Towards Energy Efficient Mobile Communications

Moshe T. Masonta
Tshwane University of Technology &
Meraka Institute at CSIR
P O Box 395, Pretoria, 0001
+27 12 841 2085
Mmasonta@csir.co.za

Mjumo Mzyece
Tshwane University of Technology
Private Bag X680, Pretoria, 0001
+27 12 382 5024
mzyecem@tut.ac.za

Ntsibane Ntlatlapa
Meraka Institute at CSIR
P O Box 395, Pretoria, 0001
+27 12 841 4421
nntlatlapa@csir.co.za

ABSTRACT

The rapid growth and development of wireless communication services and applications corresponds to an increase in associated energy consumption. For broadband wireless network deployment in rural areas affected by unreliability and unavailability of national grid electricity supply, energy efficiency becomes a major design criterion to be considered. In such areas, diesel powered generators are normally used as the main power source, while batteries become the most preferred source of energy to power wireless communication devices. In order to address increasing energy requirements, we propose an energy saving technique for mobile stations (MSs) operating under the wireless broadband access systems in this paper. Our proposed scheme is limited to the power saving class (PSC) of Type I in IEEE 802.16. Our numerical results show that more energy can be saved if the listening interval is considered under non-sleep or awake mode.

Categories and Subject Descriptors

C.4 [**Computer-Communication Networks**]: Performance of Systems–*Modeling techniques.* C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design–*Wireless communication*.

General Terms

Performance.

Keywords

WiMAX, Energy Efficiency, Power Saving Class, Broadband Wireless Access, Wireless.

1. INTRODUCTION

The high speed and wireless accessibility of Internet services is changing the way people live, communicate, do business, and also changed the learning and teaching process. For instance, today a student can complete degree online from anywhere in the world, without having to physically visit the university, irrespective of whether the university is locally or internationally based. But the lack of electricity grid-supply and economic activities in the majority of rural areas, mainly in Africa, prevents the majority of rural youth, students and entrepreneurs to have access to the Internet. In some countries, alternative sources of energy supply (such as solar, batteries or diesel generators) are used to power rural areas.

In designing and deploying mobile wireless communication systems, energy efficiency is an important design criterion to be considered due to the limited battery life of mobile devices, high data transmission rates, high electricity cost and lack of electricity supply in most African rural areas. Recently it has been reported that the volume of transmitted data increases approximately by a factor of 10 every five years [1]. Such an increase corresponds to an increase of the associated energy consumption by approximately 16-20% [1]. It has been acknowledged that Information and Communication Technology (ICT), due to the rapid increase of cellular subscribers and the demand for high data rate broadband transmission, contributes significantly to the overall energy consumption of the world; therefore there is a need on environmental grounds to make radio access networks more energy efficient [2].

Today, the majority of mobile computing devices, such as notebooks, Tablet personal computers, netbooks and e-readers, are equipped with network interface cards (NICs) to allow mobile communication and access to Internet. Since these devices are portable and mobile, they obviously operate on battery power. Unfortunately batteries offers limited lifetime before one must recharge them. As a result, power saving becomes a major design concern to be considered to prolong the battery lifetime of these devices. Some widely used NICs are based on the IEEE 802.11 [3] and IEEE 802.16 [4] technologies.

The IEEE 802.16 [4] specifies air interface for broadband wireless access (BWA) system to allow effective delivery of high speed multimedia services with guaranteed quality of service (QoS) for Wireless Metropolitan Area Networks (WMANs). The 2009 release of the IEEE 802.16 standard, also known as Worldwide Interoperability on Microwave Access (WiMAX),

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supports both fixed and mobile access. It is important to mention at this point that WiMAX is not a technology, but rather a certification mark, or stamp of approval given to equipment that meets certain conformity and interoperability tests for the IEEE 802.16 family of standards. IEEE 802.16 also specifies sleep mode operation to allow power saving in mobile stations (MS). This power saving technique is called Power Saving Class (PSC). Three PSCs are defined in IEEE 802.16 systems: PSC of Type I, PSC of Type II and PSC of Type III. PSC of Type I consist of a sequence of alternating sleep and listening intervals. The size of listening interval is fixed while the size of sleep interval is double exponentially from minimum sleep interval $(T_{\min})$ to maximum sleep interval $(T_{\max})$ for as long as there are no incoming or outgoing packets at the MS.

In this paper, we study energy saving techniques for mobile WiMAX, focusing on PSC of Type I sleep mode. We propose an energy saving scheme that can be used to analyze the performance of PSC of Type I, taking into consideration the energy consumption during the listening interval. The rest of this paper is organized as follows: Section 2 discuss some related work. Section 3 presents our proposed energy saving scheme. Performance evaluation and results are presented in Section 4. Section 5 concludes the paper.

2. ENERGY EFFICIENCY IN COMMUNICATION DEVICES

Energy efficiency in wireless communication systems can be addressed from the base station (BS) point of view and from the MS. In this section we present the types of PSCs defined in IEEE 802.16 and some related work on energy saving schemes in BWA systems.

2.1 Power Saving in Mobile IEEE 802.16

The need to reduce the energy requirement in ICT calls for new design approaches for future broadband wireless networks. A MS can operate in awake and sleep modes as shown in Figure 1. The sleep mode has been specified in IEEE 802.16 to allow energy saving and to extend the lifetime of MS before it must be recharged again. Sleep mode is a state in which a MS conducts pre-negotiated periods of absence from the serving BS air interface [4]. These periods are characterized by the unavailability of the MS, as observed from the serving BS to downlink or uplink traffic. As shown in Figure 1, listening interval exists within the sleep mode.

For a MS to enter into a sleep mode, it must first send a sleep request (MOB-SLP-REQ) message to its serving BS.

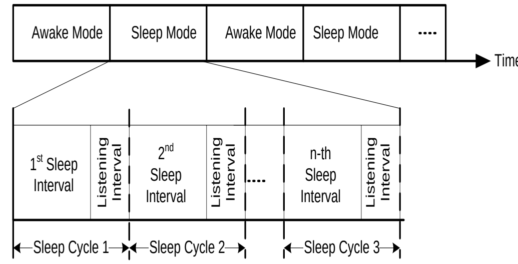

Figure 1: IEEE 802.16 Awake and Sleep modes [4]

The BS will then approve the request by sending a sleep response (MOB-SLP-RSP) message back to a MS. These messages (MOB-SLP-REQ/RSP) contain the PSC type, the sizes of initial sleep interval, final sleep interval and listening interval. The listening interval is a short interval within the sleep mode. During the listening interval, a MS temporarily wakes-up for a short interval to listen to a traffic indication (TRF-IND) message broadcasted from the serving BS. A positive TRF-IND message includes information about MSs to whom the data packets are buffered in the BS, and waiting to be sent. If there are data packets belonging to a MS, it will wake up. If there are no packets, a MS will remain in the sleep mode.

The three PSCs defined for WiMAX differ by their parameter sets, procedures of activation or deactivation and policies of MS availability for data transmission. PSC of Type I is recommended for Best Efforts (BE) and Non-Real Time Variable Rate (NRT-VR) connections. The operation of PSC of Type I is as follows: if there is no buffered traffic at the BS during the listening interval, MS will double the sleep interval size and then go back to sleep until the next listening interval. The sleep and listening procedure will repeat with updated sleep interval sizes until a MS is notified of the buffered traffic destined to itself via TRF-IND message. If the sleep interval size reaches the maximum value of the final sleep interval, it remains fixed, instead of being doubled. A MS will enter the awake mode, to receive data packets from the BS, once a positive TRF-IND message has been noticed during a listening interval. A MS stays on awake mode until the buffer of the BS remains empty for a fixed time called a time-out or close-down time. After the empty buffer during the time-out period, a MS switches to sleep mode by sending a MOB-SLP-REQ message to the BS.

PSC of Type II is commonly used for the Unsolicited Grant Service (UGS) and the Real Time Variable Rate (RT-VR) traffic type. Unlike in PSC of Type I, the sleep and listening intervals in PCS of Type II are both fixed. PSC of Type III is recommended for management operation and multicast connections. It is only valid for one sleep interval and, at the end of sleep interval a MS deactivates PSC and returns to the normal operation. In this paper, we limit our focus to the PSC of Type I.

2.2 Energy Saving Mechanisms

In this subsection, we discuss some related work on energy saving techniques in IEEE 802.16 system. Xiao [5] and Zhang & Fujise [6] proposed an analytical model to study the energy consumption and the mean delay for the PSC of Type I, focusing on a sleep interval in WiMAX systems. Xiao's model assumes that the listening interval is included in the sleep mode. Such assumption means that when a MS is on listening interval, no energy is consumed. In reality, there is a considerable amount of energy consumed during the listening interval; hence we believe that the model presented in [5] and [6] may not accurate analysis of the total energy consumption.

Hwang *et al* [7] proposed a different power saving mechanism where a MS and BS are not required to send MOB-SLP-REQ and MOB-SLP-RSP messages to each other before a MS can enter into a sleep mode. Instead, the scheme requires the BS to periodically send a TRF-IND message at the beginning of every constant TRF-IND interval to allow a MS to either go to sleep or awake mode. Their scheme can be applied in both Type I and Type II PSCs. This scheme was submitted to the ongoing IEEE 802.16m working group for considerations [7].

Chen *et al* [8] proposed multiple PSCs management algorithms for the management of the awake and sleep mode in a single MS for real-time connections. The work of Lee and Cho [9] is based on the investigation of the performance of PSC of Type I in voice over Internet Protocol (VoIP) traffic.

Though energy saving techniques presented in [5] – [9] aim at prolonging the MS battery lifetime, we still believe that more energy can be saved by exploiting the PSC types specified within the WiMAX standard. Therefore our work focuses on analyzing energy consumptions of a MS in WiMAX network using PSC of Type I. Though some similarities exist with the work in [5], our proposed scheme eliminates some major assumptions made in [5]. For instance, Xiao [5] assumes that when a MS is in listening interval it is the same as being in sleep mode. But this is not always the case because during the listening interval, a MS wakes-up to listen for a positive TRF-IND in order to decide whether to remain in sleeping mode or to enter into awake mode.

3. PROPOSED MODEL

We consider N MSs attached to a single BS in a point-to-multipoint network topology. Other issues such as mobility and security of the MSs in the network are out of the scope of this study. MS operations alternate between awake, listen and sleep modes, as shown in Figure 1. The messages are exchanged between the BS and the MSs via separate channels. A channel that delivers traffic from the BS to the MSs is called the downlink channel. The uplink channel is used to deliver traffic from the SSs to the BS. This paper will only focus on analyzing the downlink message flow.

3.1 Notation Used

For consistency and clarity, Table 1 lists the notation used in this paper.

Table 1: Notation Used in this Paper

Notation	Description
S	Sleep time
T_k	Length of the k^{th} sleep interval
$T_{\min}$	Initial minimum sleep interval
$T_{\max}$	Maximum sleep interval
T_p	Length of the pth sleep cycle
n	Number of sleep intervals before the MS goes to the awake mode
$E\ .$	Denote the mean function
λ	Frame arrival rate per unit time
e_k	Event that there is at least one frame arrival during the monitor period k
E_S	Energy consumption units per unit time in the sleep interval
E_{sleep}	Total energy consumption in sleep mode

3.2 Model Analysis

Our major contribution in this work is to propose a model that can be used to analyze energy saving scheme in PSC of Type I during the sleep mode. While the mechanism in [5] assumes the listening interval to be the sleep mode, we show that when a MS is in listening mode, it actually wakes up for a short period of time to listen for a positive TRF-IND message. The short period that a MS wakes-up is called the listening interval, and it occurs during the sleep mode. This process (of waking up to listen for a positive TRF-IND message) does consume some energy, which cannot to be neglected. Hence our proposed model takes the energy consumed during the listening interval into account.

We assume that the packet arrival rate to a MS follows a Poisson distribution with rate λ. The inter-arrival times follows an exponential distribution with mean $1/\lambda$. In this paper, we consider a MS to be awake during the listening interval. We therefore separate the listening interval from the sleep mode. This will enable us to compute accurate energy consumption during the sleep mode. Hence the length of the k^{th} sleeping time is given by T_k. Therefore, according to IEEE 802.16 PSC of Type I, where the sleep window varies, we have:

$$T_k = \begin{cases} 2^{k-1}T_{\min}, & if \quad 2^{k-1}T_{\min} < T_{\max} \\ T_{\max}, & if \quad 2^{k-1}T_{\min} \geq T_{\max} \end{cases} \quad (1)$$

Borrowing the analysis model in [5], we have the probability (P) that at least one packet arrival occurs during the sleep cycle k modeled as:

$$P(e_k = true) = 1 - e^{-\lambda T_k} \quad (2)$$

And we model the probability that at least one sleep interval occurred before the MS goes to the awake mode as:

$$P(n=1) = 1 - e^{-\lambda T_1} \quad (3)$$

If one packet arrived during the sleep cycle, then it means that at least one sleep interval occurred before the MS goes to the awake mode or to listening interval, so we will have:

$$P(e_1 = true) = P(n=1) = 1 - e^{-\lambda T_1} \quad (4)$$

$$P(n=k) = P(e_1 = false; ...; e_{j-1} = false; e_j = true)$$

$$= \prod_{m=1}^{k-1} P(e_m = false) P(e_k = true)$$

$$= e^{-\lambda \sum_{m=1}^{k-1} T_m} (1 - e^{-\lambda T_k}) \quad (5)$$

Now we can find the mean of the number of sleep intervals before the MS goes to sleep as:

$$E[n] = \sum_{k=1}^{\infty} kP(n=k)$$

$$= \sum_{k=1}^{\infty} k \left(e^{-\lambda \sum_{m=1}^{k-1} T_m} \left(1 - e^{-\lambda \sum_{m=1}^{k} T_m} \right) \right)$$

$$= \sum_{k=1}^{\infty} ke^{-\lambda \sum_{m=1}^{k-1} T_m} - \sum_{k=1}^{\infty} ke^{-\lambda \sum_{m=1}^{k} T_m} \quad (6)$$

The mean of the sleep time $E[S]$ can be obtained as follows:

$$E[S] = \sum_{k=1}^{\infty} P(n=k) \sum_{p=1}^{k} T_p$$

$$= \sum_{k=1}^{\infty} e^{-\lambda \sum_{m=1}^{k-1} T_m} \sum_{p=1}^{k} T_p - \sum_{k=1}^{\infty} ke^{-\lambda \sum_{m=1}^{k} T_m} \sum_{p=1}^{k} T_p \quad (7)$$

Now that we have found the mean, we need to obtain the energy consumed in the sleep mode (E_{sleep}). Our sleep mode energy consumption does not include the listening interval, since we consider the listening interval to be similar to awake mode (meaning energy consumption is not the same as in the sleep mode).

$$E_{sleep} = \sum_{k=1}^{\infty} P(n=k) \sum_{p=1}^{k} T_p E_S$$
$$= \sum_{k=1}^{\infty} e^{-\lambda \sum_{m=1}^{k-1} T_m} \sum_{p=1}^{k} T_p E_S$$
$$- \sum_{k=1}^{\infty} e^{-\lambda \sum_{m=1}^{k} T_m} \sum_{p=1}^{k} T_p E_S \quad (8)$$

4. PERFORMANCE EVALUATION

In this section we evaluate our energy saving scheme with analytical results.

4.1 Effects of $T_{\min}$ and Effects of λ

We check the effect of a minimum window size $T_{\min}$ over the arrival rate λ. The following parameters were used for our analytical results: $E_s = 1$ and $T_{\max} = 1024$. It can be seen from Figure 2 that a larger initial minimum sleep interval ($T_{\min}$ = 16) gives a smaller $E[n]$, that is average number of sleep intervals before MS can wake up. Whereas the smaller initial minimum sleep interval ($T_{\min}$ = 1), gives a bigger $E[n]$. Since the size of the sleep interval is doubled exponentially from $T_{\min}$ to $T_{\max}$, our results shows that using smaller will lead to a bigger $E[n]$, which translates to more energy saving.

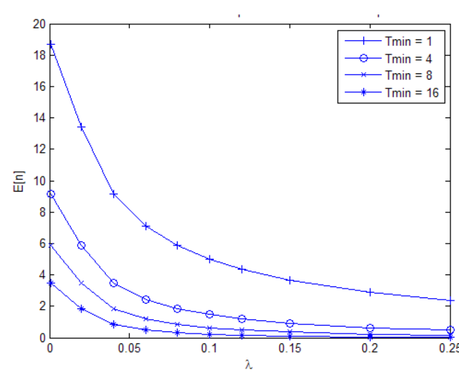

Figure 2: Performance Metrics on E[n] over λ

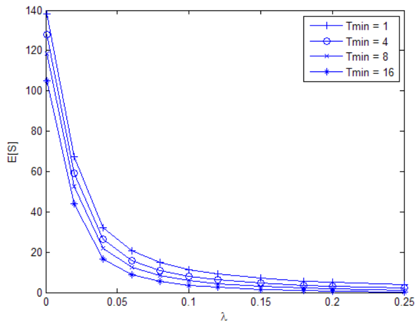

Figure 3: Performance Metric on E[S] over λ

As observed in Figure 3, the average sleep interval $E[S]$ decreases as the packet arrival rate increases. While there is no significant difference between the larger initial minimum sleep interval ($T_{\min}$ = 16) and the smaller initial minimum sleep interval ($T_{\min}$ = 1); $E[S]$ approaches zero as the frame arrival rate increases.

4.2 Energy Consumption with Listening Interval Considered

Figure 4 shows results of energy consumption per unit time in sleep mode. We compared our results with the one presented in [5]. In our case we considered the energy consumed during the listening interval, as opposed to the work in [5], where listening interval was considered as sleep mode. Our analytical results show that energy saving of about 36% can be achieved at smaller initial minimum sleep interval ($T_{\min}$ = 1). At higher initial minimum sleep interval ($T_{\min}$ = 16), energy saving of about 25% was achieved. The energy saved is due to the constant TRF-IND messages received by a MS during a sleep mode. As stated earlier, TRF-IND messages are sent periodically during the listening interval to check whether there are any messages or packets waiting at the BS.

5. CONCLUSION

In this paper, we propose an improved technique to analyze power saving in a MS operating in PSC of Type I, without neglecting the energy consumed during the listening interval. Our analytical results show that energy consumption decreases as the packet arrival rate increases. This means that more power is actually saved during the sleep mode if the listening interval is not considered as a sleep mode. In conclusion, though it is a comparatively small period, the listening interval does consume energy, and by considering during the analysis of energy saving techniques in PSC of Type I, energy saving during the sleep mode can be improved in the range of 25 to 36%. Our proposed scheme, therefore, allows an accurate energy analysis in WiMAX MSs, by considering the energy consumed during the listening interval.

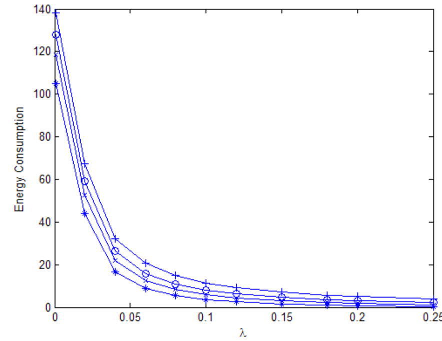

Figure 4: Energy Consumption in Sleep Mode

Our future work will be to investigate and to study the packet delay experienced by the MS when the proposed analytical technique is implemented on IEEE 802.16 based network.

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