Energy consumption model on WiMAX subscriber station

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Abstract. Mobile communication technologies move toward miniaturization. Mobile device's energy source relies on its battery endurance. The smaller the mobile device, it is expected the slower the battery drains. Energy consumption reduction in mobile devices has been of interest of researcher. In order to optimize energy consumption, its usage should be predictable. This paper proposes a model of predicted energy amount consumed by the WiMAX subscriber station by using regression analysis of active WiMAX states and their durations. The proposed model was assessed by using NS-2 simulation for more than a hundred thousand of recorded energy consumptions data in every WiMAX states. The assessment show a small average deviation between predicted and measured energy consumptions, about 0.18% for training data and 0.187% and 0.191% for test data.

1. Introduction
Worldwide Interoperability for Microwave Access (WiMAX) is a Broadband Wireless Access (BWA) technology providing high speed connection and wide coverage area standardized by IEEE 802.16 [1]. Its standard varies according to medium access and physical adaptation. WiMAX was initially set for fixed wireless broadband services dominated by point to point configuration on 10-66 Ghz frequency band. In order to enhance its bandwidth, various adaptations were made to work on 2-11 GHz so called 802.16a. Continuous enhancement changes the standard to 802.16d, 802.16e and 802.16m. Handover and roaming procedures were introduced in 802.16e to enable mobile services [2].

WiMAX configuration consists of a single base station (BS) serving many subscriber station (SS) in point-to-multipoint (PMP) operation. WiMAX is also available for mesh/ad hoc configuration [2]. In PMP configuration, BS can be connected to other BSs through TCP/IP networks. Unlike cellular networks, WiMAX is a packet based network. Its technology is compatible to 802.11 with higher data rate and coverage. If 802.11 medium access works based on flexible uplink downlink allocation, WiMAX utilizes a fixed uplink-downlink channel separation which enables WiMAX managing uplink and downlink bandwidth as well as differentiate quality of services. This feature is desired as current subscribers vary in term of QoS requirements [3]. Figure 1 shows how WiMAX allocates slots for both uplink and downlink channels. Uplink and downlink channels are separated by a small time gap. SS is managed by BS, by informing the channel map in downlink channel. SS requests channels through several schemas, from random competition, polling and reservation. All these features make WiMAX be a potential technology replacing the slower Wireless LAN infrastructure and a potential competitor for current cellular infrastructures.
Research on WiMAX varies from bandwidth allocation, physical improvements, to WiMAX applications [4]. As current traffics are dominated by mobile packet switching or TCP/IP services, WiMAX support for mobility based on mobile equipment is open for mobile phone services. However, since WiMAX allows mobile user (SS) to stream high data rates in a longer distance, energy consumption on mobile devices could be a problem. Having a high capacity connection but high energy consumption in not desired by customers. This matter invites researchers to resolve energy consumptions in WiMAX SS. This paper is interested in exploring the possible model of the energy consumption within WiMAX SS. However, there is no much work on it.

This paper found a mathematical model proposed by Bezerra, et al. [5] that normalized energy consumption level in different states such as on downlink (dl) subframe, uplink (ul) subframe, sleep mode, idle mode, turned on, ul burst and dl burst. Each states describe states in the WiMAX transceiver. Table 1 shows the normalized power determined by Bezzera et al [5].

| Operation Mode              | NS-2 state                   | Normalized power consumption |
|-----------------------------|------------------------------|------------------------------|
| On dl subframe              | While dl subframe            | 1.00                         |
| On ul subframe              | While ul subframe            | 1.00                         |
| On sleep mode               | while sleep mode             | 0.29                         |
| On idle mode                | while idle mode              | 0.06                         |
| Turned on                   | while turned on              | 1.00                         |
| Transmitting ul burst       | while ul burst ratio         | 0.17                         |
| Transmitting ul burst       | while ul burst energy ratio  | 0.01                         |

Even though the aforementioned model can predict when WiMAX SS consumes power the most, it is not able to predict how much the total power required for sending a certain traffic capacity. In order to do so, this paper proposed the trend based prediction model to determine how much power required by a WiMAX SS, in a certain background network condition for a predetermined traffic rates.

2. Proposed Power Consumption Model

In order to determine the amount of power required to transmit a certain load, this paper proposes a simple trend-based energy consumption model. Initially, states on WiMAX are identified. Bezzera [5] energy consumption model is then applied to each state. A training data on energy consumption is generated by using the same traffic background and network condition as the one that will be predicted. Training data is distributed for each state. The measured duration of each state is plotted against bit rate. Duration of each state may be constant for any bit rate or may follow a trend equation. The amount energy consumed in given bit rate can be calculated by using the Equation 1. $E_i$ is predicted energy, $D_i$ and $P_i$ are duration and normalized power for state $i$. 

**Figure 1. WiMAX Frame Structure [3]**
\[ E = \sum_{i=0}^{n} D_i P_i \] \text{.............................................(1)}

By using this equation, the predicted energy consumption of any given bit rate can be calculated as long as background traffic and network condition are similar.

3. Research method
In order to evaluate the proposed method, NS-2 simulator is employed. NS-2 is an event-based simulator that is flexible to make changes to some networks and protocols [6]. The simulator is employed for generating training data, forming mathematical model and comparing to test data. Bezzera energy consumption model is applied to Mac802_16SS.cc code. Training data is set for bitrates 40,000 Bps to 680,000 Bps. The model is assessed for bitrates 56,000 Bps to 696,000 Bps and from 64,000 Bps – 704,000 Bps. Both test rates are chosen randomly.

Network condition is set to have 7Mbps bandwidth with 4 (four) subscriber station: one is in a fixed position, (0 m/s); walking speed (1.39 m/s); cycling speed (4.44 m/s) and driving speed (6.67 m/s). WiMAX coverage has 1000 m diameter with 64 QAM and two-ray ground propagation. Simulation runs 20 times. Network configuration is depicted in Figure 2.

4. Simulation results
4.1. Training Data
Training data generation from 40,000 Bps to 680,000 Bps produces 8-states with constant durations for all bitrates and 7-states with various trend equations. Table 2 and 3 show the state durations.

| No. | Name State       | Equivalent Bezzera Model | Duration (s) |
|-----|------------------|--------------------------|--------------|
| 1   | MAC initialization| TurnOn                   | 0.001        |
| 2   | Mac arrangement  | IdlePower                | 0.000263     |
| 3   | DL-MAP processing| DLPower                  | 1.411993     |
| 4   | DCD Processing   | IdlePower                | 0.005981     |
| 5   | UCD Processing   | IdlePower                | 0.004005     |
| 6   | Ranging          | RecPower                 | 0.000026     |
| 7   | Registration     | IdlePower                | 0.000005     |
| 8   | NBR_ADV          | IdlePower                | 0.003587     |
Table 3. Duration of variable states

| No. | States                              | Equivalent Bezzera model | Trend Equation for duration (s) |
|-----|-------------------------------------|--------------------------|---------------------------------|
| 9   | Outgoing Packet Processing          | sendPower                | \( y = 58.627 \ e^{-0.004 \left(\frac{\text{bit rate}}{40000}\right)} \) |
| 10  | Sending Packet to Physical layer    | ULPower                  | \( y = -0.0084 \left(\frac{\text{bit rate}}{40000}\right)^2 + 1.3799 \left(\frac{\text{bit rate}}{40000}\right) + 6.4381 \) |
| 11  | Incoming packet processing          | recPower                 | \( y = 0.0144 \ e^{0.0263 \left(\frac{\text{bit rate}}{40000}\right)} \) |
| 12  | Process packet internally           | DLPower                  | \( y = 0.0001 \left(\frac{\text{bit rate}}{40000}\right)^2 + 0.0127 \left(\frac{\text{bit rate}}{40000}\right) + 3.5168 \) |
| 13  | UL_MAP processing                   | ULPower                  | \( y = 0.0001 \left(\frac{\text{bit rate}}{40000}\right)^2 + 0.0127 \left(\frac{\text{bit rate}}{40000}\right) + 2.0896 \) |
| 14  | Time adjustment                     | DLPower                  | \( y = 101.66 \ e^{-0.011 \left(\frac{\text{bit rate}}{40000}\right)} \) |
| 15  | Frame initialization                | ULPower                  | \( y = -0.0091 \left(\frac{\text{bit rate}}{40000}\right) + 101.1 \) |

4.2. Energy Consumption Model and Prediction Results

The generated mathematical model follows Equation 1: \( \sum_{i=0}^{n} D_i \cdot P_i \). Number of n is 15, \( D_i \) is the fourth columns of Table 2 and 3, \( P_i \) is the third columns of Table 2 and 3 where the normalized power level for Equivalent Bezzera model is converted based on Table 1.

The comparison of energy calculation between training data and generated mathematical model is plotted in Figure 3. The training data energy consumption is closed to the predicted model with deviation 0.180 %.

![Figure 3. Training data and predicted model](image)
4.3. Test Data vs Predicted Energy Consumption
Meanwhile, the test data for bitrates from 56,000 Bps to 696,000 Bps and from 64,000 Bps – 704,000 Bps show close values to prediction results. The comparisons between test data and prediction result average deviation of 0.187% and 0.191% (Figure 4).

5. Conclusion
The assessment show a small average deviation between predicted and measured energy consumptions, about 0.18% for training data and 0.187% and 0.191% for test data.

Based on state calculations, the smallest energy consumption is on state initialisation of MAC 0.001 Joule and the highest consumption is at state Uplink Frame which is 101.017226 Joule.

References
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