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A Comparative Analysis and Performance Evaluation of TCP over MANET Routing Protocols

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Abstract

A Mobile Ad-hoc Network (MANET) is a collection of mobile devices dynamically forming a communication network without any centralized control and pre-existing network infrastructure. Due to the presence of mobility in the MANET, the interconnections between stations are likely to change on a continual basis, resulting in frequent changes of network topology. Consequently, routing becomes a vital factor and a major challenge in such a network. This research aims to study the impact of four IETF (Internet Engineering Task Force) standardized routing protocols on MANETs and thereby comprehensively analyzes their performance under varying network sizes and node mobility rates. The four routing protocols that are considered in the analysis are Optimized Link State Routing (OLSR), Ad-hoc On-demand Distance Vector (AODV), Dynamic Source Routing (DSR) and Temporary Ordered Routing Algorithm (TORA). In addition, from a transport layer's perspective, it is necessary to consider Transmission Control Protocol (TCP) as well for MANETs because of its wide application, which enjoys the advantage of reliable data transmission in the Internet. However, the factors such as scalability and mobility cause TCP to suffer from a number of severe performance problems in an ad-hoc environment. Hence, it is of utmost importance to identify the most suitable and efficient TCP variants that can robustly perform under these specific conditions. Therefore, this dissertation also makes an attempt to evaluate

the performance of the three TCP variants (Reno, New Reno and SACK) under a variety of network conditions. The simulations results reveal that out of the three, the SACK variant can adapt relatively well to the changing network sizes while the Reno performs most robustly in different mobility scenarios. On the other hand, the research asserts the fact of superiority of proactive protocol, over reactive and hybrid ones when routing the same traffic in the network. Nonetheless, among the reactive protocols AODV performance (in the presence of a high mobility) has been found to be remarkable.

Keywords: *MANET, OLSR, AODV, TORA, TCP, DSR*

1 Introduction

The use of wireless technology has become a ubiquitous method to access the Internet or making connection to the local network due to its easier and inexpensive deployment with a possibility of adding new devices to the network at no or lower cost. Wireless access points, representing a fixed infrastructure, allow devices equipped with wireless adapters to be linked together in a Local Area Network (LAN) and to get access to the Internet. However, the reliance upon an existing infrastructure and its potential limitations on mobility can be a major drawback. Therefore, wireless-capable devices may operate as autonomous entities, communicating via multiple wireless hops without a pre-established fixed infrastructure. In the discussion that follows, such wireless-equipped devices are referred to as nodes and function as both clients and servers in the network to forward the data packets. Such a network is called a Mobile Ad-hoc Network (MANET), where the nodes employed in the network can change their location from time to time. A routing protocol is mainly used to discover the shortest, most efficient and correct path(s) while providing the data transmissions between different wireless devices in ad-hoc network. Routing algorithm establishes the communications and formalizes agreement among nodes, which is essential to the overall performance of a MANET [1].

A variety of MANET routing protocols has evolved over recent time. Examples of such routing protocols are, among others, Optimized Link State Routing (OLSR) protocol, Wireless Routing Protocol (WRP), Ad-hoc On-Demand Distance Vector (AODV) routing protocol, Dynamic Source Routing (DSR) protocol [10] and Temporally Ordered Routing Algorithm (TORA) [2]. A MANET is an evolving technology, which offers a cost-effective and scalable method to connect wireless devices. Lately, this technology has become increasingly popular due to its potential application in many domains. For instance, such a network can be helpful in rescue operations where there is not sufficient time or resource to configure a wired network. MANETs are also very useful in military operations where the units are moving around the battlefield in a random way and a central unit cannot be used for synchronization [8]. To the best of our knowledge, this study would be first of its kind, in undertaking experiment through analyzing the performance of three TCP variants (Reno, New Reno and SACK) and four routing algorithms (DSR, TORA, OLSR, AODV) in a MANET environment. To formulate the research questions, we consider the use of OPNET as a convenient choice. OPNET has proved as a well accredited simulation package that has been used in several previous MANET studies conducted by many researchers worldwide. OPNET ensures extensive support for simulation of routing, TCP, and multicast protocols over wired and wireless networks [1 and 9]. The rest of the document is organized as follows. Section II presents constraints affecting the TCP performance in a MANET environment. Section III describes the existing protocols for routing in MANETs. A comparison among different routing protocols is also presented. Section IV includes a discussion on aspects relating to the performance metrics used to analyze the performance of the routing protocol and the TCP variants. Configuration of the experimental setup is also discussed. Section V looks at the results of the conducted research. Section VI draws conclusions, built on the analysis, along with exploring avenues for future research.

2 TCP Performances in MANETS

Even though TCP ensures reliable end-to-end message transmission over wired networks, a number of existing researches have showed that TCP performance can be substantially degraded in mobile ad-hoc network [15]. Along with the traditional difficulties of wireless environment, the mobile ad-hoc network includes further challenges to TCP. In particular, challenges like route failures and network partitioning are to be taken into consideration. Furthermore, MANET experiences several types of delays and losses which may not be related to congestions, though TCP considers these losses as a congestion signal. These non-congestion losses or delays mostly occur due to the inability of TCP's adaptation to such mobile network. Appropriate cares have to be taken for assessing such losses and also to distinguish them from congestion losses so that TCP can be sensitive while invoking the congestion control mechanism. The different types of constraints influencing the TCP performance in MANET environment are:

- High BER
- Route Failures
- Path Asymmetry Impact
- Network Partitioning
- Power Scarcity
- Multipath Routing
- Interaction between MAC Protocol & TCP
- Hidden and Exposed Node Impact

3 The Routing Protocols

In the latest years, research has been conducted on improving the performance of the MANET routing protocols. To deal with the complexity of the routing protocols, MANET has become a vital issue for The Internet Engineering Task Force (IETF) and therefore a MANET working group (WG) is established by IETF. The role of this group is to be involved in the development of different routing protocols such as OLSR, DSR, AODV, TORA and so on. These protocols are categorized into two groups as Reactive and Proactive based on the updated time of the routing information. In addition, the WG also offers a converged approach, for instance, a hybrid routing protocol. There are two other classes of routing protocol present based on the content of the routing table which are defined as distance vector class and link state class. The distance vector protocols disseminate the distance lists to the destination while the link state protocols involves in maintaining the network topology. Generally, the link state protocols exhibits more stability and robustness than the distance vector protocols though they are found much more complex to use in MANETs.

The different MANET routing protocols are OLSR, AODV, DSR, TORA. The Optimized Link State Routing (OLSR) is operated as a proactive (table-driven) routing protocol i.e. frequently exchanges topology information with other nodes of the network. This protocol is basically an optimization of traditional link state protocol developed for mobile ad-hoc network. The Ad-hoc On Demand Distance Vector (AODV) is considered an efficient MANET routing protocol and supports both unicast and multicast routing mechanisms. The AODV routing protocol utilizes an on-demand technique in order to discover the routes. This means that the route between two endpoints (nodes) is formed as per requirement for the source node and maintained as long as the routes are needed. Moreover, the protocol uses a destination sequence number to recognize the most recent path and to guarantee the freshness of the routes. Reactive protocols like AODV shrinks the control traffic overhead at the cost of higher latency in discovering new routes. Dynamic Source Routing (DSR) is a widely used reactive (on-demand) routing protocol which is designed particularly for the mobile ad-hoc networks. DSR permits the network to run without any existing network infrastructure and thus the network becomes as a self-organized and self-configured network. This protocol maintains an on-demand approach and hence extinguishes the periodic table-update messages needed in the table-driven approach [10]. The Temporally-Ordered Routing Algorithm (TORA) is a highly efficient distributed routing protocol and known as a hybrid protocol which can simultaneously support both table-driven and on-demand approach in multi-hop wireless networks. This protocol belongs to the family of the link reversal routing mechanism based on the Gafni-Bertsekas (GB) and The Lightweight Mobile Routing (LMR) algorithms [2]. The TORA protocol’s reaction to link failure is structured as a temporally-ordered sequence of diffusing computations, where all computations comprising of a sequence of directed link reversals. TORA implements four mechanisms in the network, which are known as creating routes, maintaining routes, erasing routes, and optimizing routes. Table 3.1 depicts the differences between four MANET routing protocols. The parameters used for the comparison, are routing mechanism, routing updates, loop freedom, advantages, disadvantages etc.

Table 3.1: Differences between four MANET routing protocols

Parameter	OLSR	DSR	TORA	AODV
Routing Mechanism	Table-driven	On-demand	On demand or Table-driven	On-demand
Multiple route mechanism	No	Yes	Yes	No
Source routing mechanism	No	Yes	No	No
Structure of the routing mechanisms	Flat	Flat	Flat	Flat
Network information maintenance	Route table	Route cache	Route table	Route table
Routing method	Flooding	Broadcast	Broadcast	Broadcast or Flooding
Update of routing information	Periodically	As required	As required	As required
Multicasting possibilities	No	No	No	Yes
Depth of information	The whole topology	Path information towards the destination node	The height of the neighbor nodes	Up to neighbor nodes
Control messages	Hello message, Topology Control and Multiple Interface Declaration	No beacon or hello message	LMR messages	Only hello messages used for neighbor detection
Loop free Routing	Yes	Yes	Yes	Yes
Drawbacks	The MPR sets could be overlapped	Large end-to-end delays, scalability problems caused by flooding and source routing mechanisms.	Temporary routing loops results in larger delays in the network.	Scalability and large delay problem.
Advantages	Trim down the number of broadcasts.	Provide multiple routes and avoid loop formation.	Multiple, loop free, reliable routes.	Much more efficient to dynamic topologies.

4 Experimental Design and Implementation

This section describes how the study is carried out. More specifically, it deals with the analytical framework, including the methodological issues, such as evaluation procedure, methods of assessments, scenarios and parameters, implied limitations and scope of the study.

4.1 Evaluation Platform

The research is conducted using discrete event simulation software known as OPNET Modeler, which is just one of several tools provided from the OPNET Technologies suite. In order to undertake the experimental evaluation, the most recently available version, namely the OPNET Modeler 16 has been adopted in our study. The OPNET is one of the most extensively used commercial simulators based on Microsoft Windows platform, which incorporates most of the MANET routing parameters compared to other commercial simulators available [1]. OPNET has a comprehensive built-in development environment to design and simulate network models.

4.2 Performance Metrics

The performance metrics such as **Throughput, End-to-End Delay, Upload Response Time, Download Response Time, Retransmission Attempts,** are being used to evaluate the network efficiency.

The network models of the current study are designed, in the OPNET simulator, by taking help of different network entities. An example of such network models is presented in Figure 4.1 where a network size of 100 nodes is confined in a (1000×1000) square meter area. The network entities used during the design of the network model are wireless server, application configuration, profile configuration, mobility configuration and workstations (nodes). These model objects are basically a series of network components that allow attribute definition and tuning. Application configuration is an essential object that defines the transmitted data, file size and traffic load. More often, it supports common applications, namely, HTTP, FTP, Database, Email, Print and so on. We have chosen FTP and HTTP applications for data traffic analysis where each application is considered with heavy traffic load (individually), in line with the requirement for bandwidth utilization. On the other hand, profile configuration determines where the data is received by specifying the interaction between servers and clients [32]. This is employed to create the user profiles whereas these profiles are specified on different nodes in the network for generating the application traffic. For instance, an FTP profile is created in a profile configuration entity in order to support the FTP traffic, which is generated by an application configuration entity. One of the other important entities is the mobility configuration, which is used for the purpose of determining the mobility model of the nodes. Moreover, it has to select several appropriate parameters such as speed start time, stop time, pause time and the like, to properly control the movement of the nodes in the network. The reason for configuring the mobility object is to allow the nodes to move within the specific allocated network area, which is chosen as 1000 square meters in our simulation network model. In other words, the traffic generated from outside this specific range, if any, will not be taken into account. Nevertheless, in order to configure the nodes with a mobility option, a widely used mobility model known as the default random waypoint mobility is used for all simulation purposes in the present study. Random waypoint model allows the mobile nodes to keep moving until they arrive at a random destination defined by such algorithm.

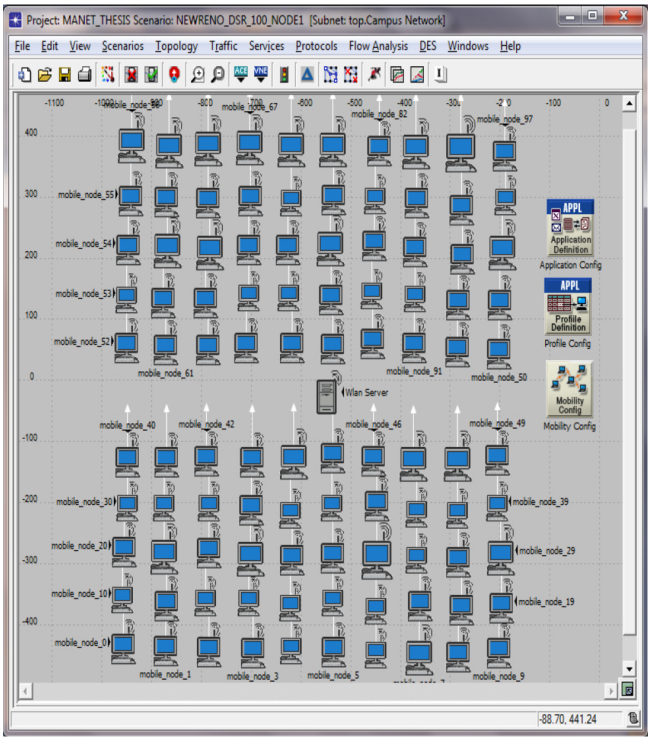


Fig 4.1: An example of 100 nodes simulated network model in MANET

Upon arrival at this destination, the nodes get stop at this place for a period of time, which is called the pause interval. A new movement is further made with a random direction and speed as soon as the pause time is expired. The combination of pause time and velocity sets up relative degrees of mobility between mobile nodes in the simulated network. In order to symbolize the mobile behavior of the nodes, the speed of the node is initially set to 10 m/s with a pause time of 50 sec to observe the network behavior with low mobility.

Table 4.1: Description of the Experimental Scenarios for Different Node Sizes

Node size Investigations (Scalability)	
Types of Scenario	**Description**
Scenario 1 (Small Size Network)	Scenario 1 is similar to what is shown in Figure 4.1 ; this is a network environment designed with different entities, configured for a network size of 30 nodes, the file size of 50,000 bytes (for FTP) and 1000 bytes (for HTTP), a node speed of 10 m/s with a pause time of 100 sec. Thereafter, different MANET routing protocols and TCP algorithms are employed in the network and their performance is evaluated for the small-sized network (i.e. node size = 30), based on the analysis of the performance metrics.
Scenario 2 (Medium Size Network)	Scenario 2 represents a medium-sized network where the network model is designed with 60 nodes. However, the value of node speed and the file size have not been subject to changes but set at, as in Scenario 1. The intention is to observe the performance of the routing protocols and the TCP variants through varying the node sizes from 30 to 60.
Scenario 3 (Large Size Network)	This network scenario (Scenario 3) is similar to that of Scenario 1 and Scenario 2, except that the network size is increased to 100 nodes, so as to observe the impact of scalability in MANET.

Table 4.2: Description of the Experimental Scenarios for Different Node Mobility Rates

Node speed Investigations (Mobility)	
Type of Scenario	**Description**
Scenario 4 (Low Mobility Network)	The network scenario is designed for a node speed of 10 m/s, a pause time of 50 sec, a network size of 60 nodes and the file size of 50,000 bytes (for FTP) and 1000 bytes (for HTTP). The justification of designing such a scenario includes evaluating the network performance with lower mobility rate within a medium size MANET.
Scenario 5 (Medium Mobility Network)	The scenario focuses on analyzing the effects of routing protocols and TCP variants whilst the mobility rate is varied from 10 m/s to 20 m/s in a medium size network. The pause time value is kept same as scenario 4.
Scenario 6 (High Mobility Network)	Similar to the scenario 1 and 2, a network environment is designed with different network entities and configured with a network size of 60 nodes; however the node speed is increased to 30 m/s with a pause time of 50 sec. The purpose of designing such scenario is to evaluate the impact of high mobility in a medium size network. Particularly, this scenario aims to investigate the behavior of the routing protocols and TCP variants when the node speed changes from 20 m/s to 30 m/s.

At some later stage, the speed is increased to 20 and 30 m/s with the same pause time so that the nodes can travel with greater speed in the network. The reason for increasing the node speed is to observe the impact of mobility on MANET performance. Three scenarios are described under two specific categories, presented in tabular form. Table 4.1 presents different scenarios for the network scalability while various scenarios for the node mobility are shown in Table 4.2.

5 Results and Analysis

This section presents experimental results for two different network scenarios in a MANET environment. Section 5.1 outlines the impact of network size extension on the performance of routing protocols and TCP versions while 5.2 deals with mobility issue and its impact on the network performance. Section 5.3 summarized the performance results of the routing protocols and TCP variants, respectively.

5.1 Varying Network Size

The routing performance is evaluated using TCP SACK variant since this is considered as a newer and widely deployed version now-a-days. On the other hand, the performances of different TCP variants are assessed with DSR routing protocol as the DSR interacts with TCP more efficiently than the other protocols under different realistic MANET scenarios [15]. To observe the impact of node variation on routing and TCP performance, the target applications are run with various network sizes (30, 60 and 100 nodes). Though this section deals with network size issue; it is much more realistic for a MANET environment to generate at least a low mobility rate instead of keeping it fully static. Accordingly, a moving speed of 10 m/s with an average pause time of 100 sec is set to allow the mobile nodes to move slowly in the network.

Figure 5.1 demonstrates the average throughput of OLSR, DSR, AODV and TORA under various network scenarios. The X axis shows the simulation time in seconds while the Y axis shows the throughput in bits/sec. In a small network (Figure 5.1a), when transmitting an FTP and HTTP traffic in the network, OLSR exhibits quite satisfactory performance compared to the other three routing protocols, receiving an average throughput of about 735,422 bits/sec. Considering the reactive protocols, AODV provides better performance than DSR and TORA, achieving up to 278,145 bit/sec throughput on average. Meanwhile, the average throughput for TORA and DSR are found to be 82,205 bits/sec and 78,259 bits/sec, respectively. The packet received for TORA is found to be slightly better than DSR due to the presence of mobility in the network. However, the performance of TORA tends to fall at 420 seconds whereas DSR is found to experience some improvement at the same time. With the network size shifting to a medium one (Figure 5.1b), the overall throughput tends to increase since more nodes are available to route the packets to the destination. It is apparent that

OLSR keeps outperforming other routing protocols through achieving a higher throughput of 4,670,035 bits/sec on average. On the other hand, DSR and TORA achieve the lowest amount of throughput in the network, approximately 170,950 bits/sec and 141,743 bits/sec, respectively. Meanwhile, AODV receives an average throughput of 1,063,200 bits/sec and is favored over DSR and TORA thereby. In a large network (Figure 5.1c), the average throughput of OLSR is about 4,900,240 bits/sec, which is approximately 1.05 and 6.66 times higher than that of a medium and a small network, respectively.

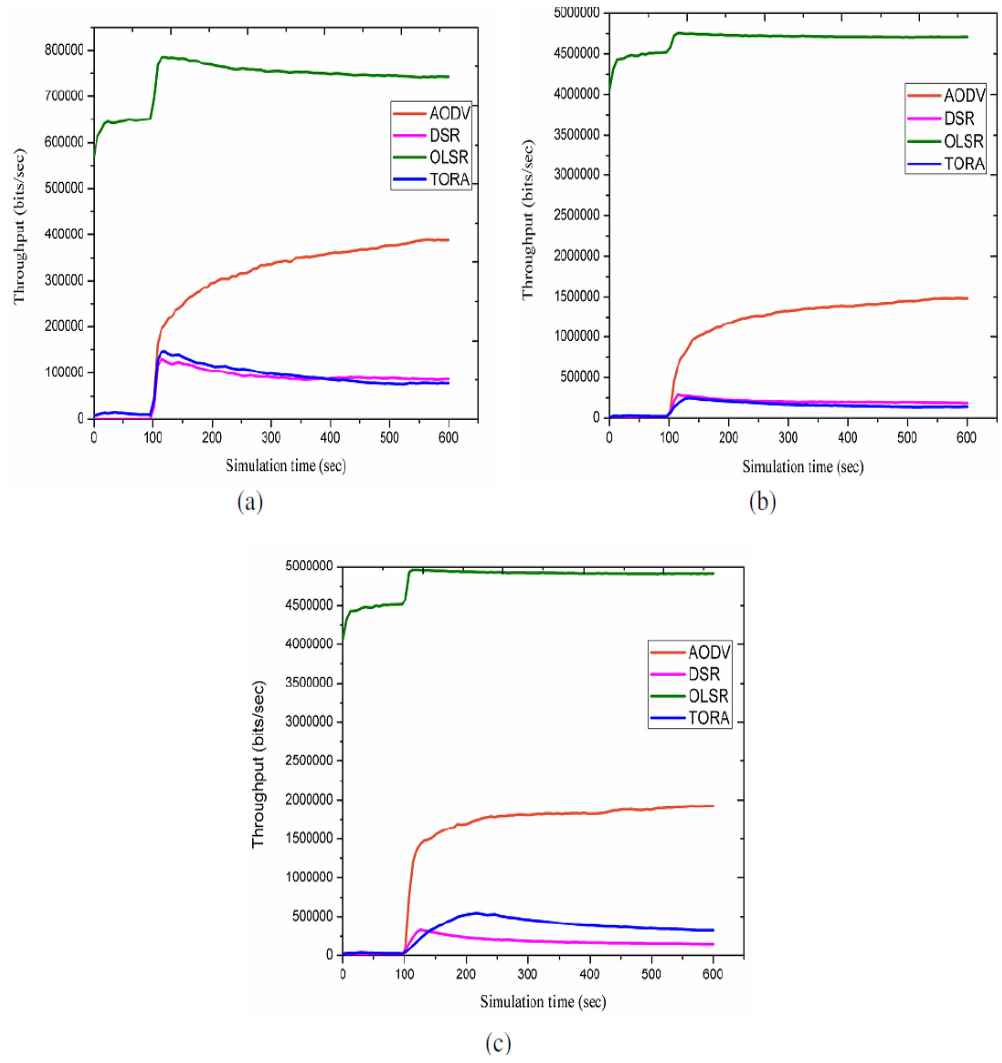


Fig. 5.1: Average throughput for different routing protocols; (a) Small network size (node=30), (b) Medium network size (node=60) and (c) Large network size (node=100).

In such a network, OLSR protocol continues to be dominating over AODV, DSR and TORA. On the other hand, AODV has been found to perform better than those with TORA and DSR. In a large network, a consistent throughput of 1,455,589 bits/sec (on average) is maintained by AODV, which is 1.37 and 5.23 times higher than that of a medium and a small network, respectively. Over and above, the average throughput for TORA and DSR are found to be 328,978 bits/sec and 160,546bits/sec, respectively. However, initially DSR receives slightly higher throughput than with the TORA. TORA starts outperforming over DSR at 140 seconds, which is maintained until the end of the simulation time.

5.2 Varying Node Mobility

This section presents details of the experiments carried out to evaluating the routing and TCP performance whilst the mobility rate is varied in a MANET environment. The analysis is elaborated based on three experimental scenarios 4, 5 and 6 as presented in the preceding section. The scenarios considered in this analysis consist of 60 nodes moving with node speeds of 10, 20 and 30 m/s. The pause time is set to 50 sec for all node speeds. Figure5.2 displays a graphical representation of a comparative analysis on the throughputs derived from various mobility scenarios. The X axis shows the simulation time in seconds while the Y axis shows the throughput in bits/sec. In Figure 5.2 (a), the topmost curve represents the AODV throughput, generated when the mobility rate is of 10 m/s. As can be seen, at the very beginning the throughput rises gradually and starts surpassing 1,500,000 bit/sec at some later stage. The average throughput of AODV received in such a network is about 1,063,001 bit/sec. When the node mobility is shifted to a medium rate (20 m/s), lower throughput is achieved, amounting to approximately 977,152 bit/sec, on average. Similar to the medium mobility network, the throughput in a high mobility network keeps on rising gradually, however, with a lower rate than that of the medium rate network. The average throughput received in a 30 m/s network is about 957,896 bit/sec, although the performance tends to show improvement towards the end of the simulation period. Meanwhile, in the case of DSR protocol (Figure 5.2b), the decrease of the throughput is somewhat noticeable but not dramatic in high mobility scenarios.

Among the three scenarios, it appears that the low mobility results in the highest average throughput of 169,220 bit/sec, which is approximately 1.03 and 1.06 times as much as that of a medium and a high mobility rate. On the other hand, as depicted in Figure 5.2c, the throughput of TORA initially increases for all mobility speeds and then reaches a peak, followed by, a gradual reduction until approaching the end of the simulation task. When the mobility rate varies in TORA, a slightly lower throughput is observed in a high mobility scenario, compared to that in a low and a medium mobility. Now turning to Figure 5.2d, it can be observed that OLSR protocol attains a higher throughput, followed by those with AODV, DSR and TORA.

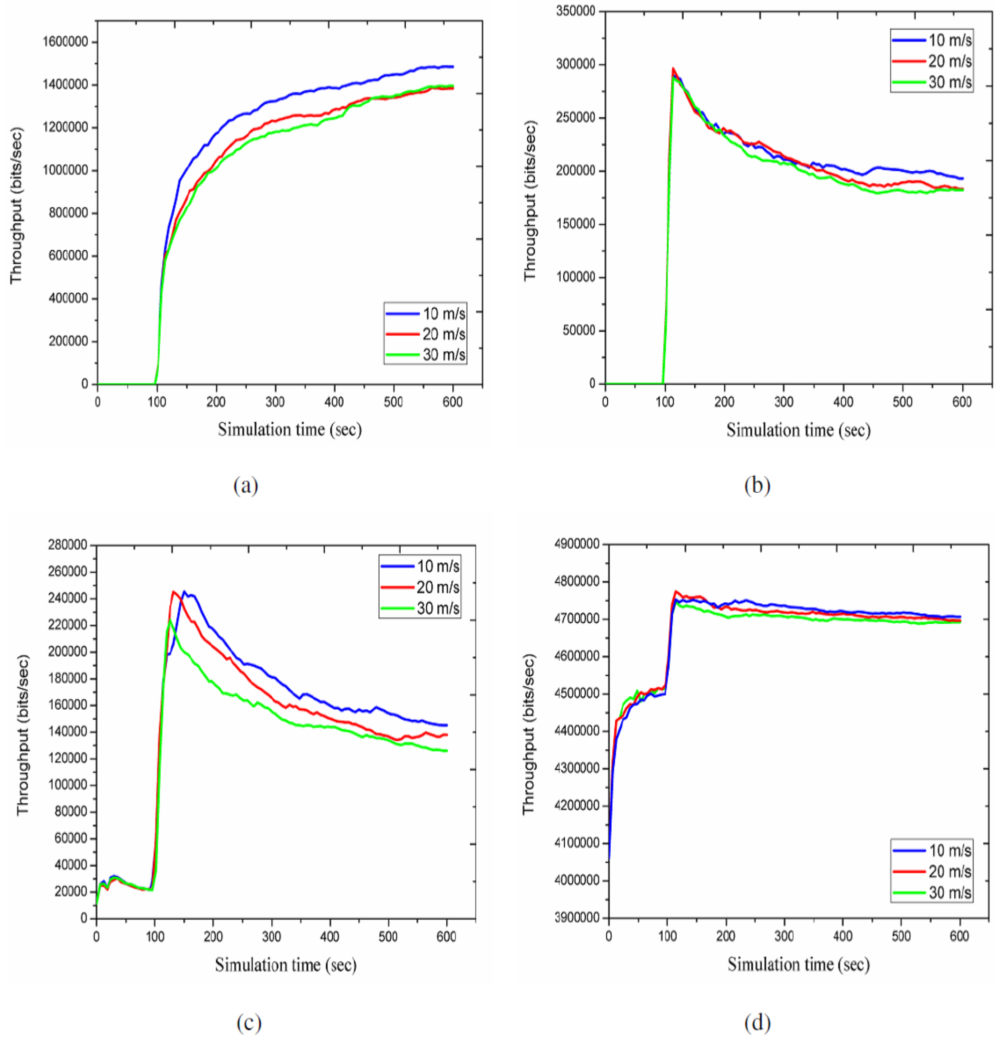


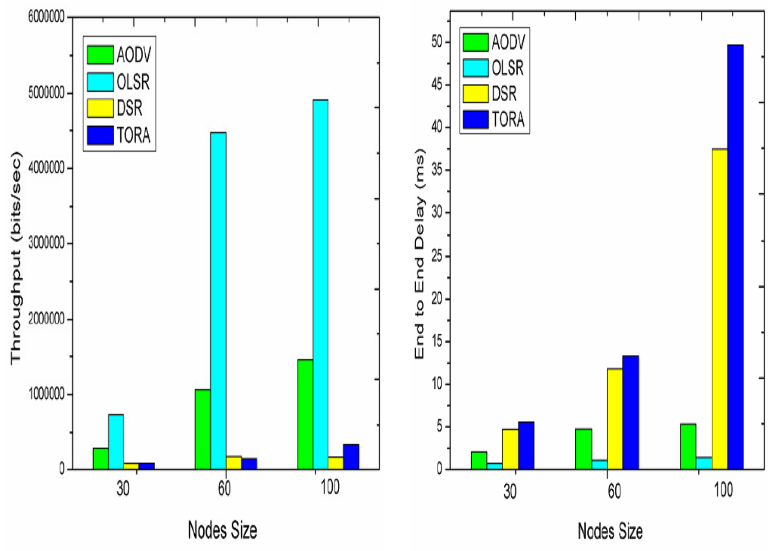
Fig. 5.2: Average throughput for different node speeds (i.e., 10 meters/sec, 20 meters/sec and 30 meters/sec); (a) AODV Protocol, (b) DSR protocol, (c) TORA protocol and (d) OLSR protocol.

Throughout the entire simulation, OLSR is found to maintain a consistent throughput. Even with higher mobility rates in the network, OLSR keeps its performance at a steady level. The highest average throughput of OLSR is attained in a 10 m/s speed, which is approximately 4,669,010 bit/sec. Subsequently the throughput reduces to 4,665,608 bit/sec and 4,652,745 bit/sec when the mobility rate is increased to 20 m/s and 30 m/s, respectively.

5.3 Summary of Routing Protocols Performance

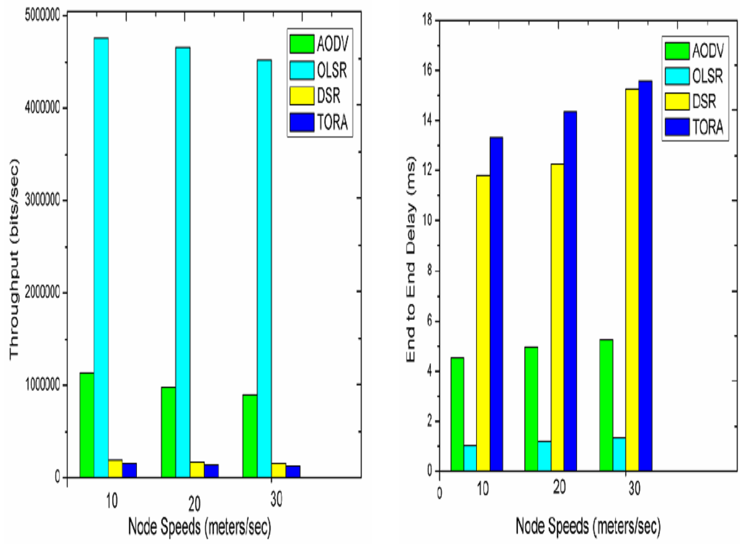
5.3.1 Performance evaluation with varying network density

This section presents the summary results on the routing protocols performance in terms of throughput and end-to-end delay.



(a) (b)

Fig. 5.3.1: Performance of routing protocols for different network sizes; (a) In terms of throughput (b) In terms of end-to-end delay



(a) (b)

Fig. 5.3.2: Performance of routing protocol for different node speeds; (a) In terms of throughput (b) In terms of end-to-end delay.

Amongst the four routing protocols, Figure 5.3.1 represent the performance graphs for different network densities in terms of throughput and end-to-end delay where it can be seen that the different properties of each protocol have led to a variety of differences in their performances.

5.3.2 Performance evaluation with varying mobility rate

Figure 5.3.2 represent the performance graphs for different node speeds in terms of throughput and end-to-end delay where it can be seen that the different properties of each protocol have led to a variety of differences in their performances.

6 Conclusion

This research makes contribution in three areas. Firstly, the study undertakes an analysis towards a comprehensive performance evaluation of four IETF standardized routing protocols in a MANET environment. The considered routing protocols are DSR, AODV, OLSR and TORA, covering a range of design choices, including source routing, hop-by-hop routing, periodic advertisement and on-demand route discovery. Secondly, the study analyzes the performance of the three most widely used TCP variants (Reno, New Reno and SACK) in an ad-hoc environment. In this respect, an investigation is made into aspects as to how well these variants respond to different network conditions, particularly with respect to extension of network size and variation of mobility rate.

Finally, using the simulation environment, an analysis is carried out on the results of throughput, end-to-end delay, upload response time, download response time and retransmission attempts. These results have facilitated in determining the most suitable routing protocols and TCP variants that can perform more efficiently and robustly in a mobile ad-hoc network.

The study also reveals some interesting findings on TCP variants when their performances are evaluated over dynamic topologies in a MANET environment. It has been observed that the performance of all TCP versions studied in this research decreases when the number of nodes is increased in the network. When the time required for re-establishing a broken link is shorter than the RTO, the TCP experiences no packet loss and consequently it does not trigger the time-consuming congestion control mechanisms. This eventually leads the TCP to exhibit a better performance in the network. All these findings mentioned above thus answer to our third research question.

7 Open Problem

Obviously, our future work will address all the limitations mentioned in the previous section. Aside from that, many interesting issues have surfaced during the course of this study, which need to be mentioned to give others some future research directions. For instance, in our research, we have considered two network factors (node size and mobility); the pursuit of future research may include aspects relating to evaluation of the MANET performance under other important factors like network load and transmission range. In this dissertation, a comparative analysis on four MANET routing protocols (viz. OLSR, AODV, DSR and TORA) has been carried out to evaluate their performance, the outcomes of which would be useful in many other situations.

However, there are other protocols such as DSDV, ZRP and SSR that can be pursued in any future research. Aside from this, an investigation as to how ad-hoc network performance can be improved, using the cross-layer interactions can also be an important area of future research. Furthermore, since a MANET is formed without centralized controls, it is posing vulnerable to security attacks now-a-days. Hence, in any future study, such security issues in an ad-hoc network can be pursued. Future work should analyze and evaluate performance of other traffic models such as CBR(Constant Bit Rate), VBR(Variable Bit Rate) and HTTP over TCP performance with respect to the MANET Routing protocols.

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