國立交通大學

資訊科學與工程研究所

碩 士 論 文

# 在 IEEE 802.16e 下一個節省能源的增進型睡眠模式運作方式

# Enhanced Sleep Mode Operation for Energy Saving in IEEE 802.16e

研 究 生：鄭思賢

指導教授：王國禎 教授

中 華 民 國 九 十 六 年 六 月

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資 訊 科 學 與 工 程 研 究 所


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# 在IEEE 802.16e下一個節省能源的增進型睡眠模式運作方式

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## 摘 要

近年來，無線寬頻網路(如 IEEE 802.16e)已經有愈來愈受歡迎的趨勢。對於在無線寬頻網路的的行動用戶來說，所有的運作都依賴著有限的電池能源，該如何節省能源是一個重要的問題。行動用戶被允許可以進入睡眠模式，以達到節省電源消耗的目的。在 IEEE 802.16e 中，它將所有的連線服務依照省電的運作方式，分成三種不同的省電類型(I, II 及 III)。一般而言，在基地台和行動用戶之間，可能存在著一條以上的連線服務。為了更有效率的省電，我們必須同時考慮所有的連線服務。在本論文中，我們只考慮單一播送的連線服務。我們去除了在省電類型 I 中的聆聽視窗，同時考慮在延遲限制下，聚集數個省電類型 II 的封包並延遲在同一個訊框中傳送，這樣可以減少類型 II 的聆聽視窗個數。而在類型 II 的聆聽視窗

中，行動用戶可以收到所有連線服務的 MOB_TRF-IND 訊息。藉由減少聆聽視窗的個數，行動用戶可以在所有的連線服務中，得到更多的共同空閒時間，因此可以停留在睡眠模式下更久。如果有愈長的睡眠時間，則行動用戶就可以達到更好的省電效果。模擬結果顯示，關於能源消耗方面，我們提出的方法(E-LCFT)比 IEEE 802.16e 的方法，可以提高 33%到 68%的省電效果，但是相對地有比較長的封包延遲時間。即使如此，我們的方法依然滿足了類型 II 的 QoS(延遲)需求。我們所提出的方法和原有的 IEEE 802.16e 標準依然相容，因為我們的方法只需要調整基地台的類型 I 和類型 II 之睡眠視窗參數，並沒有更改到其它的協定。

**關鍵詞**：能源消耗，能源效率，IEEE 802.16e，省電類型，睡眠模式，WiMax。

# Enhanced Sleep Mode Operation for Energy Saving in IEEE 802.16e

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## Abstract

The broadband wireless access (BWA) network, such as IEEE 802.16e, becomes more and more popular in recent years. The power saving for mobile subscriber stations (MSSs) in this network is a very important issue, because all MSSs operate on the limited battery power. The MSSs are allowed to switch to the sleep mode to reduce their power consumption. In the IEEE 802.16e, it classifies service connections into different types of power saving classes, types I, II and III, for power saving operation. In general, there may be more than one service connection between a base station (BS) and an MSS. For efficient power saving, we have to consider all service connections as a whole. In this thesis, we focus on unicast service connections only (types I and II). We eliminate the listening windows of the power saving classes of type I. We also group several type II packets into a single frame for transmitting later while meeting its delay constraint. This is to reduce the number of listening windows of the power saving classes of type II. During the listening windows of type II, the MSS will receive the traffic indication (MOB_TRF-IND) message of all types. In this way, the MSS can have more common free time among service connections in order to stay in sleep mode longer. The longer the sleep periods is the more power saving the MSS can achieve. Simulation results have shown that our proposed E-LCFT (enhanced longer common free time) performs 33% to 68% better than the IEEE 802.16e Standard in terms of percentage of sleep periods, which reflects power consumption. The overhead of the proposed E-LCFT is that it has longer average packet delay than the IEEE 802.16e Standard. However, the QoS requirements of type II connections are still guaranteed. The proposed E-LCFT scheme is still compatible to the IEEE 802.16e Standard, because our schemes only need to adjust the sleep windows of types I and II.

**Keywords**: energy consumption, energy efficiency, IEEE 802.16e, power saving class, sleep mode, WiMax

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# Chapter 1

# Introduction

The original IEEE 802.16 standard [1] only supports fixed broadband wireless access (BWA) in which all subscriber stations (SSs) are in fixed locations. The emerging IEEE 802.16e standard [2] enhances the mobility on the original standard so that mobile subscriber stations (MSSs) can maintain its operation during their moving. The energy saving of mobile devices is a very important issue, because the operation of mobile devices depends on limited battery power.

In the IEEE 802.16e, there is always a base station (BS) to be a control center for many MSSs in its radio range. Multiple MSSs may share an uplink channel via TDD to transmit data, voice, and so on. For all MSSs, there are two operation modes: normal mode (or called active mode) and sleep mode. The normal mode is the state that the MSSs transmit/receive data with the BS. The sleep mode is a state in which an MSS conducts pre-negotiated periods of absence from the serving BS air interface. These periods are characterized by the unavailability of the MSS, as observed from the serving BS [2]. Every time MSSs want to enter the sleep mode, they have to negotiate with the BS. The MSS stays at normal mode until it gets the permission of entering the sleep mode from the BS. The goal of sleep mode operation is intended to minimize the power usage of MSSs and to prolong the life time of MSSs.

## 1.1 Sleep Mode Operation in IEEE 802.16e

When a connection is established, in order to reduce the power consumption, an MSS can switch to the sleep mode if there is no packet to transmit.

The specification defines the sleep mode operation. In the sleep mode operation, the time is divided into fixed sizes, called frames. A frame is the basic unit of time to send, receive and listen. Before entering the sleep mode, the MSS has to send a sleep request frame to the BS. If the MSS gains the approval from the BS, then it will enter the sleep mode. When an MSS enters the sleep mode, it sleeps during the sleep window and wakes up at the listening window to receive the MOB_TRF-IND (mobile traffic indication) message. If there is no buffered packet for itself, it sleeps again until the next listening window. The actions of sleeping and listening with updated size of sleep window are repeated until there is buffered data for the MSS to transmit. The MSS also wakes up from the sleep mode when the MSS has data to transmit to the BS.

## 1.2 Power Saving Classes in IEEE 802.16e

The IEEE 802.16e defines three power saving classes for different applications which have different properties. Power saving class is a group of connections that have common demand properties [2]. For different connections between the BS and the MS, there are different QoS requirements. So we group different connections into different power saving classes to match their QoS requirements. We first describe some common parameters in the power saving classes as shown in Table 1

Table 1. Common parameters for power saving classes

| Parameter | Description |
|---|---|
| $T_{min}$ | the length of minimum time for one sleep window, which is equal to $T_{init}$ |
| $T_{max}$ | the length of maximum time for one sleep window |
| $T_L$ | the length of listening window in the sleep mode for MSSs to check whether there is buffered data in the BS |

The three types of Power Saving Classes are described as follows [2]:

### 1.2.1 Power Saving Classes of Type I

It is recommended for connections of BE (best-effort) or NRT-VR (non-real time-variable rate) service. The nth sleep window, called $T_n$, is a variable. In the beginning of the sleep mode, there is an initial sleep window $T_{min}$. If it enters a continuous sleep period, the sleep window will become a double of the previous one, until the length of sleep window equals to the $T_{max}$. The sleep window will stop increasing and become a fixed value. Equation (1) presents the variation of $T_n$.

$$T_n = \begin{cases} \min(2^{n-1}T_{\min}, T_{\max}), & n > 1 \\ T_{\min}, & n = 1 \end{cases} \quad (1)$$

During the power saving classes of type I, the MSS is not expected to send or to receive any MAC SDUs (service data unit). Fig. 1 shows the operation of power saving classes of type I.

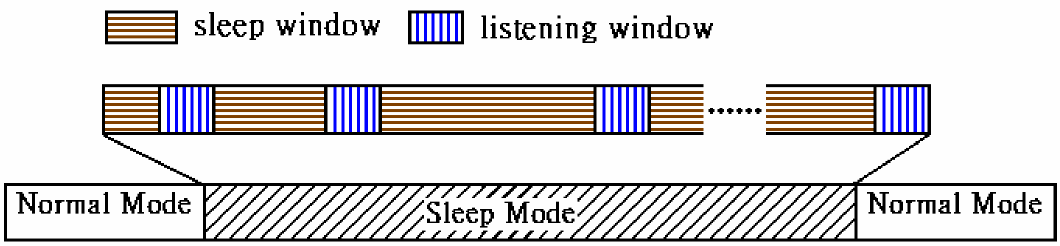


Fig. 1. Operation of power saving classes of type I.

### 1.2.2 Power Saving Classes of Type II

It is recommended for connections of UGS (unsolicited grant service) or RT-VR service. The nth sleep window, $T_n$ is a constant. It will not change during the sleep mode operation. Each sleep window has the same size as $T_{init}$. Equation (2) presents the value of $T_n$.

$$T_n = T_{init} \quad (2)$$

During the listening windows of power saving classes of type II the MSS may send or receive any MAC SDUs. Fig. 2 shows the operation of power saving classes of type II.

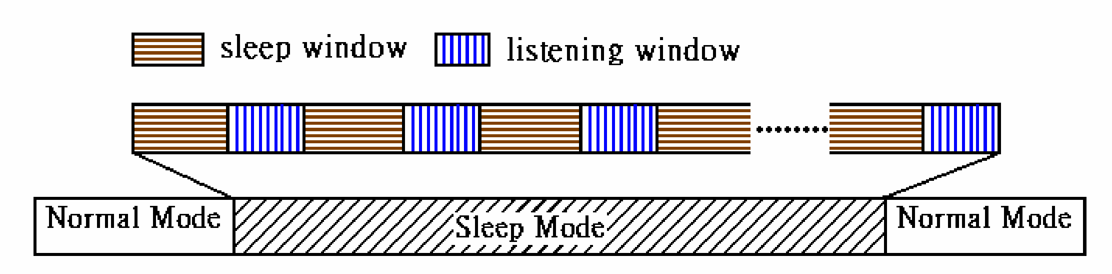


Fig. 2. Operation of power saving classes of type II.

### 1.2.3 Power Saving Classes of Type III

It is recommended for multicast connections or management operations All the MSSs that entered the sleep mode use a pre-negotiated sleep window. After this period all MSs will awake again to do their job. Equation (3) presents the value of sleep window T.

$$T = T_{init} \quad (3)$$

Fig. 3 shows the operation of power saving classes of type III.

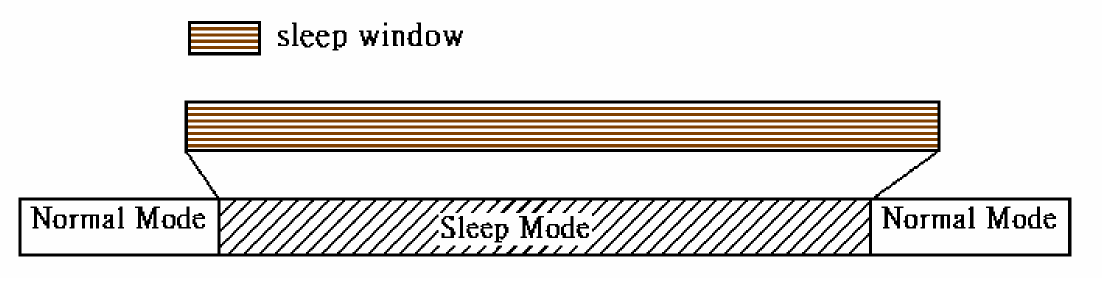


Fig. 3. Operation of power saving classes of type III.

# Chapter 2

# Problem Statement

In general, there is usually more than one connection between the BS and the MSS at one time. There are also different connection types among them. If we want to consider the power saving efficiency, we have to consider all service connections as a whole. We define free time as the total periods of sleep windows in the sleep mode for one connection and common free time as the common periods of free time among several connections.

Fig. 4 is an example of sleep mode operation with two power saving classes (type I and type II). Each connection has its own free time indicated by sleep windows. In the state of the MSS, the periods which are marked as “Sleep Time” is the common free time between the two connections. The periods of sleep time is the actual time duration for the MSS to enter the sleep mode to save power. Note that in Fig. 4, each connection has more free time in its own sleep mode operation. However, the common free time that the MSS can enter the sleep mode is much less than the free time of each connection. This is because the listening windows are not at the same time periods between two connections.

To enhance power saving, the MSS needs a longer periods of common free time among different connections. The basic idea of our approach is to reduce the number of listening windows by grouping packets in the BS, that are originally scheduled to send in multiple listening windows, and send them in one single listening window while meeting the delay constraints of different connections so as to lighten the effect of dispersive listening windows.

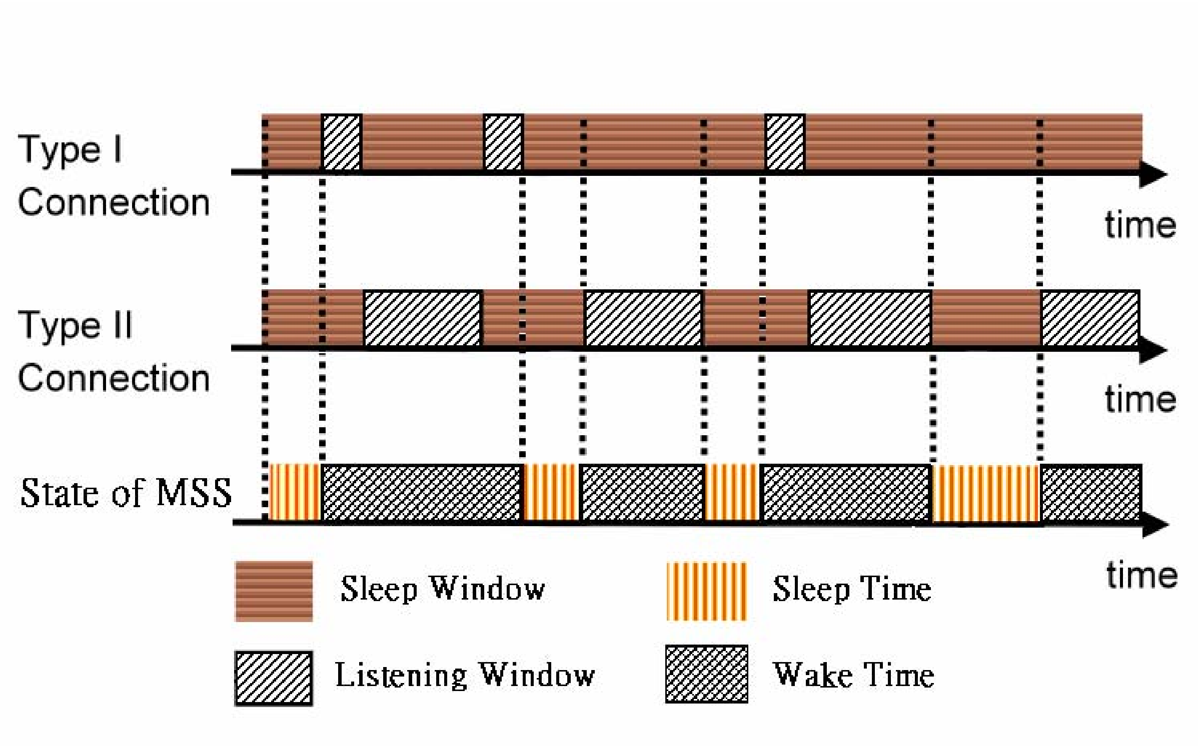


Fig. 4. Example sleep mode operation with two power saving classes.

# Chapter 3

# Related Work

In recent years, several researches focused on the performance analysis of sleep mode operation in the IEEE 802.16e. However most of them only concentrated on the performance analysis of power saving classes of type I. In [3][4][5], the authors proposed a model for performance analysis of the sleep-mode operation for energy saving considering both incoming and outgoing frames of MSSs. In [6], it examined the sleep mode operation in IEEE 802.16e in terms of the dropping probability and the mean waiting time of packets in the queue buffer of BS. In [7], it adaptively configures different parameters ($T_{min}$, $T_{max}$, and power saving threshold size) to adapt for different traffic types to achieve better power saving. Two examples of FTP and CBR traffic were used to show its idea.

In [8], the authors proposed an MILI (multiple increase and linear increase) scheme to adjust the sleep window dynamically based on different traffic patterns to save power and reduce delay for the power saving classes of type I. They thought the doubling method is not good for some traffic environments. Under light traffic, the sleep period should be larger. That is, a longer sleep window should be used. On the other hand, if the traffic is heavy, a longer sleep window may result in longer delay. Therefore, a shorter sleep window should be used. In [9], they analyze and evaluate the sleep mode operation in the power saving classes of type

I and II. They showed that in order to achieve an optimal efficiency of energy saving, the MSS should pre-negotiate with the BS to do the adaptive switching between power saving classes of types I and II according to the measured traffic intensity. In [10], they proposed two scheduling algorithms (PS and AS) for power saving classes of type II connections. The schemes minimize the power consumption of an MSS and also guarantee the requirement of QoS. They group packets into the same frame to reduce the number of listening windows. Fig. 5 gives an example that applies the PS. It groups two type II packets into a single frame. The number of listening windows is reduced and the sleep periods increase. As a result, there is more free time for the MSS to enter the sleep mode and save more power. Table 2 summaries the basic idea and characteristics of just mentioned existing approaches [7][8][10] and our two proposed schemes (LCFT and E-LCFT).

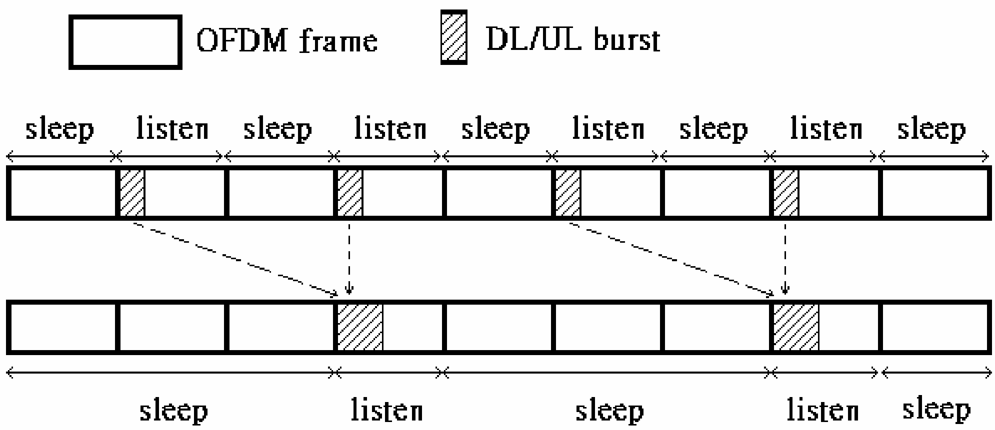


Fig. 5. Periodic on-off scheme (PS) [10]

Table 2. Qualitative comparison of existing IEEE 802.16e power saving schemes.

| Scheme | Type | Basic idea | Characteristics |
|---|---|---|---|
| Adaptive power saving strategy [7] | I or II | Set different $T_{min}$ and $T_{max}$ for different traffic types to achieve the best effect | Using examples of FTP and CBR to explain how to evaluate the worse case of transmission and set the parameters $T_{min}$ and $T_{max}$ to save power |
| MILI [8] | I | Adjust the size of sleep windows dynamically by different traffic patterns | The size of sleep windows does not just double the previous one; it should be adapt to real traffic patterns to save power |
| Periodic on-off scheme (PS) [10] | II | Group type II packets in one connection and schedule them using a smaller number of OFDM frames | Reduce the number of frames to send from BS to MSS in order to increase the sleep periods of the MSS to save its power |
| Aperiodic on-off scheme (AS) [10] | II | Group type II packets among different connections and schedule them using a smaller number of OFDM frames | Reduce the number of frames to send from BS to MSS in order to increase the sleep periods of the MSS to save its power |
| LCFT (proposed) | I & II | Remove the listening windows of type I | Increase the sleep periods of the MSS to save its power |
| E-LCFT (proposed) | I & II | Remove the listening windows of type I and group type II packets in one connection and schedule them using a smaller number of OFDM frames | Further increase the sleep periods of the MSS to save its power and enhance the power saving of the LCFT |

# Chapter 4

# Proposed Energy Saving Schemes

Because there are usually more than one service connection between a BS and an MSS, we have to consider these connections as a whole. From Fig. 4, we know that if there is more than one connection, the total common free time will decrease, because the total common free time is the common periods of free time among all connections. If we can reduce the number of listening windows in any connection, we can have more common free time among connections, thus have more sleep time to save power. In this thesis, we propose two energy saving schemes to increase the length of common free time and to enhance the energy saving of sleep mode operation. Our schemes were designed for an environment that has both power saving classes of type I and type II connections. In our schemes, we didn’t consider the power saving classes of type III, which is for multicast connections, since we focused on the unicast connections only.

The first proposed scheme is called Longer Common Free Time (LCFT). Because the power saving classes of type II (for UGS, RT-VR) is time-sensitive, we only modify the operation of the power saving classes of type I to have more common free time. For type I connections, the MSS wakes up to listen the traffic indication message at each listening window. The MSS returns to sleep mode again when there is no buffered data in the BS. The basic idea of our LCFT scheme to removes the listening windows from the power saving classes of type I connections and the traffic indication messages of power saving classes of type I will be handled during the listening windows of power saving classes of type II connections. The reason to do so is because the power saving classes of type I is for connections of BE and NRT-VR, which are time-insensitive.

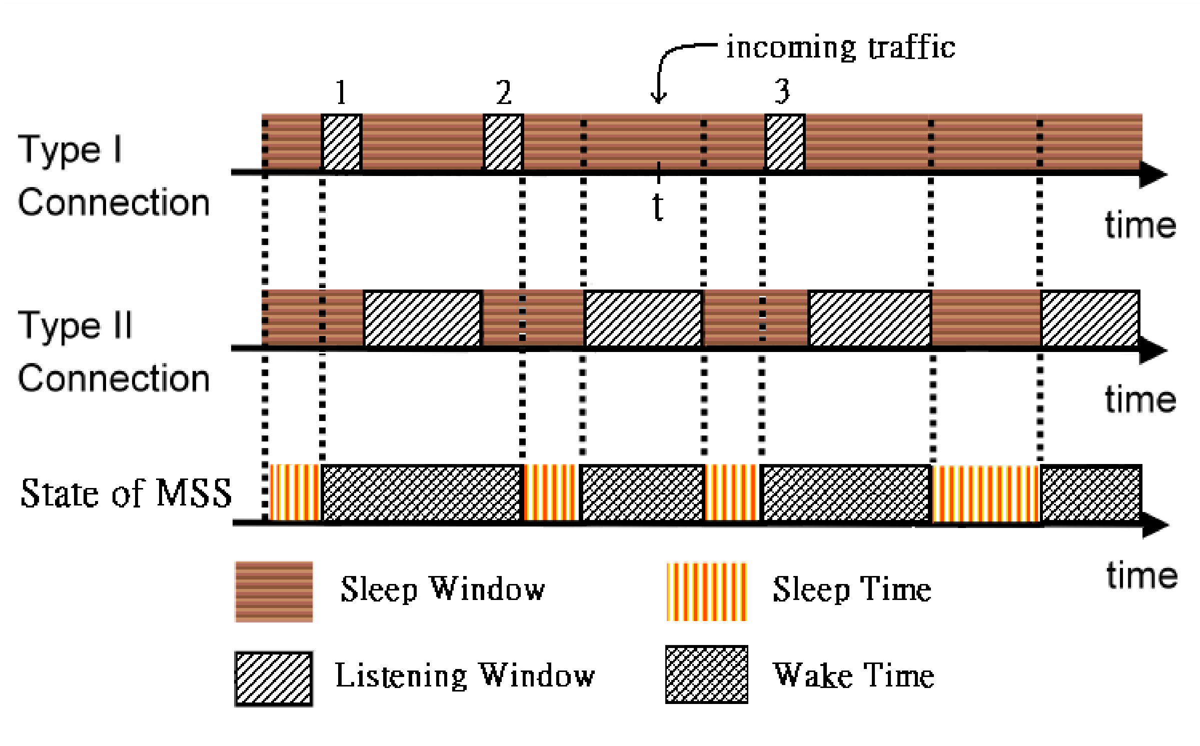


Fig. 6. Original scheme of power saving classes

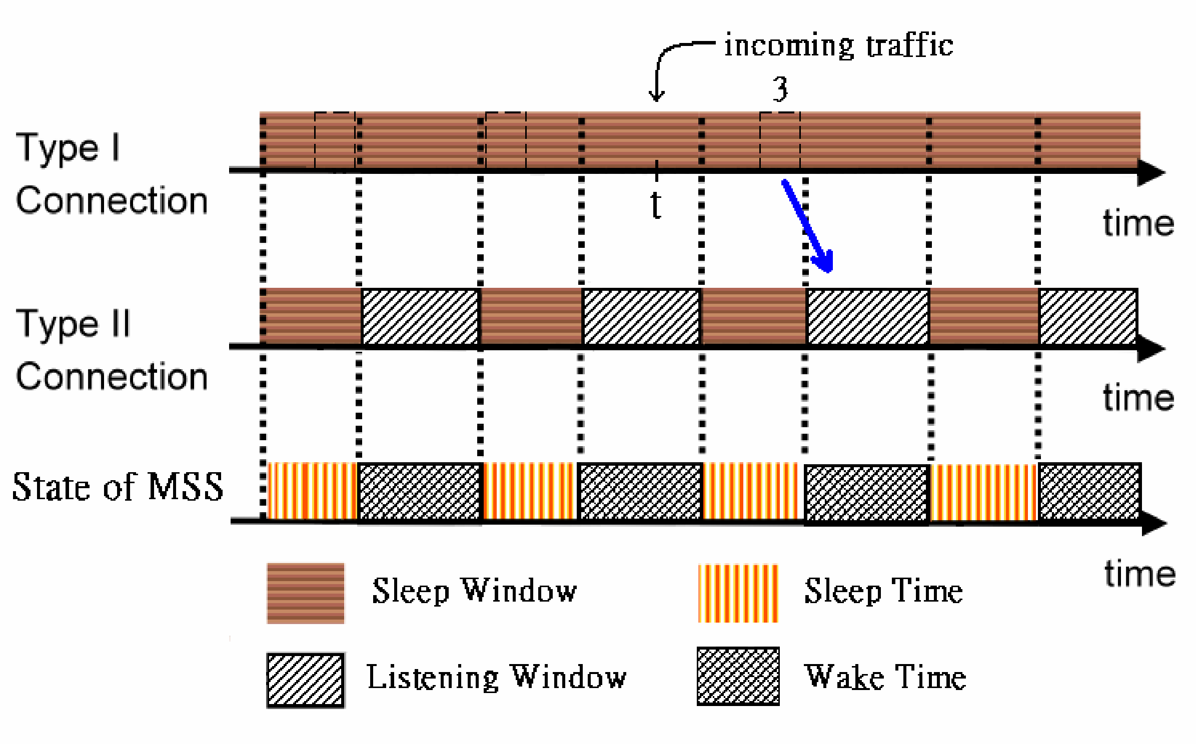


Fig. 7. Proposed method of power saving classes

In Fig. 6, there are three listening windows in the type I connection. The MSS has to wake three times to listen the traffic indication message. If there is only one data coming at time t, in the first and second listening windows, the MSS beeds to wake up and then return to sleep right away. We can have longer common free time if we can keep sleeping at these two listening windows.

In Fig. 7, the proposed LCFT method removes the listening windows from the power saving classes of type 1 connection and the traffic indication message transmitted by the BS will be handled during the listening windows of type II connection. For example, in Fig. 7, the incoming traffic at time t will be handled during the third listening window of type II connection. The advantage of our LCFT scheme is that for type I connections, the MSS doesn't need to wake up at all to listen the traffic indication messages from the BS. This method reduces the effect of type I connections on common free time, and the MSS shall have longer free time to enter the sleep mode. On the other hand, the method uses the periodic characteristic of type II connections to read type I traffic indication messages if any. Note that the type II connection wakes up in a fixed period, so the delay of type I connections can be bounded. In summary, this method eliminates of the listening windows of type I connections to save more power while type I connections have bounded delays.

Besides the LCFT, we combine the idea of [10] to enhance the LCFT scheme. We called it enhanced LCFT (E-LCFT). This E-LCFT scheme groups several type II packets in one connection into a single frame for transmission to reduce the number of frames that need to transmit packets from BS to MSS. In this way, the sleep periods of this connection can be increased. As a result, the MSS can have more common free time among different connections to enter the sleep mode and save more power. The proposed two schemes, LCFT and E-LCFT are compatible with the original IEEE 802.16e standard in terms of no change of MSSs and no change of the communication mechanism between BS and MSS. The only requirement is that the BS needs to be aware of LCFT and E-LCFT in order to set appropriate values of $T_{min}$ and $T_{max}$. For the LCFT, assume a type I connection of the MSS sends a request of sleep mode operation to the BS. Then, if the BS permits the request, it will set the parameter $T_{init}$ to a very large number. For this type I connection, the MSS will not wake up periodically to listen to the traffic indication message. If there are buffered packets for the type I connections in the BS, the BS can transmit the packets to the MSS via the frames of type II connections. If the data size of power saving classes of type I is small enough, we can use the unused frame space of a type II connection to transmit. Otherwise, the BS will transmit the data to the MSS in the next frame and the MSS will stay awake to receive the data. For the E-LCFT, the BS may group several type II packets that are to be sent in separate frames, into a single frame for transmitting later. In this situation, the BS only needs to adjust $T_{min}$ to allow the MSS to sleep longer. Again, for E-LCFT to work, the only requirement is the BS needs to be aware of E-LCFT. No other changes are necessary in the MSS or the communications between BS and MSS.

Our schemes are designed for an environment with both power saving classes of type I and type II connections. If there are many connections of type I and less connections of type II, our schemes may not achieve a good performance. Because if too many buffered data have to be transmitted with type II frames, the average packet delay of type I connections will be extended and the advantage of using unused frame space of type II connections will not work well.

# Chapter 5

# Simulation Results and Discussion

## 5.1 Simulation Environment

We used Visual C++ to simulate and evaluate the performance of LCFT, E-LCFT and the sleep mode operation in the IEEE 802.16e in terms of the percentage of sleep periods and average packet delay. The percentage of sleep periods, which reflects the power consumption of an MSS, is defined as (number of sleep frames) / (number of sleep frames + number of listening frames + number of awake frames). The average packet delay is the average elapsed time from the time that a packet enters the BS to the time that the packet completes its transmission to the MSS. The simulation environment is similar to that in [10]. The duration of an OFDM frame is assumed 5 *ms*, and the maximal data rate that a BS can offer an MSS is assumed 1600 *kbps*. That is, the frame length is 1000 *bytes*. Eight different traffic connections were defined and the parameters of them are described in Table 3 and Table 4. Some parameters were referred from [4] and [10] and we modified part of them to demonstrate the energy efficiency of our proposed schemes in every respect.

Connections A, B, C and D are power saving classes of type I, and connections E, F, G and H are power saving classes of type II. The main difference between connections in each type is the variations of packet size and interval of packet arrival. This is to evaluate the performance under different traffic loads. The values of packet size and interval of packet arrival for each packet in type I connections were randomly generated from the ranges specified in Table 3.

Table 3. Parameters of type I connections

| Connection | A | B | C | D |
|---|---|---|---|---|
| Type | I | I | I | I |
| Packet size (*Bytes*) | 1~1000 | 1~1000 | 1000~2000 | 1000~2000 |
| Sleep Period (*ms*) | [5, 320] | [5, 160] | [5, 320] | [5, 160] |
| Interval of packet arrival (*ms*) | 1~350 | 1~180 | 1~350 | 1~180 |

Table 4. Parameters of type II connections [10]

| Connection | E | F | G | G |
|---|---|---|---|---|
| Type | II | II | II | II |
| Packet size (*Bytes*) | 160 | 160 | 800 | 800 |
| Interval of packet arrival (*ms*) | 20 | 30 | 20 | 30 |
| Delay constraint (*ms*) | 100 | 100 | 100 | 100 |

## 5.2 Simulation Results and Discussion

In Fig. 8, it shows the percentages of sleep periods using the three different schemes (802.16e, LCFT and E-LCFT). The higher percentage of the sleep period is, the longer common free time that an MSS can enter the sleep mode and save more power. The notation A+E means that there are only two connections, A and E. It is a simple traffic environment. By increasing the number of connections, the traffic environment becomes more complex. We found that if the traffic environment becomes more complex, the percentage of sleep periods will become smaller in all the three schemes. In all cases, both the proposed two schemes performed better than the IEEE 802.16e. In Fig. 8, it shows that the percentages of sleep periods of LCFT and E-LCFT are 14% to 50% and 33% to 68% more than IEEE 802.16e, respectively.

The overhead of the proposed schemes (LCFT, E-LCFT) is that they have longer average delay than the scheme of IEEE 802.16e. The reason is that we delay the listening windows and reduce the number of listening windows. The buffered data in the BS are sent only after the listening windows of type II connections. However, we bounded the delay. The listening windows were postponed by the evaluation with delay constraint of type II connections. For connections of power saving classes of type II, we also guarantee their QoS. For the connections of power saving classes of type I, we wouldn't make their average delay longer than the delay constraint of type II.

Fig. 9 shows the average packet delay in different traffic environments. For type I (T1) connections, the LCFT has 6% to 31% longer average packet delay than the IEEE 802.16e scheme and the E-LCFT has 71% to 77% longer average packet delay than the IEEE 802.16e scheme. For type II (T2) connections, the LCFT has the same average packet delay as the IEEE 802.16e scheme since the LCFT did not modify the sleep mode operation of type II connections. The E-LCFT has 84% to 88% longer average packet delay than the IEEE 802.16e scheme. The IEEE 802.16e scheme achieves the lowest packet delay, because its MSS wakes up more frequently to transmit packets. Nevertheless, the simulation results indicate that all schemes, no matter type I or type II connections all satisfied the QoS requirement in terms of delay constraints specified in Table 4.

Since we can bound the average packet delay under the delay constraint of type II connections in our schemes, here we present another simulation results of the percentage of sleep periods and average packet delay with a tight delay constraint in Fig. 10 and Fig. 11, respectively. The parameters of connections E', F', G', and H' are the same with connections E, F, G and H respectively, except the delay constraint. We changed from the loose delay constraint of 100 ms to a tight delay constraint of 30 ms. The simulation results still show that the LCFT is 14% to 50% better than IEEE 802.16e and the E-LCFT is 26% to 57% better than IEEE 802.16e in terms of the percentage of sleep periods. The average packet delay of the LCFT is still the same as the IEEE 802.16e scheme, but the average packet delay in the

E-LCFT decreases obviously. This is because the value of delay constraint affects the length of sleep interval in type II connections. For type I connections, the E-LCFT has 38% to 44% longer average packet delay than the IEEE 802.16e scheme. For type II connections, the E-LCFT has 33% to 67% longer average packet delay than the IEEE 802.16e scheme. If the delay constraint is set smaller, the average packet delay in the E-LCFT will become smaller. This is because we use the delay constraint to calculate the number of packets that can be grouped into a single frame for transmitting and thus to guarantee the QoS.

The listening windows of type II connections can transmit the MAC SDUs (service data units). If the size of a type II packet is smaller, the unused space in the listening window will be larger. In this situation, we can have higher probability to transmit type I packets within the type II listening window. Then the MSS will have more frames to enter the sleep mode. In Fig. 12, it shows the effect of packet size on the percentage of sleep periods. The A+E and C+E have more sleep periods than the A+G and C+G, respectively, because the packet size in connection E is smaller than that in connection G. The A+E also has a higher percentage of sleep periods than the C+E, because the packet size of A is smaller than that of C.

Note that the proposed two schemes were designed to piggyback the type I connection's traffic indication message at the type II connection's traffic indication message. If the number of type II connections is much less than type I connections, the percentage of sleep windows of our schemes will become smaller and the average delay may become longer. In the following, we will evaluate this situation. In Fig. 13, there is only one type II connection E in the following cases: A+E, A+B+E and A+B+C+D+E. The average packet delay increases when the number of type I connections increases. This is because the total size of buffered packets is larger than the unused space that a listening window of type II can provide. The BS then has to transmit the unsent packets with another frame(s) and the packet delay becomes longer. In the case of A+B+C+D+E+F, there are two type II connections of equal packet size. Comparing between A+B+C+D+E and A+B+C+D+E+F, the average packet delay of the latter is smaller than the former, since the latter has more type II connections of equal packet size. Therefore, the proposed two schemes are suited to environments that allow type II connections to utilize its unused space in a frame to carry type I's packets.

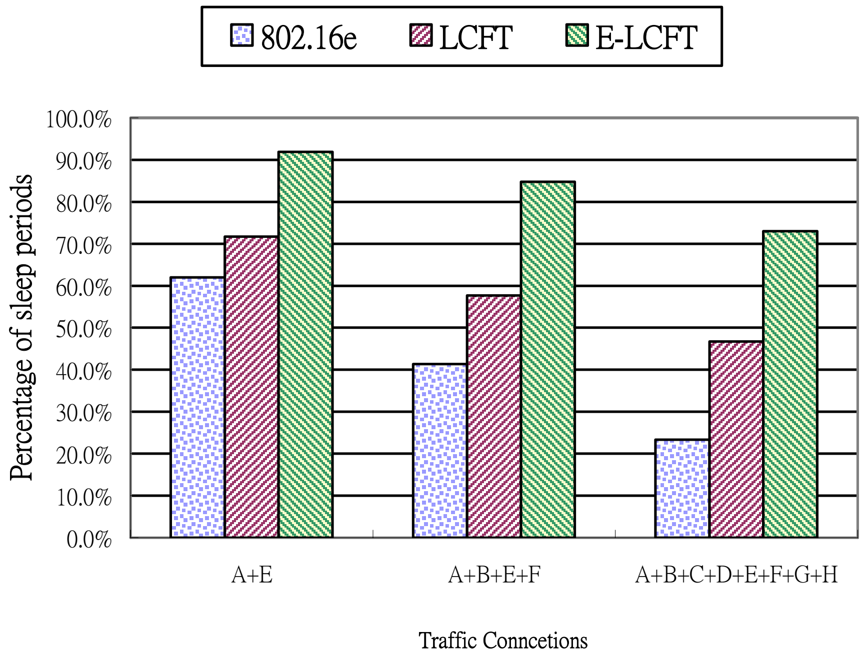


Fig. 8. Percentage of sleep periods under the loose delay constraint (100ms)

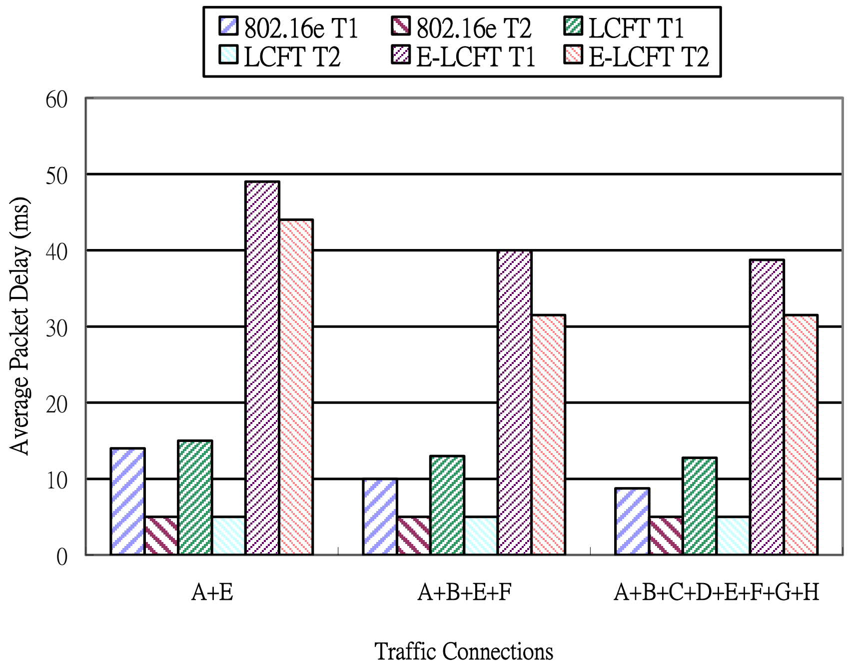


Fig. 9. Average packet delay under the loose delay constraint (100ms)

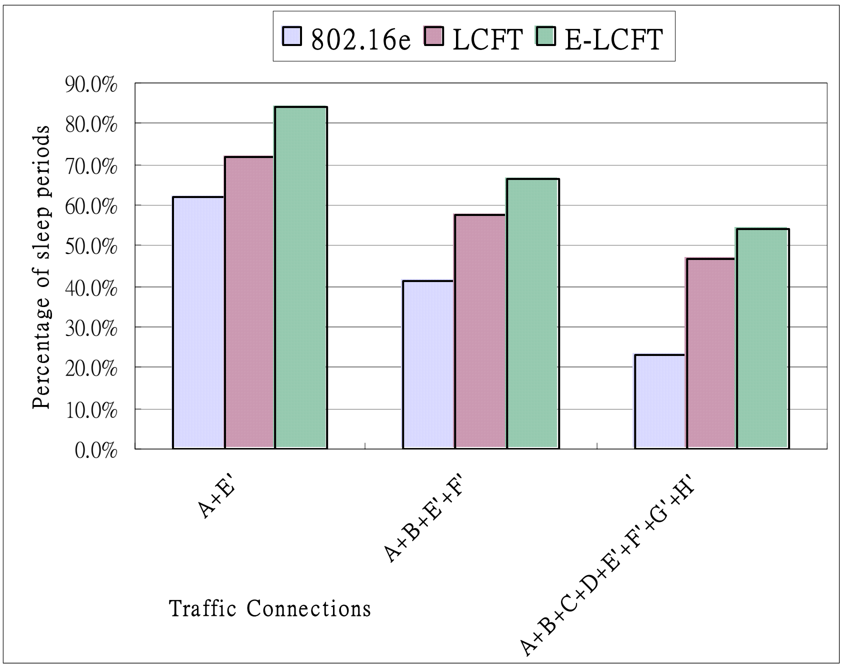


Fig. 10. Percentage of sleep periods under the tight delay constraint (30ms)

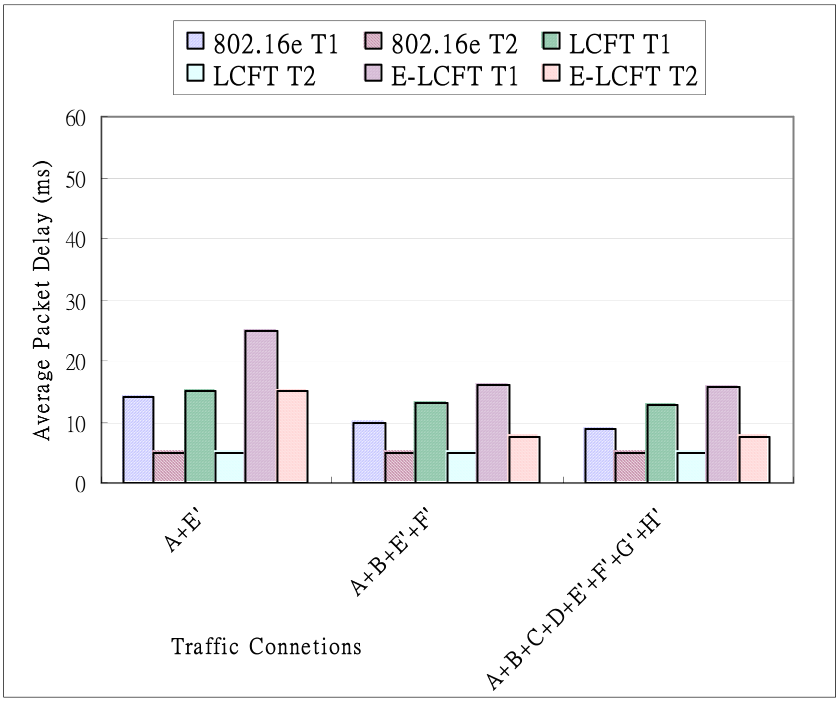


Fig. 11. Average packet delay under the tight delay constraint (30ms)

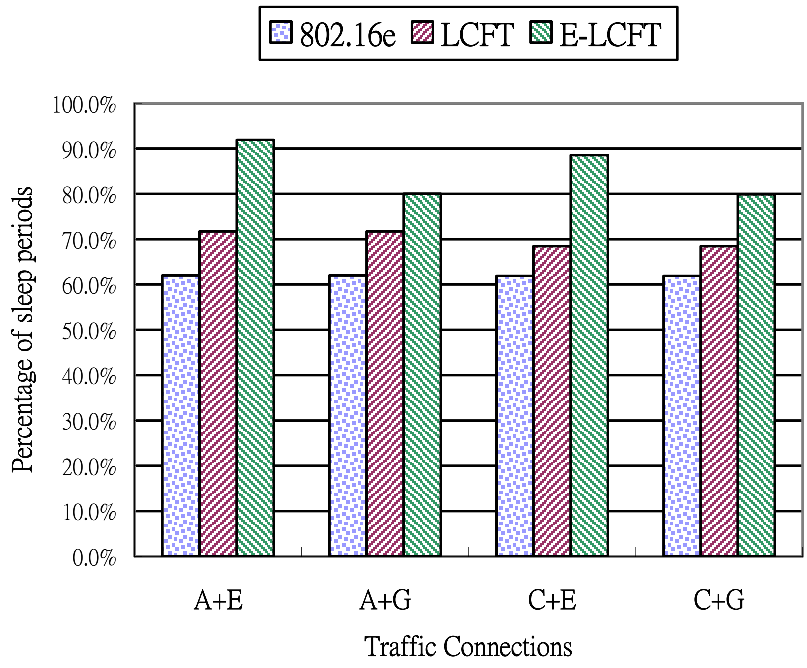


Fig. 12. The effect of packet sizes on percentage of sleep periods

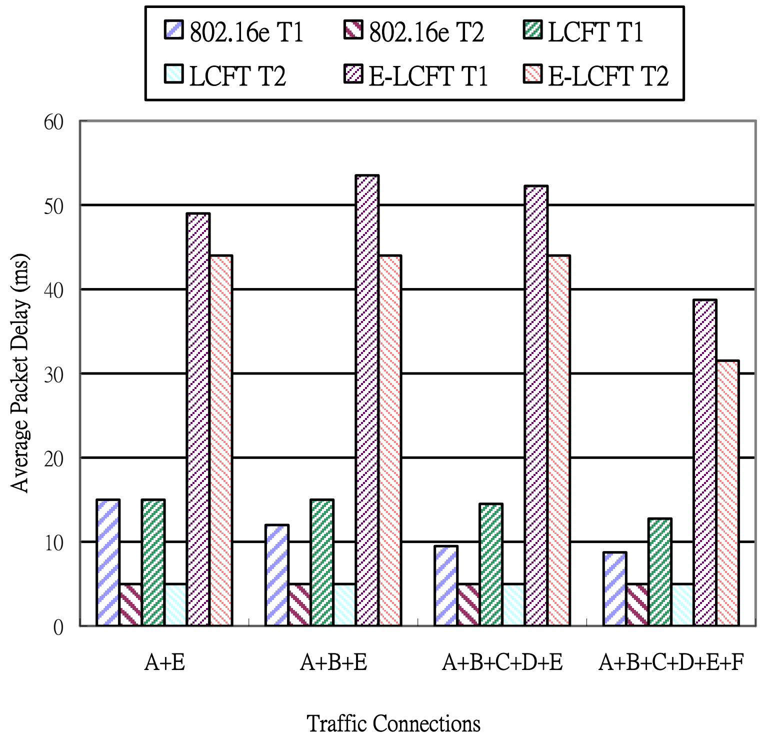


Fig. 13. The effect of number of type II connections on average packet delay

# Chapter 6

# Conclusions and Future Work

## 6.1 Conclusions

We have presented two efficient energy saving schemes for the sleep mode operation in IEEE 802.16e. We remove the listening windows of power saving classes of type I and group several type II packets into a single frame for later transmitting. The main idea of our proposed schemes is to reduce the number of listening window in all service connections, so that there is more common free time for the MSSs to enter the sleep mode and save more power. From simulation results, the LCFT and E-LCFT performed 14% to 50 % and 33% to 68% better than the IEEE 802.16e scheme, respectively, in terms of percentage of sleep periods. However, the overhead of our proposed schemes is higher average packet delay. The LCFT and E-LCFT have 6% to 77% and 84% to 88% longer average packet delay than the IEEE 802.16e scheme, respectively. Nevertheless, the delay of each type II connection still met its delay constraint. That is, the QoS requirements of type II connections in our proposed two schemes are still guaranteed. The proposed schemes are compatible with the original IEEE 802.16e standard, because we only need to adjust the parameter values of sleep mode operation of types I and II in the base station.

## 6.2 Future Work

In this work, we did not consider the buffer size in the BS and we created the type I and II connection traffic for possible cases. In the future, we may consider a limited buffer size in the BS to address possible packet loss and use real traffic patterns of different types of connections to further evaluate the energy efficiency of the proposed approaches.

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