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Radio Resource Allocation on Complex 4G Wireless Cellular Networks

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Abstract. In this article we consider the heuristic algorithm which improves step by step wireless data delivery over LTE cellular networks by using the total transmit power with the constraint on users' data rates, and the total throughput with the constraints on the total transmit power as well as users' data rates, which are jointly integrated into a hybrid-layer design framework to perform radio resource allocation for multiple users, and to effectively decide the optimal system parameter such as modulation and coding scheme (MCS) in order to adapt to the varying channel quality. We propose new heuristic algorithm which balances the accessible data rate, the initial data rates of each user allocated by LTE scheduler, the priority indicator which signals delay- throughput- packet loss awareness of the user, and the buffer fullness by achieving maximization of radio resource allocation for multiple users. It is noted that the overall performance is improved with the increase in the number of users, due to multiuser diversity. Experimental results illustrate and validate the accuracy of the proposed methodology.

1. Introduction

Nowadays users are demanding continuous delivery of increasingly higher data over the Internet, in both wired and wireless networks. Due to its real-time nature, wireless data delivery typically has bandwidth, delay, and loss requirements. Moreover, the 3GPP Long Term Evolution (LTE) is the new standard developed to cope with future mobile data and emerging media applications. The generic characteristics of wireless networks are time-varying and their performance is generally inferior to those of wired networks. Therefore, it is still a challenging problem to efficiently provide data delivery service of high quality over 4G LTE Wireless Networks. However, for wireless data delivery in LTE, higher data rate could lead to higher packet loss rate, thus degrading the user's Quality of Experience (QoE). Generally, wireless communication systems should support a large number of users with flexibility in their quality of services (QoS), and Quality of Experience (QoE). The challenges to ensure the fulfillment of these requirements arise from the limited availability of frequency spectrum, and the nature of the wireless channel. To solve this issue, intelligent radio resource algorithms interacting in both the physical and the application layers are critical. Radio resource allocation are categorized into two major classes with different objectives. The objective of the first class is to

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minimize the total transmit power with the constraint on users' data rates whereas in the second class, the objective is to maximize the total throughput with the constraints on the total transmit power as well as users' data rates [1-4].

2. Radio Resource Allocation

The main task of the scheduler is to allocate radio resources to all users equipments (UEs) in a multi-user scenario. Radio resources are elements from the time, frequency, and spatial domain of the LTE system [1,2,4]. Consider a wireless 4G-system with K -users and N -subCarriers. The data rate of the k th user R_k in bits/s is given by:

$$R_k = \frac{B}{N} \sum_{k=1}^K \sum_{n=1}^N subCarrier_{k,n} \log_2(1 + SNR_{k,n}) \quad (1)$$

where B is the total bandwidth of the system. The effective Signal-to-Noise-Ratio (SNR) has to be adjusted according to the modulation and coding scheme (MCS) for a desired Bit Error Rate (BER). Hence, knowing the MCS, the effective $SNR_{k,n}$ is adjusted accordingly to meet the BER requirements. Moreover, in a wireless 4G-system system with K users and N subcarriers, each of N subcarriers is to be allocated to one of K users. In addition, the power allocated to each of K users should be optimized.

The total transmit power of the system P_T is given by

$$P_T = \sum_{n=1}^N \sum_{k=1}^K subCarrier_{k,n} p_{k,n} \quad (2)$$

where where $p_{k,n}$ is the power allocated for user k in sub-channel n

The resource allocation problem is formulated as follows

$$max_{k,n} \frac{B}{N} \sum_{k=1}^K \sum_{n=1}^N subCarrier_{k,n} \log_2(1 + SNR_{k,n}) \quad (3)$$

$$min_{k,n} \sum_{n=1}^N \sum_{k=1}^K subCarrier_{k,n} p_{k,n} \quad (4)$$

subject to :

Constraint 1:

$$\sum_{n=1}^N \sum_{k=1}^K subCarrier_{k,n} p_{k,n} \leq \Delta_{k,n}$$

where $\Delta_{k,n}$ denotes the priority indicator which signals transmission delay- throughput- packet loss rate (PLR) awareness of the k th user. It should be noted that PLR is affected by the varying channel quality and the adopted MCS on the resource blocks. On the other hand, the optimal MCS can effectively decrease the transmission delay while satisfying the constraint of packet loss rate (PLR). At the PHY layer, a set of possible modulation and coding schemes (MCS) are available for transmission. Although the formulation considers all combinations of modulation and coding schemes, the link

adaptation algorithm implicitly drops combinations that provide lower throughput and higher PLR than their counterparts.

Constraint 2:

$$\sum_{k=1}^K R_k \geq R_{k,min}$$

where R_k and $R_{k,min}$ are the accessible, inside the available rate region C , and the minimum required data rate for the k th user, respectively. The maximum rate could be still achieved by assigning each subcarrier to the user with the largest channel gain on it. The available rate region C defined by the LTE scheduler. Hence, $R_k \leq C$

Constraint 3:

$$\sum_{k=1}^K R_k \leq B_k(i)$$

where $B_k(i) = B_1(1), B_1(2), B_2(1), \dots$, denotes the buffer fullness at each time instant (i) and based on predefined thresholds, which depend on each User Equipment (UE)-capabilities. Therefore the limitation in buffer storage capacity is considered, which means that clients will continue access data as long as the channel characteristics and buffer fullness allows for it. Hence, the buffer at the receiver is monitored and the state is fed back to the transmitter to be used in source adaptation. The playback buffer starvation constraint is intended to avoid aggressive attempts to maximize quality that could potentially result in data freezes and re-buffering, specifically, in a bandwidth-limited environment. LTE's scheduler can make use of information defined in the proposed method to optimize radio resource allocation among the different users' equipments (UEs).

The objective is to maximize the total rate within the total power constraint of the system while maintaining rate proportionality among the users indicated in various constraints (Constraint 1-Constraint 3).

3. Experiments

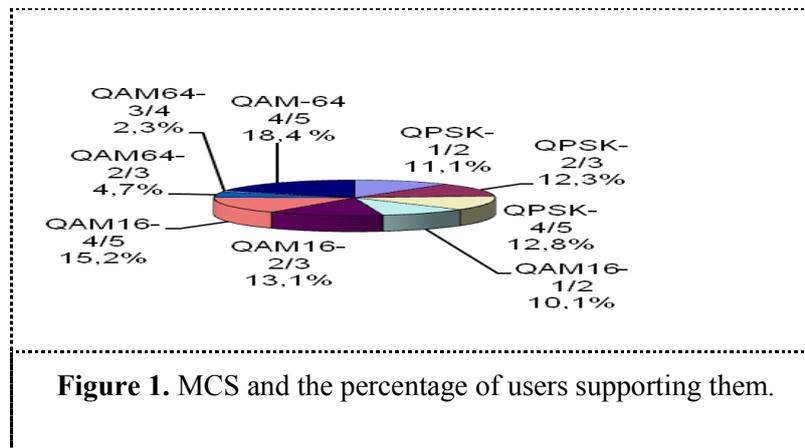
We consider a scenario with $k = 200$ active users per cell (5MHz), where most of the users are far from the Base Station (BS) with resulting average SNR ranging from 2 to 19 dB. Without losing generality, we assume that there are $K= 200$ active users with variable delays constraints 16.66 ms, 20 ms, 33.33 ms, and 41.66 ms [1-3]. The available modulation and coding schemes (MCSs) are chosen from QPSK 1/2, QPSK 2/3, QPSK 4/5, 16-QAM 1/2, 16-QAM 2/, 16-QAM 4/5, 64-QAM 2/3, 64-QAM 3/4 and 64-QAM 4/5. We use nine types of MCSs as in the LTE standard [1]. Table I lists the MCSs we use in our simulations as well as the SNR minimum requirements for each MCS and the average spectrum efficiency (bps/Hz) for channel model based on 3GPP [2]. Average spectrum efficiency is defined as the aggregate throughput of all users (the number of correctly received bits) over a certain period of time (bps/Hz) [1,2]. Fig. 1 indicates the percentage of users that can support each MCS in our simulations. It is worth pointing out that the channel conditions of the users vary in a wide range. We adopted the LTE system model defined in [2]. Given an average SNR, the instantaneous link quality can be randomly produced from Rayleigh distribution [1-3]. User Equipment (UE) is the device that a consumer uses for 4G wireless communication. We assume that the initial pre-buffer at the UEs is set to 1ms. It should be noted that the buffer size can be used to tune the trade-off between quality and the mean playback buffer size. From a user quality of experience (QoE) viewpoint, playback buffer starvation is unwanted because it results re-buffering.

The data rate is calculated considering equal minimum power on all the subcarriers. Adaptive minimum power allocation has a very significant role in maximizing the total accessible data rate by using multiuser diversity. Specifically the optimal set of subcarriers is selected and the total power is equally distributed among those subcarriers involved in data transmission. Fig. 2 shows the comparison of proposed algorithm and the two conventional algorithms in terms of the total accessible data rate versus different numbers of users. In the simulation results, the two conventional algorithms referred to as “rate adaptive”, and “margin adaptive (MA)”, respectively. The optimization problem in MA allocation algorithm is formulated with the objective of minimizing the total transmit power while providing each user with its required quality of service in terms of data rate and BER [6]. On the other hand, the RA objective is to maximize the total data rate of the system with the constraint on the total transmit power [5].

As shown in Fig. 2, significant performance enhancement is achieved by using the proposed algorithm compared to conventional approaches, the RA and MA, respectively. We compare the proposed algorithm, where the design goal is to maximize the total rate within the total power constraint of the system while maintaining rate proportionality among the users indicated in various constraints. The graph with the highest spectral efficiency in Fig. 2 belongs to the proposed algorithm. In this algorithm, the data rate is calculated considering equal minimum power on all the subcarriers. Based on this result, one may conclude that in a system with K -users and N sub-channels, adaptive minimum power allocation has a very significant role in maximizing the total accessible data rate by using multiuser diversity, and consequently would always give close to optimum performance under the variable given- application delays constraints.

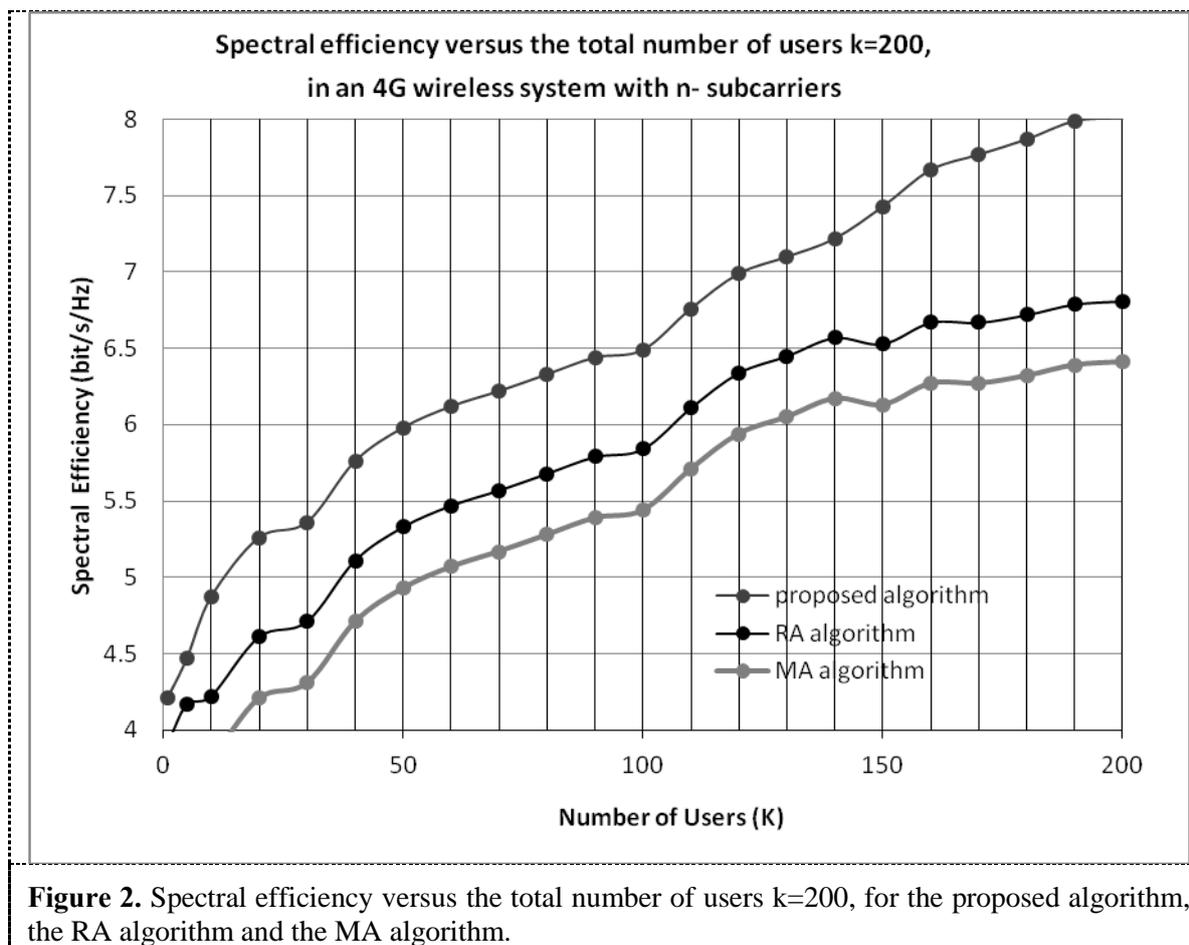
Table 1. MCS with SNR minimum requirements and Average efficiency

	Code	Aver. Efficiency (bps/Hz)	SNR[dB]
QPSK	1/2	0.15	[2]
QPSK	2/3	0.41	[4.3]
QPSK	4/5	1.05	[6.2]
QAM16	1/2	1.48	[7.9]
QAM16	2/4	1.89	[11.3]
QAM16	4/5	2.38	[12.8]
QAM64	2/3	3.37	[15.3]
QAM64	3/4	4.14	[17.5]
QAM64	4/5	5.05	[18.6]



4. Conclusion

We proposed a new heuristic algorithm which balances the accessible data rate, the initial data rates of each user allocated by LTE scheduler, the priority indicator which signals delay- throughput- packet loss awareness of the user, and the buffer fullness by achieving maximization of radio resource allocation for multiple users. It is noted that the overall performance is improved with the increase in the number of users, due to multiuser diversity. Future work will estimate Quality of Experience (QoE) parameters from Quality of Service (QoS) parameters with a high degree of accuracy for LTE and LTE-Advanced radio access networks. It will also investigate the performance of the proposed methodology over hybrid LTE and Digital Video Broadcasting (DVB) channels. This is expected to be an active area of research in years to come.



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