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Comparative Performance Evaluation of Different TCP Derivatives over MANET

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URL Conference Papers Series: www.atiner.gr/papers.htm

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ISSN **2241-2891**

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This paper should be cited as follows:

Dafalla, Z. I. and Hammoshi, Mayyada (2012) "**Comparative Performance Evaluation of Different TCP Derivatives over MANET**" Athens: ATINER'S Conference Paper Series, No: COM2012-0046.

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Abstract

Reliable transport protocols such as TCP were designed to work in traditionally fixed networks where packet losses occur mostly because of congestion. However, in wireless networks and networks with lossy links, TCP suffers from performance degradation due to bit errors and handoffs. TCP normally responds to all losses by invoking congestion control and congestion avoidance algorithms. This results in end-to-end performance degradation in wireless networks and lossy systems. In this paper, a comparison is made to several TCP derivatives that have been proposed in the literature to improve the performance of TCP in such networks. We investigated TCP derivatives such as, TCP Reno, NewReno, SACK and Tahoe under uncertain channel conditions that are normally experienced in wireless networks especially MANET, in combination with AODV and DSR routing protocols. We then present the results of several system simulations that were executed under different MANET environment, using access delay and throughput as the metrics of performance comparison. Our results show that there was no significant difference in terms of delay and throughput when all TCP derivatives were compared. We also demonstrated that AODV routing protocol had significant performance improvements in terms of throughput as compared to DSR under all TCP derivatives.

Keywords: *MANET, TCP, DSR, AODV, SACK, Performance.*

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1. Introduction

Despite the fact that TCP provides reliable end-to-end delivery of data over wired networks, recent studies focused on the poor performance of the TCP over wireless connections. Comparison between wired and wireless networks shows that the wireless network have a very low bit error rate, more delayed packets, and less channel reliability than wired networks [1] [2]. Due to the high bit error rates over wireless networks, packets may get corrupted and lost considerably. Traditional TCP, when used over wireless networks, incorrectly interprets packet loss as a sign of congestion, backs off from further transmission, and reduces the congestion window. This consequently leads to degradation in the overall connection throughput. The delay that could occur may also degrade the performance of the network. Non-congestion losses/delays mainly occur because TCP cannot adapt well to such mobile wireless multi-hop networks [1][3][4][5][6][7][8][9][10]. TCP does not have any resilience mechanisms that are specially designed to deal with link failures. From the viewpoint of TCP, there is no difference between link failure and network congestion. As a result, when part of the network fails and some TCP egments are dropped, TCP will assume that there is congestion somewhere in the network, and the TCP congestion control mechanisms will start dealing with the segment loss. TCP congestion control mechanisms have improved over time. The main versions of TCP are Tahoe, Reno, NewReno and selective acknowledgement (SACK). Tahoe is the oldest version and only a few old systems use it. Reno, NewReno and SACK are widely implemented [11]. Routing is an important problem in mobile ad hoc networks (MANET). In this study we focused on the performance of two routing protocols used in MANET namely dynamic source routing (DSR) and adhoc on demand distance vector (AODV) protocols in combination to few derivatives of TCP [12].

The modeling and analysis of TCP over IEEE 802.11 based ad hoc network is hard due to several reasons:

- The IEEE 802.11 MAC protocol is a complex protocol that involves a four-way handshake [13].
- The TCP protocol is characterized by an end-to end closed loop flow control; in contrast, IEEE 802.11 MAC is a closed loop flow control on a per link basis. The interaction of TCP with IEEE 802.11 MAC thus becomes complex.
- Wireless networks based upon IEEE 802.11 suffer from what is known as the “hidden-node problem” [14]. To reduce collisions caused by hidden terminals in the network, 802.11 use a four way RTS/CTS/DATA/ACK exchange. The dynamics of the four ways handshake (RTS/CTS/DATA/ACK) coupled with the closed-loop nature of TCP make the study of TCP over such networks a challenging task [15].

The rest of the paper has been organized as follows: section 2 covers factors affecting TCP performance over MANET, section 3 covers variants of TCP, section 4 covers simulation methodology, section 5 covers results and finally section 6 concludes the paper.

2. Factors Affecting TCP Performance in MANETs

In addition to the traditional problems of wireless networking, the mobile multihop ad hoc environment brings more challenges to TCP. In this section, we present a detailed analysis of all the factors that cause degradation in the performance of TCP over MANETs [10]. The factors are summarized as follows:

- *High Bit Error Rate (BER):* Wireless links are susceptible to high bit error rates due to signal attenuation, Doppler shift and multipath fading. This leads to the loss of TCP data segments or acknowledgments. Hence, the TCP sender will unnecessarily invoke congestion control.

- *Path Asymmetry:* In MANET, path asymmetry may manifest in several forms like bandwidth asymmetry, loss rate asymmetry, and route asymmetry. If the ACKs get bunched up, the sender may transmit data in a burst, which could lead to packet loss on the forward path. Also, disruption of the ACK stream can disrupt window growth and degrade performance to a fraction of the available bandwidth.

- *Route Failures:* The main cause of route failures is node mobility. The route re-establishment duration depends on the underlying routing protocol, mobility patterns of nodes, and traffic characteristics. It is possible that discovering a new route may take significantly longer than the retransmission time out (RTO) at the sender. As a result, the TCP sender will unnecessary invoke congestion control.

- *Network Partitioning:* It is due to node mobility or energy-constrained operation of nodes. If the sender and the receiver of a TCP connection lie in different partitions, all the sender's packets get dropped by the network resulting in the sender invoking congestion control. Frequent disconnections cause a condition called serial timeouts at the TCP sender. This may lead to long idle periods during which the network is connected again, but TCP is still in the back off state.

- *TCP congestion window size:* In MANETs, since the routes change many times during the lifetime of a TCP connection, the relationship between the congestion window size and the tolerable data rate becomes too loose. In [16], the authors show that if the congestion window size is greater than an upper bound, the TCP performance will degrade. Also, the authors in [8] reported that, given a specific network topology and flow patterns, there exists an optimal TCP's window size *W* by which TCP achieves the best throughput. But, unfortunately, TCP operates at an average window size that is much larger than *W*; this leads to increased packet loss due to the contention on the wireless channel.

- *Power Scarcity:* Because batteries carried by each mobile node have limited power supply, the life time is limited. Since each node acts as a router as well as an end system, unnecessary retransmissions of TCP segments consume this scarce power resource causing inefficient utilization of available power.

- *Multipath routing:* Some routing protocols maintain multiple routes between source and destination to minimize the frequency of route re-computation. Unfortunately, this sometimes results in a significant number of out-of-sequence packets arriving at the receiver causing the generation of duplicate ACKs which cause the sender to invoke congestion control.

3. TCP Variants

The TCP versions that have been used in our performance studies are TCP- Reno, TCP-New Reno and TCP SACK. The reason behind using these versions is their use in most of our today's networks. Below is a brief over view of these versions.

3.1 TCP-Reno

TCP-Reno is an implementation of TCP used by most networks today [17]. It uses different congestion control algorithms. They include Congestion Avoidance mechanisms, Fast Recovery, Fast Retransmit and Slow Start. TCP-Reno exploits packet losses in the network to estimate the available bandwidth in the network. It activates Slow Start process in the start of a TCP connection as well as after timeouts during the connection. During this process it initially increases the congestion window (CWND) exponentially but after Slow Start Threshold it increases the CWND linearly which is known as Congestion avoidance mechanism. Fast Retransmit and Fast Recovery mechanisms are initiated after receiving three duplicate Acknowledgements (ACKs) or when a timeout occurS. These two mechanisms improve the performance of TCP-Reno which interprets timeout as an indication of serious congestion in the network [18]. However Fast Recovery and Fast Retransmit mechanisms result in more efficient transfer of packets in the network.

3.2 TCP-New Reno

TCP-New Reno is a variant of Reno with an improved Fast Recovery (FR) algorithm in order to solve the timeout problem where multiple packets are lost from the same window. Congestion Control components of TCP-New Reno and TCP-Reno are identical [19]. TCP-New Reno distinguishes a Full ACK (FA) from a Partial ACK (PA) by modifying TCP-Reno's Fast Recovery behavior after it receives a non-duplicate ACK. FA acknowledges all the outstanding segments at the beginning of FR. However PA acknowledges only some of the outstanding data. TCP New Reno unlike Reno can recover from multiple segment losses by retransmitting only one lost segment in the same window per RTT and remains in Fast Recovery unless and until a full ACK is received [18].

3.3 TCP-Selective Acknowledgement (SACK)

Selective Acknowledgement (SACK) like Reno encounters the problem of multiple packet losses. However in TCP-SACK, acknowledgement is only provided for the selective segments which have been received successfully [19]. TCP-SACK thus requires retransmission of only those segments that have not yet been acknowledged. This in turn reduces the number of retransmissions required by the network. Each acknowledgement contains information of up to three noncontiguous blocks received by the sender. TCP-SACK uses same Fast Recovery procedure as used by TCP-Reno which activates Congestion Avoidance algorithm even for a single packet loss. For situations where multiple packet losses occur in an outstanding data window, TCP-SACK outperforms standard TCP. However scheme implemented by TCP-SACK is not efficient for situations where sender's window has small size [20].

3.4 TCP Tahoe

TCP is based on a principle of 'conservation of packets', i.e. if the connection is running at the available bandwidth capacity then a packet is not injected into the network unless a packet is taken out as well. TCP implements this principle by using the acknowledgements to clock outgoing packets because an acknowledgement means that a packet was taken off the wire by the receiver. It also maintains a congestion window CWD to reflect the network capacity [21].

4. Routing Protocols

To investigate the performance of TCP on MANET we studied routing protocols commonly used in MANET and their impact on TCP performance under variety of channel and network conditions. In MANET network nodes have no fixed infrastructure. Hence nodes that are in close proximity communicate through one another. The routing protocols used in this study were dynamic source routing protocols (DSR) and adhoc on demand distance vector. The routing protocols represent two different classes of routing protocols – reactive and proactive, respectively, and AODV which is considered as a combined protocol between reactive and proactive. In our simulation, we will focus on access delay, end- end delay and throughput verses number of nodes. These protocols can be used to detect network states by measuring their values at end nodes.

4.1 Dynamic Source Routing (DSR) Protocol

Dynamic Source Route (DSR protocol) uses on-demand mechanism for Route Discovery and Route Maintenance. When a source node wants to send packets to a destination, it first checks the route in the cache. If the route is not available in its cache, it initiates a Route Discovery process. It does so by broadcasting a Route Request (RREQ) message in the network. If the receiving node has a route to the destination it sends a Route Reply (RREP) message, otherwise it rebroadcasts the RREQ message in the network. Eventually when the RREQ message reaches to the destination, destination sends a RREP message back to the source. A connection is then established and all subsequent packets have the complete route in the packet header. In DSR intermediate nodes do not maintain any routing information. For Route Maintenance, data link layer issues a route error notification when it encounters a transmission error on the network and a new RREQ process is initiated [20].

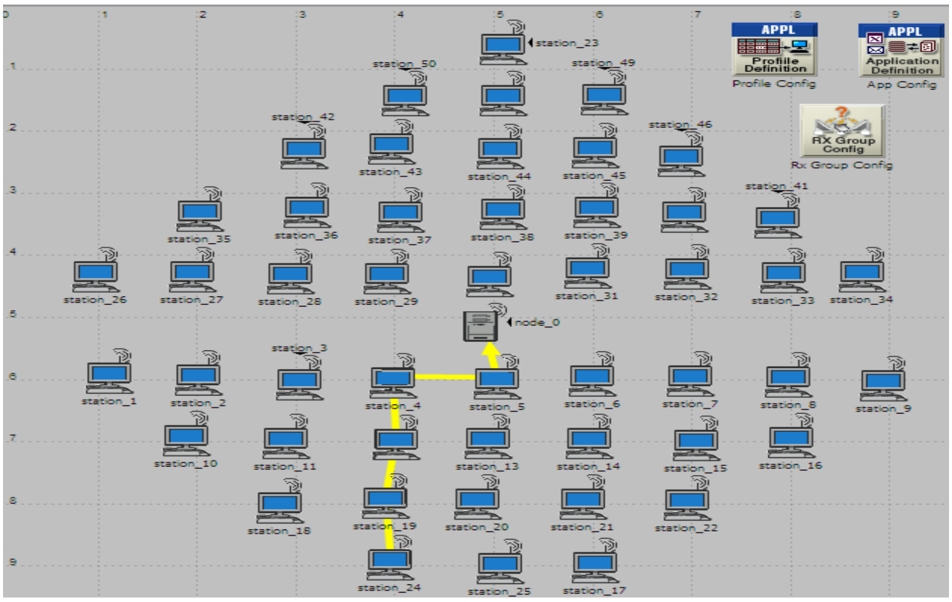
4.2 AODV (Ad hoc On-demand Distance Vector) Routing Protocol

Ad-Hoc On-demand Distance Vector routing (AODV) protocol combines features of DSR and DSDV. When a source needs a path to the destination, it broadcasts RREQ message in the network until it reaches a node that knows about a route to the destination. Destination generates a RREP message which propagates along the reverse route. This RREP message establishes information about the forward route at the intermediate nodes. Each node in DSDV does not contain the information about the entire route but just only about next hop like in DSR. Hello messages are used to detect any link failures. When a link breaks the upstream nodes are notified about this link breakage and destination is updated as unreachable in the routing table of nodes [20].

5. Simulation Methodology

We carried out detailed systems simulations by using Optimized Network Engineering Tool (OPNET v14.5) software for the studies carried out in this paper. Figure 1 shows the network model used in our studies. The simulation environment had 50 mobile workstations and one fixed WLAN server. Each mobile workstation can support one underlying WLAN connection at 1 Mbps, 2 Mbps, 5.5 Mbps, and 11 Mbps. We configured the entire nodes in the two scenarios to work with 5.5 Mbps. The network size was of 1000 x 1000 meters. The workstations were involved in exchanging high FTP load. Few scenarios were executed during simulation time. For example the performance of routing protocols that we studied in this paper namely DSR and AODV was tested under different TCP variants. Each scenario was run for 60 minutes of simulation time. Performance parameters studied were TCP delay and throughput.

Figure 1: *Simulation Platform*



6. Results

In this section detailed analysis of the simulation results is done. The simulation scenarios are based on the performance of TCP variants such as Reno, New Reno and SACK in combination with DSR and AODV routing protocols. Figures 2 and 3 show the delay experienced by different TCP variants namely TCP Reno, TCP New Reno, TCP SACK and TCP Tahoe in combination with DSR and AODV routing protocols. The number of nodes was set to 50. As can be observed, TCP delay under various TCP variants was high in AODV as compared to DSR.

Figure 2: *TCP Delay when Reno and New Reno were used*

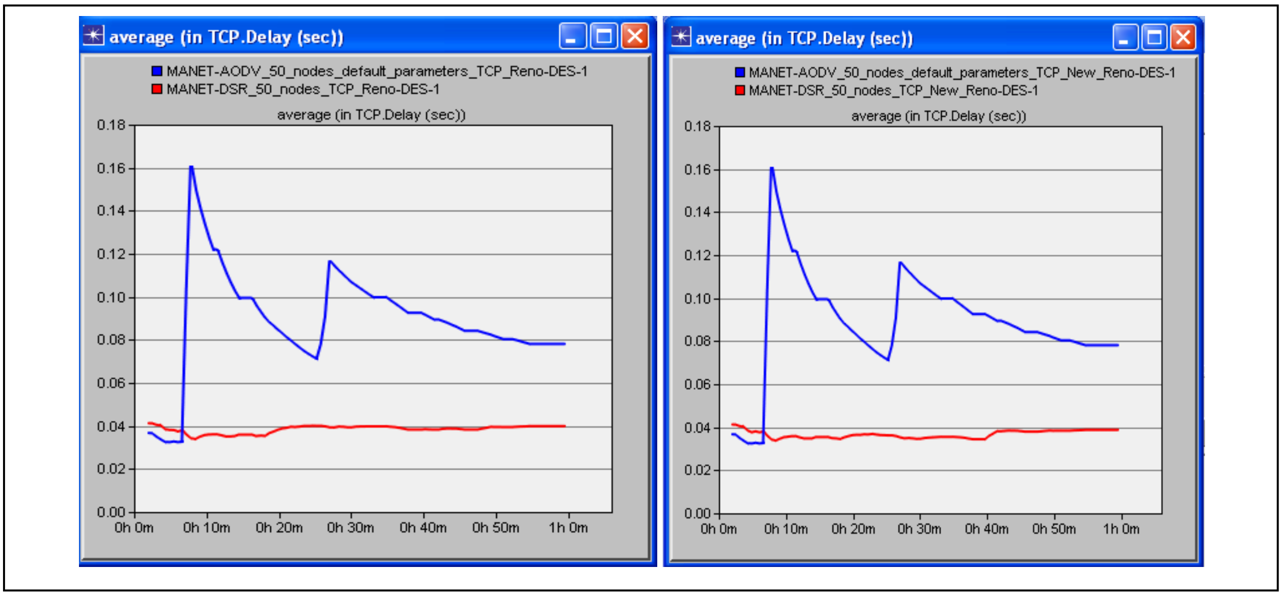


Figure 3: *TCP Delay when SACK and TAHOE were used*

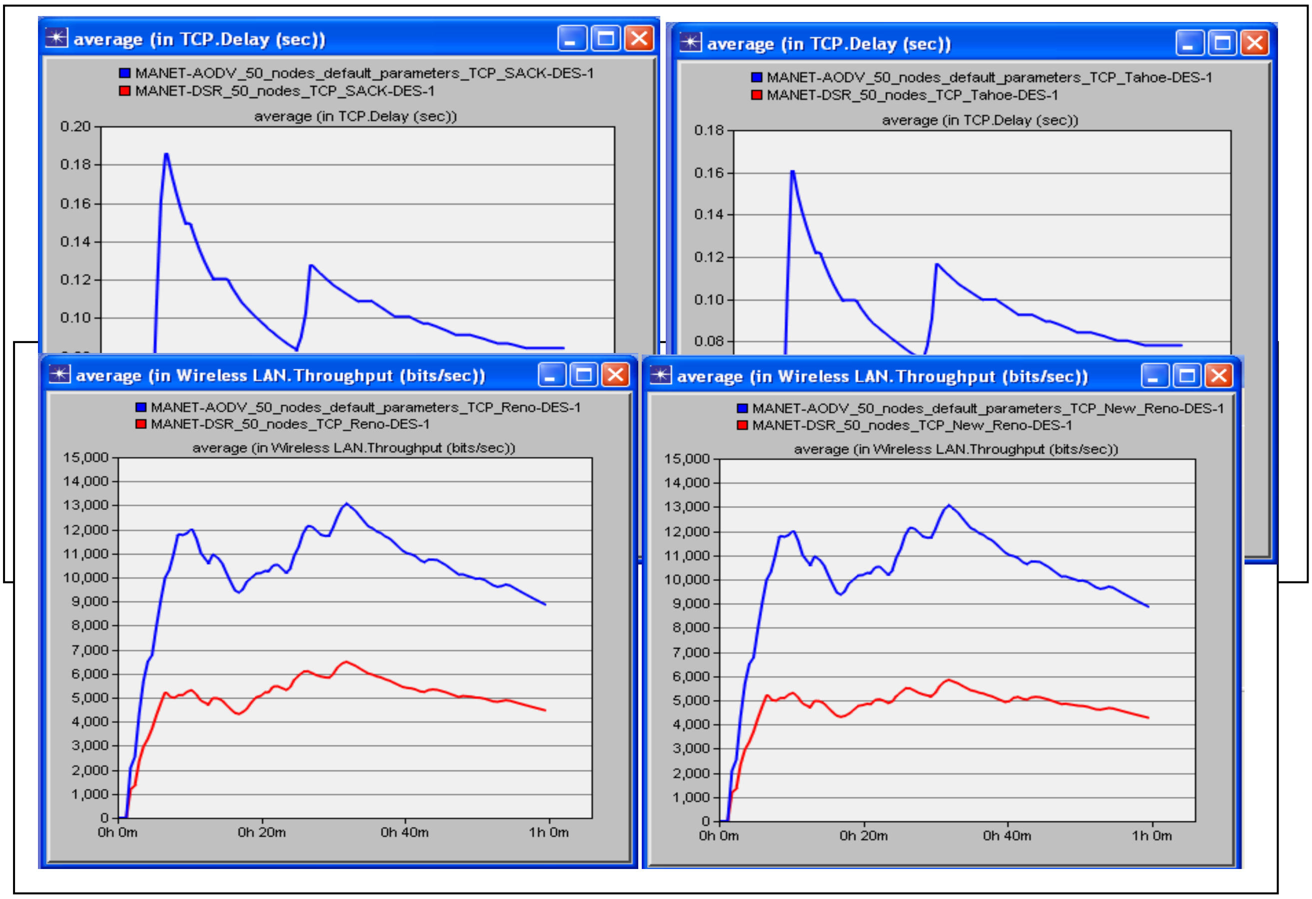
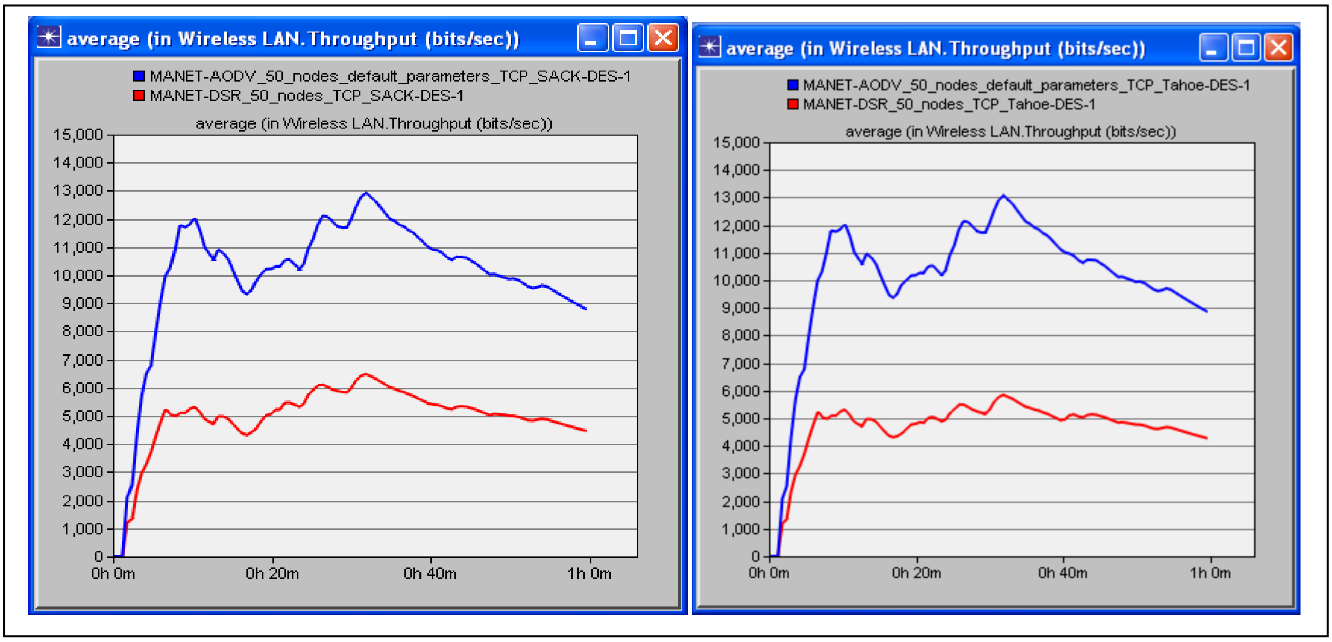


Figure 5: *MANET throughput when TCP SACK and Tahoe protocols were used.*



that are normally experienced in wireless networks especially MANET, in combination with AODV and DSR routing protocols. We then present the results of several system simulations that were executed under different MANET environment, using access delay and throughput as the metrics of performance comparison. Our results show that there was no significant difference in terms of delay and throughput when all TCP derivatives were compared. We also demonstrated that AODV routing protocol had significant performance improvements in terms of throughput as compared to DSR under all TCP derivatives.

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