The Impact of Doppler Spreading on Delay Performance over Multi-hop Wireless Communications

Jia Chen and Yang Yang

University College London

Abstract: Multi-hop wireless communications are very promising technologies to provide high data rate transmission through wireless link in multi-hop networks. Packets transmitted over wireless link will go through a time-varying wireless channel resulting in queuing delay. For delay-sensitive applications it is very important and challenging to study end-to-end delay performance over multi-hop wireless transmission. In this paper, we study the impact of Doppler spreading on delay performance over multi-hop wireless communications. Delay performance with different Doppler spreading are compared and discussed under different traffic load conditions. It is found that end-to-end delay performance is better for larger maximum Doppler spectrum under wireless channel without decoding errors compared with that for smaller maximum Doppler spectrum.

1 Introduction

Multi-hop wireless communications are very promising technologies for next generation network to provide high data rate transmission through wireless link. As multi-hop wireless transmission brings much benefit to the networks, such as larger transmission range, more frequency efficiency, flexible organizing and power saving, networks involving this technologies are increasingly used, i.e., wireless mesh networks (WMNs), wireless ad hoc networks and wireless sensor networks. WMNs are uaually used as an extension of existing wireless local area networks (WLANs), wireless personal area networks (WPANs) and wireless metropolitan area networks (WMANs) to solve the limitations and improve the network performance [1]. For example, WMNs can solve the problem of "last mile", which is the access networks between internet service provider (ISP) and users [2]. Wireless sensor networks are applied in military, environment monitoring and health, where the gathering information from sensor nodes is transmitted through multi-hop wireless link to a sink node [3]. The advantages of multi-hop networks, i.e., scalability, high capacity, self-organization, large coverage range and compatible with other networks make the study of multi-hop wireless communication very significant.

Quality of Service (QoS) parameters, such as source rate, end-to-end delay and jitter, are key parameters to measure the performance of the network. For delay sensitive applications over multi-hop wireless connections, end-to-end delay performance is a very important research topic. In [4], end-to-end delay performance for multi-hop wire transmission route is studied based on a connection-oriented network with first come first serve (FCFS) queuing principle. Delay performance of different MAC schemes for multi-hop wireless networks has been studied for both MAC schemes, m-phase TDMA and probabilistic slotted ALOHA [5]. Effective capacity (EC) model has been recently proposed as a simple but accurate data link layer model for QoS support under flat-fading and frequency-selective fading radio channel conditions for single-hop wireless transmission [6] [7]. Based on the delay distribution, admission control and resource allocation in wireless network can be deployed effectively [8].

Unreliable wireless link brings many challenges for study delay performance over multi-hop wireless networks. The packets transmitted will go through both multi-path fading and Doppler spreading, hence resulting in unavoidable queuing delay. Doppler spreading introduced by the movement of the mobile unit, brings a frequency shift of transmitted wave, which is determined by $f_n = f_m \cos\alpha_n$ [9]. In this case, α_n is angle of arrival defined by the direction of arrival of the n^{th} wave and direction of the mobile node, while f_m is the maximum Doppler frequency connected with the speed of mobile node v, the speed of light c_0 and carrier frequency f_0 by the equation $f_m = vf_0/c_0$ [9]. A larger f_m leads to a faster changing wireless channel. Coherence time T_c defined by the time over which the channel is coherence, can be approximated by [10]

$$T_c \approx \frac{9}{16\pi f_m}. \quad (1)$$

The mobility of the transmitter and/or receiver in multi-hop networks brings on intense and random fluctuations of the received signal, which makes study of delay performance over multi-hop networks with Doppler spreading a challenge and important research topic.

In [8], EC model is used to estimate the delay performance in a tandem network where all the traffic goes through series of nodes and arrive at the destination nodes directly. An analytical approximations of delay bound violation probability for WMNs has been proposed in [11]. In this paper, we study delay bound violation probability in different wireless channel scenarios and traffic load. Especially, we study the end-to-end delay bound violation probability under different maximum Doppler spectrum over multi-hop wireless transmission with both light and heavy traffic load.

The rest of the paper is organized as follows. The network system model is proposed in Section 2. Large simulation results are compared and discussed in Section 3. Section 4 concludes the paper.

2 System Model

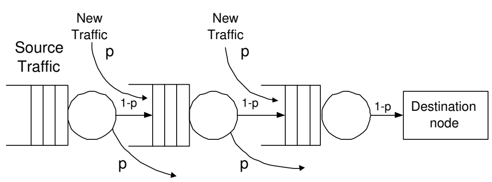


Figure 1: System model for WMNs.

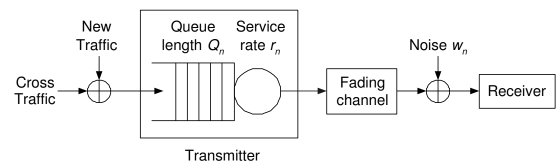


Figure 2: The queueing and wireless channel model for single-hop packet transmissions.

The system under study is multi-hop wireless link comprised of a number of tandem nodes, say n, including source node (generating traffic), intermediate nodes (relaying traffic) and destination node (receiving traffic) as shown in Fig. 1. Fig. 2 shows the queuing and wireless channel model for single-hop packet transmissions. We use w_n and r_n to denote respectively the instantaneous AWGN value and service rate (channel capacity) at the n^{th} sampling interval. For every hop in the network, same statistical wireless channel condition is assumed, i.e., maximum Doppler spectrum, AWGN channel capacity and average SNR. The channel is assumed to be flat and slow with Raleigh fading.

For an h-hop routing path, combined traffic T_{all} is mixed with cross traffic T_{cr} coming from the previous node at a changeable rate r_n depending on the dynamic wireless channel condition, and newly-generated traffic T_{new} arriving at a constant rate μ. Let p denote the proportion of the new traffic T_{new} for every hop, only a proportion of $(1-p)^h$ traffic will go through h-hop route path to the destination node. Each node contains one queue and applies the simple first-come first-served (FCFS) discipline for serving both the new and cross traffic. Analytical result for delay bound violation probability for such system is derived as [11]

$$Prob\left\{\sum_{i=1}^{h} D_i > x\right\} = 1 - \sum_{j=1}^{h} \binom{h-1}{h-j} (1-\gamma)^{h-j}\ \gamma^{j-1} \left[1 - e^{-\theta x}\left(\sum_{i=1}^{j-1} \frac{(\theta x)^{i-1}}{(i-1)!} + \frac{\gamma(x\theta)^{j-1}}{(j-1)!}\right)\right]. \quad (2)$$

3 Numerical and Simulation Results

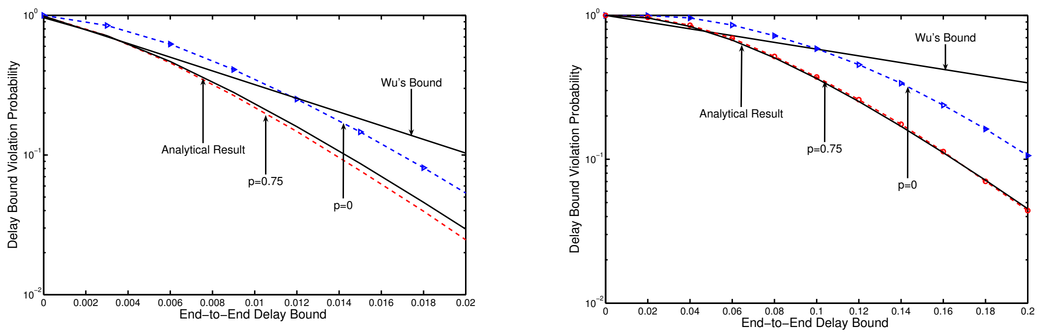
In this part we simulated a 3-hop (4 nodes) network shown in Fig. 1. Parameters of analytical result γ and θ can be derived from [6]. By replacing γ and θ in equation(2), the analytical result for end-to-end delay performance over multiple wireless hops can be obtained. We assume the transmitter can transmit packets without decoding error due to the high channel estimation technologies, strong channel coding and advanced receiving technologies. At the n^{th} sampling interval, the received signal amplitude g_n is a Raleigh distributed random variable and assume the independent additive complex Gaussian noise w_n has zero mean and unit variance. The corresponding service (transmission) rate r_n is approximated (actually up-bounded) by the capacity of the fading channel [6]

$$r_n = \frac{r_{awgn}\ \log_2(1+|g_n|^2)}{\log_2(1+SNR_{avg})}\ , \quad (3)$$

where SNR_{avg} is the average SNR, i.e. $SNR_{avg} = E[|g_n|^2]$, and r_{awgn} is the capacity of the equivalent AWGN channel with the same SNR_{avg} value. A fluid model is used for traffic generation, so the size of a packet is infinitesimal. Compared with queuing delay, the propagation delay over a single wireless link is negligible. Table 1 summarizes the important parameters for computer simulation.

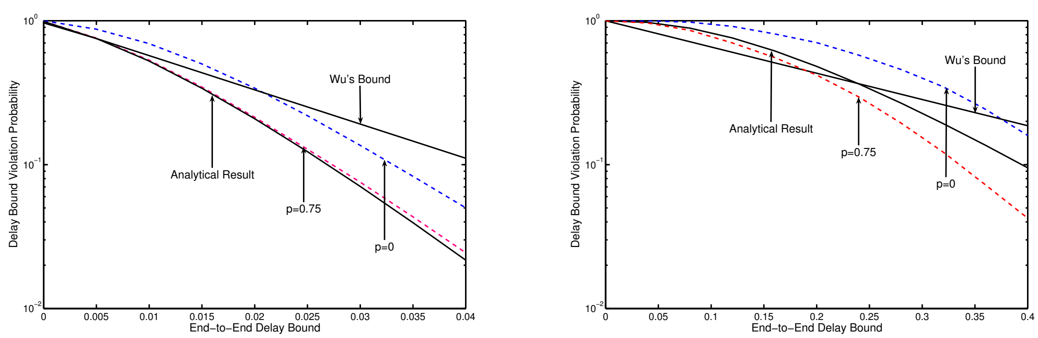
Table 1: Simulation Parameters

Parameter	Value
Average SNR: SNR_{avg}	15 dB
AWGN channel capacity: r_{awgn}	100 kbps
Maximum Doppler spectrum: f_m	5, 15 and 30 Hz
Coherence time : T_c	36, 12 and 6 ms
Combined rate of new and relayed traffic: μ	75 and 85 kbps
Sampling interval: T_s	$1/\mu$
Routing path length: h	3 hops



(a) $\mu = 75$ kbps (b) $\mu = 85$ kbps

Figure 3: Delay bound violation probability for $f_m = 30hz$



(a) $\mu = 75$ kbps (b) $\mu = 85$ kbps

Figure 4: Delay bound violation probability for $f_m = 15hz$

Fig. 3, Fig. 4 and Fig. 5 show the analytical (in solid line) and simulation results (in dashed line) for delay bound violation probability as a function of end-to-end delay over 3-hop routing path. p is the proportion of the new generating traffic arriving at every hop. For both traffic load conditions end-to-end delay bound violation probability increases with the decreasing of maximum Doppler spectrum for the same end-to-end delay bound. Specially for D_{max}=0.02, μ=75kbps and p=0.25, delay bound violation probabilities are 0.676, 0.2134, and 0.034 when maximum Doppler spectrum $f_m = 5, 15$ and 30 hz respectively. This indicates that for special delay requirement, the probability of packets getting cross the routing path and arriving at the destination node is more for larger f_m than that for smaller f_m. Moreover, given a pacific delay bound violation probability, the delay bound for larger f_m is more than that for smaller f_m, which means the packets transmitted under smaller f_m are prone to experience more delay than that under larger f_m.

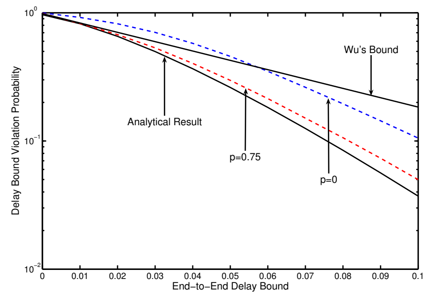


Figure 5: Delay bound violation probability for $f_m = 5hz$ and $\mu = 75kbps$

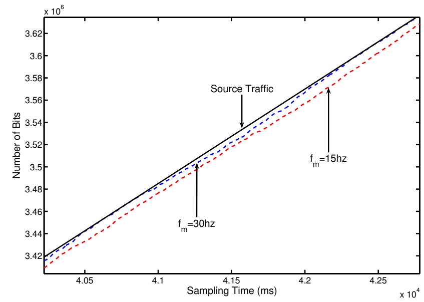


Figure 6: Relation between service curve and delay for single hop with source rate $\mu = 85kbps$

Fig. 6 shows the number of bits being served by wireless channel as a function of time in a single queue for source rate μ=85kbps, with maximum Doppler spectrum f_m=15hz and 30hz. Channel coherence time T_c are 12ms and 6ms for Doppler spectrum f_m=15hz and 30hz from equation (1). Smaller channel coherent time, i.e., 6ms, indicates a faster channel changing rate, resulting in a smaller bits number in the queue, and hence smaller end-to-end delay.

4 Conclusions

In this paper, we analyze the impact of Doppler spreading on the delay performance over multi-hop wireless communications. Simulation results of delay performance with different maximum Doppler spectrum are compared and discussed under different traffic load conditions. It is found that the end-to-end delay performance is much better for larger maximum Doppler spectrum in wireless channel without decoding errors compared with that for smaller maximum Doppler spectrum. We will further investigate mean end-to-end delay under different Doppler spreading over multi-hop wireless communications.

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