Performance Evaluation of Variants of TCP Based on Buffer Management over WiMAX

Ashish Chhabra
Research Scholar, M.Tech (CSE)
MVEC, Jagadhri-India
Affiliated to Kurukshetra University
Email ID: ash1491@gmail.com

Ankush Dhiman
Research Scholar, M.Tech (CSE)
MVEC, Jagadhri-India
Affiliated to Kurukshetra University
Email ID: dhiman.ankush@outlook.com

Mauli Joshi
Assistant Professor in Computer Science & Engg
MVEC, Jagadhri-India
Affiliated to Kurukshetra University
Email ID: mauli.joshi@gmail.com

Abstract

Currently, Worldwide Interoperability for Microwave Access (WiMAX) is one of the hottest technologies in wireless based on the IEEE 802.16 wireless technology which offers high throughput broadband connections over long distance that supports Point to Multi-point (PMP) broadband wireless access. In this paper work, we focuses on TCP sender side mechanisms and appropriate buffer management algorithm to handle higher offered load, random losses and retransmission timeouts in high delay networks in such a way as to keep congestion window as high as possible, while keeping the congestion under control and keep retransmissions to minimal. The TCP proposed mechanisms are assessed against TCP New Reno, TCP Westwood, and TCP CUBIC to view how they fare against congestion under higher mobility speed. Ns2 simulator is selected as the simulation tool because of the ease of use of the graphical interface provided and extensive support of TCP.

1. Introduction

WiMAX is an acronym for Worldwide Interoperability for Microwave Access. It is based on OFDMA (Orthogonal Frequency Division Multiple Access) technology that offers preferable spectral efficiency as well as overall capacity than the 3G network currently being deployed. The main motive of WiMAX is use to support multiple services such as multimedia broadcasting, web browsing, video streaming and voice etc. Essentially, WiMAX is a next-generation wireless technology that enhances broadband wireless access. WiMAX is expected to solve the problems of rural connectivity, as it is suited for remote places that don't have an established infrastructure of power lines or telephone poles. WiMAX provides both enhanced range and download speeds. It is a telecommunications protocol that provides fixed and mobile Internet access.

WiMAX comes in two phases: fixed wireless and mobile. Fixed version – It is known as IEEE 802.16d (2004), was designed to be a replacement or supplement for broadband cable access or DSL. A recently ratified version, IEEE 802.16e (2005), also can support fixed wireless applications, but it allows for roaming among base stations as well. WiMAX is a wireless broadband solution that offers a rich set of features with a lot of flexibility in terms of deployment options and potential service offerings.

TCP (Transmission Control Protocol) is a connection-oriented point-to-point protocol. TCP is the protocol that supports nearly all Internet applications. TCP is utilized by a large number of IP applications like email, Web services, and TELNET. TCP ensures that data is transferred reliably from a source to a destination. In this research paper, we target on TCP sender side mechanisms and appropriate buffer management algorithm to handle higher offered load, random losses and retransmission timeouts in high delay networks in such a way as to keep congestion window as high as possible, while keeping the congestion under control and keep retransmissions to minimal. The TCP proposed mechanisms are assessed against TCP New Reno, TCP Westwood and TCP CUBIC to see how they fare against congestion under higher mobility speed. Ns2 simulator is selected as the simulation tool because of the ease of use of the graphical interface provided and extensive support of TCP. The free license availability for research purpose encouraged us to select ns2 simulator as well.

2. Background

2.1 Definition of WiMAX

"WiMAX refers to collection of products, standards and service offerings obtained from the IEEE 802.16 family of standards which is based on OFDMA (Orthogonal Frequency Division Multiple Access) technology that offers preferable spectral efficiency as well as overall capacity than the 3G network currently being deployed."

2.2 Features of WiMAX

In general WiMAX has set of salient features which are as follows:

- High Data Rate – WiMAX supports very high peak data rates. Indeed, the peak PHY data rate can be as high as 74 Mbps.
- Mobility – In mobile system, WiMAX has mechanisms to support secure seamless handovers and power saving mechanism as well that distend the battery life of handheld subscriber devices.
- Scalable Bandwidth and Data Rate Support – WiMAX has scalable physical layer architecture that support for operation in distinct frequency bands and channelization.
- Support for TDD and FDD – WiMAX supports both time division duplexing and frequency division duplexing that allows for a low cost system implementation.
- QoS of WiMAX MAC is constructed to support a large number of users with multiple connections per terminal each with its own QoS necessity.

2.3 WiMAX Networks Architecture

WiMAX has been introduced as a circean wireless communication technology owing its capability to provide high data rate communications for metropolitan areas. So far, a number of specifications for WiMAX were standardized by the IEEE 802.16 Working Group. As per standards, WiMAX can support upto 75 Mbps data rate and can cover on how it can offer cost effective solutions for a variety of existing and potential services. Figure 1 represents the WiMAX network architecture.

- **Access Services Network (ASN) –** It is the access network of WiMAX and it offers the interface between the user and the core service network.

- **Base Station (BS) –** It provides the interface between the mobile user and the WiMAX network. The coverage radius of BS in urban areas is around 500–900m and a rural area is nearly around 4 km.

- **ASN Gateway** – It performs functions of connection and mobility management and inter-service provider network boundaries via processing of subscriber control and bearer data traffic.

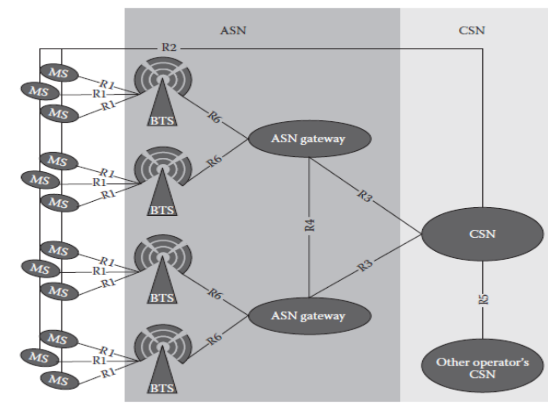

Figure 1 WiMAX Network Architecture

Currently, specifications in WiMAX standards can be categorize into two parts: the Physical (PHY) Layer and the Medium Access Control (MAC) Layer.

2.3.1 Physical (PHY) Layer Specification

WiMAX Physical Layer is based on OFDM (Orthogonal Frequency Division Multiplexing) technology that enables high speed data, video and multimedia communications. IEEE 802.16 supports four PHY specifications: wireless MAN-SC (Single Carrier, 10-66 GHz), Wireless MAN-SCa (Single Carrier below 11 GHz), Wireless MAN-OFDM (Orthogonal Frequency Division Multiplexing, below 11 GHz), and Wireless MAN-OFDMA (Orthogonal Frequency Division Multiple Access, below 11 GHz).

2.3.2 Medium Access Layer Specification

WiMAX was constructed for point to multipoint broadband wireless access applications. Its main task is to provide an interface between the higher transport layers and the physical layer.

2.3.2.1 Classification of WiMAX MAC

IEEE802.16 MAC supports two modes*: Point-to-Multipoint* and *Mesh Modes*. *Point-to-Multipoint*

(PMP) is basically designed to provide the last-mile access to the Internet Service Providers (ISPs). In PMP, a WiMAX network is divided into cells and sectors consisting of one base station (BS) and many subscriber stations (SSs). PMP can be seemed as a tree topology in which the root is base station (BS) and leaves are the Subscriber Stations (SSs). *Mesh Network* is a multihop adhoc network in which subscriber stations can connect with one another directly. In mesh network, BS can provide access to the service provider.

2.3.2.2 WiMAX MAC Features

The main objective of WiMAX MAC is used to optimize system level application performance. Here some of the salient features of WiMAX are presented below as:

- Connection based Service differentiation
- Scheduling types and opportunistic scheduler
- Link Adaption and ARQ (Automatic Repeat Request)

3. Related Work

K. Tsiknas et al. evaluate through simulations the performance characteristics of various TCP schemes namely -TCP New Reno, Vegas, Veno, Westwood and BIC, in WiMAX networks, by taking into account the effects of wireless channel errors, link congestion in both forward and They also suggest Binary Increase Adaptive Decrease (BIAD) paradigm will be benefited by both the quick window expansions of BIC and by the appropriate window adaptations of Westwood, thus offering in overall a better performance in WiMAX networks.

Parab et al. had discussed that TCP is being used as a highly reliable end-to-end protocol for transporting applications. TCP was originally designed for wired links where the error rate is really low and actually assumed that packet losses are due to congestion in the network. But TCP performance in wireless networks suffers from significant throughput degradation and delays.

Md. Shohidul Islam et al. focuses on analysis of eleven variants-Tahoe, Full-Tcp, TCP-Asym, Reno, Reno-Asym, Newreno, Newreno-Asym, Sack, Fack, Vegas and Vegas-RBPas source and five-TCPSink, TCPSink-Asym, Sack, DelAckand Sack1-DelAck as destination, implemented in Network Simulator (NS-2). Performance of TCP versions indicates how they respond to various network parameters-propagation delay, bandwidth, TTL (time to live), RTT (round trip time), rate of packet sending and so on. Such analysis is immensely in need to be aware of which TCP is better for a specific criterion, wherefrom an appropriate one will be selected in respective network to optimize traffic goal.

F. Furqan Doan et al. propose a mechanism namely WiMAX Fair Intelligent Congestion Control (WFICC) to avoid congestion at the base station. WFICC ensures that the traffic is scheduled in such a way that the base station output buffer operates at a target operating point, without violating the QoS requirements of connections. A detailed simulation study is performed in ns-2 to evaluate the effectiveness of proposed algorithm to meet the QoS requirements of different Class of Services (CoSs).

Shraddha Bansal et al. investigate the performance of mobile WiMAX, its physical layer is simulated using Matlab and bit error rate (BER) performance is observed. Further performance improvement is achieved using forward error correction codes (FEC). Two codes, convolution code (CC) and low density parity check code (LDPC) are considered for this purpose. BER performance is evaluated for these codes under different conditions.

4. TCP Variants

TCP is connection oriented data transfer protocol with well established mechanism for flow and congestion control based on the sliding window. In this study, we utilize TCP variants and outline the basic operations as well. Interested readers are referred to the original literature for more details.

4.1 TCP Reno

TCP Reno employs the principle of Tahoe like slow starts and the congestion avoidance. Reno requires that we receive immediate acknowledgement whenever a segment is received. The main idea behind this is that whenever we receive a duplicate acknowledgment then his duplicate acknowledgment could have been received if the next segment in sequence expected, has been delayed in the network and the segments reached there out of order or else that the packet is lost. If we receive a number of duplicate acknowledgements then that means that sufficient time have passed and even if the segment had taken a longer path, it should have gotten to the receiver by now. There is a very high probability that it was lost. So Reno suggests an algorithm called _Fast Re-Transmit‘. Whenever we receive 3 duplicate ACK_s we take it as a sign that the segment was lost, so we re-transmit the segment without waiting for timeout. Thus we manage to re-transmit the segment with the pipe almost full. Another modification that RENO makes is in that after a packet loss, it does not reduce the congestion window to 1. Since this empties the pipe. It enters into an algorithm which we call Fast-Re-Transmit'**.**

4.2 TCP New Reno

TCP New RENO has slight modification over TCP-RENO. It is able to detect multiple packet losses and thus is much more efficient that RENO in the event of multiple packet losses. Like RENO, New-RENO also enters into fast-retransmit when it receives multiple duplicate packets, however it differs from RENO in that it does not exit fast-recovery until all the data which was out standing at the time it entered fast recovery is acknowledged.

The fast-recovery phase proceeds as in Reno, however when a fresh ACK is received then there are two cases:

- If it ACK_s all the segments which were outstanding when we entered fast recovery then it exits fast recovery and sets CWD to threshold value and continues congestion avoidance like Tahoe.

- If the ACK is a partial ACK then it deduces that the next segment in line was lost and it re-transmits that segment and sets the number of duplicate ACKS received to zero. It exits Fast recovery when all the data in the window is acknowledged.

4.3 TCP Sack

TCP with Selective Acknowledgments is an extension of TCP RENO and it works around the problems face by TCP RENO and TCP New-RENO, namely detection of multiple lost packets, and re-transmission of more than one lost packet per RTT. SACK retains the slow-start and fast retransmits parts of RENO. It also has the coarse grained timeout of Tahoe to fall back on, in case a packet loss is not detected by the modified algorithm. SACK TCP requires that segments not be acknowledged cumulatively but should be acknowledged selectively. If there are no such segments outstanding then it sends a new packet**.** Thus more than one lost segment can be sent in one RTT.

4.4 TCP Fack

FACK or Forward Acknowledgement is a special algorithm that works on top of the SACK options, and is geared at congestion controlling. FACK algorithm uses information provided by SACK to add more precise control to the injection of data into the network during recovery – this is achieved by explicitly measuring the total number of bytes of data outstanding in the network. FACK decouples congestion control from data recovery thereby attaining more precise control over the data flow in the network. The main idea of FACK algorithm is to consider the most forward selective acknowledgement sequence number as a sign that all the previous acknowledged segments were lost. This observation allows improving recovery of losses significantly.

4.5 TCP Vegas

TCP Vegas is a modification of RENO. It builds on the fact that proactive measure to encounter congestion is much more efficient than reactive ones. It tried to get around the problem of coarse grain timeouts by suggesting an algorithm which checks for timeouts at a very efficient schedule. Also it overcomes the problem of requiring enough duplicate acknowledgements to detect a packet loss as well as suggests a modified slow start algorithm which prevents it from congesting the network.

4.6 TCP Westwood

TCP Westwood makes no attempt to correct the problem of non-congestion packet loss in wireless networks solely like Veno, but rather to improve the efficiency of TCP in all heterogeneous networks. It estimates the network's bandwidth by properly low-pass filtering and averaging the rate of returning acknowledgment packets per RTT. It then uses this bandwidth estimate to adjust the *ssthresh*and the *cwnd*to a value close to it when a packet loss is experienced *(adaptive decrease).* In particular, when three DUPACKs are received, both the *cwnd* and *ssthresh*are set equal to the *Estimated Bandwidth (BWE)* times the minimum measured RTT *(RTTmin)*; when a coarse timeout expires, the *ssthresh* is set as before, while the *cwnd* is set equal to one. The improvement of Westwood is a more realistic bandwidth estimation in comparison to TCP Vegas, which significantly increases TCP throughput over wireless links. TCP Westwood has also been tested in against handovers in simulated

5. Simulations

This chapter is rooted on simulation scenarios, performance measures and the final results. Here performance of variants of TCP is gauged over WiMAX. The results of simulation will retraced that which transport layer protocol conveys preferable performance. The performance measures employed in these scenarios are Throughput, Average Delay, Packet Data Ratio and Routing Load.

5.1 NS-2 Simulators

The Simulator employed in this thesis is NS-2 that is Network Simulator Version 2. It is an open source and discrete event simulator focused at networking research. NS-2 offers extensive support for simulation of TCP, routing and multicast protocols over wired and wireless networks. NS-2 is basically an Object-oriented script interpreter that offers feature like simulation event scheduler and network component object libraries. It is based on two main languages that is OTcl (Object Oriented Tool Command Language) and C++. Figure 2 represents the simulation cycle of NS-2.

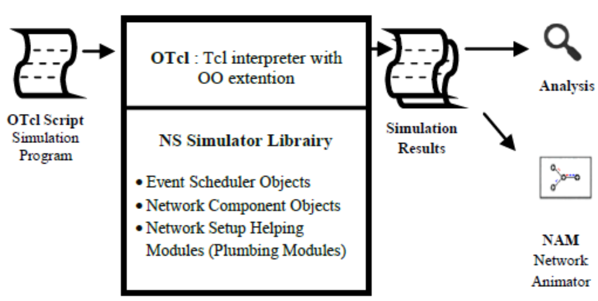

Figure 2 Simulation Cycle of NS-2

5.2 Simulation Environment

This simulation process considered a wireless network of network size consisting of 50 nodes which are placed within a 1000m x 1000m area. FTP traffic is generated among the nodes. The simulation runs for 200 Seconds. Table I shows the important simulation parameters used in the simulation process.

Table 1: Important Simulation Parameters

Parameter	Value
Simulation time	200 Sec
Simulation area	1600m x 1600m
Antenna	Omni antenna
No. of nodes	50
TCP –Variants	TCP-New Reno, TCP- Westwood, and TCP-CUBIC
Modulation & Coding	BPSK ½
Traffic	FTP
TCP segment size	1024 bytes
Cyclic prefix	¼
Frame duration	10 msec
Mean speed	30, 40, 50, 60, 70, and 80

5.3 Performance Parameter

- **Throughput –** Throughput is rate of number of packets received at the receiver with respect to the time taken. Units are bytes/sec or bits/sec.
- **Packet Delivery Ratio (PDR) –** PDR is the ratio of number of packets received over connections to destination to the total number of packets sent over the destinations through these connections.
- **Average Delay -** The average delay a data packet takes to travel from the source to the destination node. Delay in the arrival of a packet is introduced due to queuing of packets at the interface of node, time of transmission, time of retransmission due MAC, delay due to buffering during route discovery.
- **Routing Load –** It is calculated as total number of control packets transmitted. The increase in routing message overhead reduces the performance of the ad hoc network. Routing a packet to its destination is done by network layer.

6. Results and Analysis

In this paper, we presented the performance evaluation of various TCP variants under based on traffic generators like FTP under higher offered load network scenario based on varying mean speed of subscriber's nodes exploiting NS-2. Firstly we will discuss the simulation scenarios and model as well as the network topology and movement of nodes with traffic models will be the next. Then detail simulation results and analysis will be presented.

6.1 Simulation Scenarios and Model

A simulation model based on NS-2 has been exploited in the evaluation and in order to perfectly evaluate the effect of out-of-order packet while multi-path routing protocol is utilized in distinct simulation scenarios have been used.

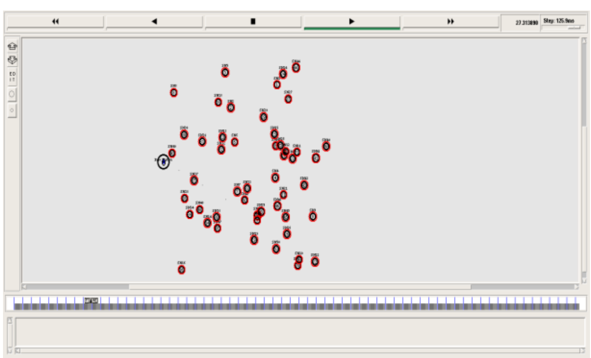

Figure 3 Nam animation trace with node deployment.

The NS-2 simulator supports for simulating wireless networks consists of different network components including physical, data link, and medium access control (MAC) layer models. *IEEE 802.16* for wireless networks is used as the MAC layer protocol. All packets sent by the routing layer are queued at the *interface queue* until the MAC layer can transmit them. The *interface queue* has a maximum size of 50 packets and is worked as a priority queue. The routing protocols that have been chosen at the network layer are OLSR under multi-path route between base station and subscriber station.

6.2 The Traffic and Mobility Models

FTP is a data generator utilized the TCP agent for traffic source and application. The source-destination pairs are spread instant over the network. Mobility models were created for the simulations using 50 nodes and this model was set in such a manner that first all the 50 nodes were offered with initial location in the given rectangular topography field. The field configuration used is: 1600 m x 1600 m field. Then all the nodes move within their boundary by setting their final destination and the speed that each node move with. All the simulations are run for 200 simulated seconds. Different mobility and identical traffic scenarios are used across the protocol to collect fair results.

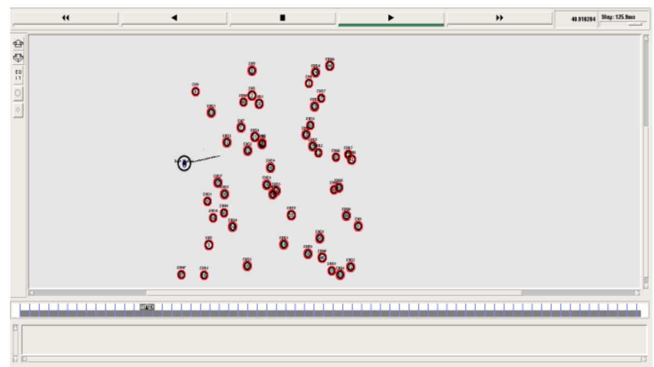

Figure 4 Nam animation trace with TCP- New Reno mobility rate 30 m/s and node density of 50 nodes.

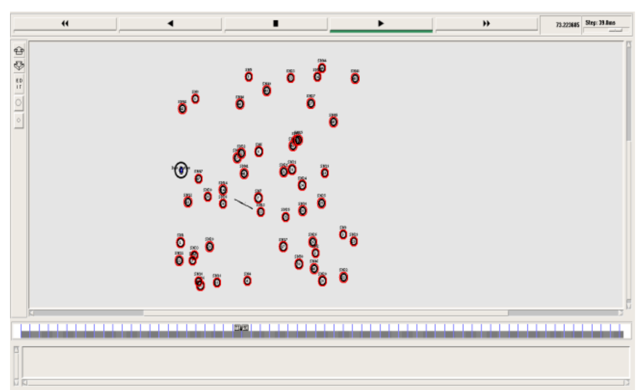

Figure 5 Nam animation trace with TCP-Westwood mobility rate 30 m/s and node density of 50 nodes.

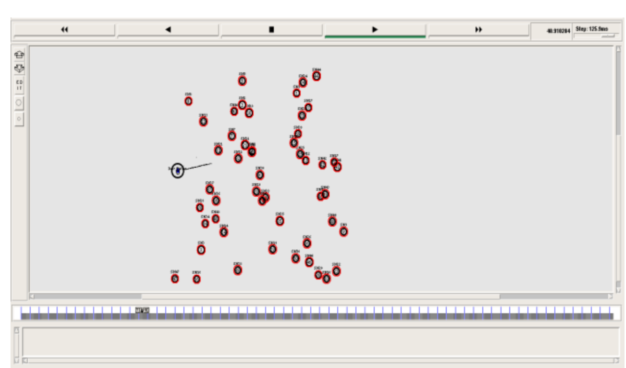

Figure 6 Nam animation trace with TCP- CUBIC mobility rate 30 m/s and node density of 50 nodes.

6.3 Performance Evaluation and Result Analysis

Now we will present the impact of mobility rates of subscriber's stations on the performance of TCP-variants with the help of graphs in terms of packet delivery ratio, end-to-end delay, throughput and normalized routing load. A detail simulation study is presented below.

Throughput

The figure 7 shown below represents the impact of mean speed of subscriber's stations on the throughput over distinct mobility rates. From this graph, it is observed that the throughput of TCP-CUBIC and TCP-WESTWOOD is better than other TCP variants. When the mobility rate is higher the throughput is maximum.

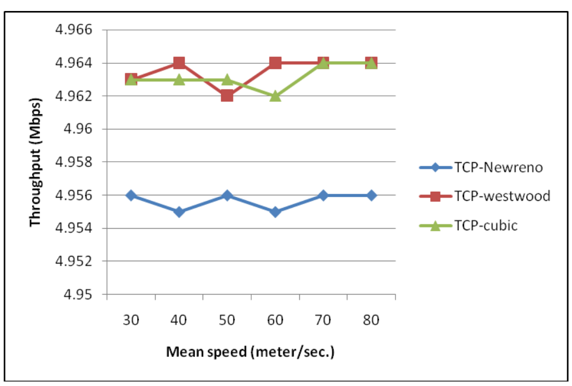

Figure 7 Throughput versus mean speed

Packet Delivery Ratio (PDR)

Figure 8 represents the packet delivery ratio for different TCP versions when the mean spped is varied. Simulation results shows TCP-CUBIC protocol gives higher performace when mobility rate is small. It is observed that the packet delivery ratio of TCP Westwoodis better than both TCP-New Reno and TCP-CUBIC .

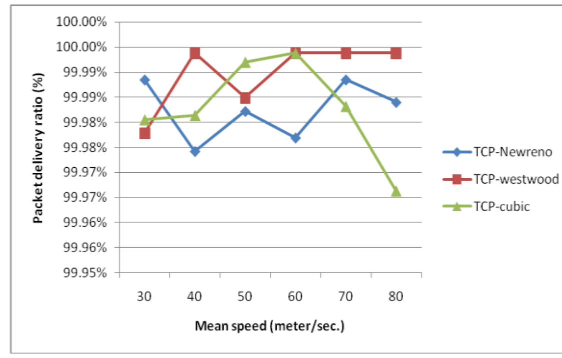

Figure 8 PDR versus mean speed.

Average Delay

The figure 9 presents the impact of cyclic prefix on the end-to-end delay The end-to-end delay of TCP-Westwood is better than other two TCP-variants. TCP calculates the network's bandwidth by properly low-pass filtering and averaging the rate of returning acknowledgment packets per RTT.

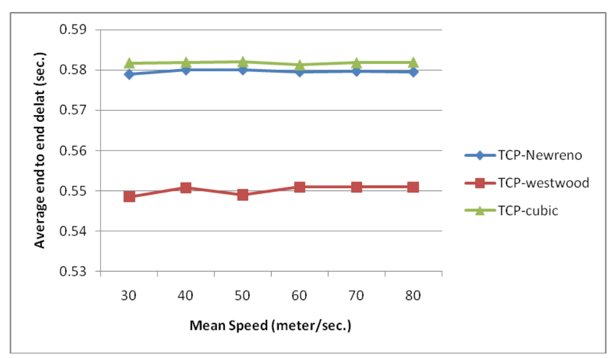

Figure 9 Average Delay versus mean speed

Routing Load

The figure 10 represents the impact of mean speed on the routing load. It is observed that the routing load of TCP-CUBIC is better than TCP-New reno and TCP-Westwood for higher mobility rates.

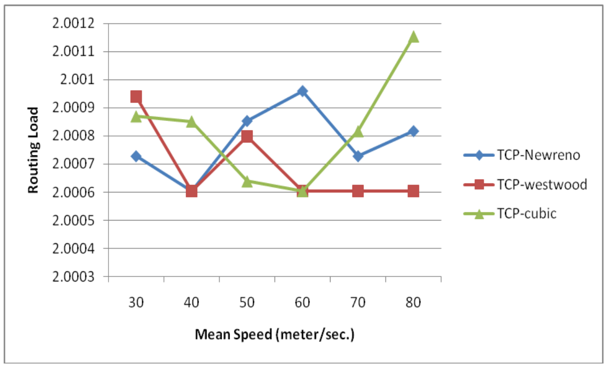

Figure 10 Routing overhead versus mean speed

7. Conclusion and Future Work

It has been observed that TCP can experience significant performance degradation during hand-off if multiple packet droppings, packet re-ordering or exorbitant hand-off delays occur. We also have shown that the reaction on packet droppings and re-ordering is much related to the employed TCP variant. These TCP variants behave differently in distinct conditions. Some of the TCP variants which are TCP-New Reno, TCP-Westwood and TCP-CUBIC and here we have performed the comparison of these variants under distinct mobility condition.

Through simulation, we noted that TCP throughput reduces notably when node movement cases link failures owing TCP's inability to recognize the difference between link failure and congestion. From the view of throughput, average delay and packet delivery ratio, TCP CUBIC is the exquisite congestion control scheme out of selected TCP variants. However, from the view of average delay, TCP-Westwood shows better results than TCP cubic. From analysis, we found that TCP-CUBIC is better than other TCP variants in case of increasing Random Packet Loss as well as in case of increasing mobility.

On the basis of the results obtained from simulation graphs and some trials in the literature, we can expand this work by improving TCP-cubic performance over WiMAX environment using QoS bandwidth allocation schemes, which is our interesting future work.

5. References

[1] B. Chen, I. Marsic, R. Miller, “Issues and Improvements in TCP Performance over Multihop Wireless Networks”, IEEE Sarnoff Symposium, 2008.

[2] Georgi Kirov, “A Simulation Analysis of the TCP Control Algorithms”, International Conference on Computer Systems and Technologies, 2005.

[3] Konstantinos Tsiknas, George Stamatelos,” Performance Evaluation of TCP in IEEE 802.16 Networks”, Wireless communication and networking conference: mobile and wireless network, IEEE, 2012.

[4] C. Chen, H. Wang, Xin Wang, M. Li, A.O. Lim, “A Novel Receiver-aided Scheme for Improving TCP Performance in Multi-hop Wireless Networks”, in Proc. of Int. Conference on Communications and Mobile Computing, pp. 272–277, 2009.

[5] Parab, A. Nikose and P. Bhosale, “Comparative analysis of different TCP variants in a wireless environment”, Electronics Computer Technology ICECT, 3rd International Conference on, Vol. 4, 2011, pp no. 158 – 162.

[6] Md. Shohidul Islam, M.A Kashem, W.H Sadid, M. A Rahman, M.N Islam,” TCP Variants and Network Parameters: A Comprehensive Performance Analysis”, Proceedings of the International Multi-Conference of Engineers and Computer Scientists, vol. 2, pp - 978-988, 2009.

[7] P. Omprakash, R. Sabitha,”Performance Analysis of TCP over WiMAX”, IEEE, 2011.

[8] Fatima Furqan and Doan B. Hoang, “WFICC: A New Mechanism for Provision of QoS and Congestion Control in WiMAX”, The 10th Annual IEEE CCNC-Wireless Networking, IEEE, 2013.

[9] T. Anouar and A. Haqiq,"Performance Analysis of VoIP Traffic in WiMAX using various Service Classes" International Journal of Computer Applications, vol. -20, 2012, pp. 29-33.

[10] Shraddha Bansal, Raksha Upadhyay, "Performance Improvement of Wi-Max IEEE 802.16e in Presence of Different FEC Codes", CICSYN, IEEE, 2009.

[11] M. Rehan Rasheed," Performance of Routing Protocols in WiMAX Networks", International Journal of Engineering and Technology, vol.2, no.5, October 2010.

[12] Injong Rhee, and LisongXu," CUBIC: A New TCP-Friendly High-Speed TCP Variant", SIGOPS, ACM, vol. - 42, 2008.

[13] HumayunBakht, "Survey of Routing Protocols for Mobile Ad-hoc Network", International Journal of Information and Communication Technology Research, vol.1, no. 6, ISSN-2223-4985.

[14] VikramMehta,"Performance Analysis of QoS Parameters for WiMAX Networks", International Journal of Engineering and Innovative Technology, vol.1, issue-5, May 2012.

[15] R. Wang, M. Valla, M.Y. Sanadid and Mario Gerla, "Efficiency/Friendliness Tradeoffs in TCP Westwood" Proceedings of the Seventh International Symposium on Computers and Communications (ISCC'02), IEEE, 2002, pp. 304-311.

[16] Tuan Anh Le, Choong Seon Hong, and Eui-Nam Huh, "Coordinated TCP Westwood Congestion Control for Multiple Paths over Wireless Networks" International Conference on Information Networking (ICOIN), IEEE, 2012, pp. 92-96.

[17] Chih-He Chiang, Wanjiun Liao, and Tehuang Liu," Adaptive Downlink and Uplink Channel Split Ratio Determination for TCP-Based Best Effort Traffic in TDD-Based WiMAX Networks", journal on selected areas in communications, IEEE, vol. 27, no. 2, 2009.

[18] L. Subedi, M.Najiminaini, and L. Trajković,"Performance E Evaluation of TCP Tahoe, Reno, Reno with SACK, and NewReno Using OPNET Modeler", Proceeding of International Conference on Methods and Models in Computer Science, IEEE, 2009.

[18] Jeng-Ji Huang, Jin-Fu Chang," A New Method to Improve the Performance of TCP SACKover Wireless Links", IEEE, 2003.

[19] Matthew Mathis and Jamshid Mahdavi," Forward Acknowledgment: Refning TCP Congestion Control", Computer Communication Review, ACM – SIGCOMM, vol. -26, no. 4, october 1996.

[20] B. Puzzolante, G. Redaelli, and G.Grazia, "Nationwide implementation of a WiMAX mobile access network at CEFRIEL" STEM, 2006.

[21] R. Hincapie, J. Sierra, R. Bustamante, "Remote locations coverage analysis with wireless mesh networks based on IEEE 802.16 Standard" IEEE Communications Magazine, 45(1): 120–127, January 2007.

[22] Schroth, "The evolution of WiMAX service providers and applications", Yankee Group Report. September 2005.

[23] IEEE. Standard 802.16-2004. Part16: Air interface for fixed broadband wireless access systems. October 2004.

[24] A. J. Goldsmith, "Wireless Communications", Cambridge University Press, 2005.