1.169177	0.005620	1.540248	2.715045
6	0.438860	0.005620	2.174000	2.618480
7	0.013859	0.005620	2.294999	2.314479
8	0.228660	0.005620	2.761770	2.996050
9	0.590042	0.005620	3.600829	4.196491
10	0.998408	0.005620	4.394898	5.398926
11	0.211080	0.005620	4.689530	4.906230
12	0.061059	0.005620	4.829371	4.896050
13	0.005833	0.005620	4.972033	4.983486
14	0.033423	0.005620	5.846360	5.885403
15	1.494151	0.005620	6.900714	8.400485

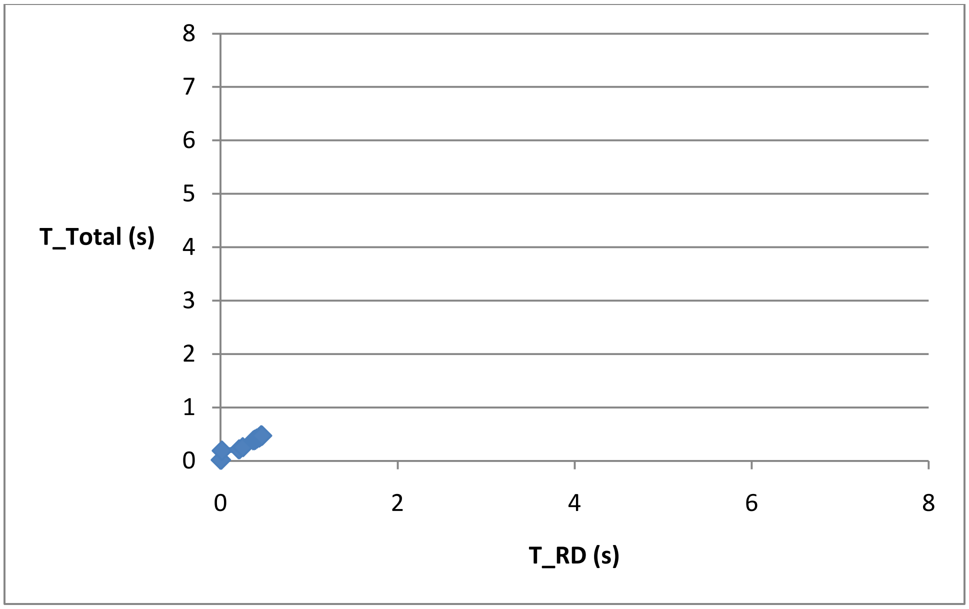

FIGURE 2

ROUTE DISCOVERY TIME vs PACKET SERVICE-TIME FOR SCENARIO 1

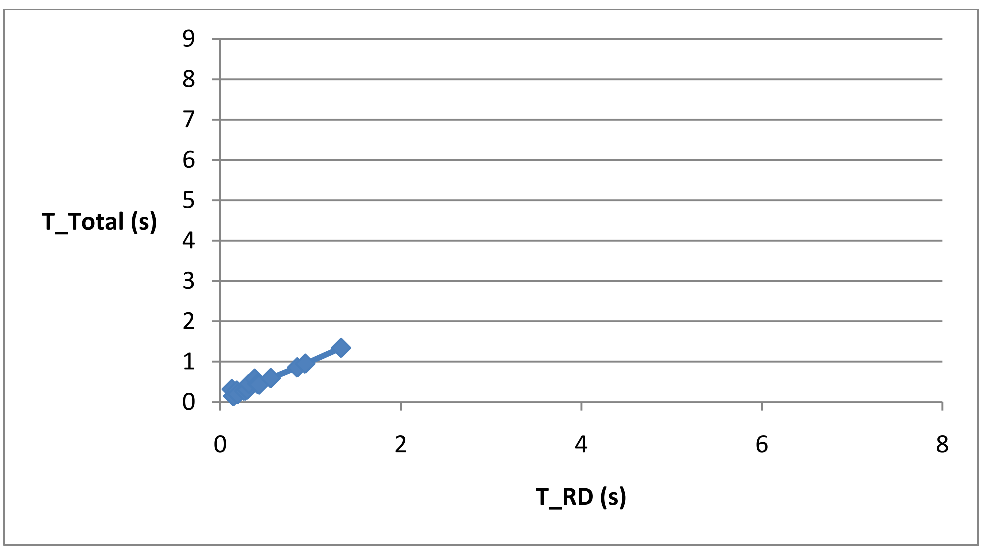

FIGURE 3

ROUTE DISCOVERY TIME vs PACKET SERVICE-TIME FOR SCENARIO 2

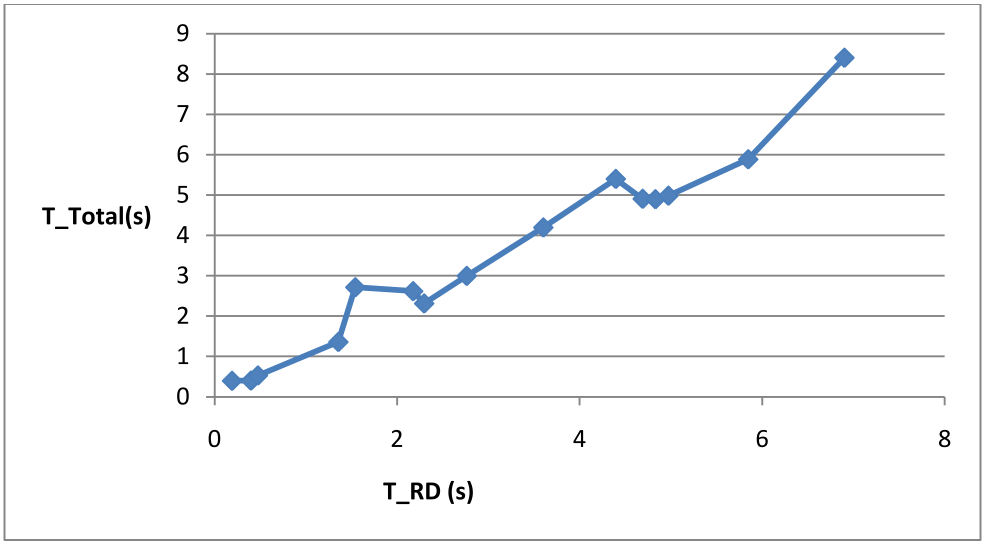

FIGURE 4

ROUTE DISCOVERY TIME vs PACKET SERVICE-TIME FOR SCENARIO 3

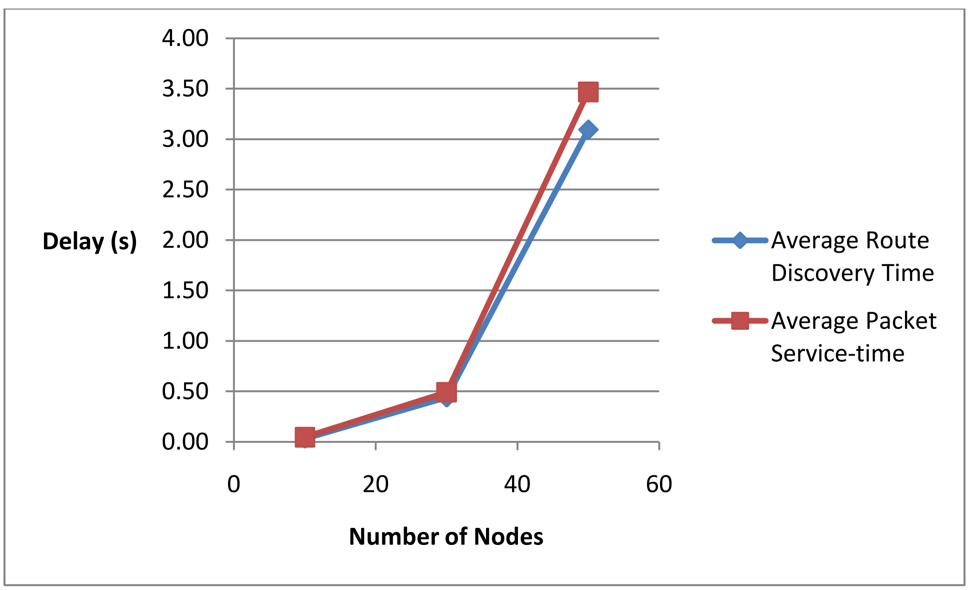

FIGURE 5

NUMBER OF NODES vs DELAY OF AVERAGE ROUTE DISCOVERY TIME AND AVERAGE FRAME SERVICE TIME

4.2 Routing Delay:

In Tables 3, 5, and 7, field T_RD represents the route discovery time and T_Tot represents the total service-time. Figures 2, 3, 4 and 5 were plotted using the results obtained from the simulation, as in tables 3, 5 and 7. It is observed, both from the simulated results and the plots, that with the increase in the route discovery time, the packet service time also increases. The route discovery time for all 15 readings in all 3 scenarios were 0.002370s, 0.013804s, 0.207872s, 0.248531s, 0.370308s, 0.383998s, 0.385367s, 0.385367s, 0.406025s, 0.427154s, 0.433502s, 0.438977s, 0.455690s, 0.456357s, 0.466115s, 0.127530s, 0.143243s, 0.147542s, 0.183775s, 0.190475s, 0.268524s, 0.295625s, 0.317372s, 0.381756s, 0.410546s, 0.427542s, 0.559115s, 0.851956s, 0.940818s, 1.337302s, 0.189588s, 0.396720s, 0.473107s, 1.354432s, 1.540248s, 2.174000s, 2.294999s, 2.761770s, 3.600829s, 4.394898s, 4.689530s, 4.829371s, 4.972033 5.846360s, and 6.900714s. The respective packet service times were 0.016940s, 0.190735s, 0.213912s, 0.254582s, 0.382261s, 0.392076s, 0.394945s, 0.394945s, 0.416171s, 0.433364s, 0.440347s, 0.445127s, 0.461940s, 0.478995s, 0.473032s, 0.322623s, 0.149543s, 0.154534s, 0.285105s, 0.196635s, 0.275524s, 0.308019s, 0.452426s, 0.579764s, 0.458436s, 0.433247s, 0.594231s, 0.860784s, 0.952249s, 1.345275s, 0.397769s, 0.403250s, 0.530364s, 1.360178s, 2.715045s, 2.618480s, 2.314479s, 2.996050s, 4.196491s, 5.398926s, 4.906230s, 4.896050s, 4.983486s, 5.885403s, and 8.400485s. The results prove that, in the mobile scenario the packet service time depends on the route discovery time. The spike in route discovery for results 14th and 15th of Figure 3, and for results 11th and 15th of Figure 4 is because of multiple route discovery attempts of the node. For results 4th and 8th of Figure 3, and for results 5th, 11th, and 15th of Figure 4 spike in packet service-time is because of multiple RTS transmissions to gain the medium access.

TABLE 8

END-TO-END DELAY SAMPLES FOR SCENARIO 1 WITHOUT ROUTE DISCOVERY EVENTS

S_ID	Hops	PathtotheDestination	EtoEdelay(sec)
1	2	2-1-9-	0.01348
3	3	8-4-9-	0.03157
5	4	0-3-8-7-9	0.04724
2	3	3-8-4-9	0.04774
4	4	0-3-8-7-9	0.10543

TABLE 9

END-TO-END DELAY SAMPLES FOR SCENARIO 2 WITHOUT ROUTE DISCOVERY EVENTS

S_ID	Hops	PathtotheDestination	EtoEdelay(sec)
1	4	18-19-14-22-28	0.11097
2	3	0-27-17-29	0.11463
3	4	6-13-21-25-29	0.18190
4	3	11-15-20-28	0.62681
5	3	9-14-23-28	2.58226

TABLE 10

END-TO-END DELAY SAMPLES FOR SCENARIO 3 WITHOUT ROUTE DISCOVERY

EVENTS

S_ID	Hops	PathtotheDestination	EtoEdelay(sec)
1	2	34-42-48	1.12724
2	6	3-11-20-26-35-41-49	1.79155
3	4	15-12-27-24-48	5.79032
4	9	5-12-18-41-49-18-25-35-41-49	11.73882
5	8	6-12-18-25-35-41-10-27-49	21.52905

4.3 End-to-End Delay with route discovery:

In Tables 3, 5, and 7, field T_Tot represents the packets service time on a particular node. The End-to-End delay is not calculated because, due to route discovery time and queue congestion, the packets were dropped before reaching the destination. It is observed that with an increase in contention the route discovery time increases, which inturn, increases the queuing delay. Higher route discovery times and queuing delays results in more packet loss, which is observed in scenario 3.

4.4 Packet End-to-End delay without route discovery:

Tables 8, 9, and 10 represent the packet end-to-end delays for scenarios 1, 2, and 3 where a path already exists between the source and the destination. Few packets have a higher service time with less number of hops, which is due to the extra queuing delay on few nodes. If the intermediate node is in the transit node for many sources or is surrounded with nodes that have more information to send, the queuing delay for the node is higher. It is observed that only medium access delay affects the packet service-time when the route is already established between the source and the destination.

CHAPTER 5

CONCLUSIONS

This thesis work presents a detailed analysis of the route discovery process in ad hoc networks, including the cause and consequence of the route discovery process. Furthermore, the effect of MAC delays on the route discovery time, and the effect of the route discovery time on the packet service-time and the packet end-to-end delays were analyzed. The simulation results support the theoretical conclusions that the medium access delays affect the route discovery time, and that the route discovery time affects the packet service-time and packet end-to-end delay.

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