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Inter-cellular scheduler for 5G wireless networks

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ABSTRACT

Enhancing the Quality of Experience (QoE) in wireless networks is a crucial issue. Many acknowledged works focus on intra-cellular scheduling. They have shown that when the channel impairment is taken into consideration by the opportunistic scheduling approaches, it allows to reach higher throughputs and, for the most efficient ones, a higher fairness. However, if some of these works provide results near to optimum considering a single cell, high QoE cannot be guaranteed for scenarios where the cells are overloaded. In this article, we propose a new inter-cellular scheduler able to help the overloaded cells thanks to a dynamic cell bandwidth allocation. Our resource allocation technique is based on an adequate emergency parameter called Mean Cell Packet Delay Outage Ratio (MCPDOR). Performance evaluation shows that the proposed scheduler widely outperforms existing solutions in various scenarios. A variant of our solution that does not consider MCPDOR is also proposed and evaluated.

1. Introduction

Providing mobile multimedia transmission services with an adequate Quality of Service (QoS) is very challenging. In contrast with wired communications, wireless transmissions are subject to many channel impairments such as path loss, shadowing and multipath fading [1–4]. These phenomena severely affect the transmission capabilities and in turn the QoS experienced by applications, not only in terms of data integrity but also in terms of the supplementary delays or packet losses that appear when the effective bit rate at the physical layer is low. The past decades have witnessed intense research efforts on wireless digital communications. Among all the studied transmission techniques, Orthogonal Frequency Division Multiplexing (OFDM) [5] has clearly emerged for future broadband wireless multimedia networks (4G [6] and 5G [7] systems). It is already widely implemented in the most recent wireless systems like 802.11a/g or 802.16. The basic principle of OFDM for fighting the negative impact of multipath propagation is to divide the available channel bandwidth into several subfrequency bands, such that their width is less than the coherence bandwidth of the channel (inverse of the delay spread). The transmission of a high speed signal on a broadband frequency selective channel is then substituted by the transmission of slow speed signals on multiple subcarriers, which are immune to intersymbol interference and subject to flat fading. This subdivision of the overall bandwidth into multiple channels provides frequency diversity. This frequency diversity, along with the time and the multiuser diversity results in a very spectrally efficient system subject to an adequate scheduling.

In this context, much interest has recently been given to the design of intra-cellular scheduling algorithms that improve the performance of multiuser OFDM systems [8–11]. Opportunistic scheduling techniques take advantage of multiuser diversity by preferably allocating the resources to the active mobile(s) with the most favorable channel conditions at a given time. This technique was first explored in single carrier communications [12]. More

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recently, opportunistic scheduling has been exploited in multicarrier systems [13,14]. These schemes are derived from the Maximum Signal-to-Noise Ratio[1] (MaxSNR) technique that allocates the resource at a given time to the active mobile with the greatest SNR. Dynamically adapting the modulation and coding allows then to always make the most efficient use of the radio resource and come closer to the Shannon limit. This maximizes the system capacity from an information theory point of view. However as much efficient the intra-cellular scheduler is, QoS and QoE cannot be guaranteed when the considered cell is overloaded. Consequently, 5G systems require new strategies in order to avoid cell overloading.

The 5G network should be able to serve massive number of UEs in the extreme cases. For instance, data rates of several tens of Mbit/s should be supported for tens of thousands of UEs in crowded areas, such as stadiums or open-air events [7]. Another example is providing 1 Gbit/s simultaneously to tens of UEs in the same office floor. 5G deals with a very large number of connections per square meter, and a huge traffic density. Moreover, it should be able to provide 10 ms end-to-end latency in general, and 1 ms end-to-end latency for the use cases that require extremely low latency [15]. Thus, more sophisticated techniques are required to manage the available spectrum efficiently and to satisfy these QoS requirements.

In this article, we propose an inter-cellular scheduler for efficient support of multimedia services in multi-user 5G wireless networks. Our solution is called *Inter-cellular Bandwidth Fair Sharing scheduler* (IBFS). It dynamically allocates the available bandwidth between the cells, taking into account their relative difficulties to ensure high QoS. The concept is to help the overloaded cell by allocating the potential useless part of bandwidth of its neighbors to it. Consequently, more subcarriers are allocated to the overloaded cell, which helps it to absorb its traffic congestion and decrease user dissatisfaction without penalizing the donor cells that keep only the optimal quantity of radio resource units to ensure QoS to their own users.

This article also deals with the metric used to select the best candidate cell to receive additional bandwidth from its neighbors. Indeed, the logical metric could be to base our approach on the global cell traffic load, but we will show that it is not the optimal metric. Indeed, cell's mobiles have no reason to use the same data rate profiles (less or more elastic) and the same applications with the same delay constraints. Intra-cellular schedulers of the cells with more elastic traffic profile or more restrictive QoS constraints have a more difficult task to ensure QoS. They could require more bandwidth than the schedulers of other cells with higher global throughput but less restrictive QoS constraints or lower peak data rate demands. Consequently, the IBFS scheduler should be based on a reliable metric, which is a crucial issue for its performance. Our second contribution is to propose an adequate metric in order to select the best cell to help. This metric, called *Mean Cell Packet Delay Outage Ratio* (MCPDOR), measures the cell emergency to access to more radio resources, and it allows to always select the appropriate cell to help.

The rest of this article is organized as follows. Section 2 describes the state-of-the-art techniques, including methods that consider the inter-cellular scheduling approaches. Section 3 describes the IBFS solution, and gives details about our proposed algorithm. In Section 4, we present a detailed performance evaluation of our proposed solution through a simulation study. Section 5 concludes the article and summarizes our contributions.

2. Related work

Rather than promoting standardized Inter-Cell Interference Coordination (ICIC) techniques, the Third Generation Partnership Project (3GPP) provides support for proactive and reactive schemes, and it allows constructors and operators to configure a wide range of non-standardized ICIC techniques [16–18]. We classify these techniques into centralized, decentralized, and hybrid schemes.

The centralized approach requires the existence of a central management entity. It collects information related to channel quality and UE throughput demands. Then, it finds the optimal resource allocation between the existing base stations, and it also performs resource allocation among UEs (scheduling). Although the centralized approach offers the optimal resource allocation, a large amount of signaling messages is generated. The decentralized approach allows each cell to determine its own resource allocation, without the need to cooperate with other cells. This approach does not generate any additional signaling overhead, and it is characterized by a low implementation complexity. However, it does not guarantee the optimal resource allocation. Hybrid approaches are proposed as a compromise between centralized and decentralized approaches. In these schemes, a centralized control entity collects channel quality information and UE throughput demands in order to adjust resource allocation between the network cells, while RB allocation to the active UEs is locally performed by each base station.

The frequency reuse-N model, Fractional Frequency Reuse (FFR), and Soft Frequency Reuse (SFR) techniques [19] have been widely suggested to minimize interference between adjacent cells. Traditionally, adjacent cells of a mobile network are grouped into clusters where only a portion of the available spectrum is used in each cell. Therefore, interference is reduced since frequency resources are not simultaneously used by adjacent base stations. If g is the number of cells within a cluster (also called: *cluster size*), then $\frac{1}{g}$ of the available subcarriers are used in each cell according to frequency reuse-g model. Fig. 1 illustrates a mobile network where the frequency reuse-3 model is used to manage frequency resources distribution between the different cells.

FFR and SFR are not able to dynamically adapt to situations where throughput demands or UE positions are not homogeneously distributed between the different cells. To improve the performance of FFR, resource allocation and interference coordination problems are jointly considered in [20]. The proposed scheme searches for the optimal dimensions of cell-center and cell-edge zones as well as the

[1] Also known as Maximum Carrier to Interference ratio (MaxC/I).