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A Multi-Class on Time Call Admission Control for Wireless Broadband Cognitive Networks

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Abstract: Wireless Broadband Cognitive Networks (WBCN) are new trend in networking for better utilization of spectrum and resources. However, in multiservice WBCN networks, Call Admission Control (CAC) is a challenging point to effectively control different traffic loads and prevent the network from being overloaded and thus provide promised QoS. In this Study, we propose a CAC framework and formulate it as an optimization problem, where the demands of both WBCN service providers and cognitive subscribers are taken into account. To solve the optimization problem, we developed an opportunistic multivariate CAC algorithm based on a joint optimization of utility, weighted fairness and greedy revenue algorithms. Extensive simulation results show that, the proposed call admission control framework can meet the expectations of both service providers and subscribers in wireless broadband cognitive networks.

Keywords: Fairness, opportunistic Call Admission Control (CAC), Quality of Service (QoS), revenue, utility, Wirless Broadband Cognitive Networks (WBCN)

INTRODUCTION

Over the last decade, an explosive growth of wireless Internet users and broadband applications has been witnessed. Currently, most broadband Internet access methods are based on wired communications like T1, DSL, and cable-modem. But in many regions in the world it's difficult to deploy wired infrastructures due to geographical or economic reasons. Wireless Broadband networks like IEEE802.16, IEEE802.22 and LTE are standards of wireless technology that advocate solutions to broadband wireless Internet access (Andrews *et al*., 2007; De Pellegrini *et al*., 2007). Most of these standards support variety of services that can be categorized as constant rate service, Real-Time service, Non-Real-Time service and Best Effort service. Another challenge that faces wireless broadband networks is the scarce of resources (spectrum, bandwidth, etc.). To handle heterogeneous traffic load in wireless broadband networks, it is important to find an opportunistic, resource management mechanism that can efficiently allocate resources to different subscribers and applications. These types of networks we will call wireless broadband cognitive networks. With an appropriate scheduling and Call Admission Control (CAC), the system can efficiently provide promised QoS to all types of services.

The objective of this paper is to provide a new CAC algorithm that is capable of achieving high revenue to service providers while maintaining fairness among the different application classes of the users. The proposed CAC algorithm is modeled as an opportunistic optimization problem with a certain objective function. This objective function is chosen to maximize the revenue of service providers while maintaining the satisfaction of cognitive subscribers. With respect to CAC optimization, previous studies focused on the constrained optimal revenue strategies (Rong *et al*., 2007, 2008) which have the same fairness constraint for each traffic class. In this paper we will propose a utility- and weighted fairness-constrained greedy revenue strategy as a modification to increase the benefit of service providers while maintaining the satisfaction of subscribers.

DEPLOYMENT AND FORMULATION OF CAC IN WBCN NETWORKS

WBCN networks: WBCN networks aim at providing the required QoS to subscribers while persevering and efficiently utilizing the networks' scarce resources. In its general form, WBCN consists of a cognitive base station and N cognitive subscribers as illustrated in Fig. 1.

Each subscriber is associated to a CAC module in the base station connected to it. In that CAC module, all the QoS requirements are translated to allocating and managing resources to guarantee these requirements and

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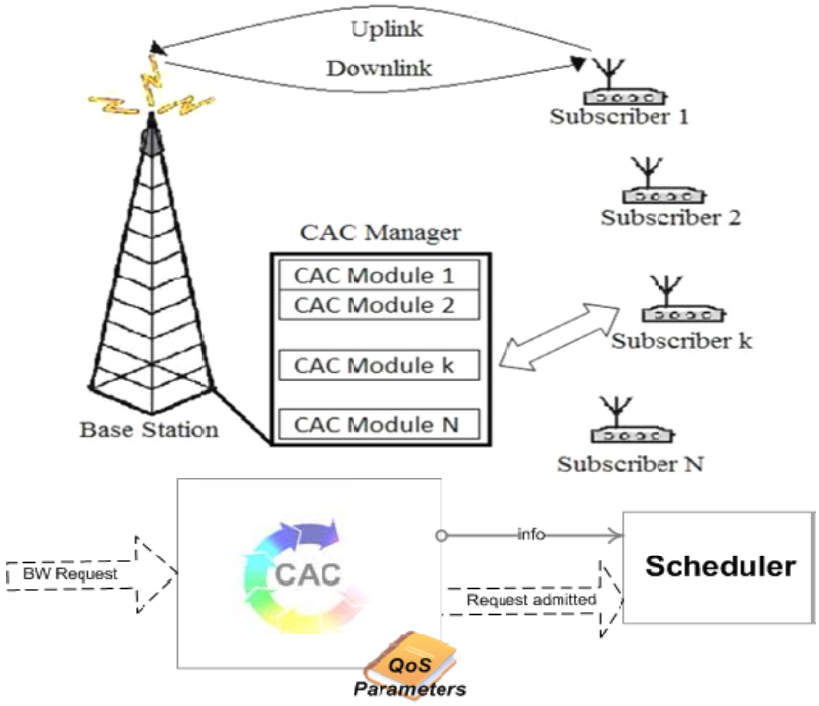

Fig. 1: CAC admission control in WBN

this is administered through the scheduler component in the base station.

WBCN standards (IEEE 802.16, 2004) support multiple physical-layer profiles for different propagation purposes. For example, IEEE 802.16 supports a single-carrier-based physical layer, an OFDM-based physical layer, and an OFDMA-based physical layer. In general, Single carrier approach is designed for Line of Sight (LOS) propagation (Wang *et al*., 2007; Song and Li, 2005a, b). The OFDM approach is used in short distance applications and employs Fast Fourier Transform (FFT) of size 256. The OFDMA is proposed as a multiple access techniques with a larger FFT space (2,048 and 4,096 subcarriers), which is further divided into sub channels. These streams may employ different modulation, coding and amplitude levels to address subscribers with different channel characteristics. WBCN standards also support two types of duplexing. The first is the Time Division Duplexing (TDD) and the second is Frequency Division Duplexing (FDD). FDD is usually deployed in symmetric communication scenarios, where the applications require equal bandwidth on the Uplink (UL) and the Downlink (DL). In the contrary TDD has flexibility in choosing uplink-to-downlink data rate ratios. For this reason, TDD has a much higher spectrum utility efficiency than FDD in the asymmetric communication scenarios. Since WBCN is intended to provide the wireless Internet access as assumed in this paper, which is a typical asymmetric communication scenario. Then, we will study WBCN OFDMA with TDD duplex.

CAC deployment: In WBCN running different types of services, implementing the CAC mechanism is very essential to guarantee the QoS requirements of different services by preventing the system from being overloaded (Rong *et al*., 2008). CAC also gives WBCN the possibility to assign different priorities to traffic classes by varying their blocking probabilities. Before making a decision, CAC should confirm that if the new incoming call is accepted, the QoS of current connections is not axed, and the system can assure QoS requirements of the new call (Yang and Lu, 2006). The CAC manager proposed consists of N CAC modules; each module is assigned to handle one subscriber traffic load. As illustrated in Fig. 1, the CAC manager is placed at the WBCN base station in order to compute the uplink/downlink bandwidth capacity of subscriber k from the physical layer of the base station.

For subscriber *k* requesting a service from his WBCN, he first sends a connection request to the CAC manager with the bandwidth requirements for upstream and downstream, b^U and b^D respectively. Second, an admission control check is performed on uplink and downlink simultaneously by the CAC module assigned to this subscriber and finally a decision is made on whether to accept this new connection or block it as the required QoS parameters cannot be satisfied.

Optimization problem formulation: In order to separate the admission check on uplink and downlink, CAC module exploits two distinct policies for uplink and downlink, and the connection request is accepted only if passing the admission check for the two policies. Since WBCN considered in this paper is an asymmetric communication scenario, the upstream traffic is assumed to be a fraction of the downstream traffic. In this case downlink admission control has the dominant role than uplink admission control; that's why we focus on the downlink CAC optimization only. As for the uplink admission control, we assume that there are always enough resources to serve the uplink arriving connection requests.

Call admission control policy is the process of regulating traffic volume in WBCN and ensuring certain level of quality (Sarangan *et al*., 2005). Most CAC policies regulate the total utilized bandwidth, the total number of calls, or the total number of packets or data bits/subcarriers passing a specific point per unit time (Yang and Lu, 2006). If a defined limit is reached or exceeded, a new call may be prohibited from entering the network until at least one current call terminates. Based on this definition of CAC policy, we can formulate the resource allocation problem in WBCN as an opportunistic policy that takes the number of subscribers, number of classes of traffic and bandwidth available and makes a decision on how to allocate resources efficiently. Thus For a given subscriber who supports *M* classes of traffic sharing *B* units of downlink bandwidth resource, we can state that for a given class "*i*" traffic:

- Call requests arrive following Poisson distribution with average rate λ_i
- The connection service time is exponentially distributed with $1/\mu_i$ sec
- The bandwidth requirement of a connection is fixed to b_i
- The revenue rate of a connection is rer_i

The revenue rate of each type of service is defined as the revenue generated by a bandwidth unit during a time unit. Let rer^{crS}, rer^{rtS}, rer^{nrtS} and rer^{beS} be the revenue rates of constant rate Service, real-time Service, non-real-time Service, and best effort Service,

We can define the bandwidth requirements of M classes as a vector $\vec{b} = (b_1, b_2, \ldots, b_M)$ and the number of classes connections in the system as another vector $\vec{n} = (n_1, n_2, \ldots, n_M)$. We define Ω_{CA} as the set of all possible admitted calls (*CA* stands for Call Admittance), which means that an incoming connection will be accepted if sufficient bandwidth resources are available in the downlink of a subscriber. It can be expressed as $\Omega_{CA} = \{\vec{n} | \vec{n} \cdot \vec{b} \leq B\}$.

A CAC policy, denoted by Ω, will be a subset of Ω_{CA} such that a connection request will be accepted if and only if the number of classes connections in the system remain in Ω after the connection being accepted.

PROPOSED WEIGHTED FAIR CAC OPTIMIZATION

Some of previous work investigating CAC strategies addressed schemes that bring high revenue to service providers only (Ross and Tsang, 1989; Beard and Frost, 2001). While others developed constrained CAC optimization strategies that can give a good tradeoff between expectations of service providers and requirements of subscribers (Rong *et al*., 2007, 2008).

The authors in Gunawardena and Zhuang (2011) proposed an opportunistic scheduling for users with Quality of Service (QoS) requirements. Their contribution was based on cumulative distributed function that makes tradeoff between efficiency and fairness in full-load scenario. While authors in Wang *et al*. (2011) investigated homogeneous voice traffic in a single channel Cognitive Radio Network (CRN) and proposed two Call Admission Control (CAC) algorithms for a non-fully connected network with slot-ALOHA channel access.

In Tsai *et al*. (2010), a CAC scheme is proposed which improves the performance of Video on Demand (VoD) by maintaining User Stream Buffers (USB) with different states to dynamically improve the performance based on those states.

In this study we propose weighted constrained optimal revenue strategies in order to maximize revenue of service providers compared with existing strategies in the literature, while maintaining the satisfaction of cognitive user subscribers.

CAC optimization strategy: The scheduler shown in Fig. 1, implements an algorithm that separates the overall bandwidth resource B into M non-overlapped bands/subcarriers, denoted by B^1_P, B^2_P,…, B^M_P. So a policy "P" can be decomposed into M independent sub-policies, and the ith sub-policy takes care of ith traffic class. The ith sub-policy can be modeled as an M/M/N/N queuing system, in which the number of servers is $s_i = B^i_P/b_i$. The long term average revenue obtained from i^{th} class traffic can be modeled as the revenue generated by a bandwidth unit during a time unit multiplied by number of accepted calls for the ith traffic. Thus the long term average revenue is given by:

$$R_i(P) = rer_i b_i \rho_i (1 - Pb_i) \quad (1)$$

where, Pb_i stands for the blocking probability of ith class traffic and $\rho_i = \lambda_i/\mu_i$, the overall long-term average revenue of the P policy is defined as $R(P) =$

$\sum_{i=1}^{M} R_i(P)$. Ω^* is used to denote the optimal revenue policy.

The subscribers' demands are met by satisfying the following requirements.

Utility requirements: Subscribers prefer the CAC policy that achieves maximal utility such as the maximum accessible bandwidth. This demand leads to the optimal utility CAC policy, denoted as Ω^+. Let SB denotes the statistical bandwidth that the subscriber can achieve after a CAC policy takes effect. The statistical bandwidth of ith class traffic is modeled as the average utilized bandwidth and is given by:

$$SB_i(P) = b_i \rho_i (1 - Pb_i) \quad (2)$$

Correspondingly, the overall statistical bandwidth and the utility of the P policy can be calculated as $SB(P) = \sum_{i=1}^{M} SB_i(P)$ and $U(P) = (1/B)\sum_{i=1}^{M} SB_i(P)$ respectively.

Fairness requirements: When deploying optimal revenue or optimal utility strategy, some classes of traffic may be severely underserved while others can easily achieve required bandwidth and more. Therefore, the fairness among different traffic classes becomes another major issue that subscribers concern about. The Absolute Fairness (AF) is achieved in a stressful network, by giving each traffic class the same blocking probability, whereas the utility of the CAC policy is maximized (Rong *et al*., 2008). Then, the blocking probability of each class is given by:

$$pb^{AF} = 1 - \frac{U(\Omega^{AF})B}{\sum_{i=1}^{M} b_i \rho_i} \geq pb_{lb}^{AF} \quad (3)$$

where, $pb_{lb}^{AF} = 1 - (B/\sum_{i=1}^{M} b_i \rho_i)$ is the lower bound of pb^{AF}.

The fairness constraint requires that the highest blocking probability among all traffic classes is lower than the threshold PB^{th}, where ($pb^{AF}_{lb} < PB^{th} < 1$). Consequently, normalized blocking probability threshold is defined as pb^{th}, where ($0 < pb^{th} < 1$). The relationship between pb^{th} and PB^{th} is given by:

$$PB^{th} = (1 - pb_{lb}^{AF})pb^{th} + pb_{lb}^{AF} \quad (4)$$

Ω^{F*} is used to represent the fairness-constrained optimal revenue policy.

The utility constraint requires that the utility of a CAC policy must be higher than a threshold U^{th}. If the fairness constraint is already known, then U^{th} must satisfy $0 < U^{th} < U(\Omega^{F+})$, where $U(\Omega^{F+})$ denotes the utility of the fairness-constrained optimal utility strategy. Consequently, the normalized utility threshold is defined as u^{th}, which satisfies $U^{th} = u^{th} U(\Omega^{F+})$, where ($0 < u^{th} < 1$). Ω^{UF*} is used to represent the utility and fairness constrained optimal revenue policy.

We can define the "P" policy of "optimal revenue", "optimal utility" ,"fairness-constrained optimal revenue" and "utility- and fairness-constrained optimal revenue" as P^*, P^+, P^{F*}, and P^{UF*} respectively, which can be viewed as the approximate solution for Ω^*, Ω^+, Ω^{F*}, and Ω^{UF*}.

Weighted blocking probability threshold: To achieve high total revenue from the system; the revenue of each traffic class given by (1) must be maximized. From the equation; the long term average revenue of class-i increases with rer_i , b_i, , λ_i, and $1/\mu_i$ and decreases with Pb_i. Therefore in this paper we will maximize the revenue by minimizing the blocking probability of class-i at which rer_i is maximum. In other words, the traffic class with higher revenue rate rer will have a lower blocking probability threshold PB^{th}, so it will have a lower blocking probability Pb_i. Thus, blocking probability threshold for different classes should not be assumed constant, instead it's dynamic according to different parameters such as revenue.

According to Erlang B formula (Altman *et al*., 2001), the blocking probability of ith class traffic is:

$$Pb_i(P) = B(s_i, \rho_i) \quad (5)$$

where, Erlang *B* formula can be calculated as:

$$B(s_i + 1, \rho_i) = \frac{\rho_i B(s_i, \rho_i)}{s_i + 1 + \rho_i B(s_i, \rho_i)} \quad (6)$$

$$B(0, \rho_i) = 1$$

In order to assign different PB^{th} to different traffic classes we will recalculate the relation between PB^{th} and pb^{th} given by (4), while taking the value of the revenue rate into consideration.

Since $rer^{crS} > rer^{rtS} > rer^{nrtS} > rer^{beS}$, thus we can assume that $rer^{crS} > x\ rer^{beS}$ and we will define (e_i) as the weighting factor for the blocking probability threshold assigned to class "i" traffic depending on its revenue rate, e_i is calculated by:

$$e_i = 1 - \frac{rer_i}{rer^{crS} + rer^{beS}}$$

$$e_i = 1 - \frac{rer_i}{(1 + x)rer^{beS}} \quad (7)$$

where, $(\frac{1}{1+x} < e_i < \frac{x}{1+x})$. Then we will define the normalized weighted blocking probability threshold assigned to class i traffic $pb^{th}_r(i)$:

$$pb_r^{th}(i) = e_i\, pb^{th} \quad (8)$$

Since ($0<pb^{th}<1$), then the valid range for $pb^{th}_r(i)$ is $(0 < pb^{th}_r(i) < \frac{x}{1+x})$.

From the above discussion, the weighted blocking probability threshold assigned to class "*i*" traffic is given by:

$$PB_i^{th} = \frac{1+x}{x} e_i\, pb^{th}\left(1 - pb_{lb}^{AF}\right) + pb_{lb}^{AF} \quad (9)$$

where, ($pb^{AF}_{lb}<PB^{th}_i<1$) According to (9) the traffic class with higher revenue rate will have a lower blocking probability threshold, in order to maximize the overall revenue of the network. In the next section we will develop a heuristic algorithm for utility- and weighted fairness-greedy revenue policy Ω^{UWF*} and weighted fairness-constrained greedy revenue policy Ω^{WF*}.

Utility- and weighted fairness-constrained greedy revenue algorithm: Utility- and weighted fairness-constrained greedy revenue algorithm to approximate P^{UWF*} is presented in the below mentioned pseudo-code, which contains three phases. The first phase calculates the weighted blocking probability threshold for each traffic class. As shown in line 5 of the code, the weighting ratio x is calculated and from it the weighting factor is calculated as in line 8 and finally the blocking probability of each class is found in line 8. The second phase allocates each traffic class a certain amount of bandwidth resource from the total free bandwidth, so that the fairness constraint calculated in the first phase is guaranteed. The third phase employs the utility constrained optimal revenue strategy to allocate the remaining bandwidth. In this phase as long as there is free bandwidth and the utility constrained is satisfied as shown in line 28 and 30 of the code, bandwidth will be allocated to the traffic that will maximize the revenue.

The revenue rate and the utility of the jth server achieved by accepting class i connection are:

$$r_S^i(j,\rho_i) = rer_i\rho_i[B(j-1,\rho_i) - B(j,\rho_i)] \quad (10)$$

$$u_S^i(j,\rho_i) = \rho_i[B(j-1,\rho_i) - B(j,\rho_i)] \quad (11)$$

Utility and weighted fairness constrained greedy revenue algorithm:

- Input u^{th}, pb^{th}
- Capture the traffic load profile in the kth subscriber's local network
- Collect the CSI from the physical layer, calculate B_k^D for DL CAC and let $B = B_k^D$
- /* PHASE 1: Calculate PB_i^{th} for each traffic class*/
- $x = \frac{rer^{UGS}}{rer^{BE}}$; $pb_{lb}^{AF} = 1 - (B/\sum_{i=1}^{M} b_i\lambda_i/\mu_i)$
- **for** $i = 1$ to M **do**
- $e_i = \frac{rer_i}{(1+x)rer^{BE}}$
  $PB_i^{th} = \frac{1+x}{x}(1-e_i)pb^{th}(1-pb_{lb}^{AF}) + pb_{lb}^{AF}$
- **end for**
- /* PHASE 2: Allocate bandwidth resources to satisfy the fairness constraint */
- $B_{free} = B$
- **for** $i = 1$ to M **do**
- $B_{CP}^i = 0;\ s_i = 0;\ B(s_i,\rho_i) = 0$
  $Pb_i = B(s_i,\rho_i);\ SB_i = 0$
- **end for**
- **for** $i = 1$ to M **do**
- **while** $Pb_i > PB_i^{th}$ **do**
- $B_{free} = B_{free} - b_i; B_{CP}^i = B_{CP}^i + b_i$
  $B(s_i+1,\rho_i) = \rho_i B(s_i,\rho_i)/(s_i+1+\rho_i B(s_i,\rho_i))$;
  $Pb_i = B(s_i+1,\rho_i); SB_i = SB_i + b_i\rho_i[B(s_i,\rho_i) - B(s_i+1,\rho_i)]$
  $s_i = s_i + 1$
- **end while**
- **end for**
- /*Calculate the value of Uth after fulfilling the fairness constraint */
- $U^{th} = \frac{u^{th}B - \sum_{i=1}^{M} SB_i}{B_{free}}$
- /* PHASE 3: Allocate the remaining free bandwidth resources according to utility constrained optimal revenue strategy. */
- *I=M+1*
- **for** $i = 1$ to M **do**
- $B(s_i+1,\rho_i) = \rho_i B(s_i,\rho_i)/(s_i+1+\rho_i B(s_i,\rho_i))$
  $r_S^i = rer_i\rho_i[B(s_i-1,\rho_i) - B(s_i,\rho_i)]$
  $u_S^i = \rho_i[B(s_i-1,\rho_i) - B(s_i,\rho_i)]$
- **end for**
- **while** $I > 0$ **do**
- $Set_U = \{i | i \text{ satisfies } \frac{U_S^i b_i + \sum_{i=1}^{M} SB_i}{(B - B_{free} + b_i)} > U^{th}\}$ /* the set of traffic classes qualified for utility constraint. */
- $I = \arg max_{i \in Set_U}\{r_S^i\}$
- **if** $b_I \le B_{free}$ **then**
- $B_{free} = B_{free} - b_I; B_{CP}^I = B_{CP}^I + b_I$
  $SB_I = SB_I + U_S^I b_I; s_I = s_I + 1$
  $B(s_I+1,\rho_I) = \rho_I B(s_I,\rho_I)/(s_I+1+\rho_I B(s_I,\rho_I))$
  $r_S^I = rer_I\rho_I[B(s_I-1,\rho_I) - B(s_I,\rho_I)]$
  $u_S^I = \rho_I[B(s_I-1,\rho_I) - B(s_I,\rho_I)]$
- **else**
- /* Capacity limit begins to take effect. */
- $r_S^I = 0;\ U_S^I = 0$
- $U^{th} = 0$; /* change to use pure greedy revenue algorithm. */
- **if** $\sum_{i=1}^{M} r_S^i = 0$ **then**
  $I = -1$; /* the algorithm is completed. */
- **end if**

Table 1: Traffic load configuration

	Service type	BW req.	Arrival rate (calls/h)	Service time (min./call)
Class 1	crS	64 Kbps	550	25
Class 2	crS	2 Mbps	7	60
Class 3	rtS	500 Kbps	64	25
Class 4	rtS	3 Mbps	6	90
Class 5	nrtS	200 Kbps	100	60
Class 6	nrtS	1 Mbps	50	25
Class 7	beS	20 Kbps	0→800	30

- **end if**
- **end while**
- Return $\{B_{CP}^{i}, 1 \le i \le M\}$ as the final bandwidth allocation decision

Notice that, if we let $u^{th} = 0$, the algorithm degenerates into the weighted fairness-constrained greedy revenue algorithm to approximate P^{WF*}.

SIMULATION RESULTS

The performance of the proposed WBCN CAC optimization policies is extensively simulated and evaluated. We first compare the capability of different CAC policies with respect to three metrics (revenue, utility and fairness) then we show the overall benefit of our proposed WBCN CAC scheme in such networks, compared to the policies previously discussed in the literature. In particular we studied the performance of the proposed policies Ω^{WF*}. And Ω^{UWF*} and compare them with Ω^{*}, Ω^{+}, Ω^{F*} and Ω^{UF*} from Rong *et al.* (2008), then we calculated the Figure of Merit (FM) of revenue and utility for Ω^{WF*} and Ω^{UWF*}, with respect to Ω^{F*} and Ω^{UF*}, respectively.

In this simulation scenario, the total downlink bandwidth capacity B is set to be 75 Mbps, the revenue rate is priced as $rer^{crS} = 5$, $rer^{rtS} = 2$, $rer^{nrtS} = 1$, $rer^{beS} = 0.5$, and the downlink traffic load is configured as in Table 1. Moreover, for the utility constraint, we set $u^{th} = 90\%$; for fairness constraint, we set $pb^{th} = 60\%$. In Fig. 2 and 3, revenue and utility are normalized by $R(\Omega^{*})$ and $U(\Omega^{+})$ respectively. While in Fig. 4, the highest blocking probability keeps original value.

From Fig. 2 and 3 our proposed resource allocation policies Ω^{WF*} and Ω^{UWF*} give better revenue compared with un-weighted policies; Ω^{F*} and Ω^{UF*}, while they almost perform the same in terms of utility. From Fig. 2, we notice that Ω^{WF*}. Outperforms Ω^{F*} as the first maximizes revenue proportional to the importance of the traffic and not maximizing with same fairness as in the latter. We also notice that Ω^{UWF*} approaches Ω^{F*}, with high traffic arrival rate thus achieving the revenue and satisfying user requirements. This can also be seen clearly in Fig. 3.

An advantage of our model is seen in Fig. 4 where the highest blocking probability is not affected by the proposed weighing of traffic classes.

Figure 5 and 6 give the Figure of Merit (FM) of revenue and utility respectively for weighted policies Ω^{WF*} and Ω^{UWF*} compared to Ω^{F*} and Ω^{UF*}.
The figure of merit for revenue is given by:

$$\text{Revenue FM}(\Omega^{WF*}) = \frac{R(\Omega^{WF*}) - R(\Omega^{F*})}{R(\Omega^{F*})} * 100$$

$$\text{Revenue FM}(\Omega^{UWF*}) = \frac{R(\Omega^{UWF*}) - R(\Omega U^{UF*})}{R(\Omega^{UF*})} * 100$$

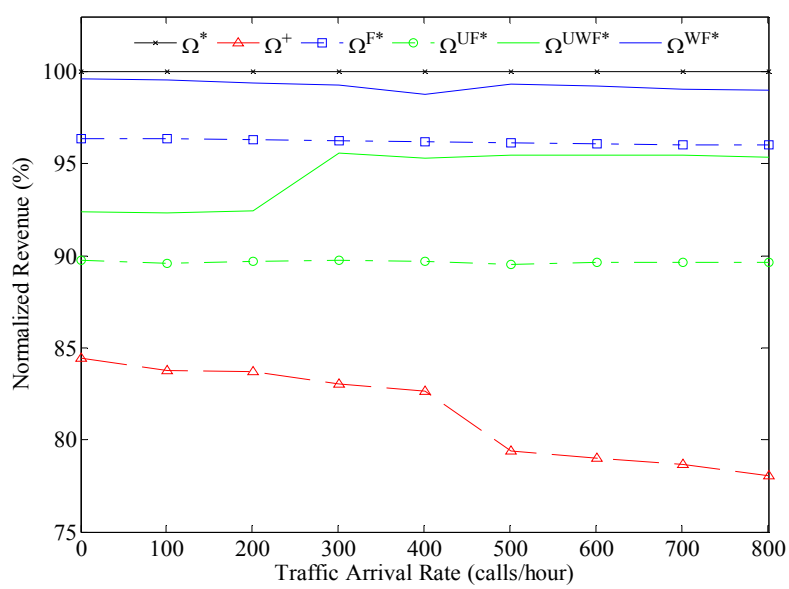

Fig. 2: Revenue of different CAC optimization policies while varying the arrival rate of class-7 traffic

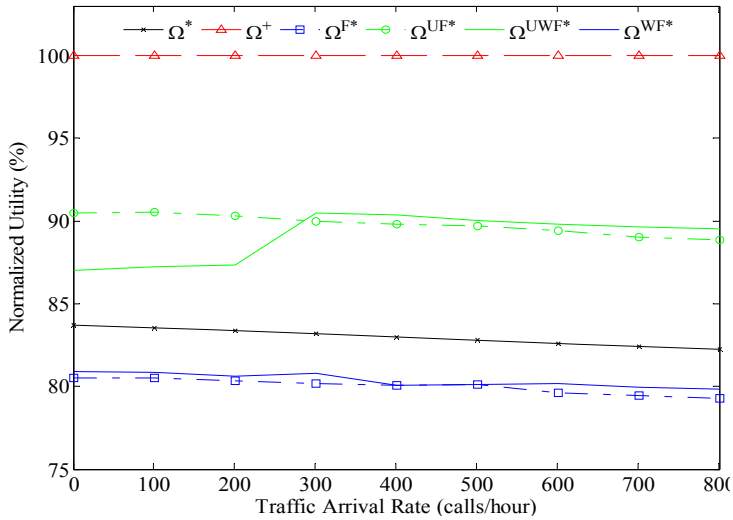

Fig. 3: Utility of different CAC optimization policies while varying the arrival rate of class-7 traffic

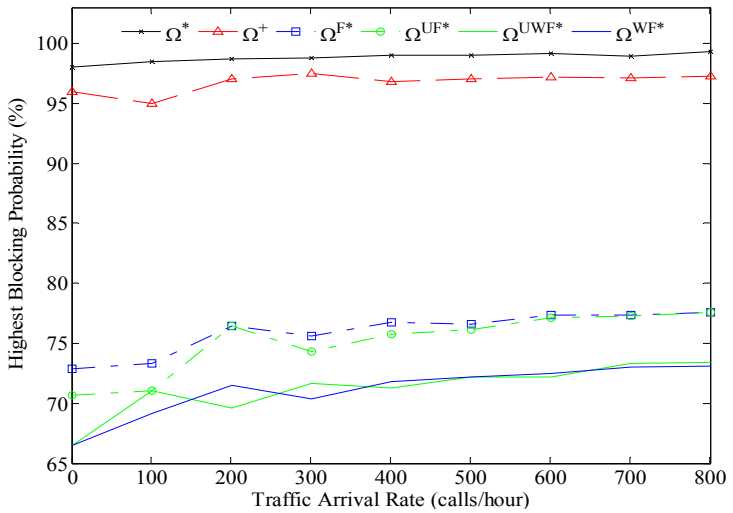

Fig. 4: Highest blocking probability of different CAC optimization policies while varying the arrival rate of class-7 traffic

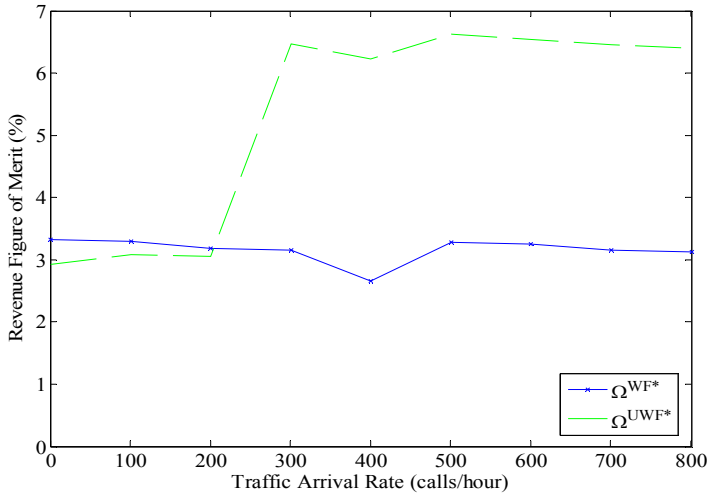

Fig. 5: Revenue figure of merit of Ω^{WF*} and Ω^{UWF*} compared to Ω^{F*} and Ω^{UF*} respectively while varying the arrival rate of class-7 traffic

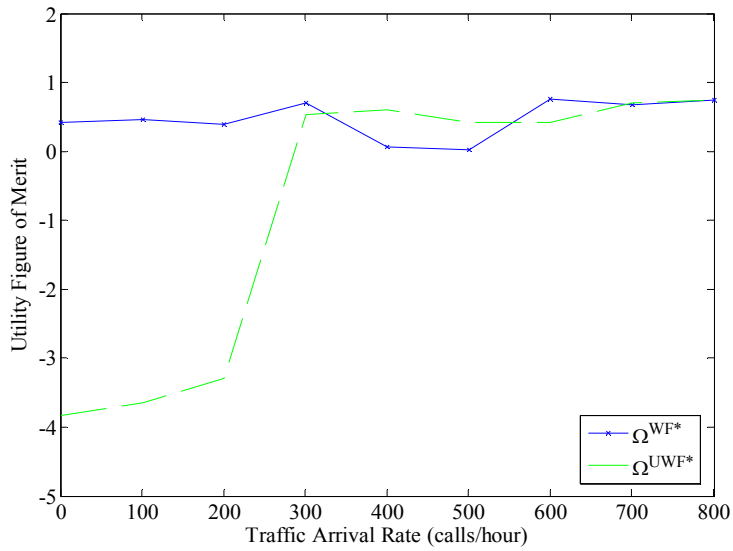

Fig. 6: Utility figure of merit of Ω^{WF*} and Ω^{UWF*} compared to Ω^{F*} and Ω^{UF*} respectively while varying the arrival rate of class-7 traffic

The figure of merit for utility is given by:

$$\text{Utility FM}(\Omega^{WF*}) = \frac{U(\Omega^{WF*}) - U(\Omega^{F*})}{U(\Omega^{F*})} * 100$$

$$\text{Utility FM}(\Omega^{UWF*}) = \frac{U(\Omega^{UWF*}) - U(\Omega U^{UF*})}{U(\Omega^{UF*})} * 100$$

CONCLUSION

In this study we propose two algorithms; weighted fairness-constrained greedy revenue algorithm, and utility-weighted fairness-constrained greedy revenue algorithm as a modification for existing CAC policies for WBCN networks. The proposed algorithms are intended to maximize the revenue of service providers while maintaining the satisfaction of cognitive radio subscribers. Simulation results proofed that our approach can give better revenue if compared with the un-weighted algorithms, while achieving the utility and fairness constraints. The results show an increase of at least 3% in the former proposed algorithm and at least 6% increase in revenue in latter proposed algorithm with nearly no sacrifice in the user utility.

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