Power Saving Mechanisms in the IEEE 802.16e/m *

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Abstract In the IEEE 802.16e WiMAX or WiBro, power saving is one of the important issues for the battery-powered mobile stations (MSs) due to the mobility. The IEEE 802.16e standard provides different power saving classes (PSCs) depending on parameters sets, procedures of activation or deactivation, and policies of MSs availability for data transmission. PSC I is recommended for Best Effort (BE) and non-real-time variable rate (NRT-VR) traffics while PSC II is recommended for unsolicited grant service (UGS), real-time variable rate (RT-VR) traffics. PSC I is different from PSC II in the followings: first, PSC I adopts the binary exponential increasing algorithms for the size of sleep windows in case of no pending packets for the tagged MS, whereas PSC II uses a fixed size of sleep windows. Second, as opposed to PSC I, under the operation of PSC II the MS sends or receives packets during a listening window.

In this talk, we present performance analysis for the PSCs in the standard. Mathematical modelings for the PSC I and PSC II are given with an embedded Markov chain and a semi-Markov process by considering both uplink traffic and downlink traffic. Performance measures such as the sleep mode ratio, average power consumption and mean delay are provided by the analysis. We can obtain the optimal initial-sleep window and optimal final-sleep window while satisfying QoS on delay constraint.

As an enhancement of IEEE 802.16e, the IEEE 802.16m is currently being processed for standardization. According to the principle of reuse of the fundamental design concept in IEEE 802.16e, and of lower signaling overhead by allowing returning to sleep mode without explicit exchange of management messages, proposals for new sleep mode in IEEE

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802.16m are submitted by Samsung Electronics. These new proposed sleep mode schemes are called *the power saving mechanism (PSM) with periodic traffic indications*, and *the PSM with binary exponential traffic indications*, both of which omit sleep request/response (MOB-SLP-REQ/RSP) messages required in IEEE 802.16e standard.

In the PSM with periodic traffic indications, a traffic indication (TRF-IND) message is sent *periodically* at the beginning of every constant time interval called a *TRF-IND interval*, whereas the PSM with binary exponential traffic indications allows the length of a sleep window to be increased binary-exponentially for the case of a negative TRF-IND message like the PSC I. The latter follows the merits of the original PSC I in the IEEE 802.16e standard and the PSM with periodic traffic indications. The lengths of the minimum TRF-IND interval and a close-down time are determined initially when the MS sets up its connection with its base station (BS) according to QoS constraint on delay. The merits of the two proposed PSMs are quite simple implementation, reduction of energy consumption and saving of the resource compared to the standard PSC.

We investigate the performance of the PSMs in two ways: simulation and analytical method. For analysis we model our proposed PSMs as a variation of $M/G/1$ and derive the Laplace Stieltjes transforms (LSTs) of the lengths of an awake interval and a sleep interval as well as the LST of queueing delay of a message. We obtain sleep interval ratio, average power consumption and mean delay. Using our analytical results, we find the optimal system parameters such as a TRF-IND interval and a close-down time, which minimize the power consumption of MS while satisfying the required QoS on delay constraint. Numerical results show that the proposed scheme consumes less energy than the PSC I under an equal delay bound and it has smaller delay under an equal power consumption bound.

Bong Dae Choi is a Professor at Department of Mathematics and the Director of Telecommunication Mathematics Research Center, Korea University, Korea. He received Ph.D. in Mathematics from Ohio State University. He had worked as a professor in KAIST, in Korea, during 1983-1999. He received best paper award from IEE in 2000 and Seoul Culture Prize in Science in 2001. He is a fellow of Korea Academy of Science and Technology. He is an associate editor of two Journals : Queueing Systems and Asia-Pacific Journal of Operational Research. His areas of interest include queueing theory and its applications to the communication systems. His recent interest is in performance evaluation of IEEE 802.11, 15.4, 16e. He has published about 90 papers in referred journals. His papers have appeared in Queueing Systems, Journal of Applied Probability, IEEE, IEE, IEICE, Performance Evaluation, Telecommunication Systems, Computer Networks and others.