

Service-Class-Based Joint Call Admission Control and Adaptive Bandwidth Management Scheme for Heterogeneous Wireless Networks

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Abstract—Joint call admission control (JCAC) can significantly improve connection-level quality of service (QoS) in heterogeneous wireless networks. This paper proposes service-class-based JCAC and adaptive bandwidth management scheme to enhance connection-level QoS in heterogeneous cellular networks, where each cellular network is optimized to support specific classes of service. We develop an analytical model for the JCAC scheme using a multi-dimensional Markov chain. Two connection-level QoS metrics, new call blocking probability and handoff call dropping probability, are derived and evaluated for the heterogeneous cellular network. Numerical results show that the proposed JCAC scheme reduces handoff call dropping probability and new call blocking probability in heterogeneous cellular networks.

Index Terms—Call admission control, radio access technology, call dropping, call blocking, Markov chain, QoS, mobile users.

I. INTRODUCTION

Next Generation Wireless Networks (NGWN) will combine existing and new technologies to provide high bandwidth access anytime, anywhere for multimedia services. In these heterogeneous wireless networks, mobile users will be able to communicate through different radio access technologies (RATs) and roam from one RAT to another, using multimode terminals (MTs) [1].

Existing cellular networks are optimized to support different classes of service. For example, CdmaOne (IS-95A) and GSM networks are optimized to support voice services, EV-DO network is optimized to support data services, UMTS is optimized to support both voice and data services, etc.

The coexistence of these cellular networks in the same geographical area necessitates joint radio resource management (JRRM) to enhance quality of service provisioning. The concept of JRRM arises in order to efficiently manage the common pool of radio resources that are available in each one of the existing RATs [2].

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Radio resource management (RRM) algorithms have been extensively studied in homogeneous cellular networks. However, for heterogeneous cellular networks, not many approaches to JRRM problem are available in the literature. The interest has been mainly focused on architectural aspects of JRRM, and not many specific algorithms have been provided to investigate JRRM among different RATs, even in simple scenarios [3].

Romero et al [4], propose a RAT selection policy for heterogeneous wireless networks with co-located cells. They illustrate the selection policy using heterogeneous network comprising GERAN and UTRAN supporting a mix of voice and interactive users. However, handoff calls are not considered in the study. The algorithm deals with initial RAT selection only for new calls. Moreover, no analytical model is presented in the study, and connection-level QoS are not investigated.

This paper proposes service-class-based joint call admission control (JCAC) algorithm and adaptive bandwidth management scheme for heterogeneous cellular networks. The JCAC scheme is designed to simultaneously achieve the following objectives:

- (1) Make RAT selection based on service classes,
- (2) Guarantee the QoS requirements of all admitted calls,
- (3) Prioritize handoff calls over new calls,
- (4) Adapt the bandwidth of ongoing calls based on traffic, conditions to enhance connection-level QoS.

Selection of RAT for incoming calls based on service classes improves QoS because different networks are optimized to support different classes of traffic. It is necessary to prioritize handoff calls over new calls because dropping of handoff calls due to unavailability of radio resources is more annoying to users than blocking a new call.

The contributions of this paper are twofold. Firstly, we combine service-class-based JCAC and adaptive bandwidth management to enhance connection level QoS in heterogeneous wireless networks. Secondly, we develop an analytical model for the combine JCAC and adaptive bandwidth management scheme, and derive new call blocking (NCBP) and handoff call dropping probability (HCDP).

The rest of this paper is organized as follows. In section II,

we describe the system model and assumptions. The combined JCAC and bandwidth management scheme is presented in III. A Markov chain model is developed for the JCAC scheme in section IV. In section V, we investigate the performance of the proposed JCAC algorithm through simulations.

II. SYSTEM MODEL AND ASSUMPTIONS

We consider a heterogeneous cellular network which comprises a set of RATs H with co-located cells in which radio resources are jointly managed. Cellular networks such as GSM, UMTS, EV-DO can have the same and fully overlapped coverage, which is technically feasible, and may also save installation cost [5, 6]. Set H is given as follows.

$$H = \{RAT\ 1, RAT\ 2, \dots, RAT\ J\}$$

where J is the total number of RATs in the heterogeneous cellular network. The heterogeneous cellular network supports k -classes of calls, and each RAT in set H is optimized to support certain classes of calls. Let H_i ($H_i \subseteq H$) denote the set of RATs which can support class- i calls in the heterogeneous cellular network, and let h_i ($h_i \subseteq h$) denote the set of indices of all RAT j which belong to H_i , where $h = \{1, 2, \dots, J\}$. Furthermore, let J_i ($J_i \leq J$) denote the total number of RATs that can support class- i calls. Let D_j ($D_j \subseteq D$) denotes the set of call classes that can be supported by RAT j ($j=1, 2, \dots, J$) where $D = \{\text{class-1}, \text{class-2}, \dots, \text{class-}k\}$. Note that the idea that different networks support different classes of calls is true in reality. For example, UMTS network can support video streaming whereas GSM network cannot support video streaming.

Fig. 1 is an example of heterogeneous cellular networks. It consists of three RATs and supports two classes of calls. RAT 1 is optimized to support only class-1 calls, RAT 2 is optimized to support both class-1 and class-2 calls, and RAT 3 is optimized to support only class-2 calls.

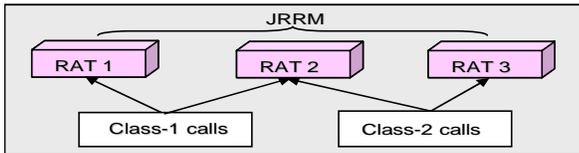


Fig.1. Example of heterogeneous cellular networks with JRRM

As shown in the Fig. 1, $H = \{RAT\ 1, RAT\ 2, RAT\ 3\}$, $H_1 = \{RAT\ 1, RAT\ 2\}$, $H_2 = \{RAT\ 2, RAT\ 3\}$, $h = \{1, 2, 3\}$, $h_1 = \{1, 2\}$, $h_2 = \{2, 3\}$. $D = \{\text{class-1}, \text{class-2}\}$, $D_1 = \{\text{class-1}\}$, $D_2 = \{\text{class-1}, \text{class-2}\}$, and $D_3 = \{\text{class-2}\}$.

Each cell in RAT j ($j = 1, \dots, J$) has a total of C_j basic bandwidth units (bbu). The physical meaning of a unit of radio resources (such as time slots, code sequence, etc) is dependent on the specific technological implementation of the radio interface [6]. However, no matter which multiple access technology (FDMA, TDMA, or CDMA) is used, we could interpret system capacity in terms of effective or equivalent bandwidth [7-8]. Therefore, whenever we refer to the

bandwidth of a call, we mean the number of bbu that is adequate for guaranteeing the desired QoS for this call, which is similar to the approach used for homogeneous networks in [8-9]. The unit of bbu can be 100 kbps, 1Mbps, etc [9].

It is assumed that packet-level QoS is stochastically assured by allocating at least the minimum effective bandwidth required to guarantee a given maximum probability on packet drop, delay, and jitter [10].

In our approach, we decompose heterogeneous cellular network into groups of co-located cells as shown in Fig. 2. For example, cell 1a, cell 2a, and cell 3a form a group of co-located cells. Similarly, cell 1b, cell 2b, and cell 2c form another group of co-located cells, and so on.

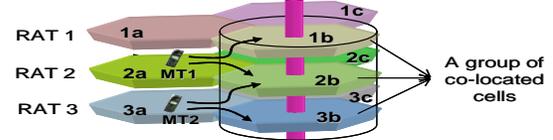


Fig. 2. Example Of heterogeneous cellular networks with co-located cells.

Following the common assumption which is made in homogeneous cellular networks, we assume that the types and amount of traffic are statistically the same in all cells of each RAT [8]. Therefore, the types and amount of traffic are statistically the same in all groups of co-located cells.

When a mobile user with an ongoing call is moving outside the coverage area of a group of co-located cells, the call must be handed over to one of the cells that can support the call in the neighboring group of co-located cells. For example, in the two-class three-RAT heterogeneous cellular network illustrated in Fig. 2, an ongoing class-1 call can be handed over from cell 2a to cell 2b, or from cell 2a to cell 1b (Fig. 2). Similarly, an ongoing class-2 call can be handed over from cell 3a to cell 3b, or from cell 3a to cell 2b. Note that handoff comprises both horizontal and vertical handoffs.

The correlation between the groups of co-located cells results from handoff connections between the cells of corresponding groups. Under this formulation, each group of co-located cells can be modeled and analyzed individually. Therefore, we focus our attention on a single group of co-located cells.

As mentioned earlier, the heterogeneous network supports k classes of calls. Each class is characterized by bandwidth requirement, arrival distribution, and channel holding time. Each class- i call requires a discrete bandwidth value, $b_{i,w}$, where $b_{i,w}$ belongs to the set $B_i = \{b_{i,w}\}$ for $i = 1, 2, \dots, k$ and $w = 1, 2, \dots, W_i$. W_i is the number of different bandwidth values that a class- i call can be allocated. $b_{i,1}$ (also denoted as $b_{i,\min}$) and b_{i,W_i} (also denoted as $b_{i,\max}$) are respectively, the minimum and maximum bandwidth that can be allocated to a class- i call. Note that $b_{i,w} < b_{i,(w+1)}$ for $i = 1, 2, \dots, K$ and $w = 1, 2, \dots, (W_i - 1)$.

The requested bandwidth of an incoming class- i call is denoted by $b_{i,\text{req}}$ where $b_{i,\text{req}} \in B_i$. Let $m_{i,j}$ and $n_{i,j}$ denote respectively, the number of ongoing new class- i calls and

handoff class- i calls, in RAT j with $1 \leq c \leq m_{i,j}$ (for new calls) and $1 \leq c \leq n_{i,j}$ (for handoff calls). Let $b_{i, \text{assigned } c}$ denote the bandwidth assigned to call c of class- i in RAT- j in the group of co-located cells where $b_{i, \text{assigned } c} \in B_i$. A call c of class- i is degraded if $b_{i, \text{assigned } c} < b_{i, \text{req}}$ whereas the call is upgraded if $b_{i, \text{assigned } c} > b_{i, \text{req}}$.

If a class of calls (i.e. class- i calls) requires a fixed number of channels (i.e. constant bit rate service), it becomes a special case in our model in which $b_{i, \text{min}} = b_{i, \text{max}}$ and the set B_i has only one element. However, it will not be possible to upgrade or degrade this class of calls.

Following the general assumption in cellular networks, new and handoff class- i calls arrive in the group of co-located cells according to Poisson process with rate λ_i^n and λ_i^h respectively. The call holding time (CHT) of a class- i call is assumed to follow an exponential distribution with mean $1/\mu_i$.

To characterize mobility, the cell residence time (CRT), i.e., the amount of time during which a mobile terminal stays in a cell (same as the time it stays in a group of co-located cells) during a single visit, is assumed to follow an exponential distribution with mean $1/hh$, where the parameter hh represents the call handoff rate. We assume that the CRT is independent of the service class.

The channel holding time is the minimum of the CHT and the CRT. Because minimum of two exponentially distributed random variables is also exponentially distributed [8], the channel holding time for new class- i calls, and for handoff class- i call, is assumed to be exponentially distributed with means $1/\mu_{ni}$ and $1/\mu_{hi}$ respectively.

Note that this set of assumptions has been widely used for homogeneous cellular networks in the literature, and is found to be generally applicable in the network where the number of mobile users is larger than the number of channels [10, 11].

III. PROPOSED JCAC AND BANDWIDTH ALLOCATION SCHEME

In this section, we present the service-class-based JCAC and adaptive bandwidth management scheme, which comprises three components: call admission controller, threshold-based bandwidth allocation unit, and bandwidth adaptation unit.

A. Joint Call Admission Control Controller

Service-class-based JCAC controller executes the JCAC algorithm, which makes call admission decisions based on service class of the incoming call and current load in each of the available RATs in which the call can be admitted.

During call setup, a multi-mode mobile terminal requesting a service sends a request to the joint call admission controller. The service request contains the call type, service class, and bandwidth requirements.

Let x_{ij} and y_{ij} denote the residual bbu available for new and handoff class- i calls respectively, in RAT j ($\text{RAT } j \subseteq H_i$).

When a new (or handoff) class- i call arrives in the heterogeneous network, the JCAC algorithm determines x_{ij} (or y_{ij}) available for new (or handoff) class- i calls in each RAT j belonging to set H_i . The JCAC algorithm then selects the least-loaded RAT in set H_i , and determines if the incoming call can be admitted with b_{req} into the RAT. If the least-loaded RAT does not have enough bbu to accommodate the class- i call, the next least-loaded RAT is selected for the call, and so on. If none of the RATs in set H_i has enough bbu to accommodate the call, and if the requested bandwidth ($b_{i, \text{req}}$) is more than the minimum bbu ($b_{i, \text{min}}$) for the call, the JCAC algorithm reduces the requested bandwidth by one step, and try again if the call can be admitted into any of the RATs in set H_i , starting with the least-loaded RAT. If the call cannot be admitted into any of the RATs in set H_i with at least $b_{i, \text{min}}$, bandwidth adaptation algorithm will be invoked to reduce the bandwidth of some ongoing call(s) in order to free just enough bbu for the incoming call. For new class- i calls, if the call still cannot be admitted with $b_{i, \text{min}}$ to any of the RATs in set H_i after downgrading all the ongoing calls, the new call will be rejected. For handoff calls, if the call cannot be admitted with $b_{i, \text{min}}$ to any of the RATs in set H_i after downgrading all the ongoing new and handoff calls. The handoff call will be rejected.

B. Bandwidth Reservation Unit

In order to maintain lower handoff dropping probability, we reserve certain bandwidth exclusively for handoff calls in all cells of each group of co-located cells. Fig. 3 shows the bandwidth allocation policy for the two-class three-RAT heterogeneous network. The different colour codes show the bbu available for use by different classes of calls.



Fig. 3. Bandwidth allocation policy

C. Bandwidth Adaptation Unit

Bandwidth adaptation unit executes the bandwidth adaptation algorithm (BAA). The BAA performs two main procedures: downgrades and upgrades ongoing calls. The downgrading procedure is activated when a call arrives to an overloaded group of co-located cells. BAA reduces the bandwidth of some ongoing call(s) randomly selected in the system to free just enough bbu to accommodate the incoming call. The BAA upgrading procedure is activated when there is a call departure event. When a call departs from a RAT in the group of co-located cells, some of the ongoing new or handoff call(s) randomly selected in RAT where the call departs may be upgraded.

IV. MARKOV MODEL

Based on the assumptions made in section 2, the proposed

JCAC and bandwidth management scheme can be modeled as a multidimensional Markov chain. The current state of the heterogeneous system is represented as follows.

$$x = (m_{i,j}, n_{i,j} : i = 1, \dots, k, j \in \{h_i\}) \quad (1)$$

The non-negative integers $m_{i,j}$ and $n_{i,j}$ denote respectively, the number of ongoing new and handoff class- i calls in RAT j .

We illustrate the proposed JCAC and bandwidth management scheme using the two-class three-RAT JCAC heterogeneous network in Fig 1. The state space of the two-class three-RAT heterogeneous cellular network is as follows:

$$x = (m_{11}, m_{12}, m_{22}, m_{23}, n_{11}, n_{12}, n_{22}, n_{23})$$

Let S denote the state space of all admissible state as it evolves over time. An admissible state s is a combination of the numbers of users in each class that can be simultaneously supported in the group of co-located cells while maintaining adequate QoS and meeting resource constraints. The state S of all admissible states is given as:

$$S = \{x = (m_{11}, m_{12}, m_{22}, m_{23}, n_{11}, n_{12}, n_{22}, n_{23}) \mid$$

$$\sum_{c=1}^{m_{1,1}} b_{1, \text{assigned}_c} \leq T_{11} \wedge \left(\sum_{c=1}^{m_{1,1}} b_{1, \text{assigned}_c} + \sum_{c=1}^{n_{1,1}} b_{1, \text{assigned}_c} \leq C_1 \right) \wedge$$

$$\sum_{c=1}^{m_{1,2}} b_{1, \text{assigned}_c} \leq T_{2,1} \wedge \left(\sum_{c=1}^{m_{1,2}} b_{1, \text{assigned}_c} + \sum_{c=1}^{n_{1,2}} b_{1, \text{assigned}_c} \leq T_{22} \right) \wedge$$

$$\sum_{c=1}^{m_{2,2}} b_{2, \text{assigned}_c} \leq (T_{23} - T_{22}) \wedge$$

$$\left(\sum_{c=1}^{m_{2,2}} b_{2, \text{assigned}_c} + \sum_{c=1}^{n_{2,2}} b_{2, \text{assigned}_c} \leq (C_2 - T_{22}) \right) \wedge$$

$$\sum_{c=1}^{m_{2,3}} b_{2, \text{assigned}_c} \leq T_{31} \wedge \left(\sum_{c=1}^{m_{2,3}} b_{2, \text{assigned}_c} + \sum_{c=1}^{n_{2,3}} b_{2, \text{assigned}_c} \leq C_3 \right) \quad (2)$$

The constraints simply state that the sum of the bandwidth units of all admitted class- i calls cannot be more than the total bandwidth units available for that class of calls.

The decision epochs are the arrival or departure of a new or handoff call. Joint call admission decisions are taken in the arrival epoch. Every time a new or handoff class- i call arrives in the group of co-located cells, the JCAC algorithm decides whether or not to admit the call, and in which RAT to admit it. Note that no call admission decision is made in the group of co-located cells when a call departs. When the system is in state s , an accept/reject decision must be made for each type of possible arrival in the group of co-located cells. The possible JCAC decisions in the arrival epoch are as follows:

1) Reject the new or handoff class- i call in the group of collocated cells, in which case the state s does not evolve.

2) Admit the new or handoff class- i call into RAT j (RAT $j \in H_i$) without adapting the bandwidth of ongoing call(s) in the RAT, in which case the state s evolves.

3) Admit the new or handoff class- i call into RAT j (RAT $j \in H_i$) after adapting the bandwidth of ongoing call(s) in the RAT, in which case state s evolves.

Thus, the call admission action space A can be expressed as follows:

$$A = \{a = (a_1^n, \dots, a_k^n, a_1^h, \dots, a_k^h) : a_i^n, a_i^h \in \{\pm v : v = 0 \text{ or } v \in h_i\}, \quad \forall i \quad (3)$$

where a_i^n denotes the action taken on arrival of a new class- i call within the group of co-located cells, and a_i^h denotes the action taken on arrival of a handoff class- i call from an adjacent group of co-located cells. a_i^n (or a_i^h) = 0 means reject the new (or handoff) class- i call. a_i^n (or a_i^h) = +1 means accept the new (or handoff) f class- i call into RAT 1 without adapting the bandwidth of existing call(s). a_i^n (or a_i^h) = -1 means accept the new (or handoff) class- i call into RAT 1 after adapting (degrading) the bandwidth of some existing call(s). a_i^n (or a_i^h) = + j means accept the new (or handoff) class- i call into RAT j ($j \in h_i$) without adapting the bandwidth of existing call. a_i^n (a_i^h) = - j ($j \in h_i$) means accept the new (or handoff) class- i call into RAT j after adapting the bandwidth of existing call. For the two-class heterogeneous cellular network, $a_1^n, a_1^h = (0, 1, -1, 2, -2)$, $a_2^n, a_2^h = (0, 2, -2, 3, -3)$.

In the departure epoch, the bandwidth adaptation unit makes the decision to adapt (upgrade) or not to adapt the bandwidth of ongoing call(s). Thus, the call departure action space W can be expressed as follows:

$$W = \{w = (0, 1)\}$$

where $w = 0$ means do not adapt the bandwidth of the ongoing call(s) and $w = 1$ means adapt the bandwidth. of the call(s).

A. Splitting of the Arrival Process

For new class- i calls, let Cn_{ij} denotes the total bbu available in RAT j (RAT $j \in H_i$), α_{ij} denotes the fraction of bbu available in RAT j over the summation of bbu available in all the RATs in set H_i , and x_{ij} denotes the residual bbu available in RAT j . For handoff class- i calls, the corresponding values are Ch_{ij} , β_{ij} , and y_{ij} respectively. Then:

$$\alpha_{ij} = \frac{Cn_{ij}}{\sum_{j \in H_i} Cn_{ij}} \quad \forall i \quad (4)$$

$$\sum_{j \in H_i} \alpha_{ij} = 1 \quad \forall i \quad (5)$$

Similarly,

$$\beta_{ij} = \frac{Ch_{ij}}{\sum_{j \in H_i} Ch_{ij}} \quad \forall i \quad (6)$$

$$\sum_{j \in H_i} \beta_{ij} = 1 \quad \forall i \quad (7)$$

When a new or handoff call arrives into a group of co-located cells, the JCAC algorithm selects the least loaded RAT in set H_i for the incoming call. The action of selecting a RAT for each arriving new or handoff call in the group of co-located cells leads to splitting of the arrival process. Fig. 4 illustrates the splitting of the arrival process for the two-class three-RAT heterogeneous network.

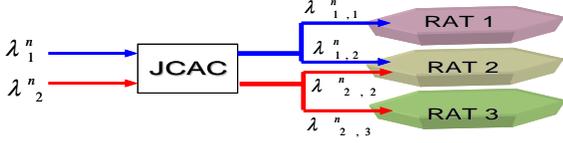


Fig. 5. Splitting of the arrival process in the group of co-located cells.

As shown in Fig. 4, the arrival rate of class- i calls in the group of co-located cells is split among all the RATs in set H_i . Each RAT has a fraction of the arrival rate (λ_i^n). The JCAC algorithm try to uniformly distribute traffic load of class- i calls among all the RAT in set H_i by always selecting the least loaded RAT in the set. Therefore the mean arrival rates of class- i calls into each RAT in set H_i in the group of collocated cells are as follows:

$$\lambda_{i,j}^n = \alpha_{i,j} \lambda_i^n \quad \forall i, j \in h_i \quad (8)$$

$$\lambda_i^n = \sum_{j \in h_i} \lambda_{i,j}^n \quad \forall i \quad (9)$$

Similarly $\lambda_{i,j}^h = \beta_{i,j} \lambda_i^h \quad \forall i, j \in h_i \quad (10)$

$$\lambda_i^h = \sum_{j \in h_i} \lambda_{i,j}^h \quad \forall i \quad (11)$$

where λ_i^n and λ_i^h denote the arrival rates of new class- i calls and handoff class- i calls respectively, into the group of co-located cells. $\lambda_{i,j}^n$ and $\lambda_{i,j}^h$ denote the arrival rates of new class- i calls and handoff class- i calls respectively, into RAT j in the group of co-located cells

The arrival rates of a split Poisson process are also Poisson [12]. Therefore, given that the mean arrival rate of class- i calls into the group of co-located cells is Poisson, the mean arrival rates of the split class- i calls into RAT j (\forall RAT $j \in H_i$) are also Poisson.

For the two-class three-RAT heterogeneous network shown in Fig. 4, $\lambda_{11}^n = \alpha_{11} \lambda_1^n$, $\lambda_{12}^n = \alpha_{12} \lambda_1^n$, $\lambda_{22}^n = \alpha_{22} \lambda_2^n$, $\lambda_{23}^n = \alpha_{23} \lambda_2^n$. Similarly, $\lambda_{11}^h = \alpha_{11} \lambda_1^h$, $\lambda_{12}^h = \alpha_{12} \lambda_1^h$, $\lambda_{22}^h = \alpha_{22} \lambda_2^h$, $\lambda_{23}^h = \alpha_{23} \lambda_2^h$.

Based on its Markovian property, the proposed JCAC scheme can be model as a multi-dimensional Markov chain. Let $\rho_{new\ i,j}$ and $\rho_{han\ i,j}$ denote the load generated by new and handoff class- i calls, respectively, in RAT j . Then,

$$\rho_{new\ i,j} = \frac{\lambda_{i,j}^n}{\mu_i^n} \quad \forall i, j \in h_i, \quad (12)$$

$$\rho_{han\ i,j} = \frac{\lambda_{i,j}^h}{\mu_i^h} \quad \forall i, j \in h_i \quad (13)$$

From the steady state solution of the Markov model, performance measures of interest can be determined by summing up appropriate state probabilities. Let $P(s)$ denotes the steady state probability that the system is in state s ($s \in \mathcal{S}$). From the detailed balance equation, $P(s)$ is obtained as:

$$P(s) = \frac{1}{G} \prod_{i=1}^k \prod_{j \in h_i} \frac{(\rho_{new\ i,j})^{m_{i,j}} (\rho_{han\ i,j})^{n_{i,j}}}{m_{i,j}! n_{i,j}!} \quad \forall s \in \mathcal{S} \quad (14)$$

where G is a normalization constant given by:

$$G = \sum_{s \in \mathcal{S}} \prod_{i=1}^k \prod_{j \in h_i} \frac{(\rho_{new\ i,j})^{m_{i,j}} (\rho_{han\ i,j})^{n_{i,j}}}{m_{i,j}! n_{i,j}!} \quad (15)$$

B. Call Blocking Probability and Call dropping Probability

In the heterogeneous wireless network, a new class- i call will be blocked in the group of co-located cells if none of the RATs in set H_i can accommodate the call. For the two-class three-RAT heterogeneous cellular network, a new class-1 call is blocked in the group of co-located cells if it cannot be admitted with $b_{1,\min}$ into RAT 1 or RAT 2 after downgrading all new class-1 calls. Let $S_{b_1} \subset \mathcal{S}$ denotes the set of states in which a new class-1 call is blocked in the group of co-located cells. It follows that:

$$S_{b_1} = \{s \in \mathcal{S} : (b_{1,\min}(1 + m_{11}) > T_{11} \vee b_{1,\min}(1 + m_{11} + n_{11}) > C_1) \wedge (b_{1,\min}(1 + m_{12}) > T_{21} \vee b_{1,\min}(1 + m_{12} + n_{12}) > T_{22})\} \quad (16)$$

A new class-2 call is blocked in the group of co-located cells if it cannot be admitted with the $b_{2,\min}$ into RAT 2 or RAT 3 after downgrading all new class-2 calls. Let $S_{b_2} \subset \mathcal{S}$ denotes the set of states in which a new class-2 call is blocked in the group of co-located cells. It follows that:

$$S_{b_2} = \{s \in \mathcal{S} : (b_{2,\min}(1 + m_{22}) > (T_{23} - T_{22}) \vee b_{2,\min}(1 + m_{22} + n_{22}) > (C_2 - T_{22})) \wedge (b_{2,\min}(1 + m_{23}) > T_{31} \vee b_{2,\min}(1 + m_{23} + n_{23}) > C_3)\} \quad (17)$$

Thus the blocking probability, P_{b_i} ($i=1, 2$) for a new class- i call in the group of co-located cells is given by:

$$P_{b_i} = \sum_{s \in S_{b_i}} P(s) \quad (18)$$

A handoff class-1 call is dropped in the group of co-located cells if after degrading all ongoing class-1 calls, the incoming handoff class-1 call cannot be admitted with $b_{1,\min}$ into RAT 1 or RAT 2. Let $S_{d_1} \subset \mathcal{S}$ ($i=1$) denotes the set of states in which a handoff class- i call is dropped in the group of co-located cells. It follows that:

$$S_{d_1} = \{s \in \mathcal{S} : (b_{1,\min}(1 + m_{1,1} + n_{1,1}) > C_1) \wedge (b_{1,\min}(1 + m_{1,2} + n_{1,2}) > T_{22})\} \quad (19)$$

A handoff class-2 call is dropped in the group of co-located cells if after degrading all ongoing class-2 calls, the incoming handoff class-2 call cannot be admitted with $b_{2,\min}$ into RAT 2 or RAT 3. It follows that:

$$S_{d_2} = \{s \in \mathcal{S} : (b_{2,\min}(1 + m_{2,2} + n_{2,2}) > (C_2 - T_{22})) \wedge (b_{2,\min}(1 + m_{2,3} + n_{2,3}) > C_3)\} \quad (20)$$

Thus the call dropping probability, P_{d_i} , for a handoff class- i call in the group of co-located cells is given by:

$$P_{d_i} = \sum_{s \in S_{d_i}} P(s) \quad (21)$$

V. RESULTS

In this section, we investigate the performance of our JCAC and adaptive bandwidth management scheme (AJCAC) in the two-class three-RAT heterogeneous cellular network with respect to NCBP and HCDP. For comparison, we also model the JCAC algorithm without adaptive bandwidth management in heterogeneous cellular network and derive NCBP and HCDP for the non-adaptive JCAC (NAJCAC) scheme. The arrival rate of handoff class- i calls in the group of co-located cells is assumed to be proportional to the arrival rate of new class- i calls by: $\lambda_i^h = (hh/\mu)\lambda_i^h$ where hh is the handoff rate.

Fig. 5 and Fig. 6 show the effect of varying the new call arrival rate on the NCBP (Pb) and HCDP (Pd). The following system parameters are used: $C_1=20$, $T_{11}=10$, $C_2=50$, $T_{21}=10$, $T_{22}=20$, $T_{23}=35$, $C_3=30$, $T_{31}=15$, $hh=0.5$, $b_1 = 1$, $b_2 = 3$, $\mu_1=\mu_2=0.5$, $\lambda_{n1}=\lambda_{n2}=[1,6]$, $B_1=\{2, 3\}$ where $b_{1,min}=2$, and $b_{1,req}=3$, $B_2=\{4, 7\}$ where $b_{2,min}=4$, and $b_{2,req}=7$.

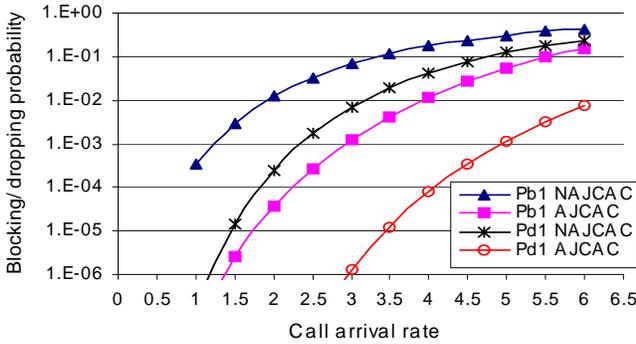


Fig.5. Effect of varying the call arrival rate on NCBP/ HCDP of class-1 calls.

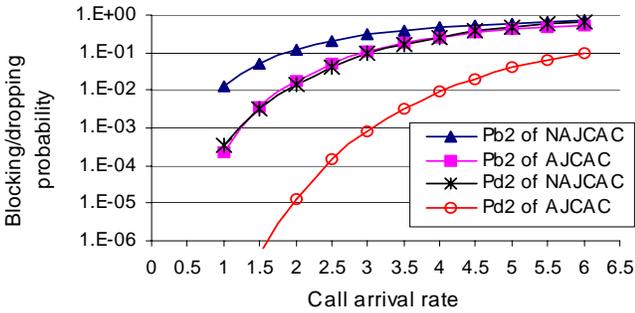


Fig.6. Effect of varying the call arrival rate on NCBP/ HCDP of class-2 calls.

As shown Fig. 5, for class-1 calls, the NCBP (Pb1) and HCDP (Pd1) increase as the new call arrival rate increases for AJCAC and NAJCAC. However, NCBP (Pb1) and HCDP (Pd1) of the AJCAC are always less than the corresponding NCBP (Pb1) and HCDP (Pd1) of the NAJCAC. Moreover, for AJCAC and NAJCAC, HCDP (Pd1) is always less than the corresponding NCBP (Pb1) because handoff calls are prioritized over new calls. Class-2 calls follow a similar trend in Fig 6. NCBP (Pb2) and HCDP (Pd2) of the AJCAC are always less than the corresponding NCBP (Pb2) and HCDP

(Pd2) of the NAJCAC. Furthermore, for AJCAC and NAJCAC, HCDP (Pd2) is less than the corresponding NCBP (Pb2) because handoff calls are prioritized over new calls.

VI. CONCLUSION

This paper proposes service-class-based JCAC and adaptive bandwidth management scheme for heterogeneous cellular networks. The JCAC scheme makes call admission decision based on service class of incoming calls, requested bu, and current load in each of the available RATs. Using Markov chain, we develop an analytical model and derive new call blocking probability and handoff call dropping probability for the JCAC scheme. Performance of the JCAC scheme is compared with that of non adaptive JCAC scheme in the same heterogeneous cellular network. Results show that new call blocking probability and handoff call dropping probability can be significantly reduced by using the proposed JCAC scheme.

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