Resource Allocation for Real Time Services Using Cooperative Game Theory and a Virtual Token Mechanism in LTE Networks

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***Abstract*—In this paper a two level resource allocation scheme is proposed to enhance the Quality of Service (QoS) for multimedia services in LTE downlink system. It corresponds to a solution that combines cooperative game theory, a virtual token mechanism, and the EXP-RULE algorithm. By using cooperative game theory such as bankruptcy game and Shapley value, the proposed mechanism works by forming coalitions between flow classes to distribute bandwidth fairly. EXP-RULE algorithm has been modified to use a virtual token mechanism to improve its performance. By taking into account constraints such as Shapley value fairness and the virtual token robustness, the proposed mechanism can increase remarkably the performance for real time flows such as video and VoIP in downlink system. 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

Due to the 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. Non-Real Time (NRT) services must have a minimum bit-rate and Real Time (RT) services need a high QoS level. To satisfy this demand, several packet scheduling algorithms have been proposed M-LWDF, PF, EXP-RULE [8][4][17]. In these 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). The aim of this paper is to adapt a game theory negotiation using bankruptcy games and the Shapley value to distribute the bandwidth among flow classes in a fair manner. This scheme is combined with the modified EXP-RULE algorithm using a virtual token mechanism to improve the resource allocation scheduling in downlink. In previous works, the Shapley value has been proposed 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 [14][13]. The EXP rule has been modified to be used in conjunction with a virtual token mechanism to perform resource allocation in High Data Rate (HDR) systems [19][20]. It has been shown in [20] that by adapting the EXP rule by using a token queue mechanism over HDR, a mixture of RT and NRT services can be supported with high efficiency. Given that multimedia services such as video and VoIP are becoming the most important applications in telecommunications technology, this work is focused on these services. 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 and the virtual tokens method. 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.

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The eNodeB has a complete information about the channel quality by the use of Channel State Information (CSI). Users report their instantaneous downlink channel conditions (e.g signal-to-noise-ratio, SNR) to 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. 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, 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 $v : 2^n \to \mathbb{R}$ 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[12].

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 [12] 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 [15] 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 [15] 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.

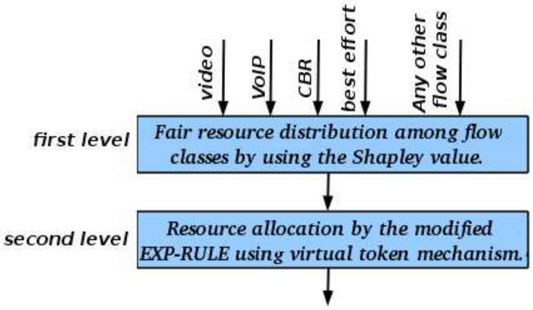

Figure 1. Resource allocation levels

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 re-distribution 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.

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 $kbps$

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 classes using Shapley value method is performed. On the second level, having the proportion of resource destined to each class (video, VoIP, CBR, etc) a resource allocation is performed by using the modified EXP-RULE adapted to use a virtual token mechanism, respecting the amount of resource that Shapley value assigned to each class (Fig. 1).

A. Fair resource distribution among flow classes by using Shapley value (First Level)

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

Bearing in mind section III where resource allocation game approach was described, let us consider the following scenario to explain with an example 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 caracteristic functions we have:

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

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

B. Exponential Rule modified by using a virtual token mechanism (Second Level)

Considering that there is two types of flows, RT and NRT, EXP-RULE has been divided into two parts, for RT flows we use the EXP-RULE [17], and for NRT flows we use PF rule [4]. At time slot t, the metric is computed to choose the flow j for transmission as follows

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

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 [4]. $a_i = 6/d_i$ where d_i is the is the maximal delay target of the th user's flow. $W_i(t)$ is the HOL packet delay.

Thus, knowing that EXP-RULE makes scheduling decisions based on the actual packet delays, we propose to modify EXP-RULE algorithm by combining it with a virtual token mechanism. For doing so, a virtual token queue is associated to each flow, into which tokens arrive at constant rate r_i, the desired guaranteed minimum throughput of flow i. Let us define $V_i(t)$ to be the delay of the head of line token in the flow i token queue. Note that we do not need to maintain the token delays. As the arrival rates of tokens are constant,

$$V_i(t) = \frac{Q_i(t)}{r_i} \tag{4}$$

where $Q_i(t)$ is the token queue length (a counter value at time t). The value for r_i is 1 in our simulation scenario, like this, the same desired minimum throughput is given to all flows.

Then, we use the EXP-RULE algorithm with $W_i(t)$ being replaced by $V_i(t)$. After the service of a real queue, the number of tokens in the correspondent token queue is reduced by the actual amount of data transmitted.

V. SIMULATION ENVIRONMENT

To perform our resource allocation model, we define a scenario as follows. We use a single cell where there are 50% of users using video flows and 50% using VoIP flows. Users are constantly moving at speed of 3 kmph in random directions (random walk). LTE-Sim simulator is used to perform this process[11]. LTE-Sim provides a support for radio resource allocation in a time-frequency domain. According to [11], resource allocation is performed at each TTI, each one lasting 1 ms. One 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 (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 [16]. For VoIP flows, G.729 voice flows are generated by the VoIP application. 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 [9]. 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 fairness among users is measured using the Jain's fairness method [18]. The LTE propagation loss model is composed by 4 different models [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

This study seeks to improve the resource allocation performance by combining the Shapley value fairness property, a virtual token mechanism and the exponential rule. To better understand the obtained results, the following notation is used: "EXP-RULE" represents the non-modified exp rule, "VIRTUAL-TOKEN" represents the modified exp rule by using a virtual tokens mechanism, "SHAPLEY" represents the exp rule combined with the Shapley value, and "EXP-RULE-VT-SH" represents the expon rule modified by using a virtual token mechanism combined with the Shapley value method.

The throughput gain for video flows is shown in (Fig. 2). EXP-RULE-VT-SH shows a sharp rise compared to the non-modified EXP-RULE. When using EXP-RULE-VT-SH the throughput increases up to 30% when the cell is charged by 50 users, which means that the video service is still acceptable for 50 users while EXP-RULE supports only 33 users. By adopting the view that HOL is removed from EXP-RULE when it uses a virtual token mechanism, we can explain its throughput gain because of video flows need a high bit-rate, therefore, video flows have a higher quantity of tokens. On the other hand the Shapley value division guarantees resource allocation at each TTI for each flow class, like this the virtual token method negligence to flows that always have a low quantity of tokens is compensated.

VoIP throughput is maintained when using all scheduling modifications. One possible explanation for this no-variation is the ON/OF periods used in simulation (Fig. 5).

PLR for video flows decreases by up to 46% when using EXP-RULE-VT-SH compared to EXP-RULE (Fig. 3). For VoIP flows, Fig. 6 shows a sharp increase of PLR when VIRTUAL-TOKEN is performed compared to EXP-RULE. The main cause of this increase is the priority that the virtual tokens mechanism grants to video flows, this could produce a buffer overflow in other flows classes. Nevertheless the all PLR values are lower than 3% that is the highest limit of accepted loss. However, there is not a considerable difference of PLR when performing EXP-RULE-VT-SH, because of Shapley value method controls this problem by guaranteeing resource allocation for all flow classes at each TTI.

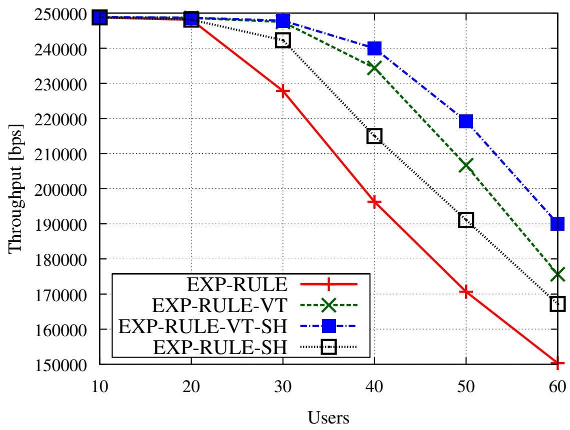

Figure 2. Average throughput per video flow

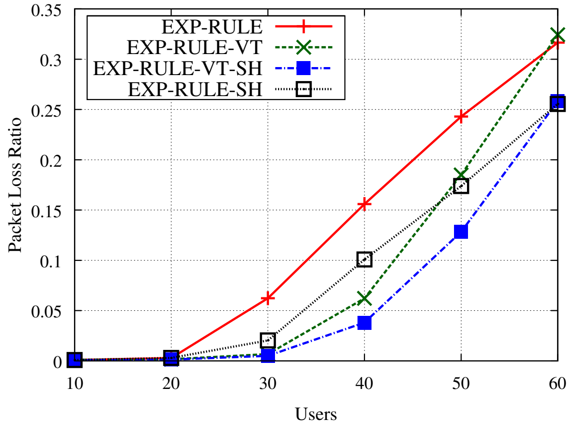

Figure 3. Packet loss ratio for video flows

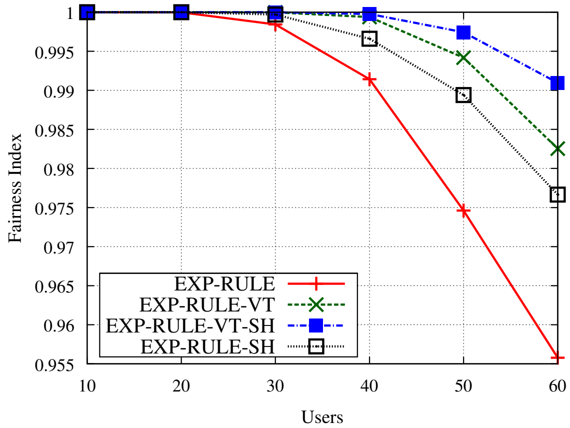

Figure 4. Fairness Index for video flows

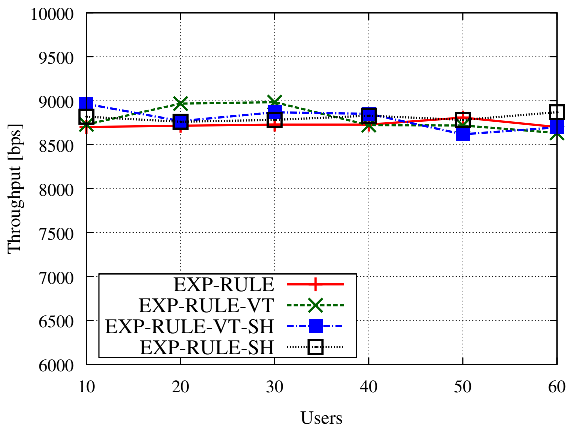

Figure 5. Average throughput per VoIP flow

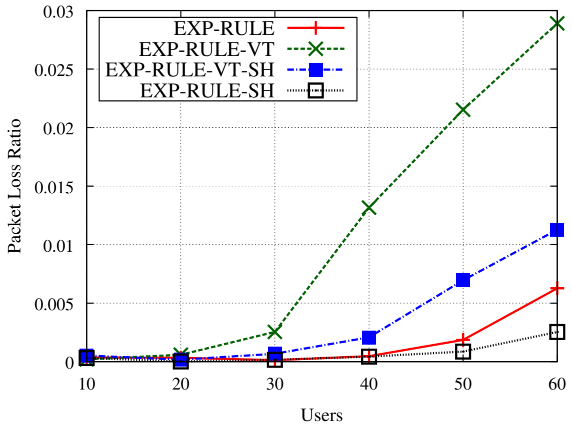

Figure 6. Packet loss ratio for VoIP flows

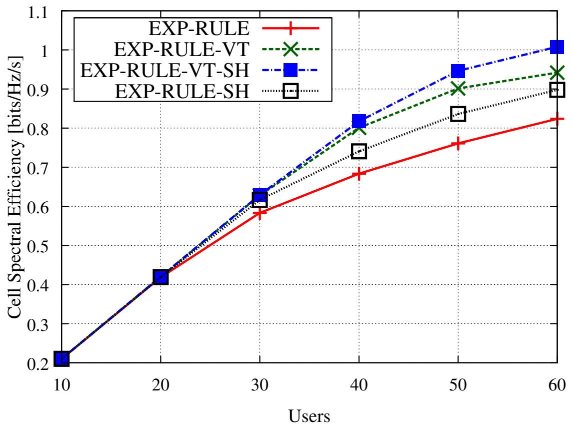

Figure 7. Total spectral cell efficiency

Fairness Index for video flows (Fig. 4), increases up to 4% when the cell is totally charged by 60 users. This can be explained by the Shapley value concept, where each flow class always gets resource allocation at each TTI. Spectral cell efficiency increases up to 36% when the cell is totally charged by 60 users. The main cause of this rise is the sharp video throughput increase early described (Fig. 7).

VI. CONCLUSIONS

This study paper has focused attention on resource allocation in downlink system for real time services in LTE networks. We defined four performance metrics, namely, throughput, PLR, fairness index and total cell spectral efficiency. With respect to these measures we can conclude that by modifying the EXP-RULE scheduler to use a virtual token mechanism the EXP-RULE performance can be enhanced. Similar results have been obtained by combining the EXP-RULE with Shapley value method. A fusion of these two mechanisms improves the EXP-RULE performance considerably by using the robustness of virtual token method, and fairness as the particular characteristic of Shapley value. The proposed scheme allows a low complexity implementation, which is suitable for practical wireless systems. Future work could be focused in using game theory mechanisms to propose a fair distribution of resources in uplink system.

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