Service Differentiated Non-cooperative Random Access Protocol for OFDMA based Wireless Communication System

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Abstract— **In this paper random access problem for the OFDMA based communication system is addressed in perspective of service differentiated non cooperative game for gaining distributed control over the system. In order to provide diverse QoS demands from users, an access priority based scheme for effectively supporting various ASCs (Access Service Classes) according to the different QoS (Quality of Service) requirement profiles is proposed and analyzed by using game theory. Performance analysis of the proposed random access protocol, SDNcRA is made in terms of success probability attained and delay encountered versus number of mobile terminals present in the system. Two ASCs, ASC0 and ASC1, are treated in this paper and it is varified that ASC0 UEs which have higher priority than ASC1 UEs always receive high success probability and less delay.**

I. Introduction

OFDM (Orthogonal frequency Division multiplexing) is one of the applications of parallel transmission scheme which can combat hostile frequency selective fading environment. The robustness against frequency selective fading is very attractive, especially for high speed data transmission. So it is well understood that OFDM based wireless systems will provide the solutions for future generation wireless communications [1]. OFDM scheme has matured well through research and development for high rate WLANs and terrestrial DVB and already been proposed for IEEE 802.11a Wireless LAN and IEEE 802.16 wireless MAN. Compared with single-carrier multiple-access systems, OFDMA offers increased robustness to narrowband interference and allows straightforward dynamic channel assignment. So OFDMA is the preferred choice for multiplexing technique these days.

Wireless channel is shared medium and interference-limited. To access and share the wireless channel, many schemes have been studied and proposed so far. Contention based medium access is a well studied scheme to access and share the wireless channel among the contending wireless nodes. For the high traffic load, however, contention based access may lead to channel instability. In order to overcome this instability, access control mechanism based on access permission with probability could be applied.

Contention resolution algorithm based on the persistence mechanism is the matter of interest in this paper. In this persistence mechanism each wireless node maintains a persistence probability and access the channel with this probability when the UE (User Equipment) is ready to transmit after receiving the probability by BS. In order to achieve high channel efficiency, we need to maintain appropriate persistence probability for each UE depending on the system conditions. We modeled the proposed SDNcRA (Service Differentiated Non-cooperative Random Access) scheme as a random access game and analyze the performances of that.

The trend of using Game theory in field of economics, social and political science and to some extent in mathematical optimization practice is now also associated in wireless communication field [2]. Specifically Medium Access as a game is studied in [3]-[4] and the concept of service differentiation in multi provider network for differently revenue paying users is introduced in [5]. Similarly, we differentiate services according to ASCs (Access Service Classes) in our work as provisioned in [6].

In conventional game theory, a game consists of three tuples: players, their strategy and the payoff they receive for playing these strategies. In our game for random access the players can be UEs, strategy of players are persistence probabilities and player's payoff is the aggregated sum of utility gain from channel access and the cost that is incurred for that successful access. The set of preferences is set of access priorities for service differentiated class of users. The corresponding access priorities are mapped to utility function in conjunction with ASCs resource and changed with respect to the given system load. For utility function, joint strategy where no player can increase his utility by unilaterally deviating, Nash Equilibrium, is obtained. This suggests access probability which each differentiated service class will receive. The response of the network for each access service class for those equilibrium access probabilities is obtained in terms of success probability and delay.

The organization of the rest of the content of this paper is as stated below. Random access channel model is presented in section two. Analysis of that random access Game is presented in section three. Simulation results are presented in fourth section and the paper is wrapped up with the conclusion at the end.

II. Random Access Channel Model

We consider OFDMA based random access strategy in this paper. The uplink OFDMA FDD MAC frame is considered to be consisted of traffic channels and N number of random access subchannels, RA-SCs. To increase the RA capacity and to reduce the collision risk in the system where access request is high, PN code is used. In the physical layer, PN-code is multiplied by subcarriers allocated in each RA-SC as shown in Fig 1.

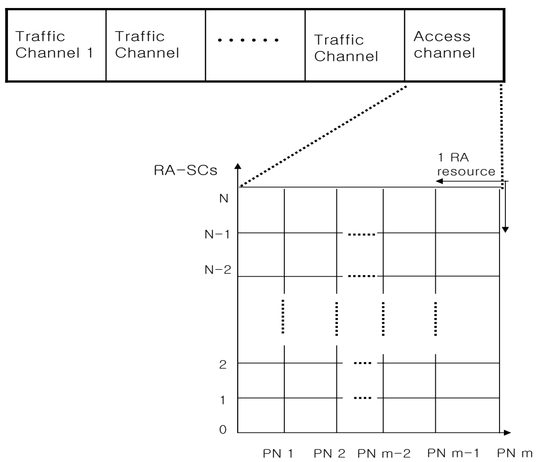

Fig. 1. Uplink MAC frame structure of OFDMA FDD based system

The use of PN codes makes it possible that more UEs attend simultaneously the RA procedure, because there is no collision in case one UE selects different code although the UE chooses the same RA-SC. In the physical layer, the PN code is multiplied by subcarriers allocated in each RA-SC with the same length as it has. Therefore, the expanded number of RA resources available will be the product of the number of RA-SC and the number of PN-codes, N * m . Whenever any UE want to attend RA procedure it will select randomly one RA-SC of the corresponding ASC and one PN-code considering the information about the available RA-SC and PN-Codes broadcasted by BS in broadcast channel of downlink and attempts the access. If the UE receives Acknowledgement (ACK) message, the random access procedure is successful and if it receives Negative acknowledgement (NACK), the random access procedure is initialized.

III. Analysis of Random Access Game

Cooperative game required additional signalization or agreements between the decision makers and solution based on them might be more difficult to realize and might occupy some proportion of the available RF spectrum which we want to save more. So we modeled the system as non cooperative game with the assumption that move is sequential and cooperation is only self-enforced. In this non cooperative approach, number of decision makers are assumed to be rational that means they want to maximize payoff, aggregated sum of utility gain from channel access and the cost that is incurred for that successful access.

According to the service the UEs are looking for, We differentiate UEs in two groups, ASC0 and ASC1, with the consideration that ASC0 users are more critical in the timing constraints having less tolerable jitter than ASC1 users. It can be thought that ASC0 users are users looking for emergency services and ASC1 users are like some Best Effort traffic. In this paper it is also assumed that system is loaded with 30% of ASC0 users and 70% of the ASC1 users.

We define a game $G = (J, ap_{\text{asci}}, U_{\text{asci}})$ with $J \in (1, 2, \cdots, J)$ is the number of UEs in ASC0 and ASC1 looking for access, $ap_{\text{asci}} \in [0, 1]$ is the access probability and U_{asci} is the payoff for the ith ASC UE. If any user of any ASC is looking for access, two possibilities can occur. Either it will gain access or access is denied. For the former case payoff is simply 1 and for later case payoff is zero, if the strategy space is pure. For successful access, some positive value is deducted as cost that is incurred for that successful access. Every user in each service class is looking to increase his payoff every time since they are assumed to be rational. So this attitude may lead to the situation that always every user sticks to the highest value it can attain. So to control this, C is assigned so that each user doesn't look for the highest value of the strategy, i.e. access probability greater than the actual requirement. Mathematically payoff function is characterized as follows

$$U_{asc0} = ap_{asc0}(1 - ap_{asc1})(1 - C) - C \prod_{i=0}^{i=1} ap_{asci} \quad (1)$$

$$U_{asc1} = ap_{asc1}(1 - ap_{asc0})(1 - C) - C \prod_{i=0}^{i=1} ap_{asci} \quad (2)$$

The matrix for the ASC0's UEs strategy is 1*n row vector where n is any arbitrary number up to which we want to divide the pure strategy, [0,1], and the matrix for ASC1's strategy is n*1. So if we consider the mixed strategy for each ASC with regard to other's strategy we can get n*n matrix for each case. For example for ASC_i we can specify that matrix as AP_i. Every element of AP_0 are ap_{asco}, but one at a time.

$$AP_i = \begin{bmatrix} 1/n^2 & 2/n^2 & \dots & n \\ (n+1)/n^2 & (n+2)/n^2 & \dots & 2n/n^2 \\ \vdots & \vdots & \ddots & \vdots \\ ((n^2-n)+1)/n^2 & ((n^2-n)+2)/n^2 & \dots & 1 \end{bmatrix}$$

And as stated above the strategy for the ASC1 is simply the complement of above matrix. These values of the access probabilities are used in the equation 1 and 2 to get the payoff matrix. The Nash Equilibrium that occurs in that matrix is the equilibrium payoff and the corresponding access probabilities for the equilibrium payoff are assigned as the access probability for respective ASC. Nash Equilibrium is the consistent prediction of the outcome of the game. In this equilibrium no players has incentive to unilaterally deviate the strategy.

In general uniqueness and existence of Nash Equilibrium is not guaranteed; neither is convergence to equilibrium when one exists. But it is already proved that for mixed strategy at least one Nash Equilibrium exists [7]. The proof for the existence for the Nash Equilibrium is presented in [7] using fixed point theorem and Kakutani theorem. The random access game considered in this paper is mixed strategy game with continuous payoff profile. So in our game Nash Equilibrium is always to exist.

In the pool of J UEs attempting random access, probability that only j UEs succeed in accessing and other $k = J - j$ UEs fail [8] is given by

$$P_{j,k} = \binom{J}{j} P_{\text{success}}(j|J) P_{\text{collision}}(k|j,J) \tag{3}$$

Throughout our calculation we assumed that channel is perfect, i.e. packet loss is only by collision. On the basis of (3) we derive the success probability and delay performance of each ASC. Let us take the access probability of each ASC as $ap_{\text{asc}i}$ = access probability of ASC_i Where $0 \leq ap_{\text{asc}i} \leq 1$. When total J UEs of two ASCs are attempting the access, we assume that the number of UEs of each ASC is given by

$$J_{\text{ASC}0} = \lfloor (loadingfactor) * J \rfloor \tag{4}$$

$$J_{\text{ASC}1} = J - J_{\text{ASC}0} \tag{5}$$

Let us define (J_0, J_1) as a vector which consists of the number of succeeded attempts of UEs, where $0 \leq J_0 \leq J_{ASC0}$ and $0 \leq J_1 \leq J_{ASC1}$.Then the probability that the event (J_0, J_1) occurs is given by

$$P(J_0, J_1) = \prod_{i=0}^{1} \binom{J_{\text{ASC}i}}{J_i} ap_{\text{asc}i}^{J_i} (1 - ap_{\text{asc}i})^{J_{\text{ASC}i} - J_i} \tag{6}$$

The probability that only J_0 among J_{ASC0} UEs of ASC0 succeed in the access attempt is derived to be

$$P_{success,ASCi}(j|J_0) = \sum_{J_1=1}^{J_{ASC1}} P_{\text{s},ASCi}(j|J_0) P(J_0, J_1) \tag{7}$$

The average success probability of accessing number of UEs of ASC0 to the AP without collision, average success probability of ASC0 is given by

$$P_{\text{success,ASC0}} = \frac{\sum_{j=1}^{J_{\text{ASC0}}} j \sum_{J_0=1}^{J_{\text{ASC0}}} P_{\text{success, ASC0}}(j|J_0)}{J_{\text{ASC0}}} \tag{8}$$

Similarly average success probability of ASC1 can be derived. The time delay is characterized as the time needed for the successful connection. It is represented as

$$D_{\text{ASC}i} = T_{\text{frame}} \times \sum_{x=1}^{\infty} x (1 - P_{\text{success,ASC}i})^{x-1} P_{\text{success,ASC}i} = \frac{T_{\text{frame}}}{P_{\text{success,ASC}i}} \tag{9}$$

where T_{frame} is the duration of one MAC frame.

From equation 8 we can find the success probability for the ASC0 user and similarly we can obtain for the ASC1's user as well. Likewise equation 10 provides information about the delay.

IV. Simulation Results

The simulation is carried out in integrated environment of MATLAB and GAMBIT. The parameters chosen for the simulation are summarized in TABLE 1.

TABLE I
SIMULATION PARAMETER

Parameters	Value
J_{max}	30
ASC0 Loading	30%
ASC1 Loading	70%
C	0.050
T_{frame}	1

The simulation is carried for the 30 number of mobile terminals, $J_{\max}$, with the assumption that 30 percentile loading in service group ASC0 and remaining 70 percentile in another service group, ASC1. The number of elements in access probability matrix for each ASC is considered to be 16, i.e 4*4 matrix. The frame length is considered to be 1 s. The value of the constant C in payoff equation for this particular case is taken as 0.050. The effect of increase of C in the payoff function is shown in Fig.2. It is noteworthy that the payoff

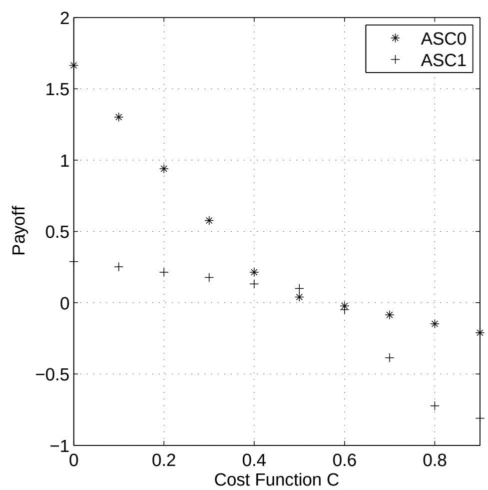

Fig. 2. Payoff with the change in the cost function value

decreases as the value of C increases. Hence it is desirable to reduce C as much as possible. Since there is change in the payoff function value because of change in C, the equilibrium resulted from that payoff values shift to some other values as shown in Fig.3.

The Nash equilibrium for the generated payoff for this particular case when 30 users are present in the system is found to be 1.4828 and 0.273 for ASC0 and ASC1 respectively. For this equilibrium, the corresponding access probability is found

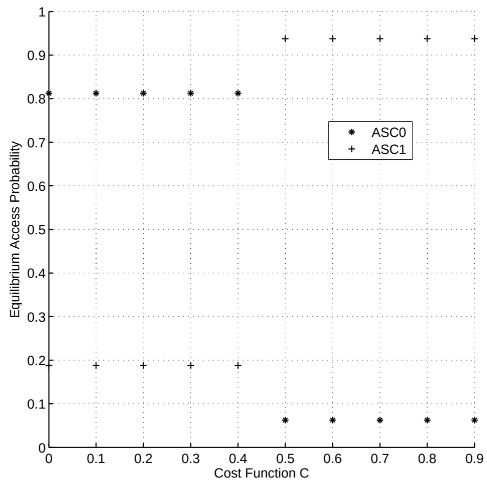

Fig. 3. Change in equilibrium with the change in C

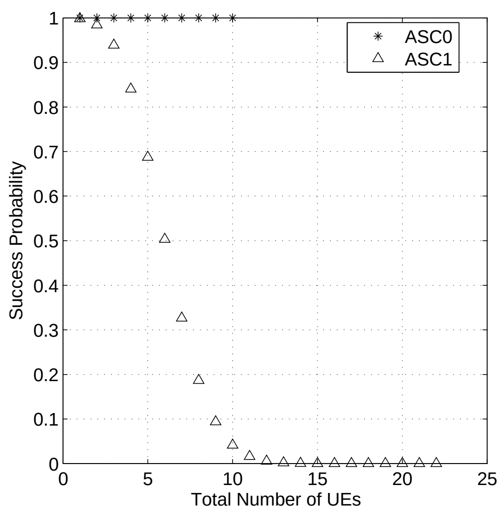

Fig. 4. Individual success probability for ASCs

to be 0.8125 and 0.1875. This equilibrium access probability is obtained when the value of C is 0.05. If the cost function is maintained well below 0.45, the equilibrium will not shift but if the C exceeds 0.45 the equilibrium alters to some undesirable value which yields low access probability for high priority ASC, ASC0. So C should be maintained below 0.45 for the proper performance of SDNcRA.

Performance of the SDNcRA is monitored in terms of success probability and the delay encountered. The success probability and the delay for this set of access probabilities are plotted in Fig.4 and Fig.5 respectively. The provision we made for the emergency class UEs, ASC0, is to guarantee them the constant reliable success probability within very less delay. From Fig. 4 and Fig. 5 well maintained success probability and delay for ASC0 UEs can be observed. Success probability for all ASC0 UEs are almost one. Success probability of less priority class, ASC1 UES, however decrease with increase in the number of UEs and eventually falls to zero yielding some UEs deprive of getting successful access. As the success

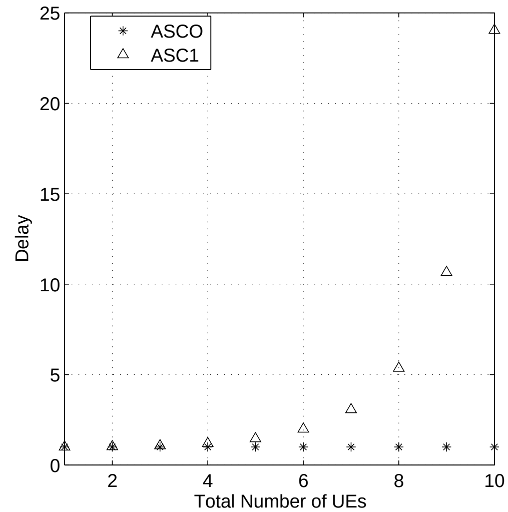

Fig. 5. Delay encountered for ASC0 and ASC1 UEs

probability of ASC1 UEs gradually drops, it is obvious that delay will be elongated as presented in Fig. 5.

V. Conclusion

In this paper the random access scheme for the OFDMA based systems with the service differentiation is modeled as a Random access non cooperative Game and performance is measured in terms of the success probability gained and the delay encountered. Since the game is noncooperative, ASCO users donot care about another service group and behaves greedily. Due to this greediness its success probability sticks on high value with comparatively very less delay than other low priority service group,ASC1. The price to be paid, however, is the reduction in success probability for another lower priority service group. In terms of both success probability and delay, higher priority ASC0's UEs performance is always more. So it can be said that always the performance of this SDNcRA scheme guarantees more success probability and less delay for higher priority ASC users.

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