Improving TCP Performance on CSMA/CA Connections

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***Abstract*—In IP networks, most of packets, that have been dropped, are recovered after the expiration of retransmission timeouts. These can result in unnecessary retransmissions and needless reduction of congestion window. An inappropriate retransmission timeout has a huge impact on TCP performance. In this paper we have proved that CSMA/CA mechanism can cause TCP retransmissions due to CSMA/CA effects. For this we have observed three wireless connections that use CSMA/CA: with good link quality, poor link quality and in presence of cross traffic. The measurements have been performed using real devices. Through tracking of each transmitted packet it is possible to analyze the relation between one-way delay and packet loss probability and the cumulative distribution of distances between peaks of OWDs. The distribution of OWDs and the distances between peaks of OWDs are the most important parameters of tuning TCP retransmission timeout on CSMA/CA networks. A new perspective through investigating the dynamical relation between one-way delay and packet loss ratio depending on the link quality to enhance the TCP performance has been provided.**

***Keywords:* CSMA/CA, TCP performance, retransmission timeout, wireless.**

I. INTRODUCTION

With the popularity of third generation wireless wide-area networks (WWAN), the CDMA technology [1] is fairly mature now. Fourth generation WWAN, basically based on LTE [2][3] and WiMAX [4] technology, are being increasingly deployed throughout the world. Besides 3G and 4G networks, wireless LAN networks are widely used at homes, schools and enterprises. Besides the common telephone speech data, contemporary mobile access networks are increasingly used to convey data traffic to the internet – for private as well as for business users. With this trend, wireless access networks will convey all the burden of personal and business data traffic in the future. Consequently, efficient data transport will become the key for a commercial success of many mission- and business-critical applications. As the most popular transport protocol in internet, TCP performance in such wireless connections is crucial. Media Access Control (MAC) is the core of the data link layer. Although the wireless MAC Layer has defined two types of access methods, Distributed Coordination Function (DCF) [5] and Point Coordination Function (PCF) [6], only the DCF mechanism, which is based on CSMA/CA [7] technology, is used in the most commercial products [8]. So, an increase of TCP performance on CSMA/CA networks is an important task that will have a broad and significant impact on the exploding mobile based applications.

TCP uses two types of retransmissions: one is based on timeout and the other is based on the receiving of duplicated ACKs. When a timeout based retransmission occurred, TCP sender reduces its Congestion Window Size (CWS) down to one segment and continues transmission within slow-start phase until the CWS reaches the half of the value that was before the timeout. Then the sender enters the congestion avoidance phase. As a reaction on ACKs-duplication based retransmission, the sender only halves its CWS, then immediately enters the congestion avoidance phase. The timeout based retransmissions have bigger impact on TCP performance than the duplicated ACKs. When the value of TCP retransmission timeout is too small, after a timeout, TCP sender assumes that the outgoing packet is lost and the slow-start phase is triggered. However the acknowledgment will be returned back shortly. If the retransmission timeout is too large, it will also affect the TCP performance. This paper is motivated by recent researches [9][10][11]. In [9] and [10], authors have shown that 70% of the dropped packets are recovered after expiration of retransmission timeouts. In addition, the study in [11] has proposed that more than 20% of the retransmission timeouts are caused spuriously by transmission delay of packets which results in unnecessary retransmissions and needless reduction of congestion window size. The idea of setting the retransmission timeout properly is the focus of our further work.

In this work, we have proved that the usage of CSMA/CA mechanism can cause TCP retransmissions and proposed a new perspective to improve the TCP performance on CSMA/CA connections. Within the accomplished experiments the salient part is that tracking each outgoing packet in data link layer with the measurement tool LTest [12] on CSMA/CA connections was realized. The basic assumption hereby is that through analyzing of the relation between one-way delay and packet loss probability, the normal calculation of retransmission timeouts can be adapted to the CSMA/CA characteristic in the future.

II. RELATED WORK

The performance of TCP over wireless networks has been studied intensively in recent decades. Early research [13][14][15][16], showed that high Bit Error Rates (BER) of wireless links affects the TCP performance significantly, since they are designed for wired networks TCP and can't distinguish whether packet losses are caused from congestion or other reasons, and invoke congestion control and congestion avoidance algorithms to respond on packet losses, that is a reason of a degraded performance in wireless connections. The proposal [17] showed the interest in adding SACK mechanism to TCP that provides to the sender sufficient information for quick recovering in presence of multiple packet losses within a single transmission window.

Work in [18][19][20] have reveal, that local retransmissions and error correction have reduced loss ratio on the wireless link. But at the same time the adverse effect of variations in packet transmission delay on upper layer protocol TCP has been brought.

In [21][22][23][24], the impact of data rate and latency variations on TCP performance using wireless links has been evaluated. In [21], an enhancement to TCP's error recovery has been proposed. Hereby, extra information in TCP header is used to eliminate the spurious timeouts, then the load is restored and next unsent packet is retransmitted. In [22] several recommendations like the use of Selective Acknowledgments, Large Window Size and Explicit Congestion Notification and enabling the timestamp option has been presented, to improve the performance of TCP on CSMA/CA connections. In [23], the ACK regulator has been presented as a solution to avoid multiple packet drops at the congested router for long-lived flows. In [24], Window Regulator Algorithm is proposed to maximize long–lived TCP performance in the presence of channel variations for any given buffer size at the congested router.

There are also some studies [25][26][27] proposed analyze of the data link layer to promote the TCP performance on CSMA/CA networks. In [25], authors show that the proper choice of parameters of backoff mechanism has a huge influence on the network performance. The most crucial point is to select minimal Contend Window (CW_{min}) and maximal Contend Window (CW_{max}) depending on the number of stations between the hosts. In [26], a simple self-adaptive Contention Window adjustment algorithm-MIMLD for CSMA/CA has been proposed. It adjusts the initial contention window dynamically to a near optimal point according to the traffic activity. In [27], a novel scheme has been proposed. This scheme is supposed to decrease protocol overhead, that causes the inefficiency of CSMA/CA and further achieve a higher data link rate.

In more recent research [12] and [28], solutions for detecting congestion retransmission timeouts and non-congestion timeouts have been presented. The paper [28] has further differentiated the two different types of non-congestion timeouts, random loss and spurious retransmission timeouts.

Although so many suggestions to improve TCP performance in this field have been proposed, but we have not found researches related to investigation of CSMA/CA influence on retransmissions and CWS of TCP. This paper is devoted to this topic.

III. TESTBED TOPOLOGY DESCRIPTION

The testbed topology used for the investigations of this paper contains:

- three computers with the CPU Modell Intel Pentium (R) E5500 @2.8GHz, Memory 1890M, under operation System Linux OpenSuSE 12.3, kernel 3.7.10-1.16;
- two CAT.6 SSTP 4X2XAWG27/7 patch cables
- one Linksys wireless broadband router which supports 802.11 b/g, model WRT54GL, firmware v4.30.7;
- two TP-LINK USB wireless adapters supported with 802.11 b/g/n.

The 802.11g supports a maximal link speed of 54 Mbps, however in real tests it is possible to achieve only about 40% of this maximal value. Since we want to track each outgoing packet into the radio link, besides those listed equipment, we need measurement tool LTest and network analysis tool Wireshark installed on these computers. The main goal is to achieve the observation of data link layer. Since LTest runs on application layer and there is partly wired connection, shown in Fig. 1, before performing of the test it is necessary to be sure whether these factors affect the CSMA/CA character or not. Usually the time delay of CSMA/CA is high and changes very often with a high standard deviation. For wired connection the back-off is only applied when the collision occurred, however due to the use of a switched full duplex connection, not collisions can occur at all. The packet delays in the wired Ethernet network is by orders of magnitude less than on the wireless links. LTest measures the one-way delay between two computers. In the wired local network is permanently about 200 µs. To get rid of the delay that caused not by wireless link, we conducted tests locally on PC and got the latency of 10 µs. It's obvious that these factors can be omitted when to study the characteristic of CSMA/CA.

The chosen wireless mode is the most common infrastructure mode, which, in comparison with ad-hoc mode offers advantage of stability, scalability, improved reach and centralized security. The experiment consists of three scenarios:

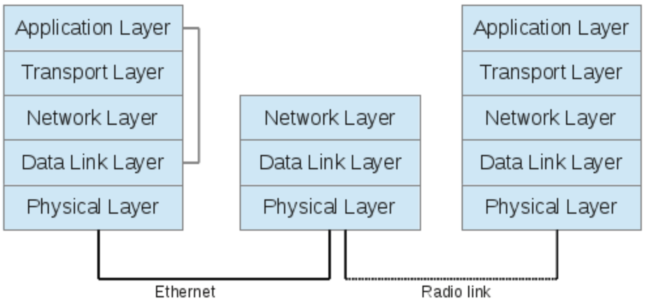

Fig. 1. Network layer topology.

- connection with good link quality and signal level;
- connection with a bad link quality and signal level;
- connection in presence of cross traffic

These three cases allow emulating the most common types of wireless environment. Fig. 2 shows the topology for scenario 1 and scenario 2. This topology allows observing how CSMA/CA works on each packet, because here CSMA/CA is only used in the downlink direction. Otherwise CSMA/CA would affect the results on both, uplink and downlink.

Computer 1 is connected via wire to the access point. The second and third workstations are connected to AP via wireless links. LTest-client on computer 1 sends packets to LTest-servers on computer 2 or 3. In scenario 1 computer 2 and access point are about 1 meter away from each other. For scenario 2, the computer 3 is moved 8 meters away from the access point and separated by a concrete wall in another room to get worse wireless conditions. The link parameters of both scenarios are shown in Table 1.

TABLE I
LINK INDICATORS

Scenario	Link Quality	Signal Level
1	65/70	-45 dBm
2	51/70	-59 dBm

The topology of scenario 2 is used to prove the assumption that the CSMA/CA mechanism can cause TCP retransmissions, though no packet loss is occurred. Fi. 3 shows the logic connections in Scenario 2. Two LTest servers on computer 3 are started on the same interface on different ports. After Wireshark is started on computer 1 to monitor interface, one LTest client uses TCP to connect to LTest Server 1 and the other LTest client uses UDP to connect to LTest Server 2. Both clients send data with a constant bit rate of 5 Mbps with MTU 1024 bytes. The duration of both measurement sessions is 5 minutes.

In scenario 3, additionally cross traffic is emulated. For this purpose the connection with third machine is used. In this scenario cross traffic is generated between machines 1 and 3 and the probe traffic is generated between machines 1 and 2. Worth to mention that cross traffic is acting during performing of test on scenario 3. Fig. 4 shows the described connections

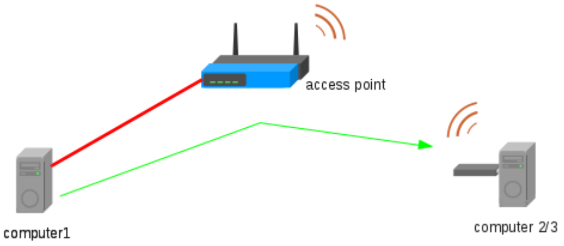

Fig. 2. Technical view of topology.

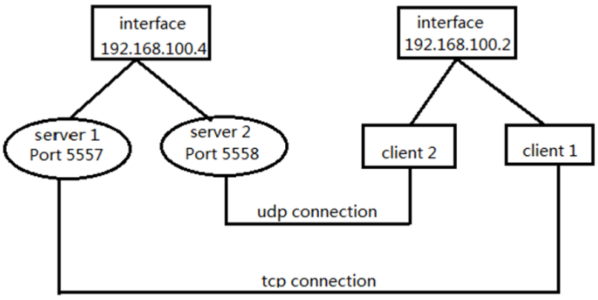

Fig. 3. Logic connections.

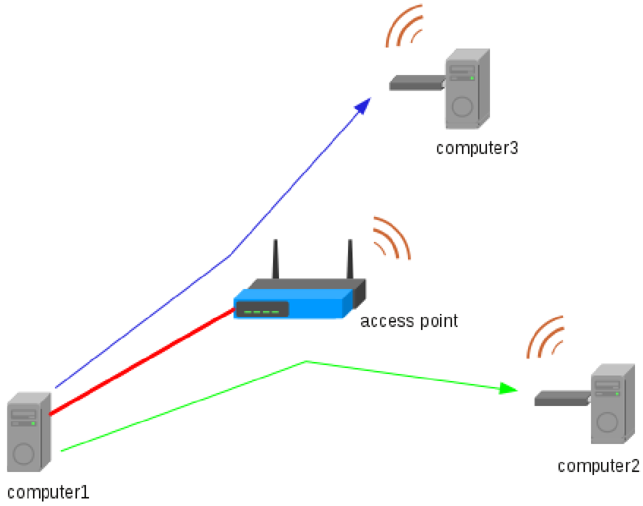

Fig. 4. cross traffic topology.

IV. EXPERIMENTAL RESULTS

During the experiment according to Fig. 3 6 retransmissions have occurred in the TCP session. At the same time there were only 2 packet losses in the UDP-connection. Sending time of TCP retransmissions and UDP packet losses are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. UDP has no timeout mechanism, so the packets were in fact lost. It means that at least two retransmissions over TCP-connection could be caused due to poor link quality. At least the other 4 retransmissions are then caused by TCP timeout. TCP timeout is caused by the long delay of CSMA/CA mechanism.

TABLE II
TCP RETRANSMISSION AND UDP PACKET LOSSES

Sending time of TCP retransmissions[s]	Sending time of UDP packet losses[s]
10.812	
26.885	26.822
28.999	
70.622	
92.924	
121.087	121.032

The TCP retransmissions that happened almost at the same time with UDP losses are not that valuable, since they happened due to real losses in the media. The behavior of TCP and UDP OWDs of around of the TCP retransmission at 92.924 s are plotted in Fig. 5. From the plot it is clear that TCP retransmission, depicted as a vertical line in the figure, occurred near the peak of UDP OWDs, where TCP OWD is almost twice bigger than UDP OWD. It is obvious that this TCP retransmission is caused by CSMA/CA mechanism.

The experiment for each scenario consists of 20 tests that have been made. Each test for all experiments is a transmission of data traffic with a constant bit rate of 5 Mbps using UDP with MTU 1024 bytes via AP from client machine to server machine. The duration of each test is 5 minutes. As the result of experiments the behavior of one-way delay (OWD) for each packet is collected for all the tests. These data will be used to show the delay profiles of CSMA/CA. The plot in Fig. 6 shows the behavior of OWD for one test of Scenario 1.

In Fig. 6 is worth to mention that one packet is delayed by about 10.9 ms after 6.44 s from the beginning of measurement, caused by the timeout in data link layer, then the other 7 packets will be buffered in buffer, after 10.9 ms these packets are sent successively, it can be easily proved on (1).

$$\text{Interpacket time} = \frac{1000\,ms}{5000000\,bit} * \frac{1024{*}8\,bit}{1\,packet} = 1.638\,\frac{ms}{packet} \qquad (1)$$

The amount of buffered packets (n) can be got through (2):

$$n = \frac{10.9\,ms}{1.638\,ms/packet} = 7 \qquad (2)$$

In a wireless environment in presence of impairments, these peaks, caused by collisions and bit errors, can appear very often and even cause successive packet losses. Each retransmission in data link layer leads to increasing of contention window, naturally the time delay between transport layers will be also increased. If the retransmission timeout in TCP is not properly set, it could also cause packet losses. It highlights the importance of this work to study profile of trfaffic that passes CSMA/CA connection, then tune TCP on CSMA/CA.

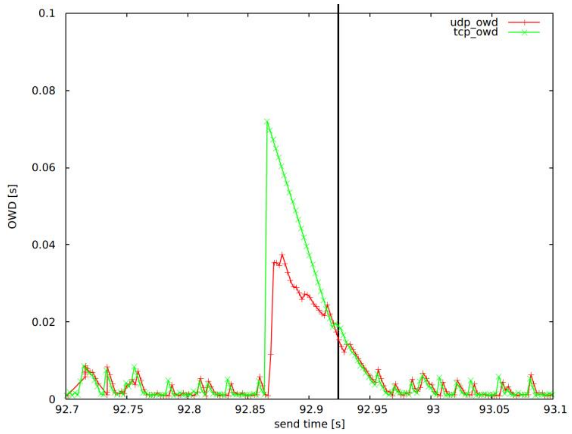

Fig. 5. OWDs over TCP-and UDP-connection.

There are no packet losses for first scenario, during the test. The result shows that the mean value of OWDs is about 900 µs. In comparison with scenario 1, in presence of packet loss ratio between 0 to 0.005 %, the mean value of OWDs increases up to approximatly 1800 µs in scenario 2. In scenario 3 packet losses are between 0.0001 and 0.21 % and the mean value of OWDs between 2000 µs and 8500 µs are retrieved.

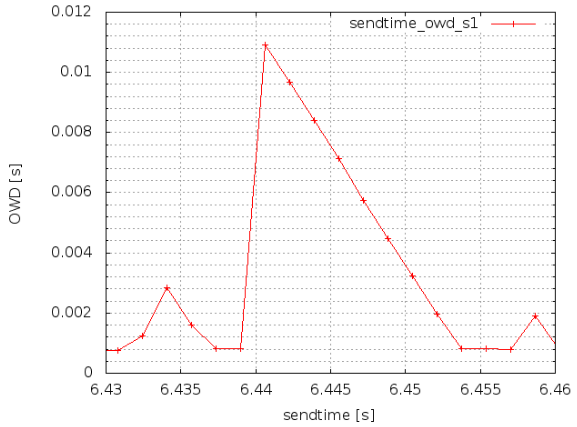

Fig. 6. OWD

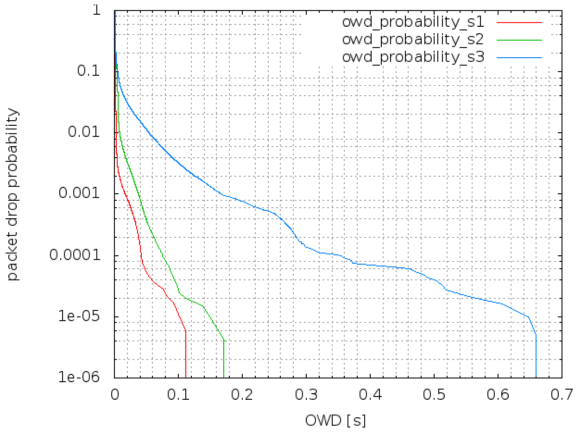

Fig. 7. Cumulative distribution of OWDs in 3 scenarios.

In Fig. 7 the cumulative distribution of OWDs is displayed in 3 scenarios.The OWDs in scenarios 1, 2 and 3 are distributed in the interval from 0 s to 0.12 s, from 0 s to 0.18 s and from 0 s to 0.67 s accordingly. The curves of scenarios 1 and 2 are much steeper than the of scenario 3. It means that the packet loss probability of scenario 1 and 2 decreases very rapidly with the increasing OWD. With a probability of 10^{-5},when a CSMA/CA off period occurs, it will cause in scenario 1 and 2 a delay of at least 0.101 s and 0.152 s respectively, however in scenario 3 it would cause an off-time of 0.65 s with the same probability. To suppress the packet loss rate, occurred on CSMA/CA peaks below 10^{-6}, in scenario 3 the actual retransmission timeout must be set to at least 0.67 s, whereby in scenario 1 and 2 a timeout of 0.12 s and 0.18 s respectively would be sufficient.

Through analysis of the distance between the OWDs peaks in 3 scenarios, the frequency of the appearance of the peak of OWDs in each scenario could be figured out. In other words, it will be known how often the peaks of OWDs occur. In Fig. 8 the cumulative distribution of distances between the peaks of OWDs is displayed for 3 scenarios. All peak values in scenario 2 occur under the distance of 0.03 s . Respectively 99.9855% and 99.963% of the total peaks in scenario 3 and 1 occur under the distance of 1.1 s. Peaks less than 0.15 s in scenario 3 and 1 take almost euqal 99.9928% of the total. It is also recognized that the peaks occur most frequently in scenario 2. Then the peaks in scenario 3 appear more often than in scenario 1.

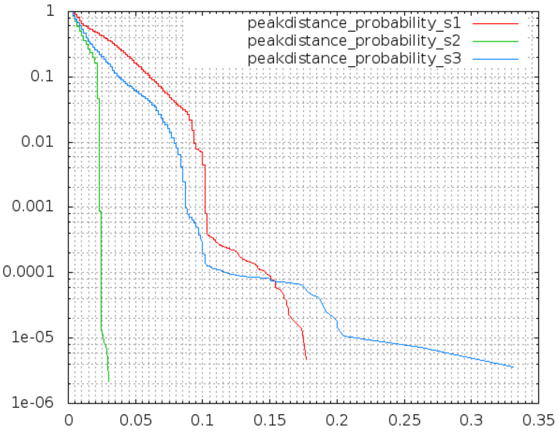

Fig. 8. Cumulative distribution of distance between peaks in 3 scenarios.

V. CONCLUSION AND FUTURE WORK

In this work we have proved that the CSMA/CA mechanism can cause TCP retransmissions. Besides, this work emulates the 3 most popular occasions in CSMA/CA connections: with good link quality, with bad link quality and in presence of cross traffic. Using LTest each packet has been traced, the influence of CSMA/CA on packet was extendedly observed. In summary, it can be determined that the CSMA/CA actually has a negative impact on TCP performance. The cumulative distribution of OWDs shows the relation between packet loss probability and OWDs.

The experiment shows that scenario 1, 2 and 3 need respectively 0.12s, 0.18s and 0.67 s to suppress the packet loss rate under 10^{-6}. In addition, the cumulative distribution of the distances between the peaks describes how often the peaks of OWDs appear. In the experiment it has been also retrieved that the peaks occur most frequently in scenario 2 and in scenario 3 the peaks appear more often than in scenario 1. It affects the performance of TCP, however if only the retransmission timeout is properly set, TCP performance will be increased. These two important informations could be used to modify the TCP-RTO. The way to improve the performance of TCP is proposed, however this work is still undergoing. In the future more measurents will be carried out in more complex test networks. We will test the relation between OWDs and packet losses probability with different link quality and contention levels, trying to get the dynamical relation CSMA/CA profiles. It would be very helpful to adjust the transmission timeout of TCP to CSMA/CA connections. The ultimate goal is to get a new algorithm for timeout in wireless network. We consist on, this will be a huge step towards tuning TCP performance over wireless network.

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