

Radio Resource Management in Heterogeneous Cellular Networks

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1. Introduction

The evolution of cellular networks from one generation to another has led to the deployment of multiple radio access technologies (such as 2G/2.5G/3G/4G) in the same geographical area. This scenario is termed heterogeneous cellular networks. In heterogeneous cellular networks, radio resources can be jointly or independently managed. When radio resources are jointly managed, joint call admission control algorithms are needed for making radio access technology selection decisions. This chapter gives an overview of joint call admission control in heterogeneous cellular networks. It then presents a model of load-based joint call admission control algorithm. Four different scenarios of call admission control in heterogeneous cellular networks are analyzed and compared. Simulation results are given to show the effectiveness of call admission control in the different scenarios.

The coexistence of different cellular networks in the same geographical area necessitates joint radio resource management (JRRM) for enhanced QoS provisioning and efficient radio resource utilization. The concept of JRRM arises in order to efficiently manage the common pool of radio resources that are available in each of the existing radio access technologies (RATs) (Pérez-Romero *et al*, 2005). In heterogeneous cellular networks, the radio resource pool consists of resources that are available in a set of cells, typically under the control of a radio network controller or a base station controller.

There are a number of motivations for heterogeneous wireless networks. These motivations are (1) limitation of a single radio access technology (RAT), (2) users' demand for advanced services and complementary features of different RATs, and (3) evolution of wireless technology. Every RAT is limited in one or more of the following: data rate, coverage, security-level, type of services, and quality of service it can provide, etc. (Vidales *et al*, 2005). A motivation for heterogeneous cellular networks arises from the fact that no single RAT can provide ubiquitous coverage and continuous high QoS levels across multiple smart spaces, e.g. home, office, public smart spaces, etc. Moreover, increasing users' demand for advanced services that consume a lot of network resources has made network researchers develop more and more spectrally efficient multiple access and modulation schemes to support these services. Consequently, wireless networks have evolved from one generation to another. However, due to huge investment in existing RATs, operators do not readily discard their existing RATs when they acquire new ones. This situation has led to coexistence of multiple RATs in the same geographical area.

In wireless networks, radio resource management algorithms are responsible for efficient utilization of the air interface resources in order to guarantee quality of service, maintain the planned coverage area, and offer high capacity. In heterogeneous cellular networks, radio resource can be independently managed as shown in Figure 1 or jointly managed as shown in Figure 2. However, joint management of radio resources enhances quality of service and improves overall radio resource utilization in heterogeneous cellular networks.

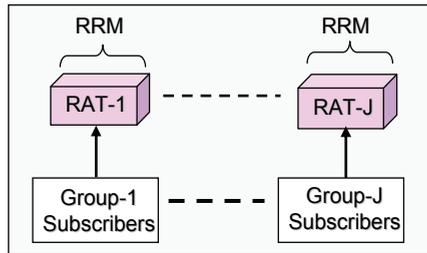


Fig. 1. Independent RRM in heterogeneous wireless networks.

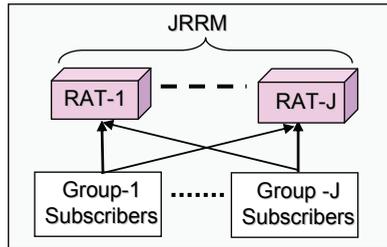


Fig. 2. Joint RRM in heterogeneous wireless networks

With joint radio resource management in heterogeneous cellular networks, mobile users will be able to communicate through any of the available radio access technologies (RATs) and roam from one RAT to another, using multi-mode terminals (MTs) (Gelabert et al, 2008), (Falowo & Chan, 2007), (Falowo & Chan, 2010), (Lee et al, 2009), (Niyato & Hossain, 2008). Figure 3, adapted from (Fettweis, 2009), shows a two-RAT heterogeneous cellular network with collocated cells.

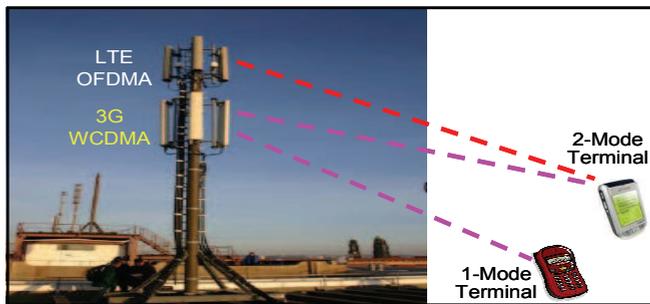


Fig. 3. A typical two-RAT heterogeneous cellular network with co-located cells.

Availability of multi-mode terminals is very crucial for efficient radio resource management in heterogeneous wireless networks. A mobile terminal can be single-mode or multi-mode. A single-mode terminal has just a single RAT interface, and therefore can be connected to only one RAT in the heterogeneous wireless network. A multi-mode terminal has more than one RAT interface, and therefore can be connected to any of two or more RATs in the heterogeneous wireless network.

As show in Figure 3, a subscriber using a two-mode terminal will be able to access network services through either of the two RATs. However, a subscriber using a single-mode terminal will be confined to a single RAT, and cannot benefit from joint radio resource management in the heterogeneous wireless network.

In heterogeneous cellular networks, radio resources are managed by using algorithms such as joint call admission control algorithms, joint scheduling algorithms, joint power control algorithms, load balancing algorithms, etc. This chapter focuses on joint call admission control (JCAC) algorithms in heterogeneous cellular networks.

The rest of this chapter is organized as follows. In Section 2, JCAC in heterogeneous cellular network is described. In Section 3, we present a JCAC model and assumptions. In Section 4, we investigate the performance of the JCAC algorithm through numerical simulations.

2. Joint Call Admission Control in heterogeneous cellular networks

JCAC algorithm is one of the JRRM algorithms, which decides whether an incoming call can be accepted or not. It also decides *which of the available radio access networks is most suitable to accommodate the incoming call*. Figure 4 shows call admission control procedure in heterogeneous cellular networks.

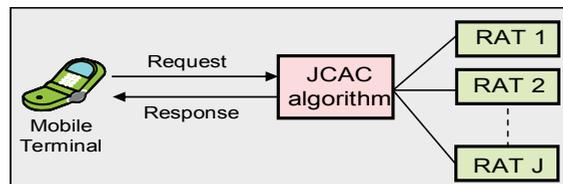


Fig. 4. Call admission control procedure in heterogeneous cellular networks.

A multi-mode mobile terminal wanting to make a call will send a service request to the JCAC algorithm. The JCAC scheme, which executes the JCAC algorithm, will then select the most suitable RAT for the incoming call.

Generally, the objectives of call admission control algorithm in heterogeneous cellular networks are:

1. Guarantee the QoS requirements (data rate, delay, jitter, and packet loss) of accepted calls.
2. Minimize number vertical handoffs,
3. Uniformly distribute network load as much as possible,
4. Minimize call blocking/dropping probability,
5. Maximize operators' revenue,
6. Maximize radio resource utilization

All the above objectives cannot be simultaneously realized by a single JCAC algorithm. Thus, there are tradeoffs among the various objectives.

2.1 RAT selection approaches used in JCAC algorithms

A number of RAT selection approaches have been proposed for JCAC algorithms in heterogeneous cellular networks. These approaches can be broadly classified as single-criterion or multiple-criteria. Single-criterion JCAC algorithms make call admission decisions considering mainly just one criterion, such as network load, service cost, service class, random selection, path loss measurement, RAT layer, and terminal modality. On the other hand, multiple-criteria JCAC algorithms make RAT selection decisions based on a combination of multiple criteria. The multiple criteria are combined using computational intelligent technique (such as fuzzy logic, Fuzzy-neural, Fuzzy MADM (Multiple Attribute Decision Making, etc.) or non-computational intelligent technique (such as cost function). Figure 5 summarizes the different approaches for making RAT selection decisions by JCAC algorithms.

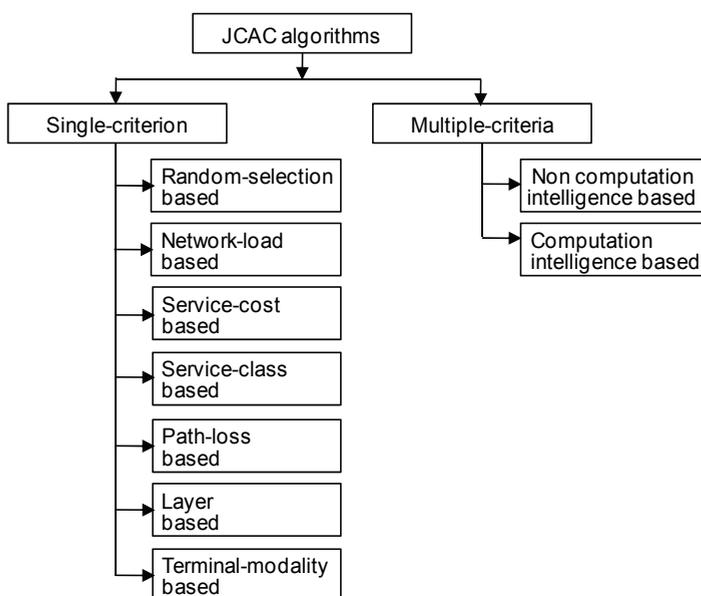


Fig. 5. RAT selection approaches for JCAC algorithm in heterogeneous cellular networks.

2.2 Bandwidth allocation techniques

In order to give different levels of priorities to different calls in wireless networks, it may be necessary to allocate certain block of basic bandwidth units (bbu) for new and handoff calls as well as for different classes of calls such as voice, video, etc.. In this section, bandwidth allocation strategies for wireless networks are reviewed. Bandwidth allocation strategies for wireless networks can be classified into four groups namely complete sharing, complete partitioning, handoff call prioritization, and service class prioritization. This classification is summarized in Table 1.

Bandwidth Allocation Strategy	Main Idea	Advantage	Disadvantage
Complete Sharing	An incoming call is accepted, regardless of the class/ type, as long as there is enough radio resource to accommodate it.	Implementation simplicity and high radio resource utilization	High handoff call dropping probability. No differential treatment for calls with stringent QoS requirements
Complete Partitioning	Available bandwidth is partitioned into pools and each pool is dedicated to a particular type of calls. An incoming call can only be admitted into a particular pool.	Implementation simplicity	Poor radio resource utilization
Handoff Call Prioritization	Handoff calls are given more access to radio resources than new calls. New calls may be blocked whereas handoff calls are still being admitted.	Low handoff call dropping probability	High new call blocking probability
Service-Class Prioritization	Certain classes of calls are given preferential treatment over some other classes of calls. For example, class-1 calls may be blocked whereas class-2 calls are still being admitted.	Differential treatments of calls based on QoS requirements	Implementation complexity

Table 1. Summary of Bandwidth Allocation Strategies for Wireless Networks.

2.2.1 Complete sharing

Complete sharing scheme is a first come first serve scheme and it is the simplest bandwidth allocation policy. It is a non-prioritization scheme in which new and handoff calls are treated the same way. An incoming call is accepted as long as there is enough radio resource to accommodate it. When the network gets to its maximum capacity, a new call will be blocked while a handoff call will be dropped. Two major advantages of complete sharing CAC scheme are implementation simplicity and good radio resource utilization. However, it has a high handoff call dropping probability because it does not give preference to any call. Consequently, complete sharing CAC scheme has a poor QoS performance (Ho, C. & Lea, C. 1999). Figure 6 is the state transition diagram for complete sharing scheme where $\lambda_n, \lambda_h, \mu_n$ and μ_h represent new call arrival rate, handoff call arrival rate, new call departure rate, and handoff call departure rate respectively.

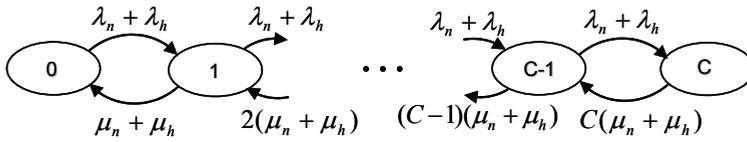


Fig. 6. State transition diagram for complete sharing policy.

2.2.2 Complete partitioning

In the complete partitioning CAC scheme, entire available bandwidth is partitioned into pools. Each pool is dedicated to a particular type of calls (new or handoff calls) and/or particular traffic class of calls. An incoming call is admitted if there is an available channel in the pool allocated for the type/class of the incoming call. This policy allocates a fixed bandwidth C_1 (C_2) to service s_1 (s_2) such that $C_1 + C_2 \leq C$. The acceptable states of this policy are a subset of the complete sharing case. This is a case of two independent queues, and the blocking probability is given by the well known Erlang-B formula.

Figure 7 and Figure 8 are the state transition diagrams of a system where the available resource (C) is partitioned into two (C_1 and C_2). C_1 is used for new calls (Figure 7) whereas C_2 is used for handoff calls (Figure 8).

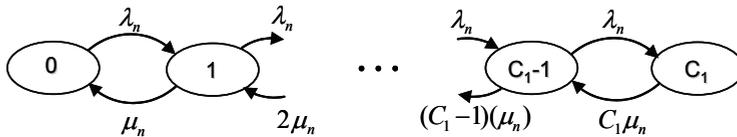


Fig. 7. State transition diagram for complete partitioning policy: first partition.

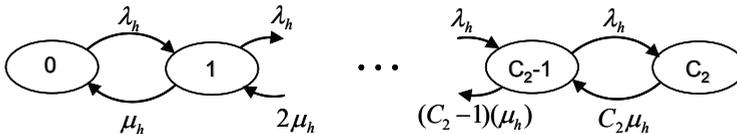


Fig. 8. State transition diagram for complete partitioning policy: second partition.

2.2.3 Handoff call prioritization

Due to users' mobility within the coverage of wireless networks, an accepted call that has not been completed in the current cell has to be transferred (handed over) to another cell. The call may not be able to get a channel in the new cell to continue its service due to limited radio resources in wireless networks. Eventually, it may be dropped. However, wireless network subscribers are more intolerant to dropping a handoff call than blocking a new call. Therefore, in order to ensure that handoff call dropping probability is kept below a certain level, handoff calls are usually admitted with a higher priority compared with new calls. Handoff call prioritization has an advantage of low handoff call dropping probability. However, the advantage of low handoff call probability is at the expense of new call blocking probability, which is high. Several handoff-priority-based schemes have been proposed in the literature. Some of these schemes are briefly reviewed as follows:

Guard Channel

In Guard Channel scheme, some channels (referred to as guard channels) are specifically reserved in each cell to take care of handoff calls. For example, if the total number of available channels in a single cell is C and the number of guard channels is $C - H$, a new call is accepted if the total number of channels used by ongoing calls (i.e., busy channels) is less than the threshold H , whereas a handoff call is always accepted if there is an available channel (Hong & Rappaport, 1986). 1. Guard channel (GC) scheme can be divided into two categories namely static and dynamic strategies. In static guard channel scheme, the value of H is constant whereas in dynamic guard channel scheme, H varied with the arrival rates of new and handoff calls. Figure 9 shows the state transition diagram for a single-class service using guard bandwidth scheme.

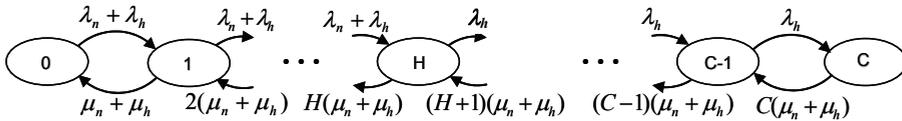


Fig. 9. State transition diagram for guard bandwidth scheme.

Fractional Guard Channel

In fractional guard channel scheme, handoff calls are prioritized over new calls by accepting an incoming new call with a certain probability that depends on the number of busy channels. In other words, when the number of busy channels becomes larger, the acceptance probability for a new call becomes smaller, and vice versa. This approach helps to reduce the handoff call dropping probability. The policy has a threshold, H for limiting the acceptance of new calls. A handoff is accepted as long as there is a channel available. Before the wireless system gets to threshold, H , new calls are accepted with a probability of 1. After threshold, H , a new call is accepted with a probability of α_p where $0 \leq \alpha_p \leq 1$ and $H < p < C$. New calls are rejected when the system reaches the maximum capacity. Figure 10 is the state transition diagram for fractional guard bandwidth policy.

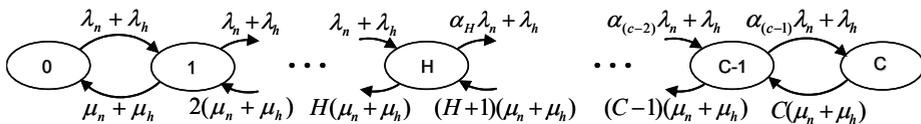


Fig. 10. State transition diagram for fractional guard bandwidth policy.

Queuing Priority Scheme

Queuing priority scheme accepts calls (new and handoff) whenever there are free channels. When all the channels are occupied, handoff calls are queued while new calls are blocked or all incoming calls are queued with certain rearrangement in the queue. When radio resource becomes available, one or some of the calls in the handoff queue are served until there is no more resource. The remaining calls are queued until resource becomes available again. However, a call is only queued for a certain period of time. If radio resource is not available within this period, the call will be dropped.

The main disadvantage of queuing priority scheme is that it needs a lot of buffers to deal with real-time multimedia traffic. It also needs a sophisticated scheduling mechanism in

order to meet the QoS requirements of delay-sensitive calls, i.e. to guarantee that the queued data will be transmitted without excessive delay. (Chen, *et al*, 2002).

QoS Degradation Scheme

QoS degradation can either be bandwidth degradation or delay degradation. In bandwidth degradation method, calls are categorized as adaptive (degradable) and non-adaptive (non-degradable) calls. Degradable calls have flexible QoS requirements (e.g., minimum and maximum data rates). For most multimedia applications, e.g., voice over IP or video conferencing, service can be degraded temporarily as long as it is still within the pre-defined range. Bandwidth degradation reduces handoff call dropping by reducing the bandwidth of the ongoing adaptive calls during network congestion. When a handoff call arrives and there is network congestion, the system is able to free some radio resource to admit the handoff calls by degrading some of the ongoing adaptive calls. In delay degradation method, the amount of radio resources allocated to non-real-time (delay-tolerant) services is reduced during network congestion. When a handoff call arrives and there is no radio resource to accommodate the handoff call. Some non-real-time services are degraded to free some bandwidth, which is used to accommodate the incoming handoff call.

2.2.4 Service-class prioritization

In wireless systems which support multiple service classes, the limited bandwidth has to be shared among the multiple traffic classes. Complete sharing scheme allows the network radio resource to be shared among the various service classes without preference for any class. However, one major challenge in the design of CAC policy is to provide preferential treatment among users of different service classes while still utilizing the system resources efficiently. Preferential treatments are given to certain classes of calls for the following reasons: (1) some calls (such as voice call) have stringent QoS requirements and therefore require preferential treatment. (2) Some subscribers in a particular service class are willing to pay more for better QoS. Service class prioritization scheme is more complicated than complete sharing and complete partitioning schemes.

Figure 11 shows the prioritization scheme used in this paper. As shown in the figure, the two-class J-RAT heterogeneous wireless network (where J is the total number of RATs in the network) has different thresholds for prioritizing the two classes of calls. T_{h1j} and T_{h2j} are the thresholds for rejecting class-1 and class-2 handoff calls in RAT j, respectively whereas T_{n1j} and T_{n2j} are the thresholds for rejecting class-1 and class-2 new calls in RAT j, respectively. It can be seen that handoff calls are prioritized over new call by using higher thresholds for handoff call. It can also be seen that class-1 calls are prioritized over class-2 calls. The rejection thresholds can be static or dynamic. Static thresholds are very simple to implement but are less efficient whereas dynamic threshold are more efficient but are more complicated.

Bandwidth allocation to individual calls in cellular networks can be static or adaptive. In static bandwidth allocation, a fixed unit of radio resource is allocated to each call, and the allocated unit is fixed during the entire duration of the call. In adaptive bandwidth allocation, resource allocated to each call varies between a minimum value and a maximum value. When the network is underutilized, maximum amount of radio resources are allocated to certain type of calls (adaptive calls). However, when the network is being over subscribed, minimum amount of radio resources are allocated to adaptive calls in order to free up some amount of radio resources to accommodate more calls. Adaptive bandwidth allocation improves radio resource allocation efficiency but it is more complicated. They also

incur more signalling overhead. Figure 12 shows adaptive bandwidth allocation allocation for class-i calls, where $b_{i,min}$ and $b_{i,max}$ are the minimum and maximum bandwidth units that can be allocated to class-i calls respectively. For fixed bandwidth allocation, $b_{i,min} = b_{i,max}$.

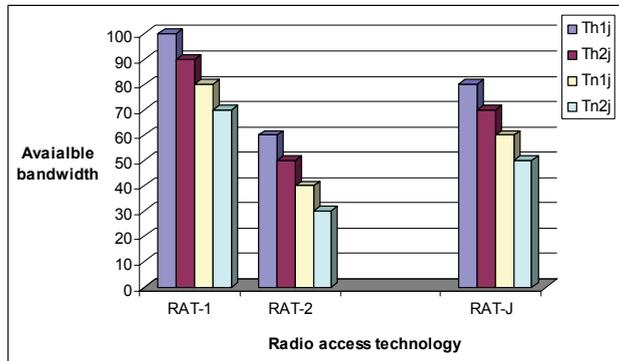


Fig. 11. Call prioritization in a two-class J-RAT heterogeneous wireless network.

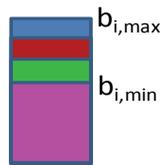


Fig. 12. Bandwidth allocation for adaptive calls.

3. Modelling of joint call admission control algorithm in heterogeneous cellular networks

We present a model of a load-based JCAC algorithm in a two-RAT heterogeneous cellular network supporting two classes of calls: class-1 call (voice) and class-2 call (video). The load based-JCAC algorithm admits an incoming call into the least loaded RAT in the heterogeneous wireless networks (scenarios 1 and 2 in Table 2). We also consider independent call admission control (ICAC) where radio resources are independently managed in the two RATs (scenarios 3 and 4 in Table 2). The four scenarios considered in the simulations are summarized in Table 2.

Scenario	Bandwidth allocation for class-1 and class-2 calls	Resource management	Acronym
1	Adaptive allocation	joint	AJCAC
2	Fixed allocation	joint	FJCAC
3	Adaptive allocation	independent	AICAC
4	Fixed allocation	independent	FICAC

Table 2. Scenarios Considered in the Simulations.

Scenarios 1 and 3 use adaptive bandwidth allocation where full rate bandwidth is allocated to class-1 calls when the network is underutilized whereas half rate bandwidth is allocated

to class-1 calls when the network is over subscribed. Similarly, class-2 calls are allocated a maximum amount of bandwidth when the network is underutilized whereas they are allocated a minimum amount of bandwidth when the network is oversubscribed.

Scenarios 2 and 4 use fixed bandwidth allocation where fixed amount of bandwidth (full rate) is allocated to class-1 calls and fixed amount of bandwidth (maximum rate) is allocated to class-2 calls at all times.

3.1 System model and assumptions

We consider a generic heterogeneous cellular network, which consists of J number of RATs with co-located cells, similar to (Zhang, 2005). Cellular networks such as GSM, GPRS, UMTS, EV-DO, LTE, etc, can have the same and fully overlapped coverage, which is technically feasible, and may also save installation cost (Holma & Toskala, 2001).

We consider cases where radio resources are independently or jointly managed in the heterogeneous network and each cell in RAT j ($j = 1, \dots, J$) has a total of B_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, CDMA, or OFDMA) is used, we could interpret system capacity in terms of effective or equivalent bandwidth. 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 wireless networks in (Falowo & Chan, 2007).

Our approach is based on decomposing a heterogeneous cellular network into groups of co-located cells. As shown in Fig. 3, overlapping cells form a group 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. If the call cannot be admitted into any of the cells it will be blocked. 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. Note that the arrival rates of a split Poisson process are also Poisson (Bertsekas & Tsitsiklis, 2002). The channel holding time for class- i calls is exponentially distributed with mean $1/\mu_i$ (Orlik & Rappaport, 2001).

3.2 Markov model

The load-based based JCAC algorithm can be modeled as a multi-dimensional Markov chain. The state space of the group of co-located cells can be represented by a (2^{*K*J}) -dimensional vector given as:

$$\begin{aligned}
 S = \{ \Omega = (m_{i,j}, n_{i,j} : i = 1, \dots, k, j = 1, \dots, J) : \\
 \sum_{c=1}^{m_{i,j}} b_{i, assigned_c} \leq T n_{i,j} \quad \forall i, j \wedge \\
 \sum_{c=1}^{n_{i,j}} b_{i, assigned_c} \leq T h_{i,j} \quad \forall i, j \wedge \\
 \sum_{i=1}^k \sum_{c=1}^{m_{i,j}} b_{i, assigned_c} + \sum_{i=1}^k \sum_{c=1}^{n_{i,j}} b_{i, assigned_c} \leq B_j \quad \forall j \}
 \end{aligned} \tag{1}$$

The non-negative integer $m_{i,j}$ denotes the number of ongoing new class- i calls in RAT j , and the non-negative integer $n_{i,j}$ denotes the number of ongoing handoff class- i calls in RAT j . S denotes the state space of all admissible states of the group of collocated cells. $B_{i,\text{assigned}}$ is the number of bbu allocated to an incoming class- i call, and the values varies between $b_{i,\text{min}}$ and $b_{i,\text{max}}$.

Let $\rho_{\text{new } i,j}$ and $\rho_{\text{han } i,j}$ denote the load generated by new class- i calls and handoff class- i calls, respectively, in RAT- j . Let $1/\mu_i^n$ and $1/\mu_i^h$ denote the channel holding time of new class- i call and handoff class- i call respectively, and let $\lambda_{i,j}^n$ and $\lambda_{i,j}^h$ denote the arrival rates of new class- i call and handoff class- i call in RAT j , respectively, then,

$$\rho_{\text{new } i,j} = \frac{\lambda_{i,j}^n}{\mu_i^n} \quad \forall i, j, \quad (2)$$

$$\rho_{\text{han } i,j} = \frac{\lambda_{i,j}^h}{\mu_i^h} \quad \forall i, j \quad (3)$$

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 system is in state s ($s \in S$). From the detailed balance equation, $P(s)$ is obtained as:

$$P(s) = \frac{1}{G} \prod_{i=1}^k \prod_{j=1}^J \frac{(\rho_{\text{new } i,j})^{m_{i,j}} (\rho_{\text{han } i,j})^{n_{i,j}}}{m_{i,j}! n_{i,j}!} \quad \forall s \in S \quad (4)$$

where G is a normalization constant given by:

$$G = \sum_{s \in S} \prod_{i=1}^k \prod_{j=1}^J \frac{(\rho_{\text{new } i,j})^{m_{i,j}} (\rho_{\text{han } i,j})^{n_{i,j}}}{m_{i,j}! n_{i,j}!} \quad (5)$$

A new class- i call is blocked in the group of co-located cells if none of the RATs in the group of co-located cells has enough bbu to accommodate the new call. Let $S_{b_i} \subset S$ denote the set of states in which a new class- i call is blocked in the group of collocated cells. Thus the new call blocking probability (NCBP), P_{b_i} , for a class- i call in the group of co-located cells is given by:

$$P_{b_i} = \sum_{s \in S_{b_i}} P(s) \quad (6)$$

A handoff class- i call is dropped in the group of co-located cells if none of the RATs in the group of collocated cells has enough bbu to accommodate the handoff call. Let $S_{d_i} \subset S$ denote the set of states in which a handoff class- i call is dropped in the group of co-located cells. Thus the handoff call dropping probability (HCDF) for a class- i call, P_{d_i} , in the group of co-located cells is given by:

$$P_{d_i} = \sum_{s \in S_{d_i}} P(s) \tag{7}$$

4. Numerical results

In this section, the performance of the JCAC scheme is evaluated through simulations. Results for both class-1 calls and class-2 calls are presented for the four scenarios shown in Table 2. The parameters used in the simulations are $B_1=20$, $B_2=40$, $Tn_{1,1}=Tn_{2,1}=12$, $Th_{1,1}=Th_{2,1}=20$, $Tn_{1,2}=Tn_{2,2}=24$, $Th_{2,1}=Th_{2,2}=40$, $\mu_1=\mu_2=0.5$. Some other parameters used are shown in Table 3.

Scenario	Bandwidth allocation
1	$b_{1,min}=1bbu, b_{2,min}=3bbu, b_{1,max}=2bbu, b_{2,max}=7bbu$
2	$b_{1,min}=b_{1,max}=2bbu, b_{2,min}=b_{2,max}=7bbu$
3	$b_{1,min}=1bbu, b_{2,min}=3bbu, b_{1,max}=2bbu, b_{2,max}=7bbu$
4	$b_{1,min}=b_{1,max}=2bbu, b_{2,min}=b_{2,max}=7bbu$

Table 3. Simulation Parameters.

4.1 Comparison of new call blocking probabilities for the four scenarios

Figure 13 shows the variation of new class-1 call blocking probability (Pb1) with call arrival rates for the four scenarios. Pb1 increases with increase in arrival rates for each of the four scenarios. However, the AJCAC scheme has the lowest call blocking probability whereas the FICAC scheme has the highest call blocking probability. Thus joint radio resource management and bandwidth adaptation reduces new call blocking probability in heterogeneous cellular networks.

Figure 14 shows the variation of new class-2 call blocking probability (Pb2) with call arrival rates for the four scenarios. Pb2 increases with increase in arrival rates for each of the four scenarios. Moreover Pb2 in each of the scenarios is higher than the corresponding Pb1 because class-2 calls require more bbu than class-1 calls. Thus, it is possible to block a class-2 call when it is still possible to admit a class-1 call into the network. However, the AJCAC scheme has the lowest call blocking probability for class 2 calls whereas the FICAC scheme

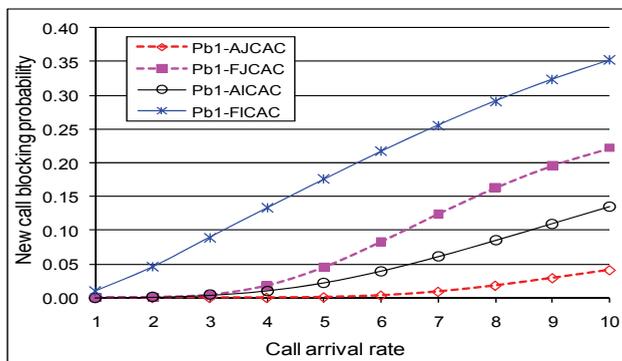


Fig. 13. New class-1 call blocking probability against call arrival rate.

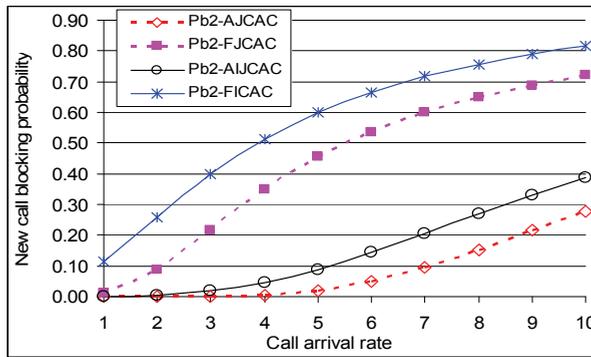


Fig. 14. New class-2 call blocking probability against call arrival rate.

has the highest call blocking probability. Thus joint radio resource management and bandwidth adaptation reduces new call blocking probability in heterogeneous cellular networks.

4.2 Comparison of handoff call dropping probabilities for the four scenarios

Figure 15 shows the variation of handoff class-1 call dropping probability ($Pd1$) with call arrival rates for the four scenarios. $Pd1$ increases with increase in arrival rates for each of the four scenarios. However, the AJCAC scheme has the lowest call dropping probability whereas the FICAC scheme has the highest call dropping probability. Thus joint radio resource management and bandwidth adaptation reduces handoff call dropping probability in heterogeneous cellular networks.

Figure 16 shows a similar trend to Figure 15. The AJCAC scheme has the lowest call dropping probability for class 2 calls whereas the FICAC scheme has the highest call dropping probability. Thus joint radio resource management and bandwidth adaptation reduces handoff call dropping probability in heterogeneous cellular networks.

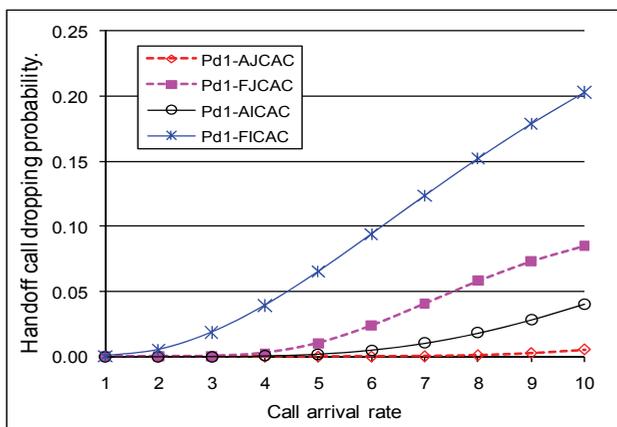


Fig. 15. Handoff class-1 call dropping probability against call arrival rate.

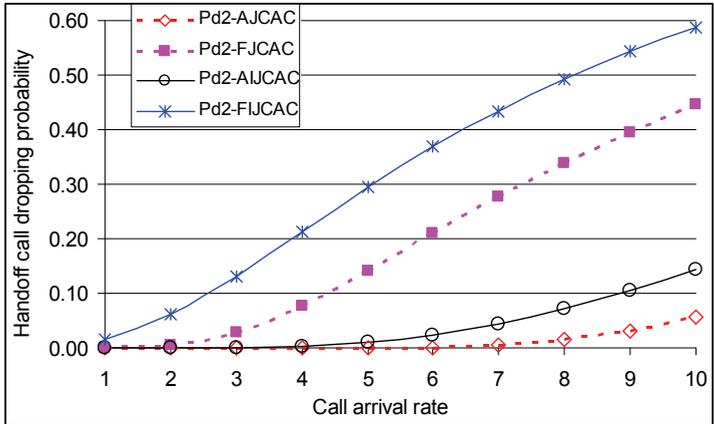


Fig. 16. Handoff class-2 call dropping probability against call arrival rate.

4.3 Comparison of call blocking/dropping probabilities for scenarios 1 and 2

Figure 17 compares the new class-1 call blocking probability and handoff class-1 call dropping probability for the Fixed and adaptive JCAC schemes. It can be seen that the Pd1 of AJCAC is less than the Pb1 of AJCAC. Similarly, the Pd1 of FJCAC is less than the Pb1 of FJCAC. Thus, handoff calls are prioritized over new calls by using the threshold based prioritization scheme shown in Figure 11.

Figure 18 compares the new class-2 call blocking probability and handoff class-2 call dropping probability for the Fixed and adaptive JCAC schemes. It can be seen that the Pd2 of AJCAC is less than the Pb2 of AJCAC. Similarly, the Pd2 of FJCAC is less than the Pb2 of FJCAC. Thus, handoff calls are prioritized over new calls by using the threshold based prioritization scheme shown in Figure 11.

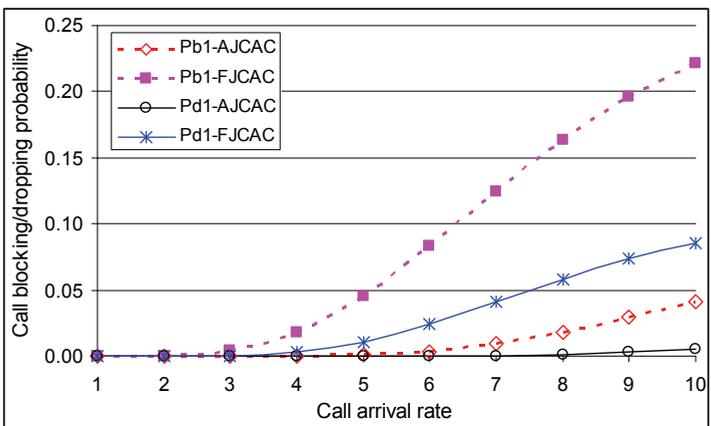


Fig. 17. Class-1 call blocking/ dropping probability for JCAC schemes.

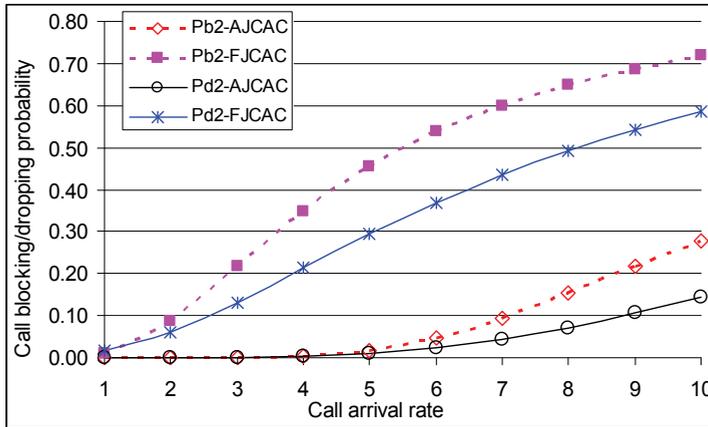


Fig. 18. Class-2 call blocking/dropping probability for JCAC schemes.

4.4 Comparison of call blocking/dropping probabilities for scenarios 3 and 4

Figure 19 compares the new class-1 call blocking probability and handoff class-1 call dropping probability for the Fixed and adaptive ICAC schemes. It can be seen that the Pd1 of AICAC is less than the Pb1 of AICAC. Similarly, the Pd1 of FICAC is less than the Pb1 of FICAC. Thus, handoff calls are prioritized over new calls by using the threshold based prioritization scheme shown in Figure 11.

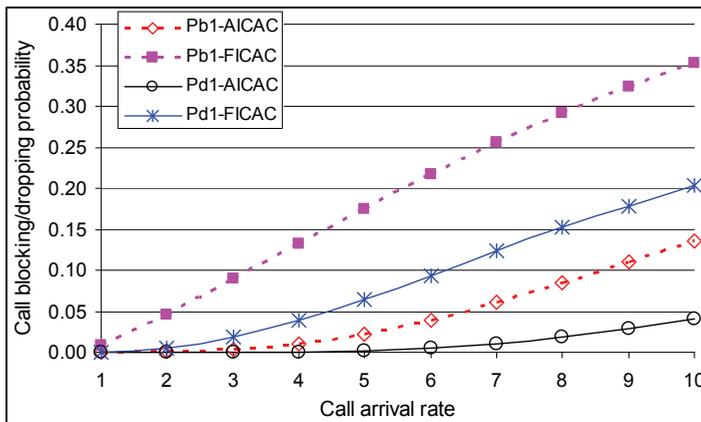


Fig. 19. Class-1 call blocking/dropping probability for ICAC schemes.

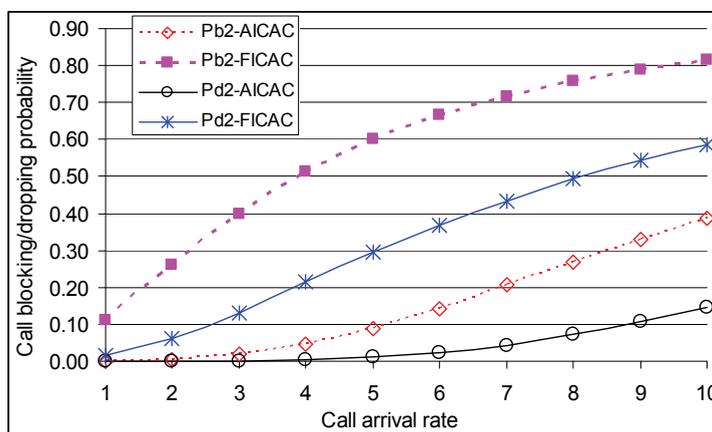


Fig. 20. Class-2 call blocking/dropping probability for ICAC schemes.

Figure 20 compares the new class-2 call blocking probability and handoff class-2 call dropping probability for the Fixed and adaptive ICAC schemes. It can be seen that the Pd2 of AICAC is less than the Pb2 of AICAC. Similarly, the Pd2 of FICAC is less than the Pb2 of FICAC. Thus, handoff calls are prioritized over new calls by using the threshold based prioritization scheme shown in Figure 6.

7. Conclusion

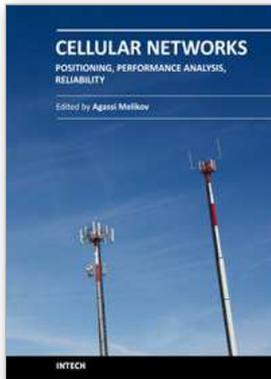
The coexistence of multiple cellular networks in the same geographical area has enabled more efficient utilization of radio resources and enhanced quality of service provisioning through joint radio resource management. An overview of joint call admission control in heterogeneous cellular networks has been given in this chapter. Different approaches for selecting RATs in heterogeneous cellular networks namely: random-selection, network load, service-cost, service-class, path-loss, layer, terminal modality, computational intelligence, and non computational intelligence techniques have been itemized. A Markov model for a load-based JCAC algorithm has been presented. Considering four different scenarios, simulation results are obtained and compared. Results show that joint management of radio resources and bandwidth adaptation reduce call blocking/dropping probability in heterogeneous cellular networks.

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Cellular Networks - Positioning, Performance Analysis, Reliability

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Wireless cellular networks are an integral part of modern telecommunication systems. Today it is hard to imagine our life without the use of such networks. Nevertheless, the development, implementation and operation of these networks require engineers and scientists to address a number of interrelated problems. Among them are the problem of choosing the proper geometric shape and dimensions of cells based on geographical location, finding the optimal location of cell base station, selection the scheme dividing the total net bandwidth between its cells, organization of the handover of a call between cells, information security and network reliability, and many others. The book focuses on three types of problems from the above list - Positioning, Performance Analysis and Reliability. It contains three sections. The Section 1 is devoted to problems of Positioning and contains five chapters. The Section 2 contains eight Chapters which are devoted to quality of service (QoS) metrics analysis of wireless cellular networks. The Section 3 contains two Chapters and deal with reliability issues of wireless cellular networks. The book will be useful to researches in academia and industry and also to post-graduate students in telecommunication specialities.

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