

# Low-duty Mode Operation of Femto Base Stations in a Densely Deployed Network Environment

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**Abstract**—Interference management is an important issue due to the wide deployment of femtocells by subscribers. An elementary solution to the interference mitigation problem is to restrict transmission of pilot signals by femto base stations (BSs) which have no serving subscribers, i.e. idle listening state operation. However, the implementation of the idle listening state in a femto BS opens a possibility of having a problem in location update because a femto BS in idle listening state and a user equipment (UE) in idle mode are not able to communicate with each other. This happens because none of these initiates communication, i.e. the deadlock problem. We consider three types of solutions to this problem; UE based, femto BS based, and network assisted solutions. Our proposed solutions handle the deadlock problem as well as the interference mitigation problem. In addition, our proposed solutions are able to be with any existing power control based interference mitigation scheme. Through simulations and numerical analysis, we show that our proposed solution considerably enhances the network capacity and save energy consumption.

## I. INTRODUCTION

An important way of achieving high capacity is reducing the cell size, which has contributed to an increase of up to 1,600 times in throughput, while the advanced physical (PHY) layer and the media access control (MAC) layer technologies, such as modulation and resource management schemes, have contributed only 25 times [1]. One of the state-of-the-art techniques to make a cell size smaller, is to use the femtocell technology [2]. An important issue for successful deployment of femtocells is the interference mitigation problem.

Most of the existing interference management schemes for femtocell networks have focused on frequency (or subchannel) allocation [3], [4] and adaptive power control. [5], [6]. The work in [7] shows that deactivating some users leads to better performance than activating all the users simultaneously in a densely deployed network. Therefore, a solution to the interference mitigation problem can be preventing some femto BSs from transmission when they have no serving user equipments (UEs) within their coverages.

For instance, femtocells installed in a residential [industrial] area may have no subscribed UEs during the day [night] time. If these femto BSs keep sending their pilot signals, macro BSs and neighboring femto BSs with UEs should unnecessarily use limited power and frequency band, since BSs normally measure the interference level from neighboring BSs' pilot

signals in Code-Division Multiple Access (CDMA) cellular systems<sup>1</sup>. This is called the 'pilot pollution' problem [8]. To avoid this problem, the two major standardization groups of 3GPP and WiMAX define low-duty mode operation of a femto BS in their specifications, but there is no algorithm about when a femto BS should enter the low-duty mode [9], [10].

Li et al. [11] have employed a concept in which all femto BSs are tightly controlled by a central coordinator. The idea of utilizing the sleep functionality to increase energy efficiency has been investigated in [12], [13]. In [12], the authors have proposed a sleep functionality, but they assumed to use a secondary control channel to wake up a sleeping femto BS. In [13], a femto BS uses the sleep mode to lower energy consumption. The sleep mode femto BS only wakes up when a corresponding UE starts communication. Then, the UE is handed over from macro BS to femto BS. Considering the handover failure rate of 2 % or more [14], their proposed solution is not safe and can not be used when a femto BS is installed in a shaded area.

Due to the introduction of the sleep operation, a new problem has been raised, that is, no communication is possible when a femto BS and its corresponding UE both stay in sleep state. This is called 'deadlock problem.' In this paper, we tackle this problem and propose three types of solutions to it; they are UE based, femto BS based, and network assisted solutions. Our proposed schemes solve both the pilot pollution and deadlock problems, leading to improved network capacity. Our proposed schemes solve the interference mitigation problem by reducing the number of femto BSs in pilot sending, so it can be with any other power control based interference mitigation scheme. Our finding is that when we apply our scheme with a power control scheme for interference mitigation, there is no outage user even in a densely deployed network. Finally, thanks to deactivating femto BSs' transceivers, our proposed schemes reduce energy consumption too.

The rest of the paper is organized as follows. The femtocell network architecture and the interference mitigation problem are briefly reviewed in Section II, and Section III explains operation modes of a UE and a femto BS. Then, we address the deadlock problem and propose three types of solutions to it in Section IV. After evaluating our proposed schemes in Section V, we conclude our paper in Section VI.

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<sup>1</sup>In a UMTS cellular network, the channel quality is measured through the pilot signal, i.e. Common Pilot Channel (CPICH). Differently from CDMA systems, in Orthogonal Frequency-Division Multiple Access (OFDMA) based cellular systems, each OFDM subchannel's quality is measured from a reference signal sent through each subcarrier.

## II. FEMTOCELL NETWORK

### A. Femtocell network architecture

A recommended femtocell network architecture is proposed by the Femto Forum. A femto BS and a macro BS use the Internet and a dedicated private line as their backhauls, respectively. The Internet backhaul lowers operational/capital expenditure (OPEX/CAPEX) of the network operator, but it cannot guarantee secure communication and quality of service (QoS). To resolve this problem, the femtocell network uses two additional entities, named femto gateway (FGW) and femto management system (FMS)<sup>2</sup>. FGW takes charge of secure communication (e.g., using IPSec), and FMS controls data exchange between a femto BS and the core network. Despite the use of these entities, the information exchange in a few msec for the femtocell network is a challenging issue because of the ‘best effort’ service nature of the Internet. In a macro network, radio network controller (RNC) connects the macro BS to the core network.

### B. Femtocell interference mitigation

The interference management in a femtocell network is worse than that in a conventional macrocell network due to a couple of reasons.

First, while macro BSs are deployed by the network service operator in a planned manner, femto BSs are deployed by subscribers randomly. And the number of femto BSs is much higher than that of macro BSs. Second, since femto BSs have no dedicated control channel to the central coordinator, interference control in a timely manner is very difficult. Therefore, the interference management scheme in the femtocell network should work in a distributed manner with the expectation of some extra delay [4].

The SINR experienced by a macro/femto UE is defined as

$$\text{SINR} = \frac{P_t|h_t|^2}{P_m|h_m|^2 + \sum_{f \in F} P_f|h_f|^2 + N_0}, \quad (1)$$

where  $P_t$ ,  $P_m$ , and  $P_f$  denote the transmit powers of the associated femto BS, macro BS, and a neighboring femto BS, respectively.  $F$  is the set of neighboring femto BSs.  $h_t$ ,  $h_m$ , and  $h_f$  denote Rayleigh fading channel gains to the macro/femto UE from the associated femto BS, macro BS, and a neighboring femto BS, respectively. To achieve higher SINR, previous work has tried to solve the interference problem by lowering  $P_f$  under some constraints while our proposed solution tries decreasing the size of  $F$ . Since the power control based scheme and our femtocell set size control scheme deal with two different terms of  $P_f$  and  $F$ , respectively, they can be applied together.

## III. FEMTO BS AND UE OPERATIONS

Battery powered UEs periodically turn on and off their radio transceivers to make their lifetime longer, while macro BSs do not since they are plugged into the electricity source. We

<sup>2</sup>Conceptually, FGW and FMS are two different entities, but both can be installed in a same machine.

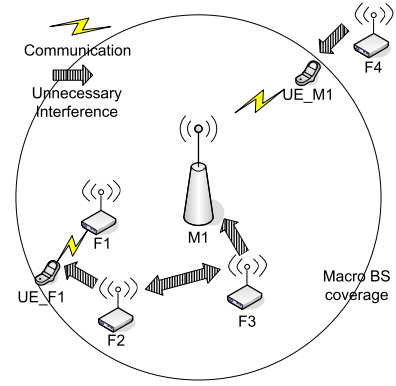


Fig. 1. An example of the pilot pollution problem with one macro BS, four femto BSs and two UEs. UE\_M1 is associated with the macro BS M1, and UE\_F1 with femto BS F1. If three femto BSs (F2, F3 and F4), which have no serving UE, keep sending their pilot signals, M1 and F1 can not utilize the whole resources, such as power and frequency band.

express these states of UEs as radio ON and OFF, respectively. Femto BSs perform a similar action to battery powered UEs to reduce interference as well as energy consumption. These states of femto BSs are called pilot sending and idle listening states, respectively.

### A. UE operations

To save energy consumption, a UE should turn off its radio transceiver as much as possible. A UE in the power saving mode periodically wakes up to check the existence of pending data packets at the network side. There are two modes of ‘idle’ and ‘sleep’ for power saving<sup>3</sup>. An idle mode UE has no specific associated BS. Each BS in the same paging group<sup>4</sup> periodically broadcasts the paging message that contains the paging group ID and a list of UEs which have pending data packets.

The idle mode UE periodically enters ON state to receive the paging message. If it notices that its paging group ID has been changed, it performs location update. Without waiting next paging cycle, it can start communication through the ranging procedures. A sleep mode UE also periodically changes its state from ON to OFF and OFF to ON. The sleep mode period is shorter than the idle mode period. The key difference between sleep mode and idle mode is that a sleep mode UE is associated with a BS while an idle mode UE is not. Therefore, a sleep mode UE can perform handover when it moves into the coverage of another BS. An active mode UE always is in ON state.

### B. Femto BS operations

Due to the pilot signals broadcasted by femto BSs that have no active UEs, adjacent macro BSs or femto BSs cannot fully utilize their resources such as power and frequency band. This is called the pilot pollution problem. Fig. 1 shows an example of this problem where UE\_M1 and UE\_F1 are associated with

<sup>3</sup>We use the term defined in the mobile WiMAX, but the same functions are also in the 3GPP LTE.

<sup>4</sup>A typical paging group size consists of several BSs at minimum.

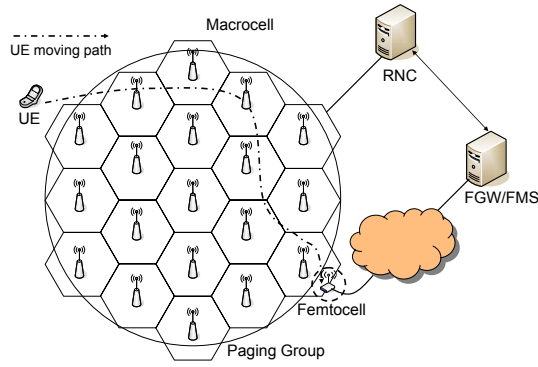


Fig. 2. A UE at the upper left is approaching the femto BS at the bottom right. If the femto BS is in the idle listening state and the UE in the idle mode, they do not aware of each other's existence.

macro BS M1 and femto BS F1, respectively. In this example, although femto BSs F2, F3 and F4 have no serving UEs, they keep sending pilot signals, and interfere with the two communication pairs in progress (M1 and UE\_M1, F1 and UE\_F1).

By restricting the transmission of pilot signals from F2, F3 and F4, the two pairs can improve their throughput, i.e. network capacity. To this end, a new idle listening state is needed, which prevents femto BSs from sending their pilot signals. The operation of a femto BS in idle listening state is different from that of a UE in OFF state. A femto BS in the idle listening state can receive any signal from any UE while a UE in the OFF state can not from any femto BS.

#### IV. DEADLOCK PROBLEM AND SOLUTIONS

##### A. Deadlock problem

An example of the deadlock problem is shown in Fig. 2. A UE at the upper left is approaching the femto BS located at the bottom right. We assume that the femto BS has a different paging group ID from the macro BS. On this event, there are four possible operation scenarios according to the UE mode and the femto BS state while the UE is traversing the coverage of the corresponding femto BS.

- Femto BS in pilot sending state and UE in active mode: The UE's handover from the macro BS to the femto BS occurs.
- Femto BS in pilot sending state and UE in idle mode: The UE should change its paging group ID from macro to femto, i.e. location update.
- Femto BS in idle listening state and UE in active mode: The femto BS can hear the UE's signal. When the femto BS becomes aware of the UE's existence, it changes its state from idle listening to pilot sending to welcome the UE, and its handover follows.
- Femto BS in idle listening state and UE in idle mode: Since the two entities do not send any signal, they cannot recognize each other's existence, i.e. the deadlock problem occurs.

The current system functionality can handle the first three cases without significant changes, but cannot the last case. The

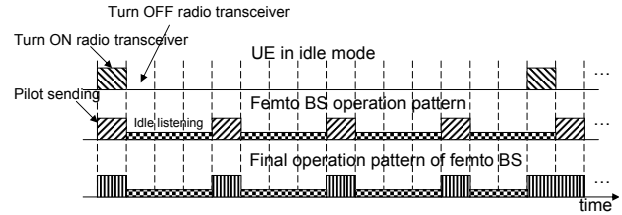


Fig. 3. An example of a low-duty mode operation pattern. The final operation pattern of the femto BS is the union of turning on time slots of UEs and itself.

femto BS may not be able to provide any service for the UE in this case. Especially, if a femto BS is installed like F4 in the shaded area of Fig. 1, the approaching idle mode UE cannot get any service either from macro BS or femto BS. Therefore, the UE should wake up and keep scanning frequency bands to hear a pilot signal [10], and the femto BS in idle listening state also waits for a signal from the UE. As a result, the UE and the femto BS cannot get to know each other's existence<sup>5</sup>.

##### B. Proposed solutions

To understand each other's existence, one of the two should wake up and transmit a signal to notify the other of its existence. According to which one takes the initiative, we can consider three possible solutions to the deadlock problem.

1) *UE based solution*: In this solution, when an idle mode UE turns on its radio transceiver to hear the paging message, it also sends a signal to notify the femto BS in idle listening state of its existence. This solution aims to minimize the network interference since an idle listening state femto BS does not send pilot signals at all. However, the idle mode UE should always send the wake up message even if it is not within the coverage of its corresponding femto BS, resulting in lots of energy consumption of the UE. In [12], the authors proposed a similar solution which needs another communication channel to wake up the idle listening state femto BS. Therefore, it is an impractical solution.

2) *Femto BS based solution*: A femto BS based solution for the deadlock problem is that an idle listening state femto BS periodically broadcasts pilot signals, that is, changing its state from idle listening to pilot sending and pilot sending to idle listening. When an idle mode UE receives a pilot signal containing a paging message with a different paging group ID from the corresponding femto BS, it should update the paging group. The UE initiates a communication with the femto BS for location update, i.e. changing the paging group. This solution does not require any change in UE's specification, but the femto BS should periodically keep sending pilot signals. This is called 'low-duty mode' operation.

Fig. 3 shows an example of a low-duty mode pattern. A UE in idle mode wakes up according to the paging cycle, and a femto BS in low-duty mode also periodically wakes up. Then the final low-duty mode operation pattern of the femto

<sup>5</sup>As we mentioned in the introduction, the work in [13] cannot solve the deadlock problem in this situation.



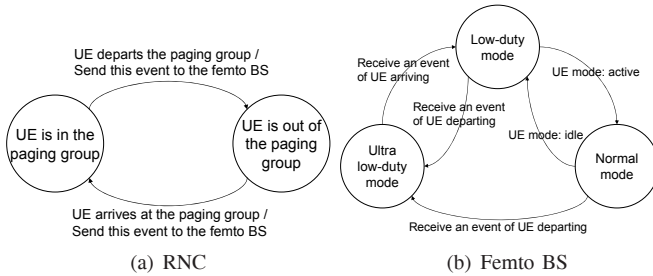


Fig. 4. Mode change diagrams for RNC and a femto BS according to the operation phase of the network assisted solution.

BS follows the union of slot operations of UEs and itself as shown in Fig. 3 .

3) *Network assisted solution*: In this solution, the location information of an UE provided by the core network is used to help the femto BS have an agile response. Owing to the information, the femto BS properly knows when it should be in the pilot sending state. According to the UE's location, the femto BS divides the low-duty mode into two detailed modes: ultra low-duty mode and low-duty mode. A femto BS in ultra low-duty mode assumes that there is no UE in the coverages of its corresponding macro BS as well as itself. This assumption gives it an opportunity of entering the idle listening state longer. A femto BS in low-duty mode acts the same as in Fig. 3.

Our scheme runs in two phases: initial and operation phases. It enters the initial phase when a femto BS is installed. In this phase, UEs are required to register at the femto BS that knows its neighboring macro BS's ID and paging group ID. The femto BS sends the information about registered UEs, its macro BS ID, and its paging group ID to the FGW/FMS. The FGW/FMS forwards this information with the femto BS ID to the closest radio network controller (RNC).

Fig. 4 shows the mode change diagrams for RNC and a femto BS in operation phase. The RNC is in charge of handling main events in the operation phase, and each femto BS changes its mode according to the received event information from RNC and the modes of UEs. In operation phase, RNC keeps tracking registered UEs' paging group IDs. If a registered UE enters the registered paging group area, the corresponding RNC informs the FGW/FMS of this event. The femto BS, which receives the message about the UE's coming, changes its mode from ultra low-duty to low-duty mode. If the UE moves into the femto BS's coverage, it changes its paging group from macro to femto, i.e. location update. On the other hand, if the UE gets out of the macrocell's paging group, RNC also notifies the femto BS of this event. Then, the femto BS enters the ultra low-duty mode again.

The signaling delay between FGW/FMS and a femto BS cannot guarantee a strict delay bound such as several micro- or milli-seconds since the femtocell network uses the Internet as its backbone network. Internet backbone research [15] has shown that the average network latency in USA is about 35 ms, so we can assume that the signaling delay does not exceed a

few seconds. Considering the fact that the common coverage of a macrocell is a few hundreds of meters in radius and a paging group consists of several BSs, it will take at least several minutes for an UE to move into the coverage of a femtocell. Therefore, the allowed delay of several seconds is sufficient for the femto BS to welcome an incoming UE by changing its mode from ultra low-duty to low-duty.

Our proposed scheme can be combined with any power control based interference mitigation scheme. The combination of a power control based scheme and our proposed scheme shows significant performance improvement in a densely deployed network environment. In addition, our proposed scheme gets the benefit of energy saving.

### C. Number of normal mode femto BSs

Our proposed scheme has a characteristic of lowering the number of normal mode femto BSs<sup>6</sup>, resulting in reduced interference level and increased network capacity. Through a simple Markov chain model, we can get the average number of normal mode femto BS. If a UE under a low-duty mode femto BS receives a call, the femto BS changes its mode from low-duty to normal mode. Similarly, if the UE ends a call, the femto BS goes back to the low-duty mode.

Assume there are  $N$  femto BSs in the network, and denote the number of normal mode femto BSs by state  $n$ . Let  $\lambda$  and  $\mu$  denote the call arrival rate and the service rate of an idle UE, respectively. Following an  $M/M/1$  queueing system, we obtain the steady state probability as  $P_n = \frac{1}{(1+\lambda/\mu)^N} \binom{N}{n} (\lambda/\mu)^n$ . Then, the average number of normal mode femto BSs is given as  $\sum_{n=1}^N nP_n$ .

## V. PERFORMANCE EVALUATION

In this section, we evaluate the performance of our proposed scheme in terms of network capacity and connection setup delay through simulations in comparison with the legacy scheme. In the legacy scheme, all the femto BSs are always in normal mode while they change their modes between normal, low-duty, and ultra low-duty in our network assisted solution. Then we compare the legacy scheme and our proposed solution with and without a power control based interference mitigation scheme [6]. With a power control based scheme, a femto BS adjusts its transmit power so that the average received signal strength at the femtocell edge is the same as that from the macro BS. Then, we simply investigate energy saving in our scheme.

There is no proper reference scheme to our proposed solution. The work in [12] is not practical in the current femtocell network due to the need secondary control channel. Since the scheme in [13] cannot completely solve the deadlock problem, comparison of network capacity is not meaningful.

### A. Simulation environments

We use a dense-urban model described in the reference document from Femto Forum [16, Section 20.3]. Each block

<sup>6</sup>Differently from the two low-duty mode operations, a femto BS in normal mode keeps sending pilot signals always.

TABLE I  
SIMULATION PARAMETERS

Parameter	Value
Macro BS Tx power	43 dBm
Femto BS Tx power	20 dBm
Noise power	-174 dBm/Hz
Outdoor path loss	$28 + 40\log(d)$ dB
Indoor path loss	$38.5 + 20\log(d) + L_{wall}$ dB
Outer wall Attenuation	5 dB
Inner wall Attenuation	0.7 dB

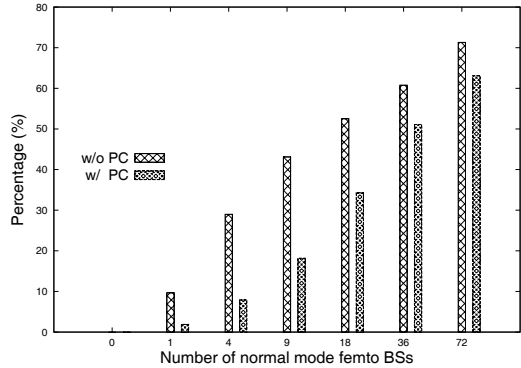


Fig. 5. Percentage of heavily interfered area where an MUE has spectral efficiency lower than 0.02 bps/Hz.

in the model represents two stripes of apartments where each stripe has 2 by 10 apartments. We place 9 blocks (3 by 3), that is, the total of 360 apartments are in the area of  $360\text{m} \times 210\text{m}$ . In our simulations, we only consider the heavily interfered area since macro UEs (MUEs) outside of the area are not affected by femto BSs' signals. There are one macro BS covering the radius of 1km and 72 femto BSs deployed for 360 apartments (deployment ratio = 0.2), each with one femtocell UE (FUE). The macro BS and femto BSs use the same spectrum. A femto BS is randomly installed in each apartment unit, and operates as a closed access network.

An MUE associates with the macro BS while a FUE associates with a better channel BS, i.e. either the macro BS or the femto BS. Although we consider the downlink case, we expect that the uplink case will show a similar result if uplink and downlink channels are assumed to be estimated by a downlink reference signal. It is assumed that one frame period is 10 ms, and an idle UE listens to the paging information every six seconds (600 frames). If a femto BS is in ultra low-duty mode, it sends the pilot signal every six seconds (paging cycle). In low-duty mode, it sends the pilot signal every second while synchronizing with an idle UE. Table I summarizes the system parameters used in simulations, following the femto forum document [16].

### B. Network capacity and call set-up delay

Fig. 5 shows the percentage of MUEs whose spectral efficiencies are lower than 0.02 bps/Hz and 'PC' stands for power control. The threshold value of 0.02 bps/Hz comes from the spectral efficiency requirement of a cell edge user in WCDMA systems. This result demonstrates the effective

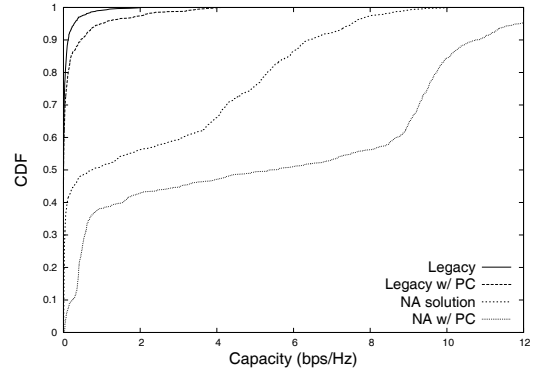


Fig. 6. CDF of MUEs. PC and NA stand for power control and network assisted, respectively.

TABLE II  
AVERAGE SPECTRAL EFFICIENCY PER UE (BPS/Hz)

	$1/\lambda = 60$		$1/\lambda = 10$	
	FUE	MUE	FUE	MUE
Legacy	2.96	0.055	2.96	0.055
Legacy w/ PC	2.96	0.179	2.96	0.179
NA solution	11.8	2.44	5.68	0.946
NA solution w/ PC	10.8	5.32	5.66	3.40

region of the power control based interference mitigation scheme. Up to 10 normal mode femto BSs, the power control based scheme has a great effect on performance, showing more than 50 % reduction in the heavily interfered area. As the number of normal mode femto BSs increases, the gain decreases. Consequently, in a densely deployed network, the power control based scheme shows a limited improvement, i.e. about 10 % reduction under 72 normal mode femto BSs. This result shows that only the power control based scheme is not enough to solve the interference problem in a densely deployed network.

For  $1/\lambda = 60$  min and  $1/\mu = 3$  min, the average number of normal mode femto BSs is calculated as 3.42. This means that our proposed solution works effectively and achieves extra improvement when combined with the power control based scheme, which is shown in Fig. 6. We randomly deployed 1,000 MUEs in the heavily interfered area to get this CDF graph.

About 71 %, 63 %, and 22 % of MUEs achieve the spectral efficiency of smaller than 0.02 bps/Hz in 'Legacy,' 'Legacy with PC,' and 'NA solution' schemes, respectively, where 'NA' stands for network assisted. However, in 'NA solution with PC' scheme, almost all MUEs get the spectral efficiency of greater than 0.02 bps/Hz. Not only heavily interfered MUEs but also overall MUEs significantly improve their performance in our scheme. In our proposed scheme, the CDF graph shows two steps shape curve. It is because of two groups of MUEs: One group of MUEs inside the apartment block and the other group of outside the apartment block. The MUEs in the outside group experience strong signals from the macro BS and low interference from femto BSs resulting in higher spectral efficiency, i.e. more than 8 bps/Hz.

Table II shows the average per tier spectral efficiency (bps/Hz) for the both schemes under low ( $1/\lambda = 60$ ) and high ( $1/\lambda = 10$ ) call arrival rates. The average number of normal mode femto BSs are 3.42 and 16.62 in low and high call arrival rates, respectively. In the legacy scheme, there is no difference for the two cases. In our proposed scheme, the high call arrival rate case shows low spectral efficiency. The spectral efficiencies of all the UEs are significantly improved owing to the decrease in interference from femto BSs. The power control based scheme enhances the performance of MUEs with slight performance decrease of FUEs.

In our proposed scheme, we synchronize the wake up period of the low-duty mode femto BS with those of idle FUEs, so the call set-up delay when an idle FUE is called is the same as that in the legacy scheme. However, when an idle FUE initiates a call, our proposed scheme has a call set-up delay of 0.5 second longer than the normal mode operation scheme. This is because the idle FUE should wait until the low-duty mode femto BS sends its pilot signal.

### C. Energy saving

We now evaluate the energy saving gain of our proposed scheme using the same way as in [13]. Let  $P_{PS}$  and  $P_{IL}$  denote the power consumptions of a femto BS in pilot sending and idle listening states, respectively.  $P_{saved}(= P_{PS} - P_{IL})$  represents the amount of energy saved by the idle listening state operation of the femto BS. The energy saving gain  $\Omega$  is defined as

$$\Omega = \frac{P_{saved}}{P_{PS}}(1 - D_{avg}), \quad (2)$$

where  $D_{avg} = T_{active}/(T_{active} + T_{sleep})$  is the average duty cycle of a UE. To get  $P_{PS}$ ,  $P_{IL}$  and  $P_{saved}$ , we use the same parameters as in [13].

Then, we obtain  $P_{PS} = P_{Micro} + P_{FPGA} + P_{TX/RX} + P_{etc} = 10.2W$  where  $P_{Micro}$ ,  $P_{FPGA}$ ,  $P_{TX/RX}$ , and  $P_{etc}$  denote power consumptions of microprocessor, FPGA, communication, and the others, respectively. Again,  $P_{TX/RX}$  is composed of  $P_{PA}$ ,  $P_{TX}$ , and  $P_{RX}$  where these are power consumptions at power amplifier, transmitter and receiver, respectively. Then, the amount of saved energy in our proposed scheme is  $P_{saved} = P_{PA} + P_{TX} = 3W$ .

When we use the same duty cycle as in [13],  $D_{avg}$  is 0.05. With the same parameter values of  $\lambda$  and  $\mu$ , we get the energy saving gain as  $\Omega = \frac{3.0}{10.2}(1 - 0.05) \approx 0.28$ . This indicates that our proposed scheme saves energy consumption by about 28 % than the normal mode operation scheme while the scheme in [13] saves by about 39 %, which is better than ours. This is because the authors in [13] have focused on energy saving only, so ‘sleep’ mode femto BSs in their scheme turn off receiver modules also. Due to such an operation, their scheme cannot handle the deadlock problem when the femto BS is installed in a shaded area. Differently from this scheme, our proposed one solves the problem in any scenario with moderate energy saving.

## VI. CONCLUSION

Operating femto BSs in idle listening state longer as much as possible is an efficient way of mitigating the femtocell interference in a densely deployed femto environment. Owing to the new idle listening state operation of a femto BS, both of a UE and the corresponding femto BS may not be aware of each other’s existence, i.e. the deadlock problem occurs. Simulation and numerical results show that our proposed scheme solves the deadlock problem and enhances the network capacity with a slight increase in a call set-up delay. Especially, when our proposed scheme is applied with a power control based interference mitigation scheme, almost all UEs successfully achieve more throughput than a minimum QoS level such as  $> 0.02$  bps/Hz, even under a densely deployed network environment. In addition, our proposed network assisted solution saves energy consumption by about 28 %.

## REFERENCES

- [1] M.-S. Alouini and A.J. Goldsmith, “Area Spectral Efficiency of Cellular Mobile Radio Systems,” *IEEE Trans. Vehic. Tech.*, vol. 48, no. 4, pp. 1047-1066, Jul. 1999.
- [2] V. Chandrasekhar, J.G. Andrews, and A. Gatherer, “Femtocell Networks: A Survey,” *IEEE Commun. Mag.*, vol. 46, no. 9, pp. 59-67, Sep. 2008.
- [3] C.-H. Ko and H.-Y. Wei, “On-demand Resource-sharing Mechanism Design in Two-tier OFDMA Femtocell Networks,” *IEEE Trans. Veh. Technol.*, vol. 60, no. 3, pp.1059-1071, Mar. 2011.
- [4] M. Rahman and H. Yanikomeroglu “Enhancing Cell-Edge Performance: A Downlink Dynamic Interference Avoidance Scheme with Inter-Cell Coordination,” *IEEE Trans. on Wireless Commun.*, vol. 9, no. 4, pp. 1414-1425, Apr. 2010.
- [5] H.-S. Jo, C. Mun, J. Moon, and J.-G. Yook, “Self-optimized Coverage Coordination in Femtocell Networks,” *IEEE Trans. Wireless Communun.*, vol. 9, no. 10, pp.2977-2982, Oct. 2010.
- [6] M.-S. Kim, H.W. Je, and F.A. Tobagi, “Cross-tier Interference Mitigation for Two-tier OFDMA Femtocell Networks with Limited Macrocell Information,” in Proc. *IEEE GLOBECOM*, Miami, USA, Dec. 2010.
- [7] M.Y. Arslan, J. Yoon, K. Sundaresan, S.V. Krishnamurthy, S. Banerjee, “FERMI: A Femtocell Resource Management System for Interference Mitigation in OFDMA Networks,” in Proc. *ACM MobiCom*, Las Vegas, USA, Sep. 2011.
- [8] Y. Zhang, Y.-Y. Li, E.S. Sousa, and Q. Zhang, “Pilot Power Minimization in HSDPA Femtocells,” in Proc. *IEEE GLOBECOM*, Florida, USA, Dec. 2010.
- [9] 3GPP TR 36.922, “TDD Home eNode B (HeNB) Radio Frequency (RF) requirements analysis;” v. 9.0.0, Apr. 2010; <ftp://ftp.3gpp.org>
- [10] IEEE 802.16m/D6, Part 16: Air Interface for Broadband Wireless Access Systems: Advanced Air Interface, Apr. 2010.
- [11] Y.-Y. Li and E.S. Sousa, “Base Station Pilot Management for User-deployed Cellular Networks,” in Proc. *IEEE ICC*, Dresden, Germany, Jun. 2009.
- [12] I. Haratcherev, C. Balageas and M. Fiorito, “Low Consumption Home Femto Base Stations,” in Proc. *IEEE PIMRC*, Tokyo, Japan, Sep. 2009.
- [13] I. Ashraf, L.T.W. Ho and H. Claussen, “Improving Energy Efficiency of Femtocell Base Stations via User Activity Detection,” in Proc. *IEEE WCNC*, Sydney, Australia, April 2010.
- [14] D.-W. Lee, G.-T. Gil, and D.-H. Kim, “A Cost-Based Adaptive Handover Hysteresis Scheme to Minimize the Handover Failure Rate in 3GPP LTE System,” *EURASIP J. Wireless Commun. Netw.*, vol. 2010, no. 1, page ID 750173, 2010.
- [15] L. Ciavattone, A. Morton, and G. Ramachandran, “Standardized Active Measurements on a Tier 1 IP Backbone,” *IEEE Commun. Mag.*, vol. 41, no 6, pp. 90-97, Jun. 2003.
- [16] Femto Forum, “Interference Management in OFDMA Femtocells,” <http://www.femtoforum.org/femto/>, Mar. 2010.