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Topology Influence on TCP Congestion Control Performance in Multi-hop Ad Hoc Wireless

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Abstract**—**Wireless ad hoc nodes are freely and dynamically self-organize in communicating with others. Each node can act as host or router. However it actually depends on the capability of nodes in terms of its current power level, signal strength, number of hops, routing protocol, interference and others. In this research, a study was conducted to observe the effect of hops count over different network topologies that contribute to TCP Congestion Control performance degradation. To achieve this objective, a simulation using NS-2 with different topologies have been evaluated. The comparative analysis has been discussed based on standard observation metrics: throughput, delay and packet loss ratio. As a result, there is a relationship between types of topology and hops counts towards the performance of ad hoc network. In future, the extension study will be carried out to investigate the effect of different error rate and background traffic over same topologies.

Keywords**—**NS-2, network topology, network performance, multi-hops

I. Introduction

COMMUNICATION in wireless ad hoc mode can be categorized into single hop or multi-hop [1]. In the former mode, no intermediate node whenever it delivers packets as well as not requires any routing protocol. Therefore, the success of communication can still be managed as long as both nodes are in the transmission range of each other [2]. The failure happens when node start moving out of transmission range or weak of signal strength. Meanwhile, in the latter mode which is our attention in this paper involves at least one or more intermediate nodes to transmit packets to a dedicated destination. Normally, the dedicated destination cannot be accessed directly since it is located out of the source node's transmission range. The following figures illustrate the differences between single hop and multi-hops.

In Fig. 1, Node A transmits packet to Node B. In this case, Node B is located in Node A's transmission coverage. Meanwhile, the opposite situation happens in Fig. 2 where Node C cannot directly communicate with Node A.

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Therefore, Node B is responsible to route packet from Node A to Node C as an alternative. Here, a routing protocol is applied to ensure the logical path of packet delivery is met.

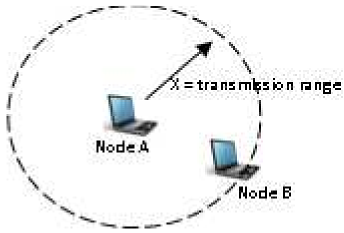

Fig. 1a Single hop where two nodes communicates directly within transmission range

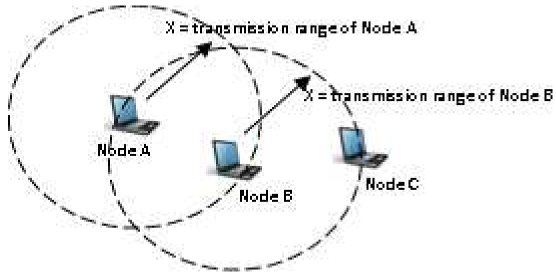

Fig. 1b Multi-hops (with 2 hops) where a destination node is out of source node's transmission range

Based on the functionality of transmission control protocol or TCP, the cycle of packet delivery is considered complete whenever a simple type of packet known as acknowledge (ACK) has been received within sender's expected duration. If not, a possible network pathology [3] has been occurred which is either packet delay or packet lost. One of the common network actions towards this situation is applying Congestion Control mechanism [4]. For wired network, packet lost is a main indicator of congestion problem and it will invoke sender to adjust their sending rate according to current network traffic situation. However, packet lost in wireless network might come from several causes such as high bit error rate [5], hidden or exposed nodes, power level, signal strength, contention [6], interference [7] and others. The assumption of packet loss caused by congestion will then lead to drastic network performance degradation in wireless environment.

Here, we evaluate TCP version likes TCP Tahoe, TCP Reno and Newreno which perform differently in ad hoc network but all still suffer the same problem of inability of distinguish packet loss caused by congestion or wireless channel [1]. In our study, we simulate static ad hoc network in different network topology. The objective of this study is to observe the effects of network topology [8] over multi-hops communication. Therefore, there are three network topologies have been selected: string, ring and grid [9]. The rest of the paper is organized as follows. Section II reviews the basic variants of TCP Congestion Control in wired and network topology that has been selected in our study. Section III describes the simulation process stages. The simulation results will be analyzed in Section IV. Section V concludes the findings of this study and possible extensions of our work.

II. Background Study

A. TCP Tahoe, Reno, Newreno

The first solution for network congestion problem has been proposed by Jacobson [10] in year 1988. The modification of traditional TCP specification with Congestion Control (CC) mechanism has been done because almost 90% of Internet traffic is TCP-based [11-13]. TCP Tahoe consists of three main algorithms as stated in RFC793 [14] which are Slow Start, Congestion Avoidance and Fast Retransmit.

At the beginning of packet delivery, the Slow Start phase is used to determine the available bandwidth in network and the size of packet or congestion window (cwnd) is initiated with 1 MSS or 1 packet. It will later be increased by double up cwnd for each RTT. Once cwnd reach Slow Start threshold (ssthresh), the Congestion Avoidance plays its role. In this stage, Additive Increase Multiplicative Decrease (AIMD) algorithm is used to react towards the presence of packet loss. The indication of packet loss can be divided into two types [15] : timeout or duplication of ACKs.

When there is no ACK received within sender's timer, sender retransmits a lost packet based on last sequence number. Then, the Fast Retransmit only initiated whenever there is tri-duplicate ACKs. As a result, the cwnd is reset to 1 MSS as a Slow Start stage previously.

The weakness of restart Slow Start in Tahoe has been overcome by TCP Reno where it has been skip and introduce a Fast Recovery algorithm [16]. In this new algorithm, the last successful cwnd has been maintained as a temporary cwnd and it increased by 1 MSS for every new dupACK. This action allows new packet transmission across network link. It will be ended when sender receives acknowledgement that the retransmission of lost packet has been received. The Congestion Avoidance is entered and cwnd starts grow starting from the latest cwnd size.

Potential of handling multiple packets losses in same window has been catered by TCP Newreno as a new improvement of Reno [17] . The cwnd size only adjusted when it detects the first loss and allows Fast Retransmit to recover multiple losses while sender only receives a partial new acknowledgement. The Fast Recovery exit when all lost packets have been acknowledged.

B. Multi-hops Network Topology

Multi-hops communication is frequently can be found in ad hoc network applications such as sensor network, wireless mesh network and home/ office network. Nodes have been configured into several topologies included string, ring, grid, cross and random. The string topology is the simplest case of wireless multi-hops network [18]. Throughout static ad hoc topologies, multi-hops pose to several possible issues such as hidden and exposed nodes problem [19], selfish node [20, 21] and others. Fig. 3 summarizes a collection of network topology which usually used in the evaluation of wireless network performance.

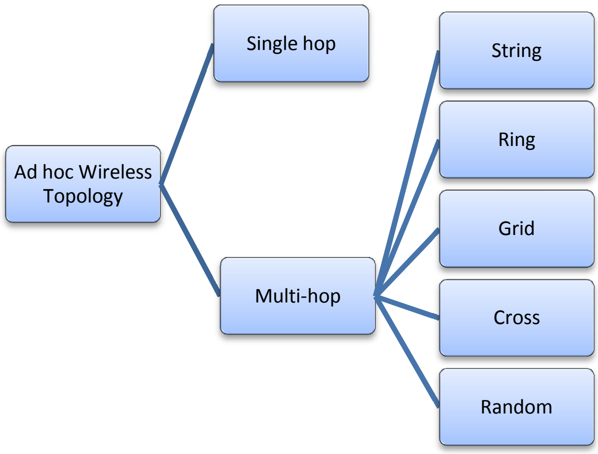

Fig. 2 Topology for Single hops vs. Multi-hops

III. Experimental Approach

A. Network – Setup, Design and Observation Metrics

In this sub-section, we illustrate selected network topologies to be studied. In Fig. 4, all wireless nodes are considered as static ad hoc network which are using IEEE 802.11b with basic data rate 1 Mbps. The standard distance between two neighboring nodes is given as 200 meter [18, 22].

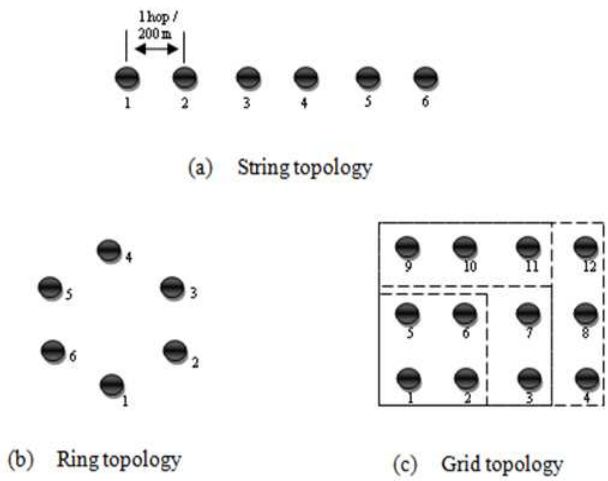

Fig. 3 Nodes configuration according to the different topologies- string, ring and grid

In this study, a comparative analysis only involves up to 5 hops or 6 nodes communication [23]. Here, we plan to have only one TCP flow between two nodes communications over different variants of TCP Congestion Control which are TCP Tahoe, TCP Reno and TCP Newreno. A pair of nodes communication has been described in the following Table I. For routing, we implement a reactive routing protocol named as Ad hoc On-Demand Distance Vector (AODV) routing where the path is established based on demand and it offers a quick connection setup. Detail information regarding to simulation parameter has been described in Table II.

TABLE I
SUMMARY OF NODES PAIR AND ITS POTENTIAL ROUTE IN DIFFERENT TOPOLOGIES

Hop (s)	Node Pairs				
	String	Ring		Grid	
			Routes		Routes
1	[1,2]	[1,2]	-	[1,2]	-
2	[1,3]	[1,3]	2	[1,6]	2 or 5
3	[1,4]	[1,4]	2,3 or 6,5	[1,7]	2,3 or 2,6 or 5,6
4	[1,5]	[1,5]	2,3,4	[1,11]	2,3,7 or 2,6,10 or 5,9,10 or 5,6,10 or 5,6,7
5	[1,6]	[1,6]	2,3,4,5 **	[1,12]	2,3,4,8 or 2,3,7,8 or 2,3,7,11 or 2,6,7,8 or 2,6,10, 11 or 5,9,10,11 or 5,6,7,8 or 5,6,10,11

** Node 6 has been moved out of Node 1's transmission range

TABLE II
SIMULATION PARAMETERS

Parameters	Value
Routing Protocols	AODV
MAC Protocol	IEEE 802.11b
Channel rate	1 Mbps
RTS-CTS	On
Simulation Time	100 seconds
Simulation Topology	String, Ring and Grid
Number of Nodes	6 (string & ring) ; 12 (grid)
Packet Size	1000 bytes
Application Protocol	FTP
NS-2 version	2.34

In this study, an open source simulation tool named as NS-2 version 2.34 [24, 25] has been used. We collect some performance metrics such as end-to-end throughput, end-to-end delay and packet loss ratio. This selection is based on possible output to represent possible network performance degradation over multi-hop communications.

IV. NUMERICAL RESULT & ANALYSIS

A. *Hop Count vs. Throughput*

From the overall perspective, throughput at the transport layer decreased when the number of hop is increased [1]. It proves that any packet transmission over wireless is highly potential to loss compared to wired network. Many factors contribute to loss problem as mentioned in many research [5, 26]. Here, the simulation study has been conducted over a variant of TCP Congestion Control (CC) mechanisms (which are TCP Tahoe, TCP Reno and TCP Newreno) in order to make a benchmark of the TCP flow behavior in wireless multi-hops cases.

In Fig. 5 to Fig. 7, it can be seen that the value of throughput for all topologies are equal between the three CC variants up to 3 hops. However, this trend changed when the number of hops has been extended to more than 3 for both string and grid. For the first three hops, this happens when RTS-CTS mechanism has been actively avoid concurrent transmission created by hidden and exposed nodes issue within the 3 hops communication [19, 27]. However, this mechanism is not applicable in more than 3 hops. At this time, collision occurred among the data and ACK in the same flow.

For ring, the changes happen only after 4 hops. By comparing TCP CC variants, TCP Newreno always present high throughput for all topologies indeed. This might be supported by the feature offered by TCP Newreno where it can recover multi-packet losses which also considered as burst errors that always happen in wireless network.

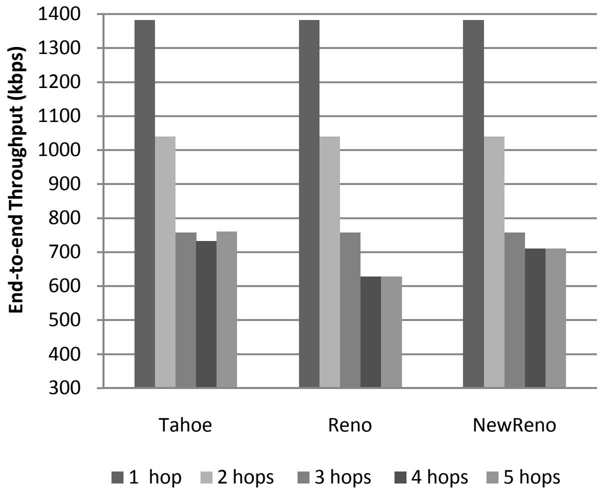

Fig. 4 Throughput for String topology

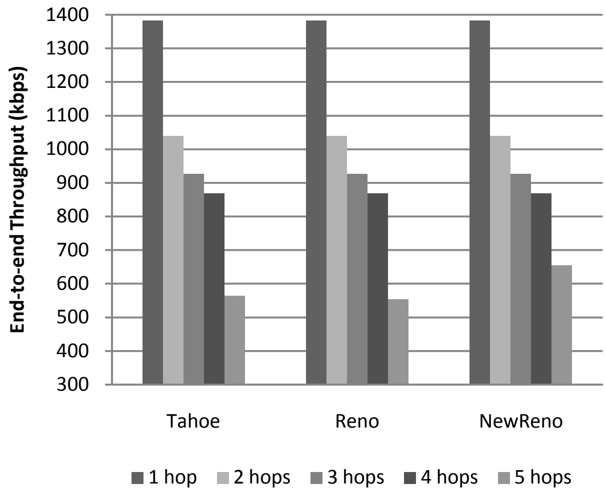

Fig. 5 Throughput for Ring topology

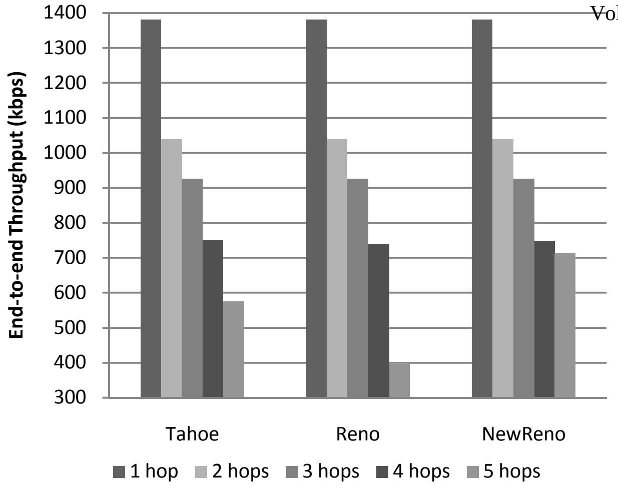

Fig. 6 Throughput for Grid topology

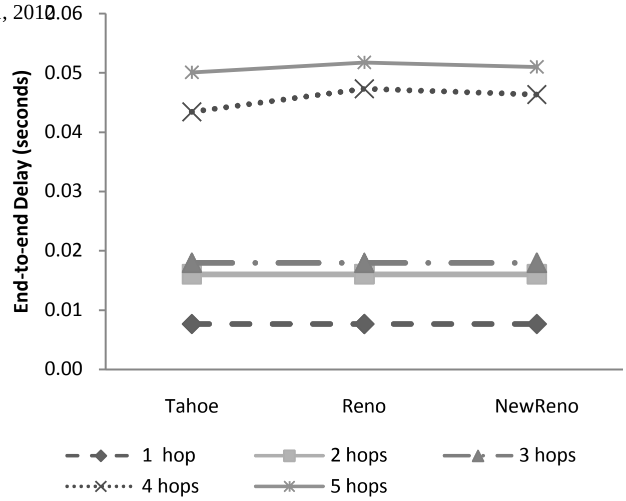

Fig. 7 End-to-end delay for String topology

B. *Hop Count vs. Delay*

In this sub-section, we analyzed the relationship between the number of hops and delay. From the network definition, delay or round trip time (RTT) is an expression of the certain duration taken by a sending packet until it has been acknowledged. In a common sense, it will be increased once the distance between two communicating nodes is increased.

From Fig. 8 to Fig. 10, it can be seen that the value of delay for all topologies over a variant of TCP CC mechanisms is given as nearly 0.02 seconds whenever the communication distance involves up to 3 hops. When distance reaches more than 3 hops, it shows that the delay becomes bigger which is between 0.04 seconds and 0.16 seconds. This is because of the collisions that happen at MAC layer among data and ACK. Therefore, the following discussion will focus on 4 and 5 hops in each topology.

Referring to string topology, Fig. 8 indicates that the delay for both hops is closely followed each other. The values for 4 and 5 hops are given as 0.04 seconds and 0.05 seconds respectively. In term of a variant of TCP CC, the delay in TCP Reno is slightly higher compared to others.

In ring topology in Fig. 9, the delay conveys some different information. For the packet transmission involving 4 hops, the delay maintains almost over difference TCP CC at almost 0.04 seconds similar to the case as in string topology. Meanwhile in the case of 5 hops, the delay changed from 0.09 seconds to 0.12 seconds in TCP Reno and TCP Newreno. For grid topology, the delay of 4 hops communication is slightly higher than in ring topology which is 0.06 seconds. This also happens in 5 hops case where the delay was recorded as 0.16 seconds over all TCP CC mechanisms.

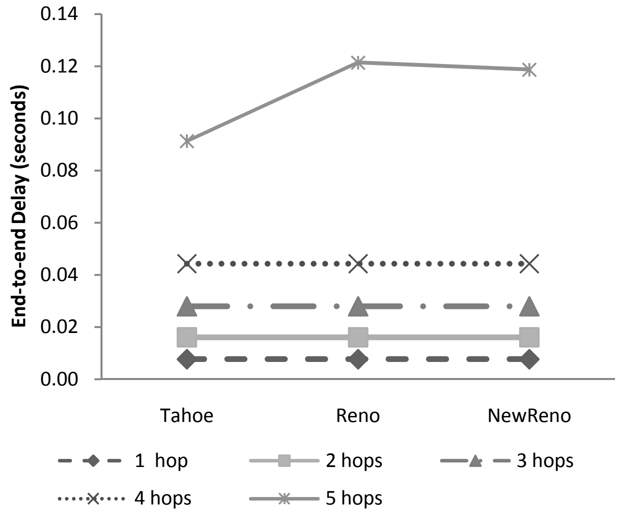

Fig. 8 End-to-end delay for Ring topology

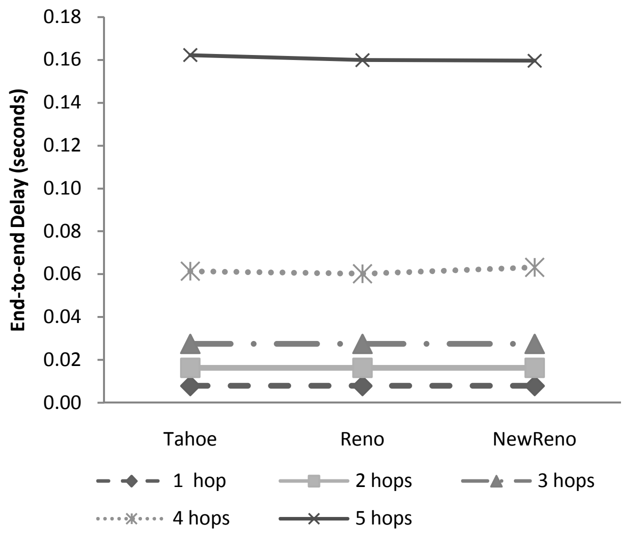

Fig. 9 End-to-end delay for Grid topology

C. Hop Count vs. Packet Loss Ratio

The packet loss ratio is calculated based on the differences between number of sent packets and number of received packets over total sent packets. Based on the simulation result, there is less number of packet losses occurred within 3 hops communication. In this case, the value of packet loss ratio is almost zero percentage. This insignificant figure represents the effectiveness of RTS-CTS mechanism on handling concurrent transmission. From other research, the fact of packet loss ratio increased when number of hops is more than 3 also has been proved [28]. Therefore, the following discussion only emphasizes on the packet loss ratio for more than 3 hops as illustrated in Fig. 11 to Fig. 13.

In string topology, the packet loss ratio over variants of TCP CC is between 3.0% until 5.0% for both 4 and 5 hops cases. It can be seen that number of packet loss in 4 hops is always higher than 5 hops. Meanwhile, for ring topology, packet loss is only detected when 5 hop communications is involved and it has been measured to be not more than 3.0%.

Fig. 13 represents packet loss ratio for grid topology; communication involves 4 hops over different TCP CC gives very low value at less than 0.5% compared to 5 hops which can reach up to nearly 6.0%.

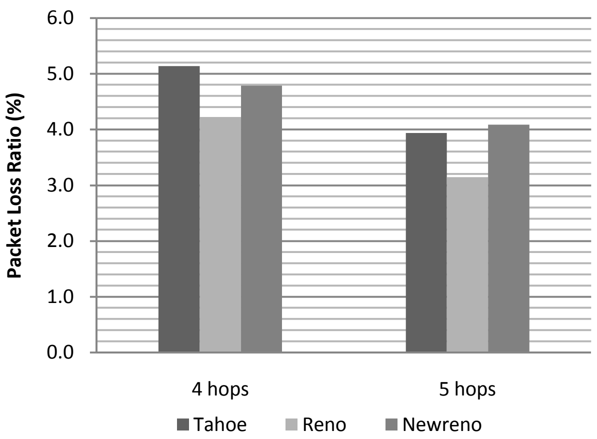

Fig. 10 Packet loss ratio for String topology

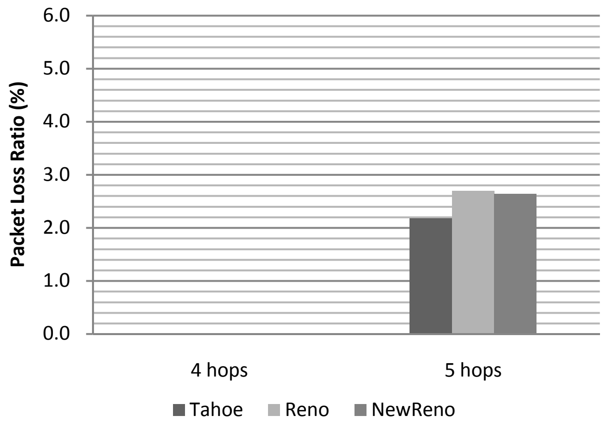

Fig. 11 Packet loss ratio for Ring topology

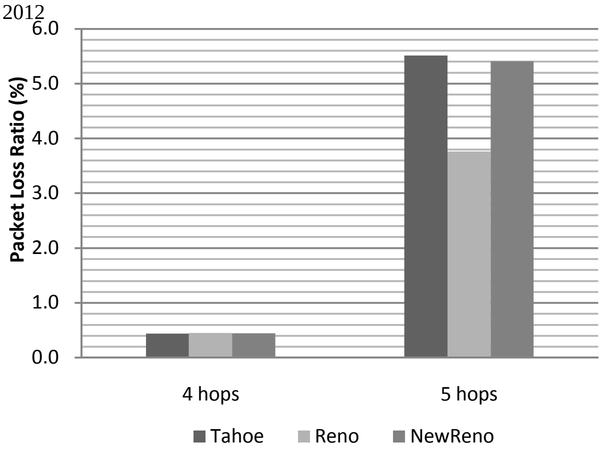

Fig. 12 Packet loss ratio for Grid topology

V. CONCLUSION

Based on the above findings, we can conclude that packet transmission over multi-hops network has been influenced by network topology itself. Even though the packet transmission only occurred within transmission range, there is another element that needs to be taken into consideration. It is related to interference range which is given as 2 times of transmission range (2X). From our observation, both ring and grid are exposed to the overlapping of interference range. This becomes worse when there are more than 3 hops communications. In term of difference TCP CC mechanism, TCP Newreno is recommended to be a benchmark for our future investigation in the effect of different error rate and background traffic over same topologies.

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REFERENCES

[1] Samal, C.K., *TCP Performance through Simulation and Testbed in Multi-Hop Mobile Ad hoc Network.* International Journal of Computer Networks & Communications (IJCNC) 2010. 2 (4): p. 109-124.
[2] Leung, K.C. and V.O.K. Li, *Transmission control protocol (TCP) in wireless networks: issues, approaches, and challenges.* Communications Surveys & Tutorials, IEEE, 2006. 8(4): p. 64-79.
[3] Paxson, V., *End-to-end internet packet dynamics.* IEEE/ACM Transactions on Networking (TON), 1999. 7(3): p. 277-292.
[4] Jain, R., *Congestion control in computer networks: issues and trends.* Network, IEEE, 1990. 4(3): p. 24-30.
[5] Xu, K., Y. Tian, and N. Ansari, *TCP-Jersey for wireless IP communications.* Selected Areas in Communications, IEEE Journal on, 2004. 22(4): p. 747-756.
[6] Jindal, A. and K. Psounis, *Wireless contention in mobile multi-hop networks*. 2007, Citeseer.
[7] Chen, K., Y. Xue, and K. Nahrstedt. *On setting TCP's congestion window limit in mobile ad hoc networks*. 2003: IEEE.
[8] Floyd, S. and V. Paxson, *Difficulties in simulating the internet.* IEEE/ACM Transactions on Networking (TON), 2001. 9(4): p. 392-403.
[9] Gerla, M., K. Tang, and R. Bagrodia. *TCP performance in wireless multi-hop networks*. 1999: IEEE.
[10] Jacobson, V. *Congestion avoidance and control*. 1988: ACM.
[11] Li, T. and D.J. Leith, *Buffer sizing for TCP flows in 802.11 e WLANs.* Communications Letters, IEEE, 2008. 12(3): p. 216-218.

[12] Ali, M.M., A.K.M.S. Alam, and M.S. Sarker, *TCP Performance Enhancement in Wireless Mobile Ad Hoc Networks.* International Journal, 2011. 1.

[13] Low, S.H., F. Paganini, and J.C. Doyle, *Internet congestion control.* Control Systems Magazine, IEEE, 2002. 22(1): p. 28-43.

[14] Postel, J., *RFC 793: Transmission control protocol*. 1981, September.

[15] Aaron, A. and S. Tsao, *Techniques to improve TCP over wireless links.* Final Report, EE. 359.

[16] Ho, C.Y., Y.C. Chen, and Y.C. Chan, *Fast retransmit and fast recovery schemes of transport protocols: A survey and taxonomy.* Computer Networks, 2008. 52(6): p. 1308-1327.

[17] Floyd, S. and T. Henderson, *The NewReno modification to TCP's fast recovery algorithm.* 1999.

[18] Prabakaran, M., A. Mahasenan, and A. Kumar. *Analysis and enhancement of TCP performance over an IEEE 802.11 multi-hop wireless network: single session case*. 2005: IEEE.

[19] Al Hanbali, A., E. Altman, and P. Nain, *A survey of TCP over ad hoc networks.* IEEE Communications Surveys & Tutorials, 2005. 7(3): p. 22-36.

[20] Hallani, H. and S. Shahrestani, *Improving the Performance of Wireless Ad-hoc Networks: Accounting for the Behavior of Selfish Nodes.* Communications, 2011. 2011.

[21] Gupta, S., C.K. Nagpal, and C. Singla, *Impact of Selfish Node Concentration in MANETs.* International Journal, 2011. 3.

[22] Fu, Z., et al. *The impact of multihop wireless channel on TCP throughput and loss*. 2003: IEEE.

[23] Fu, Z., X. Meng, and S. Lu. *How bad TCP can perform in mobile ad hoc networks*. 2002: IEEE.

[24] *Information Sciences Institute, The NS-2 simulator, www.isi.edu/nsnam/ns.*

[25] Breslau, L., et al., *Advances in network simulation.* Computer, 2000. 33(5): p. 59-67.

[26] Habbal, A.M.M. and S. Hassan. *Loss Detection and Recovery Techniques for TCP in Mobile Ad Hoc Network*. 2010: IEEE.

[27] Nahm, K., A. Helmy, and C.C.J. Kuo, *Cross-layer interaction of TCP and ad hoc routing protocols in multihop IEEE 802.11 networks.* IEEE Transactions on Mobile Computing, 2007: p. 458-469.

[28] Ikeda, M., et al. *Mobility effects of wireless multi-hop networks in indoor scenarios*. 2010: IEEE.

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