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Resource Allocation Based Game Theory in a Converged Macro/Femto LTE Networks

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Abstract— **In this article, we propose two levels of resource allocation method in a converged scenario for Macro and Femtocells LTE system. We use a Soft Frequency Reuse for guaranteeing the Quality of Service (QoS) for different Service Data Flows (SDFs) in the converged wireless networks. The first level of our method includes the use of bandwidth allocation between macro and femtocells and admission control based on bankruptcy game which is a special type of a cooperative game. A coalition among the converged scenario is formed to offer bandwidth to a new connection. Then, the second level will be coordinating the allocation among different SDFs in both networks. Our scheme for resource blocks allocation balances between maximizing the overall throughput of the system while guaranteeing the QoS requirements for a mixture of real-time and non-real-time SDFs. We present simulations to demonstrate the various degrees of macro/femtocell coordination and to take advantages of multiuser diversity. We find a feasible resource allocation that is combined with soft frequency reuse scheme and game theory to guarantee the QoS for different SDFs in the integrated scenario.**

Keywords— **femtocell, macrocell, QoS, soft frequency reuse**

I. Introduction

Long Term Evolution (LTE) is a 3GPP based technology. It presents a set of powerful characteristics contributing in rich opportunities of deployment options. Also it provides variety of service offerings. LTE presented Femtocell. Femtocell is an emerging network technology. It is a low-cost and low power owning cellular access point. It operates in licensed spectrum to connect conventional and unmodified User Equipments (UEs) to a mobile operator's network. The femtocell coverage ranges are tens of meters. The femtocell coverage area is limited to tens of meters. The femtocell Base Station called Home eNodeB (HeNB) is providing the access to its users. Usually, they are positioned on the edge of the macrocell as well as in the residential building. A converged wireless networks for future networks, LTE macrocell and femtocell can be integrated in order to extend the coverage area for inner and outer door users. Femtocells have a secondary purpose - offload traffic from the Macro cells in the network. They help in de-congestion at Urban and dense Urban areas. But, in situations where femtocells and macro cell are integrated. Then, some problems may raise such as mobility management, resource allocation and interference mitigation. In this article we focused on resource allocation in an integrated network of macro/femtocells while mitigating interference [1].

One of the salient features of LTE is the use of Orthogonal Frequency Division Multiple Access (OFDMA) communication system that utilizes 15khz subcarriers which are then grouped into Resource Blocks (RBs). The RB can be considered as the main unit of resource allocation in OFDMA frame [2]. There are various options on how these RB can be allocated for LTE radio planning where frequency reuse of one is used, i.e. all cells operate on the same frequency channel to maximize spectral efficiency. However, due to heavy Cochannel Interference (CCI) in frequency reuse of one deployment, UEs at the both networks may suffer degradation in connection quality. This is why LTE introduced the Soft Frequency Reuse (SFR) which enables the system to maximize the capacity of the network by enabling each cell/sector to utilize the full bandwidth. To do this, SFR adjusts the power which is allocated to certain RB's in order to mitigate Inter-Cell Interference. It also enables the Evolved NodeB (eNB) to allocate the full bandwidth to users that are close to the cell, thereby achieving higher peak rates.

Interference mitigation with resource allocation over an integrated macro/femtocell networks have worked. Also, in interference mitigation over macro/femtocell networks, graph based solutions are given. Interference mitigation problem may be given as an interference graph. In the graph, UEs correspond to the nodes and relevant interference relations between UEs correspond to the respective edges. For minimizing the interference, connected UEs should not be allocated the same set of resources. This is a kind of graph coloring problem, where every one of colors corresponds to a disjoint set of frequency resources. The idea is giving a definite color to every node on the graph, without assigning the same color to the connected nodes. In graph coloring algorithms, the originally intended bit rate is not guaranteed. In the

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method, every HeNB utilize a fraction of the whole bandwidth and in the worst case, 1/4 of the total bandwidth [3]-[8].

Proposed solutions in other works are based on frequency reuse, in [9], the authors propose frequency reuse schemes with allowing the femtocells (which have a lower priority than macro users) to access the resources that are not being used by the macro users around them. The authors proposed a scheme of a reuse factor of 1 which is combined with a reinforcement learning and an equal priority between macro and femto users. In [10], [11] a frequency sharing mechanism is given. The mechanism utilizes frequency reuse which is coupled with pilot sensing to be able to minimize cross- tier/co-channel interference between macrocell and femtocells. In the scheme, Fractional Frequency Reuse (FFR) of 3 or more is applied to the macrocell. A HeNB is turned on, then it senses the pilot signals arriving the eNB. The HeNB discards the sub-band with the largest received signal power, and it utilizes the rest of the frequency sub-bands resulting in an increased Signal-to-Interference-Noise-Ratio (SINR) for Macrocell UEs (MUEs). The whole network throughput is enhanced with using high-order modulation schemes.For LTE femtocells, another interference management scheme is given based on FFR in [12]. Downlink cross-tier interference is avoided by assigning sub-bands from the entire allocated frequency band to the HeNBs which are not being utilized in the macrocell sub-area. The macrocell is composed of centre zone (corresponding to 63% of the whole macrocell coverage area) and edge region with three sectors for every region, in the given scheme [8].

Self-Power Control Mechanisms (PCM) is proposed to avoid the interference neighbour problem. Here, femtocell measures the signal power of the closest macro BS and sets its transmission power to a appropriate level. In PCM, the eNB and FBSs use the whole bandwidth with interference coordination. Dynamic/adjustable power settings are chosen over fixed HeNB/eNB power setting. And they are utilized either in proactive or in reactive manner. At radio resource management, power control methods are utilized in cellular systems to provide interference mitigation [8], [13]-[17].

In this article, we propose a radio resource allocation scheme for an integrated macro/femtocells in LTE systems. Our scheme allocates the requested bandwidth to a new connection which is based on the available bandwidth in each network and the subscription level for that connection to each of the LTE networks. This problem is formulated as bankruptcy game. A coalition is formed among the LTE networks to ensure that the allocation satisfies all the networks in the system. In the standard method of game theory, the core is used to obtain feasible bandwidth allocation scenarios. Then, to obtain the solution (i.e., the amount of allocated bandwidth in each network for a new connection), Shapley value is used. Based on the bandwidth allocation algorithm, a scheduling algorithm is proposed to ensure that the amount of bandwidth allocated (from all the networks) to the new connection is high enough to satisfy the corresponding UE's requirement. This article is structured as follows: Section 2 presents the system model scenario, Section 3 introduces cooperative game theory that is used in the resource allocation model. Sections 4 and 5 present problem formulation and proposed solution respectively. Finally, Section 6 demonstrates some numerical analysis and Section 7 concludes the article.

II. System Model

We consider a geographical area that is totally covered by LTE macro and femtocells. Within the macrocell, an eNB coordinates all data transmissions for UEs while in each femtocell, the HeNB is the principal entity of controlling transmissions inside the cell. Generally, a UE is able to connect to each network if it is in the corresponding coverage area. And perfect power control is assumed to ensure uniform available transmission rate across the coverage area. The used architecture to integrate both macro and femtocells is illustrated in Fig. 1. Here, the interconnection between eNodeBs is provided by interface X2 and the connection between the eNodeBs and Serving Gateways (S-GWs) are performed with interface S1. S5 is a signaling interface between the S-GW and the Packet Data Network Gateway (P-GW) or between S-GWs [18]. The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) is considered as an access network in LTE network which permits to connect the eNB and HeNB to their gateways. The HeNB GW or the S-GW routes and forwards user data packets between both networks through Mobility Management Entity (MME). In our case MME can be considered as a centralized entity that controls the resource allocation and interference mitigation between both networks.

The interference mitigation is performed by the use of Soft Frequency Reuse (SFR) which is used by MME. The SFR scheme is characterized by frequency reuse factor of one in the central region of a cell, and by frequency reuse factor greater than 1 at the outward cell region close to the cell edge. In the system model under consideration, a UE can subscribe to different Service Data Flow (SDF) which has different bandwidth requirements. The subscription class is determined when the UE initiates the connection and we assume that an ongoing connection remains in the same flow until it terminates. Every SDF is associated with a bearer as a connection established between the Packet Data Network gateway and the UE, in LTE. Mostly, two types of bearers are considered: (1) *Guaranteed bit rate (GBR)*: It is a permanent bearer and (2) *Non-guaranteed bit rate (non-GBR)*: It is an IP connectivity bearer. GBR and Non-GBR bearers are associated with different bearer level Quality of Service (QoS) parameters. It is known as QoS Class Identifier (QCI) and presented in Table I [1].

III. Cooperative Game Theory

A cooperative game is a game. Groups of players which are coalitions can enforce cooperative behavior. The game is a competition of coalitions of players, rather than

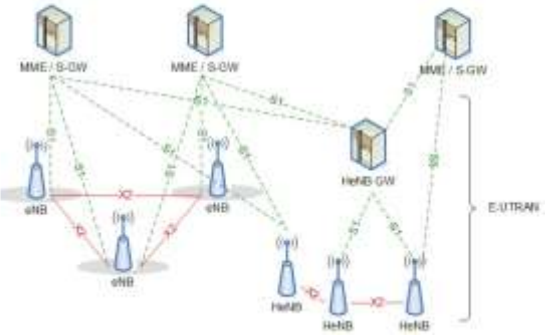

Figure 1. LTE macro and femtocell integration architecture

TABLE I. STANDARDIZED QCI CHARACTERISTICS

QCI	**Type**	**Priority**	**Delay(ms)**	Error Loss Rate	**Example**
1	GBR	2	100	10^{-2}	Conversational voice (CVo)
2	GBR	4	150	10^{-3}	Conversational video (CVi)
3	GBR	3	50	10^{-3}	Real-time gaming (rtG)
4	GBR	5	300	10^{-6}	Non conversational video (buffering)
5	NON-GBR	1	100	10^{-6}	IMS signaling
6	NON-GBR	6	300	10^{-6}	Video based buffering (VBS)
7	NON-GBR	7	100	10^{-3}	Voice, video, interactive game

among individual players [19]. The behavior of decision makers which are players concerned because their decisions affect each other. A player list and characteristic function are utilized in a cooperative game. A set of players are given as *N*, a coalition need to be provided by the players to transfer benefits between them. A game is a pair (N,v), a finite set of players is $N=\{1,\ldots,n\}$, $n=|N|$ and v is a characteristic function $v:2^n\rightarrow\Re$ such as $v(0)=0$. Coalitions are subsets $S\subseteq N$. The complement set to N is denoted by $N\setminus S$. There are 2^n possible coalitions, in a game with n players [20].

A. *Bankruptcy games*

With the analysis of bankruptcy situations, to prescribe how to ratio an amount of perfectly divisible resources between a group of players is thought. It is concerned according to a profile of demands which, in the aggregate, exceeds the quantity to be distributed [21]-[23].

A bankruptcy situation is modelled with a triple (N,C,g). Here, $N=\{1,\ldots,n\}$ is the set of players as defined before. The benefit is represented by $C\in\Re_+$. $g=\{g_1,\ldots,g_n\}\in\Re_+^n$ is the players vector of claims. (N,C,g) an associated bankruptcy game (N,vc_g) is defined in [21] for each bankruptcy problem. With O'Neill approach, the value of a coalition S is the part of the benefit which remains after paying the aggregated players in $N\setminus S$ all their bandwidth needs, that is (1) as in [20].

$$vc_g(S)=\max\left\{C-\sum_{i\in N\setminus S}\mathrm{g}_\mathrm{i},0\right\}$$

$$v(N)=C \qquad (1)$$

B. *Shapley Value*

Shapley value is a Game Theory concept [22]. It aims to present the fairest allocation of collectively gained profits among many collaborative players. To emerge the relative importance of every player regarding the cooperative activities is the main criterion.

In the game for Shapley Value, we defined a function $\phi(v)$ for the worth or value of player i with characteristic function v. When the player enters in the coalition randomly, then the Shapley value is the average payoff to a player. The formula of Shapley presented in [20], [22] is:

$$\phi(v)=\sum_{S\subseteq N}\frac{(|S|-1)!\,(n-|S|)!}{n!}(v(S)-v(S\setminus\{\mathrm{i}\})) \qquad (2)$$

For equitable division, the Shapley Value is a common method. It is based on symmetry, efficiency and additivity axioms. Pareto efficiency is an efficiency condition. A player cannot obtain a better allocation without making another player worse allocation is guaranteed. The player's last allocation does not based on the order of the players arriving the game in symmetry. The Shapley Value is thought as a fairness standard with the symmetry property. The values of different games need to be related to each other is explained with the additivity axiom. When the allocation is determined for two independent games, then it is also valid for a composite game [20].

IV. Link Model

We used a macrocell/femtocell area covering the femtocell locations in streets that are situated at the edge of a macrocell coverage area. UEs can be represented by a set of $(l=1,\ldots,L)$. System transmissions are OFDMA-based, so all MUEs and Femtocell UEs (FUEs) entirely use the same frequency band consisting of k RBs. At the resource allocation step of these RBs, eNB and HeNBs request periodical reports of their signal quality from their UEs. The signal quality is defined in Channel Quality Indicator (CQI) in terms of SINR. For a specific UE on RB k, the receiver downlink SINR can be computed as:

$$SINR_{UE_l}^{k} = \frac{P_{UE_l}^{k}\,|G_{UE_l}^{k}|^2}{N_0 + \sum_{l\in Z_{i,k}} P_{UE_l}^{k}\,|G_{UE_l}^{k}|^2} \qquad (3)$$

where $P_{MUE_l}^{k}$ is the present transmission power that is allocated on RB k by the serving cell regardless of its type. $|G_{UE_l}^{k}|^2$ is the channel gain between UE_l and its serving cell on RB k. In similar way, $P_{UE_l}^{k}$ is the transmission power of neighboring cells on RB k. $Z_{i,k}$ is the set of all Base Stations accommodating around the area regardless of their types. $|G_{UE_i}^{k}|^2$ is the channel gain between the UE_l and the neighboring BSs on RB k. N_0 is the white noise power spectral density.

The instantaneous achievable rate at RB n for UE k is modelled as

$$R_{l,n} = \Delta B\,\Delta\mathrm{T}\log_2(1+SINR_{UE_l}^{k}) \quad \text{[bits/sec]} \qquad (4)$$

It is assumed that F is the time duration of an OFDMA frame, then the l th UE achievable data rate (bps) for one frame is

$$U_{l,k} = \frac{1}{F}\sum_{l=1}^{M}\sum_{k=1}^{K} R_{l,k} \qquad (5)$$

V. PROPOSED RESOURCE ALLOCATION BASED GAME THEORY

Based on a standard bankruptcy game described earlier, we propose a resource allocation algorithm for MME where the resource allocation is done at each Transmission Time Interval (TTI) in two levels. On the first level, a fair resource distribution among classes using Shapley value method is performed. After that, on the second level, having the proportion of resource destined to each SDF (CVi, CVi, rtG, etc.) a resource allocation is performed using our algorithm respecting the amount of resource that Shapley value has assigned to each SDF (See Fig. 2).

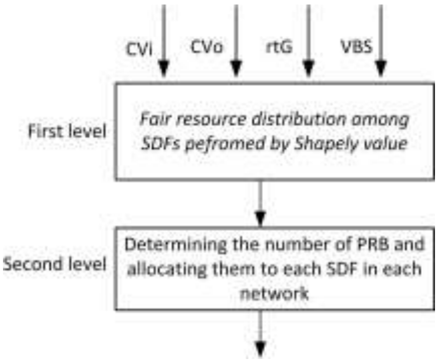

Figure 2. Levels of the proposed resource allocation

A. *First Level*

At this level a game is carried out, taking into account the parameters as shown in Table II [20].

We considered the following scenario to explain our resource allocation model. Three SDF classes are given as $A = CVi$, $B = CVo$ and $D = rtG$. $N = \{A, B, D\}$ is players in our scenario. $C = 32Mbps$ (50 RBs per TTI). The needed bandwidth by a flow of every SDF is $b = (242, 8.4, 2)\mathrm{kbps}$. There is a dynamic allocation. It is based on simultaneous flows quantity $K = (k_A, k_B, k_D)$. We modelled our bandwidth game as $(N; vc_g)$ where $|N| = 3$ and $vc_g(S) = \max\{C - \sum_{i\in N\backslash S} \mathrm{g}_\mathrm{i}, 0\}$, with $v(N) = C$. Developing the characteristic functions we have the following results as in [20]:

$$vc_g(1) = \max\{32000 - (8.4k_B + 2k_D), 0\}$$

$$vc_g(2) = \max\{32000 - (242k_A + 2k_D), 0\}$$

$$vc_g(3) = \max\{32000 - (242k_A + 8.4k_B), 0\}$$

$$vc_g(1,2) = \max\{32000 - 2k_C, 0\}$$

$$vc_g(1,3) = \max\{32000 - 8k_B, 0\}$$

$$vc_g(2,3) = \max\{32000 - 242k_A, 0\}$$

$$vc_g(1,2,3) = 32000$$

We had Shapley value to calculate the resources related to every class based on K [20].

B. *Second Level*

Shapley value is used to determine the bandwidth for each SDF in both Macro and Femtocells. An SFR is applied to enable initial resource allocation for both networks in terms of RB. For each network, we identify the number of RB for macro and femto cell users. The determination of the number of RB for each eNB and HeNB is done according to the information about the types of SDFs, their data rates, their channel qualities that are provided by the CQI message from the UEs. Upon receiving information, the eNB and HeNB decide the number of RBs through the following equation:

$$n = \left\lceil \frac{U_i}{\frac{1}{|M_t|}\sum_{j\in M_t} U_j}\;\frac{\overline{\mu}_i}{\frac{1}{|M_t|}\sum_{j\in M_t} \overline{\mu}_j} \right\rceil \qquad (6)$$

TABLE II. BANKRUPTCY GAME VARIABLES

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

For connection i, $\overline{\mu}_i$ is the average traffic rate. Multiuser diversity is exploited by this allocation. It is performed with allocating more RBs to the SDFs with better channels. We assumed that the average traffic rate of whole connection is the same. And the factor $u_i / \frac{1}{|M_t|}\sum_{j\in M_t} u_j$ is equal to one. A connection with relatively good channel conditions, such as, its $\overline{\mu}_i(t) > \sum_{j\in M_t} \overline{\mu}_j(t)/|M_t|$, will be allocated by two or more RBs. Relatively bad channel conditions having a UE, will be allocated by only one RB. Weighting factor is $u_i / \frac{1}{|M_t|}\sum_{j\in M_t} u_j$. It is used to weight the allocation proportional to SDF's average rate [1].

The next step is the RB assignment among UEs in both networks. Firstly, the eNB and HeNB perform the assignment for the UEs in the macrocell then the UEs in the femtocell. Each UE has one SDF, i.e., there is one-to-one mapping between a UE and its SDF through a connection. Since CVo has strict QoS constraints, therefore, we prioritize it over all other types by allocating first and the best RBs to it.

VI. Numerical Results

We propose simulation results to illustrate the performance of our algorithms. We utilized system parameters proposed by 3GPP release 8 to simulate realistic environment and wireless communication system in LTE [1], [2].

A. *Simulation Environment*

The OPNET simulator is used to evaluate the performance of our proposed algorithms. Simulation parameters are given in Table III.

B. *Simulation Results*

In order to study the performance of our algorithm, we used real-time SDFs in order to investigate their QoS requirements. We considered a scenario where there is one LTE macrocell and seven femtocells owning networks. Two applications were used: voice and video for different users in macro and femtocells. Simulation results used to illustrate four scenarios: (1) the use of SFR combined with our algorithm which we denoted SFR QoS, (2) SFR without our algorithm as the RBs are allocated randomly with no QoS guarantee(SFR NQoS), (3) the use of FFR with our algorithm (FFR QoS) and finally (4) the FFR with a random allocation for RBs (FFR NQoS).

Thus the first performance parameter that we measured is the packet delays for CVo. Figs. 3 and 4 illustrate delay comparison for the different algorithms for MUEs and FUEs. SFR QoS performs better in terms of delay than other schemes since it assigns highest priority for the CVo SDFs even when the load of the cell increases, there is no violation of the delay. The approach of FFR QoS performs better in terms of delay but it is higher than our approach since there is no calculation for the number of RBs. Consequently, this will lead to dissatisfaction for CVo SDFs in terms of RBs as there is no reallocation method for the RBs compared to our approach. The approach of FFR NQoS performs worst since it treats equally to all the types of SDFs and RBs that are assigned randomly among UEs regardless of their types. From Figs. 3 and 4, we noticed that the delay is slightly higher for FUEs than in macrocell due to the use of SFR, however due to the re-allocation scheme no violation is occurred for all UEs having CVi SDFs.

TABLE III. SIMULATION PARAMETERS

Simulation Parameters	**Values**
Channel bandwidth	10 MHz
Carrier Frequency	2 GHz
Number of PRBs	48
Number of cells	7
CVo maximum traffic rate	64 Kbps
CVi traffic rate	5 Kbps-384 Kbps
VBS traffic rate	0.01 Mbps-100 Mbps
Channel model	6-tap Rayleigh Fading

Finally, we investigated the Packet Loss Rate (PLR) for CVi SDFs for both MUEs and FUEs. Figs. 5 and 6 depict PLR versus different loads. The PLR values of random method with FFR NQoS are increasing drastically with the increase of load. The PLR in both of our methods (SFR QoS and SFR NQoS) is less than their correspondence of FFR, this is due to the use of SFR as it tries to mitigate

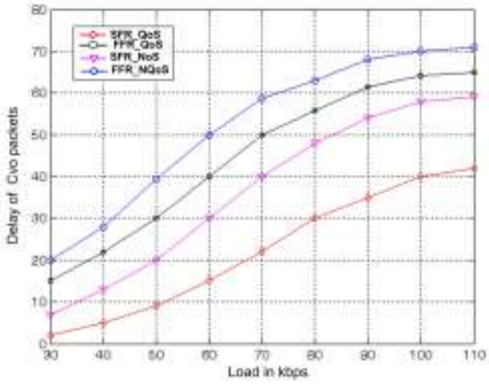

Figure 3. Delay comparison of CVo SDFs in macrocell versus load

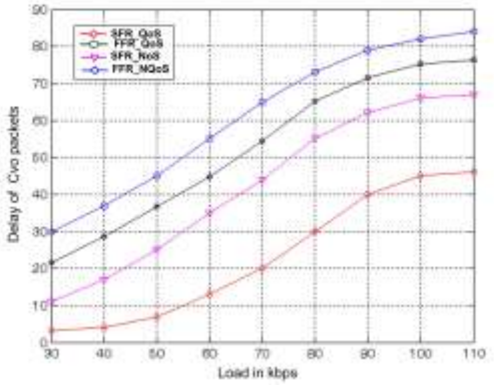

Figure 4. Delay comparison of CVo SDFs in femtocells versus load

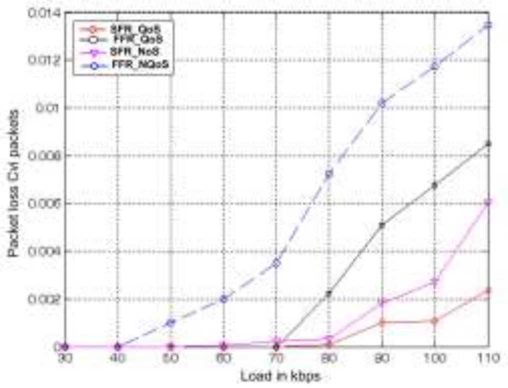

Figure 5. PLR comparison of CVi SDFs in macrocell versus load

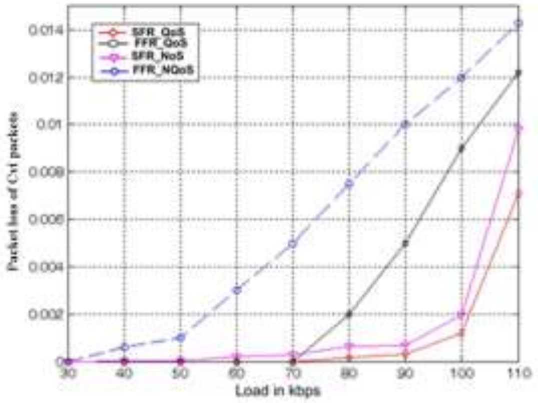

Figure 6. PLR comparison of CVi SDFs in femtocells versus load

interference while increasing the throughput. Even when a random method of RB is achieved, the SFR guarantees the assurance of QoS.

VII. Conclusion

In this article, we have presented a centralized bandwidth allocation and an admission control algorithm for an integrated architecture of Macro/femtocells OFDMA based LTE networks. We have formulated the problem of bandwidth allocation in this system as a bankruptcy game. With a bankruptcy game, each network can cooperate to provide the requested bandwidth to a new connection. By using Soft Frequency Reuse method in our scheme, QoS requirements for the different SDFs in both networks are guaranteed. Our scheme does not only coordinate the macro/femtocells interference but also utilizes opportunistic scheduling to increase the overall throughput of the system while guaranteeing QoS needs in terms of delay for rtG SDFs and packet loss rate for CVi SDFs.

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