Energy-Efficient Radio Resource Management Scheme for Heterogeneous Wireless Networks: a Queueing Theory Perspective

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***Abstract*—The omnipresence of heterogeneous wireless networks (HetNets) plays a key role in 4G wireless networks delivering services anytime and anywhere, and it is expected that this momentum will continue to happen. However, the full time operation of the HetNets' Base Stations (BSs) has resulted in an increase in energy costs, along with negative impact on the environment. To cope with these two serious emerging problems, an effective green network design is imperative. In this paper, a new Joint Radio Resource Management (JRRM) scheme in HetNets, (so-called green JRRM) is proposed, which employs a Dynamic Coverage Management (DCM) algorithm to determine when a microcell has to be switched off/on according to the network load and a threshold mechanism on the macrocell occupancy. A framework of queueing theory is also used to analyze our proposed scheme. Results are given, showing the system performance versus threshold setting for different traffic load values, and highlighting the opportunities of our design scheme in saving energy.**

Keywords-Energy efficiency; HetNets; joint radio resource management (JRRM); macrocell and microcell occupancy; green network design.

I. INTRODUCTION

Nowadays, a plethora of wireless access networks such as Global System for Mobile Communications (GSM), Wideband Code Division Multiple Access (W-CDMA), Worldwide Interoperability for Microwave Access (WiMaX), Wireless Local Area Networks (WLANs), etc., coexist in a given geographical area [1], supporting users with different types of applications ranging from the traditional voice services to Internet services such as Facebook, Skype, to name a few. This conglomerate of wireless access networks has been referred to as heterogeneous wireless networks (or HetNets for short) [2].

HetNets have two important characteristics. First, they are formed by networks with different features such as capacity, access technology, security, power consumption, delay, coverage, and access cost. Second, given the differences in the coverage range, they naturally build an overlay architecture. These two main characteristics can be used to match multiple design purposes such as: boosting the system capacity, increasing the coverage range, enhancing the user's satisfaction (or QoS provisioning), supporting users with different access costs.

In order to take advantage of these characteristics, the radio resource management (RRM) procedure in HetNets, renamed as Joint RRM (JRRM) [2], is designed to determine whether an incoming call should be accepted or not, and whether the selection of the access network can better suit a given targeted objective, such as access cost, security, data rate, mobility, energy efficiency, to name a few.

Currently, HetNets arise as one of the main tenets of the 4G wireless networks. They can be viewed as a way for delivering services anytime and anywhere. However, this ubiquity brings an uneasiness for the society as well as for Mobile Network Operators (MNOs). Today, the Information and Communications Technologies (ICT) sector contributes with 2% of the global greenhouse gas (GHC) emissions annually [3]. Behind this environmental threat is the huge amount of electrical energy needed to keep the ICT sector in operation. Within this percentage, wireless mobile network operators already represent 0.2% of the total energy consumed [3]. But with the traffic load growing at a great pace, it is expected that this huge increase in energy consumption will continue to rise up. From the MNOs perspective, it directly impacts the overall expenditures (OPEX). Therefore, both the society and network operators have embrace for a more sustainable green network design.

The huge amount of electrical energy required to operate wireless networks is mainly due to the following facts: 1) Base Stations (BS) consume a major portion of the energy consumed by mobile network operators, nearly 57% [3]; 2) Traditionally, the ICT sector runs 24 hours per day and 7 days per week. In summary, the wireless infrastructure, which can be considered as the main part of the overall network, represents the Achilles'heel of the energy efficiency in mobile networks. A way to overcome this roadblock is to resort to one the aforementioned characteristics of HetNets, the overlay architecture. By exploring this multi-layer architecture, it is possible to dynamically manage the coverage range, switching off some layers or cells in them according to the traffic load fluctuations so long as the other layers can cope with the total offered traffic load. Following this practice, it is feasible to achieve the green design goal.

In this paper, we address this issue by proposing a green JRRM for HetNets. Our main goal can be stated as achieving the energy efficiency while keeping the system performance at a satisfactory level. To this end, we propose a Dynamic Coverage Management (DCM) algorithm that supports the decision making as to when to switch off/on a network layer, based on the network load state as well as a threshold setting on the macrocell occupancy. We study the viability of our DCM algorithm using the framework of queueing theory. Numerical results show the system performance versus threshold setting for different traffic load values. The opportunities of our design in saving energy consumption is also highlighted.

The rest of the paper is organized as follows. Section II presents an overview of the literature related to energy efficiency in HetNets and DCM algorithms. Section III describes our green JRRM as well as our proposed DCM algorithm. Section IV introduces our novel queueing model used for the analysis of our proposed green JRRM scheme. In Section V, simulation results are presented. Finally, Section VI concludes our work.

II. Related work

The overlay architecture of HetNets if correctly explored has an immense potential to reduce the power consumption by means of the application of the DCM algorithms. With DCM, the JRRM scheme can determine, based on some criteria, when and which cells inside the covered geographical area can be turned off or on [4]. Indeed, the main idea behind the application of DCM algorithms in HetNets is the traffic load fluctuations in time and space. In order to cope with it, the combinations of cells with different sizes and capacities are often employed, with the goal to find the optimal or at least a good combination. For instance, if on one hand the design using only macrocells is quite inefficient due to the high data rates required for actual data services; on the other hand, the design with only smaller cells suffers from the coverage issue, which may lead to high handoff rates.

From the energy efficiency perspective, it has been shown [4,5] that the energy increases when the number of micro/picells increases. In spite of it, a dense deployment of femtocells, for example, can lead to a significant energy consumptions [1]. However, applying power saving schemes that turn femtocells off when no traffic load is offered can result in a power saving of more than 30 % in average [6]. Similarly, optimizing a dense deployment of WLANs according to daily traffic load can also yield a reduction in energy consumption [8]. In spite of these results, according to [1], addressing energy efficiency at the RRM level in HetNets is still a challenging issue.

In general, the problem of resource management in wireless networks can be defined as the problem of assigning a server for an incoming service request as long as it does not violate the service provisioning of the other ongoing users and there is enough capacity to accept it. In HetNets, this problem is more pronounced due to the fact the radio resources are extremely scarce, offered traffic loads can be huge, and Quality of Service (QoS) requirements of the involved applications can be quite diverse and often conflicting.

To address these shortcomings, RRM in HetNets makes use of traffic management techniques such as call admission control (CAC) and scheduling. The main function of CAC is to maintain the QoS provisioning in face of the service integration while achieving the required QoS of each service class. To do this, CAC takes a decision about the acceptance of incoming service requests considering the QoS requirements of each service and the amount of idle resources. On the other hand, an effective scheduling technique can help determining which data packet from which data session (already accepted at the CAC level) should be transmitted in the radio resources.

Resource management in HetNets has been investigated from various perspectives including power control, access control, modeling frameworks, cognitive and software defined radio; prefetching and caching; handoff; cross-layering; optimization perspectives [11]. Few representatives such works are described as follows.

In [12], Ahmad et al. proposed a virtual resource provisioning scheme (called VPR) for HetNets which combines the QoS requirements from each network entity, a virtual resource provisioning technique, and a load balancing method, all to predict the resource released by multiple co-located wireless networks.

In [13], Lopez-Benitez et Gozalvez proposed a set of methods (so-called common radio resource management (CRRM)) that can be used to effectively distribute the heterogeneous traffic among available radio access technologies (RATs), based on the radio resources that are available at each RAT.

In [14], Hasib and Fapojuwo investigated the same problem initiated in [13] by adding the service cost, user mobility, service type, and location information, as additional design criteria. This results to an enhanced version of the CRRM solution [13]. Their so-called adaptive CRRM approach typically consists in balancing the cell loads of the coexisting RATs.

In [15], Atanasovski et al. proposed an architecture for RRM in HetNets (so-called RI-WCoS) which uses the concept of Media Independent Handover Function (MIHF) user, a key component of the IEEE 802.21 framework. The suitability of their method in handling emergency-related application scenarios was proven by simulation.

In [16], Suleiman et al. considered access technologies such as nature of individual access network, occupancy level in individual access networks, load balance in individual acess networks, as criteria to design an effective joint RRM scheme for HetNets.

In [17], Kajioka et al. proposed an adaptive RRM scheme for HetNets in which each node is capable of determining the network resources that it should assign to every application that it supports. This is realize by means of their so-called attractor composition model that takes care of handling the global activity shared among the different entities that are involved in the HetNets architecture.

In [18], Pei et al. investigated the RRM problem in HetNets composed of CDMA and WLANs networks. Their proposed RRM solutions are realized through solving two optimization problems where the goal is to maximize the total network welfare (case of CDMA) and the aggregate social welfare of the WLAN (case of WLAN) under certain resource-usage constraints.

In [19], Falowo and Chan addressed the issue of unfairness in radio resources allocation among low-capability heterogeneous mobile terminals in HetNets. They derived a terminal-modality based joint call admission control method that uses both the RAT terminal capability and the network load as criteria for call admission control decisions.

In [20], Ngo and Le-Ngoc proposed some distributed RRM-based methods to optimally allocate subcarriers and power in OFDMA-based cognitive radio ad hoc networks. The RRM problem is formulated as an optimization problem where the throughput is maximized subject to some network-related constraints such as the number of subchannels that each individual unlicensed users may occupy, a tolerable interference at the primary network level, etc.

In [21], Guerrero-Ibanez proposed a QoS-based dynamic pricing approach (so-called QoSDPA) for services and resource provisioning in HetNets. In their proposed scheme, an access network selection mechanism is designed that helps selecting the appropriate network for each requested user's service and preferences.

In this paper, a DCM algorithm is proposed which uses a threshold on macrocell and information about network occupancy, to bolster the decision making process of deciding when the microcell has to be switched on or off. Our goal is to reduce the energy consumption. To the best of our knowledge, our proposal is the first attempt on using a queueing performance model to address this issue.

III. GREEN JRRM DESIGN

The green design of HetNets is one of the most important aspects of future 4G wireless networks due to social consciousness and economic factors. As pointed out earlier, the BS is the villain in terms of energy consumption on wireless networks; therefore, every attempt to turn it off aiming at avoiding waste of energy is welcome. In order to effectively handle this issue, we propose a green JRRM. In our approach, the overlay characteristic of HetNets is explored as well as the fact that the offered traffic load varies during the day. Using this information as input, a DCM algorithm can be implemented to determine which BS or layer in the overlay structure should be switched off as long as its offered traffic load could be carried out by an active BS.

Here, we propose a threshold-based algorithm. For the sake of simplicity and without loss of generality, we assume that our green JRRM is applicable to an environment with two layers: microcell and macrocell, as depicted in our system architecture (Fig. 1). In Fig. 1, the number of radio channels in microcell and macrocell are C_m and C_M, respectively. Besides, the macrocell has a threshold K, whose role is to aid in the decision about turning on/off a BS. Moreover, two modules can be highlighted, namely, the Load Control (LC) and the DCM modules. The role of the LC module is to periodically monitor the macrocell and microcell radio occupancies and transmit them to the DCM module. With that information in hand, our proposed DCM algorithm can decide when the microcell can be turned off/on.

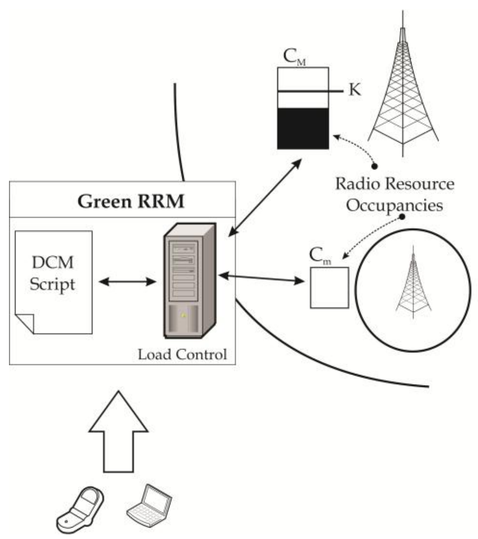

Figure 1: Green JRRM Architecture

In the following, we assume that the macrocell is always active. Additionally, it is planned to cover the entire geographical area regardless of the microcell state (on/off). With these assumptions, we can guarantee both low chances of handoff dropping and no holes in the coverage area when the DCM switches a microcell off. It is quite important to assure these conditions inasmuch as the green target cannot be accomplished by violating the main system goals, namely, providing wireless access and supporting the user mobility.

Table 2: Green JRRM. Transitions from state $\Phi=(\iota_M, \iota_m)$.

Next State	Conditions	Rate	Event
(ι_M+1,ι_m)	$\iota_M < K$	$\lambda_M + \lambda_m$	Arrival of calls in macrocell when its the occupancy is less than the value of the threshold K.
(ι_M+1,ι_m)	$K \le \iota_M < C_M$	λ_M	Arrival of calls in macrocell when its the occupancy is greater than or equal to the value of the threshold K.
(ι_M-1,ι_m)	$0 < \iota_M < K$	$\iota_M(\mu_M+ \mu_m)$	Departure of an ongoing call in macrocell when its occupancy is less than the value of the threshold K.
(ι_M-1,ι_m)	$\iota_M=K \wedge \iota_m=0$	$\iota_M(\mu_M+ \mu_m)$	Departure of an ongoing call in macrocell when its occupancy is equal to the threshold value K and the microcell is off.
(ι_M,ι_m-1)	$\iota_M=K \wedge \iota_m>0$	$\iota_M\mu_M + \iota_m \mu_m$	Departure of an ongoing call in macrocell when its occupancy is equal to the threshold value K and the microcell is on.
(ι_M-1,ι_m)	$\iota_M>K$	$\iota_M\mu_M$	Departure of an ongoing call macrocell when its occupancy is greater than the threshold value K.
(ι_M,ι_m+1)	$\iota_M\ge K \wedge \iota_m<C_m$	λ_m	Arrival of calls in microcell when the macrocell occupancy is greater than or equal to the threshold value K.
(ι_M,ι_m-1)	$\iota_M>K \wedge \iota_m>0$	$\iota_m \mu_m$	Departure of an ongoing call in microcell when the macrocell occupancy is greater than the threshold value K.

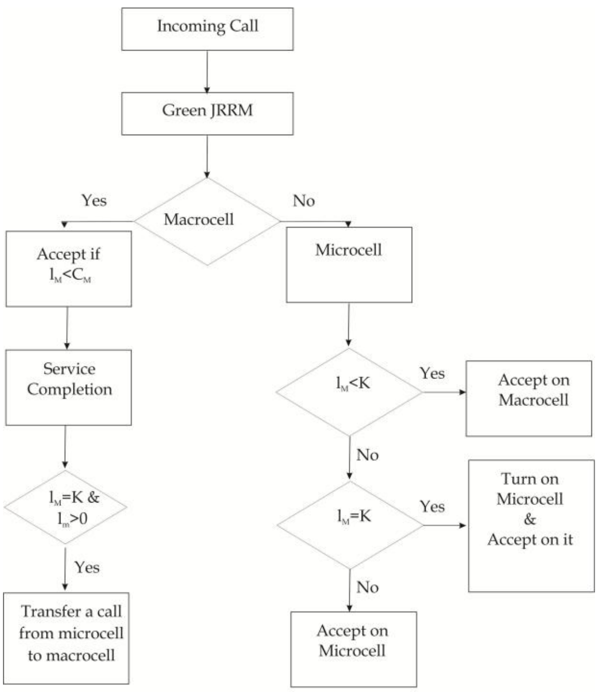

Figure 2: Proposed DCM-based green JRRM algorithm.

Fig. 2 depicts the flowchart of the DCM algorithm used in our proposed green JRRM scheme. In Fig. 2, ι_M is the number of ongoing calls in the macrocell and ι_m is the number of ongoing calls in the microcell. As shown, when an incoming call arrives, the green JRRM verifies if it belongs to the macrocell or microcell. In the first case, it is accepted as long as there are enough radio channels to support it. Furthermore, when a call leaves the macrocell, the green JRRM scheme checks the radio resource occupancy on it by questioning the LC module and if it is equal to the threshold K and there are ongoing calls in the microcell, then it hands off one call from microcell to macrocell. By acting this way, we can empty the microcell as fast as possible and save energy. On the other hand, if the mobile user is inside the double coverage area (microcell and macrocell), then the green JRRM queries the load control module about the macrocell and microcell radio channels occupancies. If the macrocell occupancy is less than the value of the threshold ($\iota_M < K$), then the incoming call is accepted in it and the microcell continues in off state saving energy. Otherwise, it is activated and two situations can happen: the occupancy in macrocell is equal to the threshold (i.e. $\iota_M =K$) or is greater than the threshold (i.e, $\iota_M > K$). In the former case, the green JRRM selects the microcell to accept the incoming call. In the later case, i.e. $\iota_M > K$, the microcell handles its own calls and the macrocell is alleviated as long as it has to cope with calls originated in other places of the covered area. Therefore, the fundamental principle of our proposed green JRRM design is to hold the offered traffic load on the macrocell whenever possible based on the fact that it is always operational.

IV. PROPOSED QUEUEING PERFORMANCE MODEL

We consider an overlay wireless network with two layers: macrocell and microcell. Arrivals of calls in each layer occur according to Poisson processes with rate λ_M (case of macrocell) and λ_m (case of microcell). Additionally, we assume that the call holding times are exponentially distributed random variables with means $1/\mu_M$ (case of macrocell) and $1/\mu_m$ (case of microcell). In order to mathematically specify the green JRRM design depicted in Fig. 1, based on the procedure outlined in Fig. 2, we utilize a bi-dimensional Continuous Time Markov Chain (CTMC) model, whose state is defined as:

$$\Phi = \{(l_M, l_m)/0 \le l_M \le C_M, 0 \le l_m \le C_m\}, \quad (1)$$

where the number of states in Φ is calculated as $(C_M+1)(C_m+1)-KC_m$. Table 1 reports all the transitions starting from state Φ to all possible successor states together with their rates and condition under which the transitions exist. The last column of Table 1 indicates the type of event to which a transition refers to. In order to illustrate the dynamics of the green JRRM scheme, the state transition diagram for a small-scale system with C_M=5, C_m=4, K=3 is shown in Fig. 3.

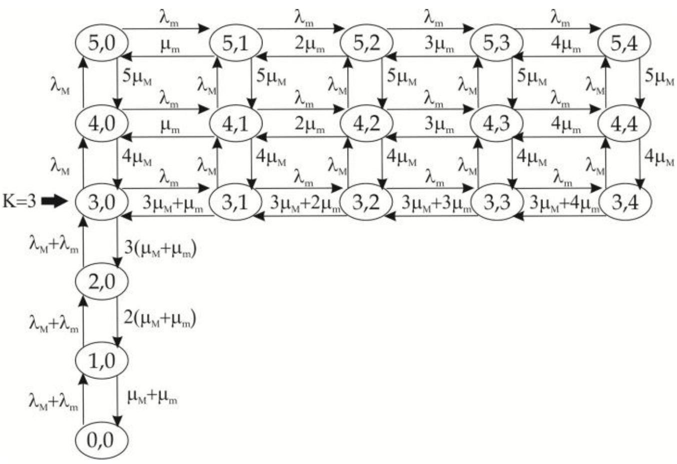

Figure 3: State transition diagram for the green JRRM scheme with C_M=5, C_m=4, K=3

Following the rules described in Table 1, we can build the matrix Q, also known as infinitesimal generator. Using this matrix, we can obtain the steady-state probability π(Φ) by numerically solving the system πQ=0 together with the normalization condition Σπ(Φ)=1. From this point, P_{BM} the blocking probability in the macrocell and P_{Bm} the blocking probability in the microcell are obtained as:

$$P_{BM} = \sum_{l_m=0}^{C_m} \pi(l_M = C_M, l_m), \quad (2)$$

$$P_{Bm} = \sum_{l_M=0}^{C_M} \pi(l_M, l_m = C_m). \quad (3)$$

The analysis of blocking probabilities is widely well accepted in the design of wireless systems. However, in the context of green network designs, this type of analysis is yet to be confirmed. Indeed, the proper definition of green metrics is still an open discussion in industry and academia [1][7]. To overcome this issue, the generic idea of ``green opportunity'' was introduced [11]. In our context, it means all the chances that our JRRM design has to reduce the power consumption in HetNets. With respect to our proposed DCM algorithm, this corresponds to the opportunities to find out the microcell in idle state, which can be computed as:

$$P_{idle} = \sum_{l_M=0}^{C_M} \pi(l_M, l_m = 0). \quad (4)$$

V. Performance Evaluation

In this section, we analyze the performance of our proposed DCM-based green JRRM scheme. We consider two system configurations: scenario #1 and #2. In scenario #1, only the microcell experiences an increase in traffic load while in scenario #2, both layers fell that increase. Our goal is to challenge the green JRRM scheme in situations where the traffic load in the microcell grows fast. The case where the traffic load on the microcell is constant is not analyzed since in such situations [1], the microcell may be turned off. Hence, in terms of resource management strategies [11] [17], doing such analysis will add no novelty. Unless specified otherwise, we use the following system configuration: C_M=20 radio channels, C_m=10 radio channels, the threshold K in macrocell occupancy: K = 2, 6, 10 respectively, and the average voice call holding times, $(1/\mu_M)=(1/\mu_m)$, are set 2 minutes [10].

A. Scenario #1

In this scenario, we consider that the traffic load on the macrocell is constant and equal to 12 Erlangs. On the other hand, the offered traffic load on the microcell varies from 2 Erlangs to 12 Erlangs approximately. Results obtained for this analysis are outlined in Fig. 4, Fig.5, and Fig.6, respectively.

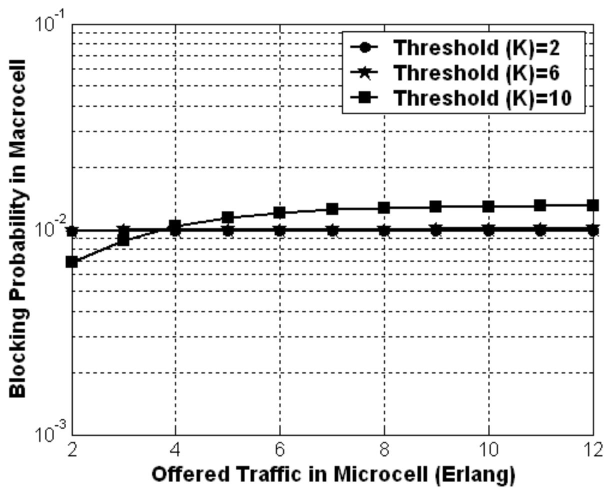

Figure 4: Macrocell blocking probability versus offered traffic load on microcell

In Fig. 4, it can be observed that increasing the threshold K results in higher blocking probability on macrocell. This can be attributed to the fact that more radio channels are shared between users on both layers. However, as Fig. 5 shows, it also leads to a lower blocking probability on the microcell. This can be explained by the fact that the green JRRM design with K = 10 holds the offered traffic on the macrocell for a longer time period when compared to the green JRRM design with K = 2 and K=6; this way, alleviating the microcell, which keeps saving the energy.

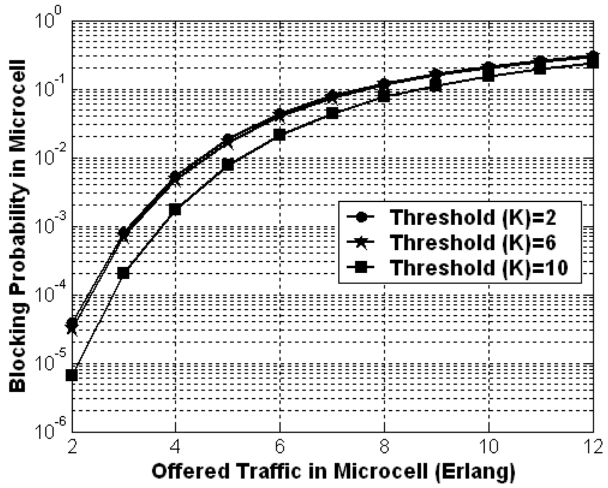

Figure 5: Microcell blocking probability versus offered traffic load on microcell

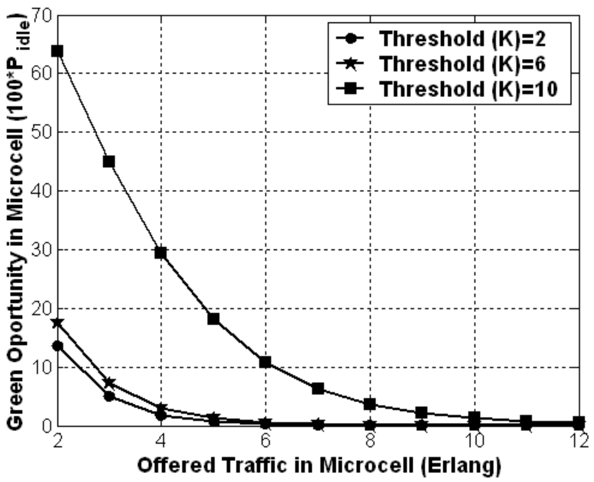

Figure 6: Green Opportunity in microcell versus offered traffic load on microcell

From the green design perspective, the most relevant result is depicted in Fig. 6. As shown, it can be observed that for a low traffic load in microcell, the green opportunities surpass 60% for K=10 and are close to 17% and 13% for K=6 and K=2, respectively. This is an important result in terms of how much energy could be saved by switching off the microcell. Fig. 6 also shows that as the traffic load grows, the configurations with K=2 and K=6 see their green opportunities vanishing while the green opportunity in the set up with K=10 decays more slowly. The reason behind these observations is the fact that by operating with K=2 or K=6, the radio channel occupancy on macrocell quickly reaches the threshold value and our green JRRM scheme decides to turn on the microcell to carry out its own traffic load. In general, the configuration with K=10 yields a very promising green opportunity as well as economy of energy. However, as the traffic load increases, the green opportunities also decreases and the microcell will find few chances of being turned off.

B. Scenario #2

Now, we consider a typical rush hour scenario in which all layers in the wireless access network experiment a traffic growth. To emulate this situation, we vary the offered traffic load from 12 Erlangs to 22 Erlangs (in the macrocell) and from 2 Erlangs to 12 Erlangs (in the microcell) approximately. The results on the blocking probabilities in macrocell, the blocking probabilities in microcell, and the green opportunity are captured in Fig.7, Fig. 8, and Fig. 9, respectively.

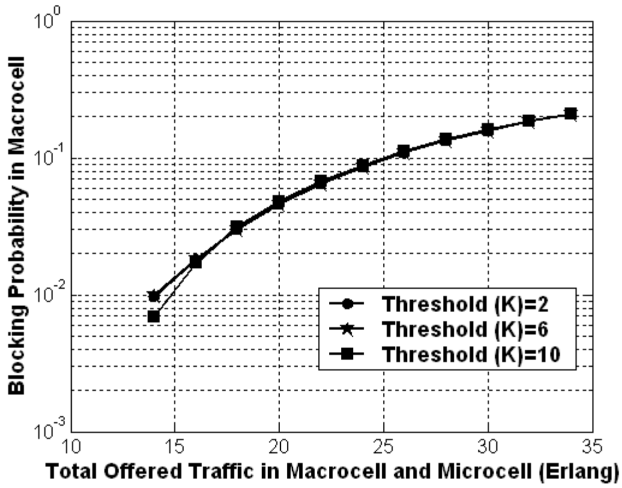

Figure 7: Macrocell blocking probability versus total offered traffic load

Fig. 7 reveals that the blocking probabilities on the macrocell converge approximately towards the same value for both values of K. This is due to the fact that with the growth in traffic load in the macrocell, the radio resource channel occupancy rapidly reaches the value of the threshold K. As a consequence, our green JRRM scheme turns on the microcell and selects it to handle its own offered traffic load. In the microcell, even though there is a slight difference between both configurations, the blocking probabilities are very close as shown in Fig.8.

As depicted in Fig. 9, green opportunities fall quickly due to the rush hour and only for low to medium traffic load, they seem to be considerable. Again, the configuration with K=10 outperforms the ones with K=2 and K=6. For instance, analyzing the green opportunity for approximately 20 Erlangs, we obtain close to 5% for K = 10 compared to almost 0% for the others. Since every contribution at long run will make the difference in terms of energy savings, the green JRRM design with K=10 has a considerable gain up to 20 Erlangs, but after that point, the rush hour hardly reduces the green opportunities.

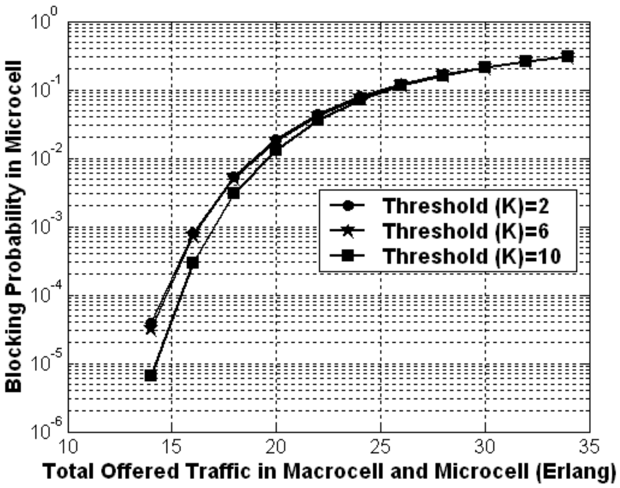

Figure 8: Microcell blocking probability versus total offered traffic load

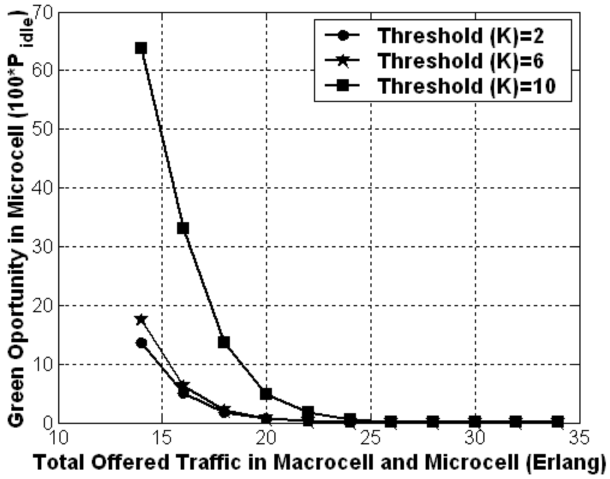

Figure 9: Green Opportunity in microcell versus total offered traffic load

C. Discussion

Looking at the above considered scenarios, we can conclude that in spite of green network design and system performance being conflicting objectives, we have been able to achieve a good balance between system performance and green opportunity, by properly setting up the threshold value in our proposed green JRRM design. Indeed, scenario #1 indicates that our green JRRM provides an opportunity to achieve a green system operation; particularly, for K=10. On the other hand, during rush hours (i.e. in scenario #2), our green JRRM design positively responds well only for low to medium traffic load. However, it is worth mentioning that during rush hours, the system is obligated to resort all its resources to ensure that users will feel minimum blocking experiences. Therefore, microcells in hot spot areas must be turned on, which will result in lower green opportunities.

VI. CONCLUSION

In this paper, we have introduced a novel DCM-based energy- efficient RRM scheme for HetNets. The embedded DCM algorithm takes into consideration the network occupancy as well as the threshold configuration to balance system performance and energy savings. Using a queueing theory framework, we have evaluated the feasibility of our proposed DCM algorithm. Results revealed that our JRRM scheme achieves a good balance between energy-efficient network design and system performance by properly setting up the value of the threshold.

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