Downlink Scheduling Algorithms for Real-Time Multimedia Services in 3GPP LTE Mobile Networks

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Abstract

Long Term Evolution (LTE) is one of the fastest growing technologies which supports variety of applications like video conferencing, video streaming, VoIP, file transfer, web browsing etc. In order to support multiple applications, Radio Resource Management (RRM) procedure is one of the key design roles for improving the system performance. LTE system effectively utilizes the resources by dynamically scheduling the users in both frequency and time domain. However, scheduling algorithms are not defined in the Third Generation Partnership Project (3GPP) specifications. Therefore, it becomes one of the special interests for service providers. In this paper a study of downlink scheduling algorithms for real-time multimedia services in 3GPP LTE mobile networks was carried out and some existing algorithms were carefully studied and analyzed. Six existing downlink scheduling algorithms were considered for this work. A summary of all the presented schemes was shown as well as the strengths and weaknesses of the schemes. It can be seen that all the schemes reviewed focuses only on Real-Time multimedia services therefore they don't treat Non-Real Time services with utmost fairness.

Keywords: LTE, Mobile Networks, Scheduling, Downlink Scheduling, Real-Time Multimedia

1 Introduction

The continuous rise of real-time multimedia services in the Internet and the need for an ubiquitous access to them are driving the evolution of cellular networks. Beside the huge bandwidth requirements, real-time multimedia flows need to be treated differently from other ones in order to achieve a target quality-of-service (Piro et-al, 2011). In general, the most important objective of a multimedia service is the satisfaction of end users, i.e., the quality-of-experience (QoE). This is strictly related to the system ability to provide to application flows a suitable QoS (Khirman & Henriksen, 2002), generally defined in terms of network delivery capacity and resource availability, i.e., limited packet loss ratio and delay. As example, a limited packet loss ratio enhances the quality of a reconstructed video, limiting distortions due to lack of video data packets, while a low delay allows to reproduce multimedia content at receiver side in real-time, i.e., with a small playout delay. In real-time multimedia services, such as VoIP or video-conference, end-to-end delay constraints in content delivery have to match the requirements related to the human perception of interactivity. For the Internet telephony, a delay of 100 ms is considered as the limit for a good perceived quality, while the delay has to be less than 300 ms for a satisfactory quality (Na & Yoo, 2002). In order to respect audio/video synchronization, also for video delivery, the delay bounds have to be the same. Su et-al (2007) for example, a delay of 200 ms is considered for video interactive applications. Once the video decoding process starts with a playout delay chosen in this range, the respect of this deadline becomes mandatory for every encoded packet. Every packet will be decoded with a playout delay after its generation time and, if the packet does not arrive within the deadline, it will be considered lost. In this regard, in multimedia services, granting bounded delivery delays actually means lowering packet losses. In this paper, a review and study of six different existing downlink scheduling algorithms for real-time multimedia services is presented. The rest of the paper is organized as follows: In section II: Overview of LTE networks, Section III: Scheduling In 3GPP LTE Mobile networks, Section IV: Downlink scheduling algorithms for real-time multimedia services, Section V: Summary of the reviewed schemes, Section VI: Conclusion and Section VII: References.

2. Overview of 3GPP LTE Mobile Network

The LTE technology as specified by the third-generation partnership project (3GPP) is a cutting-edge radio access technology that improves the conventional systems by offering higher data rates, improved spectral efficiency and low latency compared with the third-generation networks. The orthogonal frequency division multiple access (OFDMA) technology has been adopted in the downlink due to its immunity to frequency selective fading of the radio channels and its robustness against the inter-symbol interference. The LTE radio access network includes merely one node between the core network and the user, identified as eNodeB that is responsible to achieve all radio resource management (RRM) tasks. The most significant RRM function is achieved through the packet scheduler which is responsible for distributing radio resources among users in an efficient way, taking into consideration the flow requirements, physical constraints, and fulfilling the users' QoS requirements.

LTE is flat, Internet Protocol (IP) based architecture with respect to the previous 3G systems (Sulthana & Nakkeeran, 2014). In previous system, separate Radio Access Network (RAN) that consists of Radio Resource Control (RRC), Radio Link Control (RLC) and Medium Access Control (MAC) protocols is used to interface with User Equipment (UE). But in LTE, eNB takes care of the above-mentioned protocol functions. So it requires lesser number of nodes that reduces the system latency and improves overall performance (Kumar, Sengupta & Liu, 2012). The network architecture of LTE consists of core network called Evolved Packet Core (EPC) and access network called Evolved-Universal Terrestrial Radio Access Network (E-UTRAN) as shown in Figure 1 below:

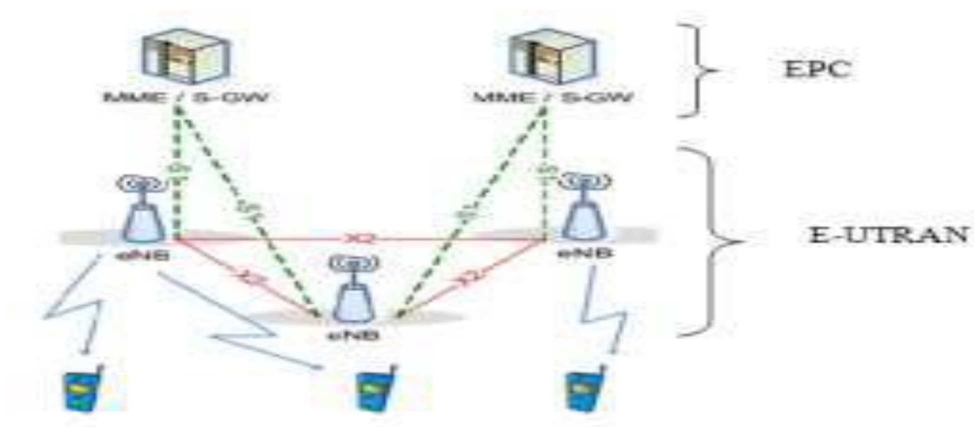

Figure 1: System Architecture of E-UTRAN

The responsibility of eNB in the access network is to ensure that the necessary QoS for a bearer over the interface is met. Each bearer has an associated QoS Class Identifier (QCI) (3GPP Tech Specification,

2003) and each QoS class is characterized by priority, tolerable packet loss, and tolerable delay. Generally, bearers can be classified into two categories based on the nature of the QoS they provide: Guaranteed Bit-Rate (GBR) bearers which are real time bearers and non-GBR bearers which are non-real time bearers as shown in Table 1. At the physical layer, LTE supports both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) modes. OFDMA is chosen as the DL access technology. The available bandwidth is divided into multiple Resource Blocks (RBs) based on time and frequency domains

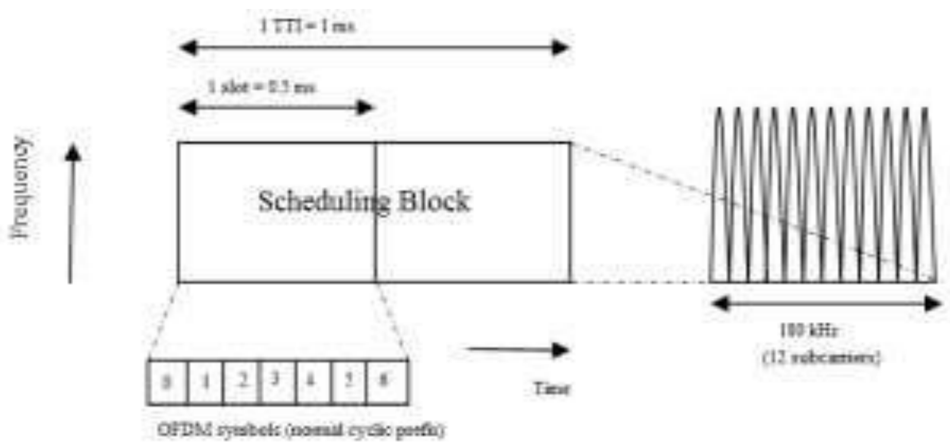

Figure 2: LTE Downlink resource block structure.

A RB is the smallest allocation unit in LTE which can be modulated independently. In the frequency domain the RB consists of 12 consecutive subcarriers and in the time domain it is made up of one time slot of 0.5 ms duration and adopts two slots as allocation period. The scheduling period is called as one Transmission Time Interval (TTI) and it lasts for 1 ms duration as shown in Figure 2.

Table 1: Standardized QCI for LTE

QCI	**Resource Type**	**Priority**	**Packet Delay Budget [ms]**	**Packet Loss Rate**	**Example services**
1	GBR	2	100	10^{-2}	Conversational voice
2	GBR	4	150	10^{-3}	Conversational video (live streaming)
3	GBR	5	300	10^{-6}	Non-Conversational video (buffered streaming)
4	GBR	3	50	10-^{3}	Real time gaming
5	non- GBR	1	100	10^{-6}	IMS signalling
6	non- GBR	7	100	10^{-3}	Voice, video (live streaming), interactive gaming
7	non- GBR	6	300	10^{-6}	Video (buffered streaming)
8	non- GBR	8	300	10^{-6}	TCP based (e.g., WWW, e-mail), chat, FTP,
9	non- GBR	9	300	10^{-6}	P2P file sharing

3. Scheduling in 3GPP LTE Mobile Networks

The scheduler which is found in the eNB, controls the assignment of RBs to UEs to avoid intra-cell interference. In general, the function of scheduler is to find the optimal allocation of the resource unit (time, frequency, power etc) to UEs such that QoS requirements of users are satisfied. The scheduler selects the UE to be scheduled and number of RB to be assigned based on two factors: the channel quality and the QoS requirements. In DL, the scheduler can assign any random set of RBs for a particular UE whereas in the UL the RBs allocated have to be adjacent to each other because of single carrier property. To facilitate the channel dependent scheduling on DL, the eNB has to get the channel quality reports from the UE. Each UE calculates the signal-to-noise (SNR) ratio based on its channel condition. It sends the Channel Quality Indicator (CQI) value to eNB based on its calculated SNR to choose the appropriate modulation and coding scheme (MCS) (Sulthana & Nakkeeran, 2014). Resource allocation for each UE is usually based on the comparison of per-RB metric. This metric can be interpreted as the transmission priority of each UE on a specific RB. The scheduling strategies of any wireless network can be broadly classified as shown in Figure 3.

Channel independent scheduling is based on the assumption that channel is time invariant and error-free. Examples of channel independent scheduling are First-in-First-out (FIFO), Round Robin (RR), Weighted Fair Queuing (WFQ), Earliest Deadline First (EDF), Largest Weighted Delay First (LWDF) etc (Sulthana & Nakkeeran, 2014). In this case, some algorithms satisfy the QoS requirements and some simply schedules. With the help of CQI reports which are periodically sent by UEs to eNB, the scheduler can estimate the channel quality experienced by each UE. The scheduling performed by these schedulers is called channel sensitive scheduling. In this type of scheduling the scheduler may try to maximize the QoS requirements of each UE (QoS aware scheduling) or it may try to provide fairness among UEs (QoS unaware scheduling). Examples of channel sensitive scheduling are Maximum Throughput (MT), Proportional Fairness (PF), Throughput To Average (TTA), Modified- Largest Weighted Delay First (MLWDF), Exponential Proportional Fairness (EXP/PF), Exponential rule (EXP rule), Logarithmic rule (LOG rule) etc. In LTE only channel sensitive scheduling is done based on the CQI reports from the UE.

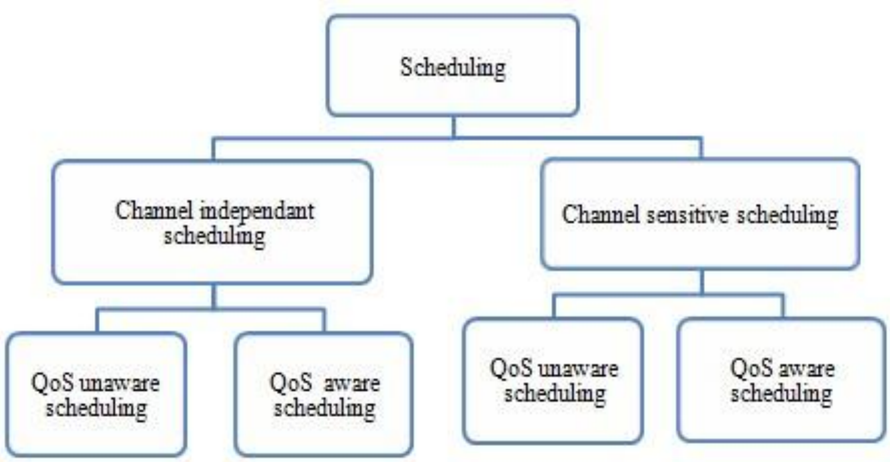

Figure 3: General Classification of Scheduling

Apart from the above-mentioned scheduling algorithms, many different types were proposed. different types were presented by Sulthana and Nakkeeran (2014):

a. Delay-based algorithms
b. Power based algorithms
c. QCI feedback based algorithms
d. Service based algorithms
e. Queue based algorithms
f. QoE based algorithms

As stated earlier, this paper will focus on Real-time multimedia service are classified under the Service-based algorithms. The schemes considered for this work are:

i. Two Level Downlink Scheduling for Real-time Multimedia services (2011).
ii. Quality of Service (QoS) aware packet scheduler for Real Time (RT) services (2015).
iii. A delay based Priority Scheduling Algorithm for Downlink Real-Time Traffic (DP-VT-MLWDT) (2016).
iv. A scheduling scheme that was based on the Earliest Due Date (EDD) strategy. (2016)
v. An efficient layered scheduling algorithm for Real Time services. (2016).
vi. An Exponential-based packet scheduling scheme for RT traffic. (2017).

4. Review of Some Downlink Scheduling Algorithms for Real-Time Multimedia Services

In this section, a review of six downlink scheduling algorithms for real-time multimedia services.

Piro et-al, (2011) proposed a two-Level Downlink Scheduling for Real-time Multimedia service. The scheme was built on two levels. These two level interact with each other in order to dynamically assign radio resources to UEs. They take into account the condition of a channel, the data source behaviors and the maximum tolerable delays. At the upper level of the scheduler, a resource allocation algorithm named FLS defines frame by frame the amount of data that each real-time source should transmit to meet its delay constraint. Once FLS has accomplished its task, the lower layer scheduler, every TTI, assigns RBs using the PF algorithm (Brehm & Prakash, 2013) by considering bandwidth requirements of FLS. The lowest layer scheduler, instead, allocates RBs at each TTI to achieve a trade-off between fairness and system throughput. The scheme significantly outperforms some of the existing algorithms especially in the presence of real-time video applications but in the presence of Non-Real Time applications, the scheme is not an efficient one.

Ali et-al (2015) proposed a Quality of Service (QoS) aware packet scheduler for Real Time (RT) services. The scheme was based on a Resource Block (RB) preservation which uses an RB preservation strategy. It operates in two layer: upper layer and the lower layer. At the upper layer, the scheme takes into consideration the RT services and how they flow in order to satisfy the QoS requirements of the users. The layer assigns free RBs RT applications (if they are available) to the NRT services for the purpose of allocating the RBs to each sub-frames. By this process, the strategy will preserve the wasted RBs of the RT applications and the packets of the NRT will be assigned in these preserved RBs. At the lower layer of the scheme, the allocation of RBs to different classes depending on the service type is done. For the NRT applications, a Proportional Fair (PF) algorithm is employed for the purpose of achieving fairness among the services while for RT applications a different metrics PF_Max is used to achieve some level of fairness for the RT services. The scheme satisfies the QoS requirements for the RT services but fails to satisfy the QoS requirements of NRT services.

A delay based Priority Scheduling Algorithm for Downlink Real-Time Traffic (DP-VT-MLWDT) was proposed by Li et-al (2016) to ameliorate the QoS performance of Real Time (RT) applications. The scheme also tries to achieve some acceptable performance in Non-Real Time (NRT) services in the network by utilizing a delay priority function. It takes into consideration the packets whose delay is nearer to the threshold and it gives higher priority to these packets. They are then transmitted using a delay priority function. The scheme also takes into account the average throughput of the past time and the CQI which has a significant influence in resource allocation determination. The scheme also uses all parameters that are considered by the VT-MLWDF scheduler for ameliorating the QoS performance of RT applications and the MLWDF2 for improving the performance of RT traffic such as average throughput, fairness etc. the scheme achieves a significant improvement for QoS performance parameters of RT applications such as Packet Loss Rate (PLR), average throughput and fairness index etc. However, the scheme is not fair to NRT applications due to higher priority given to RT applications by the scheme.

A scheduling scheme that was based on the Earliest Due Date (EDD) strategy was proposed by (Elhadad et-al, 2016) to enhance the performance of RT flows in LTE. The scheme is based on EDD strategy which gives higher priority to RT services with the highest packet delay. It takes into consideration, the condition of a channel and past average throughput for the purpose of achieving a high bit rate and a reasonable level of fairness among active User Equipment (UEs). The scheme then decides to serve the UEs who has packets with the earliest due date and at the same time with the best channel condition. Also the past be taken into account for the enhancement of the spectral efficiency and providing high level of fairness among all active users. The performance of the scheme was compared with that of FLS, Exp-Rule and LOG-Rule schedulers. It provides the lowest Packet Loss Rate (PLR) for RT services but it fails to treat NRT services fairly due to priority given to the RT services.

Chen et-al, (2016) proposed an efficient layered scheduling algorithm for Real Time services. The scheme treats delay constraint and the object for maximal throughput separately. It uses a Delay Priority Scheduler (DPS) that gives priority to the delay constraint and employs a greedy strategy to select the RBs for the UEs that are closer to their deadline. The scheme gives priority to the UE that are nearest to their deadline, which means the potential pairs of UE and RB with larger transmission rate will be discarded. The scheme operates in two layers. At the first layer, the scheduler takes delay constraint into account in the same way as the DPS but here only UEs are considered not these near to the deadline. At the second layer, the scheduler uses the remaining which means that if the data size of a UE is smaller than the transmission rate of the RBs so that there will be no waste of resources, the UE will choose to wait and leave the resources to other UEs, ensuring the utilization efficiency of the RBs. The scheme was compared with some conventional scheduling algorithms; LOG rule, EXP rule, EXPF and the scheme achieves a better performance in terms of fairness, Packet Loss Rate (PLR) for RT services but it fails to achieve the same performance for the NRT services.

Finally, an Exponential-based packet scheduling scheme for RT traffic was presented by (Aiyetoro & Takawara, 2017). The scheme was designed on the principle of cross-layer approach, acceptable level of fairness and high throughput. It uses the ration of instantaneous data rate to the average data rate. Also, the scheme uses the ratio of difference between the delay deadline and waiting time in order to achieve the acceptable level of QoS. It also uses a control variable to know the level at which the QoS function subdue the throughput function. The scheme was compared with two most widely used QoS-aware schedulers and it produces the best throughput and spectral efficiency performance. It also achieves the highest level of fairness and QoS for RT services. However, for the NRT services, none of the above achievement if found for the NRT services.

5. Summary of the Reviewed Schemes

Table 2: Summary of the schemes reviewed.

S/N	Name of Scheme	Strength(s)	Weakness(s)
1	Two Level Downlink Scheduling for Real-time Multimedia services (2011).	It achieves a significant improvement especially for real-time videos	It is not efficient for NRT services
2	Quality of Service (QoS) aware packet scheduler for Real Time (RT) services (2015)	QoS requirements for RT services are satisfied.	QoS requirements for NRT services are not satisfied
3	A delay based Priority Scheduling Algorithm for Downlink Real-Time Traffic (DP-VT-MLWDT) (2016).	It achieves improvement for QoS performance parameters of RT applications.	It is not fair to NRT applications due to higher priority given to RT applications by the scheme
4	A scheduling scheme that was based on the Earliest Due Date (EDD) strategy. (2016)	It provides the lowest Packet Loss Rate (PLR) for RT services. Also it achieves a high bit rate for multimedia services.	It fails to treat NRT services fairly due to priority given to the RT services.
5	An efficient layered scheduling algorithm for Real Time services. (2016).	It achieves a better performance in terms of fairness, Packet Loss Rate (PLR) for RT services	It fails to achieve the same performance for the NRT services.
6	An Exponential-based packet scheduling scheme for RT traffic. (2017).	It produces the best throughput and spectral efficiency performance and It also achieves the highest level of fairness and QoS for RT services.	NRT services did not achieve any of the achievements of the RT services.

6. Conclusion

Resource scheduling is a very important issue worth studying in 3GPP LTE mobile networks. So many scheduling algorithms has been developed by scholars and Researchers in order to address the issues of scheduling in LTE networks. Some of the schemes focuses on RT services while some on NRT. Some schemes tries to have both RT and NRT on the same algorithm. Some other schemes are interested in the uplink while some are interested in downlink section of the scheduling. In this paper, downlink resources scheduling for real time multi-media services was the interest of the Researchers. Six existing schemes were carefully studied and it was found that all the schemes favored RT applications over NRT applications. The work can be extended by studying resources scheduling schemes in uplink and other classes such as the NRT applications.

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