Design and Implementation of a QoS-Based Scheduling Algorithm Based on the LTE QCI Specifications

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Abstract

LTE 3GPP standard defines several QCI (QoS Class Identifier) classes to provide differential QoS, depending on the requirements of different user applications.These QCI values have been characterized in terms of priority, packet loss and delay budget. In spite of the availability of this robust QoS framework in LTE, there is no such scheduling algorithm that has its working principle based on this framework. The responsibility of fulfilling the user requirements, while satisfying the service class requirements is left upon the cellular service provider and it is an open issue at present. To solve this problem, we have proposed a MAC scheduler, which defines the priority of different users based on their bearer specification and provides desired QoS in terms of the achieved throughput through the resource block allocation based on calculated user priority.

I. Introduction

The Long Term Evolution (LTE) standard has been developed by the Third Generation Partnership Project (3GPP) to improve the potential of existing standards by increasing data transfer rates and extending the Quality of Service (QoS) support for various types of end user applications [1]. It is a successor of UMTS and HSPA networks. High data rates achievable by the LTE are a result of a number of key technologies, OFDM and MIMO being two of them.

In recent years, there has been a rapid increase in the use of data carried by cellular services, and it is expected to grow exponentially in the future.The main reason behind this data explosion is the increase in the number of mobile users as well as the types of applications being used. As mentioned in the Cisco visual networking index, 2012-2017[3], data traffic reached 885 petabytes per month at the end of 2012, and the monthly global mobile data traffic is expected to surpass 10 Exabytes by 2017. Mobile devices are becoming more powerful and thus able to consume and generate more data traffic. To cater to this ever-growing increase in data volume, there is a demand for increased data transmission speeds and lower latency. Hence, further development of cellular technologies is required [2].

To satisfy this rapidly growing demand, network operators and service providers have placed significant efforts on various channel allocation schemes and spectrum efficiency improvements so as to allocate resources more efficiently to users. The main motive is to manage the existing resources while providing some minimum QoS to different multimedia applications based on the scheduling requirements described in the LTE standard.With the evolution of the cellular networks, and invention of many advanced mobile applications, QoS provisioning has become an important issue. There is a need for a QoS framework that provides a balance between the economic constraints and the physical spectrum limitations, while satisfying the needs of the end users.

Several schedulers have been proposed for scheduling users over a shared packet data channel [4][5][6][7][8]. Some of them support QoS while others provide only some degree of fairness. Different scheduling algorithms have tried to provide QoS with respect to different parameters such as delay, throughput, etc., but none of them complies with the QCI framework for LTE, as defined by the 3GPP. At present, there is no current standard scheduler and hence QoS based scheduling in LTE is still an open issue.

In this paper we propose a simple QoS based MAC scheduler that takes into consideration the QCI specification as defined in LTE standard. The paper is organized as follows: Section I describes the problem being addressed; Section II provides an overview of LTE QoS framework. Section III describes the proposed scheduler and Section IV contains simulation and results, which illustrate the effectiveness of the proposed approach. Finally we provide a summary and conclusions of the work.

II. LTE QoS Framework

A. QCI Classification

In the LTE networks, QoS is implemented between UE and Packet Data Network (PDN) Gateway with the help of a set of bearers. A bearer is basically a virtual concept, which is a set of network configuration parameters to provide differential QoS to the end users. For example, VoIP packets are given a higher priority by network as compared to best effort web browser traffic. When a UE first connects to the network, it will be assigned the default bearer. Default bearer provides the best effort service. Each default bearer comes with an IP address. UE can have additional default bearers as well. Dedicated bearer acts as an additional bearer on top of default bearer. It does not require separate IP address due to the fact that only additional default bearer needs an IP address and the dedicated bearers are always connected to one of the default bearer that had been established previously. The default bearer

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is always non-Guaranteed Bit Rate (GBR), however, a dedicated bearer can be GBR or non-GBR.

LTE standard defines 9 QCI classes and their associated QoS requirements in terms of resource type, priority, packet delay budget, and packet error loss rate, as described in Table I [1]:

TABLE I. LTE QoS FRAMEWORK

QCI	Resource Type	Priority	Packet Delay Budget (NOTE 1)	Packet Error Loss Rate (NOTE 2)	Example Services
1 (NOTE 3)	GBR	2	100 ms	10^{-2}	Conversational Voice
2 (NOTE 3)		4	150 ms	10^{-3}	Conversational Video (Live Streaming)
3 (NOTE 3)		3	50 ms	10^{-3}	Real Time Gaming
4 (NOTE 3)		5	300 ms	10^{-6}	Non-Conversational Video (Buffered Streaming)
5 (NOTE 3)	Non-GBR	1	100 ms	10^{-6}	IMS Signalling
6 (NOTE 4)		6	300 ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7 (NOTE 3)		7	100 ms	10^{-3}	Voice, Video (Live Streaming) Interactive Gaming
8 (NOTE 5)		8	300 ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9 (NOTE 6)		9			

The QCI value is a scalar that is used to represent various parameters that affect the traffic forwarding decisions (e.g. admission control, scheduling weights, queue management threshold, delay budget, etc.) pertaining to a particular node. These parameters can be pre-configured by the operator who owns the node or the base station (eNodeB).

B. *LTE Frame Structure*

The 3GPP LTE system has defined a standard frame and subframe structure for the purpose of synchronization and to enable the system to coordinate the different types of information that need to be transferred between the base-station or the eNodeB (extended Node B) and the mobile node or the User Equipment (UE) [2].

Each LTE frame has total length of 10 ms. The frame is further divided into 10 subframes, each of which has a length of 1 ms. Each subframe is further divided two physical resource blocks (RBs). In the LTE standard specification, each RB spans 0.5ms and is composed of a block of 6 to 7 symbols with 12 sub-carriers in frequency domain. The detailed frame structure is shown in Figure 1:

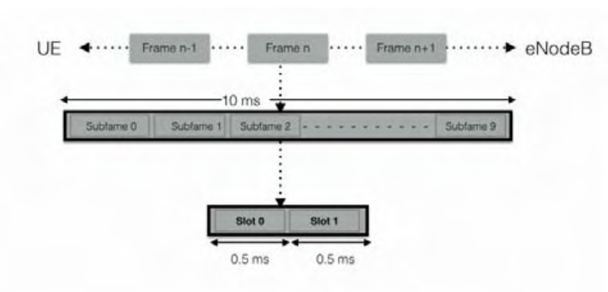

Fig. 1. LTE Frame Structur

III. Proposed Model

We have proposed a scheduling algorithm for LTE, which is a variation of the traditional Proportional Fair (PF) scheduler [9]. The utility function is defined in terms of the past throughput performance achieved by a user and its QCI class/priority, as defined by the dedicated bearer between the UE and the eNodeB. At the start of each sub-frame, each RB is assigned to a certain user. The index *i* to which RB k is assigned at time t, is determined as:

$$i_k(t) = argmax_{j=1\ to\ N}\left(\frac{R_j(k,t)}{T_j(t)}\right) * \frac{1}{QCI.Priority}$$

Where,

$R_j(k,t)$ is the achievable bit rate by user j on RB k at subframe t

$T_j(t)$ is the past throughput performance perceived by the user, calculated using exponential moving average approach

QCI.Priority is the multiplicative factor that is calculated based on the QCI value corresponding to the resource type and the throughput requirement of the associated bearer.

In case of traditional PF algorithm, the perceived user throughput is compared to the channel quality index and a user is scheduled if the channel quality index is higher than the perceived user throughput. This provides some degree of fairness, however, the drawback of this approach is that it does not take into consideration, the QoS requirements of different types of traffic classes, as defined in the LTE standard.

We have modified the PF algorithm to include the QCI class information in the priority calculation. In this way we have tried to provide higher priority to the higher service classes such as VOIP, real-time gaming, etc., while maintaining some degree of fairness for the lower classes of traffic. This priority can be a function of throughput and/or delay depending on which QoS metric is of concern for the flow. The resource block is allocated to the user with the highest priority. As the proportional fair scheduler is taken as the base, so the proposed scheduler also tries to maintain some degree of fairness for the low priority applications. We plan to extend this work by including the delay budget and packet loss constraints in the future work. Note that if a particular service requires constraints on both throughput and delay then, at any given time, only one of them will be dominant and so resources can be allocated based on the more stringent QoS requirement.

IV. Performance Evaluation

The proposed work has been implemented and evaluated using simulation. The simulations were performed using the LTE model of Network Simulator 3 (NS-3) [9][10], which has been designed to support the evaluation of various aspects of LTE systems including QoS-aware Packet Scheduling, Radio Resource Management, etc. The parameters used for simulation have been summarized in Table II.

TABLE II. SIMULATION PARAMETERS

Number of UEs	4 to 60
Scheduling Algorithm (MAC) for comparison of results	Proportional Fair
Target Bit Rate	250 Mbps
Cell Radius	50 meters
Number of eNodeB	1
Propagation Model	Friis Spectrum Propagation Model
Simulation Time	10 seconds
Mobility Model	Constant Position Mobility Model

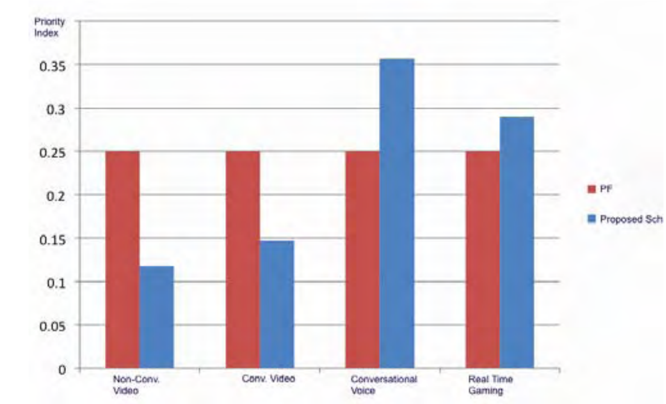

Fig. 2. Comparison of Priority Index for Different Traffic Types between the PF and the Proposed Scheduler.

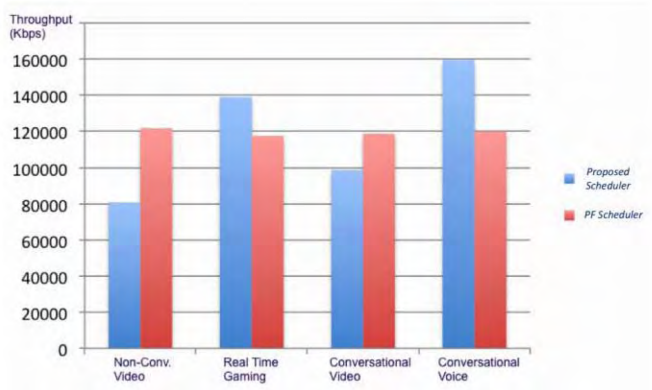

Fig. 3. Comparison of Throughput for Different Traffic Types between the PF and the Proposed Scheduler.

In the first part of simulation, the proposed scheduler performance was compared to the PF scheduler for different types of traffic and the results are shown in Figures 2 and 3. In case of proportional fair scheduler, no consideration is given to the type of traffic and the QoS requirements, and hence the average priority index for each user is approximately 1/n, n being the number of users. But in case of the proposed scheduler, priority of the users is defined based on their QCI class bearer definition and hence the VOIP user has a higher priority than the non-conversational video user, although both belong to the GBR class. Similarly, the achieved throughput in the proposed scheme reflects the QCI class to which the user belongs, as shown in Figure 3. In case of the proportional fair scheduler, the throughput experienced by different types of traffic is approximately close to each other. However, in case of the proposed MAC scheduler, the throughput achieved by the conversational voice is highest. This clearly indicates that higher priority is given to users with higher QCI value, while maintaining some degree of relative fairness for the applications with lower QCI values.

In the second part of the simulation, to simulate the load in the system, the number of UEs was increased dynamically and the calculated priority metric was monitored. The results are shown in Figure 4. It clearly indicates, that as the number of user equipments increase, the average priority increases. Also, as we can clearly see in the graph, the priority for VOIP increases at a rate, which is higher than the rate of increase in priority for the real-time gaming user.

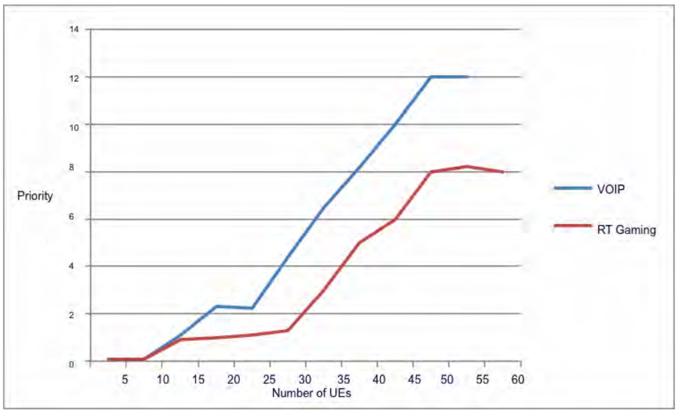

Fig. 4. Priority vs. Number of UEs for Different Applications

V. Conclusion and Future Work

With the evolution of the cellular networks, and invention of many advanced mobile applications, QoS provisioning has become an important issue. The proposed scheduler has been designed based on standard LTE specifications. It defines the priority of different user applications based on their bearer specification and also provides desired QoS in terms of the achieved throughput through the resource block allocation based on calculated user priority. It provides higher priority to the higher QCI classes, while maintaining some degree of fairness for the lower classes. In the future work, we will enhance the scheduler to satisfy the delay and packet loss constraints as well.

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