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Performance analysis of prioritized Automatic Repeat-request systems in the presence of self-similar traffic ☆

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ABSTRACT

Automatic Repeat reQuest (ARQ) is a promising forward error control mechanism for improving the reliability of data transmission over wireless channels. Traffic self-similarity has been discovered to be a ubiquitous phenomenon in communication networks with a significant impact on the network performance and user-perceived Quality-of-Service (QoS). However, due to the high complexity and challenges of modelling traffic self-similarity, there has not been any analytical model reported for ARQ under self-similar traffic. To fill this gap, we develop a novel analytical model of multi-buffer ARQ systems in the presence of prioritized self-similar traffic for reliable data transmission and QoS differentiation. This model can be used to investigate the probabilities of queueing loss and transmission loss in the multi-buffer ARQ systems. The validity of the analytical model is demonstrated via extensive comparison between analytical and simulation results. The model is further adopted to investigate the effects of service capacity and delay bound of ARQ on the system performance.

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1. Introduction

With the rapid development and advances in communication technologies, wireless applications have been extensively involved in diverse domains, for instance, finance, industry, and healthcare. In practice, various unpredictable errors occur during data transmission over wireless channels and thus degrading the performance of communication systems and deteriorating the user-perceived Quality-of-Service (QoS). As a consequence, the provisioning of reliable data transmission is always an imperative demand. The Automatic Repeat reQuest (ARQ) is a promising forwarding error control mechanism for improving the quality and reliability of data transmission over wireless channels [1–4]. In particular, Selective-Repeat ARQ (SR-ARQ) [5] has been identified as an efficient ARQ scheme because it retransmits only the negatively acknowledged packets. In SR-ARQ, a negative ACK requests the retransmission of one packet only [6,7]. Hence, it can achieve higher throughput than the stop-and-wait ARQ [8] and Go-back-N ARQ [9] strategies.

In the realistic communication environment, dropping packets still happens even if the ARQ protocol is employed due to the stringent Quality-of-Service (QoS) requirements of various network applications. For example, real-time voice traffic cannot tolerate transmission delay and jitter. As a result, packet loss occurs if packets are overdue or become ineffective. Packet loss has great impact on the efficiency of communication systems. As a consequence, loss analysis of ARQ has attracted many research efforts [10,11]. However, most existing studies have focused on single buffer ARQ systems [1,2,11] or the sojourn

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time of ARQ systems is modelled by the traditional Poisson process under the constraints of packet delay [12,13]. Recently, Larsson and Johansson [14] modelled an ARQ system with multiple input traffic flows where all packets are fed back to a single ARQ buffer. The disadvantage of using a single ARQ buffer is that the retransmitted packets are equally treated regardless of their different delay and QoS requirements.

In modern communication networks, multimedia applications are expected to receive differentiated services according to their QoS requirements. For instance, real-time voice and video applications are time-sensitive, while text data applications can usually tolerate a certain extent of delay. For this purpose, the Differentiated Service architecture was proposed to provide QoS differentiation [15]. In particular, the Priority Queueing (PQ) scheduling has been proven efficient in implementation of the Differentiated Service architecture owing to its capability and simplicity of providing differentiated priorities to individual traffic classes [16] and thus has been extensively studied [17,18]. For instance, the authors in [17] investigated the performance behaviour of priority scheduling mechanisms under heterogeneous network traffic. Xhafa and Tonuz [19] analyzed the handover performance of priority schemes in wireless cellular networks.

However, the existing related studies [1,2,16,19] were primarily focused on the performance of either PQ scheduling systems or single buffer ARQ systems, separately. To the best of our knowledge, there is hardly any analytical model of ARQ reported for provisioning of both differentiated QoS and reliable data transmission over wireless channels. To bridge this gap, this paper proposes an analytical model for a multi-buffer ARQ system subject to prioritized self-similar traffic. Self-similar traffic was first observed in Ethernet local area networks by Leland et al., [20]. Subsequently, traffic self-similarity was widely demonstrated in other communication networks, such as, ad hoc networks [21] and IP networks [22]. Traffic self-similarity is characterized by the scale-invariant burstiness and large-lag correlation and has a significant impact on the design, control, and analysis of communication networks and protocols.

The main contribution of this paper focuses on the development of a new analytical model for investigating the packet loss probability in individual buffers of the multi-buffer ARQ system. To this end, we propose to isolate each buffer in the original complex system through a queue-decomposition approach and divide the multi-buffer ARQ system into a collection of Single-Server Single-Queue (SSSQ) systems, which are statistically equivalent to the corresponding original queue. Hence, the loss probabilities of individual queues of the multi-buffer ARQ system are derived by examining the resulting SSSQ systems. The validity and accuracy of the obtained loss probabilities are validated through extensive comparison between analytical and simulation results under different working conditions. Finally, the developed model is further adopted to investigate the effects of the service capacity and delay bound of ARQ on the system performance.

The rest of the paper is organized as follows. Section 2 describes the system model in detail and presents the preliminaries of this study. Section 3 presents a decomposition approach to partition the original ARQ system and obtain the effective service capacity of the resulting subsystems. Next, the queueing and transmission loss probabilities of individual subsystems are derived. Section 4 compares the analytical and simulation results under various parameter settings to validate the accuracy of the developed model. Section 5 illustrates the application of the developed model for design and implementation of prioritized service systems coupled with ARQ. Finally, this paper is concluded in Section 6.

2. Preliminaries

This section will present the prioritized ARQ system and formulize self-similar traffic flows.

2.1. System description

Fig. 1 shows a schematic diagram of the prioritized multi-buffer ARQ system. This system contains two subsystems, each of which is composed of an *arrival buffer* and an *ARQ buffer* with the infinite capacity to store the newly arrived packets and retransmission packets, respectively. The two subsystems are scheduled by the PQ mechanism. For the sake of clarity, we

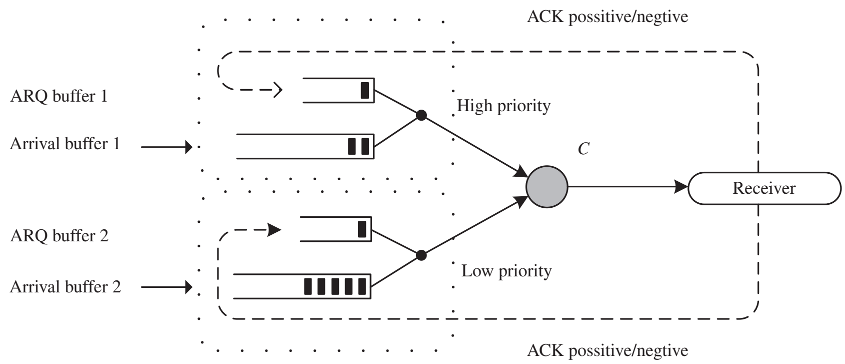

Fig. 1. The schematic diagram of the multi-buffer ARQ system.

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