A Study of TCP Performance with Snoop Protocol over Fading Wireless Links

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Abstract**—**In this paper, we have analyzed TCP performance over wireless correlated fading links with and without Snoop protocol. For a given value of the packet error rate, TCP performance without Snoop protocol is degraded as the fading is getting fast (i.e. the user moves fast). When Snoop protocol is introduced in the base station, TCP performance is enhanced in most wireless environments. Especially the performance enhancement derived from using Snoop protocol is large in fast fading channel. This is because packet errors become random and sporadic in fast fading channel and these random packet errors (mostly single packet errors) can be compensated efficiently by Snoop protocol's local packet retransmissions. But Snoop protocol can't give a large performance improvement in slow fading environments where long bursts of packet errors occur. Concerning to packet error rate, Snoop protocol results in the highest performance enhancement in the channel with mid-high values of packet error rate. This means Snoop protocol cannot fully fulfill its ability under too low or too high packet error rate environments.

Index Terms**—**Snoop, TCP, Fading, Markov model

I. INTRODUCTION

Nowadays, wireless communications are popularly used in our daily life. Wireless data applications such as e-mail, Web browsing, mobile computing, etc. are gaining increased attention due to rapid advances in the areas of wireless communications and the Internet. Transmission Control Protocol (TCP) is a reliable end-to-end transport protocol and widely used in many applications such as telnet, ftp, http, etc. TCP was mainly developed for fixed (wired) networks with relatively reliable links and its low bit error rate (BER). However, a wireless channel is generally characterized by its high BER. When used in a wireless environment, TCP wrongly assumes data packet loss due to wireless link errors to be a sign of network congestion and invokes congestion control mechanisms that curb the flow of packets on that connection. For better throughput, however, a packet loss due to wireless link errors must be detected and retransmitted as quickly as possible. There are many proposals to improve TCP performance over networks with wireless links [1] and most of them, in one form or another, rely on the base station to improve performance. Snoop protocol is one of the ways and has been shown to be the best performing solution [2]. Snoop protocol maintains TCP end-to-end semantics while recovering the wireless errors locally and can enhance TCP performance efficiently. This protocol works by modifying the network layer software at the base station and mobile host, and involves no other changes to any of the fixed hosts elsewhere in the network.

Snoop protocol can be used to improve TCP performance in the systems supporting high data transmission rate over wireless links, such as Portable Internet, 3G services, and WLAN. Until now many researches have been made for the analysis of TCP performance with Snoop protocol but none of them have focused on the performance variation due to changing fading characteristics of channel. The systems supporting user mobility especially have to concern the effect of fading changes because the characteristics of packet loss are varied depending on the fading rate that is closely related with the moving speed of users.

In this paper, we study about TCP performance with and without Snoop protocol in various correlated multipath fading environments. The wireless environment is modeled according to Korea Portable Internet 'WiBro' specification. Portable Internet system not only costs significantly less than 3G services (e.g. WCDMA) but also supports wider coverage than WLAN and allows users to connect to the Internet while moving with high transmission speed. Because it supports high data rate and user mobility, Portable Internet system is adequate system to adopt Snoop protocol to improve TCP performance.

The rest of the paper is organized as follows. In section 2, two-state Markov modeling of wireless correlated fading channel is presented. Section 3 describes the simulation model and the results of simulation are mentioned in section 4. Conclusions are provided in section 5.

II. WIRELESS CHANNEL MODELING

A. Two-state Markov model

When the wireless channel is subject to correlated multipath fading, the probability of getting an error among the packets being transmitted is not independent and identically distributed (i.i.d.). Instead, there are high correlations between consecutive packets being transmitted [3]. The fading process is closely related with the

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characteristics of packet error. When the fading process is very correlated, long bursts of packet errors occur; on the other hand, for little correlated fading process, successive packets of the channel are almost independent resulting in short bursts of packet errors [4]. The normalized Doppler frequency is directly related to the correlation properties of the error process and usually used to describe the changing rate of fading. The normalized Doppler frequency is derived as

$$f_d T = \frac{v}{\lambda} T \tag{1}$$

where v is the user speed, λ means carrier wavelength, f_d is the maximum Doppler spread and T is the time duration of a packet. The Doppler spread governs how rapidly channel changes over time and how long the wireless link stays in a fade. The higher Doppler spread is, the faster the fading changes. Depending on the Doppler spread and the data rate, i.e. the normalized Doppler frequency, the fading can be considered as 'fast' or 'slow'. When it is small ($f_dT < 0.1$), the fading is considered as slow fading whereas the fading is told as fast fading if it is large ($f_dT > 0.2$) [5]. Large f_dT means fast fading caused by little correlated fading process and results in short packet error bursts frequently while small f_dT implies slow fading caused by high correlated fading process and long error bursts occur rarely for a given packet error rate.

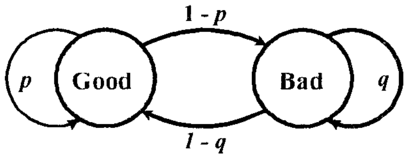


Fig. 1 Two-state Markov model

In this paper, we use two-state Markov model to model correlated multipath fading channels. This model is simple and can represent fading channel having correlation well. Two-state Markov model can be described by Markov chain having two states, 'Good' state and 'Bad' state, as shown in Fig. 1. With this model, it is assumed here for simplicity that the channel state does not change during packet duration. In the Fig. 1, 'Good' represents the state where all packets are correctly received by the receiver and 'Bad' means the packets transmitted in such state are not correctly received by the receiver. The transition probability matrix of the Markov chain is given as

$$T = \begin{pmatrix} p & 1-p \\ 1-q & q \end{pmatrix} \tag{2}$$

where p is the transition probability from 'Good' to 'Good' state and q is the transition probability from 'Bad' to 'Bad' state. In other words, p is the conditional probability that a packet is correctly received when the previous transmitted packet was correct and q is defined the same way. Those transition probabilities can be calculated with the normalized Doppler frequency and the fading margin.

B. Wireless channel modeling for Portable Internet

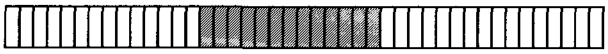
To obtain p and q in (2), we use the model developed in [4], in which these parameters are related to the Doppler spread of the channel, and the user (vehicle) speed. By choosing different packet error rate (P_E) and f_dT values, we can establish fading channel models with different degree of correlation in the fading process.

In this paper, wireless channel is modeled according to 'WiBro' specification. The uplink and downlink wireless data links have 3Mbps and 1Mbps transmission rates, respectively in 2.3GHz frequency band. We assume a TCP packet size is 1040 bytes and an ACK packet size is 40 bytes. Table 1 shows the Markov parameters p and q, and the average packet error burst length for different values of P_E and f_dT. Note that F is the fading margin and *Burst* represents the average length of a burst of packet errors. The fading margin is the maximum fading attenuation that still allows correct reception. Therefore, the packet error rate P_E is directly decided by the fading margin F. The fading rate of the wireless channel depends on the normalized Doppler frequency, f_dT.

Table 1 Markov parameters at different values of P_E and f_dT

v (km/h)	f_dT	P_E	F (dB)	p	q	*Burst*
0.1693	0.001	0.001	29.998	0.99992	0.92089	12.641
		0.01	19.978	0.99975	0.97513	40.201
		0.1	9.7732	0.99919	0.99268	136.56
1.6933	0.01	0.001	29.998	0.99933	0.32945	1.4913
		0.01	19.978	0.99752	0.75431	4.0701
		0.1	9.7732	0.99187	0.92685	13.671
16.933	0.1	0.001	29.998	0.99900	0.00543	1.0055
		0.01	19.978	0.99043	0.05221	1.0551
		0.1	9.7732	0.93002	0.37021	1.5878
169.33	1.0	0.001	29.998	0.99900	0.00105	1.0011
		0.01	19.978	0.99001	0.01051	1.0106
		0.1	9.7732	0.90051	0.10456	1.1168

Table 1 shows that as the user speed is increased, the value of f_dT is also getting large and p, q and *Burst* are getting small for a given P_E. When the value of f_dT is small, the fading process is very correlated. For example, the average length of packet error burst is about 136.6 for $f_dT = 0.001$ and $P_E = 0.1$ in Table 1. However, for large f_dT value the fading process is little correlated. When $f_dT = 1.0$, the fading is so fast that the packet errors are more like i.i.d. resulting that average packet burst length is about 1.1 for $P_E = 0.1$. Because q, transition probability from 'Bad' to 'Bad' state, is quite high (about 99.3%) in $f_dT = 0.001$ and $P_E = 0.1$, it is more likely to stay continuously in 'Bad' state once the state is changed to 'Bad' state causing average 136.6 consecutive packets are corrupted. Whereas, under fast fading ($f_dT = 1.0$ and $P_E = 0.1$), q is low (about 10%) so that even though the state is changed to 'Bad' state, the state easily returns to 'Good' state at the next packet resulting in the number of packet consecutively lost is just about 1.1. This is shown clearly as a graph in Fig. 2 where each square represents a TCP packet and dashed square means a corrupted packet. We can also confirm from Table 1 that *Burst* is larger with higher P_E for the same fading speed (same f_dT).



(a) $f_dT = 0.01$ ($Burst = 13.671$)

(b) $f_dT = 1.0$ ($Burst = 1.1168$)

Fig. 2 Characteristics of packet loss for different f_dT under the same packet error rate ($P_E = 0.1$)

III. SIMULATION MODEL

In our evaluations, we use network simulator ns-2 [6], public domain software from Lawrence Berkeley National Laboratory. The very well known wired-cum-wireless topology shown in Fig. 3 is used in our simulation where one Fixed Host (FH) is directly attached to a base station through a wired network and one Mobile Host (MH) is one hop away from the base station. Because there is only one node each in wired and wireless link, no packet loss caused by packet collision occurs in the channel. This ensures that TCP performance is entirely influenced by only packet loss in the wireless link.

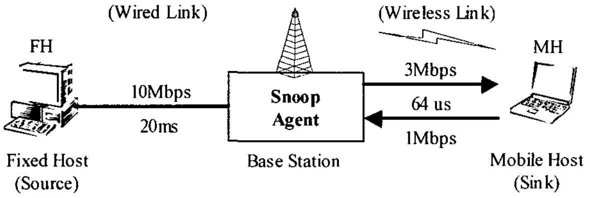


Fig. 3 Simulated network

Table 2 Simulation parameters

Parameters	Values
TCP packet size	1040 bytes
ACK packet size	40 bytes
Application data type	FTP
Transport protocol	TCP-NewReno
Error model	Two-state Markov
Wired link BER	0
Wireless link BER (Good state)	0
Wireless link BER (Bad state)	1

A one-way TCP transfer is established from FH to MH and finite DropTail buffer is adopted in the base station. The wired link bandwidth is 10Mbps with 20ms latency and error-free. The wireless side has 3Mbps downlink and 1Mbps uplink with negligible delay (64 micro seconds). We also assume downlink is erroneous but uplink is error-free. These assumptions are reasonable because in wireless local environments the propagation delays are small, and ACK packets are relatively smaller in size than TCP packets (40 bytes vs. 1040 bytes). The traffic is assumed to be FTP transfers and TCP-NewReno is used as transport layer protocol. Table 2 shows the parameters used in the simulation. Each simulation is run for 150 seconds with varying packet error rate P_E and the normalized Doppler frequency f_dT. The results are averaged over ten independent runs (i.e. each run starts with a different random number seed).

IV. SIMULATION RESULTS

In Fig. 4, TCP performance with and without Snoop protocol is plotted as a function of the normalized Doppler frequency for different values of P_E. Firstly, we consider the case where Snoop protocol is not introduced in the base station. Fig. 4 shows that TCP performance is degraded as the value of f_dT is increased (i.e. a user moves faster) for a given value of P_E. The degree of performance degradation is more significant at large values of P_E (e.g $P_E = 0.1$). As mentioned earlier, short packet error bursts (mostly single packet error) happen frequently in fast fading channel and long packet error bursts occur occasionally in slow fading channel for the same P_E environment. The occurrence of packet error burst initiates a slow start phase in the TCP sender shrinking congestion window and lowering TCP performance. Because more packet error bursts occur in fast fading channel than slow fading channel, TCP performance is worse in fast fading than slow fading without Snoop protocol. That means that for the same packet error rate P_E, a channel with clustered errors results in better TCP performance.

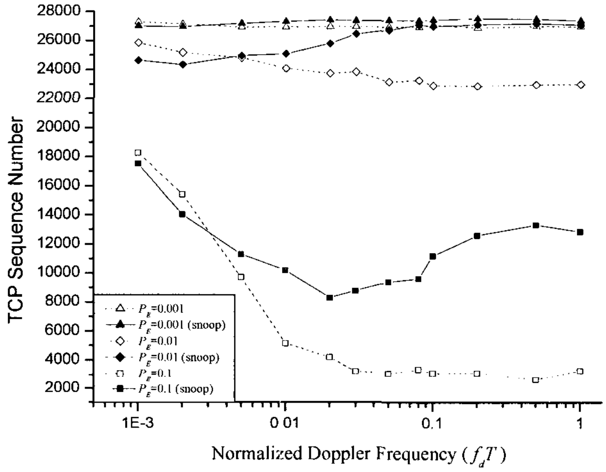


Fig. 4 TCP performance vs. f_dT for different values of P_E with and without Snoop protocol

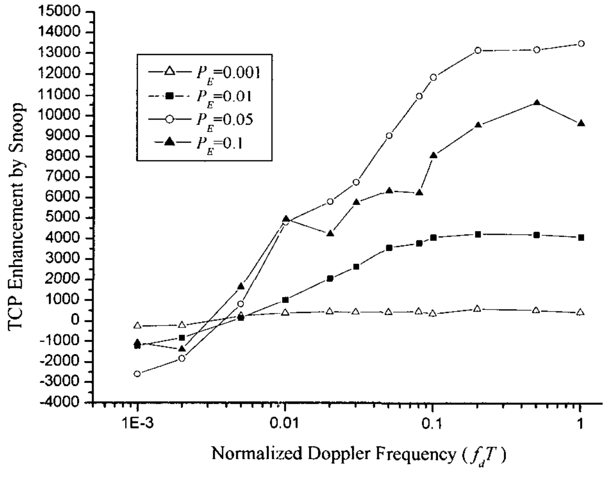


Fig. 5 TCP enhancement according to f_dT

Next, the case where Snoop protocol is adopted in base station will be discussed. When Snoop protocol is installed in base station, TCP performance is different from that derived without Snoop protocol. The degree of TCP performance enhancement is dependent on both P_E and f_dT. From the Fig. 4, the enhancement is large for high value of P_E (e.g. $P_E = 0.1$) but there are little performance improvements for low values of P_E (e.g. $P_E = 0.001$). We've done more simulations for this phenomenon

Fig. 5 shows TCP performance enhancement obtained by using Snoop protocol as a function of f_dT for different packet error rates. In Fig. 5, we can see that little enhancement is obtained in very low P_E environments. In $P_E = 0.001$, there is almost no improvement from using Snoop protocol. But, we can get large enhancements in case of $P_E = 0.01$, 0.05, and 0.1 – about 4000, 13000, and 9000 more TCP packets are successfully sent to the receiver by Snoop protocol for $f_dT = 1.0$ environment. The best performance enhancement is achieved in $P_E = 0.05$. The improvement is small in low values of packet error rate because the packet errors happen rarely in these environments and there are few chances for Snoop protocol to cope with the packet errors. When packet error rate is above 0.01, packet errors happen frequently and these errors can be properly dealt with Snoop protocol resulting in large performance enhancement. The improvement is getting larger as the packet error rate is higher until $P_E = 0.08$. But when the packet error rate is as high as 0.08, packet errors occur so frequently that Snoop protocol cannot handle all packet errors completely causing the TCP sender to notice packet loss. As soon as it notices the packet loss, the TCP sender starts congestion control such as slow-start resulting in TCP performance degradation. In Table 3, we list the number of slow-start that the TCP sender has initiated for different packet error rates.

Table 3 The number of slow-start TCP sender invokes during 150 sec simulation time ($f_dT = 0.1$)

P_E	0.001	0.01	0.03	0.05	0.08	0.1
# of Slow-Start	0	0	0	0	1.3	3.2

From the table, we can see that the packet loss occurred in the wireless channel cannot be hidden to TCP sender and TCP sender initiates slow-start when the P_E is higher than 0.08. For $P_E = 0.1$, TCP sender have invoked more slow-start (3.2 times) so that the TCP enhancement is a bit lower than that derived in $P_E = 0.08$ (the result is not shown in the Fig. 5).

And from Fig. 5, it is observed that in fast fading channels (e.g. $f_dT = 1.0$), the performance enhancement is larger than that derived in slow fading channel (e.g. $f_dT = 0.01$) for a fixed packet error rate. This result also can be verified from Fig. 6. Fig. 6 is the graph of TCP sequence numbers vs. time for different values of f_dT under $P_E = 0.1$. To understand the reason behind this phenomenon, we have to look into the channel characteristics implied by slow and fast fading. In slow fading channel where longer error bursts occur because the correlation degree of fading process is very high, packets retransmitted locally by Snoop protocol are also easily corrupted in burst packet loss-prone channel causing the TCP sender to invoke congestion control. Therefore, a big enhancement is hardly derived by Snoop protocol. However, in fast fading channel where short error bursts or random packet errors usually happen, packets retransmitted by Snoop protocol cope with the packet loss well resulting in large performance improvement.

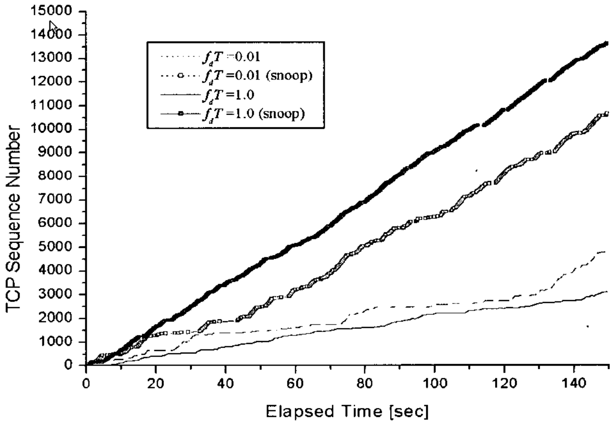


Fig. 6 TCP sequence numbers vs. time for different values of f_dT with and without Snoop protocol ($P_E = 0.1$)

IV. CONCLUSIONS

In this paper, we have analyzed the performance of TCP-NewReno with and without Snoop protocol over wireless fading links having memory. From the simulation results, TCP performance is degraded as fading is getting fast for a given packet error rate without Snoop protocol. But when Snoop protocol is used in the base station, TCP performance enhancement is obtained in most wireless fading environments. Especially, Snoop protocol improves TCP performance much at the channel with mid-high values of packet error rate. This means Snoop protocol doesn't work well in the channels with too low or too high packet error rate. And more performance enhancement can be obtained in fast fading link than slow fading link for a given packet error rate. The reason is that short burst packet errors occur sporadically in fast fading link (almost i.i.d. link) and these short burst packet errors can be compensated efficiently by Snoop protocol's local packet retransmissions.

From the results, when Snoop protocol is introduced to the wireless system supporting high mobility and high data transmission rate, TCP performance can be drastically enhanced especially in fast fading links or in the links with mid-high values of packet error rate.

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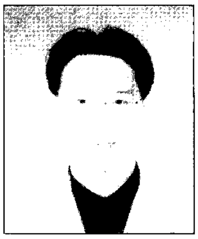

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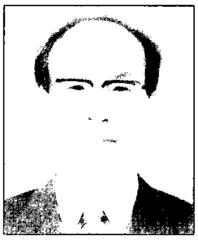

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