Maximizing Sum-Rate of LTE Users Considering QoS and Co-existence Issue in Unlicensed Band

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***Abstract*—Both academia and industry are engaging different new technologies to deal with the current traffic cyclone in cellular networks. Long Term Evaluation-Advanced (LTE-A) is such a recent technology that serves heavy mobile traffic. But with insufficient licensed spectrum, LTE-A also cannot meet the quality of service (QoS) requirements of all it's users. So, by augmenting the benefits of LTE-A into unlicensed spectrum known as LTE-U, we can boost the performance of 4G/5G cellular network. The process will sure to conflict with other technologies which are already using same unlicensed band. Moreover, if multiple cellular network operators (CNOs) use the same unlicensed band then they will diminish the benefits of each others. In this paper, we explore the CA of licensed and unlicensed spectrum when QoS of user cannot be met with licensed spectrum by deploying dual mode small cell base station (SBS) and considering minimum requirement of unlicensed WiFi access points (WAP). Here, we try to solve this problem with the help of Nash bargaining game (NBG) between LTE-U and WAP by cooperative approach.**

I. Introduction

During the past decade, mobile data traffic has already shown exponential outgrowth and in the next five years, it is anticipated to flourish the amount 1000 times[1]. To meet this huge demands, new technologies like LTE or LTE-A, massive multiple-input multiple-output (MIMO), device-to-device (D2D) communication are coming forward with scarce licensed spectrum. CNOs are trying to meet this huge users' demand by deploying SBSs which require low-cost and low power with the help of reusing technique of licensed spectrum.

But this actions are not enough to cope with the exponentially increasing data traffic and meet the stringent QoS of emerging wireless services in the next generation cellular system using limited licensed spectrum. So, some CNOs have already deployed WAPs to offload part of their traffic in unlicensed band. But such initiatives are not so effective due to the inferior performance of WiFi technology and not cost effective as CNOs also need to invest on backhaul and core network to integrate WAPs with cellular system. This shortcomings can be overcome by extending the blessings of LTE-A in the unlicensed spectrum known as LTE-U. This can be technically assured via the use of CA technology which was standardized in LTE Releases 10-12. LTE-U is already inaugurated (part of the LTE Release 13) to allow consumers for accommodating licensed and unlicensed carrier under a single LTE network infrastructure[2].

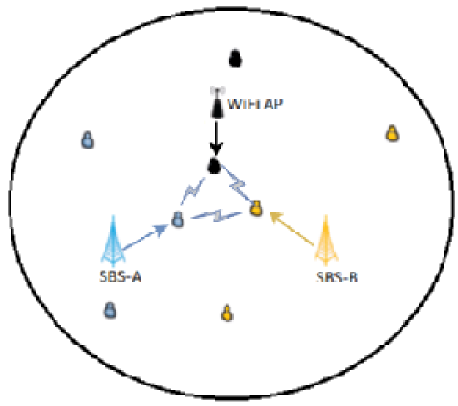

Fig. 1: System Model

As LTE-U and WiFi are diminishing each others performance and within themselves, this interactions can be modeled as a game theory framework namely bargaining game to improve their performance. There are several proposals to coexist fairly of this two, but few of them have considered inter-operator interaction and nobody has seen it in the eye of bargaining game. In this paper, we have tried to maximize LTE-U sum-rate considering the QoS requirement of the users and co-existence issue with WAPs by using bargaining game. Here, we formulate the problem as an optimization one and then solve it using bargaining game.

II. System Model and Problem Formulation

As SCNs are feasible solution to meet data demand of the users, cellular operators are deploying more and more SBSs to facilitate growing services. This ultra dense nature of SBSs from different operators bound to conflict with each other and also with local WAPs if they want to operate in unlicensed spectrum to provide guaranteed QoS. As each operator can control the interference between MBS and its SBSs, we are considering an environment where there is a set of dual-mode LTE-A SBSs, S={1,2,..,N} operated by N different operators and a set W={1,2,..,M} of M WAPs. Each SBS i can serve downlink operation of maximum users U^i at a time with it's licensed spectrum B_l^i. Both SBSs and it's associated users are distributed randomly in the area of interest. As only one user can be served by WAP at a time, we assume that there are M WiFi users distributed randomly in the same area. Both SBSs and WAPs operate in the same unlicensed band B_u. SBSs work in SDL mode with CSAT and CA technology.

When LTE-U user j of SBS i is using both spectrum then the achieved rate of that user by using Shannon's capacity shown in equation (1).

$$R_j^i = (b_{lj}^i + b_{uj}^i) log_2 (1 + \frac{(b_{lj}^i + b_{uj}^i)P^i h_{ij}}{\sum_{k \in S, k \neq i} b_{uj}^{ik} P^k h_{kj} + P^w h_{wj} + \sigma^2}) \quad (1)$$

But study [3] shows that WiFi presence affects negligibly to the LTE-U performance. So we can ignor the interference generated by WiFi system to LTE-U user and equation (1) reforms like shown in equation (2).

$$R_j^i = (b_{lj}^i + b_{uj}^i) log_2 (1 + \frac{(b_{lj}^i + b_{uj}^i)P^i h_{ij}}{\sum_{k \in S, k \neq i} b_{uj}^{ik} P^k h_{kj} + \sigma^2}) \quad (2)$$

From equation (2), we find that a major part of interference is coming from other SBSs that are also operating in the same unlicensed band. To take the advantage of this band, SBSs can form a coalition and allocate the unlicensed resources in orthogonal fashion like licensed spectrum. In that case there is no interference from other SBSs and equation (2) changes it's form like:

$$R_j^i = (b_{lj}^i + b_{uj}^i) log_2 (1 + \frac{(b_{lj}^i + b_{uj}^i)P^i h_{ij}}{\sigma^2}) \quad (3)$$

According to study [4], the saturation capacity of M WiFi (APs employ CSMA/CA with binary slotted exponential back-off) users sharing same unlicensed bandwidth is shown in the equation (3).

$$R^W = \frac{P_{tr} P_s E[P] M^{-1}}{(1 - P_{tr})T_\sigma + P_{tr} P_s T_s + P_{tr}(1 - P_s)T_c} \quad (4)$$

R^w is achievable when WiFi network only access the unlicensed channel. But if WAPs and SBSs are deployed in the same conflicting area, then WiFi users get almost no access in the channel and achieve an insignificant data rate. So, for fair coexistence of WiFi and LTE-U need to share the time slot in such a way that WAPs can maintain a minimum data rate and SBS can guarantee the QoS of its users. As LTE-U system manages the physical resource in a centralized manner rather than DCF of WAPs, SBSs need to decide appropriate portion of time to achieve minimum rate of each WAP. So, when SBSs give $T \in [0, 1]$ time slot to WAPs then the achievable rate of LTE-U user and WAP are shown in the equations (6) and (7) respectively.

$$R_j^i(T) = (b_{lj}^i + (1-T) b_{uj}^i) log_2 (1 + \frac{(b_{lj}^i + (1-T)b_{uj}^i)P^i h_{ij}}{\sigma^2}) \quad (5)$$

$$R^w(T) = R^W T \quad (6)$$

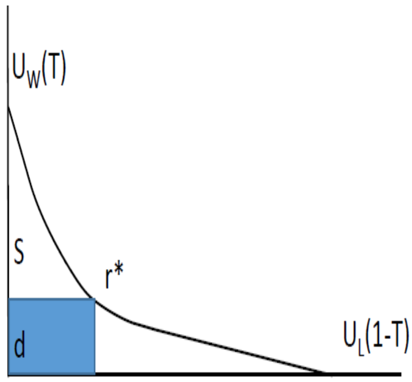

Fig. 2: NBS in two players' game

III. Solution with NBG

Bargaining game is a typical cooperative game that is fair in case of resource allocation. So, this interaction can be considered as a two player bargaining game shown in Figure 2, where $P = \{L, W\}$ are the set of players. Let **S** be a closed and convex subset of $\mathcal{R}^{|P|}$ which represents the set of feasible payoff allocations that the players can achieve if they cooperate using utility function $U_i(T_i), \forall i$. Let **d** be a set of disagreement payoff. Then the ordered pair (**S**,**d**) is called a $|P|$-player bargaining game.

Theorem 1: There exists a unique solution concept $\phi(\mathbf{S}, \mathbf{d})$ that satisfies all six axioms of Nash bargaining solution and it follows (7) where $\mathbf{B} = \{(r_1, r_2) \in S | r_2 \geq Q_w\}$[5].

$$r^* = \phi(\mathbf{S}, \mathbf{d}) \in argmax_{\mathbf{r} \in \mathbf{B}} \prod_{i=1}^{|P|} (r_i - d_i) \quad (7)$$

Theorem 2: The point in which just the minimum rate of WAPs are satisfied is the solution of the bargaining game.

IV. Conclusion

In this short paper, we have tried to meet the QoS requirements of the users by augmenting unlicensed spectrum with licensed one in LTE-A network. Here, LTE-A network use SDL scheme to take advantages of unlicensed spectrum while maintaining minimum requirement of other WAPs who use the same unlicensed band in the conflicting region. For this we have solved the problem by utilizing cooperative approach like NBG which provides a unique solution of the problem.

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