# Green Femtocell Networking with IEEE 802.16m Low Duty Operation Mode

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**Abstract.** Femtocell technique has become a radical approach to improve network capacity and coverage. To efficiently reduce interference between femto BS and other BSs, low duty operation mode (LDM) is deemed as a good method to mitigate the interference. In this work, we develop a mechanism that incorporates the power saving mechanism in both femto BS (LDM mode) and MSs (sleep mode). To correspond to the current IEEE 802.16m system architecture, we build a practical system model and analyze the performance of the proposed modification. The simulation shows that with simple sleep-cycle operation, our mechanism can achieve both a high sleep ratio and an acceptable low delay without generating more control overhead than original system requirement. With the above characteristics, our mechanism provides a solid basis to create a green communication system.

**Keywords:** femtocell, low-duty operation mode, sleep mode.

## 1 Introduction

Along with the raising environmental awareness, green communications capture the public's attention. X. Wang *et al.* [1] provided a comprehensive survey of green techniques for mobile networks. The authors pointed out the importance of femtocell in green communication. The key for communications to go green is to redesign the network's infrastructure into a more efficiency one. Among the existing technologies, power-saving design is especially crucial in wireless communication that needs to be addressed in this issue. IEEE 802.16m [2] specifies two power saving mechanisms : sleep mode for mobile station (MS) and low duty operation mode (LDM) for femto BS. The former one, sleep mode in 802.16m, inherits the design in 802.16e, and has further improvements to the power efficiency. The latter one, LDM on femtocell [3][4], supports the function of scheduling availability intervals, i.e. puts the femto BS to a passive mode that activated on air interface when receiving a connection request. This reduces the system resources that are allocated for the use of femto BS. For a light-loaded femto BS, LDM operation enables power saving and interference mitigation with

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tolerable delay performance. In short, LDM shows great promises to efficiently improve the network capacity with its strength of low cost, small coverage and low transmission power. However, in the current standard, an integrated design of both LDM and sleep mode is not yet supplied, which undermines the power-saving performance of LDM when the femto BS serving multiple MSs at the same time. This is because the MSs have diverse traffic patterns that place different timings of listening window. The objective of this paper is to achieve an efficient power use for femto BS and MSs by means of integrating LDM and sleep mode.

## 2 Related Work

Much research has conducted to evaluate the performance of PSC (power saving class) Type I and Type II in IEEE 802.16e. The first theoretical model of sleep mode is proposed by Xiao [5]. Considering downlink traffic, this work modeled PSC Type I with Markov Chain, in which states represents the sizes of sleep cycle. Zhang and Fujise [6] proposed an analytical model considering both downlink and uplink traffic, which also addresses the effect of traffic direction ratio : the heavier uplink traffic, higher the power consumption. Han and Choi [7] developed a model considering both sleep and awake mode, providing detailed discussions about the effect of parameters. Kong *et al.* [8,9,10] analysed power consumption and traffic delay in PSC Type I and Type II, proposing a Markov Decision Process (MDP) framework to select the best PSC for MS.

Some research offers performance analysis on the enhancement of sleep mode for IEEE 802.16m. Baek *et al.* provided a 2-dimensional Markov chain to model 802.16m with listening window extension in [11]. In [12], Jin *et al.* proposed a mechanism considering both realtime and non-realtime traffic. Recently, some research conducted on innovative designs for 802.16m architecture. In [13], Kalle *et al.* the authors addressed the issue of increasing number of PSC connections worsening the power saving efficiency. They proposed a mechanism that manages joint power class to aggregate individual traffic. This work improves the power efficiency on mobile phones, whereas ours improves the power saving efficiency both mobile phones and femto BS at the same time.

The mentioned works primarily address power consumption issue on MS, while similar research on femto BS is not yet supplied. The objective of this paper is to enhance power efficiency on both femto BS and MS. To achieve that goal, we propose a novel sleep mode scheme that can enhances the power efficiency of femto BS significantly, providing a complete performance analysis on both femto BS and MS.

## 3 Power Saving Mechanism

### 3.1 Sleep Mode in 802.16m

The main reason of power-saving is to prolong the lifetime of mobile phone. Furthermore, the energy-consumption in MSs rises rapidly. Hence, power-saving mechanism of MS is essential in green communication. In the IEEE 802.16m standard, MSs can support Sleep Mode for saving power. Sleep Mode is a state in which an MS conducts periods of absence from the serving BS air interface. During the activation of Sleep Mode, the MS is provided with series of Sleep Cycles that consist of a Listening Window followed by a Sleep Window. During Listening Window, the MS is expected to receive all downlink transmissions same way as in Active Mode. During Sleep Window, the BS shall not transmit downlink traffic to the MS, therefore the MS may power down some physical operation components.

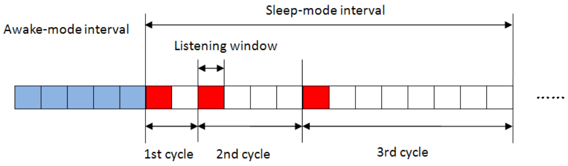

**Fig. 1.** An example of the 802.16m PSC Type I operation

**Power Saving Class of Type I**

PSC type I is recommended for connections of Best effort and Non-Real Time service type, as illustrated in Fig.1. The sleep cycle begins with a listening window, and then a sleep window follows. The length of Listening Window $T_L$ is fixed. During the listening window, MS should wake and listen to the channel. At first, the sleep cycle is the Initial (Minimal) Sleep Cycle $T_{min}$. The sleep cycle will grows doubly until it reaches the Final (Maximum) Sleep Cycle $T_{max}$ if the traffic indication is negative. To sum up, the MS and BS shall update the length of the Sleep Cycle when traffic indication is negative as follows:

$$\text{Current Sleep Cycle} = \min\,(2 \times \text{Previous Sleep Cycle}, \\ \text{Final Sleep Cycle})$$

On the other hand, if the traffic indication is positive, then MS and BS can negotiate the next sleep cycle length. The general case is that MS reset the sleep cycle to Initial Sleep Cycle when the traffic indicator is positive.

**Power Saving Class of Type II**

When the Final Sleep Cycle is equal to the Initial Sleep Cycle, the length of sleep cycle is fixed. Those kind of Power Saving Class are PSC type II. PSC type II recommended for connections of UGS and RT-VR service connection. Due to the fixed length of sleep cycle, the packet delay is restricted in a range. Compare to Type I, MS pays more power for reducing delay in Type II.

### 3.2 Low Duty Mode in Femtocell BS

Besides the normal operation mode, femto BSs may support low-duty operation mode, in order to reduce interference to neighbor cells and save power. In LDM mode, femto BS is (a)periodically active and inactive on air interface. An on-off cycle, named low duty cycle, consists of available intervals (AIs) and unavailable intervals (UAIs). When in UAIs, no transmission is performed on air interface, whereas in AIs femto BS can be active on air interface, such as doing ranging, signaling procedures, or data traffic transmission. A LDM pattern is composed of a sequence of AIs and UAIs.

For illustrating the relationship between MS and BS, we shows the following equation:

$$A(i)_{BS} = \begin{cases} 1 & \text{i is a multiple of } T_{LDM}, \\ \cup_{j=1}^{N} A(i)_{MS_j} & \text{otherwise} \end{cases}$$

where $T_{LDM}$ is the default LDM cycle of femto BS. $A(i)_{BS}$ represents the mode of BS in the i-th frame. If BS is awake in the i-th frame, then $A(i)_{BS} = 1$. Otherwise, $A(i)_{BS} = 0$. Similarly, $A(i)_{MS_j}$ represent the mode of the j-th MS in the i-th frame.

According to [14], a femto BS can enter LDM mode under two conditions : either all MSs served by this femto BS are in sleep or idle mode, or no MS is in the service range of the femto BS. That is, only when all MSs are light-loaded can femto BS be in LDM mode. Besides, [2] specifies that femto BS can freely schedule AI periods based on operational requirement. In other words, current documentations provide the flexibility of design LDM pattern design.

## 4 Proposed Sleep Mode Scheme

As mentioned previously, the benefits of LDM are power-saving and interference-mitigation. And both of these merits are based on fewer available intervals. However, when the number of MSs attached to the the same femto BS increases, the power-saving efficiency of femto BS degrades. The fact is illustrated in Fig.2, in which 3 MSs in the Sleep Mode are attached to the same femto BS. Each MS has the parameters $T_{min} = 2$ frames and $T_{max} = 8$ frames. And the default LDM cycle of femto BS are 8 frames. We assume the Sleep Cycle will be reset to Initial Sleep Cycle if the traffic indicator is positive. In Fig.3, we can observe that the length of Sleep Cycle in each MS begins different as the packets arrives, which means the Listening Windows of each MSs are in different frames. Femto BS still wakes frequently even though there is no traffic after the third LDM cycle. Therefore, the power-efficiency of BS becomes lower. An intuitive solution is to synchronize the Listening Window of each MS by choosing the same Sleep Cycle. Because the amount of data traffic is small in Sleep Mode, so femto BS is supposed to serve all the MSs at one frame. However, the delay tolerance of each MS may be different. It is not feasible to set the same Sleep Cycle of each MS. To enhance the power-efficiency of BS and take account of different traffic type, we propose a new sleep mode which is based on the IEEE 802.16m standard. The proposed solution is to minimize necessary AIs by synchronizing Listening Window of MSs at the same frame time. Hence, the Available Intervals of femto BS can be reduced.

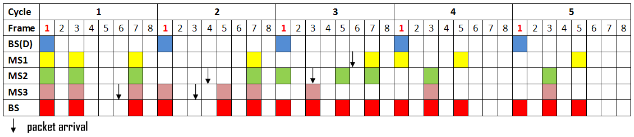

**Fig. 2.** An example of original PSC Type I operation with downlink traffic

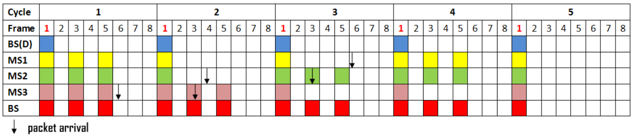

**Fig. 3.** An example of our sleep mode operation with downlink traffic

As we mentioned before, when the number of MSs attached to the the same femto BS increase, the power saving efficiency of femto BS decreases. The fact is illustrated in Fig.2, in which 3 MSs in sleep mode (PSC Type I) are attached to the same femto BS. Each MS has the parameters $T_{min} = 2$ frames and $T_{max} = 8$ frames. And the default LDM cycle of femto BS are 8 frames. If the traffic indicator is positive, then reset the sleep cycle to initial sleep cycle. Observe that the length of sleep cycle in each MS comes to be different as the packets arrives, which means listening windows of MSs are in different frame time. Therefore, femto BS has to apply more AIs and thus leading to lower power-saving efficiency in BS. The proposed solution is to minimize necessary AIs by aligning listening window of MSs on the same frame time. Here three parameters are listed below :

- $T_{MS_i}$: current sleep cycle size of the i-th MS.
- $T_{total}$: sum of historical and current sleep cycle size.
- $T_{BS}$: the interval from current AI to next AI of femto BS.

**Algorithm 1.** proposed sleep cycle scheme

```
if traffic indicator is negative then
    if $T_{total}$ mod $2T_{MS} == 0$ then
        $T_{MS} \Leftarrow min(2T_{MS}, T_{max})$
    else
        $T_{MS} \Leftarrow T_{MS}$
    end if
else {traffic indicator is positive}
    $T_{MS} \Leftarrow T_{min}$
end if
```

Algorithm 1 is our sleep mode scheme algorithm. The algorithm should be executed in listening window for each MS whenever a new sleep cycle starts.

This algorithm will determine the next sleep cycle length. If the traffic indicator is negative, then MS calculates $T_{total}$ modulo $T_{MS}$. If the value is 0, then $T_{MS} = min(2T_{MS}, T_{max})$. Otherwise, maintain the sleep cycle until next listening window. If the traffic indicator is positive, then reset $T_{MS}$ to initial sleep cycle.

We modify the original design when the traffic indicator is negative. In the original IEEE 806.16m standard, the sleep cycle will be double when traffic indicator is negative. In our scheme, we add a restriction for increasing sleep cycle. In this way, our algorithm can ensure the listening windows of each MS will locate in the $(T_{MS} \times K + 1)$-th frame. Where $K$ is zero or positive integer. Therefore, we can ensure that $T_{BS} = \min\{T_{MS_i}\}$. However, in the original sleep mode scheme, because each MS has different traffic pattern, their listening windows locate disorderly. Hence, $T_{BS}$ is less than or equal to $\min\{T_{MS_i}\}$. It is obvious that our sleep mode scheme outperforms than the original sleep mode in the perspective of femto BS due to longer $T_{BS}$.

Fig.3 illustrates our sleep mode scheme with the same traffic pattern in Fig.2. In Fig.2, the total available intervals are 16 frames; however, in Fig.3, the total AIs are only 13 frames by listening window alignment. Please note that compared with PSC Type I, more power of femto BS but less power of MS does proposed alignment procedure save. This is because proposed scheme put one more restriction on MS's sleep cycle doubling.

# 5 Analytical Model

## 5.1 Assumptions

For simplicity, we assumes the packet of each MS arriving at femto BS follows Poisson process with arrival rate $\lambda$. Besides, the transmission rate is 1 packet/frame in listening window.

## 5.2 Markov Chain Model

We propose a two-dimensional Markov chain analysing the performance of MS. Now we define the state notation $S_{x,y}$. The variable $x$ represents the sleep cycle in the state. For example, Sleep cycle $T_{min}$ corresponds to $x = 1$ ; $2 \times T_{min}$ corresponds to $x = 2$; etc. We denote $T_i$ as the sleep cycle in the states whose $x$ variable is $i$. Hence, $T_i = 2^{i-1} \times T_{min}$. There are $\frac{T_{max}}{T_i}$ states whose $x$ variable is $i$. The parameter $y$ correspond to the remainder of $T_{total}$ divided by $T_{MS}$. In state $S_{x,y}$, the sleep cycle is $T_x$, and the remainder of $T_{total}$ divided by $T_{MS}$ is $T_x \times (y - 1)$. We denote the steady state probability in $S_{x,y}$ as $\pi_{x,y}$. For convenience, we use the following notation:

- $N_{NS}$ represents the total number of sleep cycle size.
- $N_X$ represents the number of states whose $x$ variable is X.

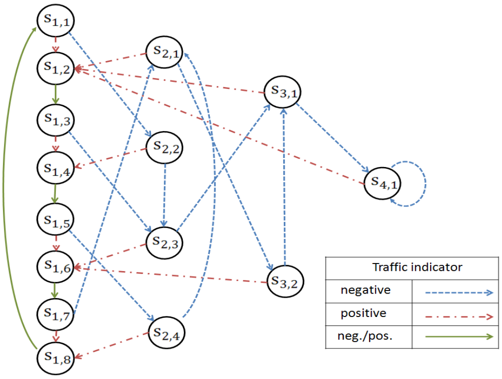

**Fig. 4.** A state diagram of MS with $T_{min} = 1$ and $T_{max} = 8$

According to the above definition, we can get $N_{NS} = log_2(\frac{T_{max}}{T_{min}}) + 1$ and $N_X = \frac{T_{max}}{T_X}$.

Fig.4 shows the state diagram of an MS with $T_{min} = 1$ and $T_{max} = 8$. We can see that the sleep cycle will be reset to initial sleep cycle if the traffic indicator is positive. On the other hand, whether the sleep cycle will maintain or increase depends on the state when the traffic indicator is negative.

After constructing the Markov Chain model, we derive the state transition probability. We define transition probability $P_{m,n,r,s} = P(S_{m,n}$ in i+1-th cycle $|S_{r,s}$ in i-th cycle ). And we classify the different cases by the parameters $r$ and $s$ as follow:

$r = 1$, $s$ is odd number,

$$\begin{cases} P_{r,s+1,r,s} = 1 - e^{-\lambda T_r} \\ P_{r+1,mod(\frac{s+1}{2},N_{r+1})+1,r,s} = e^{-\lambda T_r} \end{cases} \tag{1}$$

$r = 1$, $s$ is even number,

$$P_{r,s+1,r,s} = 1 \tag{2}$$

$N_{NS} > r > 1$, $s$ is odd number,

$$\begin{cases} P_{r+1,mod(\frac{s+1}{2},N_{r+1})+1,r,s} = e^{-\lambda Tr} \\ P_{1,(s-1)\times\frac{T_r}{T_1}+2,r,s} = 1 - e^{\lambda Tr} \end{cases} \tag{3}$$

$N_{NS} > r > 1$, $s$ is even number,

$$\begin{cases} P_{r,mod(s+1,N_r),r,s} = e^{-\lambda Tr} \\ P_{1,(s-1)\times\frac{T_r}{T_1}+2,r,s} = 1 - e^{-\lambda Tr} \end{cases} \tag{4}$$

$r = N_{NS}$,

$$\begin{cases} P_{r,s,r,s} = 1 - e^{-\lambda T_r} \\ P_{1,2,r,s} = e^{-\lambda T_r} \end{cases} \tag{5}$$

According to equation (1)-(5), we can find the balance equation of the Markov chain as follows:

$r = 1$, $s$ is odd number,

$$\pi_{r,s} = \pi_{r,s-1} \tag{6}$$

$r = 1$, $s$ is even number,

$$\pi_{r,s} = \pi_{r,s-1} \times \left(1 - e^{-\lambda T_1}\right) + \sum_{m,n}^{s-2=\frac{T_m}{T_1}\times(n-1)} \pi_{m,n} \times \left(1 - e^{-\lambda T_m}\right) \tag{7}$$

$N_{NS} > r > 1$, $s$ is odd number,

$$\pi_{r,s} = \pi_{r-1,mod(2s-3,T_{r-1})} \times e^{-\lambda T_{r-1}} + \pi_{r,s-1} \times e^{-\lambda T_r} \tag{8}$$

$N_{NS} > r > 1$, $s$ is even number,

$$\pi_{r,s} = \pi_{r-1,mod(2s-3,T_{r-1})} \times e^{-\lambda T_{r-1}} \tag{9}$$

$r = N_{NS}$,

$$\pi_{r,1} = \pi_{r-1,1} \times e^{-\lambda T_{r-1}} \tag{10}$$

With the normalization condition

$$\sum_{m=1}^{N_{NS}} \sum_{s=1}^{N_r} \pi_{r,s} = 1 \tag{11}$$

We can solve the steady state probabilities by equation (6)-(11).

## 6 Performance Evaluation

To evaluate the performance of sleep mode, we define the steady state probability $\pi_i = \sum_{j=1}^{N_i} \pi_{ij}$.

### 6.1 Sleep Ratio of MS

**Definition 1.** We define *sleep ratio* of MS $\phi$ as the sum of sleep window interval divided by the sum of sleep cycle length during total sleep mode interval.

Please note that even when an MS operates in sleep mode, it should wake and listen channel aperiodically. Hence the *sleep ratio* of MS represents the ratio of real power saving duration in sleep mode. Our goal is trying to enhance the ratio without degrading other performance metrics.

we can evaluate the sleep ratio as follows:

$$\phi = \frac{\sum_{i=1}^{N_S} \pi_i (T_i - T_L)}{\sum_{i=1}^{N_S} \pi_i T_i} \tag{12}$$

The denominator represents the normalized length of sleep cycle, and the numerator represents the normalized length of sleep window. By equation (12), we can determine the sleep ratio with the steady state probability.

### 6.2 Sleep Ratio of Femto BS

**Definition 2.** We define *sleep ratio* of BS $\theta$ as the sum of active intervals divided by the total LDM intervals.

The *sleep ratio* of BS represents the ratio of power saving duration of a femto BS during Low-duty operation mode. Similar to the *sleep ratio* of MS, we hope to increase this ratio as much as possible.

**Definition 3.** We define 1 *unit* $= T_{min}$ frames.

For evaluating sleep ratio of BS, we use following notation:

- $begin(i)$ : it is a set that the sleep cycle begins in the i-th unit
- $begin_L(i,s)$ : it is a subset of $begin(i)$. The sleep cycle of elements should not exceed $s$ units.
- $B(i)$: total steady state prob. in $begin(i)$
- $B_L(i,s)$ : total steady state prob. in $begin_L(i,s)$
- $P_{MS}(i)$ : the prob. that a sleep cycle begins at the i-th unit in MS; in other word, it is the prob. that listening window occurs at the i-th unit in BS.
- $P_{BS}(i)$ : the prob. that a sleep cycle begins at the i-th unit in BS; in other word, it is the prob. that listening window occurs at the i-th unit in BS.

Our goal is finding the sleep ratio of BS. But it is hard to get the value directly, so we find $P_{MS}(i)$ first, and then we can calculate $P_{BS}(i)$ and sleep ratio of BS easily. The prob. that cycle begins at the i-th unit is equal to the prob. that cycle ends at the i-1 th unit. If no cycle end is the k-th unit, then we can assure that there is a long sleep cycle begins at the k-s th unit and the cycle length exceed s units. According to the above knowledge, we derive the general form of $P_{MS}(i)$ as follows:

$$P_{MS}(i) = P_{MS}(k)\frac{B_L(k, i-k)}{B(k)} \tag{13}$$

where $k$ is the largest integer which satisfied the following conditions:

$$k \bmod 2^n = 0, n \in N; k < i$$

$k$ is the key position which dominates the behavior of the i-th unit. As long as the sleep cycle doesn't exceed i-k units at the k-th unit, some cycle is sure to begin at the i-th unit. We only need to consider $\frac{T_{max}}{T_{min}}$ units ( or $T_{max}$ frames ), because $T_{max}$ is the largest sleep cycle. Please note that $P_{MS}(1) = 1$.

We assume a femto BS serves N identical MSs. Hence we can get $P_{BS}(i) = 1 - (1 - P_{MS}(1))^N$. Finally, we can calculate sleep ratio of BS by the following equation:

$$\theta = 1 - \frac{\sum_{i=1}^{T_{max}} P_{BS}(i)}{T_{max}} \tag{14}$$

Where $\sum_{i=1}^{T_{max}} P_{BS}(i)$ means the average active intervals in $T_{max}$ frames.

### 6.3 Packet Delay

**Definition 4.** We define *packet delay* $D$ is the interval between packet arriving and successfully received.

For simplicity, we assume packet arrivals follows the Poisson distribution. And there is no transmission error. Thus, M/G/1 queue with vacation is the best model to describe the behavior of traffic. According to the Pollaczek-Khinchin formula for M/G/1 with vacations :

$$\begin{cases} W = \frac{\lambda \bar{X^2}}{2(1-\rho)} + \frac{\bar{V^2}}{2\bar{V}} \\ T = \frac{1}{\mu} + W \end{cases} \tag{15}$$

where the notations are defined as Table 1.

**Table 1.** Notations of M/G/1 model

| Notation | meaning |
|---|---|
| $\lambda$ | packet arrival rate |
| $W$ | packet waiting time in queues |
| $T$ | total waiting time |
| $X$ | service time, i.e. the transmission time |
| $\mu$ | service rate, i.e. the packet transmission rate |
| $\rho$ | the ratio of $\lambda$ to $\mu$ |
| $V$ | vacation interval, i.e. the sleep window size of MS |
| $\bar{V}$ | the first moments of the vacation interval |
| $\bar{V^2}$ | the second moments of the vacation interval |

According to [10], a compensation term $d_s$ should be added to total delay. Where $d_s = \frac{V}{2}\rho$. So the mean packet delay $E[D]$ can be evaluated by

$$E[D] = T + d_s \tag{16}$$

Obviously, the transmission time $X$ is $\frac{1}{\mu}$, our work is to find $\bar{V}$ and $\bar{V^2}$. Again we can find those by steady state probability as follows:

$$\begin{cases} \bar{V} = \sum_{i=1}^{N} \pi_i V_i \\ \bar{V^2} = \sum_{i=1}^{N} \pi_i V_i^2 \end{cases} \tag{17}$$

where $V_i$ is the length of Sleep Window in the states whose $x$ variable is $i$, hence $V_i = T_i - T_L$.

## 7 Simulation Results and Discussions

To verify our theoretical model, we write an event-driven simulator which implemented in Matlab code. At first, we compare the simulation results of MS in the proposed sleep mode scheme to the theoretical value.

**Table 2.** Parameter setting

| Parameters | Setting |
|---|---|
| Initial Sleep Cycle | 2 Frames |
| Final Sleep Cycle | 512 Frames |
| Listening Window | 1 Frame |
| Transmission Rate | 1 per frame |

The simulator parameter setting of MS is shown in Table 2 and the default LDM cycle of femto BS are 512 frames.

Fig.5 has two parts. The left part shows the sleep ratio of MS based on proposed sleep mode in different arrival rate. We can see that if the packet arrival rate increases, the sleep ratio decreases. The right part shows the mean packet delay of MS based on the novel sleep mode in different arrival rate. The mean packet delay decreases when the arrival rate increases. The reason is that the sleep cycle will be reset to initial sleep cycle when traffic arrived. Fig.6 shows the sleep ratio of BS and MS in different number of MS. The sleep ratio of BS reduces when number of MSs increase. It is clear that the analysis and the simulation match each other very well.

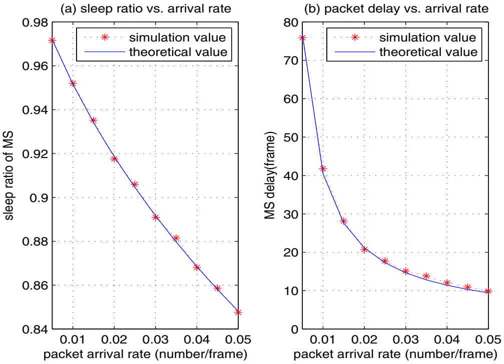

**Fig. 5.** The simulation result and theoretical value in our sleep mode scheme

To reveal the advantage of our design, we choose the original PSC type I sleep mode as the control group. The performance metrics we considered are the sleep ratio of BS, the sleep ratio of MS and the mean packet delay. We define the sleep ratio of BS as the ratio of total unavailable interval to total low-duty mode interval. In Fig.7 and Fig.8, we assume a femto BS serving 5 MSs. In proposed scheme and original scheme, each MS has the same parameters as Table 2. Fig.7 shows sleep ratio of MS and femto BS according to packet arrival rate. We can see that the sleep ratio of BS in proposed scheme is higher than that of original scheme. Please recall that proposed algorithm can align the listening window of each MS. Hence, the Active Intervals of femto BS can be reduced. On the other hand, the sleep ratio of MS in proposed scheme is lower than that of original

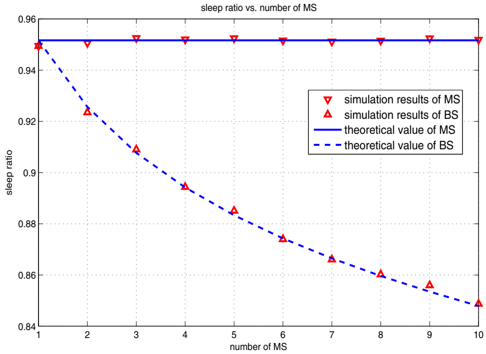

**Fig. 6.** Sleep ratio of MS and femto BS according to number of MS

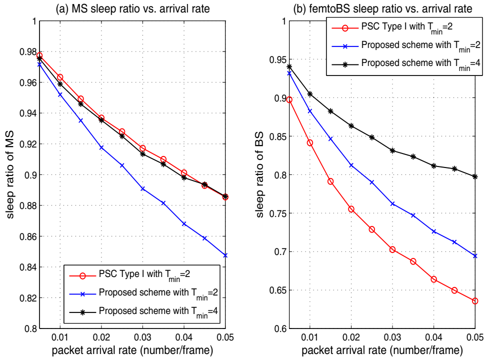

**Fig. 7.** Sleep ratio of MS and femto BS according to packet arrival rate

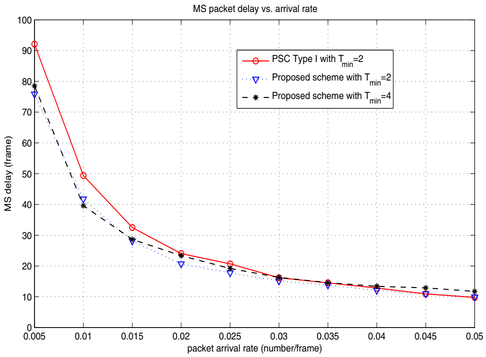

**Fig. 8.** Mean packet delay according to packet arrival rate

scheme. The reason is that we put a restriction of increasing sleep cycle, so the sleep cycle in our scheme is less than or equal to the original scheme. Fig.8 shows the mean packet delay with different arrival rate. In proposed scheme with $T_{min} = 2$, the packet delay is always lower than that of original scheme because its sleep cycle is less than or equal to that of original scheme.

Now we have a brief summary : in the same parameters, our scheme has higher power sleep ratio of BS and has lower mean packet delay but cost more power in MS. Please note that there is a trade-off relationship between power and delay. And we can save more power in exchange of longer delay by adjusting the parameters. For example, if we want to increase the sleep ratio of MS, then we can choose a bigger initial sleep cycle. Due to the larger initial sleep cycle, both the sleep ratio in MS and mean packet delay are increased. According to Fig.7 and Fig.8, the curves of MS sleep ratio and MS packet delay between "PSC Type I with $T_{min} = 2$" and "Proposed scheme with $T_{min} = 4$" are very close. However, the sleep ratio of BS in proposed scheme is much higher than that of original scheme. It is obviously that our sleep mode scheme outperforms than original scheme.

We illustrate the relationship between sleep ratio of BS and number of MS in Fig.9. It is clear that if femto BS serves more MSs, the sleep ratio of BS in low duty mode will decrease. The downtrend of sleep ratio in proposed scheme is much gentler than the original scheme. Because our scheme can efficiently align the listening window of each MS. To sum up, our scheme can save a great deal of power in femto BS and still maintain the performance of MS. And the advantage of our scheme become more significant when the number of MS increases.

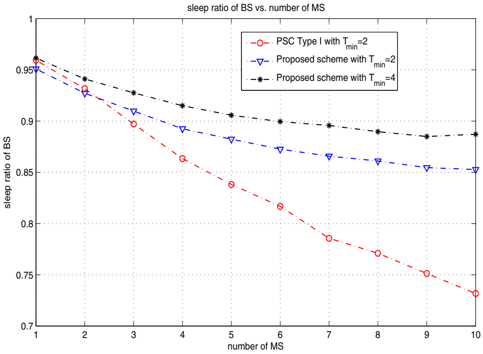

**Fig. 9.** Sleep ratio of BS according to number of MS. (Packet arrival rate = 0.01 per frame)

## 8 Conclusions

In this paper, we develop a power saving scheme to satisfy the criteria of green communications. As addressed, power efficiency can be further improved by means of incorporating two kinds of power-saving mechanisms, i.e. LDM for femto BS and sleep mode for MS. We provide a complete performance analysis of sleep ratio and packet delay by applying Markov Chain model and M/G/1 queueing model. Simulation results show that the proposed scheme achieves higher power efficiency in femto BS with a negligible delay increase. Our main contribution is to propose a simple and implementable mechanism to achieve both power efficiency and interference mitigation in femtocell network. Such mechanism takes only some simple distributed calculation with a slight overhead increase to achieve power efficiency. To the authors best knowledge, this is the first work incorporating both LDM operation and sleep mode into the power efficiency design.

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