Analysis of Call Admission Control for Multi-service Cognitive Radio Networks

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***Abstract*—In cognitive radio networks (CRNs), call admission control (CAC) is an important functionality to ensure the quality of service (QoS) for secondary users (SUs). A call admission control (CAC) scheme for multi-service cognitive radio networks (CRNs) is investigated here. We adopt a Markov chain model to describe the procedure of the proposed CAC and spectrum handoff strategy. The quality of service (QoS) requirements, such as call blocking probability, call dropping probability, and spectrum utilization, are evaluated for each service class. This CAC scheme has the flexibility to allow tradeoff between call dropping and call blocking, according to QoS requirements. Our CAC scheme can also adjust priority for different class services. We model this CAC scheme and obtain the stationary distribution of the number of SUs calls. We also show how to apply the result for deriving explicit expressions of QoS for each class of SUs calls.**

***Index Terms* — cognitive radio network, call admission control, secondary users, quality of service and spectrum handoff**

I. INTRODUCTION

BASED on the report of the Federal Communication Commission (FCC) [1], the current static spectrum policy which only allows licensed operations on the spectrum, causes severe underutilization of the spectrum. The network using licensed spectrum is called *primary radio network* (PRN). For example, the *mobile cellular network* (MCN) is one kind of primary radio network. The users of the primary network are called *primary users* (PUs). The inefficient usage of the existing spectrum can be improved through opportunistic access to the licensed bands without interfering with the existing primary users. As next generation networks, the *cognitive radio networks* (CRNs) are designed to provide the capability to use or share the unused spectrum in an opportunistic manner. The users who use *secondary networks*, like the *cognitive radio networks* (CRNs), are *secondary users* (SUs). The *call admission control* (CAC) is an important functionality to ensure the *quality of service* (QoS). CAC has been investigated intensely for traditional *mobile cellular networks* (MCN) [2][3][4]. Typical polices in multiclass networks are *complete sharing* (CS), *complete partitioning* (CP), *threshold*, etc. Choi et al. [2] presented a centralized CAC for mobile cellular network (MCN). Kwon et al. [3] proposed a distributed CAC. Yang Xiao et al. [4] gave an optimal CAC solution using *semi-Markov decision process* (SMDP). All these CAC analyses are for PRNs, like *mobile cellular network* (MCN). Very little of CAC analysis exists for *cognitive radio network* (CRN) [5][6][7]. Huang et al. [5] analyzed a CAC for CRN with simulation for a total of 6 channels. Zhu et al. [6] analyzed a CAC for CRN with single class primary users and single class secondary users. Wang et al. [7] analyzed the network selection problem when there are multiple networks with spared spectrum. In this paper we investigate a *call admission control* (CAC) scheme for multi-service *cognitive radio network* (CRN). We adopt a Markov chain model to describe the procedure of the proposed CAC and spectrum handoff strategy. The quality of service (QoS) requirements, such as call blocking probability, call dropping probability, and spectrum utilization are evaluated for each service class. This CAC allows us to control the call blocking probability and the call dropping probability. This CAC scheme has the flexibility to allow the tradeoff between call dropping and call blocking, according to QoS requirements. Our CAC scheme can also adjust priorities for different service classes. We model the CAC scheme with a Markov chain model and obtain the stationary distribution of the number of SUs calls. Then we show how to apply the result in deriving an explicit expression of QoS for each class of SUs calls.

The remainder of the paper is organized as follows: Section II presents the system model of multi-class CAC for cognitive radio network and the detailed Markov chain model analysis of secondary users (SUs) in stationary state. Section III analyzes QoS such as call blocking probability and call dropping probability. Section IV presents numerical and simulation results. Finally, section V concludes the paper.

II. MULTICLASS CAC MODEL FOR COGNITIVE RADIO NETWORK

Currently, Mobile Cellular Networks (MCNs) are using fixed/licensed spectrum bands. Most of the allocated spectrum bands are observed to be underutilized. All these existing

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radio networks are called *primary radio networks* (PRNs). The users that have exclusive license to use certain spectrum bands in PRNs are the primary users (PUs). The (temporarily) unused spectrum bands in PRNs are called "spectrum holes". Cognitive Radio Network (CRN) is a promising technology that can identify and exploit the spectrum holes. Cognitive Radio Networks are designed to work with primary radio networks (PRNs). The users in CRNs using the spectrum holes left by PRNs are the secondary users (SUs).

A. Analysis Of PRNs With One Class Service

The existing PRNs work just like there is no CRN. So there are no hardware or software changes required for PRNs. But CRNs need to work with PRNs, and the CRNs' performance analysis depends on the traffic statistics of PRNs. Therefore, we need to analyze PRNs first. We can model PRNs as a standalone system. We first assume there is only one class of Pus and each PU uses one unit of spectrum band (called a channel). The Markov chain model of single class PRN with total C channels is shown in Fig. 1. PRNs always accept handoff calls when there is channel available. B is the primary new call blocking threshold in PRN.

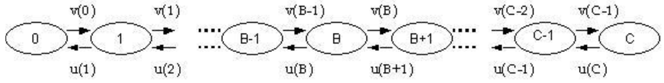

Fig. 1. The Markov chain model of single class PRN

For PRN, different CAC and handoff policy will lead to a different Markov chain model and results in different stationary probabilities, as that of the CRN. The CRN performance depends only on the PRN stationary probabilities. The PRN is not our focus. The CRN is our focus and will be analyzed later in detail. Here simple assumptions and definitions for this PRN are given as follow to get one kind of stationary probabilities.

1) The required bandwidth of a call is one unit (one channel).
2) A handoff call request is always admitted if there is an available channel.
3) We have altogether *C* channels in a single cell PRN.
4) *B* is the primary users' new call blocking threshold in PRN.
5) The new calls are generated in PRN according to a Poisson process with rate V_p^n. The handoff calls are generated in PRN according to a Poisson process with rate V_p^h. The total length of time, that a call uses for a new call, is exponentially distributed with mean $1/U_p^n$. The cell residence time, which is defined as the length of time a call stays in the cell and depends on the velocity and the direction of the mobile terminal of a call, is exponentially distributed with mean $1/U_p^h$.

Based on the model, we show the Markov chain in Fig. 1 for a single PRN cell in isolation. It is a birth and death process with birth rates

$$V_p(m) = V_p{}^n \times I(m < B) + V_p{}^h, m = 0,1,..., C-1 \quad (1)$$

and death rates

$$U_p(m) = m \times (U_p{}^n + U_p{}^h), m = 1,2,..., C \quad (2)$$

where *I(A)* is the indicator function taking value 1 if event *A* occurs and zero otherwise. And here $V_p(C)= 0$, $U_p(0)= 0$. Since Fig. 1 is a one dimensional Markov chain, we can easily show, using standard results from Markov chain theory, that its stationary distribution is given by

$$\pi_p(m) = \pi_p(0)\prod_{j=1}^{m}\frac{V_p(j-1)}{U_p(j)}, m = 1,2,..., C \quad (3)$$

where $\pi_p(0)$ is the normalization constant. Then the stationary distribution of PRN with m occupied channels has the form

$$P_p(m) = G^{-1}\pi_p(0)\prod_{j=1}^{m}\frac{V_p(j-1)}{U_p(j)}, m = 1,2,..., C \quad (4)$$

and

$$P_p(0) = G^{-1}\pi_p(0)$$

here the normalization constant *G* is

$$G = \sum_{m=0}^{C} \pi_p(m), m = 0,1,..., C \quad (5)$$

B. Analysis Of PRNs With Two Service Classes

Consider now are two classes of PUs in PRN, named PU0 for class 0, and PU1 for class 1. We assume class 0 is the higher priority class and both classes of the users use same one unit of spectrum band. The Markov chain model of multi-class PRN with a total of *C* channels is shown in Fig. 2.

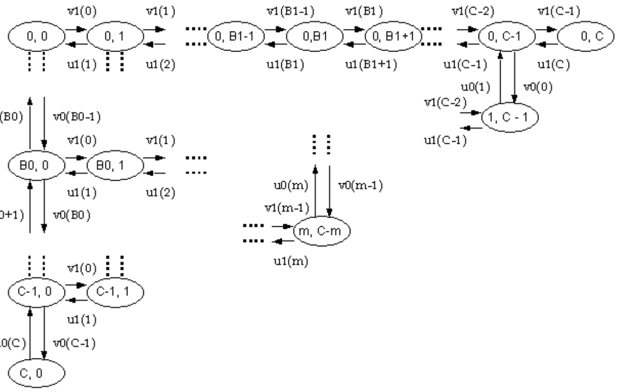

Fig. 2. Markov chain model of multiclass PRN

PRNs always accept handoff calls when there is channel available. B_0 and B_1 are the primary new call blocking thresholds for class 0 and class 1, respectively.

For PRN, different CAC and handoff policies will give different Markov chain models and different stationary probabilities. Let $X_i(t)$, $(i=0,1)$ be the number of class *i* calls in the system at time *t*, Then $X_i(t)$, $(i=0,1)$ is a birth and death process with birth rates

$$V_{p0}(m_0) = V_{p0}{}^n \times I(m_0 < B_0) + V_{p0}{}^h, m_0 = 0,1,..., C-1 \quad (6)$$

$$V_{p1}(m_1) = V_{p1}{}^{n} \times I(m_1 < B_1) + V_{p1}{}^{h}, m_1 = 0,1,..., C-1 \quad (7)$$

and death rates

$$U_{p0}(m_0) = m_0 \times (U_{p0}{}^{n} + U_{p0}{}^{h}), m_0 = 1,2,..., C \quad (8)$$

$$U_{p1}(m_1) = m_1 \times (U_{p1}{}^{n} + U_{p1}{}^{h}), m_1 = 1,2,..., C \quad (9)$$

where *I(A)* is the indicator function taking value 1 if event *A* occurs and zero otherwise. Here m_i is the number of primary calls in PRN for class *i, (i=0,1)*. Let $X(t)=\{X_0(t),X_1(t)\}$ be the vector number of class calls in a cell at time *t*. Since $X_i(t)$, *(i=0,1)* is a reversible process, thus the stationary distribution of *X(t)* satisfies the truncation property (see [10]). That is, if we concentrate on the truncated state space

$$S_C = \{(m_0, m_1); 0 \le m_0 + m_1 \le C\} \quad (10)$$

then the stationary distribution of *X(t)* has the following form

$$\pi_p(m_0, m_1) = \pi_p(0,0) \prod_{j_0=1}^{m_0} \frac{V_{p0}(j_0 - 1)}{U_{p0}(j_0)} \prod_{j_1=1}^{m_1} \frac{V_{p1}(j_1 - 1)}{U_{p1}(j_1)} \quad (11)$$

where $(m_0,m_1) \in S_C$ and $\pi_p(0,0)$ is the normalization constant. Then the stationary distribution of PRN with (m_0,m_1) occupied channels has the following form

$$P_p(m_0, m_1) = G^{-1} \pi_p(m_0, m_1) \quad (12)$$

where the normalization constant *G* is

$$G = \sum_{(m_0, m_1) \in S_C} \pi_p(m_0, m_1) \quad (13)$$

For two classes PUs in PRN, the probability with PUs using total *M* channels is the following:

$$P_p(M) = \sum_{m_0=0}^{M} P_p(m_0, M - m_0), M = 0,1,..., C \quad (14)$$

C. Analysis Of CRNs With Two Class Services

Now we analyze the cognitive radio network (CRN). When a single cell in isolation of PRN with *C* total PRN channels is using *M* channels then the considered CRN can only use up to *(C-M)* channels for SUs. There are two classes of calls (such as voice and video) for SUs. We define our call admission control (CAC) scheme in table I.

And we model a single cell CRN as shown in Fig. 3.

Detailed section A of Fig. 3 is shown in Fig. 4.

Detailed section B of Fig. 3 is shown in Fig. 5.

Detailed section C of Fig. 3 is shown in Fig. 6.

Detailed section D of Fig. 3 is shown in Fig. 7.

Detailed section E of Fig. 3 is shown in Fig. 8.

Fig.3 only shows the case that PUs are using *M* channels while SUs can use up to *(C-M)* channels. From the PU's point of view, the probability for this situation is $P_p(M)$. *M* can be 0 to *C*. The SUs in CRN could use up to *(C-M)* channels. Under the condition of *(C-M)* available channels in CRN we analyze SUs in CRN. The number of class 0 and class 1 calls in the CRN system is again a birth and death process with birth rates

$$V_{s0}(n_0) = V_{s0}{}^{n} \times I(n_0 < B_{s0}) + V_{s0}{}^{h} \quad (15)$$

$$V_{s1}(n_1) = V_{s1}{}^{n} \times I(n_1 < B_{s1}) + V_{s1}{}^{h} \quad (16)$$

$$n_0 = 0,1,..., C - M - 1, n_1 = 0,1,..., C - M - 1$$

and death rates

$$U_{s0}(n_0) = n_0 \times (U_{s0}{}^{n} + U_{s0}{}^{h}), n_0 = 1,2,..., C - M \quad (17)$$

$$U_{s1}(n_1) = n_1 \times (U_{s1}{}^{n} + U_{s1}{}^{h}), n_1 = 1,2,..., C - M \quad (18)$$

Table I

Call Admission Control (CAC) definitions for CRN

Items	Definitions
1	The required bandwidth of class *k* calls *(k=0,1)* is one unit (one channel).
2	A handoff call request is always admitted if there is channel (spectrum hole) available, sensed by CRN.
3	To give priority to handoff calls, threshold value B_{sk} is predetermined for class *k* calls. This threshold value means that a class *k* new call is admitted if and only if, (a) the number of class *k* calls in CRN is less than B_{sk} *,(k = 0,1),* (b) if there is channel (spectrum hole) available sensed by CRN.
4	Class *k* new calls are generated in CRN according to a Poisson process with rate $V_{sk}{}^{n}$*,(k = 0,1).* Class *k* handoff calls are generated in CRN according to a Poisson process with rate $V_{sk}{}^{h}$*,(k = 0,1).* . The total length of time, that a call for a class *k* new call, is exponentially distributed with mean $1/U_{sk}{}^{n}$*,(k = 0,1).* The cell residence time, which is defined as the length of time a call stays in the cell and which depends on the velocity and the direction of the mobile terminal of a class k call, is exponentially distributed with mean $1/U_{sk}{}^{h}$*,(k = 0,1).*
5	CRN can do "spectrum handoff" which means CRN can switch a SU from one channel to other available channel. When a new or a handoff PU call get admitted by PRN, it may cause a channel collision. If CRN can find an available channel, it will do spectrum handoff for the collided channel. Otherwise, CRN will drop an existing channel used by SU according to SUs dropping policy.
6	We set dropping threshold values D_{sk} *,(k = 0,1),* to handle SU drop off. When CRN needs to drop an existing call, it will pick the lowest class that uses channels more than its threshold D_{sk} *,(k = 0,1).* If no class uses channels more than its threshold D_{sk} *,(k = 0,1),*CRN just drops a lowest class call.

where *I(A)* denotes the indicator function of any event *A*. Here n_i is the number of SUs calls in CRN for class *i, (i=0,1).* Let $X(t)=\{X_0(t),X_1(t)\}$ be the vector of class of calls in a cell at time *t*. Since $X_i(t)$, *(i=0,1)* is a reversible process, it is shown that *X(t)* is also a reversible process, thus the stationary distribution of *X(t)* satisfies the truncation property (see [10]). That is, if we concentrate on the truncated state space

$$S_{C-M} = \{(n_0, n_1); 0 \le n_0 + n_1 \le C - M\} \quad (19)$$

then its stationary distribution is given by

$$\pi_s(n_0, n_1) = \pi_s(0,0) \prod_{k_0=1}^{n_0} \frac{V_{s0}(k_0 - 1)}{U_{s0}(k_0)} \prod_{k_1=1}^{n_1} \frac{V_{s1}(k_1 - 1)}{U_{s1}(k_1)} \quad (20)$$

where $(n_0,n_1) \in S_{C-M}$ and $\pi_s(0,0)$ is the normalization constant. Then the stationary distribution of CRN with *(C-M)* available channels has the following form

$$P_s(n_0, n_1) = G_s{}^{-1} \pi_s(n_0, n_1) \quad (21)$$

where the normalization constant G_s is

$$G_s = \sum_{(n_0, n_1) \in S_{C-M}} \pi_s(n_0, n_1) \quad (22)$$

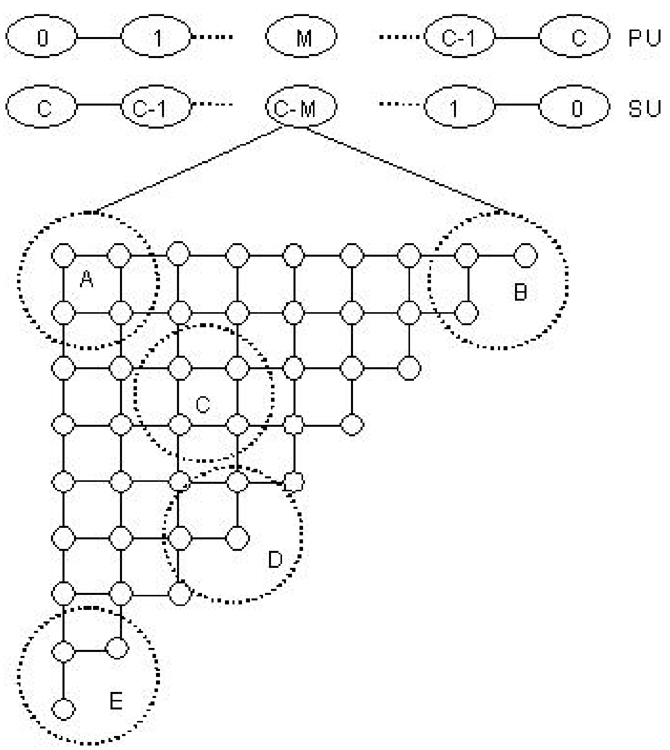

Fig. 3. The Markov chain model of multiclass CRN

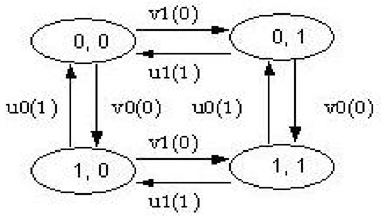

Fig. 4. Section A of Fig. 3

III. QOS DEFINITION AND FORMULA

Once the network stationary distribution $P_p(m_0,m_1)$ and $P_s(n_0,n_1)$ are obtained, we can compute many interesting *QoS* measurements for the CRN system.

A. Blocking Probabilities

To compute the blocking probabilities in the single cell CRN, we first calculate the marginal distribution for the situation when *M* channels are occupied by PUs in PRN. See Fig. 9. The new call blocking probability for class 0 with *(C-M)* channels available for SUs is

$$P_B(C-M,0) = \sum_{n_0=0}^{C-M} P_s(n_0, C-M-n_0) + \sum_{n_1=0}^{C-M-1-n_0} \sum_{n_0=B_{S0}+1}^{C-M-1} P_s(n_0,n_1), M = 0,1,..., C \qquad (23)$$

The new call blocking probability for class 1 with *(C-M)* channels available for SUs is

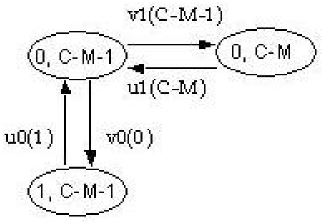

Fig. 5. Section B of Fig. 3

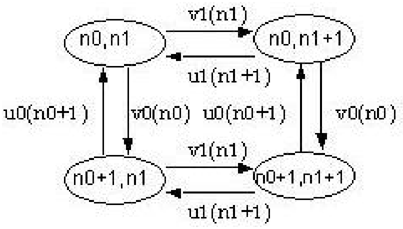

Fig. 6. Section C of Fig. 3 here ($n_0+1+n_1+1 \le C-M$)

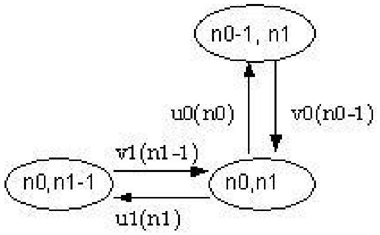

Fig. 7. Section D of Fig. 3 here ($n_0+n_1 = C-M$)

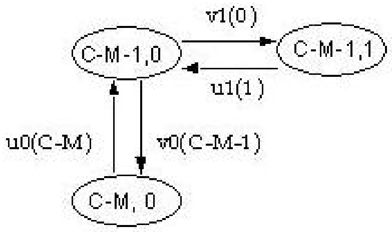

Fig. 8. Section E of Fig. 3

$$P_B(C-M,1) = \sum_{n_1=0}^{C-M} P_s(C-M-n_1, n_1) + \sum_{n_0=0}^{C-M-1-n_1} \sum_{n_1=B_{S1}+1}^{C-M-1} P_s(n_0,n_1), M = 0,1,..., C \qquad (24)$$

By combining all possible situations of *M* together we can get the new call blocking probability of CRN class 0 is

$$P_B(0) = \sum_{M=0}^{C} P_p(M) P_B(C-M,0) \qquad (25)$$

The new call blocking probability of CRN class 1 is

$$P_B(1) = \sum_{M=0}^{C} P_p(M) P_B(C-M,1) \qquad (26)$$

Here $P_p(M)$ see equation (4).

B. Dropping Probabilities

To compute the dropping probabilities in the single cell CRN, we need consider SU handoff dropping when all channels are full and the SU existing call dropping when a new call or a handoff call of PU gets admitted from PRN. We first calculate the marginal SU handoff call dropping rate for

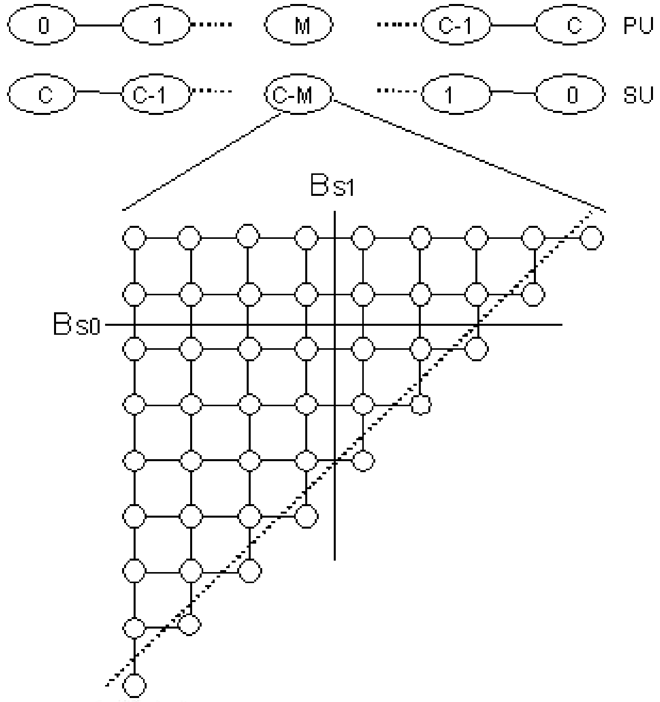

Fig. 9. CRN with PU=M, $n_0+n_1=<(C-M)$ and thresholds Bs0, Bs1

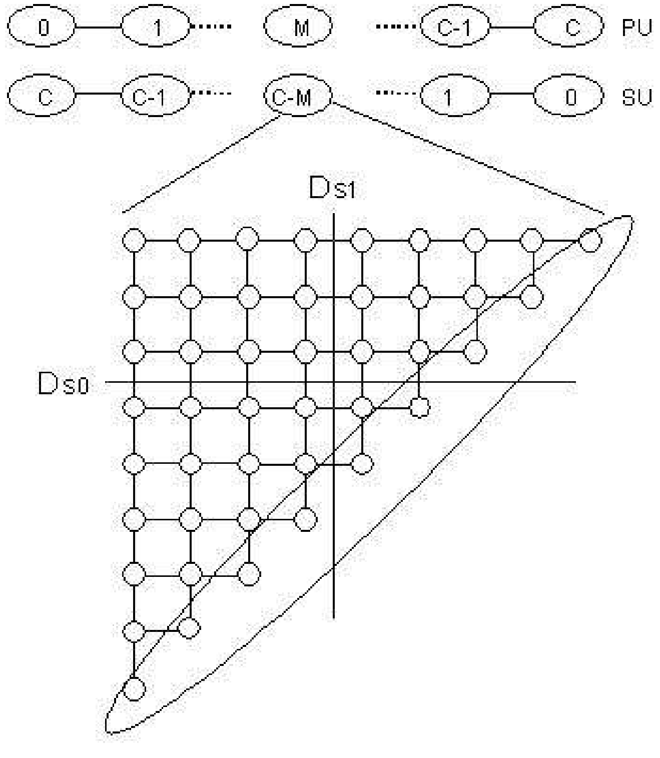

Fig. 10. . CRN with PU=M, SU=(C-M) and thresholds Ds0, Ds1

the situation when M channels are occupied by PUs in PRN and $(C-M)$ channels are taken by SUs in CRN. See Fig.10. The handoff call dropping probability for class 0 with $(C-M)$ channels available for SUs is

$$P_{D,H}(C-M,0)=\sum_{n_0=0}^{C-M} P_s(n_0,C-M-n_0) \tag{27}$$

where $M=0,1,...,C$. The handoff call dropping probability for class 1 with $(C-M)$ channels available for SUs is

$$P_{D,H}(C-M,1)=\sum_{n_1=0}^{C-M} P_s(C-M-n_1,n_1) \tag{28}$$

where $M=0,1,...,C$. Now we analyze the SU existing call dropping when a new call or a handoff call of PU gets admitted from PRN. We define $P_{PSC}(M,M+1)$ as the probability of PRN state change from state with M channels being used to state with $M+1$ channels used. For single class PUs in PRN, it can be expressed as

$$P_{PSC}(M,M+1)=P_p(M)V_p(M)/[V_p(M)+U_p(M)] \tag{29}$$

where $M=0,1,...,C$, $V_p(M)$ see equation (1), $U_p(M)$ see equation (2) and $P_p(M)$ see equation (4).

For two class PUs in PRN, $P_{PSC}(M,M+1)$ can be expressed as follow

$$P_{PSC}(M,M+1)=\sum_{n_0=0}^{M} P_p(n_0,M-n_0)[\frac{V(M,n_0)}{VU(M,n_0)}] \tag{30}$$

Where

$$V(M,n_0)=[V_{p0}(n_0)+V_{p1}(M-n_0)] \tag{31}$$

$$VU(M,n_0)=[V_{p0}(n_0)+V_{p1}(M-n_0) + U_{p0}(n_0)+U_{p1}(M-n_0)] \tag{32}$$

And here $P_p(n_0,M-n_0)$ see equation (12). Please notice here the special cases like $V_{p0}(M)=V_{p1}(M)=0$, $U_{p0}(0)=U_{p1}(0)=0$.

When PUs change from state with M channels used to state with $M+1$ channels used in PRN, the CRN will drop the lowest class which uses more channels than the drop threshold. So the SU existing class 1 call dropping probability is

$$P_{D,E}(C-M,1)=\sum_{n_0=D_{S1}+0}^{C-M} P_s(n_0,C-M-n_0) \tag{33}$$

where $M=0,1,...,C-1$. The SU existing class 0 call dropping probability is

$$P_{D,E}(C-M,0)=\sum_{n_0=0}^{D_{S1}} P_s(n_0,C-M-n_0) \tag{34}$$

where $M=0,1,...,C-1$. By combining all the possible M cases together, we get the existing call dropping probability of class 0 for whole CRN as

$$P_D(0)=\sum_{M=0}^{C-1} [P_p(M)P_{D,H}(C-M,0) + P_{D,E}(C-M,0)P_{PSC}(M,M+1)] \tag{35}$$

Here $P_{D,E}(C-M,0)$ see equation (34). The existing call dropping probability of class 1 for whole CRN as

$$P_D(1)=\sum_{M=0}^{C-1} [P_p(M)P_{D,H}(C-M,1) + P_{D,E}(C-M,1)P_{PSC}(M,M+1)] \tag{36}$$

Here $P_p(M)$ see equation (4) for one class PRN (or see equation (14) for two class PRN) and $P_{D,E}(C-M,1)$ see equation (33).

C. Channel Utilizations

The PRN channel utilization by PUs is

$$U_p = [\frac{1}{C}] \sum_{(m_0,m_1)\in S_C} [(m_0+m_1)P_p(m_0,m_1)] \qquad (37)$$

$$S_C = \{(m_0,m_1);0 \le m_0+m_1 \le C\}$$

For $P_p(m_0,m_1)$ see equation (12). The CRN channel utilization by SUs is

$$U_s = [\frac{1}{C(1-U_p)}]\sum_{M=0}^{C} P_p(M)[PS(C-M)] \qquad (38)$$

$$PS(C-M) = \sum_{(n_0,n_1)\in S_{C-M}} [(n_0+n_1)P_s(n_0,n_1)] \qquad (39)$$

$$S_{C-M} = \{(n_0,n_1);0 \le n_0+n_1 \le C-M\}$$

Here $P_p(M)$ see equation (4) for one class PRN (see equation (14) for two class PRN) and $P_s(n_0,n_1)$ see equation (21).

IV. NUMERICAL AND SIMULATION RESULTS

This section presents numerical and simulation results of the QoS performance of the proposed CAC for multi-service cognitive radio networks. Blocking probabilities, dropping probabilities and channel utilization are the key metrics that we are concerned about. In the simulations a PRN with one class PUs and CRN with two classes of SUs is considered. We use the parameters listed in table II for one class PUs in PRN for the simulation.

Table II
PRN Parameters Used for Numerical Simulations

Name	Value	Definition
C	20	Total channels in PRN
B	15	Blocking threshold for PRN
V_p^n	0.800	New call arrival rate for PRN
V_p^h	0.400	Handoff call arrival rate for PRN
U_p^n	0.080	New call service rate for PRN
U_p^h	0.040	Handoff call service rate for PRN

We use the parameters listed in table III for two classes of SUs in CRN for the simulation.

Table III
CRN Parameters Used for Numerical Simulations
None default values will be used/indicated in each chart

Name	Value	Definition
C	20	Total channels in PRN
B_{s0}	6	Call Blocking threshold for CRN class 0
D_{s0}	4	Call Dropping threshold for CRN class 0
V_{s0}^n	0.400	New call arrival rate for CRN class 0
V_{s0}^h	0.200	Handoff call arrival rate for CRN class 0
U_{s0}^n	0.080	New call service rate for CRN class 0
U_{s0}^h	0.040	Handoff call service rate for CRN class 0
B_{s1}	6	Call Blocking threshold for CRN class 1
D_{s1}	4	Call Dropping threshold for CRN class 1
V_{s1}^n	0.400	New call arrival rate for CRN class 1
V_{s1}^h	0.200	Handoff call arrival rate for CRN class 1
U_{s1}^n	0.080	New call service rate for CRN class 1
U_{s1}^h	0.040	Handoff call service rate for CRN class 1

A. Blocking Probability Results

Fig. 11 shows class 0 new call blocking probabilities for three different new call blocking thresholds in terms of the class 0 arrival rate. Fig. 12 shows class 1 new call blocking probabilities for three different new call blocking thresholds in terms of the class 1 arrival rate. By setting different new call blocking thresholds we can get different blocking probabilities for different classes of calls.

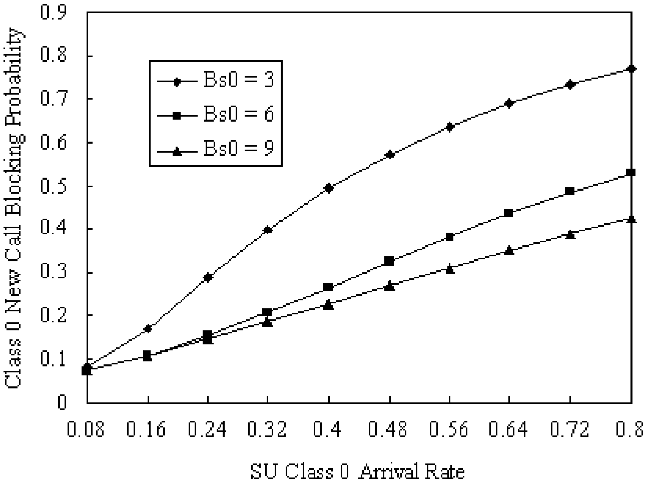

Fig. 11. Class 0 new call blocking probability vs. class 0 arrival rate

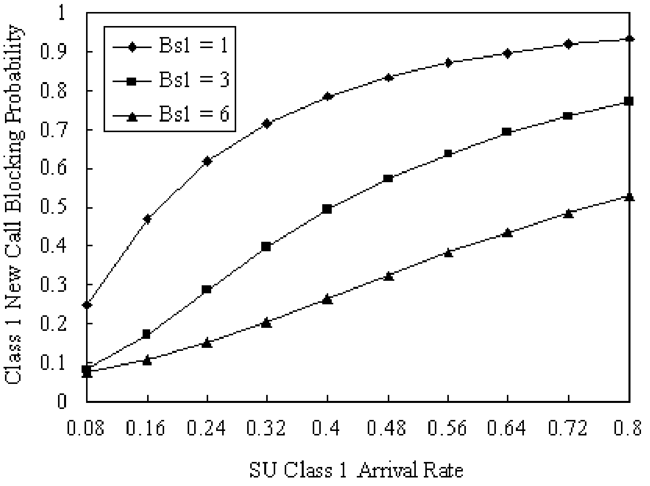

Fig. 12. Class 1 new call blocking probability vs. class 1 arrival rate

B. Dropping Probability Results

The handoff call dropping probability can be adjusted via changing the blocking threshold. Fig. 13 shows class 0 handoff call dropping probabilities for three different new call blocking thresholds in terms of the class 0 arrival rate. Fig. 14 shows class 1 handoff call dropping probabilities for three different new call blocking thresholds in terms of the class 1 arrival rate. Existing call dropping probability can also be changed by adjusting the dropping threshold. Fig. 15 shows class 0 existing call dropping probabilities for three

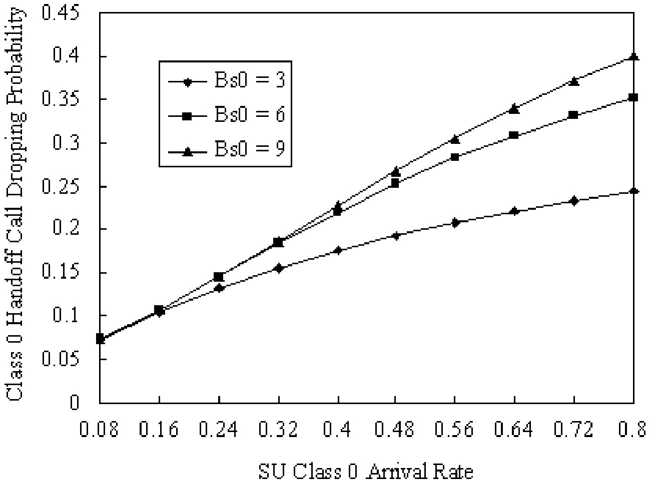

Fig. 13. Class 0 handoff call dropping probability vs. class 0 arrival rate

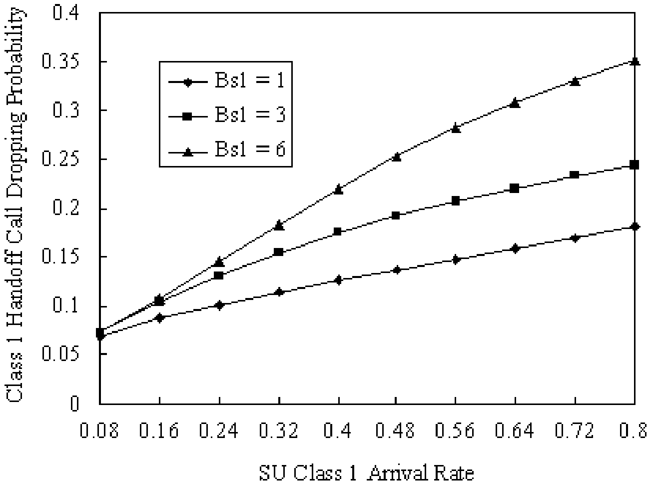

Fig. 14. Class 1 handoff call dropping probability vs. class 1 arrival rate

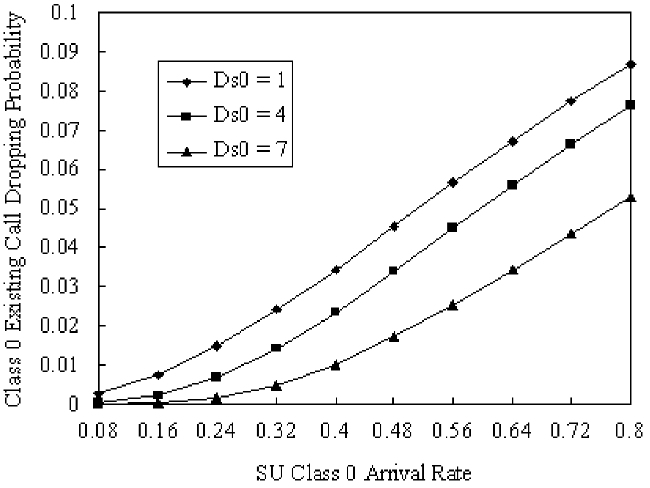

Fig. 15. Class 0 existing call dropping probability vs. class 0 arrival rate

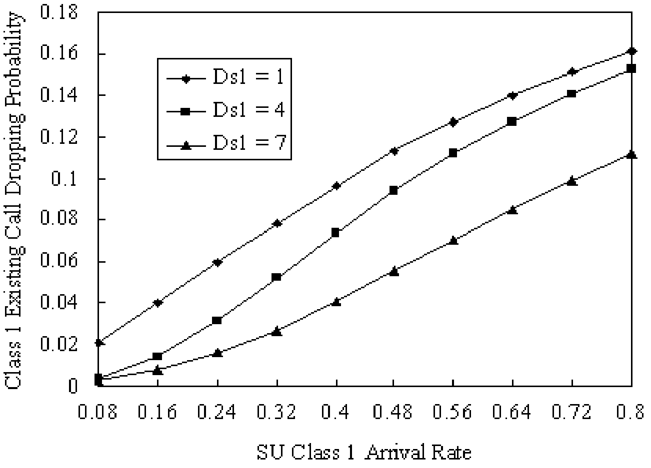

Fig. 16. Class 1 existing call dropping probability vs. class 1 arrival rate

different call dropping thresholds in terms of the class 0 arrival rate. Fig. 16 shows class 1 existing call dropping probabilities for three different call dropping thresholds in terms of the class 1 arrival rate. We can derive total call dropping probability by combining handoff call dropping probability with existing call dropping probability.

C. *Channel Utilization Results*

Channel utilization is adjusted by new call blocking thresholds for the same arrival rate. Fig. 17 shows channel utilization for three different new call blocking thresholds in terms of the class 0 arrival rate. Fig. 18 depicts channel utilization for three different new call blocking thresholds in terms of the class 1 arrival rate.

V. CONCLUSION

In this paper we have proposed a call admission control (CAC) scheme for multi-service cognitive radio networks (CRNs). We use different blocking thresholds to control call blocking rates as well as call dropping rates for various service classes. A Markov chain based analytical model is developed to analyze the proposed CAC strategy. We derived analytical formulas for quality of service (QoS) measurements, such as call blocking probability, call dropping probability and the channel utilization for each class of service. Simulation results demonstrate how the QoS depends on this CAC with respect to different parameters. Our CAC scheme has the flexibility to allow trade-off between call blocking, call dropping and channel utilization. It can also adjust priority for different service classes. Via carefully selecting blocking/dropping thresholds, we can get optimized cognitive radio network performance. The developed analytical model can also be used to further study cognitive radio network performance and CRNs optimization problems.

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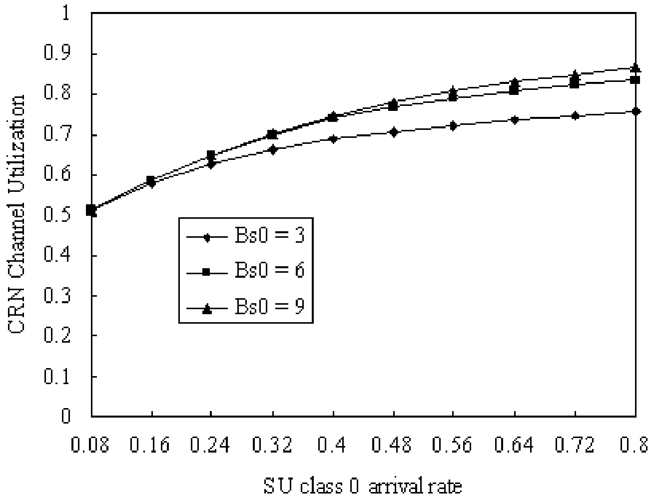

Fig. 17. CRN channel utilization vs. class 0 arrival rate

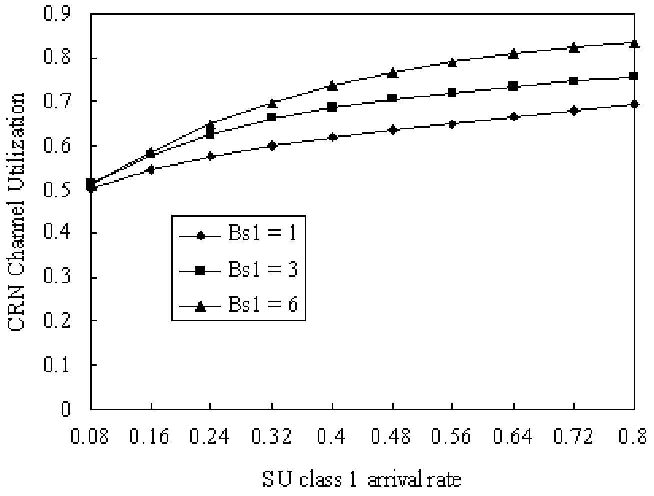

Fig. 18. CRN channel utilization vs. class 1 arrival rate

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