Analytical Model of the LTE Radio Scheduler for nonGBR Bearer

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Abstract

Long Term Evolution (LTE) is a mobile network that operates completely in packet domain. Due to the variation of radio condition in LTE, the obtainable bit rate for active users will vary. The two factors for radio variation are fading and path-loss. By analyzing the previous researches concerning with packet scheduling of LTE network, in this paper, an analytical model of the LTE radio scheduler is proposed. This model is based on the stochastic process to observe the system behavior mathematically and takes the details of the schedluler's behavior taking into account given in a state of the system, i.e. the number of the active users and their distance from the base station. Instead simulation result, the numerical result is shown. This model mainly considers the path loss variation at non-Guaranteed (nonGBR) bit rate such as FTP or HTTP.

1. Introduction

Long Term Evolution (LTE) is the evolution of the existing 3G mobile network towards a higher capacity, lower latency and more efficient radio access and core network. Its air interface is designed with Orthogonal Frequency Division Multiple Access (OFDMA) as the core access technology. LTE In OFDMA-based LTE system, scheduling strategies refer to both time dimension and frequency dimension.

LTE supports several QoS classes and tries to guarantee their requirements by defining the so called "bearer" concept. A bearer (EPS bearer) is an IP packet flow between the user side and the LTE core network with predefined QoS characteristics. Having these different QoS bearers in packet domain introduces an additional challenge on the LTE MAC scheduler design. In which the scheduler has to be aware of the different service requirements and satisfy them. Optimized Service Aware (OSA) [5] can address this challenge. OSA scheduler differentiates between different QoS classes mainly by defining several MAC bearer types such as Guaranteed (GBR) or non-Guaranteed (nonGBR) BitRate [5].

Many researches on LTE scheduling has been treating the downlink scenario, some examples are [7][8]. Analytical analysis of FTP downloading time was estimated and however, it did not consider variation of radio condition [4].

Signal variation for the LTE uplink has been worked [3] and it did not base on the service aware schemes. In the paper analytical model which accounts the user's location of nonGBR in the cell is developed after classifying bearer types by OSA. In the developed model, the state of the system, i.e. the number of the users and their distance from the base station, is used to create the Markov chain which describes the system behavior.

The paper is organized as follows: section 2 describes the works concerning the LTE packet scheduling scheme and section 3 presents general architecture of the LTE network. In section 4, the design of OSA scheduler scheme is described in detail. Section 5 will give an analytical model for the LTE downlink of nonGBR. In section 6, conclusion and future plan are given.

2. Related Works

Some of the previous researches works that are related to the proposed system are described in this section. Raymond Kwan et.al [7] discussed about allocating the resources to multiple users on the downlink of a Long Term Evolution (LTE) cellular communication system. Their numerical result showed that a limited amount of feedback information could provide a relatively good performance. The performance of a scheduler which addresses fairness among users was also presented. C. Wengerter et. al. derived a closed-form expression for the throughput of proportional fair scheduling (PFS) in wireless networks[8]. Then, an analytical model was given to provide the high accuracy of in evaluating the throughput of the PFS algorithm in Rayleigh fading environment. The theoretical results from analysis were compared with those from simulations.

Yasir Zaki et.al, presented the analytical model of FTP (File Transfer Protocol) transmission in virtualized LTE systems to investigate the advantages of virtualization on the LTE air interface [2]. They validated analytical analysis with the consideration of realistic simulation model and the mixed services of FTP and VoIP (Voice over IP) traffic. Extended multi-party spectrum sharing model was also proposed. However, radio signal variation was out of his scope. Yasir Zaki et.al, also developed LTE radio schedulers analytical model using Continuous Markov Chains [6] and represented Time Domain Schedulers as well as two different model categories: a single class model and two class model. D. C.

Dimitrova [3] presented the flow behavior analysis with the two scheduling schemes for LTE uplink. All users were scheduled in a Round Robin fashion and all were assigned an equal number of subcarriers regardless of the channel condition. The author evaluated the performance of the scheduling schemes with the comparison of the analytical model.

3. LTE Network Architecture

The LTE system is designed to work only with packet switched services, providing IP connectivity between the Packet Data Network (PDN) and the User Equipment (UE) without any service interruption even during mobility. The LTE system can be divided into two different evolutions mainly, the Enhanced Universal Terrestrial Radio Access Network (E-UTRAN) and the System Architecture Evolution (SAE). The E-UTRAN is the evolution of the UMTS radio access network which is sometimes also referred as LTE, whereas the SAE supports the evolution of the packet core network, also known as Evolved Packet Core (EPC). The combination of both the E-UTRAN and the SAE composes the Evolved Packet System (EPS). Figure 1 shows the general LTE network architecture. The LTE architecture can be said two nodes architecture. The two nodes are user equipment (UE) and evolved NodeB (eNB or eNodeB).

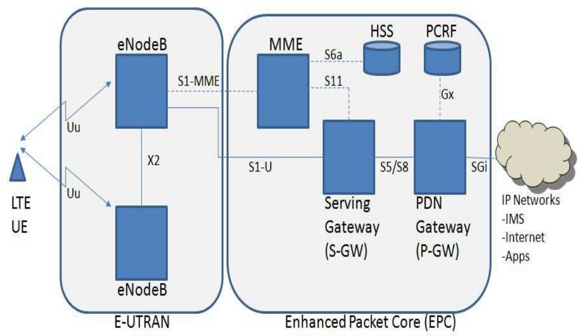

Figure 1: LTE network architecture

In LTE, the so called "bearer" concept is defined. According to [2], a bearer is an IP packet flow between the PDN-GW and the UE with a predefined QoS characteristic. Both the EPC and the E-UTRAN are responsible for setting and releasing such a bearer depending on the applications requirements. In LTE, multiple bearers can be established for users with multiple services, e.g. a user can have a voice call using Voice over Internet Protocol (VoIP) and at the same time download a file through File Transfer Protocol (HTTP). Each of these services can be mapped into a different bearer.

3.1. Uplink and Downlink of LTE

LTE works on two different types of air interfaces (radio links), one is downlink (from tower to device), and one is uplink (from device to tower). By using different types of interfaces for the downlink and uplink, LTE utilizes the optimal way to do wireless connections in both of the ways which makes a better optimized network and better battery life on LTE devices.

For the downlink, LTE uses an OFDMA (orthogonal frequency division multiple access) air interface as opposed to the CDMA (code division multiple access) and TDMA (time division multiple access) air interfaces. For the uplink, LTE uses the DFTS-OFDMA (discrete Fourier transform spread orthogonal frequency division multiple access) scheme to generate a SC-FDMA (single carrier OFDMA) signal. SC-FDMA is better for uplink because it has a better peak-to-average power ratio over OFDMA for uplink. LTE-enabled devices, in order to conserve battery life, typically don't have a strong and powerful signal going back to the tower, so a lot of the benefits of normal OFDMA would be lost with a weak signal.

3.2. LTE Radio Interface

The LTE radio interface also known as the "Uu" is the interface between the eNodeB and the UE. LTE uses OFDMA in the downlink which means that the spectrum is divided into multiple subcarriers in the frequency domain and several OFDMA symbols in the time domain. The smallest unit defined within the LTE 3GPP specification that the scheduler can allocate over the radio is called Physical Resource Block (PRB). It consists of 12 subcarriers in the frequency domain and two slots in the time domain (i.e. 14 OFDMA symbols).

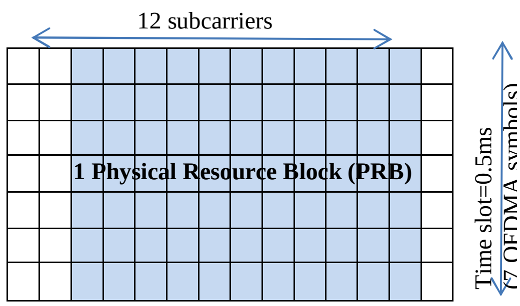

Figure 2. Downlink resource grid

Figure 2 shows the LTE downlink resource grid in over both time and frequency domains. Each subcarrier has 15 kHz bandwidth resulting in a PRB resolution of 180 KHz. This means that the LTE spectrum is divided into a number of PRBs. Table 1 shows the number of PRBs per each of the LTE transmission bandwidth. This number is not exactly the division of the spectrum by the 180 kHz since some of the subcarriers are reserved for signaling purposes.

Table 1. Number of PRBs per differ spectrum

LTE Spectrum (MHz)	1.4	3	5	10	15	20
Number of PRBs	6	15	25	50	75	100

4. OSA General Scheduler Framework

The OSA algorithm takes into the consideration of the average users channel conditions over a scalable time window.

Two main QoS radio bearer types are configured within the OSA framework: GBR and nonGBR bearers. Each of these types is mapped into one of the five different MAC-QoS-Classes. Figure 3 shows the general OSA framework. The OSA scheduler is divided into three main stages: QCI classification, TD and FD scheduling [5]. The TD scheduler normally deals with addressing the issues related to the QoS requirements, whereas the FD scheduler deals with issues related to spectrum allocation and exploiting the users' in different channel conditions.

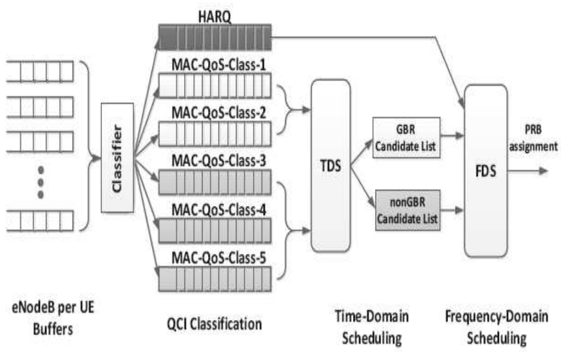

Figure 3. OSA general scheduler framework

4.1 QCI Classification

The OSA scheduler defines 4 different MAC-QoS-Classes. The first two classes are used for the GBR bearers, whereas the other three are used for the nonGBR bearers. In addition a priority queue is defined for the pending HARQ retransmissions. Each IP bearer flow is identified with DSCP value which is characterized by the Quality of Service Class Identifier (QCI) at the application level. Using the DSCP value, the scheduler maps the incoming IP packets into different MAC QoS classes which shown in Table 2.

Table 2. QCI to MAC-QoS-Class mapping

Bearer Type	Traffic Type	QCI	MAC-QoS - Class
GBR	VOIP	QCI-1	MAC-QoS–Class 1
nonGBR	Video Streaming	QCI-7	MAC-QoS–Class 3
	HTTP	QCI-8	MAC-QoS–Class 4
	FTP	QCI-9	MAC-QoS–Class 5

4.2 Time Domain Scheduling

The TD scheduler is responsible for prioritizing the bearers based on their QoS requirements. The TD scheduler separates the bearer's prioritization into two categories: GBR bearer's prioritization and nonGBR bearer's prioritization. Each Transmission Time Interval (TTI), the TD creates two separate bearers candidate lists that are used by the FD scheduler to allocate spectrum for the TTI. This candidate lists acts as a suggestion from the TD scheduler of which bearer has higher priority to be served within this TTI that are solely based on the bearer's QoS information without considering any channel conditions information.

4.3 Frequency Domain Scheduling

The FD scheduler is responsible for distributing the radio interface resources (PRBs) among the different bearers. It uses the candidate list given by the TD scheduler as a basis for choosing which bearer should be served within next TTI.

As described earlier, two different candidate lists are used by the TD scheduler, a GBR and a nonGBR candidate lists. The FD scheduler starts assigning resources with the GBR list, the assignment of the PRBs is done in a round robin manner by giving each bearer one PRB at a time, starting from the highest priority bearer to the lowest priority one at the end of the list. Each bearer is assigned with its highest SINR PRB along with the highest possible Modulation and Coding Scheme (MCS).

The FD scheduler serves the nonGBR bearers exactly the same way explained earlier for the GBR bearers but with one distinction. The FD scheduler uses a subset of the nonGBR candidate list and not the whole one as in the GBR case. The subset nonGBR list is chosen by picking the highest N nonGBR bearers from the top of the nonGBR candidate list. The reason for this is that nonGBR bearers represent the fast majority of services and that usually also requires higher data rates and since the FD scheduler has already served all the GBR bearers first the amount of resources (# of PRBs) left for the nonGBR bearers are not enough to serve them all. Therefore, only the N highest priority nonGBR bearers are served within each TTI, N is a constant value that can be set for example to be 5 nonGBR bearers.

5. Proposed Model

5.1. Parameter Settings and System Assumptions

There is only a single cell with N different zones of equal area in order to differentiate between user's distances to the base station. Only the FTP downlink connection is considered as nonGBR bearer. The result onwards is also valid for the HTTP. Mobile stations are assumed to be uniformly distributed over the cell zones. Each zone is characterized by a distance d_i measured from the outer edge of the zone.

Between the fading and path-loss which are the factors of radio condition, the fading is out of this scope. The signal deviation in each zone can be specified by the path-loss $L(d_i)$. According to [1], the path-loss model for each zone is defined as $L(d_i) = 37.6\log_{10}(D) + 128.1$, where D is the distance between the eNB which is base station and user equipment (UE). As a single cell is considered, inter-cell interference is not taken into account in the current model. According to the OPNET simulator parameters [8], the received power at UE per zone can be defined as

$$P_i^{rx} = \frac{P_{\max}^{tx}}{M \cdot L(d_i)} \quad (1)$$

Where $P_{\max}^{tx}$ the maximum transmission power by eNB is, $L(d_i)$ is the path-loss and M is the number of PRBs distributed over the whole cell. Due to the nature of OFDMA, multipath interference can be assumed to be zero. As there is the single cell consideration, inter-cell interference cannot take into account. So only thermal noise N_0 is considered in the current model. The $SINR$ (signal to noise and interference ratio) of each user located in the corresponding zones is

$$SINR = \frac{P_i^{rx}}{N_0} \quad (2)$$

Given the $SINR_i$ value, the data rate realized by a user when it is scheduled, which can be termed as instantaneous rate r_i, can be calculated according to the Shannon formula modified with a parameter σ [1].

$$r_i = (M_i(MS) * 180kHz)\sigma\log_2(1+SINR_i) \quad (3)$$

Where, r_i is the instantaneous data rate or the maximum throughput for the given SINR and $M_i(MS)$ is the number of PRBs for all active users in the particular zone.

5.2 Analytical Model

In the model, FTP-only scenario as nonGBR is presented. In the design of the scheduler it is reasonable that the entire parallel FTP downloads are scheduled in a fair way. Since all of the flows (FTP downloads) can share the radio resources equally, a Processor Sharing (PS) model can be used to model the scheduler behavior. According to [9] the expected sojourn time (the average FTP downloading time τ) for a file with size χ in M/G/1-PS is given with the arrival rate λ :

$$E_{M/G/1-PS} = \frac{\chi}{C} \cdot \Delta 1 \rho \quad (4)$$

Where, $\rho =$ mean traffic load

$\Delta 1 =$ delay factor

$C =$ capacity value

ρ is defined by the mean file size $\overline{\chi}$ and arrival rate λ as

$$\rho = \frac{\lambda \cdot \overline{\chi}}{C} \quad (5)$$

$$\Delta 1\rho = 1 + \frac{Er_c(R, R\cdot\rho)}{R\cdot(1-\rho)} \Big|_{R=1} = \frac{1}{1-\rho} \quad (6)$$

The mean traffic load in each zone is ρ_i and the arrival rate in each zone is $\lambda_i = \frac{\lambda}{N}$ due to the assumption of mobile stations are uniformly distributed in each zone. So the average file downloading time τ for a file size in zone i with $M/G/1-PS$ model can be defined as

$$\tau = \frac{\chi}{r_i} \cdot \Delta_1 \rho \quad (7)$$

5.3 Numerical Results

The cell is divided into five zones with cell radius of $1km$. A system of $5MHz$ bandwidth which results in maximum of $25PRBs$ per TTI (Transmission Time Interval), is studied. The distances of the different zones and the maximum resource block in each zone are considered as shown in Table 3. The maximum transmission power by eNodeB is $19.952\,watt$ which is appropriate for $5MHz$ bandwidth. The scenario of arrival rate $\lambda_i = 1$ and $\lambda_i = 2$ are considered. The attenuation of implementation σ is taken as 0.4. The average file size of each user in each zone is $1Mbit$. By using the proposed equation (7), the resulted changes of expected file downloading time are presented as follows. Firstly, Table 4 shows the value of signal to noise ratio (in $Watt$) measured at each user in zone i from eNodeB.

Table 3. Maximum PRB allocation

Zone Number	1 5	2	3	4
Distance	0.3 1	0.5	0.65	0.85
$M(MS)_{max}$	25 5	20	15	10

Table 4. SINR value of each user per zone

Zone	1	2	3	4	5
$SINR$	0.007 3	0.006 8	0.006 5	0.006 3	0.00 62

Secondly, Figure 4 shows the changes in downloading according to the distance from the base station. It also indicates the increase of the file downloading time when the arrival rate λ is higher. This is because multiple parallel downloads are sharing the capacity. Furthermore, the result shows that the farther the distance, the more the downloading time

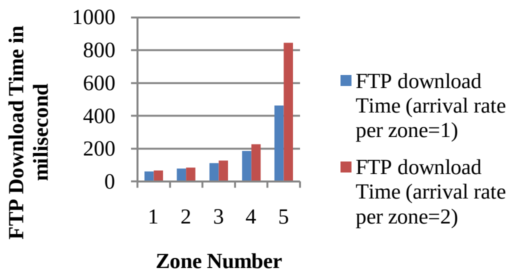

Figure: 4 FTP downloading time per zone

. Figure 5 shows that the proposed model of taking the state of the system benefits over the general analytical model without system state consideration such as path-loss. The model can give the expected file downloading time which is more specific, instead general downloading time for all users.

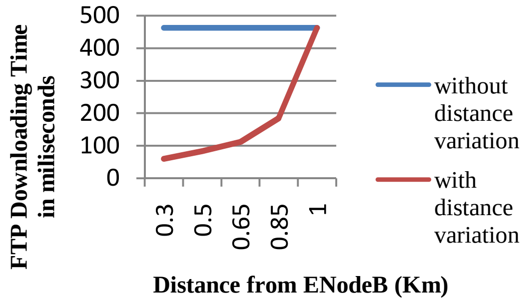

Figure: 5 Analysis of taking the state of the system

6. Conclusion

In this paper, the design of Optimized Service Aware (OSA) is described as the scheduling scheme. The OSA differentiates the QoS classes by mainly defining the bearer types such as GBR or nonGBR. The two most important factors for the radio conditions are fading and path loss which is the attenuation due to the distance. The developed analytical model gives the bit rate variation of non-Guaranteed Bit Rate (nonGBR) due to distance. However, it can capture the condition of users are equally distributed in each zone. Indeed the numerical results show that certain performance trend can be observed only if flows' behavior is considered. To be compared the result of the developed analytical model with those using simulator is an ongoing process.

The system for the users of zone transition between the two cell zones is going to be observed as our future work also. For this system, departure rate will have to be investigated since it depends on the system state.

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