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Queuing analysis of cooperative GBN-ARQ in wireless networks with peers contending for a common helper

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ABSTRACT

This paper presents a new queuing model for performance analysis of go-back-N automatic repeat request (GBN-ARQ) protocol in cooperative wireless networks. In the model, cooperative medium access control (CoopMAC) protocol and dynamic radio link adaptation are taken into consideration. We analyze the probability distribution of the total delay witnessed by packets at the source side. Multi-rate transmissions are considered for all links with link adaptation. An enhanced Markov model is introduced in our model, which encompasses the following aspects: CoopMAC protocol at the MAC sub-layer; GBN-ARQ protocol at the logical link control sub-layer and the transmission using decode-and-forward cooperative diversity at the physical layer. The stochastic process of random feedback delay because of peers contending for a common helper is analyzed. The queuing system is modeled as a GI/M/1 Markov chain to acquire statistics of the exact queue length and the total delay. We analyze the effects of Doppler frequency shift and packet arrival rate on the total delay. The analysis is validated by simulation.

1. Introduction

1.1. Cooperative transmission

IEEE 802.11 protocol is widely used in today's wireless networks like wireless LANs and hotspots. With increasing usage, tractable analytical models that estimate the performance of 802.11 protocols accurately gain more importance. A significant amount of research opened up by [1] on cooperative communication techniques is being developed to allow stations to cooperate in their transmissions in order to improve the overall performance of the network. As shown in Fig. 1, since a transmission in the wireless channel is overheard by neighboring stations, these neighboring stations can process these signals and re-transmit them in order to facilitate better reception. The destination combines the signals received from the source and the helper, thus creating spatial diversity and robustness against channel variations due to fading [2].

In recent researches, cooperative communication not only at the physical layer but also at higher layers of the protocol stack, e.g., the medium access control (MAC), or network layer, is proposed [3]. At the physical layer, adaptive modulation and coding (AMC) technique is being used in most of the 3G wireless networks to increase the transmission rate by exploiting the wireless channel variations [4]. With the aid of channel state information, AMC tries to make full use of the dynamic capacity of the time-varying channel with the aim to increase the average transmission rate [5]. ARQ protocol is an error-control method of the link layer, which guarantees reliable transferring of packets by retransmitting packets after negative acknowledgments (NACK's) being reported on the feedback channel. There are three basic ARQ protocols: stop-and-wait (SW) ARQ, go-back-N (GBN) ARQ, and selective-repeat (SR) ARQ protocols. SR-ARQ is the most efficient one in terms of throughput, however, GBN-ARQ is superior to the SR-ARQ protocol in terms of implementation simplicity. In a multi-rate wireless network, the partitioning of signal-to-noise ratio (SNR) for different transmission modes can be chosen such that the packet error rate is kept under some expected level, and the performances of these two protocols become very close to each other. Therefore, the GBN-ARQ protocol can be used to eliminate residual error in the link layer when the implementation simplicity of the radio link protocol is a major concern as in [6].

This paper focuses on queuing analysis for go-back-N automatic retransmission request (GBN-ARQ) protocol in cooperative wireless networks. Due to the fading channel in wireless links, we take into account link adaptation in the physical layer and the stochastic nature of the feedback delay of ARQ protocols because of the contention resolution in the MAC sub-layer of the common helper.

1.2. Related work

Cooperative communication plays an important role in automatic repeat request (ARQ) scheme extending that of legacy IEEE

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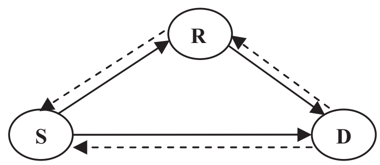

Fig. 1. Cooperative transmission scene.

802.11. Cooperative ARQ scheme aims at reducing packet transmission delay with improved reliability through relaying, and increasing network throughput [7].

The basic idea of cooperative diversity is that a wireless station with low data rate can be assisted by neighboring stations with higher data rates for its transmissions. These assisting nodes are referred to as relay nodes or helper stations. With such assistance available, the source station will be able to transmit data with a higher rate to the relay node which in turn will forward the data to the destination with a higher rate. This achieves an overall higher performance than that the source station transmit the data directly to the destination [8]. But the retransmission of data by a helper may introduce extra interference or collision with communications between other adjacent nodes. An optional Collision Avoidance (CA) mechanism is defined in the 802.11 MAC protocol by which a Request-to-Send/Clear-to-Send (RTS/CTS) handshake is established between source and destination prior to the data transmission [9], which is employed in this paper.

Liu and Tao demonstrated that cooperation among stations in a wireless network can achieve both higher throughput and lower interference in [2]. They presented a design for a medium access control protocol called CoopMAC, in which high data rate stations assist low data rate stations in their transmission by forwarding their traffic. A distributed, threshold based MAC protocol was developed in [10] for cooperative multi-input multi-output (MIMO) transmissions in distributed wireless systems. The protocol uses a threshold scheme that is updated dynamically based on the queue length at the sending node to achieve low power transmissions while ensuring stability of the transmission queues at the nodes. In paper [11], a novel protocol called vehicular cooperative media access control (VC-MAC) was proposed, which leverages the broadcast nature of the wireless medium to maximize the system throughput.

Ma and Yang presented a novel contention-based medium access control (MAC) protocol, namely, the channel reservation MAC (CR-MAC) protocol in [12]. The CR-MAC protocol takes advantage of the overhearing feature of the shared wireless channel to exchange channel reservation information with little extra overhead. Each node can reserve the channel for the next packet waiting in the transmission queue during the current transmission. By analytically deriving the CW sizes optimized for achieving the maximum throughput under both saturated and non-saturated conditions, literature [13] proposed a distributed algorithm that enables each station to dynamically adapt its CW size according to the channel status. In [14], an analytical model for IEEE 802.11 DCF protocol has been presented to accurately predict the performance for a wide range of scenario parameters in single hop networks. In fact, it is of interest to study the impacts on queuing delay by the packet arrival rate in the case of non-saturation loads, as presented in this paper.

The delay statistics for GBN-ARQ with non-instantaneous feedback delay was early discussed in [15]. It used a two-state Markov channel model, which could not capture the multi-rate transmission feature of currently deployed wireless networks. The model in [16] was extended in [17] for channels with more states. However, the transmission rate was assumed to be constant (i.e., for all channel states only one packet is transmitted in one time slot); therefore, the model did not truly take the multi-rate transmission or link adaptation technique into account. The statistics of total delay for GBN-ARQ with non-instantaneous feedback was further studied in [18], which capture the multi-rate transmission feature of currently deployed wireless networks. However, it is limited to cases that the feedback delay is constant for different packets. Delay for cooperative ARQ protocols is also studied in [19], which evaluates the delay experienced by Poisson arriving frames in slotted radio networks.

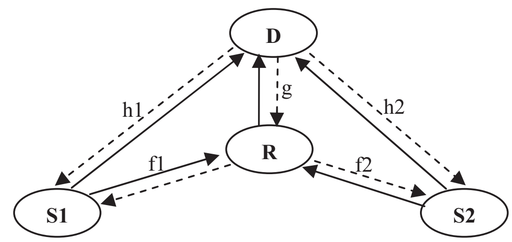

Fig. 2. Cooperative transmission system model.

The authors of [6] presented a queuing model for performance analysis of cooperative GBN-ARQ protocols in wireless networks using dynamic radio link adaptation. The stochastic nature of the feedback delay in the cooperative GBN-ARQ was investigated. The queuing problem for GBN-ARQ is formulated as a four-dimensional GI/M/1 Markov chain, the solution of which is then obtained by the classical matrix geometric method [20]. However, it was assumed that the source is the sole node to ask the help of the relay. However, in real cooperative networks, there is a great probability that a good relay may be chosen simultaneously by several sources. Contentions among these sources occur because they share a common helper. The process of contention resolution is stochastic. This leads to a new type of random round trip delay or feedback delay in cooperative GBN-ARQ protocols. Research on performance analysis of ARQ protocols taking such factor into consideration has not been reported yet.

In summarize, among the published work on performance analysis of ARQ protocols in the literature, no one is fit for GBN-ARQ protocols in wireless networks which integrate cooperative diversity and link adaptation together with different sources share a common helper. With the aim of crossing this barrier, this paper studies the stochastic nature of the delay of peers contending for a common relay and then develops a method to evaluate the statistics of the total delay of packets under the control of GBN-ARQ protocols.

The rest of this paper is organized as follows. Section 2 presents the system model and analyzes the randomly variable delay for channel accessing. Then, we formulate the queuing problem and obtain the performance metrics for GBN-ARQ protocol in the cooperative wireless system with CoopMAC in Section 3. Model validation and numerical results are provided in Section 4. Finally, Section 5 concludes the paper.

2. System model and assumptions

2.1. System description

As illustrated in Fig. 2, we consider a cooperative wireless system composed of two source nodes ($S1$ and $S2$), a relay node (R) and a destination node (D), where the relay node R functions as a partner to help the sources transmitting packets to the destination. In order to transmit packets to the relay node (R), the two source nodes become competing nodes when attempting to access the channel. At the source node ($S1$ or $S2$), input packets from higher layers of protocol stack are stored in a buffer regarded as infinite before being