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Hyper-Erlang Battery-Life Energy Scheme in IEEE 802.16e Networks

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Abstract: IEEE 802.16e networks is one of the broadband wireless technologies that support multimedia services while users are in mobility. Although these users use devices that have limited battery capacity, several energy schemes were proposed to improve the battery-life. However, these schemes inappropriately capture the traffic characteristics, which lead to waste of energy and high response delay. In this paper, a Hyper-Erlang Battery-Life Energy Scheme (HBLES) is proposed to enhance energy efficiency and reduce the delay. The scheme analytically modifies idle threshold, initial sleep window and final sleep window based on the remaining battery power and the traffic pattern. It also employs a Hyper-Erlang distribution to determine the real traffic characteristics. Several simulations are carried out to evaluate the performance of the HBLES scheme and the compared scheme. The results show that the HBLES scheme out performs the existing scheme in terms of energy consumption and response delay.

Keywords: Energy Saving Scheme; mobile WiMAX; Battery Lifetime.

1. Introduction

The IEEE 802.16e standard (IEEE, 2005) popularly known as mobile WiMAX is one of the broadband access technologies that provides mobility support, ubiquitous access and support to multimedia applications to a mobile subscriber station (MSS) (Saidu et al., 2015) . In order to support these applications while the MSS moves at vehicular speed, the MSS undergo frequent battery drain due to excessive power consumption than in traditional voice-centric technology. Thus, efficient energy schemes are highly needed.

The standard uses sleep mode operations to improve energy efficiency. The sleep modes are classified into three power saving classes: Type A, Type B, and Type C. The Type A employs for the delay insensitive traffics with an exponential increase sleep period. The Type B uses for the delay sensitive traffics with a constant sleep period. While the Type C designs for multicast and management operation with the sleep duration regulated by the base station (BS). These PSCs use idle threshold (Tit), initial sleep window (Tmin) and final sleep window (Tmax) parameters to reduce energy dissipation of the MSS. The Tit refers to a waiting time of the MSS before going to sleep. The Tmin represents a shortest duration of sleep interval. While Tmax is the longest period of sleep interval. The parameters are allocated to the MSS by the BS when it requests to sleep.

Several energy schemes were proposed based on these PSCs to extend the battery- life of the MSS (Xiao, 2005), (Xiao, 2006). Some schemes consider effects of sleep parameters on traffic arrival rate (Xiao, 2006), (Zhang & Fujise, 2006), (Xiao et al., 2006) and others, adjust the parameters with consideration to traffic load and delay requirements (Xiao et al., 2006), (Zhu & Wang, 2007), (Zhu et al., 2007), (Xue et al., 2008), (Sanghvi et al., 2008). While others (Kim et al., 2008), (Lin & Wang, 2013), (Ferng & Li, (2013), (Chou et al., 2013) dynamically adjust the parameters based on the load and the remaining energy. Among these schemes, only (Chou et al., 2013) employs all the parameters with significant energy efficiency but it wastes energy and increases response delay due to inappropriate capture of the traffic pattern.

This paper presents a HBLES to enhance energy efficiency of the MSS while reducing the response delay. The scheme modifies the sleep parameters based on a residual energy and traffic arrival pattern. It also uses a Hyper-Erlang distribution to capture the real traffic characteristics. Extensive simulations were used to evaluate the performance of the HBLES scheme and the compared scheme (Zhang, 2007). . The results show that the HBLES out performs the BLAPS scheme.

The rest of this paper is organized as follows. Section II presents related work. In Section III, the proposed HBLAPS is described. Section IV, presents performance evaluation. Finally, Section V presents conclusion of the paper.

2. Related Work

This section presents a review on some of the existing energy schemes in mobile WiMAX, which are as follows:

In (Xiao, 2005), an energy scheme is introduced to analytically model the sleep mode operation. The scheme examines the effects of Tmin and Tmax on arrival rate. It improves energy consumption with a smaller Tmin but increases the delay. The scheme also reduces delay and energy consumption with a smaller Tmax. However, it considers only the downlink (DL) traffic.

In (Xiao, 2006), an enhanced model in (Xiao, 2005) is proposed which considers both uplink (UP) and DL traffics. Although the scheme reduces energy consumption in a shorter time, it consumes high energy in a longer duration due to incessant sleep-wake mode. While the scheme in (Zhang & Fujise, 2006) differentiates between the incoming and outgoing traffics. It reduces the energy consumption but waste energy due to excessive listening operations under low traffic arrival rate.

In (Xiao et al., 2006), an enhanced energy saving scheme is proposed to reduce the listening operations. The scheme considers the initial sleep interval in the next sleep operation as half of the previous sleep interval. The scheme also uses embedded Markov chain model for analysis and a closed-form expression to enhance energy. The scheme extends battery life but it has a higher response delay due larger sleep interval.

Heuristic Scheme in (Zhu & Wang, 2007) is proposed to enhance the battery-life. The scheme utilizes a heuristics algorithm to dynamically adjust Tmin based on the traffic load. The scheme extends the battery-life of MSS, however with small increase in the delay. It is enhanced in (Zhu et al., 2007), where the mechanism adjusts the sleep parameters based on the delay and traffic requirements. The scheme bounds the delay in a certain range.

Traffic Load Aware Scheme is proposed in (Xue et al., 2008) to improve energy consumption. The scheme analyses the sleep mode operation to determine relationships among traffic load, idle check time and power consumption. It employs dynamic technique to adjust the idle check time based on the traffic load measurement. The scheme enhances the battery life and reduces the mean delay but fails the standard conformity.

Adaptive Mechanism is proposed in (Sanghvi et al., 2008) to enhance battery performance. The mechanism dynamically regulates the sleep parameters based on the request period of each initiation of awakening (Tin). The scheme improves energy but it increases response delay.

Remaining Energy Aware Power Management mechanism (REAPM) (Kim et al., 2008) is proposed to prolong the battery. The REAPM employs smoothing technique with current inter arrival time to adjust Tmax. The mechanism also employs the remaining energy and the Tmax to adjust the Tmin. It reduces the response delay under sufficient energy but increases delay under insufficient energy.

In (Lin & Wang, 2013), an adaptive waiting time threshold estimation scheme is proposed to minimize energy consumption. The scheme predicts the threshold by dynamically adjusting the idle threshold based on the DL and UP traffics. It considers the time to be small under low-traffic arrival but large under heavy traffic arrival. The scheme minimizes the energy consumption but it leads to a small increase in the delay.

Predictive and Dynamic Energy-Efficient Mechanism Scheme (Ferng & Li, 2013) is proposed to improve energy efficiency and the delay. The scheme uses a prediction mechanism to determine when a MSS should wake up. It sets the maximum sleep interval when the probability of traffic arrival is slim in order to minimize energy wastage. In addition, it also sets the smaller sleep interval when the traffic arrival is high to minimise the delay. It improves energy efficiency and minimizes delay but prediction error is not ignored.

In (Chou et al., 2013) , a battery aware scheme is proposes to prolong the battery life. The BLAPS dynamically adjusts the sleep parameters based on the residual energy and the traffic loads. The scheme enhances the battery lifetime, but it increases energy consumption and response delay due to failure to consider appropriate traffic pattern and distribution.

3. Proposed Hbles.

This section presents the proposed HBLES, which analytically modifies the sleep parameters as follows:

3.1 Idle Threshold

The T_{it} is adjusted based on residual battery lifetimes and the traffic arrival. Firstly, T_{it} is computed as:

$$T_{it} \square \begin{cases} T_{it\_min} & if\ T_{it\_min} < T_{it\_max} \\ T_{it\_max} & otherwise \end{cases} \quad (1)$$

Where, T_{it_min} and T_{it_max} is minimum and maximum idle threshold, respectively. The T_{it_min} is derived from (Saidu et al., 2015) as follows:

$$T_{it\_min} = \frac{E_w}{E_i} \quad (2)$$

Where E_w is sleep-wake energy and E_i is idle state energy.

Then the next T_{it} is predicted as:

$$T_{it} = T_{it} + \left(\frac{E_{residual}}{E_{total}}\right) * (\lambda_{new-weight} - \lambda_{old-weight}) \quad (3)$$

$$\lambda_{new-weight} = (1-\gamma)\,\lambda_{current-arrival} + \gamma * \lambda_{old-weight},\ 0 < \gamma < 1, \quad (4)$$

where γ is the proportionality constant, $\lambda_{new-weight}$ and $\lambda_{old-weight}$ is the new and old arrival rate, respectively.. $\lambda_{current-arrival}$ is current arrival rate, $E_{residual}$ and E_{total} is residual and total energy, respectively.

3.2 Initial Sleep Window

The T_{min} is dynamically updated according to the residual energy and the new weight arrival rate as follows:

$$T_{min} = max\left(\left[\frac{E_{residual}}{Etotal}\,\lambda_{new-weight}\right], 1\right) \quad (5)$$

3.3 Final Sleep Window

The T_{max} is computed when the T_{min} is determined and the frame response delay is given. Firstly, let the frame arrival follows a Hyper-Erlang distribution with pdf (Zhang, 2007) as.

$$p_{h_d}(t) = \sum_{i=1}^{I} \beta_i \frac{(\omega_i \lambda_i)^{\omega_i} t^{\omega_i - 1}}{(\omega_i - 1)!} e^{-\omega_i \lambda_i t} \quad (6)$$

Where λ_i and β_i are constants with $\lambda_i \geq 0$, $0 \leq \beta_i \leq 1$ and ω_i are positive integers.

Integrate Equation (6) from $0 < x \leq t$ to derive the CDF as

$$C_{h_d}(t) = \int_0^t f_{t_d}(x)dx \quad (7)$$

Next, suppose $h_{d,r}$ is the remaining packets inter-arrival time with pdf $p_{h_{d,r}}$. $p_{h_{d,r}}$ is computed using Equations (6) and (7) as:

$$p_{h_{d,r}} = \lambda \sum_{i=1}^{I} \beta_i \sum_{j=0}^{\omega_i - 1} \frac{(\omega_i \lambda_i t)^j}{j!} e^{-\omega_i \lambda_i t} \quad (8)$$

Integrate Equation (8) from $0 < p_{h_{d,r}} \leq t$, to obtain the CDF $C_{h_{d,r}}$ as

$$C_{h_{d,r}} = 1 - \lambda \sum_{i=1}^{I} \frac{\beta_i}{\omega_i \lambda_i} \sum_{j=0}^{\omega_i - 1} \sum_{k=0}^{j} \frac{(\omega_i \lambda_i t)^k}{k!} e^{-\omega_i \lambda_i t} \quad (9)$$

Finally, S_h denotes the summation of 1st, 2nd, . . ., hth derived as:

$$S_h = \sum_{j=1}^{h} (T_j + L), h \geq 1 \quad (10)$$

Assume T_h represents the length of the h^{th} sleep window as

$$T_h = \begin{cases} 2^{h-1} T_{\min} \text{ if h} < Y \\ T_{\max} \text{ otherwise} \end{cases} \quad (11)$$

CASE I

The probability of frame arrival at the idle state is computed as:

$$P_h(N = T_{it}) = 1 - \lambda \sum_{i=1}^{I} \frac{\beta_i}{\omega_i \lambda_i} \sum_{j=0}^{\omega_i - 1} \sum_{k=0}^{j} \frac{(\omega_i \lambda_i t)^k}{k!} e^{-\omega_i \lambda_i t} \quad (12)$$

CASE II

The probability of frame arrival during the h^{th} sleep interval is :

$$P_h(N = h) = \lambda \sum_{i=1}^{I} \frac{\beta_i}{\omega_i \lambda_i} \sum_{j=0}^{\omega_i - 1} \sum_{k=0}^{j} \frac{(\omega_i \lambda_i)^k}{k!} e^{-\omega_i \lambda_i L} \cdot [(S_{h-1} - L)^k e^{-\omega_i \lambda_i c_{h-1}} - (S_{h-1} - L)^k e^{-\omega_i \lambda_i c_h}] \quad (13)$$

$$if \;\; h < Y$$

Replacing Equations (10) and (11) into Equation (13),we have

$$P_h = A \times \left[(X - L)^k e^{-\omega_i \lambda_i X} - (Z - L)^k e^{-\omega_i \lambda_i z} \right] \quad (14)$$

Where $X = ((2^{h-1} T_{min} + hL) - (T_{min} + L)$,

$Z = (2^h T_{min} + hL) - T_{min}$ and

$$A = \lambda \sum_{i=1}^{I} \frac{\beta_i}{\omega_i \lambda_i} \sum_{j=0}^{\omega_i - 1} \sum_{k=0}^{j} \frac{(\omega_i \lambda_i)^k}{k!} e^{-\omega_i \lambda_i L}$$

$$if \;\; h \geq Y$$

Similarly, Replacing Equations (10) and (11) into Equation (13),we have

$$P_h = A \times \left[(P - L)^k e^{-\omega_i \lambda_i P} - (Q - L)^k e^{-\omega_i \lambda_i Q} \right] \quad (15)$$

Where

$P = ((2^{Y-1} T_{min} + YL) - (T_{min} + L)$ and

$Q = (2^Y T_{min} + YL) - T_{min}$

Using Equations (10), (11), (14) ,(15) and (16), the average response delay is obtained as:

$$A[R] = \frac{L}{2} + D + A \frac{T_{\max}}{2} \left[(P - L)^k e^{-\omega_i \lambda_i P} - (Q - L)^k e^{-\omega_i \lambda_i Q} \right] \quad (16)$$

Finally, from Equation (16), we obtain

$$T_{max} = \frac{2A[R] - L + 2D}{A\left[(P-L)^k e^{-m_i \lambda_i P} - (Q-L)^k e^{-\omega_i \lambda_i Q} \right]} \quad (17)$$

4. Performance Evaluation

To evaluate the performance of the HBLES and the BLAP, simulation is used. The discrete event simulation is developed using C++ Programming Language. The metrics used in the simulation are as follows:

The average energy consumption is as

$$A(E) = T_{it} + E_i \sum_{k=0}^{\infty} P_k \sum_{l=0}^{k} (T_l \; E_S + LE_L + E_W) \quad (18)$$

Where $E_S \; and \; E_L$ is the energy consumed during the sleeping and listening mode respectively.

The Equation (16) provides response delay.

The simulation parameters and the topology used are in (Xiao, 2005). The topology consists of one BS station and several MSSs. The BS transmits only non-real-time traffics to the MSSs, which is a downlink transmission. The MSSs operate on a 300 mAh initial battery capacity and use a simple linear power model. Both the MSSs and the BS use the power consumption parameters adopted in the SQN1130 System-on-Chip (SOC) (Sequans Communications). . In addition, the MSS uses 1 frame duration for the listening window because no benefit setting it higher than 1 frame.

Figures 1and 2 illustrate the average energy consumption and average response delay of the proposed HBLES and the BLAPS in terms of mean arrival rate, respectively .The HBLES achieves superior performance than the compared scheme because of the accurate capture of the traffic characteristics.

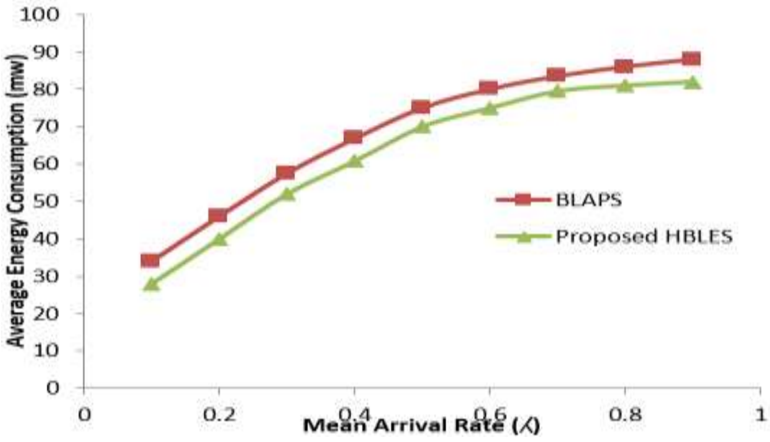

Figure 14: Graphical Figure of Logistic Regression Classifier for

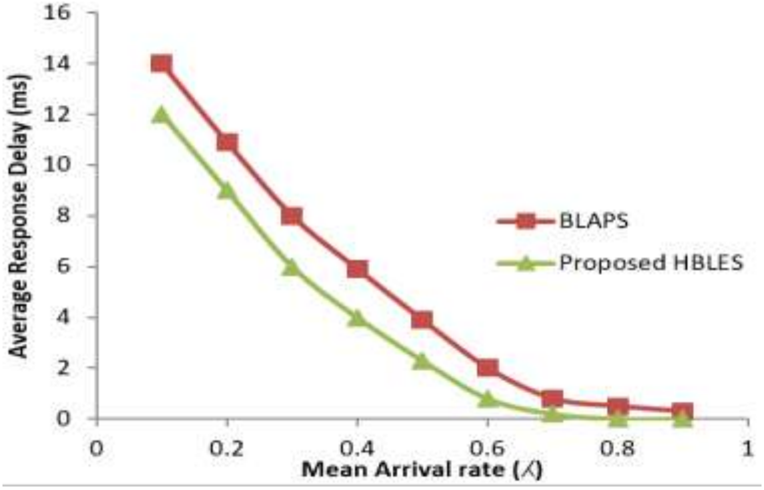

Figure 2.Response Delay vs Arrival Rate.

8. Conclusion

In this paper, an HBLES is proposed to improve energy efficiency while reducing the response delay. The scheme modifies the sleep parameters based on the remaining battery power and downlink traffic arrival pattern. It also uses Hyper-Erlang distribution to determine the actual traffic arrival characteristics. Several simulations are conducted for the evaluation of the HBLES and the BLAPS. The results demonstrate that the HBLES achieves superior performance than the existing scheme in terms of the metrics used.

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