Analysis of Joint Call Admission Control Strategies for Heterogeneous Cellular Networks

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Abstract

This paper investigates three joint call admission control algorithms (JCAC) for heterogeneous cellular networks. These algorithms are random-selection-based, service-based, and load-based JCAC algorithms. Our approach is based on decomposing heterogeneous cellular networks into groups of co-located cells. We model the JCAC algorithms as a multi-dimensional Markov chain. For each of the three JCAC algorithms, new call blocking probability and handoff call probability are derived and evaluated. The performances of the three JCAC algorithms are compared and the results are presented.

1. Introduction

The co-existence of different cellular networks in the same geographical area necessitates joint radio resource management (JRRM) for enhanced QoS provisioning and efficient radio resource utilization. With JRRM in heterogeneous cellular networks, a mobile subscriber using a multimode terminal can be connected through any of the available radio access technologies (RATs) and switch from one RAT to another.

The traditional call admission control (CAC) algorithms for homogeneous cellular networks determine whether or not a user may be admitted into the networks. Many CAC algorithms have been developed for homogeneous cellular networks. However, homogeneous CAC algorithms do not provide a single solution to address the heterogeneous architectures which characterize next generation wireless networks [1]. This limitation of homogeneous CAC algorithms necessitates the development of JCAC algorithms for heterogeneous wireless networks.

However, unlike homogeneous CAC algorithms, JCAC algorithms do not only decide whether an incoming call can be accepted or not. They also decide which of the available radio access networks is best suited to accommodate the incoming call.

Gelabert et al [2] study the impact of load balancing among different RATs in heterogeneous cellular networks. However handoff calls are not considered in the study. The algorithm deals with initial RAT selection only for new calls. Moreover connection-level QoS metrics such as new call blocking probability (NCBP) and handoff call dropping probability (HCDP) are not investigated.

Romero et al [3], propose a service-based RAT selection policy for heterogeneous wireless networks. They illustrate the selection policy using heterogeneous network comprising GERAN and UTRAN, and a mix of voice and interactive users (e.g. www browsing). However, handoff calls are not considered in study.

In the previous works mentioned above, no analytical model has been developed for JCAC algorithms in order to investigate connection-level QoS parameters in heterogeneous cellular networks. Therefore, this paper models and analyzes JCAC algorithms for heterogeneous cellular networks.

The contributions of the paper are twofold fold. Firstly, we develop analytical models for three JCAC algorithms for heterogeneous cellular networks. Secondly, we compare the performance of these JCAC algorithms using connection-level QoS metrics.

The rest of this paper is organized as follows. In section 2, we describe the three JCAC algorithms. The system model is presented in section 3. In section 4, we analyze the Markov chain model. Results are presented in section 5.

2. Description of the JCAC Algorithms

In this section, we describe the three JCAC algorithms that are investigated in this paper namely random-selection-based (RB) JCAC, load-based (LB) JCAC, and service-based (SB) JCAC.

Random-selection-based JCAC algorithm randomly selects one of the available RATs for an incoming call of any class. If there is no enough radio resource to accommodate the call in the selected RAT, the call is blocked or dropped. Random RAT selection algorithm

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is easy to implement but has high call blocking probability, and low radio resource utilization.

Load-based JCAC algorithm admits an incoming call into the least-loaded RAT in the heterogeneous cellular network. When a class-i call arrives in the heterogeneous network, the JCAC algorithm checks the current load for class-i calls in each of the RATs, and then selects the least-loaded RAT for the incoming class-i call. If the residual capacity of the least-loaded RAT is not enough to accommodate the call, the next least-loaded RAT is selected. The class-i call is blocked or dropped, only if none of the available RATs has enough radio resource to accommodate it.

Service-class-based JCAC algorithms admit calls into a particular RAT based on the service class, such as voice, real-time video, web browsing, etc. This algorithm is based on the fact that different RATs are optimized to support different classes of service. An incoming call of a certain class is admitted into a RAT that is best suited for that class of call. Service-class-based JCAC algorithms have the advantage of high packet-level QoS because the call is admitted into the RAT that can best support it. However, the algorithm may lead to highly unbalanced network load.

3. System Model

We consider a heterogeneous cellular network which consists of r number of RATs with co-located cells, similar to [2]. Cellular networks such as GSM, GPRS, UMTS, etc. can have the same and fully overlapped coverage, which is technically feasible, and may also save installation cost [4]. Fig. 1 illustrates a two-RAT heterogeneous cellular network.

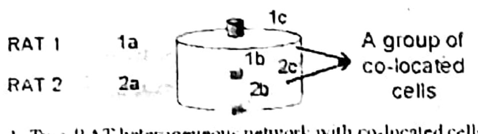

Fig. 1. Two-RAT heterogeneous network with co-located cells.

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Each cell in RAT j (j = 1,...,r) 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. 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 [5-6]. 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 in [6-7].

We decompose the heterogeneous cellular network into groups of co-located cells, as shown in Fig. 1. 1a and 2a form a group of co-located cells. Similarly, 1b and 2b form another group of co-located cells, and so on. 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 RATs [6-7]. Therefore, the types and amount of traffic are statistically the same in all groups of co-located cells.

A newly arriving call will be admitted into one of the cells in the group of co-located cells where the call is located. When a mobile subscriber using a multimode terminal and having an ongoing call is moving from one group of co-located cells to another group of co-located cells, the ongoing call must be handed over to one of the cells in the new group of co-located cells. For example (Fig. 1), an ongoing call can be handed over from cell 1a to cell 1b or from cell 1a to cell 2b. Note that the handover consists of both horizontal and vertical handovers.

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 cells can be modeled and analyzed individually. Therefore, we focus our attention on a single group of co-located cells.

The heterogeneous network supports K classes of users and all users in the same class have the same QoS requirements. Following the general assumption in cellular networks, new and handoff class-i calls (i = 1,..., k) arrive in the group of co-located cells according to Poisson process with rate λn_i and λh_i 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 (the same as the time the mobile terminal stay in a group of co-located cells) during a single visit, is assumed to follow an exponential distribution with mean 1/h, where the parameter h represents the call handoff rate. We assume that the CRT is independent of the service class. Hence, calls in any class follow the same CRT distribution.

The channel holding time is the minimum of the CHT and the CRT. As minimum of two exponentially distributed random variables is also exponentially distributed [6], then the channel holding time for new and handoff class-i calls is assumed to be exponentially distributed with means $1/\mu n_i$ and $1/\mu h_i$ respectively where $\mu n_i = \mu h_i = h + \mu_i$. We also assume that an arriving call that is not admitted immediately is blocked or dropped, i.e., a call is never buffered.

Note that this set of assumptions has been widely used in literature for homogeneous cellular networks and is found to be generally applicable in the environment where the number of mobile users is larger than the number of channels in a cell [8].

3.1. Splitting of Arrival Process

When a call arrives into a group of co-located cells, a JCAC algorithm selects one of the available RATs for the incoming call. The action of selecting a RAT for each arriving call into the group of co-located cells leads to splitting of the arrival process. Fig. 2 illustrates the splitting of the arrival process among r number of RATs in the group of co-located cells. Each of the three JCAC algorithms investigated in this paper splits the arrival process for each class of calls in different proportions.

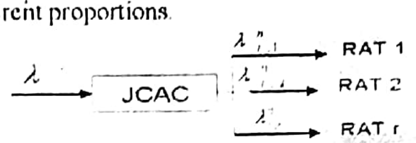

Fig. 2. Splitting of arrival process in the group of co-located cells

Let λn_i and λh_i denote the arrival rates of new and handoff class-i calls respectively, in the group of co-located cells. Furthermore, let λn_{ij} and λm_{ij} denote the arrival rates of new and handoff class-i calls respectively, in RAT j in the group of co-located cells. As shown in Fig. 2, the arrival rate of each class of calls into the group of co-located cells is split into fractional values for all the available RATs. Each RAT has a fraction of the arrival rate. It follows that:

$$\lambda n_i = \sum_{j=1}^{r} \lambda n_{ij} \quad \forall i \tag{1}$$

$$\lambda h_i = \sum_{j=1}^{r} \lambda h_{ij} \quad \forall i \tag{2}$$

Note that the arrival rates of a split Poisson process are also Poisson [9]. In the following, we explain the splitting of the arrival process by each of the three JCAC algorithms.

For random-selection-based JCAC, the probability of selecting a particular RAT for an incoming class-i call is 1/r. Therefore the algorithm splits the arrival process among the available RATs as follows:

$$\lambda n_{ij} = \tfrac{1}{r}\lambda n_i, \; \lambda h_{ij} = \tfrac{1}{r}\lambda h_i \quad \forall i, j$$

For a two-RAT heterogeneous network, r=2

$$\lambda n_{ij} = \tfrac{1}{2}\lambda n_i, \; \lambda h_{ij} = \tfrac{1}{2}\lambda h_i \quad \forall i, j$$

The service-based JCAC admits class-1 calls only into RAT1 and admits class-2 calls only into RAT 2 in a two-RAT heterogeneous network. Therefore, the algorithm splits the arrival process as follows.

Similarly [illegible]

The load-based JCAC algorithm splits the arrival process such that class-i call arrival rate into each RAT is proportional to the maximum capacity (bbu) available for class-i call in each RAT. Let α_{ij} and β_{ij} denote the fraction of bbu available in RAT j over the summation of bbu available in all the RATs for new class-i calls and handoff class-i calls respectively. Also let Cn_{ij} and Ch_{ij} denote the total bbu available in RAT j for new class-i calls and handoff class-i calls respectively. Then

$$\alpha_{ij} = \frac{Cn_{ij}}{\sum_{j=1}^{r} Cn_{ij}} \quad \forall i \tag{3}$$

Similarly,

$$\beta_{ij} = \frac{Ch_{ij}}{\sum_{j=1}^{r} Ch_{ij}} \quad \forall i \tag{4}$$

$$\lambda n_{ij} = \alpha_{ij} \lambda n_i \quad \forall i, j \tag{5}$$

$$\lambda h_{ij} = \beta_{ij} \lambda h_i \quad \forall i, j \tag{6}$$

3.2. Bandwidth Reservation Policy

In order to prioritize handoff calls over new calls we use a threshold-based bandwidth reservation policy. Fig. 3 shows the bandwidth reservation policy for a two-class two-RAT heterogeneous cellular network. T_{0j}, the total basic bandwidth units available for all new calls in RAT j, is the threshold after which new calls will be rejected in RAT j. C_j, the total bbu available in RAT j, is the threshold after which handoff calls will be rejected in RAT j. Note that $T_{0j} = Cn_{ij}$ and $C_j = Ch_{ij}$.

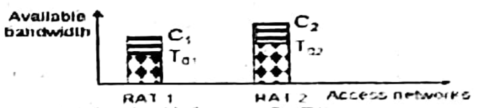

Fig. 3. Accessible bandwidth for a two-RAT heterogeneous network.

4. Markov Chains Model

The JCAC algorithms can be modeled as a multi-dimensional Markov chain. The current state of the heterogeneous system is represented by a row vector of (2*k*r) components as follows.

$$x = (m_{ij}, n_{ij}; \; i = 1, \ldots, k, \; j = 1, \ldots, r) \tag{7}$$

The non-negative integer m_{ij} and n_{ij} denote respectively, the number of ongoing new and handoff class-i calls in RAT j of the group of co-located cells.

Let S ($S \subset X$) 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 radio resource constraints. The admissible state for each of the three JCAC algorithms investigated in this paper is defined later in this section.

Every time a new or handoff class-i call arrives and requests a connection in the group of co-located cell, the JCAC algorithm decides whether or not to admit the call, and in which RAT to admit it.

When the system is in state s, an accept/reject decision must be made for each type of possible arrival, i.e., an arrival of a new class-i call, or the arrival of a handoff class-i call in the group of co-located cells. Thus, the action space A can be expressed as follows:

$$A = \{a = (a_{n_1}, \ldots, a_{n_k}, a_{h_1}, \ldots, a_{h_k}) : a_{n_i}, a_{h_i} \in \{0, 1, \ldots, r\}, i = 1, \ldots, k\} \quad (8)$$

where a_{n_i} denotes the action taken on arrival of a new class-i call within the group of co-located cells and a_{h_i} denotes the action taken on arrival of a handoff class-i call from an adjacent group of co-located cells. a_{ni} (or a_{hi}) = 0 means reject the new (or handoff) class-i call. a_{ni} (or a_{hi}) = 1 means accept the new (or handoff) class-i call into RAT 1. a_{ni} (or a_{hi}) = r means accept the new (or handoff) class-i call into RAT r. In a two-class two-RAT heterogeneous cellular network, for the random-selection-based and load-based JCAC algorithms, $a_{n_1}, a_{n_2}, a_{h_1}, a_{h_2} \in \{0, 1, 2\}$ whereas for the service-based JCAC algorithm, $a_{n1}, a_{h1} \in \{0, 1\}, a_{n2}, a_{h2} \in \{0, 2\}$.

Let ρn_{ij} denotes the load generated by new class-i calls, and let ρh_{ij} denotes the load generated by handoff class-i calls in the cell of RAT j within the group of co-located cells. Then:

$$\rho n_{ij} = \frac{\lambda n_{ij}}{\mu n_i} \quad \forall\, i, j \quad (9)$$

$$\rho h_{ij} = \frac{\lambda h_{ij}}{\mu h_i} \quad \forall\, i, j \quad (10)$$

$$\text{Let } d(s) = \prod_{i=1}^{k} \prod_{j=1}^{r} \frac{\rho n_{ij}^{m_{ij}}}{m_{ij}!} \frac{\rho h_{ij}^{n_{ij}}}{n_{ij}!} \quad (11)$$

The steady state probability that the system is in state s, $P(s)$ is given by:

$$P(s) = \frac{d(s)}{G} \quad (12)$$

where G is a normalization constant given by

$$G = \sum_{s \in S} d(s) \quad (13)$$

Let $S_{bi} \subset S$ denotes the set of states in which a new class-i call is blocked in the group of co-located cells. Thus the blocking probability P_{bi} for a new class-i call in the group of co-located cell is given by

$$P_{bi} = \frac{\sum_{s \in S_{bi}} d(s)}{G} \quad (14)$$

Let $S_{di} \subset S$ denotes the set of states in which a handoff class-i call is dropped in the group of co-located cells. Thus the dropping probability P_{di} for a handoff class-i call in the group of co-located cell is given by

$$P_{di} = \frac{\sum_{s \in S_{di}} d(s)}{G} \quad (15)$$

In the following, we define S, S_{bi} and S_{di} for each of the three JCAC algorithms.

4.1. Random-Selection-Based JCAC

The current state of the group of co-located cells is represented as $x = (m_{11}, m_{12}, m_{21}, m_{22}, n_{11}, n_{12}, n_{21}, n_{22})$.

The state space of all admissible state as it evolves over time is represented as

$$S = \{x = (m_{11}, m_{12}, m_{21}, m_{22}, n_{11}, n_{12}, n_{21}, n_{22}) :$$
$$\sum_{i=1}^{2} m_{ij} b_i \leq T_{ij}, \forall j;$$
$$\sum_{i=1}^{2} (m_{ij} + n_{ij}) b_i \leq C_j, \forall j\} \quad (16)$$

A new class-i call is blocked in the group of co-located cells if the randomly selected RAT cannot accommodate the call. The set of states, Sbi, in which a new class-i call is blocked in the group of co-located cells, is given as follows:

$$S_{bi} = \{s \in S : (b_i + \sum_{i=1}^{2} m_{i1} b_i > T_{01}$$
$$\vee\, b_i + \sum_{i=1}^{2} (m_{i1} + n_{i1}) b_i > C_1) \wedge (b_i + \sum_{i=1}^{2} m_{i2} b_i > T$$
$$\vee\, b_i + \sum_{i=1}^{2} (m_{i2} + n_{i2}) b_i > C_2)\} \quad (17)$$

A handoff class-i call is dropped in the group of co-located cells if the randomly selected RAT cannot accommodate the handoff call. The set of states, S_{di}, in which a handoff class-i call is dropped in the group of co-located cells, is given as follows.

$$S_{di} = \{s \in S : b_i + \sum_{i=1}^{2} (m_{i1} + n_{i1}) b_i > C_1) \ldots$$

$$b_{j}\sum (m_{ij}+n_{ij})b_{i}\leq C_{j}\,\} \quad (18)$$

4.2. Service-based JCAC Algorithm

New and handoff class-1 calls can only be admitted into RAT 1 while new and handoff class-2 calls can only be admitted into RAT-2. The current state of the group of co-located cells is represented as

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

Note that m_{12}, m_{21}, n_{12}, and n_{21} are all equal to zero. The state space of all admissible state as it evolves over time is represented as:

$$S=\{x=(m_{11},m_{22},n_{11},n_{22})\wedge m_{11}b_{1}\leq T_{01}\wedge m_{11}b_{1}+n_{11}b_{1}\leq C_{1}\wedge m_{22}b_{2}\leq T_{02}\wedge m_{22}b_{2}+n_{22}b_{2}\leq C_{2}\,\} \quad (19)$$

A new class-1 call is blocked if the call cannot be admitted into RAT 1. The set of states, S_{b1}, in which a new class-1 call is blocked in the group of co-located cells is given as follows

$$S_{b1}=\{s\in S:(1+m_{11})b_{1}>T_{01}\vee(1+m_{11}+n_{11})b_{1}>C_{1}\} \quad (20)$$

A handoff class-1 call is dropped if the call cannot be admitted into RAT 1. The set of states, S_{d1}, in which a handoff class-1 call is dropped in the group of co-located cells, is given as follows

$$S_{d1}=\{s\in S:(1+m_{11}+n_{11})b_{1}>C_{1}\} \quad (21)$$

A new class-2 call is blocked if the call cannot be admitted into RAT 2. The set of states, S_{b2}, in which a new class-2 call is blocked in the group of co-located cells, is given as follows.

$$S_{b2}=\{s\in S:(1+m_{22})b_{2}>T_{02}\vee(1+m_{22}+n_{22})b_{2}>C_{2}\} \quad (22)$$

A handoff class-2 call is dropped if the call cannot be admitted into RAT 2. The set of states, S_{d2}, in which a handoff class-2 call is dropped in the group of co-located cells, is given as follows

$$S_{d2}=\{s\in S:(1+m_{22}+n_{22})b_{2}>C_{2}\} \quad (23)$$

4.3. Load-based JCAC Algorithm

The state space of all admissible state as it evolves over time is represented as.

$$x=(m_{11},m_{12},m_{21},m_{22},n_{11},n_{12},n_{21},n_{22})$$

$$S=\{x=(m_{11},m_{12},m_{21},m_{22},n_{11},n_{12},n_{21},n_{22}):\sum_{i=1}^{2}m_{ij}b_{i}\leq T_{0j}\ \forall j\wedge\sum_{i=1}^{2}(m_{ij}+n_{ij})b_{i}\leq C_{j}\ \forall j\} \quad (24)$$

A new class-i call is blocked in the group of co-located cells if none of the available RATs can accommodate the new call.

$$S_{bi}=\{s\in S:b_{i}+\sum m_{ij}b_{i}>T_{0j}\vee$$

$$b_{i}+\sum (m_{ij}+n_{ij})b_{i}>C_{j},\ \forall j\} \quad (25)$$

A handoff class-i call is dropped in the group of co-located cells if none of the available RATs has enough basic bandwidth units to accommodate the handoff call.

$$S_{di}=\{s\in S:b_{i}+\sum (m_{ij}+n_{ij})b_{i}>C_{j},\ \forall j\} \quad [illegible]$$

5. Results

In this section, we present the results of the three JCAC algorithms in a two-RAT heterogeneous cellular network. The arrival rate of handoff class-i calls is assumed to be proportional to the arrival rate of new class-i calls by [illegible]

Fig. 4 shows the effect of varying the new call arrival rate on the NCBP for class-1 and class-2 calls for each of the three JCAC algorithms. The following system parameters are used: $C_1=15$, $C_2=30$, $b_1=1$, $b_2=3$, $T_{01}=8$, $T_{02}=16$, $h=0.5$, $\mu_1=\mu_2=0.5$, $\lambda n_1=\lambda n$, $\lambda n_2=0.5\lambda n$. As shown in Fig. 4, the NCBP for each of the three JCAC algorithms increases as the new call arrival rate increases. The load-based JCAC algorithm has the least NCBP for the two classes of calls whereas the random-selection-based algorithm has the highest NCBP for the two classes of calls.

Fig. 5 shows the effect of varying the new call arrival rate on the HCDP for class-1 and class-2 calls for each of the three JCAC algorithms. The system parameters used are the same as the parameters used in Fig. 4. In Fig. 5, we can see that the HCDP increases with increase in new call arrival rate. However, the load-based JCAC has the least HCDP whereas the random-selection-based JCAC has the highest HCDP. It can also been see that HCDP is always lower than the NCBP (Fig. 4) for the two call classes for each of the three JCAC algorithms.

Fig. 6 shows the effect of varying the new call threshold, T_0 on the NCBP for the three JCAC algorithms. The system parameters used are as follows: $C_1=15$, $C_2=30$, $b_1=1$, $b_2=3$, $T_{01}=T_0$, $T_{02}=2T_0$, $h=0.5$, $\mu_1=\mu_2=0.5$, $\lambda n_1=2$, $\lambda n_2=1$. At low threshold values, the NCBP, Pb1 and Pb2 for each of the three JCAC algorithms are high. As the threshold value, T_0 increases, Pb1 and Pb2 decreases. However, load-based JCAC algorithm has the least values of Pb1 and Pb2 whereas random-selection-based JCAC has the highest values Pb1 and Pb2.

Fig. 7 shows the effect of varying the new call threshold T_0 on the HCDP for the three JCAC algorithms. The system parameters used are the same as the parameters used in Fig. 6. As shown in Fig. 7, the HCDP, Pd1 and Pd2 of each of the three JCAC algorithms are very low at low threshold values. As the threshold value increases, HCDP increases because of the higher degree of sharing of the network resources between the new calls and handoff calls. However, load-based JCAC algorithm has the least values of Pd1 and Pd2 whereas random-selection based JCAC has the highest values Pd1 and Pd2.

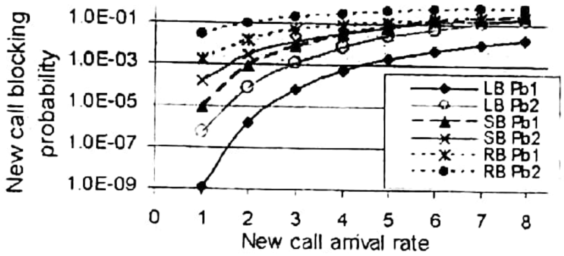

Fig. 4. Comparison of the new the call blocking probability for the three JCAC algorithms

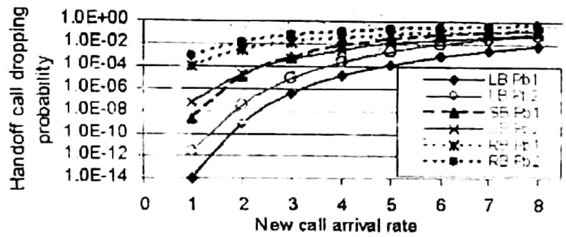

Fig. 5. Comparison of the handoff call dropping probability for the three JCAC algorithms

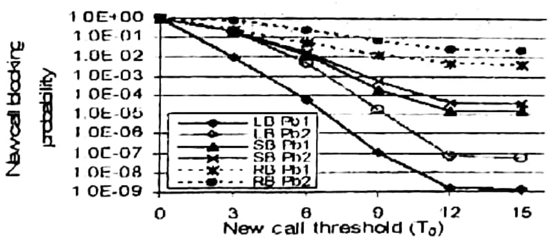

Fig. 6. Effect of varying the new call threshold on the new call blocking probability.

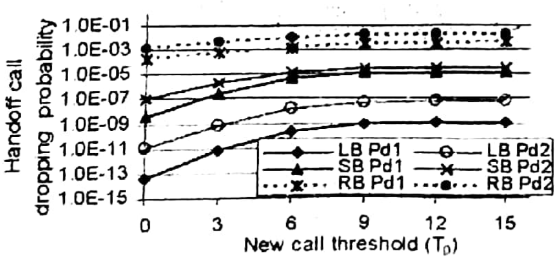

Fig. 7. Effect of varying the new call threshold on the handoff call dropping probability

6. Conclusions

This paper investigates random-selection based JCAC, service-based JCAC and load-based JCAC algorithms in heterogeneous cellular networks. We decompose heterogeneous cellular networks into groups of co-located cells and develop analytical models for the JCAC algorithms. Using Markov chain, we derive and evaluate new call blocking probability and handoff call dropping probability for each of the three JCAC algorithms. Handoff calls are prioritized over new calls by using different rejection thresholds for new and handoff calls. Performances of the JCAC algorithms are compared. Results show that random-selection based JCAC algorithm has the least connection-level QoS performance whereas load-based JCAC algorithm has the best connection-level QoS performance.

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