Adapting TCP Segment Size in Cellular Networks

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Abstract. In cellular networks, a frame size is generally made small to reduce the impact of errors. Thus, a segment of transport layer is splitted into multiple frames before transmission. A problem is that the whole segment is lost when a frame of a segment is lost. So, the segment error rate tends to be high even though the cellular network provides relatively the low frame error rate, which drops TCP performance. However, the relation between the frame size, the segment size and the error rate has not been closely investigated. In this paper, we analyze the impact of the segment size on TCP performance in cellular networks and propose a scheme alleviating the performance drop of TCP. Our result shows that our scheme reduces the drop by 82%.

1 Introduction

In cellular networks a frame, unit of transmission in physical layer, has very small size to reduce the frequent errors in hostile wireless channel conditions. Thus, a segment of TCP[1] is splitted into several frames and, then, transmitted one by one. A problem is that the whole segment is corrupted when even a frame is lost (See Fig.1). So, the segment error can occur very often though the frame error rate is low. It is very important to investigate the exact relationship among the frame size, the segment size and the frame errors closely since it makes severe influences on TCP and UDP performance.

We define some symbols to clarify the following discussions in this paper.

- s : payload size of a TCP segment.
- H : header size of IP and TCP layers.
- M : payload size of a frame in physical layer.
- n : number of frames consisting of a segment.
- p : segment corruption rate.
- e : frame error rate.

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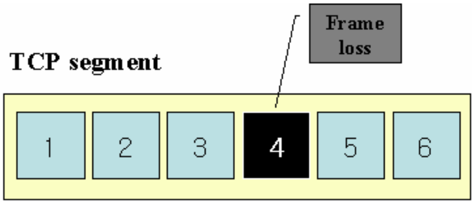


Fig. 1. Frame loss within a segment

The number of frames n is given as

$$n = \left\lceil \frac{H+s}{M} \right\rceil , \tag{1}$$

and the segment corruption rate is

$$p = 1 - (1-e)^n . \tag{2}$$

For example, when $s + H$ is 1500, M is 128, and e is 1%, p becomes about 11.4%. It says that the segment corruption rate can be extremely high even with small frame errors, depending on n.

This paper is organized as follows. In the following Section, we show the simulation results to show how the UDP and TCP throughput is affected by the segment size and frame error rate and analyze the reason. Also, some valuable guidelines for determining the segment size is derived based on the analysis. Section 3 describes a simple heuristic scheme to reduce the performance drop in TCP over cellular networks. We discuss the limit of our scheme and the need of future work in Section 4. Finally, Section 5 concludes the paper.

2 Simulation Result and Analysis

2.1 Simulation Environment

The simulation study is performed by ns 2.27 version[2], and topology is a typical cellular network shown in Fig.2. There is a link that has 2Mbps bandwidth and 200ms latency between MH (Mobile Host) and BS (Base Station). Also, a wired link has 10Mbps bandwidth and 20ms latency, and it is placed between BS and CH (Corresponding Host). In all experiments, Random uniform and Gilbert-Elliot error models are used in channel modeling, and the frame size of the cellular link is set to 128 bytes. To focus on the cellular networks, we assume that there is no packet loss event except buffer overflow at the router.

2.2 UDP Experiments

UDP is a connectionless protocol that has only the function of port multiplexing and header checksum. Therefore, UDP's behavior totally depends on the characteristic of application because it does not have any flow control and congestion

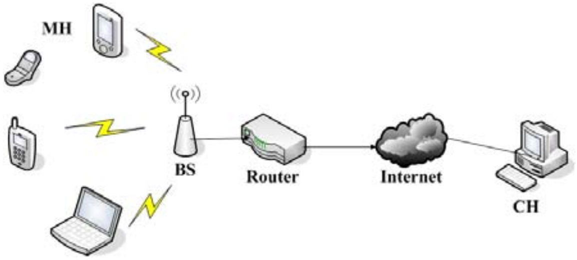
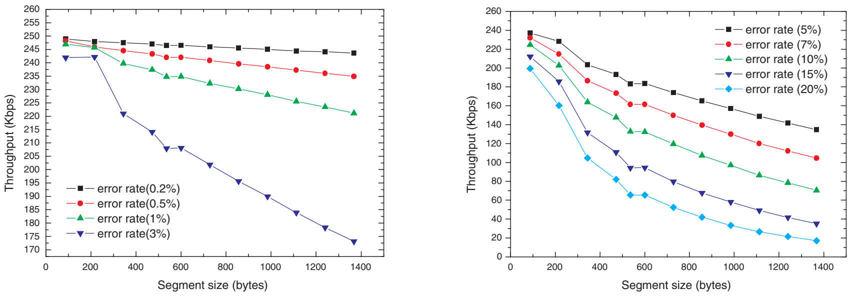


Fig. 2. Simulation topology

control mechanisms. Note that TCP's several complex mechanisms can make it difficult to observe the degree of the impact on throughput. Thus, with assumption that CBR (Constant Bit Rate) source is target application, our UDP experiment can be a basis model to understand an impact degree of the error rate and the difference of the frame and the segment size. To perform such experiments of UDP performance, we make a CBR source in the CH transmit data and a sink in the MH receive it. In all simulations, the frame size is set 128 bytes, and the throughput is measured varying the frame error rate from 0.2% to 20%, depending on the segment size. Also, same experiment is executed to observe the impact of the CBR's rate on the relation of the segment size and the error rate. Fig.3 shows how the segment size and the error rate affect the UDP throughput in case that CBR is 250Kbps. In Fig.3, we can see deeper decrease of the throughput when the error rate increases and the segment size gets large. Let us look in the case that the segment size is 1368 bytes. In this case, a segment split into 11 frames since the frame size is 128 bytes. If the link has 20% error rate in the average, only 7-8% throughput of non-error case can be achieved because about 92% segment error rate occurs. However, with 88 bytes segment, we can see almost 80% throughput of the non-error case, which means that the frame and the segment error rate are almost the same. As we can see in the simulation experiment, UDP performance is determined by the segment error rate and the header overhead. Note that the segment error rate increases as the frame number n increases by the equation 2. Fig.4 is the impact of 50Kbps CBR on the relation of the segment size and the error rate. It shows a similar decrease of the throughput although the throughput values are different.

2.3 TCP Experiments

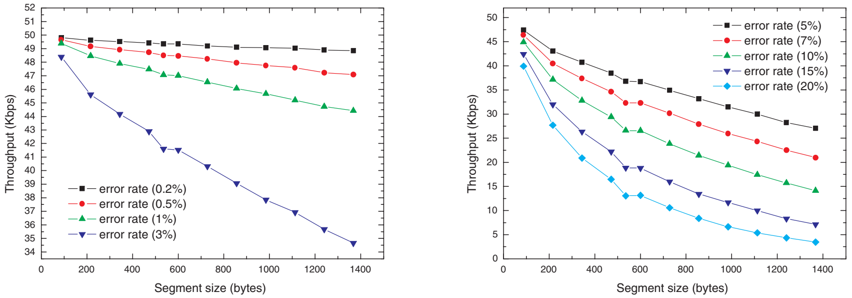
It is generally believed that TCP throughput degrades as the frame error rate increases, regardless of the segment size. Based on our UDP experiment, our conjecture is that TCP throughput varies depending on the segment size. We will prove this conjecture by simulation.



(a) Low error cases

(b) High error cases

Fig. 3. UDP throuhgput with 250Kbps CBR



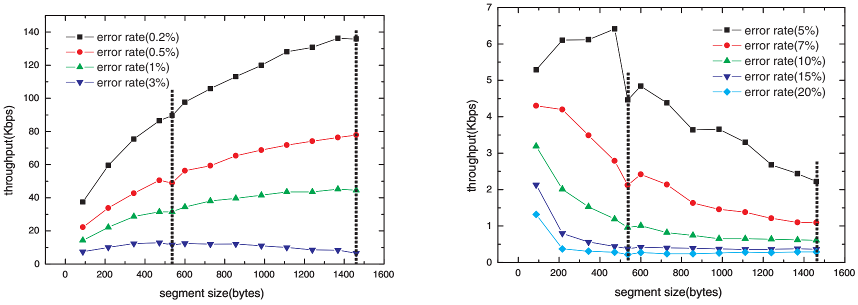
(a) Low error cases

(b) High error cases

Fig. 4. UDP throuhgput with 50Kbps CBR

2.4 Relationship of Frame Error Rate and Segment Size

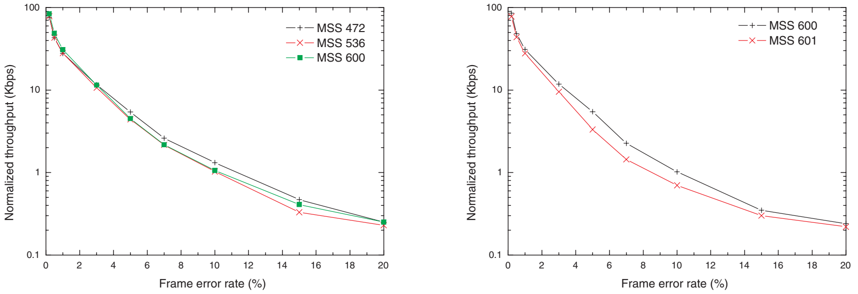
We measured TCP Reno's throughput for several segment sizes varying the frame error rate from 0 to 20%. The frame size is fixed to 128 bytes. Fig.5 shows the results for the segment sizes 88, 216, 344, 472, 536, 728, 856, 984, 1112, 1368 and 1460, which includes packet sizes frequently observed in IP networks. The gaps of TCP throughput between the high and the low error rates are so large that we present two separate figures. Fig.5(a) is when the frame error rate is low - the throughput increases with the segment size. When the frame error rate is high, the throughput decreases with the segment size as in Fig.5(b). Note the dip in the throughput graphs at the segment sizes 536 and 1460, especially in Fig.5(b). Since the segment sizes 536 and 1460 are the most common packet sizes in the Internet (the two cases are marked with dash line), we did some detailed study that is explained in the following subsection.



(a) Low error cases

(b) High error cases

Fig. 5. Throughput of TCP Reno



(a) MSS 472, 536, and 600

(b) MSS 600 and 601

Fig. 6. Normalized throughput of TCP Reno

2.5 Relationship Around the Segment Size 536

Fig.6 is the results of the detailed study around the segment size 536. Fig.6(a) says that the relationship of segment size and frame error rate is not always consistent. That is, 'MSS 600' shows better throughput than 'MSS 536' even when the error rate is high[1]. An outstanding difference of the two cases is that 'MSS 600' is aligned with the frame size[2] while 'MSS 536' is not, though they have the same number of frames. This shows that the protocol efficiency (defined as $\frac{s}{H+s}$) as well as the number of frames makes an effect on TCP performance though the degree of the influence is not high. Then, we observe the impact of

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[1] We use MSS and the segment size by same meaning.

[2] Note that 600+40 (TCP/IP header size) is a multiple of 128, the frame size.

the number of frames on TCP performance by comparing ‘MSS 600’ with ‘MSS 601’. Fig.6(b) clearly shows the difference between 5 frames (‘MSS 600’) and 6 frames (‘MSS 601’). Even if the latter has better protocol efficiency, it shows fewer throughputs than the former.

Fig.5 and 6 give us the following guidelines to determine an ”optimal” segment size.

- When the frame error rate is high, it is better to keep the segment size small.
- When the frame error rate is low, it is better to maintain the segment size large.
- In all cases, the segment size must be aligned to the frame size.

3 Heuristic Scheme

We propose a simple scheme adapting the MSS according to wireless channel conditions, whose algorithm is explained in Fig.7. Two different values of MSS are defined, small MSS and large MSS. The small MSS is used in bad channel condition and its size just fits in a frame. On the other hand, the large MSS is used in good channel condition and its size is determined by the path MTU discovery mechanism of TCP[3]. The frame error rate is used as an indicator of channel states. Fig.8 shows the performance of the proposed scheme, which keeps the TCP throughput approximately optimal in almost every case of the experiments.

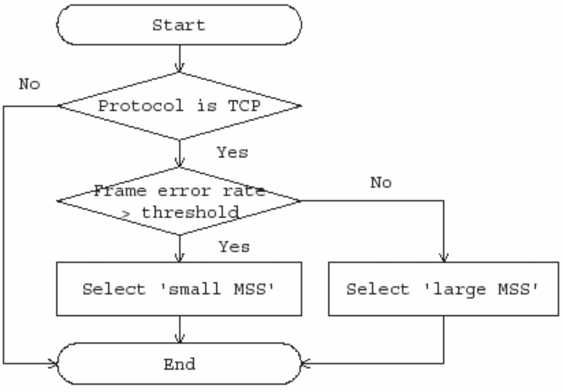

Fig. 7. Algorithm of proposed scheme

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[3] WAP forum recommends that TCP should determine the maximum segment size (MSS) through the MTU discovery mechanism such as its optimization method for Wireless Profiled TCP[3] while RFC 793 recommends that the IP packet size is set to 576 bytes for external networks.

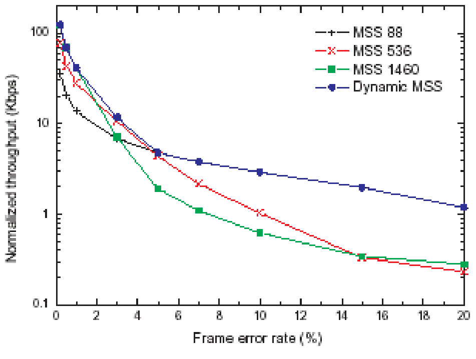

Fig. 8. Dynamic MSS adjustment

4 Discussion

The paper uses the frame error rate as an indicator of the channel state. That is to say, the scheme judges that the channel condition is bad when the error rate is over the threshold, and the state is good when the rate is under the threshold. This threshold is selected by the simulation results (5%). It is not fitful to apply our fixed threshold to all network environments since the good threshold may be different depending on the network organization. The aim of this paper is showing the impact of MSS on TCP's performance in cellular networks, so that we do not focus on a specific mechanism for the state indicator. For the purpose of the practical deployment of our scheme, however, we need additional research about a novel scheme that infers the channel condition.

5 Conclusion

In this paper, we analyze the impact of MSS on TCP's throughput in cellular networks by extensive simulations, and derive some valuable guidelines for determining an optimal segment size. Then, we propose a scheme that reduces the performance drop of TCP by adapting the segment size dynamically by the guidelines. We also find that the widely used MSS (536 and 1460 bytes) are not optimal at all, and a better MSS can be found by considering alignment with the frame size and protocol efficiency. A conclusion is that adjusting the segment size dynamically is an effective way to handle the frame errors in cellular networks.

Acknowledgement

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References

1. J.Postel, *Transmission Control Protocol*, RFC 793, IETF, 1981.
2. UCB/LBNL/VINT Network Simulator, *ns2(version 2.27)*, http://www.isi.edu/nsnam/ns/.
3. Open Mobile Alliance, *Wireless Profiled TCP*, WAP-225-TCP-20010331-a, 2001.
4. H.Schulzrinne, *Internet Traffic Measurements*, http://www.cs.columbia.edu/ hgs/internet/traffic.html.
5. J.P.Ebert, A.Willig, *A Gilbert-Elliot Bit Error Model and the Efficient Use in Packet Level Simulation*, Technical Repoert, TKN-99-002, Technical University of Berlin, March 1999.
6. J.Mogul and S.Deering, *Path MTU Discovery*, RFC 1191, IETF, 1990.