Decision of Maximum Congestion Window Size for TCP Performance Improvement by Bandwidth and RTT Measurement in Wireless Multi-Hop Networks

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Abstract: In the wireless network, TCP performs poorly because it was originally designed for wired networks and does not take into consideration wireless characteristics such as mobility, high-loss probability, and hidden-terminal problems. In particular, in the wireless multi-hop networks, a large congestion window increases the probability of contention and packet losses, and TCP performance is degraded severely as a result. So, it is necessary to limit the TCP congestion window size in order keep the probability of contention loss in the system to a minimum. In this paper, we propose a new scheme for determining the maximum congestion window size based on the measured bandwidth and Round-Trip-Time (RTT). Using ns-2 simulation, we show that the proposed scheme reduces the probability of packet contention and improves TCP performance.

Keywords: wireless multi-hop network, TCP, congestion window

1. Introduction

The increase in mobile terminals and various applications requires mobile multi-hop networks connected by wireless links. This network also needs a TCP transport layer to provide reliable data transfer. However, in the wireless multi-hop networks, we cannot expect optimal TCP performance. The main reasons for TCP performance degradation are contention between sharing terminals, hidden terminal problems, and packet losses in the MAC layer. Furthermore, path disconnections arising from mobility, reordering, and exponential retransmission backoff in the TCP layer also exacerbate performance. Therefore, a great deal of research to resolve such problems in the wireless network has been conducted to improve TCP performance.

In the wireless multi-hop networks using the IEEE 802.11 MAC protocol, mobile terminals with packets must contend with other terminals to transmit them on the shared medium. To do this, the standard 802.11 MAC suggests the RTS/CTS [1] scheme to catch the channel and prevent collisions. This scheme seems to be very effective when the transmission range and interference range are the same.

But, as we can see in the Fig. 1, this scheme suffers from serious "hidden-terminal" problems when the interference range (550m) is much greater than the transmission range (250m). Transmission range is the range within a packet that is successfully received if there is no interference from other terminals, and interference range is the range within which terminals in receive mode will interfere with an unrelated transmitting terminal and thus suffer a loss. So, in Fig. 1, if node B attempts to transmit a packet to node C while node E is transmitting a packet to node F, collisions will happen because node C is within the interference range of node E. These contention losses from hidden-terminal problems degrade TCP performance, so limiting the congestion window size for spatial reuse is very helpful in reducing the probability of contention.

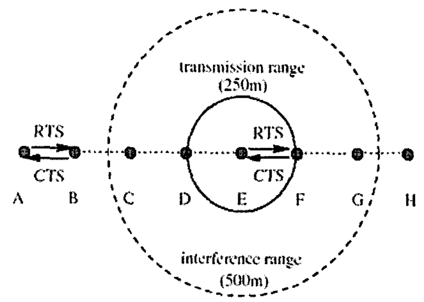

Fig. 1. Hidden-terminal problem

In this paper, we suggest a TCP performance improvement scheme by limiting the maximum congestion window size based on the measured bandwidth and Round-Trip-Time (RTT). Previous research into the contention window limit suggested that it is the function of the number of hops from the source to the destination, but that method raise many problems as we will see later. The rest of the paper is organized as follows. In Section 2, we show previous related works on TCP performance enhancement in the wireless multi-hop networks. In Section 3, our suggested

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algorithm for setting the maximum congestion window size is presented in detail. We show simulation results using ns-2 in Section 4, and our conclusions are given in Section 5.

2. Related Works

Many papers about TCP performance enhancement in the IEEE 802.11-based wireless multi-hop networks have been published. Xu and Saadawi [2][3] presented several serious problems encountered in TCP connections in an IEEE 802.11-based multi-hop network, and identified the instability, unfairness, and incompatibility problems that arise when using ns-2 simulation. Kanth and Ansari [4] proposed a modification of the IEEE 802.11 back-off algorithm such that only two back-off window sizes could be used. They adopted a larger window for the next packet after a successful transmission for allowing other nodes using the smaller window to transmit with less chance of collisions. However, this scheme assumed that all packet sizes are fixed, and this is not valid in the real wireless networks.

Slow Congestion Avoidance [5] and Congestion Window Limit [6] are also suggested as TCP performance enhancement schemes in the wireless multi-hop networks. Generally, the congestion avoidance phase of TCP commands a linear increase in the sending rate by increasing the congestion window by one full-sized segment size every RTT. But, according to the SCA scheme, the TCP agent maintains an SCA parameter and throttles the increase of the congestion window during the congestion avoidance phase by 1/[*scaparameter* × CWND]. This scheme achieves effective spatial reuse without limiting the maximum congestion window. The Congestion Window Limit (CWL) method was suggested because a large CW regularly causes the congestion control algorithm of the TCP to over-shoot, leading to network overloads and heavy contention at the MAC layer. So Chen et al. focused on the TCP's optimal CWL and proved that if the CWL value is approximately 1/5 of the round-trip hop-count (RTHC) of the path, then TCP performance can be enhanced by 8~16%. Li et al. [7] considered the spatial reuse property of the IEEE 802.11 MAC layer protocol in a chain topology. They concluded that the maximum utility of a chain topology is 1/4 of the chain length because of the transmission interference in a neighborhood area. They compared the TCP optimal window size and 1/4 of the chain length, as shown in Fig. 2.

Fig. 2 below shows that the optimal TCP window size is very close to 1/4 of the chain length, so TCP performance can be greatly improved if the congestion window does not exceed the maximum value. It results from the lower contention probability of the packets.

But all of the above CWL schemes are based on the assumption that they know the number of hops to the destination. In MANET, there is no guarantee that all of the routing protocols will provide the number of hops, so the above TCP protocols can only be used in the limited system. Also, the above TCP variants set CWL to a fixed

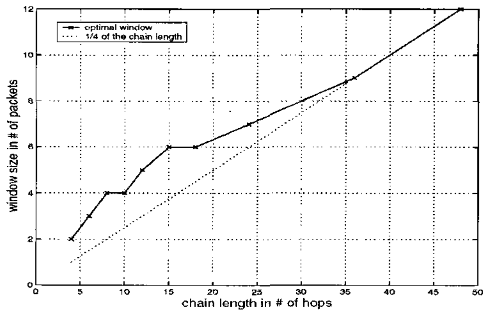


Fig. 2. TCP optimal window size v.s. 1/4 of the Fig. 2. Chain length

value irrespective of the topology and the background traffic. However, if the topology is not a chain and the background traffic is given in the multi-hop ad-hoc network, then *h*/4 (*h* is the number of hops) or RTHC/5 is not adequate for optimal performance. In addition, *h*/4 does not consider the effect of collisions from the TCP ACK packet, which reduces the TCP throughput in the wireless multi-hop network. Lastly, as shown in Fig. 2, the difference between the optimal CWL value and *1*/4 of the chain length increases as the number of hops remains below 20. It means that *h*/4 is not an accurate value and we have to find a new method in that case.

Also, unless h/4 is an integer value, it is not easy to set the CWL value.

In this paper, we suggest a new maximum congestion window size-setting algorithm that considers current channel bandwidth and RTT instead of the number of hops. This algorithm works well with any kinds of routing algorithm and shows good TCP performance in any kinds of system topology. We show a detailed maximum congestion window size-setting method in the next Section.

3. CWL Setting Scheme

A large congestion window size in the wireless multi-hop networks worsens TCP performance by increasing the probability of packet contention and packet losses from excessive collisions. We suggest a new maximum congestion window size limitation method based on the measured channel bandwidth and RTT for improving TCP performance in the wireless multi-hop networks.

There have been some previous works on TCP bandwidth measurement methods. In TCP-Westwood [8], the sender estimates the available bandwidth dynamically by measuring and averaging the rate of returning ACKs. In TCP-Peach [9], the sender probes the available network bandwidth in only one RTT with the help of low-priority dummy packets. We used a similar method to that used in TCP-Jersey [10], which was derived from the time-sliding window estimator.

Equations (1) and (2) are used to calculate the current bandwidth of the multi-hop path to the destination. As shown in Fig. 3, bandwidth measurement is performed by the TCP sender whenever it receives the TCP ACK segments from the receiver. Let BW_{E_k-1} be the calculated bandwidth at any *(k-1)-th* ACK segment, then the current measured bandwidth BW_{E_now} can be given as equation (1), where T_k is the time between *(k-1)-th* ACK and *(k)-th* ACK. $PacketSize_k$ is the total bytes of the previously transmitted packets, which were acknowledged between *(k-1)-th* ACK and *(k)-th* ACK. Equation (2) shows the smoothing method of BW_{E_k} by applying the Exponentially Weighted Moving Average (EWMA) method using α. Using (2), we can control the ratio of the newly measured bandwidth and smoothed measured bandwidth so far. Equation (3) is used to calculate the maximum congestion window size when the RTT and TCP packet size are given.

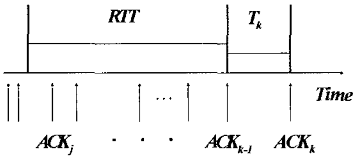


Fig. 3. Bandwidth calculation method

$$BW_{E\_now} = \frac{BW_{E\_k-1} * RTT + PacketSize_k}{RTT + T_k} \tag{1}$$

$$BW_{E\_k} = BW_{E\_k-1} * \alpha + BW_{E\_now}(1-\alpha) \tag{2}$$

$$Maxcwnd = \frac{RTT * BW}{PacketSize} \tag{3}$$

As we mentioned previously, we need to measure the bandwidth of the wireless multi-hop networks and RTT to determine the maximum congestion window size. Therefore, some time to measure bandwidth and RTT is required before applying the maximum congestion window to the TCP layer. At the beginning of the transmission of the TCP segments, the maximum congestion window size is not limited. However, this does not matter because the maximum congestion window size can be determined before many

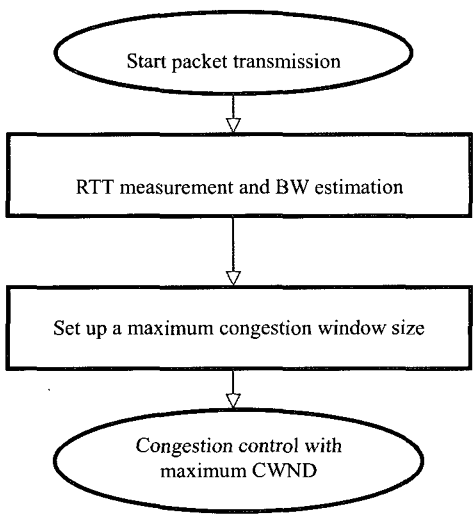


Fig. 4. Flow chart of the suggested algorithm

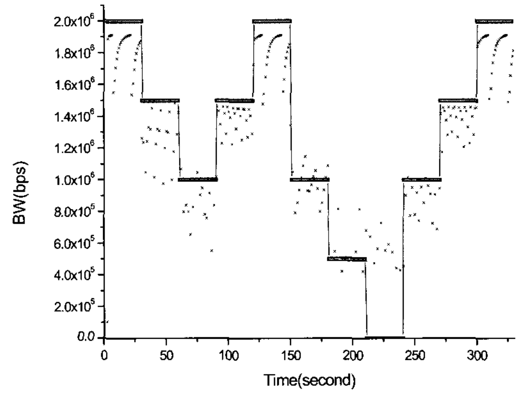


Fig. 5. Comparison of bandwidth estimator

TCP segments are sent into the system. The overall procedure for TCP congestion control is shown in Fig. 4.

Fig. 5 shows the bandwidth measurement results obtained from equation (2). From Fig. 5, we can see that the bandwidth estimator from equation (2) follows the changes of the available bandwidth fairly closely. The solid line represents the available bandwidth while the dotted spots represent the bandwidth estimation results.

This measurement can be done periodically, and if there is a predetermined deviation in the bandwidth or RTT values, we can change the maximum congestion window size to a new one. This deviation value can be determined by considering the trade-off between system overhead and TCP performance. This protocol does not need any extra overhead compared to previous protocols because we can use only RTT and the ACK sequence number.

4. Simulation Results

We used the ns-2 [11] simulator to verify the suggested algorithm. The wireless multi-hop wireless network model used in this study consists of a set of 17 nodes in a chain topology confined to a 5000mX1500m rectangular area and a DRS protocol is used as a routing protocol. We simulated the suggested scheme by increasing the chain length between TCP source and destination. Also, we compared the TCP throughput with the TCP NewReno and CWL method.

Fig. 6 shows the simulation topology. We assume the wireless link bandwidth to be 2Mbps and 11Mbps, respectively, in order to see the maximum congestion window size under the various bandwidth and RTT values.

Figs. 7 and 8 show the TCP throughput when the wireless link bandwidth is 2 and 11Mbps, respectively, as the number of hops increases. As shown in these Figures, the suggested algorithm has better performance than TCP NewReno along all the chain length. The suggested protocol has a very similar throughput to the CWL method [6], but our algorithm does not need any information about chain length. 2Mtcp denotes the throughput of TCP NewReno, 2Mcwl denotes that of the CWL method, and 2Mcnu refers to our algorithm.

Fig. 9 shows the measured bandwidth and RTT for computing maximum congestion window size in the 2Mbps and 11Mbps links respectively. The congestion window size can be dynamically determined according to the bandwidth and RTT combination irrespective of the number of hops. Thus, it can be applied in any topology and under various background traffic conditions.

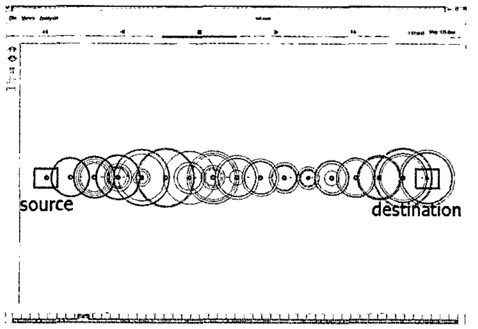


Fig. 6. Simulation topology

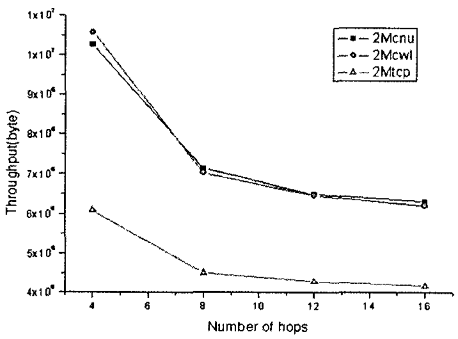


Fig. 7. TCP throughput on the 2Mbps link topology

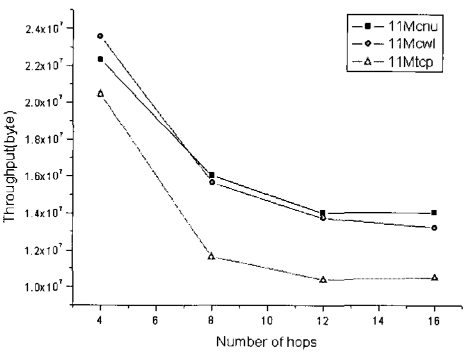


Fig. 8. TCP throughput on the 11Mbps link topology

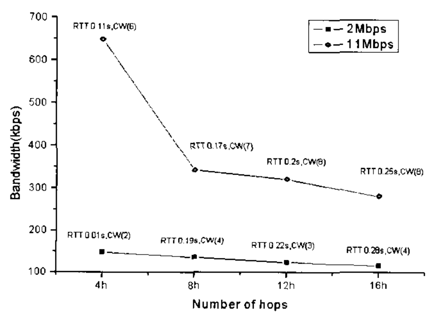
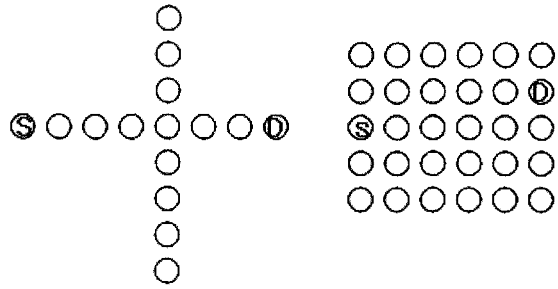


Fig. 9. Measured bandwidth and RTT



(a) Cross topology (b) Grid topology

Fig. 10. Cross and grid topology

We run simulations for 300secs on the 8*8 cross and 5*5 grid topologies respectively, as shown in Fig. 10. In both cases, we let the path length between TCP source and destination be 8-hops and vary the background traffic as 0.2, 0.5 and 0.8Mbps. Figs. 11 and 12 show the effects of topology and background traffic on the wireless multi-hop networks. As mentioned before, the CWL method [6] sets the congestion window size as $h/4$ irrespective of the topology and background traffic. But, as the background traffic increases, the congestion window size must be modified because of increased contention and a changed spatial reuse factor. However, our suggested scheme determines the maximum congestion window size based on the measured bandwidth and RTT only. So, as shown in Figs. 5 and 6, our scheme outperforms the CWL method in all cases.

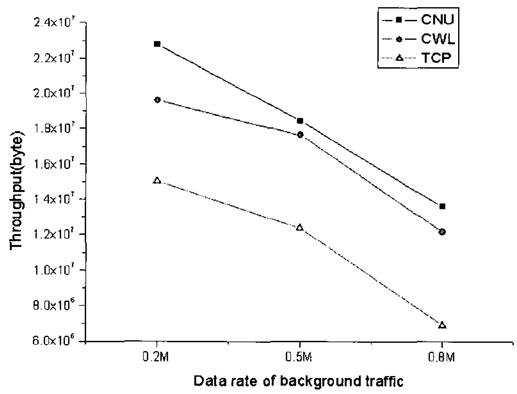


Fig. 11. TCP throughput on the grid topology

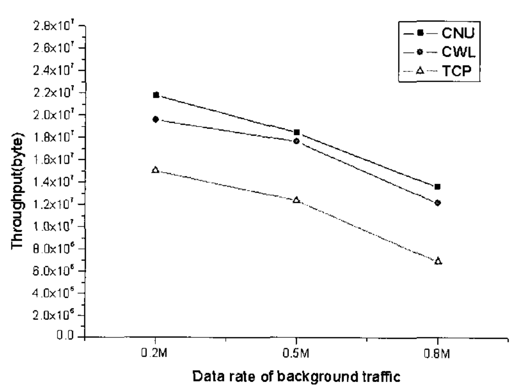


Fig. 12. TCP throughput on the cross topology

5. Conclusion

In wireless multi-hop networks, it is necessary to limit the TCP congestion window size so as not to increase the probability of congestion loss, thereby ensuring a good TCP performance. In this paper, we have suggested a new maximum congestion window setting algorithm by measuring the bandwidth of the routing path and RTT in the wireless multi-hop networks. We compare the TCP throughput with the TCP NewReno and CWL schemes using ns-2 simulation. Our suggested algorithm shows better performance than TCP NewReno in all cases of chain length. Furthermore, this protocol maintains good TCP performance under various topology and background traffic conditions. This protocol can be used with all kinds of ad-hoc routing protocols because it does not require any information from the network layer.

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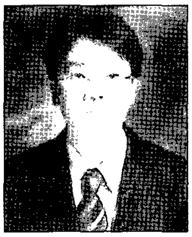

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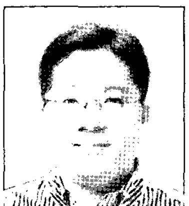

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