A Review of Downlink Packet Scheduling Algorithms for Real Time Traffic in LTE-Advanced Networks

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Abstract

Objective: In recent times, the demand for high data rates is ever increasing in any wireless network environment. Long Term Evolution-Advanced (LTE-A) is the latest 4G technology which is developed based on 3GPP specifications. Our main objective in this proposed research wok is to analyze the various packet scheduling algorithms for downlink real time data and present their scheduling metrics. **Methods:** In this review we considered more recent scheduling algorithms which are QoS aware and with specific focus on real time traffic classes such as VoIP, Video Streaming, Interactive Gaming and mobile video conference. **Conclusion:** Our most significant observation from this review is that any packet scheduling algorithm for downlink real time data should be QoS aware so that it is readily deployable in the present day multimedia networks. The scheduling schemes should also consider the latest technologies such as Carrier Aggregation (CA) and Multi Input and Multi Output (MIMO) **Applications:** The presented review will help the researchers and academicians to develop more efficient scheduling schemes for real time applications for smart phone users with better quality of experience and efficient radio resource management.

Keywords: LTE-Advanced, Packet Scheduling, QoS, Radio Resource Management, Real Time Traffic

1. Introduction

The requirements for 4G systems as specified by 3rd Generation Partnership Project (3GPP), a part of International Mobile Telecommunications-Advanced (IMT-A), is 1 Gbps downlink peak data rate and 500 Mbps uplink peak data rate[1]. Orthogonal Frequency Division Multiple Access (OFDMA), Carrier Aggregation (CA), Multi Input and Multi Output (MIMO), Coordinated Multi-Point transmission (CoMP) techniques, Relaying and Heterogeneous Networks (HetNets) deployments are some of the key technologies standardized for fulfilling IMT-A targets[1].

There are three main challenges in wireless communication that need to be met so as to enable access to information and data sharing anywhere and anytime, by anyone and anything. These are:

- Massive growth in the number of connected devices.
- Mammoth growth in traffic volume.
- An ever increasing range of wide applications with varying requirements and characteristics[2].

For these challenges to be addressed properly, certain technologies have been developed to evolve LTE-Radio Access Technology (RAT) further. A brief introduction to these technologies has been given below:

Since the spectrum is sparsely available and its cost is very high, it is not always possible to get continuous frequency bandwidth. In order to overcome this constraint, a technique called Carrier Aggregation is used. CA facilitates effective use of spectrum by allowing User

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Equipments (UE) to simultaneously aggregate different frequency fragments (e.g. 20 Mhz) to form a wider transmission bandwidth. These individual fragments are called Component Carriers (CC)[7].These carriers can be configured either within the same band (contiguous) or in different bands (non-contiguous) using different bandwidths. Since we are using these multi carriers in LTE-Advanced, developing a constraint based packet scheduling algorithm has become more challenging when compared to other single carrier systems.

Long Term Evolution-Advanced (LTE-A) release-10 proposes another technique called MIMO (Multiple Input and Multiple Output) which deploys multiple antennas at the transmitter and at the receiver in order to provide simultaneous transmission of several data streams on a single radio link. In LTE-A terms MU-MIMO (Multi User-MIMO) approach facilitates assigning the same RB (Resource Block) to different users[4].

2. Scheduling in LTE-A Networks

The following Figure 1 depicts the overall Radio Resource Management (RRM) process that interacts with the downlink packet scheduler. The whole process can be divided into a sequence of operations that are repeated, in general, every Transmission Time Interval (TTI).

- The eNB uses the Channel Quality Indicator (CQI) information for the allocation decisions and fills up a RB "allocation mask". The eNodeB uses both CA and MIMO features to take a scheduling decision based on QoS parameters and buffer status.
- The AMC module selects the best MCS that should be used for the data transmission by scheduled users.

- The information about these users, the allocated RBs and the selected MCS are sent to the UEs on the Physical Downlink Control Channel (PDCCH).
- Each UE reads the PDCCH payload and, in case it has been scheduled, accesses to the proper Physical Downlink shared Channel (PDSCH) payload.
- Each UE decodes the reference signals, computes the CQI, and sends it back to the eNB[3].
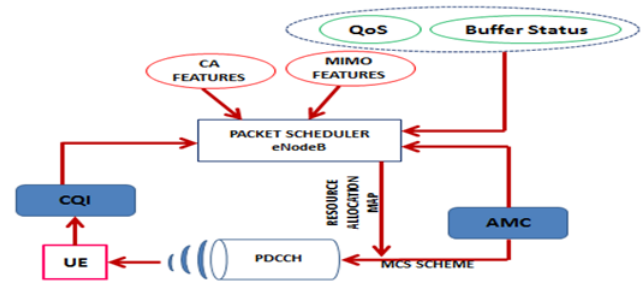

Figure 1. Basic model of a packet scheduler[3].

2.1 Radio Bearer Management and QCI classes

A radio bearer is a logical channel established between an User Equipment (UE)and the evolved-NodeB (base station). It is responsible for managingQoS provision on the E-UTRAN (Evolved-Universal Terestrial Radio Access Network) interface. When an UE joins the network, a default bearer is created for basic connectivity and exchange of control messages. It remains established during the entire lifetime of the connection. Dedicated bearers, instead, are set up every time a new specific service is issued. Depending on QoS requirements, they can be be further classified as Guaranteed Bit-Rate (GBR)

Table 1. Standardized QCI characteristics[3]

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

or non-Guaranteed Bit Rate (non-GBR) bearers[3]. Each bearer is characterized by a QoS Class Identifier (QCI). The standard QCI characteristics are summarized in Table 1[3].

In Section-3 details a thorough review of various packet scheduling algorithms for real time traffic in LTE-A and their scheduling metrics.

3. Related Work

In many related works, the scheduling problem has already been proved that it is NP-hard[5–7]. Because, the assignment of RB of a CC to a UE during a specific TTI, is largely influenced by the channel conditions with varying time, frequency and UE's location.

The Key Design Issues and a survey of various scheduling algorithms such as First In First Out (FIFO), Round Robin (RR), Blind Equal Throughput (BET), Resource Preemption (RP), Weighted Fair Queuing (WFQ), Earliest Deadline First (EDF), Modified Largest Weighted Delay First (M-LWDF), Maximum Throughput (MT), Proportional Fair Scheduler (PF) and so on were comprehensively presented in F. Capozzi et al.[3]

In the above mentioned scheduling schemes such as FIFO and RR which are QoS unaware may not be directly deployed in today's multimedia applications based networks. The age-old Maximum Throughput (MT) algorithm selects the flows experiencing the best instantaneous channel conditions and the Proportional Fair (PF) scheme chooses the flows with least running average throughput at a given TTI.

Hence, for our review we consider the more recent schemes which are QoS aware and suitable for present day real time internet applications. we present their scheduling metrics as follows:

L. Liu et al.[8] proposed a new method for radio resource allocation for LTE-A users. They have stated that since LTE-A uses multiple Component Carriers (CC), two ways of implementing the Proportional Fair (PF) Scheduler. They are,

3.1 Independent Scheduling per CC
This method is derived from the traditional single carrier scheduling by carrying out resource allocation separately in active configured CCs. Scheduler in each CC is not aware of the scheduling status of users in other CCs. The metric for this method is given as follows:

$$j = \arg\max \frac{R_{n,m}(i,k)}{I_{n,m}(i-1)} \tag{1}$$

Where $R_{n,m}(i,k)$ is throughput of nth user in ith scheduling interval at kth Resource Block (RB) mth CC. $T_{n',m}(i-1)$ is average throughput of this user in the same CC. j is the selected user to be scheduled.

3.2 Joint Scheduling Across CC
This method takes into account the user's statistics of all the configured CCs. The joint scheduler which is implemented in both serial and parallel manners can improve the overall performance of throughput.

In Blind Equal Throughput (BET) the scheduling metric is shown as follows:

$$M_{BET} = 1/(R[N]) \tag{2}$$

and in Proportional Fair (PF) the scheduling metric is given as:

$$M_{PF} = (\overline{D}[n])/(R[n]) \tag{3}$$

Where n is the user index, $\overline{D}[n]$ is the wideband throughput expected, R[n] is the past average throughput which is updated every TTI[9].

The M-LWDF scheduling algorithm considers the real time traffic service classes such as VoIP and Video Streaming flows for providing QoS. The metric for M-LWDF is given as follows:

In each time slot t, serve the queue j for which

$$M_{MLWDF} = \gamma_j \, W_j(t) \, r_j(t) \tag{4}$$

is maximal where $W_j(t)$ is the head-of the-line packet delay for queue j. $r_j(t)$ is the channel capacity with respect to flow j. γ_j is the arbitrary positive constants[10].

J. Max et al.[11] have proposed a Modified Earliest Deadline First algorithm for video and VoIP traffic in LTE-Advanced. In this algorithm, a user whose HoL (Head of Landline) packet is the most close to the headline is chosen according to the equation as in:

$$k = \arg\max \frac{1}{(\tau_i - D_{HoL,i})} \tag{5}$$

Where
k → selected user with the largest metric.
τ_i → packet delay threshold of user i.

$D_{HoL,i} \rightarrow$ HoL packet delay of the i th user at t th TTI[11].

The authors Zaki Y. et al.[12] proposed an Optimized-Service Aware (OSA) scheduler. In this scheme the resource allocation process has been divided into three separate stages - QoS classes identified classification, time domain and frequency domain scheduling. The OSA algorithm sorts each GBR bearer according to the Head of Line (HOL) packet delay in the buffer of the related bearer, while the non-GBR bearer list is ordered according to the following priority metric:

$$M_{OSA} = (\overline{D}[n])/(\theta[n])W_{QoS} \tag{6}$$

Where $\Theta[n]$ is the normalized average channel condition estimate of bearer n and W_{QoS} is the QoS weight.

S. Kumar et al.[13] have proposed a three level packet scheduler for real time traffic. The three layers are super-frame layer, frame layer and TTI layer which represent three distinct time domains at which this algorithm operates.

W. K. Lai et al.[14] have proposed a novel Packet Prediction Mechanism (PPM) which operates in three different phases. These phases include in the first phase initial scheduling for Physical Resource Blocks (PRBs) in frequency domain for effective bandwidth utilization, then managing queues and calculating expected delays for packets and finally introducing a cut-in process for meeting delay requirements.

C. Lee[15] proposed a new Adaptive Packet Scheduling Mechanism (APSM) to minimize resources interferences for Device-to-Device (D2D) communication underlaying Long-Term Evolution (LTE) networks. This APSM aims to guarantee a ceaseless packet transmission by considering Overload Check Bits (OCB) in the D2D link. The main objective of this paper was to increase the system throughput by considering the packet scheduling structure according to the Hybrid Automatic Repeat Request (HARQ) and link adaptation.

M. K. Alam et al.[16] employed three different MAC layer scheduling mechanisms such as FIFO, Random Early Detector (RED) scheduler and Weighted Random Early Detector (WRED) scheduler for analysing the performance over the network based on variation of traffic load in high speed wireless campus network (IEEE802.11e). They have done the evaluation of the proposed schedulers' performance using different performance metrics.

A detailed analysis of performance of three different scheduling algorithms via., Deficit Round Robin (DRR), Maximum Carrier to Interference Ratio (MAXCI) and PF was carried by A. Syuhada et al[17]. They evaluated the performance of these algorithms based on the characteristics such as MAC throughput, VoIP frame delay, VoIP packet delay variation. They concluded that MAXCI outperforms all the other scheduling algorithms in the characteristics evaluated as evidenced from the Figures 2 and 3.
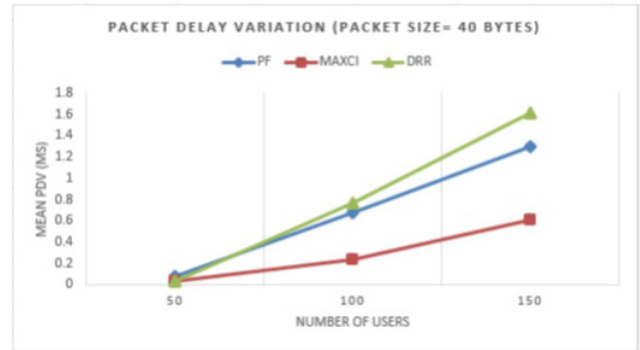

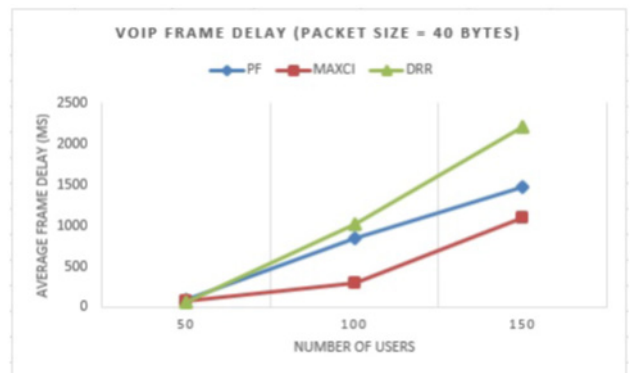**Figure 2.** Average packet delay variation.

Figure 3. Average VoIP frame delay.

4. Summary and Conclusion

In this paper we have reviewed the most important packet scheduling algorithms such as modified PF, BET, M-LWDF, OSA etc., for real time traffic in the LTE-A networks. We have analyzed the key features of these algorithms and the scheduling metrics have been given.

Our most significant observation from this review is that any packet scheduling algorithm for downlink real time data should be QoS aware so that it is readily deployable in the present day multimedia networks. It can also be noted that these scheduling schemes should take into account the latest technologies such as Carrier

Aggregation and Multi Input and Multi Output (MIMO) which are specified by the 3GPP, so that the data rate can be increased for real time applications.

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