STUDY OF DOWNLINK SCHEDULING ALGORITHMS FOR REAL-TIME MULTIMEDIA SERVICES IN LTE NETWORKS.

By:

Maniru Malami Umar[1], Sadiq Aliyu Ahmad[2], Asma'u Shehu[3] & Ziya'u Bello[4]
Usmanu Danfodiyo University Sokoto[1], Federal University Dutse, Jigawa State[2], Sokoto State University, Sokoto[3] & Usmanu Danfodiyo University, Sokoto[4].

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, Radio Resources Management in LTE networks was studied and presented. Finally, an analysis of six (6) existing downlink scheduling algorithms that mainly focus on real-time multimedia services was carried out.

Keywords: LTE, Downlink Scheduling, Radio Resource Management, Real-Time Multimedia

INTRODUCTION

The emerging applications with different throughput, delay, Packet Loss Rate (PLR) and bandwidth requirements emphasize the need of a network capable of supporting range of services. To achieve this aim, Long Term Evolution (LTE) was introduced by Third Generation Partnership Project (3GPP) (3GPP Specification, 2003) . The main objective of the LTE network is to enhance the data rate so as to provide the radio resources for variety of highly demanded services, while taking into consideration a satisfied level of Quality-of-Service (QoS) to all active users. Packet scheduler at radio base station (evolved Node B (eNB) in LTE specification) is responsible of assigning portions of spectrum shared among users. The performance of the network can differ according to the algorithms used by the scheduler. Therefore designing an effective scheduler is an important task in order to differentiate the performance of one network from another. The packet scheduler is aimed at maximizing the spectral efficiency and make the negative impact of channel quality drop into negligible (Sulthana & Nakkeeran, 2014). Different scheduling algorithms has been proposed to support different class of services. Some of these algorithms consider a special kind of traffic and most of them focus on real-time multimedia services.

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 three 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: Resources Management in LTE networks, Section IV: Downlink scheduling algorithms for real-time multimedia services, Section V: Conclusion and Section VI: References.

OVERVIEW OF LTE NETWORK

For the purpose of supporting wide variety of different applications, LTE network is designed with challenging requirements that overtakes the features of 3G networks mainly designed for voice services (3GPP Tech Specification). LTE system uses Orthogonal Frequency Division Multiple Access (OFDMA) technology in the Downlink (DL) and Single Carrier-Frequency Division Multiple Access (SC-FDMA) in the Uplink (UL). The OFDMA technology divides the available bandwidth into multiple sub-carriers and allocates a group of sub-carriers to a user based on its QoS requirements. It provides spectrum flexibility where the transmission bandwidth can be selected between 1.4 MHz and 20 MHz depending on the available spectrum. The peak data rate, which is the important parameter by which different technologies are usually compared, generally depends on the amount of spectrum used. The allowed peak data rate for the DL and UL is equal to 100 Mbps and 50 Mbps respectively. LTE targets to provide spectral efficiency two to four times better than 3G systems (15 bps/Hz in DL and 3.75 bps/Hz in UL).

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:

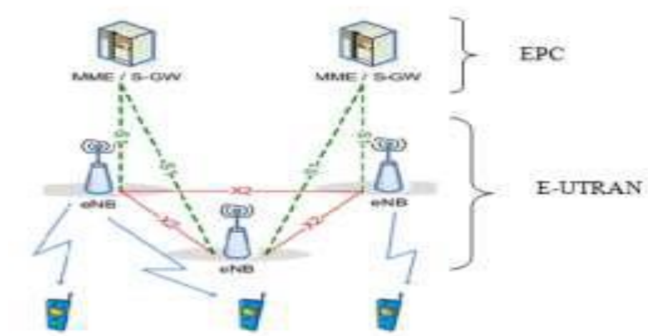

Figure 1: System Architecture of E-UTRAN

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 [9].

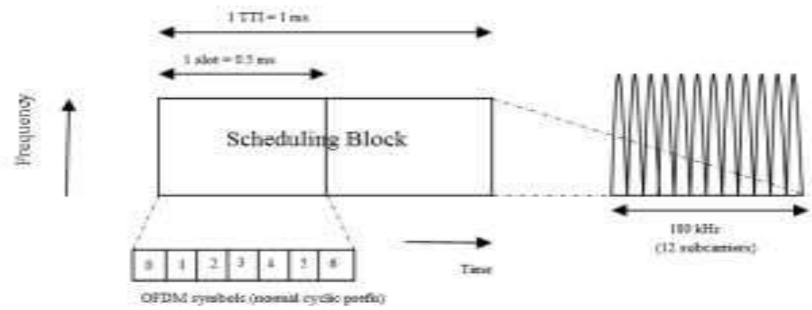

Figure 2: LTE Downlink resource block structure.

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, P2P file sharing
9	non- GBR	9	300	10^{-6}	

RESOURCE MANAGEMENT IN LTE 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.

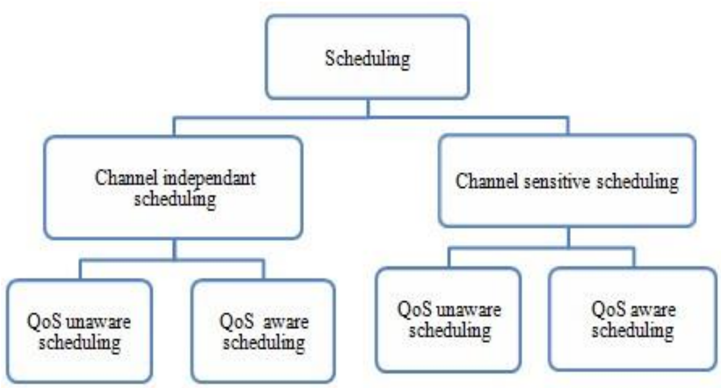

Figure 3: General Classification of Scheduling

Apart from the above mentioned scheduling algorithms, many different types were proposed. In [2], different types were presented as:

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.

DOWNLINK SCHEDULING ALGORTHMS FOR REAL-TIME MULTIMEDIA SERVICES

In this section, a review and study will be presented for three downlink scheduling algorithms for real-time multimedia services. The algorithms are:

a. Two-level downlink scheduling for Real-time multimedia services in LTE networks
b. A delay based Priority Scheduling Algorithm for Downlink Real-Time Traffic in LTE Networks
c. An efficient layered scheduling algorithm for Real Time services in LTE

a. Two Level Downlink Scheduling for Real-time Multimedia services in LTE networks: The algorithm was presented in by (Piro et-al, 2011) and was built on two level as shown in figure 4. These two level interact with each other in order to dynamically assign radio resources to UE. They take into consideration the state of the channel, the data source behaviours and the maximum tolerable delays. At the highest level, an innovative resource allocation algorithm, namely FLS, defines frame by frame the amount of data that each real-time source should transmit to satisfy its delay constraint. Once FLS has accomplished its task, the lowest 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 resource blocks in each TTI to achieve a trade-off between fairness and system throughput. It is important to note that FLS does not take into account the channel status. On the contrary, the lowest layer scheduler assigns RBs first to flows hosted by UEs experiencing the best channel quality and then (i.e., when these flows have transmitted the amount of data imposed by FLS) it considers the remaining ones. In particular, the lowest layer scheduler decides the number of TTIs/RBs (and their position in the time/frequency domains) in which each real-time source will actually transmit its packets.

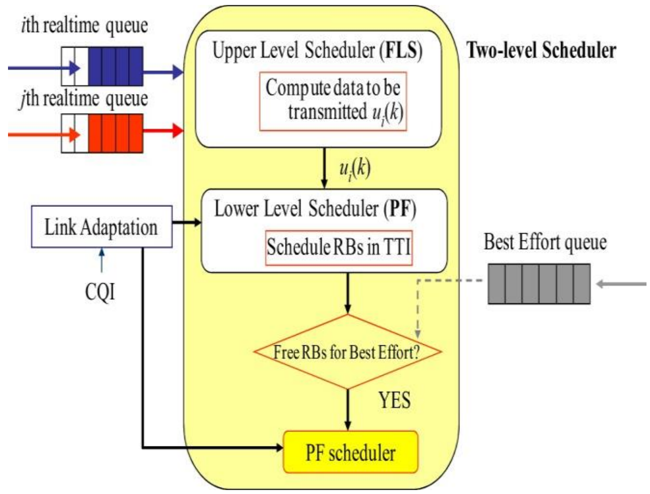

Figure 4: Two-level Scheduling Algorithm

The numerical simulation result showed that, the scheme greatly outperforms some of the existing algorithms especially in the presence of real-time video flow.

b. A delay based Priority Scheduling Algorithm for Downlink Real-Time Traffic in LTE Networks

Delay Priority Scheduling Algorithm for Downlink Real-time Traffic in LTE networks DP-VT-MLWDF was proposed in (Li et-al, 2016). For the reason that RT traffics have a higher demand for real time, clarity and stability than NRT traffics, the PLR should be kept in a lower level and the delay should be less. In order to achieve this goal, the packets whose delay is closer to the threshold should have the higher priority to be transmitted Besides the size of flow buffer, the average throughput of past time and the CQI also has a great of effects in making resource allocation determination, so the scheduler adopts all the parameters considered by the aforementioned schedulers. Consequently, the main objective of the proposed scheduling algorithm is to optimize the QoS performance of RT services. Meanwhile, the performance of NRT services should remain within an acceptable level.

The proposed algorithm whose main purpose is to ameliorate the QoS performance of RT traffics while sacrifice an acceptable performance of NRT traffics in the network by utilizing a delay priority function. The scheme achieves improvement for the QoS performance parameters for Real Time applications.

c. An efficient layered scheduling algorithm for Real Time services in LTE

A novel layered scheduler was presented by (Chen et-al, 2016) It treats the constraint of delay and the object for maximal throughput separately. The Delay Priority Scheduler (DPS) only gives priority to the delay constraint and adopt a greedy strategy to select the RBs for the UEs nearest to their deadline. It is possible that the near sight of the algorithm shall lead to a smaller total throughput. If priority is always given to the UE nearest to his deadline, then the potential pair of UE and RB with bigger transmission rate will be neglected In view of the above, a two layered scheduler for downlink data transmission was presented in (Chen et-al, 2016)

The first layer of the scheduler takes delay constraint into consideration in the same way as the DPS but in this case only the UEs rather near to the deadline e.g. satisfying the below equation (1) are treated in this way.

$$DL(n) - Max\ dl(n) < DPTI, \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where *DPTI* denotes the time interval between the generations of two packets. It means that, a user is ready to be scheduled only when the time till the delay threshold of the first packet is less than DPTI. This is because that averagely one packet can be transmitted for each user in every *DPTI*, assuring that the packet delay is under the threshold.it aims to ensure delay, but not to place it at the first place at any time

In the second layer of the scheduler, if there are remaining RBs left, the UEs satisfying the following are considered:

$$Max\ v(n) \leq \theta * data\ size(n) \ldots\ldots\ldots.. (2)$$

This means that if the data size of a UE is much smaller than the transmission rate of the RBs, in order not to waste resources, the UE will choose to wait and leave the resources to other UEs, ensuring the utilization efficiency of the RBs.The value of θ is determined by the relation between the number of users and resources and we can calculate it by simulations with historical records.

To maximize throughput and ensure fairness, a scheduling metric $P(n,r,t)$ is adopted as

$$P(n,r,t) = \frac{v(n,r,t)}{\overline{v_{max}}(n,t)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Then the pair of RB *r* and UE *n* with the maximal $P(n,r,t)$ is selected, e.g,, at time *t*, the *r*th RB is assigned to transmit the data of UE *n*. Being similar to the PF, $P(n,r,t)$ can ensure fairness. Moreover, it can also enable a higher throughput.

Finally, the simulation results show that, in comparison to the well known LOG rule, EXP rule and EXPPF algorithms, the LS algorithm can achieve at least the same performance, and sometimes better in fairness, RUR and PLR.

CONCLUSION

The 3GPP LTE standards aim to achieve revolutionary data rate, spectral flexibility with seamless mobility and enhanced QoS over the entire IP network. In this paper, a study of downlink scheduling algorithms for real-time multimedia services in LTE networks has been carried out.The first scheme that was considered was the Two Level Downlink Scheduling for Real-time Multimedia services in LTE networks. The scheme significantly outperforms the reference algorithms such as Exponential rule, Logarithmic rule and FLS especially in the presence of real-time video flow. The second scheme that was studied was the Delay Priority Scheduling Algorithm for Downlink Real-time Traffic in LTE networks. The scheme achieves significant improvement in the QoS performance parameters for RT traffics such as PLR, average throughput, fairness index. Lastly, an Efficient layered scheduling algorithm for real time services in LTE was reviewed. It was found that, the algorithm can achieve at least the same performance, and sometimes better in fairness, RUR and PLR.

REFERENCES

3GPP, Tech. Specific. Group Services and System Aspects – Policy and charging control architecture (Release 9), *3GPP TS* 23. 203

Amit Kumar, Jyotsna Sengupta, Yun-fei Liu (2012): 3GPP LTE: The Future of Mobile Broadband" *Wireless Personal Communication*, vol. 62, pp. 671-686

G.-M. Su, Z. Han, M. Wu, and K. Liu (2007): Joint uplink and downlink optimization for real-time multiuser video streaming over WLANs. *IEEE J. Sel. Topics Signal Process.*, vol. 1, no. 2, pp. 280–294.

G. Piro, L. A. Grieco, G. Boggia, R. Fortuna, and P. Camarda (2011): Two-level downlink scheduling for real-time multimedia services in LTE networks. *IEEE Trans. Multimedia, vol. 13, no. 5, pp. 1052–1065.*

Juan Chen, Wi Zhang, Suixiang Gao and Wenguo Yang (2016): An Efficient Layered Scheduling Algorithm for Real Time Serices in LTE. *Wireless Networks*.

Michael Brehm, Ravi Prakash (2013): Overload-state Downlink Resource Allocation in LTE MAC Layer. *Wireless Networks*, vol. 19, pp. 913-931.

S. F. Sulthana and R. Nakkeeran (2014): Study of Downlink Scheduling Algorithms in LTE Networks. *Journal of Networks, Academy Publisher, vol. 9(12), pp. 3381 – 3391*.

S. Khirman and P. Henriksen (2002): Relationship between quality-of-Service and quality-of-Experience for public internet service. *Proc. Passive and Active Measurement PAM, Fort Collins, CO.*

S. Na and S. Yoo (2002): Allowable propagation delay for VoIP calls of acceptable quality. *Proc. 1st Int. Workshop Advanced Internet Services and Applications, Springer-Verlag, London, U.K., 2002, pp. 47–56.*

Yuan-Ping Li, Bin-Jie Hu, Hui Zhu, Zong-Heng Wei and Wei Gao (2016): A Delay Priority Scheduling Algorithm for Downlink Real-Time Traffic in LTE Networks", *Wireless Networks*.