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# An elastic compensation model for frame-based scheduling algorithms in wireless networks

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ABSTRACT

Scheduling algorithms for high-speed wireless networks need to be simple to implement for serving packets while ensuring quality-of-service (QoS). The ordinary frame-based scheduling principle is well-known for providing fair service with low implementation complexity. However, existing frame-based scheduling algorithms cannot properly handle location-dependent burst errors in wireless networks. To utilize the advantages of frame-based scheduling algorithms in error-prone wireless networks, we propose an elastic compensation model that provides not only smooth compensations without any service disruptions of flows but also flexible compensations to flows that experience frequent errors to provide flows with fairness of service. From our analysis and simulation studies, we found that the proposed compensation model shows smooth compensation performance without any service disruption periods and good fairness performance when channel errors occur.


## 1. Introduction

Recently, the demand for high-speed data transmission and provision of quality of service (QoS) has increased rapidly in wireless communications. Broadband wireless access networks such as IEEE 802.16 [1,2] and 3GPP LTE [3,4] are considered economically viable solutions to satisfy this growing demands. In broadband wireless networks, packet scheduling is an important QoS component which strongly influences the overall processing time of systems. Thus, a packet scheduling algorithm that is simple and has a low packet processing time (such as selecting the next packet to transmit) is required in broadband wireless networks.

There have been several studies on scheduling algorithms in wireless networks. According to scheduling methods, these scheduling algorithms can be classified into three main categories: sorted-priority-based scheduling, frame-based scheduling, and opportunistic scheduling approaches. Among the three types of scheduling approaches, frame-based scheduling approach provides low packet processing time since it serves packets in sequence without time-stamping, packet reordering, or complex optimization. Thus, frame-based scheduling approach is recognized as one of the strongest candidates for broadband wireless networks. In particular, as stated in [5–7], the scheduling of downlink data traffic at a base station (BS) favors frame-based scheduling approach.

Many frame-based scheduling algorithms have been proposed. Deficit Round Robin (DRR) [8] is a simple modification to the generic frame-based scheduling approach, which provides fairness among multiple flows of different packet sizes. To support various packet sizes, at every frame DRR assigns a quantum of service for each flow and records the currently unused portion of the assigned quantum using a deficit counter for each flow. If an unused portion of the assigned quantum exists for a flow in the previous frame, DRR assigns both the unused portion of the assigned quantum and the regularly assigned quantum to the flow in the current frame. In this way, DRR provides a simple and good fairness service to users. In addition, there are some possible extensions of DRR [9–11].

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Nested-Deficit Round Robin (NDRR) [9] has been proposed to reduce the latency bound of DRR. NDRR suggests splitting a round in DRR into multiple smaller rounds in order to reduce the latency bound of low rate flows. Thus, NDRR guarantees a low latency bound, especially for low rate flows, and provides fair scheduling services. PDRR [10] has been designed to improve the order of servicing packets. PDRR adds pre-order queuing (i.e., a limited number of priority queues) to DRR, and thus it changes the transmission order of packets that could be transmitted in one round according to the flow's quantum consumption status in a round. Elastic Round Robin (ERR) [11] has been designed for wormhole networks in which the scheduler cannot know the maximum arriving packet size. ERR does not need to know the length of servicing packets, thereby allowing a flow to exceed its assigned quantum for transmitting a maximum of one packet size.

In wireless networks, scheduling algorithms are expected to provide general features [12,13] such as fairness, implementation complexity, and graceful service degradation. Here, graceful service degradation represents that a flow which has received excess service instead of flows whose channel conditions were bad should experience the smooth service degradation when giving the excess service to the flows whose channel conditions transit from bad to good. Even though the above algorithms [8–11] have attractive advantages in fairness and implementation complexity, existing frame-based scheduling algorithms (including DRR [8] and its variations [9–11]) do not provide graceful service degradation if they are used in error-prone wireless networks. Consider the operation of DRR in error-prone wireless networks. If one flow experiences channel errors, DRR provides the assigned quantum of the flow to other flows whose channel conditions are good since DRR is a work-conserving scheduler. When the channel condition of the flow that experienced channel errors is now good, the flow should receive its missed service. In this situation, DRR provides the missed service to the flow sharply. That is, other flows that received additional service experience sharp service degradation (i.e., they cannot receive service at all; we will call it 'service disruption'). Thus, due to the absence of a proper compensation mechanism, DRR cannot provide graceful service degradation for flows in error-prone wireless networks.

In this paper, we propose an elastic compensation model for frame-based scheduling algorithms. Our goals in this paper are as follows: (i) smooth compensation: the proposed compensation model gradually compensates flows (called lagging flows) that have experienced channel errors and reduces the quantum of other flows (called leading flow) that have received more service so that frame-based scheduling algorithms can provide graceful service degradation without service disruption in error-prone wireless networks. We call this smooth compensation. (ii) Flexible compensation: scheduling algorithms should provide fairness to flows (short-term fairness of error-free flows and long-term fairness of error-prone flows), as stated in [12,13]. When a compensation model compensates lagging flows with a constant compensation quantum size without considering the error characteristics (i.e., error period and interval) of flows, it can cause an unfair compensation problem. That is, long-term fairness cannot be guaranteed for error-prone flows when errors occur to some lagging flows before they are fully compensated, while other lagging flows are fully compensated since errors do not occur during their compensation period. The proposed compensation model adjusts the compensation quantum of lagging flows according to their channel error characteristics for fairness reasons. We call this flexible compensation. We will discuss this topic in detail in Section 2.

The rest of the paper is organized as follows. We present the motivation for this paper in Section 2. In Section 3, we describe the proposed elastic compensation model. Section 4 presents a fairness analysis and the implementation complexity. We show the results of our performance evaluation study in Section 5. Then, we conclude this paper in Section 6.

## 2. Motivation

Fig. 1 shows a simple numerical example of compensation by frame-based scheduling algorithms. In this example, there are three flows and they have the same weight in a system. Each of the three flows {Flow A, Flow B, Flow C} receives a quantum {A, B, C} respectively, and the quantum sizes of the flows are the same as $Q$. Fig. 1a shows a case in which the frame-based scheduling algorithm does not use any compensation model. As shown in the figure, Flow B experienced channel errors from round '$t+3$' to round '$t+10$' (this is called the 'error period'). Since Flow A and Flow C do not experience channel errors during the error period of Flow B, they receive more service than their assigned quantum (i.e., $Q + add\_Q$, where $add\_Q$ is additional quantum). The channel condition of Flow B returns to error-free at round '$t+11$' and then, Flow B receives compensation for its missed quantum. As shown in Fig. 1a, from round '$t+11$' to round '$t+14$', Flow B receives the missed quantum immediately (i.e., is sharply compensated), while Flows A and C do not receive any service (i.e., service disruption of the flows). The longer the error period of Flow B lasts, the longer the service disruption of other flows lasts. On the other hand, Fig. 1b shows a case in which the frame-based scheduling algorithm uses a smooth compensation model. The compensation model gracefully compensates Flow B by allocating a compensation quantum ($CQ$) in addition to the regularly assigned quantum $Q$. The amount of service for Flows A and C is reduced by a certain amount of quantum ($sub\_Q$) from the regularly assigned quantum $Q$. Compared to Fig. 1a, there is no service disruption in any flows during the compensation for the lagging flow (i.e., Flow B). That is, frame-based scheduling algorithms cannot provide graceful service degradation without a compensation model in wireless networks. Therefore, it is necessary to design a compensation model that provides smooth compensation to lagging flows to prevent any service disruption of flows.

As discussed in Section 1, flexible compensation should also be considered during compensation for lagging flows. Wireless channels have different error characteristics. In this example, we assume that Flow B has different channel error characteristics as shown in Fig. 1b and c. In Fig. 1b,