Resource Allocation Using Shapley Value in LTE Networks

Mauricio Iturralde*, Tara Ali Yahiya†, Anne Wei‡ and André-Luc Beylot*

*Université de Toulouse, IRIT/ENSEEIHT
† Université Paris Sud 11, LRI
‡CNAM, Laboratoire Cédric
{mauricio.iturralde, andre-luc.beylot} @enseeiht.fr
tara.ali-yahiya@u-psud.fr, anne.wei@cnam.fr

***Abstract*—The LTE specification provides QoS of multimedia services with fast connectivity, high mobility and security. However, 3GPP specifications have not defined scheduling algorithms to support real time and non-real time application services. In this paper we propose a two level scheduling scheme composed by cooperative game concept and EXP-RULE scheduling algorithm. By using cooperative game theory such as bankruptcy game and Shapley value, the proposed mechanism works by forming coalition between flow classes to distribute the bandwidth fairly. To make a performance judgment, the proposed downlink scheduling scheme has been compared to other well known schedulers such as M-LWDF and PF. Simulation results show that the proposed scheme can improve the performance on the used metrics among services. The performance evaluation is conducted in terms of system throughput, packet loss ratio (PLR), cell spectral efficiency and fairness Index.**

***Index Terms*—Wireless networks, quality of service, long term evolution, Cooperative game theory, Shapley value.**

I. Introduction

In conjunction with the useful growth of internet, multimedia and real time services, Long Term Evolution (LTE) technology has been proposed to perform this ambitious task. LTE uses Orthogonal Frequency Division Multiple Access (ODFMA) in the downlink. OFDMA divides the frequency band into a group of mutually orthogonal subcarriers, thereby improving the system capabilities by providing high data rates, supporting multi-user diversity and creating resistance to frequency selective fading of radio channels. The Quality of Service (QoS) of LTE must be satisfied by giving users the optimal balance of utilization and fairness. Real Time (RT) services need a high QoS level and Non-Real Time (NRT) services must have a minimum bit-rate. To satisfy this demand, several packet scheduling algorithms have been proposed M-LWDF, EXP/PF, PF, EXP-RULE [7][3][16]. In the above mentioned schedulers, each connection is assigned a priority value based on certain criterion, and the connection with the highest priority is scheduled at each Transmission Time Interval (TTI).

Given that multimedia services such as video and VoIP are becoming the most important applications in telecommunications technology, this work adapts a scenario to perform the resource allocation focused on these services. In previous works, the Shapley value has been utilized to perform resource allocation in heterogeneous wireless networks. By adapting the "fairness" virtue of game theory concept, an improvement of resource allocation performance has been shown in [13][12]. In [9] the performances of EXP/PF and M-LWDF for video streaming have been compared. Simulation results show a better performance of M-LWDF for lower loads and a better performance of EXP/PF for higher loads. The contribution of this paper aims to adapt a game theory negotiation using a bankruptcy game and Shapley value to carry out a fair bandwidth distribution among flow classes, combined with the EXP-RULE algorithm to improve the resource allocation scheduling (principally system throughput and fairness) for RT flows in downlink system . The proposed resource allocation scheme has been compared to the earlier mentioned schedulers M-LWDF, PF and the non-modified EXP-RULE.

This paper is organized as follows. Section II describes the downlink system model in LTE, section III describes the aforementioned cooperative game theory and its adaptation to resource allocation. Section IV exposes our resource allocation scheduling scheme. In section V, a simulation environment scenario is presented, where the traffic model is described and a numerical result analysis is exposed. Section VI concludes this paper.

II. Downlink System Model

The QoS aspects of the LTE downlink are influenced by a large number of factors such as: Channel conditions, resource allocation policies, available resources, delay sensitive/insensitive traffic. In LTE the resource that is allocated to a user in the downlink system, contains frequency and time domains, and is called resource block. The architecture of the 3GPP LTE system consists of several base stations called "eNodeB" where the packet scheduling is performed along with other Radio Resource Management (RRM) mechanisms.

The entire bandwidth is divided into 180 kHz, physical Resource Blocks (RB's), each one lasting 0.5 ms and consisting of 6 or 7 symbols in the time domain, and 12 consecutive subcarriers in the frequency domain. The resource allocation is realized at every TTI, that is exactly every two consecutive resource blocks. In this way, resource allocation is done on a resource block pair basis.

Users report their instantaneous downlink channel conditions (e.g signal-to-noise-ratio, SNR) to serving the eNodeB at each TTI. At the eNodeB, the packet scheduler performs a user selection priority procedure, based on criteria such as channel conditions, head of line (HOL) packet delays, buffers status and service types. The eNodeB has a complete information about the channel quality by the use of Channel State Information (CSI).

Packets arriving into the buffer at eNodeB, are time stamped and queued for transmissions based on a First-In First-Out (FIFO) scheme (by flow). For each packet in the queue at the eNodeB buffer, the HOL is computed, and a packet delay is computed as well.

III. Cooperative Game Theory

A cooperative game is a game where groups of players ("coalitions") may enforce cooperative behavior, hence the game is a competition between coalitions of players, rather than between individual players. This discipline concerns the behavior of decision makers (players) whose decisions affect each other. A cooperative game consist of a player list and characteristic function. Given a set of players N, the players should form a coalition to transfer benefits among them. Formally, a game is a pair (N, v), where $N = \{1, ..., n\}$ is a finite set of players, $n = |N|$ and v is a characteristic function $v : 2^n \rightarrow \mathbb{R}$ such as $v(0) = 0$. Coalitions are subsets $S \subseteq N$. $N \backslash S$ denotes the complement set to N. In a game with n players, there are 2^n possible coalitions.

A. Bankruptcy games

This work is restricted to Transferable Utility (TU) games. The analysis of bankruptcy situations tries to prescribe how to ration an amount of perfectly divisible resources among a group of players according to a profile of demands which, in the aggregate, exceeds the quantity to be distributed[11].

We model a bankruptcy situation by a triple (N, C, g), where $N = \{1, .., n\}$ is the set of players, $C \in \mathbb{R}_+$ represents the benefit and $g = \{g_1, ..., g_n\} \in \mathbb{R}_+^n$ is the vector of claims of the players. In [11] for every bankruptcy problem (N, C, g) an associated bankruptcy game (N, vc_g) is defined.

Considering O'Neill approach, the value of a coalition S is the part of the benefit that remains after paying the aggregated players in $N \backslash S$ all their bandwidth requirements, that is

$$vc_g(S) = \max\left\{C - \sum_{i \in N \backslash S} g_i, 0\right\}$$

$$v(N) = C \tag{1}$$

B. Shapley Value

Shapley value is a Game Theory concept proposed by Lloyd Shapley [14] aiming to propose the fairest allocation of collectively gained profits between the several collaborative players. The basic criterion is to find the relative importance of every player regarding the cooperative activities.

To compute Shapley Value let us define a function $\phi(v)$ as the worth or value of player i in the game with characteristic function v. The Shapley value is the average payoff to a player if the player enters in the coalition randomly. The formula given by Shapley in [14] is:

$$\phi_i(v) = \sum_{S \subseteq N} \frac{(|S| - 1)!(n - |S|)!}{n!} (v(S) - v(S \backslash \{i\})) \tag{2}$$

The Shapley Value is a very general method for equitable division. It is defined based on three axioms: symmetry, efficiency and additivity. The condition for efficiency is known as Pareto efficiency, and it gives guaranties that a player cannot obtain a better allocation without making another player allocation worse. Symmetry means that the player's final allocation does not depend on the order the players enter into the game. The symmetry property explains why the Shapley Value is considered as a fairness standard. The additivity axiom specifies how the values of different games must be related to each other. If the allocation is defined for two independent games, so it is also valid for a composite game. In this work we focus on the TU game formalism.

C. Resource Allocation Game Approach

Consider a resource allocation problem where a finite divisible bandwidth capacity C has to be divided among a finite set N of flow classes. For each $i \in N$, each flow of a group of k_i flows claim a bandwidth share $b_i \in \mathbb{R}_+$. Let $g_i \in \mathbb{R}_+$ denotes the total class bandwidth claim. The vector of class resources claim are denoted as $g \equiv (g_i)_{i \in N}$, with $g_i = k_i b_i$. Each class represents a player. The benefit to be divided is the total resources at each TTI. When several classes share an amount of resource, we interpret them as forming a coalition, and the benefits should be distributed between the members of the coalition.

An arbitrator must divide the benefits among the players of the game efficiently. The arbitrator is the eNodeB. It makes a fair resource blocks division among classes. A new redistribution of resources is performed at each TTI. When a new class joins the groups and claims for resources, the arbitrator must initiate a new game to re-distribute bandwidth, this is performed in the next TTI. The inter-class division should be done using some fairness criteria, considering the different flows needs. Each class, having its corresponding bandwidth chunk, must divide the resource among their flows.

We consider a dynamic allocation process, and the number of flows in each class is variable. In a bandwidth allocation game, the classes represent the players who benefits from capacity C. All the classes forms a coalition to get the benefit C. Under-loaded classes cooperate with overload classes, giving way unused capacity.

IV. Resource Allocation

Based on a standard bankruptcy game as described before, we propose a resource allocation algorithm for a downlink system where the resource allocation is done at each TTI in two levels. On the first level a fair resource distribution among

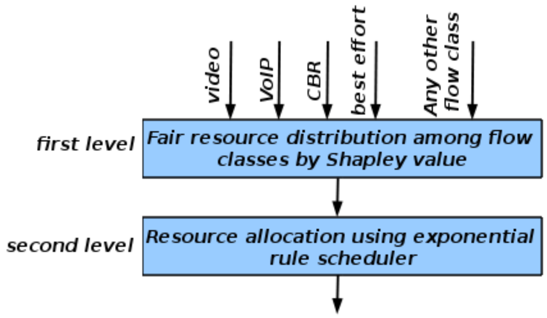

Figure 1. LTE downlink system

classes using Shapley value method is performed. After that, on the second level, having the proportion of resource destined to each class (video, VoIP, CBR, etc) a resource allocation is performed using EXP-RULE, respecting the amount of resource that Shapley value assigned to each class as can be seen in Fig. 1.

A. First Level

At this level a TU game is carried on, taking into account the parameters as shown in Table I.

Bearing in mind section III where resource allocation game approach was described, let us consider the following scenario to explain our resource allocation model.

Let us define three classes $A = video$, $B = VoIP$ and $D = CBR$ as players in our scenario $N = \{A, B, D\}$. Consider $C = 32Mbps$ (50 Resource Blocks per TTI). The bandwidth required by a single flow of each class is $b = (242, 8.4, 2)kbps$. The allocation is dynamic and depends on simultaneous flows quantity $K = (k_A, k_B, k_D)$. Thus, our bandwidth game is modeled as $(N; vc_g)$ where $|N| = 3$ and $vc_g(S) = max\{C - \sum_{i \in N \setminus S} g_i, 0\}$, with $v(N) = C$. Developing the characteristic functions we have:

$$
\begin{aligned}
v(1) &= max\{32000 - (8.4k_B + 2k_D), 0\} \\
v(2) &= max\{32000 - (242k_A + 2k_D), 0\} \\
v(3) &= max\{32000 - (242k_A + 8.4k_B), 0\} \\
v(1,2) &= max\{32000 - 2k_C, 0\} \\
v(1,3) &= max\{32000 - 8k_B, 0\} \\
v(2,3) &= max\{32000 - 242k_A, 0\} \\
v(1,2,3) &= 32000
\end{aligned}
$$

Thus, we go through to Shapley value as can be seen in (2) to compute the resources related to each class depending of K.

B. Second Level

Considering the flows classification, we have divided the scheduling algorithm in two parts, for RT flows we use the EXP-RULE [16], and for NRT flows we use PF rule [3]. At time slot t, the metric is computed to choose user j for transmission as follows

$$
j = \max_i \begin{cases} \exp\left(\frac{a_i W_i(t)}{1+\sqrt{\bar{W}}}\right) \frac{\mu_i(t)}{\bar{\mu_i}} & \text{(RT)} \\ \frac{\mu_i(t)}{\bar{\mu_i}} & \text{(NRT)} \end{cases} \tag{3}
$$

Table I

Notation and description of variables for bankruptcy game and its adaptation to LTE scenario

Variable	Bankruptcy Game	Bandwidth Allocation
n	total number of players	total number of flow classes
C	total benefit	total bandwidth capacity
g_i	player's benefit claim	flow class bandwidth claim

Table II

LTE downlink simulation parameters

Parameters	Values
Simulation duration	100 s
Frame structure	FDD
Radius	1 km
Bandwidth	10 MHz
Slot duration	0.5 ms
Scheduling time (TTI)	1 ms
Number of RBs	50
Max delay	0.1 s
video bit-rate	242 $kbps$
VoIp bit-rate	8.4 $kbps$
CBR bit-rate	2 $kbps$

where $\mu_i(t)$ denotes the data rate corresponding to the channel state of the user i at time slot t, $\bar{\mu_i}$ is the mean data rate supported by the channel, this is the proportional fair rule [3]. $a_i = 6/d_i$ where d_i is the is the maximal delay target of the th user's flow. $W_i(t)$ is the HOL packet delay.

V. Simulation Environment

To perform our resource allocation model, we define a scenario as follows. We use a single cell with interference where there are 40% of users using video flows, 40% using VoIP flows and the remaining 20% are using CBR flows. Users are constantly moving at speed of 3 kmph in random directions (random walk). LTE-Sim simulator is used to perform this process[10]. LTE-Sim provides a support for radio resource allocation in a time-frequency domain. According to [10], in the time domain, radio resources are distributed every TTI, each one lasting 1 ms. Furthermore, each TTI is composed by two time slot of 0.5 ms, corresponding to 14 OFDM symbols in the default configuration with short cyclic prefix; 10 consecutive TTIs form the LTE Frame (Table II).

A. Traffic Model

A video service with 242 kbps source video data rate is used in the simulation, this traffic is a trace based application that sends packets based on realistic video trace files which are available on [15]. For VoIP flows, G.729 voice flows are generated by the VoIP application. In particular, the voice flow has been modeled with an ON/OFF Markov chain, where the ON period is exponentially distributed with mean value 3 s, and the OFF period has a truncated exponential probability density function with an upper limit of 6.9 s and an average value of 3 s [8]. During the ON period, the source sends 20 bytes sized packets every 20 ms (i.e., the source data rate is 8.4 kbps), while during the OFF period the rate is zero because the presence of a Voice Activity Detector is assumed. The CBR application generates packets with a constant bit rate with a packet size and inter-arrival packet time can be defined for this kind of traffic. The fairness among users is measured using the Jain's fairness method [17].

The LTE propagation loss model is composed by 4 different models (shadowing, multipath, penetration loss and path loss)[1]

- Pathloss: $PL = 128 : 1 + 37 : 6\log(d)$ where d is the distance between the UE and the eNodeB in km.
- Multipath: Jakes model
- PenetrationLoss: 10 dB
- Shadowing: log-normal distribution (mean = 0dB, standard deviation = 8dB)

B. Numerical Results

In this work, the fairness Shapley Value characteristic is used to apportion resources among classes before using the EXP-RULE algorithm. This process aims to improve the resource allocation performance. Algorithms PF, M-LWDF and the classical EXP-RULE are also performed in our scenario to help to carry out the performance judgment, comparing their results with our proposed scheduling scheme. We call our proposed scheduling scheme EXP-RULE-SH.

The classical EXP-RULE algorithm, serves the packets having the best scheduling metric, no matter the type of service that packets belong. Therefore, there could be the case where a given flow class, would not be served during a given TTI. Now using Shapley value before the allocation, EXP-RULE is bound to allocate resources not only to flows which packets have the best scheduling metric; if not also, to all flow classes without any exception at each TTI. This implies more fairness among flows, throughput gain for each flow, PLR decrease, and a lower delay. In consequence, our proposed algorithms improves the classical EXP-RULE scheduler as follows:

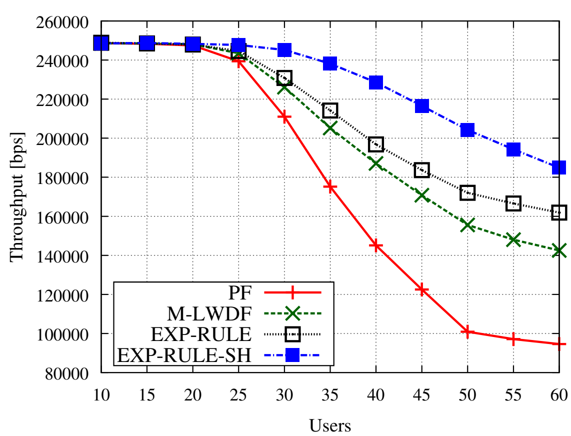

Figure 2. Average throughput per video flow

For video flows, there is a throughput gain up to 25% when using EXP-RULE-SH compared to EXP-RULE as can be seen in Fig. 2. EXP-RULE-SH supports a satisfactory video throughput until 40 users, it means 10 users more than EXP-RULE. PLR decreases by 25% when using EXP-RULE-SH compared to EXP-RULE when the cell is totally charged by 60 users (Fig. 3). EXP-RULE-SH shows a fairness index increase up to 2.1% compared to EXP-RULE (Fig. 7). For VoIP flows,

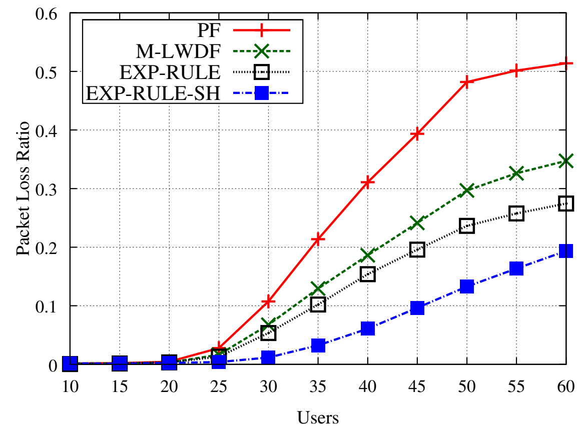

Figure 3. Packet loss ratio for video flows

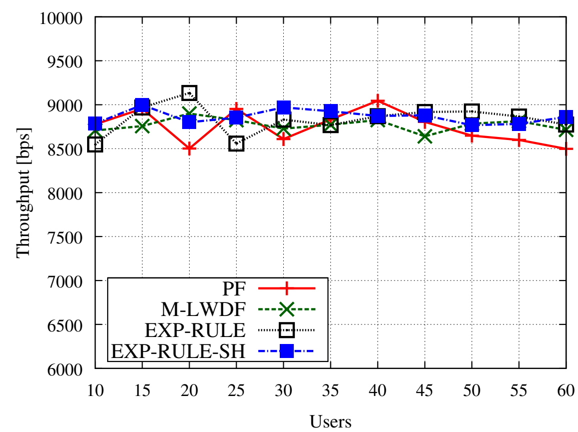

Figure 4. Average throughput per VoIP flow

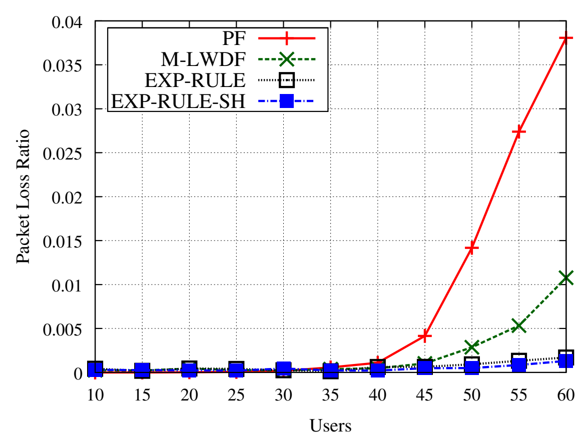

Figure 5. Packet loss ratio for VoIP flows

there is not a high variation of throughput between different algorithms but on the other hand EXP-RULE-SH shows a better stabilized throughput (Fig. 4).

PRL decreases by 24% when using EXP-RULE-SH compared to the classical EXP-RULE when the cell is charged by 60 users (Fig. 5). For CBR flows, throughput increases up to 30% when using EXP-RULE-SH compared to EXP-RULE when the cell is charged by 60 users (Fig. 6). Total cell spectral efficiency is measured as well, it grows by 10.5% when using

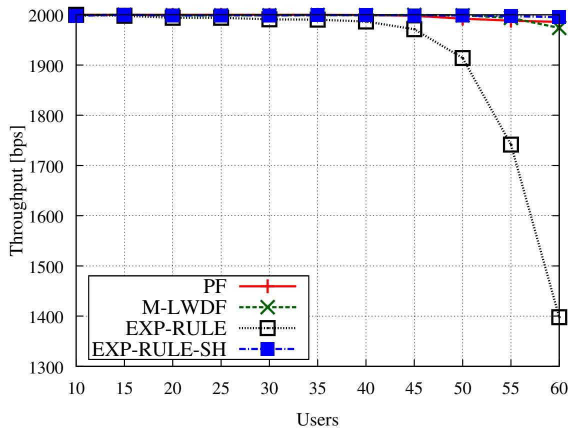

Figure 6. Average throughput per CBR flow

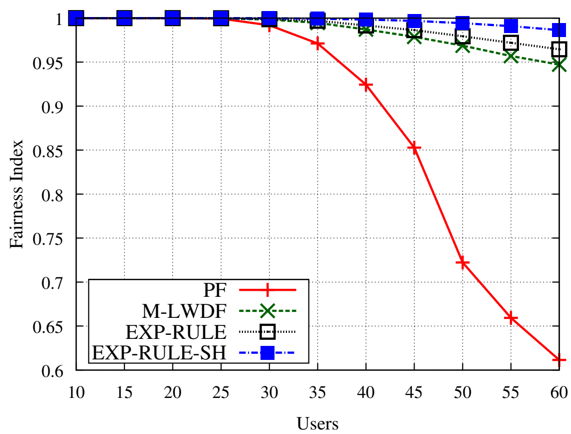

Figure 7. Fairness index value for video flows

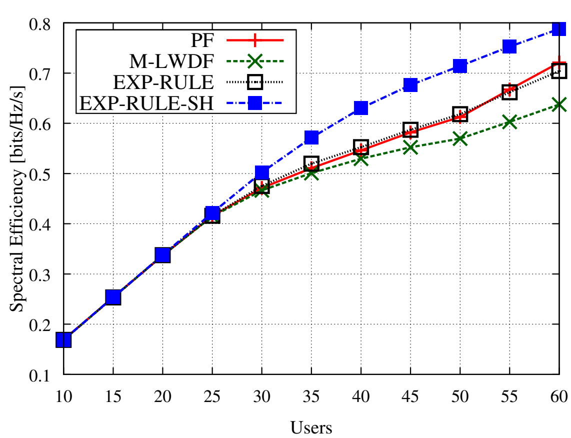

Figure 8. Total cell spectral efficiency

EXP-RULE-SH compared to EXP-RULE when the cell is totally charged by 60 users (Fig. 8). Should be noted that the Shapley value division was also tested in combination with M-LWDF and PF algorithms. These algorithms also presented a performance improve in the same metrics used in this work. Due to the fact that EXP-RULE presents the best performance between the above mentioned algorithms, for simplicity, in this paper we only present the combination of Shapley value with EXP-RULE.

VI. Conclusions

In this paper, a fair resource distribution mechanism has been implemented to improve the performance of resource allocation in LTE for downlink system. We defined four performance metrics, namely, throughput, fairness index PLR and total cell spectral efficiency. With respect to these measures, we found that it is possible to enhance the performance of resource allocation by using a game theory process making a fair bandwidth division among flow classes before making the scheduling among their flows. Our results show that, a resource distribution mechanism performed by Shapley value in transfer utility games, used in conjunction with a smart scheduling algorithm as EXP-RULE, can improve the efficiency of this algorithm by 25% to 30%. The proposed scheme allows a low complexity implementation, which is suitable for practical wireless systems. Future research could be focused on using game theory mechanisms to make a fair resource distribution between RT and NRT flows in uplink system.

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