Influence of False Congestion Alarms on Performance for Congestion Control based on Dynamic Window Flow Mechanism in Wireless Networks

Takashi Ikegawa

Influence of False Congestion Alarms on Performance for Congestion Control based on Dynamic Window Flow Mechanism in Wireless Networks

Takashi Ikegawa*
NTT Network Service Systems Laboratories, NTT Corporation
9-11 Midori-Cho 3-Chome Musashino-Shi, Tokyo 180-8585 Japan
e-mail: ikegawa.takashi@lab.ntt.co.jp

1 Introduction

The strong drive toward ubiquitous networks through end system mobility has made it necessary to include wireless networks, such as wireless local area networks (LANs) and satellite networks. Networks with wireless links suffer from significant packet-losses due to bit errors. The congestion detection mechanism of congestion control based on dynamic window flow control, which is widely used for reliable window protocols such as TCP, is well-known to be simple, but it may raise false alarms: a sender usually interprets loss as a sign of congestion and reduces the window size unnecessarily if packets were lost due to bit errors (e.g., [1]). This paper aims to 1) investigate the influence of false congestion alarms on the performance of dynamic window flow control (DWFC) in a network environment where the bit error rate is not negligible such as wireless networks and 2) provide a fundamental insight into this issue for TCP.

2 Related Work

A simulation study [2] investigated the performance degradation due to false congestion alarms for the frame-relay network with LAPD. An experimental study [3] demonstrated that error recovery is required at the layer under the transport layer which supports DWFC (i.e., the data-link layer). The performance of various algorithms of TCP's DWFC has been compared using analytical models, such as in [4].

This paper employs an analytical approach rather than simulation [2] or experiments [3]. In addition, unlike papers such as [4], we investigate under several error recovery procedures, since our model can capture various ones.

3 Dynamic Window Flow Control

Whenever a sender receives a negative acknowledgement (NACK) packet or a notice of expiration of the retransmission timer by the error-recovery function, it assumes that congestion has occurred whether a packet has been lost because of congestion or bit error, and reduces the window size. On the other hand, when it receives an acknowledgement packet via the acknowledgment function, it assumes that the network has recovered from the congestion and increases the window size (up to the *maximum* value denoted by w_{max}).

Many researchers have proposed various window size adjustment algorithms (e.g., see [5]). In this paper, we focus on the binary reduction scheme combined with a parabolic increase scheme (B-P scheme) and the sudden reduction scheme with a linear increase scheme (S-L scheme), since the algorithms are implemented in a popular version, namely, TCP-Reno.

4 Dynamic Window Stochastic Process

To derive the analytical expressions of the performance measures, let us consider a two-dimensional discrete time stochastic process $X = \{(W_{t_n}, A_{t_n}) : n = 0, 1, 2, \ldots\}$ and the sequence of nonnegative random variables $T = \{T_{n+1} = (t_{n+1} - t_n) : n = 0, 1, 2, \ldots\}$. The discrete parameter t_n means the time of the nth detection of data (DT) successful (re)transmission packet or its failure. The random variables W_{t_n} and A_{t_n} denote the current window size and the number of successful transmissions after the window size was changed, respectively, at observation time t_n. The stochastic process $\{X, T\}$ constitutes a Markov renewal process, and we refer it as a *dynamic window stochastic process*.

5 Performance Analysis

The effective throughput B_r is defined as the number of bits received correctly by a receiver per unit time when the sender is operating in the saturated state (i.e., it always has a DT-packet to be sent). To derive the mean effective throughput $E[B_r]$, which is defined as the *long-term steady state* effective throughput, we introduce a reward structure into the dynamic window stochastic process. We define the reward as the number of bits received correctly by a receiver during each renewal interval. Letting S, $\pi(i,j)$, $E[R(i,j)]$, and $E[T(i,j)]$ be the state space, the stationary probability, mean reward, and mean staying time when the state of Markov chain X is (i,j), respectively, $E[B_r]$ is given by

$$E[B_r] = \frac{\sum_{(i,j)\in S} \pi(i,j) E[R(i,j)]}{\sum_{(i,j)\in S} \pi(i,j) E[T(i,j)]},$$

where the derivations of $\pi(\cdot,\cdot)$, $E[R(\cdot,\cdot)]$ and $E[T(\cdot,\cdot)]$ can be found in [5].

6 Numerical Results and Discussion

6.1 Network model

Consider a T1-bandwidth low altitude earth orbit (LEO) satellite network with full-duplex point-to-point links whose transmission capacity and propagation delay are assumed to be 1.544 Mbps and 25 ms, respectively. DT-packet lengths are assumed to be exponentially distributed and independent. We assume that the retransmission timer value is 500 ms (constant value).

6.2 Validation

We performed event-driven simulation to validate the following approximations made in this analysis. Note that the simulation model exactly reflects the operation of the specific protocol.

Figure 1 shows the mean effective throughput as a function of the bit error rate p_e for different window size adjustment algorithms, when the single-NACK go-back-N automatic report request (ARQ) type error recovery procedure (that is specified for HDLC and LLC2) [1] is assumed to be carried out and w_{max} is 20^2. For an S-L scheme, C_L [3] of value of 5 was used[4]. As shown in Figure 1, the maximum relative approximation error is 5%. Therefore, the approximation errors are within a reasonable range.

6.3 Performance comparison of B-P and S-L schemes

Figures 2(a) and (b) show the mean effective throughputs under single-NACK go-back-N ARQ and multiple-NACK selective ARQ[5] error recovery procedures, respectively, for w_{max} = 8 and 20. They clearly show that the performance of DWFC is degraded since there is no way to distinguish losses due to bit errors from those due to congestion. In some

*The author is also with Graduate School of Information Science and Engineering, Tokyo Institute of Technology, Tokyo 152-8282 Japan.

[1] This procedure is considered to be almost identical to the error recovery specified in TCP-Reno, since the fast-retransmission mechanism is identical to the ARQ mechanism and its retransmission type is go-back-$N(=1)$.

[2] This window size is the smallest integer greater than the mean round-trip time (RTT) divided by the mean service time of the bottlenecked first-in first-out (FIFO) queue (forward link in this network model). This value leads to bottleneck queue utilization of unity, and the lowest RTT if all mean service times are constant [6].

[3] After receipt of C_L consecutive successful acknowledgements, the window size is increased by one.

[4] In general, the optimal C_L depends on the network conditions. Here, we used the value recommended for a T1-bandwidth frame relay network [2].

[5] TCP's implementation of the error recovery procedure similar to a multiple-NACK selective ARQ is described in [7].

cases, experience demonstrates that the bit error rates are as high as 1 in 10^{-5}. In the worst case (i.e., $p_e = 10^{-5}$), the mean effective throughput of DWFC is less than half the value of static window flow control as shown in Figures 2(a) and (b). This observation agrees with previous work, such as [1]. Thus, an enhancement such as explicit loss notification is required. For both error recovery procedures, a B-P scheme and an S-L scheme with $C_L = 1$ yield almost the same performance and the least possible degradation. The reduction in the unnecessary transmission rate is small because of the following observations:

- For a B-P scheme, the window size is gradually decreased upon detection of packet-loss.
- An S-L scheme with $C_L = 1$ allows the window size to increase rapidly upon receipt of an acknowledgement, although it causes a sudden window size reduction upon detection of packet-loss.

Note that a B-P scheme and an S-L scheme with $C_L = 1$ are employed in the congestion-avoidance and slow-start phases of TCP-Reno, respectively. Therefore, TCP-Reno is robust against false congestion alarms.

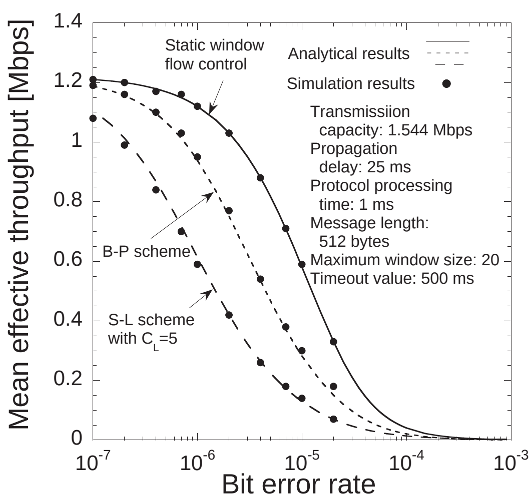
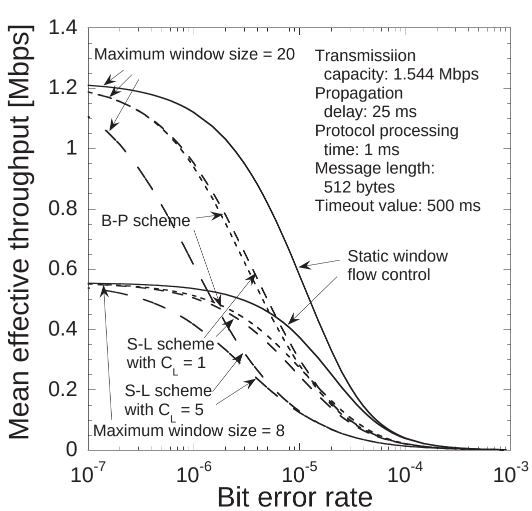
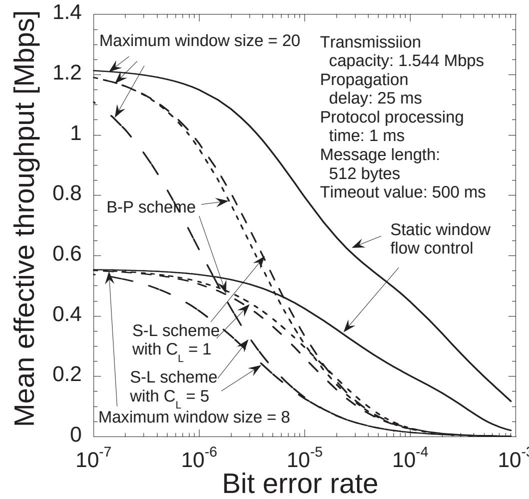


Fig. 1 Mean effective throughput as a function of the bit error rate for different window size adjustment algorithms in the case of single-NACK go-back N ARQ error recovery.



(a) In the case of single-NACK go-back N ARQ error recovery



(b) In the case of multiple-NACK selective ARQ error recovery

Fig. 2 Comparisons of performance of B-P and S-L schemes.

7 Conclusion

In this paper, we derived an analytical solution of the mean effective throughput of communication networks where congestion control based on dynamic window flow mechanism is carried out and packet losses due to bit error happen frequently such as in wireless networks. This analytical model was shown to be accurate over a wide range of bit error rates. We investigated the performance degradation caused by false detection of congestion occurrence by the sender, which is a potential problem of the dynamic window flow control mechanism, utilizing an analytical solution. Comparing the performances of window size adjustment algorithms for T1-bandwidth LEO satellite networks under various error recovery procedures, we found that the binary reduction scheme combined with a parabolic increase scheme and the sudden reduction scheme with a linear increase scheme with increase coefficient of one yielded the smallest amount of unnecessary performance degradation. A popular version of TCP (i.e., TCP-Reno), which implements these algorithms as the congestion-avoidance and slow-start phases, respectively, was shown to be robust against false congestion alarms.

Acknowledgment

The author would like to thank Professor Yukio Takahashi of Tokyo Institute of Technology for his valuable comments.

References

[1] G. Xylomenos, G. C. Polyzos, P. Mahonen, and M. Saaranen, "TCP performance issues over wireless links," *IEEE Commun. Mag.*, vol. 39, no. 4, pp. 52–58, April 2001.

[2] M. Nassehi, "Window flow control in frame-relay networks," in *Proc. GLOBECOM '88*, 1988, pp. 54.1.1–54.1.7.

[3] H. Balakrishnan, V. N Padmanabhan, S. Seshan, and R. H. Katz, "A comparison of mechanisms for improving TCP performance over wireless links," *IEEE/ACM Trans. Networking*, vol. 5, no. 6, pp. 756–769, Dec. 1997.

[4] A. Kumar, "Comparative performance analysis of versions of TCP in a local network with a lossy link," *IEEE/ACM Trans. Networking*, vol. 6, no. 4, pp. 485–498, Aug. 1998.

[5] T. Ikegawa, "Comparative performance analysis of basic window size adjustment algorithms for dynamic-window flow control in interconnected network environments," in *Proc. NPDPA 2002 (2002 IASTED International Conference on Networks, Parallel and Distributed Processing, and Applications)*, Oct. 2002, pp. 117–125.

[6] T. Ikegawa and K. Motomura, "Throughput analysis of data link protocols for bridged networks," *Trans. IEICE*, vol. J74-B-I, no. 12, pp. 1029–1041, Dec. 1991, (in Japanese).

[7] T. Ikegawa, "Enhancements of sender-side implementation for TCP-SACK option," in *The 2002 IEICE General Conference*, March 2002, pp. B–7–109.