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Study of Radio Resources Allocation in LTE for QoS

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Abstract – **In this article we are interested in an important task of the eNodeB in the LTE network architecture, it is the RRM (Radio Resource Management) its goal is to accept or reject requests for connection to the network, ensuring an optimal distribution of radio resources between the UEs (Users Equipments). It consists mainly of two elements AC (Admission Control) and PS (Packet Scheduling). In this work we will focus on the PS, which realizes an efficient allocation of radio resources in both directions i.e. Uplink (considered in our case) and Downlink.**

Several approaches and algorithms have been proposed in the literature to meet this need (allocate resources efficiently), this diversity and multitude of algorithms is linked to the factors considered allowing the optimal management of radio resource, specifically the type of traffic and QoS requested by the UE.

In this article, a study of several proposed scheduling algorithms for LTE (uplink and downlink) is made. Therefore, we offer our evaluation and reviews.

Keywords – **3G, AC, FDM, LTE, OFDMA, PS, RB, RRM, TDM, UE.**

I. Introduction

Long Term Evolution (LTE), or 3.9G systems, originally designed to achieve high data rates (50Mbit / s upstream Uplink and 100Mbit / s Downlink downstream in a band of 20 MHz), while minimizing latency by offering flexible bandwidth deployment. He is designated as the successor of 3G networks. It allows the successful implementation of emerging internet services in recent years. It uses packet switching just like 3G networks, with the difference that it uses time division multiplexing (TDM) and frequency division multiplexing (FDM) at the same time, which is not the case, for example, with HSPA which does not performs only time-division multiplexing, this allows us to have a gain of flow (in spectral efficiency) of about 40%. [1]

LTE uses OFDMA (Orthogonal Frequency Division Multiple Access), as a downlink access method (eNodeB→UE), it combines TDMA and FDMA. It is derived from OFDM multiplexing, but it allows multiple access by sharing radio resources among multiple users. Its principle is to divide the total band into multiple orthogonal sub-bands of narrow size, this process makes it possible to fight against the problem of frequency selective channels, ISI (Inter Symbol Interference), in addition, it allows for the same spectral width, a higher bit rate due to its high spectral efficiency (number of bits transmitted by Hertz) in addition to its ability to maintain high throughput even in unfavorable environments with echoes and multiple paths of radio waves. For the upstream direction (Uplink), the method used is SC-FDMA, a variant of the OFDMA, they have practically the same performances (flow, efficiency, etc.), but SC-FDMA transmits the sub-bands sequentially to minimize the PAPR (Peak-to-Average Power Ratio, OFDMA has a large PAPR), this is necessary because for the sense (UE→eNodeB), the terminal equipment has a battery with a limited life.

An important element in the LTE architecture, it is specifically in the eNB, the RRM (Radio Resource Management), consisting mainly of two tasks AC (Admission Control) and PS (Packet Scheduler).

The AC is responsible for accepting and rejecting new requests, but the PS realizes the allocation of resources effectively to the various users already accepted by the AC.

The AC processes the new requests for connection to the network, the decision to accept or reject a request depends on the network's ability to offer the QoS required by this request while ensuring the QoS of the requests already admitted in the system.

The PS for its part carries out the UE-RB mapping, that is to say. Select the UEs users that will use the channel by assigning them the RBs radio resources that allow them to maximize the system performance.

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There are several parameters to evaluate the performance of the system, for example we can mention: the spectral efficiency (total system throughput), the equity between the UEs, and the waiting time of each UE before it is served. The diversity of the performance parameters allowed the creation of several types of schedulers.

An important parameter in scheduler design is support for QoS. This forced the LTE network to distinguish between data flows and therefore we distinguish:

Conversational class: this is the class most sensitive to delays and delays; it includes video conferencing and telephony. It does not tolerate delays because it assumes that on both ends of the connection is a human.

Streaming class: similar to the previous class, but it assumes that only one person is at the end of the connection, so it is less constraining in terms of delays and delays. For example: streaming video.

Interactive class: examples of this class can be: web browsing, access to databases etc.

Unlike the previously mentioned types, the data must be delivered in a time interval, but this type of traffic focuses on the Packet Error Rate.

Background class: also called Best Effort flow class, no QoS is applied; it tolerates the delays, the loss of the packets. Examples of this class: FTP, E-mails, etc. [2].

Two other parameters affect the design of LTE Uplink scheduling algorithms. These two parameters are imposed by the access method SC-FDMA, are: the minimization of the power of transmission (to maximize the duration of life of the batteries of the UEs), in addition, the RBs allocated to a single UE must to be contiguous. This makes the allocation of radio resources for LTE Uplink more difficult than for the Downlink.

The rest of the paper is organized as follows: in section II, the mathematical modeling of the radio resource allocation problem will be presented, in section III, a state of the art will be presented on the scheduling algorithms existing in the literature, we will evaluate the performance of these algorithms with some criticisms in section VI, then a conclusion and perspectives will be presented in section V.

II. System Characteristics

In this section we will begin by giving the architecture of the LTE, then we will present the mathematical formulation of the problem of allocation of radio resources.

A. LTE Architecture

The general architecture of the LTE is essentially composed of the Evolved Packet System (EPS), which comprises: the EPC (Evolved Packet Core) core network and the radio part of the network.

EPC consists of a set of control elements: Mobility Manager Entity (MME), Home Subscriber Server (HSS), S-GW, and P-GW (Serving and Packet-data Gateway). The EPC is responsible for connecting with other 3GPP and non 3GPP networks. The radio part of the network consists of eNodeB (Enhanced NodeB) and UE (User Equipment). [3]

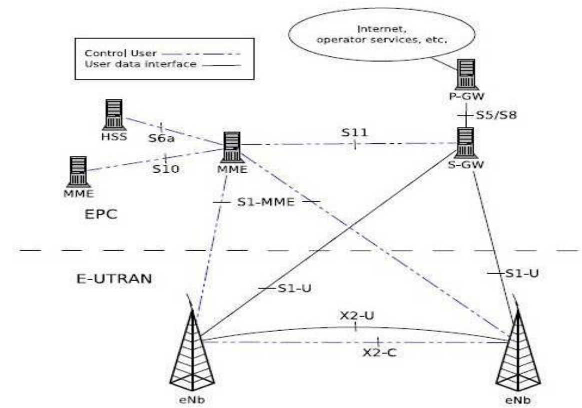

Fig 1. LTE Architecture [3]

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Consider an LTE system where there are N SBs (Scheduling Blocks the minimum resource allocated to a user is SB which represents two consecutive resource block (RBs)) with a powerful equal shared on all SBs, in addition there are K users and the minimum bit rate requested by the k[th] user is R_k Mbit/s. A SB is defined as a set of OFDM symbol N_s in the subcarrier TD and N_{sc} time domain in the FD frequency domain, in addition, because of the control signals and other pilots, only $N_{sc}^{d}(s)$subcarrier N_{sc} will be used to transmit the data of the OFDM symbol, with $s \in \{1,2,\dots,N_s\}$ and $N_{sc}^{d}(s) \leq N_{sc}$. Also assuming $j \in \{1,2,\dots,J\}$where $J$the total number of MCS (Modulation and Coding Scheme) is supported, then let $R_j^{(c)}$be the code associated with MCSj, M_j is the constellation of MCS j and T_s is the duration of the OFDM symbol, then the rate $r^{(j)}$ reachable by a single SB is:

$$r^{(j)} = \frac{R_j^{(c)} \log_2(M_j)}{T_s N_s} \sum_{s=1}^{N_s} N_{sc}^{d}(s) \qquad (1)$$

Now, we define $g_{k,n}$as the CQI (Channel Quality Indicator) of the user k on the n-th SB. The CQI of the k[th] user on the

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N SBs is $g_k = [g_{k,1}, g_{k,2}, \dots, g_{k,N}]$ and for all users on all BSs $G = [g_1, g_2, \dots, g_K]$. The CQI is defined according to the modulation scheme, coding of the channel.

The $g_{k,n}$ is returned by the user k to the sase station (eNb) for the scheduler to determine which MCS must be selected for the n-th SB associated with the user k.

For user k, the maximum CQI value on all SBs is:

$$n^* = \arg\max\left(g_{k,n}\right)_{n\in N} \quad (2)$$

Subsequently, $q_{k,\max(g_{k,n})} \in (1,2,\dots,J)$ is defined as the largest value of the MCS reached by the user k on the n^{th} SB for the CQI valueg_{k,n^*}, that is to say:

$$q_{k,\max(g_{k,n^*})} = \arg\max\left(R_j^{(c)}\log_2(M_j)\,|g_{k,n^*}\right) \quad (3)$$

Also we must not forget the fact that an SB is allocated to one and only one user, for that we define $\rho_{k,n}$resource allocation indicator for the user k on the n^{th} SB, if $\rho_{k,n} = 1$then the SB n is allocated to the user $k$and that $\rho_{k',n} = 0$ for all $k' \neq k$.

Let $b_{k,j}$, the MCS chosen by the user k on all the SBs allocated to it, $b_{k,j} = 1$ means that MCS j is chosen by the user k.

The rate reached by the user k on a single subframe is:

$$r_k = \sum_{n=1}^{N}\rho_{k,n}\sum_{j=1}^{q_{k,\max(g_{k,n^*})}} b_{kj}r^{(j)} \quad (4)$$

Therefore, the problem of radio resource allocation aims to maximize the user throughput under the following constraints:

$$\max\sum_{k=1}^{K} r_{k_{\rho_{k,n},b_{k,j}}} \quad (5)$$

Under constraint:

$$r_k \geq R_k \qquad \forall k \quad (6)$$

$$\rho_{k,n} = 1,\ \rho_{k',n} = 0 \ \ \forall k \neq k' \quad (7)$$

$$\sum_{j=1}^{q_{k,\max(g_{k,n^*})}} b_{k,j} = 1 \quad (8)$$

III. Ordering In LTE

In this section, we will present a state of the art on existing scheduling algorithms for both downlink and uplink. These algorithms are based on the mathematical formulations already mentioned, try to realize the allocation of radio resources to users of the system in an efficient way.

A. Downlink Scheduling Algorithms

The purpose of radio resource allocation algorithms is to improve system performance by increasing spectral efficiency and network equity. It is therefore essential to find a compromise between efficiency (increase in throughput) and equity between users.

Several families or categories of algorithm exist in the literature; usually each family contains a set of algorithms that have common characteristics.

1 Opportunistic Algorithms:

This type of algorithm uses infinite queues, these queues are used in the case of non-real-time traffic. The main objective of this type of algorithm is to maximize the overall flow of the system. Several algorithms use this approach as: PF (Proportional Fair), Exponential Proportional Fair (EXP-PF) etc.

Proportional Fair (PF): Its purpose is to try to maximize the overall throughput of the system by increasing the throughput of each user at the same time, it tries to ensure fairness between users [10], the objective function representing the PF algorithm is:

$$a = \frac{d_i(t)}{d_i^-} \quad (9)$$

$d_i(t)$: Rate corresponding to the CQI of the user i.

d_i^-: Maximum rate supported by the RB.

Exponential Proportional Fair (EXP-PF): It is an improvement of the PF algorithm which supports real-time streams (multimedia), by the way, it prioritizes real-time streams over others [11]. A user k is designated for scheduling according to the following relationship:

$$k = \max_{i}\frac{d_i(t)}{d_i^-}\exp\left(\frac{a_i w_i(t) - X}{1+\sqrt{x}}\right) \quad (10)$$

$$X = \frac{1}{N}\sum_i a_i W_i(t) \quad (11)$$

$W_i(t)$: Time tolerated by the flow.

a_i: Parameter strictly positive for all i.

2 Fair algorithms:

Several research studies have focused on the fairness between users in LTE networks; these algorithms generally have an insufficient speed. Note that equity does not mean equality.

Round Robin: It is a classic strategy of allocation of radio resources; the algorithm allocates the same amount of resource to users by sharing the time, therefore, the bit rate decreases considerably, since all users of the system use the radio resources according to a quantum of time.

Max-Min Fair (MMF): The algorithm distributes resources among users successively to increase the throughput of each user. Once the user allocates the requested resources to reach its speed, we move on to the next user. The algorithm stops running out of resources or the users are satisfied.

3 Algorithms Considering Delays:

This type of algorithm deals with delays in arriving and delivering packets. Mainly designed to process real-time flows (multimedia and VoIP). If a packet exceeds these

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tolerated delay values, it will be removed from the scheduling flow list, which considerably degrades the QoS. M-LWDF (Maximum-Largest Weighted Delay First) is an example of the establishment of this family.

M-LWDF: This algorithm supports flows with different QoS requirements, it tries to weight packet delays using knowledge of the channel state, at an instant t, the algorithm chooses a user k for scheduling via the formula: [12]

$$k = \max_{i} a_i \frac{d_i(t)}{\overline{d_i}} W_i(t) \tag{12}$$

It is practically the same formula of the EXP-PF algorithm, except that$a_i = -\log(p_i)T_i$, with

P_i: The probability that the deadline will not be met.

T_i: The time that user i can tolerate.

This algorithm is mainly intended for real time flow which requires respecting deadlines, it gives good results in this context, on the other hand for non-real time flows, this is really not a good choice since the delay doesn't is really not an important parameter.

4 Flow Optimization Algorithms:

This type of algorithm tries to maximize the objective function which represents the bit rate, this approach deals with real-time and non-real-time flows, the allocation of resources depends on the size of each user's queue. Example algorithm of this family EXP Rule, Max-Weight etc.

5 Multi-Class Algorithms:

This approach considers the stream classes where the processing is different for each RT and NRT class. This type of algorithm favors real time flows over real time ones, which makes it the most adequate and efficient for LTE scheduling, however equity is not really considered.

B. Uplink Scheduling Algorithms

Unlike scheduling on the downlink side, scheduling on the uplink side is much more complicated for several reasons, firstly, it is the UE that sends the data and we know very well that the UE has a source of limited energy, secondly, it is very difficult to predict the number of radio resources necessary for a UE so that it can exchange this data with the base station. According to the objective function taken into account and according to the classes of traffic which passes over the radio channels, we have three main categories of schedulers: those dealing with best-effort flows, those which take QoS into consideration and those optimizing the transmit power. In this part we will try to go around the main families of uplink LTE resource allocation algorithms.

1 Paradigms Used:

For the allocation of radio resources in uplink LTE, the PS needs an association matrix between UE-RB as input in order to be able to give as a result the best combinations which improve the performance of the system.

For the creation of this matrix, there are two major paradigms in the literature (Channel Dependent CD and Proportional Fairness PF)

The first CD, in the process of creating the matrix, CSI (Channel State Information) or the state of the channel is considered, therefore UEs which have the largest CSI values will have the chance to allocate more resources, this approach achieves best throughput values, but suffers from starvation problem.

While the PF, on the other hand, takes the CSI rate report for each UE. So equity is proportional to the CSI value of the matrix. This approach achieves good throughputs while at the same time solving the famine problem [4].

2 Modelling of the Uplink LTE System:

The uplink scheduling algorithms take as input a matrix with K rows (number of active UEs) and M columns (number of RBs). $M_{i,m}$ is the associated value in UE i and RB m. Depending on the paradigm used, this value represents the CSI (Channel State Information) of each RB for each UE, or the CSI report on throughput.

The values of the matrix represent the association between UE-RB, these values are used by the scheduler [4].

	RB_1	RB_2	….	RB_M
UE_1	$M_{1,1}$	$M_{1,2}$	…	$M_{1,M}$
UE_1	$M_{2,1}$	$M_{2,2}$	…	$M_{2,M}$
⋮	⋮		…	
UE_K	$M_{K,1}$	$M_{K,2}$	…	$M_{K,M}$

Fig 2. UE-RB association matrix

3 Best Effort Flow Schedulers:

The main objective of this type of scheduler is to maximize the use of radio resources in the system and / or the fairness of resource sharing between UEs. As we have already said, each algorithm has an objective function to optimize, this type of algorithm uses a PF metric.

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Among the old works existing on this type of schedulers (best-effort), we find greedy algorithms, they are very effective for this kind of traffic (best effort).
This algorithm uses the PF metric and it tries to maximize the following objective function:

$$U = \sum_{u \in U} \ln R(u) \quad (13)$$

$R(u)$: Average flow of UE u at time t. The use of logarithm function is for having proportional equity.
In [5] the authors proposed three algorithms: FME (First Maximum Expansion), RME (Recursive Maximum Expansion) and MAD (Minimum Area Difference). These three algorithms belong to the same category (the one dealing with best-effort flows), it is for this reason that they have the same objective function, but they differ from the way in which resources are allocated.

4 Scheduler Considering QoS:

Two important parameters in taking QoS into account are the time allowed and QoS of the UE that we want to serve and the UEs already served (depending on the type of flow). Among the proposed algorithms is PFGBR (Proportional Fair with Guaranteed Bit Rate). From its name, there are two metrics PF and GBR, the PF metric is used to schedule the UEs with non-GBR flow and for those with a GBR flow, the algorithm changes the metric to be able to differentiate the UE (give priorities to the UEs) [6].

$$M(u,c) = \begin{cases} \exp\left(\alpha.\left(R_{GBR} - R^{-}(u)\right)\right).\dfrac{R^{*}(u,c)}{R(u)} & u \in U_{GBR} \\ \dfrac{R^{*}(u,c)}{R(u)} & u \in U_{non-GBR} \end{cases} \quad (14)$$

$R^{-}(u)$: Average flow of user u at TTI t.
$R^{*}(u,c)$: Estimated bit rate of user u, on the Chunk Resource c (RC continuous set of RB) at TTI t.
The authors in [7] proposed two algorithms which consider QoS. The objective function used is defined as follows:

$$\max \sum_{u \in U} \sum_{r \in RB} \alpha_{u,r} \cdot f_r \quad (15)$$

$\alpha_{u,r}$: = 1 if the RB r is allocated to the UE u.
f_r is defined as follows:

$$f_r = \frac{R_u * D_i^{\max}}{R_i^{\min} * D_i^{\text{avg}}} \quad (16)$$

R_u: Achievable throughput.
$R_i^{\min}$: Minimum service class flow i.
$D_i^{\max}$: Max delay of class i.
D_i^{avg}: Average time for class i.

The first algorithm is called SC-PS, Single Channel-Packet Scheduling; it performs the allocation of a single RB for a given UE in a TTI. In the case where the number of UEs u requesting resources is less than the number of RBs available, the scheduler distributes all of the RBs over the UEs equally $\frac{N_{RB}}{N_u}$.Otherwise, it allocates a RB to the UE which has the wrong conditions (for example: the one who has the maximum delay is almost reached) and so on. The main objective of this algorithm is to allocate resources to UEs with more severe QoS constraints.
The second algorithm is called MC-PS, Multiple Channel-Packet Scheduling, similar to the first, with the difference that this one allows the allocation of several RBs for a single UE. This algorithm has the same behavior in the case where the number of UEs is less than the number of RBs available in the system. In the case where the number of UE is greater than that of the available RBs, then we make the allocation of the $n = \frac{R_i^{\min}}{R_u}$ RBs to the UEs according to the values of f_r (we start with those having the bad conditions), we first seek the RB which maximizes the flow and then we look to the left and right of this RB until the allocation of n RBs.

5 Schedulers Processing Signal Strength:

The main purpose of this category of algorithms is to minimize the strength of the transmitted signal, in an attempt to extend the duration of UE activity, which coincides with the objective of the SC-FDMA access method. This approach has not been really treated too much by researchers, so there are few algorithms in the literature. Let us quote for example the works [8] and [9].

IV. Discussion And Evaluation Of Performance

- PF, is a scheduler often used in 3G networks, since the speed of this type of network is limited. For networks after 3G, an essential factor comes into play, it is the delay especially for multimedia streams which represents the most important type of stream in networks after 3G, this factor is not taken into account by this algorithm, therefore, for non-real time flows it works very well by cons for real time flows it is not preferable.
- Regarding the EXP-PF, the parameters $W_i(t)$ and a_i define the level of QoS required by the flow. These parameters try to give more importance to applications with a higher level of QoS. In the case where the exponential part of the formula is equal to one, we find the formula of the PF algorithm. This scenario is possible if the flows have practically the same delays for the different users.

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- Regarding the RR, it does not take into account the QoS, because the flows do not have the same needs (VoIP, Streaming etc.), in addition allocated the same amount of resources is not really fair, because users do not necessarily have the same channel conditions, the same types of flow, etc. Networks after 3G, specifically LTE focuses on the QoS of real-time flows, cost, used RR is really not the right choice.
- Trying to satisfy all users in the MMF algorithm gives users with low requirements the advantage that they will often be served, however it penalizes users who ask for more resources. This approach does not take into account multi-user diversity and that flows have different QoS requirements and equity does not mean equality. In summary, this algorithm is really not the right choice for LTE scheduling.

In summary, the allocation of radio resources is feasible (several algorithms and approaches exist), but the diversity of flows (QoS) and the radio conditions affect the performance of the algorithm. Resource allocation is an NP-complete problem, since the algorithm tries to maximize and / or minimize several parameters at the same time. For this reason, each approach or algorithm tries to optimize the maximum of the parameters that it can.

Regarding the uplink side, it is much more complicated given the new constraints imposed, such as, the RBs allocated to a single user must be continuous, plus the constraint on the power of the transmitted signal. The algorithms processing QoS are the most suitable and the most probed, because they deal with the most important factor in LTE networks, which is the QoS of flows.

V. Conclusion

The allocation of radio resources is done in the eNB by the PS, this task is too complex, because it requires taking into account several factors at the same time, in addition it must be immediate (in real time).

The objective of this article is to present a state of the art on the allocation of radio resources in LTE. In this work, we tried to go around the existing approaches in the literature in both directions downlink and uplink, we also cited some algorithms, we showed the advantages and disadvantages of each category, then it would be wiser to focus on one type of traffic, try to improve performance, it will undoubtedly be real-time flows.

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