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An Interleaved-Sleeping-Listening scheduler for power saving in mobile stations☆

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ABSTRACT

In mobile networks, the power consumption of a mobile station (MS) can be reduced by entering sleep mode. However, when many connections coexist, the power-saving efficiency is barely satisfactory because the sleep windows of these connections do not overlap and the MS cannot enter sleep mode. Many previous studies tried to shift the sleep windows of some connections where the sleep window is a series of continuous frames. This paper proposes an Interleaved-Sleeping-Listening (ISL) scheduler, which overlaps discrete sleep frames, rather than sleep windows, of multiple connections to obtain a higher number of overlapped sleep frames. The simulation results show that ISL outperforms the previous work, Maximum Unavailability Interval (MUI). When two connections exist and the sleep ratio, the ratio of the sleep frames in a sleep cycle, for each connection is 0.5, ISL improves MUI by 37% on the ratio of unavailability and 15% on the power consumption.

1. Introduction

Rapid advances in mobile communication and wireless technology in recent decades have been accompanied by a move away from traditional cable-based and optical-based networks toward broadband wireless networks for supporting diverse applications. The mobile stations (MSs) used within such wireless networks are typically battery-operated. Such MSs consume much power when transmitting data to or receive data from a base station (BS). This in turn has generated strategies for intelligent power management to save power consumption of each individual MS, and thus to extend the overall service life of the network [1–3]. This requirement can be fulfilled by allowing the MSs to temporarily enter sleep mode whenever they are not actively engaged in data transmission or reception. To operate this sleeping mechanism, each connection maintains several parameters, such as sleep cycle, sleep window, and listening window, where a sleep cycle involves a sleep window and a listening window. A connection is regulated by its sleep window to enter sleep mode, and listening window to enter normal mode for checking whether there are packets arrived [4].

For an MS that hosts multiple connections, it must check if all connections have overlapped sleep windows and thus whether the MS can turn off the transceiver to save power. Thus, the most important thing is to schedule the sleep and listening windows involved in each connection within the Orthogonal frequency-division multiplexing (OFDM) frames with parameters such as sleep cycle, sleep window, and listening window to maximize the overlapped sleep windows.

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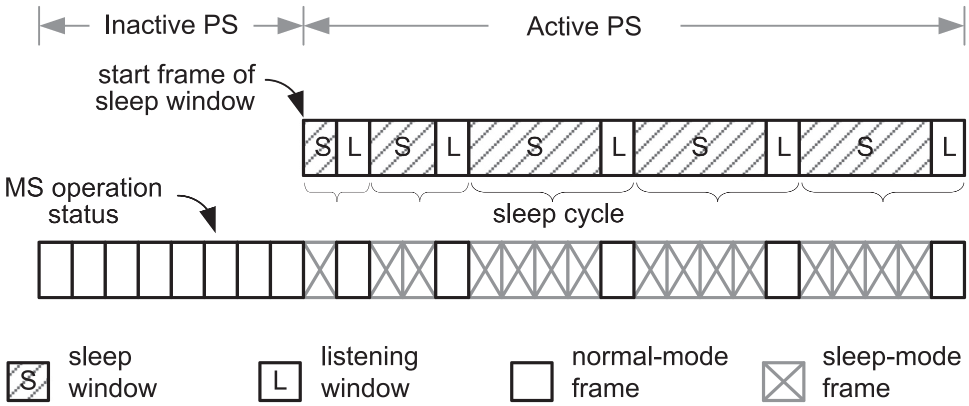

Fig. 1. The power-saving mechanism of single connection.

In order to minimize power consumption by exploiting sleep mode in an MS, a variety of novel algorithms, modeling and analyses have been proposed in earlier studies [5–22]. The studies in [5–16] exploit a power saving technique based on IEEE 802.16 standard. In [5,6], a periodic on-off scheme (PS) and an aperiodic on-off scheme (AS) selected the connection with the minimum delay bound and aggregated packets from other connections to save power. In [7], three power-saving scheduling approaches were proposed by delaying the starting time of MS's traffic transmissions so as to overlap their assigned sleep windows for balancing power-saving and bandwidth utilization. A Maximum Unavailability Interval (MUI) scheme to enhance the power-saving efficiency is proposed in [8]. It is observed that the unavailability interval, the duration that the MS can enter the sleep mode, of an MS varies with the start frame number of a sleep window. Thus, by using the Chinese Remainder Theorem (CRT), the MUI scheme selected the optimal start frame number of sleep window for each connection within an MS to maximize unavailability interval. Some of the latest studies considered additional conditions or parameters to conduct the scheduling for power saving [9–14]. The work covered in [15,16] tried to achieve power efficiency with delay consideration. On the other hand, other studies [17–22] based on sleep management technique of 3GPP standard, such as Discontinuous Reception (DRX), were proposed to reduce power consumption of the MS in Long Term Evolution (LTE).

Although the previous schemes had successfully improved power efficiency in MS, they only scheduled sleep window, i.e., a series of continuous frames. Using a series of continuous frames as a unit of scheduling loses flexibility, resulting in fewer overlapped sleep frames. In this paper we then propose an algorithm, which we term the Interleaved-Sleeping-Listening (ISL) scheduler, to exploit the sleep cycle which is composed of multiple interleaved sleep and listening frames. The ISL algorithm determines the positions of multiple interleaved sleep and listening frames for existing connections so as to minimize the power consumption of an MS. First, ISL determines the priorities of the connections according to the length of their sleep cycles, and according to these priorities, decides the sleep and listening frames of each connection one by one. Its purpose is to maximize the number of overlapped sleep frames with the former, scheduled connections. The ISL algorithm synchronizes the positions of the sleep frames and these overlapped sleep frames among multiple connections save power consumption in an MS.

In summary, this work has the following contributions: (1) using a fine granularity, sleep frame, rather than a course granularity, sleep window, to conduct the overlapping; (2) proposing a novel algorithm, ISL, to overlap sleep frames of multiple connections to maximize the unavailability interval and reduce the power consumption; and (3) conducting many simulations to verify the outperformance of ISL in term of power consumption and ratio of unavailability, compared with other previous algorithms.

The remainder of this paper is organized as follows. Section 2 provides an overview of sleeping mechanisms and related works. Section 3 defines the notations used and describes the proposed ISL algorithm in detail. Section 4 discusses the simulation results and compares the performance of ISL with other algorithms. Finally, Section 5 summarizes some conclusions.

2. Background

2.1. Power-saving mechanism

Power management functions operates in either an active power-saving (active PS) or in an inactive power-saving state (inactive PS). In active PS, where there are many sleep cycles, a sleep cycle is composed of a sleep window and a listening window. During the sleep window, an MS turns off its wireless network interface to save power and cannot receive downlink packets or transmit uplink packets.

Fig. 1 illustrates a typical scenario in which the MS goes from inactive PS to active PS that run sleep cycles. Initially the MS runs the inactive PS where the MS operates by listening to any new packet from BS or transmitting any new packet to