Cross-layer Analysis of Mobility Impact on TCP Protocols in IEEE 802.11 Wireless Networks

Toni Janevski, and Ivan Petrov

Abstract— **In this paper we provide cross-layer analysis of the impact of mobility and Medium Access Control parameters in IEEE 802.11 wireless network on variety TCP versions. Performances of the Internet transport protocols may significantly degrade when end to end connection includes wireless links where packets delays and losses are caused by mobility and transmission errors. The analysis showed that the impact of Medium Access Control parameters, such as number of retransmissions and interface queue length in 802.11 networks on the obtained throughput, is stronger for terminals with higher mobility.**

Index Terms—**TCP, Throughput, Transmission Protocols, Wireless Network.**

I. INTRODUCTION

THE rapid development of Internet and wireless technologies resulted in their integration. In that manner all IEEE wireless networks are IP native, i.e. they define physical and Medium Access Control (MAC) layers, while the network layer is reserved for IP. On one side Internet is based on TCP/IP protocol suite targeted for usage by non-real-time applications (e.g. web, ftp, email etc.) and UDP for data from real-time applications (e.g. voice over IP, streaming, etc.). On the other side, the most successful IEEE wireless networks so far are IEEE 802.11, which have been introduced almost in every device that requires wireless connectivity. Then, we have IP protocol suite running over the 802.11 protocols on lower layers, and it is not difficult for one to see the importance of understanding the cross-layer relations in such scenarios, which is main subject in this paper as well.

TCP and UDP, which are part of the TCP/IP protocol suite, which were carefully tuned in order to maximize their performance on wired networks where packet delays and losses are caused by congestion [1]-[3]. In the wireless networks, delays and losses are mainly caused by mobility handoffs and transmission errors due to bad wireless channel conditions. With the recent developments in mobile wireless networking, the performance of the Internet transport protocols in mobile wireless environment is becoming more important. We should mention that the protocols for wireless access have been designed in order to maximize the utilization of the wireless channel for web browsing and file downloading applications in an environment with restricted mobility, which is the main reason why the buffers and the local Medium Access Control (MAC) retransmissions are tuned in a way to maximize the throughput and the reliability for this kind of applications. In order to decrease packet delay the transport protocols used to deliver real time services and applications to the end user are simple and do not incorporate traffic control and packet retransmission mechanisms. We focus our attention at the impact of the diverse MAC layer and buffer settings of IEEE 802.11g wireless access technology of the Internet native transport protocol suite during the distribution of multimedia applications in realistic static and mobile scenario.

The paper is organized as follows: Section II gives brief overview of the transport protocols, discusses some related work and motivates the need for our approach. It also briefly describes the 802.11 MAC protocol. Section III describes our simulation scenario and section IV presents the simulation results. Section V concludes the paper.

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II. IEEE 802.11 AND TRANSPORT PROTOCOLS

The first TCP implementations were using cumulative positive acknowledgements and required a retransmission timer expiration to send a lost data during the transport. They were following the go-back-n model in order to provide good user throughput. Lot of work has been done in order to improve its characteristics and with time TCP has evolved. Today's TCP implementations contain variety of algorithms that enables to control the network congestion and to maintain good user throughput in the wired network. Several variants of TCP can be found in the today's wired networks. TCP Tahoe, TCP Reno, TCP New Reno, TCP Vegas and TCP Sack are few of them that are going to be used in ours simulation scenarios. The most used variant of TCP in the real world today is TCP New Reno. TCP continuously probes for higher transfer rates, eventually queuing packets in the buffer associated with the bottleneck of the connection. The wireless connection can be shared by several devices and applications. In such case it is obvious that the connection level and the queue lengths may increase, thus delaying the packet delivery and hence jeopardizing the requirements of the real-time applications. Such situation is even worse because the wireless medium allows transmission of only one packet at a time and in most of the wireless networks it is not full-duplex as in wired links [4]-[6]. This means that packets should wait their turns to be transmitted. Interference, errors, fading, and mobility are causing additional packet losses, and the IEEE 802.11 MAC layer reacts through local retransmissions which in turn cause subsequent packets to wait in the queue until the scheduled ones or their retransmissions eventually reach the receiver. The back off mechanism of the IEEE 802.11 introduces an increasing amount of time before attempting again a retransmission. In the recent years there was a lot of research regarding the problems that TCP and UDP encounters in a wireless environment [7]-[9].

III. Simulation Scenario

The network layout of the simulation scenario that is subject of the conducted analysis in this paper is presented at Fig.1. We have used the network simulator NS2 in order to simulate the outdoor environment presented in Fig.1. We can notice that the network topology is consisting of four wired nodes (A0-A3), two wireless base stations (BS0-BS1) and four wireless nodes (n0-n3). The distance between two base stations is set at 20m. The wireless stations are configured to work according the IEEE 802.11g Standard. Wired connections are configured as given in Table I. Maximum achievable bandwidth rate is 20Mbps, instead of the maximal 54Mbps for IEEE 802.11g standard, due to home environment. The queue size value used in the simulation is calculated by multiplying the longest RTT (Round Trip Time) with the smallest link capacity on the path, which is the 20Mbps throughput effectively available over the wireless link. In Table II are presented several applications that are used during the simulation. In the simulation we have used real trace files for video chat and movie traffic. Two VBR H.263 Lecture Room-Cam are used for the Video chat and high quality MPEG4 Star Wars IV trace file is used for the movie. In this simulation the game events have been generated at the client side every 60ms [7]. At the server side updates were transmitted every 50ms toward the client. The payload generated by the client has been set to 42Bytes and the payload generated by the server has been set to 200Bytes. The rest of the packets were set to standard value of 512Bytes for TCP segments. The values for different parameters used in this scenario are listed in Table III. For the simulation we have used the shadowing model. The shadowing deviation (σ_{dB}) was set to 4 while the path loss exponent (β) was set to 2.7. These parameters are common for urban environment.

IV. Analysis of transport protocols

In the following part we observe simulation results from scenario presented in Fig.1, obtained by using the configuration parameters of the links given in Table I and applications defined in Table II. We study the behavior of the UDP/TCP applications and the TCP impact on real time applications in 802.11 wireless networks regarding the throughput as the most important performance metric for non-real-time flows (which use the TCP on transport layer). The queue size at the MAC layer and the number of MAC layer retransmissions in the given situation has no impact at the TCP throughput.

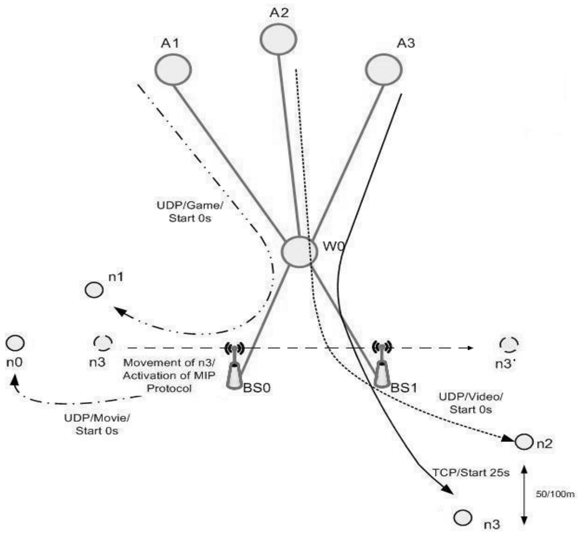

Fig. 1. Simulation Scenario

TABLE I. Configuration of wired links.

Node 1	Node 2	Delay	Capacity
A1	A0	10ms	100 Mbps
A2	A0	20ms	100 Mbps
A3	A0	30ms	100 Mbps
A0	BS0	10ms	100 Mbps
A0	BS1	10ms	100 Mbps

TABLE II. Applications and simulated traffic.

From	To	Type	Transport Protocol	Start	End
BS0	n0	Movie Stream	UDP	0s	110s
A1	n1	Game Traffic	UDP	10s	110s
n1	A1	Game Traffic	UDP	10.1s	110s
A2	N2	Video Chat	UDP	15s	110s
N2	A2	Video Chat	UDP	15.1s	110s
A3	N3	FTP	TCP	35s	110s

TABLE III. Simulation parameters.

Parameter	Values	Comments
MAC data retransmissions	1,2,3,4	Default value is set at 4
User-BS distance (m)	5, 10	Common indoor environment
MAC queue pkt. size	25,50,100	Common values
Velocity (km/h)	2; 4; 10	Random choice
TCP Transport protocol	TCP Tahoe, TCP Reno, TCP Newreno, TCP Vegas, TCP Sack	Commonly used types of TCP protocols in wired networks.

In Fig. 2 we show analyses of the throughput of an FTP application as a function of the distance, queue size and the number of MAC layer retransmissions. From the results one may conclude that the queue size of the MAC layer impacts the throughput for a given value of the number of MAC layer retransmissions. If we increase the number of the MAC layer retransmissions in this situation we are not obtaining better throughput. One may notice that the queue size (i.e. IFQ) at the MAC layer drastically impacts the throughput. It is obvious that if we increase the queue size we will obtain better throughput. It is also obvious that the same throughput is achieved for given values of the MAC layer queue size for the given MAC layer retransmissions. The best throughput is achieved when the Interface Queue (IFQ) has value of 100 packets. So far we are able to conclude that the throughput for all of these transport protocols (i.e. TCP versions) is decreasing as a function of the distance and is increasing as a function of IFQ buffer size. We are analyzing relatively small distances and defined simulation scenario where we have strong signal coverage and small attenuation. Hence, errors caused by the wireless channel conditions are small and the MAC layer has no need to activate its retransmission mechanism in order to improve the throughput. At this point one may conclude that only IFQ buffers size strongly influences the throughput. Furthermore, the best throughput is achieved when TCP SACK is used as a transport protocol (d=5m). If IFQ=50 and d=10m TCP Tahoe will have best performances, when IFQ receives value of 100 packets TCP Tahoe outperforms TCP SACK. On the other side, TCP Tahoe performs very poor for small IFQ values, i.e. it shows almost worst performances for IFQ=25 (the smallest IFQ value in our analysis) when compared with all other cases in Fig. 3. Further, TCP New Reno has slightly better performance than TCP Reno. TCP Reno has better performances than TCP Newreno when IFQ is set at value of 100 pkts which is not the case for smaller sizes of the IFQ buffer. When the distance between n3 and BS1 is set at 10m performances of the transport protocols differs from the previous one. In this case best performances are achieved with TCP Tahoe when IFQ buffer size receives values of 50/100pkts (it slightly outperforms TCP Sack) excluding the case when is set at 25 (in such case the throughput achieved with TCP Vegas has same value with the one achieved with TCP Newreno and TCP Reno). The performances of TCP SACK and TCP Newreno are overleaping (IFQ=50/100) except when IFQ receives value of 25pkts when TCP Sack outperforms TCP Newreno. TCP Vegas is on the forth place. The overall worst performances are achieved with TCP Reno. In Table IV we present average packet delay when TCP SACK is used as a transport protocol and the number of the MAC retransmissions is set to three, which are supporting the previous analysis. After we have performed detailed analysis of the throughput achieved in the simulation scenario when the nodes are static we continue with traffic analysis when n3 becomes mobile. For that purpose we have incorporated Mobile IPv4 protocol to handle the user mobility. In the first case we were analyzing static scenario when n3 was distanced from BS1 at 5 and 10m. In this case we will analyze scenario when n3 is in the radio coverage of the BS0 and starts moving towards BS1. In the way it makes handover from BS0 to BS1. In Fig. 4 we present the achieved throughput when n3 moves towards BS1 with speed of 2km/h and the results show that the number of MAC retransmissions has no impact on the achieved throughput, since the user velocity is very low.

The results are similar when we increase the velocity to 4 km/h and 10km/h for number of MAC retransmissions higher than 2. The key parameter that affects the throughput in this case is the value of the IFQ buffer size at the MAC layer of IEEE 802.11 wireless network.

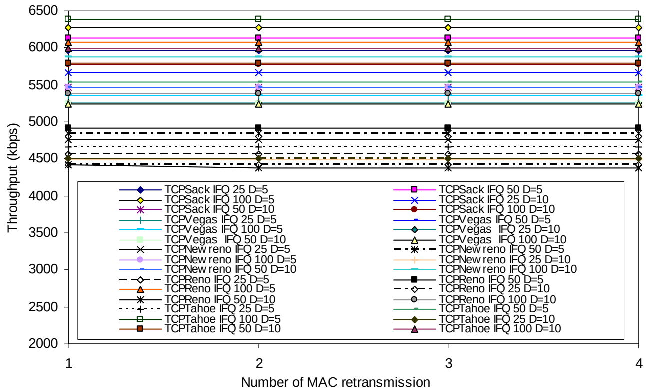

Fig. 2. TCP throughput for different TCP protocols using different MAC queue sizes and different number of MAC retransmissions; Distance between n3 and the BS1 is 5/10m.

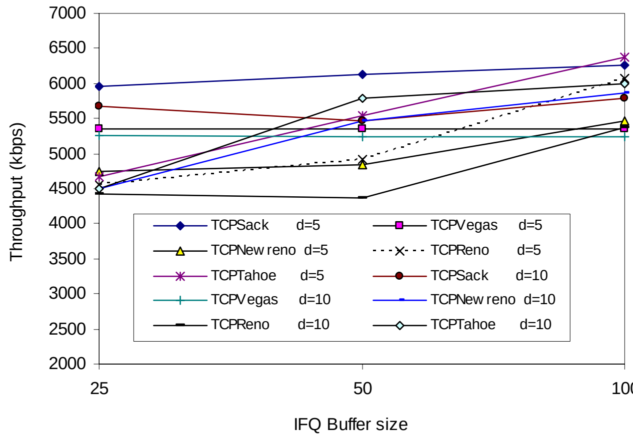

Fig. 3. Throughput of variety TCP protocols for different MAC queue sizes when the number of MAC retransmissions is set at 3; Distance between n3 and BS1 is set at 5/10m.

TABLE IV. ANALYSIS OF THE AVERAGE DELAY (MS) OF THE TCP FLOW WHEN IFQ BUFFER SIZE RECEIVES VALUE OF 25/50/100PKTS AND THE MAC RETRANSMISSIONS ARE SET AT 3.

L=3	IFQ 25 pkt	IFQ 50 pkt	IFQ 100pkt
TCPSack d=5m	52,039100	53,478400	62,162300
TCPVegas d=5m	60,672200	60,672200	60,672200
TCPNewreno d=5m	61,391700	58,365600	66,653300
TCPReno d=5m	61,441800	53,509500	64,882200
TCPTahoe d=5m	53,673500	54,577000	59,838700
TCPSack d=10m	47,2525	52,31	53,5591
TCPVegas d=10m	55,047900	55,081800	55,081800
TCPNewreno d=10m	45,4371	47,2713	60,6168
TCPReno d=10m	55,6586	52,7663	59,6343
TCPTahoe d=10m	54,166900	49,660600	64,8416

TABLE V. TCP AVERAGE THROUGHPUT WHEN MAC RETRANSMISSIONS ARE SET AT VALUE OF THREE, THE NODE N3 IS MOVING WITH VELOCITIES OF 2/4/10KMPH AND IFQ IS 50PKTS.

L=3;IFQ50	v=2km/h	v=4km/h	v=10km/h
1	TCP Tahoe	TCP Sack	TCP Tahoe
2	TCP Sack	TCP Vegas	TCP Sack
3	TCP Newreno	TCP Newreno	TCP Newreno
4	TCP Vegas	TCP Reno	TCP Vegas
5	TCP Reno	TCP Tahoe	TCP Reno

In table V are given in quality decreasing order (top is the best, bottom is the worst) the TCP transport protocols that have showed best performance for given speed when IFQ is set at 50pkts and L has value of three. From Fig. 5 and Table V one may conclude that best performances are obtained with TCP Tahoe, which is followed by TCP Sack, and third is TCP Newreno which is followed by TCP Vegas.

V. CONCLUSION

In this paper we have performed detailed traffic analyses regarding the performances of different TCP versions in 802.11 wireless networks. We have compared different transport protocols by using the throughput as a merit. The results showed the high importance of the Medium Access Control (MAC) parameters in 802.11 wireless networks regarding the throughput. After this analyzes we are able to conclude that: distance between nodes directly impacts the TCP-based traffic flow and its throughput. The throughput decreases as a function of the distance between the nodes in the wireless environment. The number of the MAC layer retransmissions for small distances does not influence the obtained throughput. MAC layer queue size directly affects the traffic flows in the wireless environment especially for shorter distances between the wireless nodes so it has to be carefully tuned in order to achieve higher wireless link utilization.

The choice of the TCP transport protocol affects the throughput in the network. Overall, best performances in static environment were provided by TCP Sack while in mobile environment were achieved with TCP Tahoe. Mobility directly impacts the throughput. The throughput decreases as a function of the speed. However, it can be optimized with proper choice of TCP version and MAC queue size in 802.11 wireless networks. The provided analysis raised the necessity for creation of open transport protocol layer, especially for the case of wireless networks in the home, vehicles or in the office. Our future work is targeted to solutions for open transport layer protocols in future wireless terminals, which is a target for wireless local networks, but certainly it will not be limited to them.

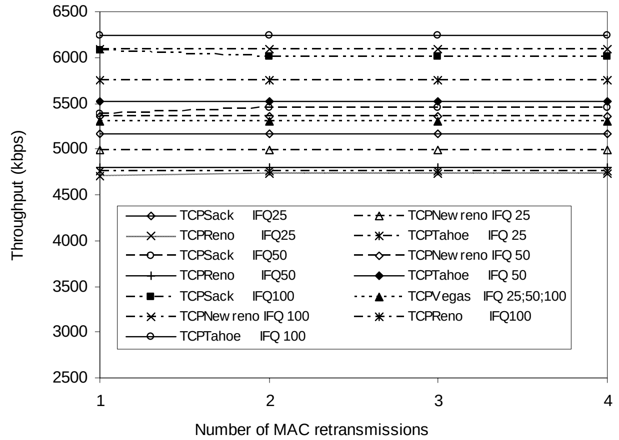

Fig. 4. Throughput when FTP flow is enabled with different TCP protocols and n3 is moving towards BS1

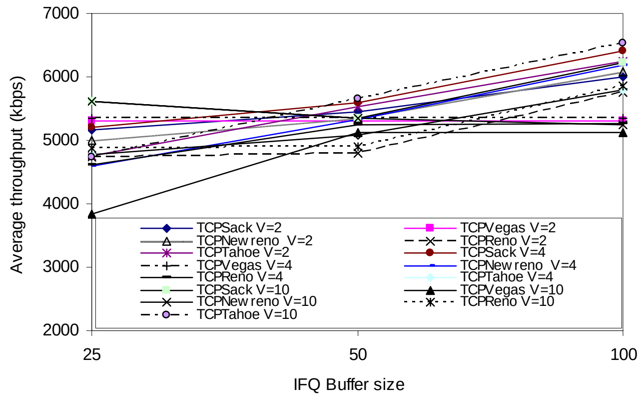

Fig. 5. Throughput of the FTP flow when the number of MAC retransmissions is three, n3 is moving toward BS1 with speed of V=2/4/10 kmph.

REFERENCES

[1] K. Fall, S. Floyd, "Simulation-based comparisons of Tahoe, Reno and SACK TCP", ACM SIGCOMM Computer Communication Review, Volume 26, Issue 3, Pages: 5 - 21, July 1996.

[2] V. Jacobson, "Congestion Avoidance and Control", SIGCOMM Symposium on Communications Architectures and Protocols, pages 314–329, 1988.

[3] V. Jacobson. "Modified TCP Congestion Avoidance Algorithm", Technical report, 30 Apr. 1990.

[4] B. Moraru, F. Copaciu, G. Lazar, V. Dobrota, "Practical Analysis of TCP Implementations: Tahoe, Reno, NewReno", 2nd RoEduNet International Conference, 2003.

[5] J. Mo, R.J. La, V. Anantharam, J. Walrand, "Analysis and comparison of TCP Reno and Vegas", IEEE INFOCOM '99, Pages 1556-1563, vol. 3, March 1999.

[6] G. Holland, N. Vaidya, "Analysis of TCP Performance over Mobile Ad Hoc Networks", Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking, Pages 219-230, 1999.

[7] Claudio E. Palazzi, Giovanni Pau, Marco Roccetti, Stefano Ferretti, Mario Gerla, "Wireless Home Entertainment Center: Reducing Last Hop Delays for Real-time Applications", ACM International Conference Proceeding Series, vol. 266, article no. 67, 2006.

[8] Martin A.V.D., Mihailovic A., Georganopoulos N., Aghvami A.H., "Adaptation of transport protocols for an IP-micromobility scheme", IEEE International Conference on Communications (ICC 2001), Pages 2462-2466, Helsinki, Finland, 2001.

[9] L. Le, S. Albayrak, M. Elkotob, A.C. Toker, "Improving TCP Goodput in 802.11 Access Networks", ICC '07, IEEE International Conference on Communications, Pages 4494-4499, Glasgow, Scotland, June 2007.