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Efficient scheduling algorithm for multiple mobile subscriber stations with unsolicited grant service in an IEEE 802.16e network

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ABSTRACT

The IEEE 802.16e standard introduces the concept of mobile subscriber stations (MSSs) to provide mobility support. Five quality of service (QoS) classes have been defined to meet the QoS requirement of different connections between a base station and a subscriber station. Among these QoS classes, unsolicited grant service (UGS) has been designed to support real-time service flows that periodically generate fixed-size data packets. Most of the existing scheduling schemes for a UGS class consider scheduling only a single MSS; even if such schemes consider multiple MSSs, the QoS requirement of such MSSs is not appropriately satisfied after scheduling. This paper proposes a scheduling scheme, which schedules multiple MSSs with UGS connections so that the QoS requirement of each MSS can be satisfied after scheduling. The simulation results showed that the proposed approach achieved a bandwidth utilization of more than 90% and did not incur a high bandwidth waste when the number of connections was high.

1. Introduction

Because of the development of wireless networks and advancement of worldwide interoperability for microwave access (WiMAX) technology, the demand for voice over internet protocol (VoIP), data transmission, and other transmission services is high. Currently, wireless and mobile transmission systems have several disadvantages including extremely high cost of infrastructure, difficult operation, and low data rate. By contrast, WiMAX is based on the IEEE 802.16 standard, which is a crucial technology for broadband wireless metropolitan area networks. The advantages of WiMAX over conventional wireless and mobile transmission systems include long transmission distance (maximum of 50 km), high data rate (maximum of 70 Mbps), fast buildup, and low cost. IEEE 802.16e provides enhancements over IEEE 802.16 to provide support for mobile subscriber stations (MSSs) (IEEE Standard 802.16e-2005, 2006; Li et al., 2007). Moreover, it implements a specific system for supportting fixed and mobile broadband wireless transmission. A basic WiMAX network includes a base station (BS) and several subscriber stations (SS) served by the BS. Five quality of service (QoS) classes are defined in the 802.16e standard: unsolicited grant service (UGS), real-time polling service (rtPS), extended rtPS, non-rtPS, and best effort. A UGS is designed for services that periodically generate fixed-size data, such as T1/E1 and VoIP. The BS assigns a fixed grant to UGS connections. Hence, the MSSs are not required to send bandwidth requests to the BS every time they need to transmit data, saving the bandwidth used to send the bandwidth request.

Several studies have focused on optimizing power consumption or scheduling in IEEE 802.16e networks (Chen and Li, 2010; Liao et al., 2012; Liao et al., 2013; Sheu et al., 2008; So-In et al., 2009; Tseng et al., 2011). Chen et al. (2008, 2009) have applied the Chinese remainder theorem to determine the start time of each connection of an MSS. Because of different start time combinations, the wake up time of the MSS drops. However, they did not consider the bandwidth used by each connection. Therefore, an MSS may be required to manage a higher number of connections than it can manage in a certain time, which degraded the feasibility of their approach. Lin et al. (2008) and Lin and Chao (2008) minimized the wake up time of an MSS comprising multiple connections for different service classes. They gathered the bursts of all connections of different service classes and transmitted these bursts together to ensure that the wakeup time of the MSS can be reduced, saving a considerable amount of energy. Although their approach is efficient, they did not consider an environment of multiple MSSs. Fang et al. (2006), Huang et al. (2007, 2008) have proposed three energy-efficiency scheduling algorithms for multiple MSSs, respectively. Fang et al. (2006) classified MSSs into two categories, namely primary and secondary, according to their QoS requirement. A primary MSS is allowed to use the bandwidth in a burst mode, whereas a secondary MSS is provided with the necessary bandwidth only to meet the requirement of its delay constraint. This approach can save

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a considerable amount of energy and prevent the occurrence of interferences between the MSSs. However, in a real-world environment, when the traffic load of all the MSSs is high, classifying the MSSs into primary and secondary categories is difficult. Huang et al. (2007) proposed a scheduling algorithm for a mulitple MSSs environment. This algorithm gathers the bursts of all connections in an MSS and transmits them collectively to minimize the wake up time of the MSSs. They were the first to consider minimum wake up time and environments with multiple MSSs. Huang et al. (2008) applied the Ford–Fulkerson algorithm to determine the time slots used by MSSs. Nevertheless, this algorithm does not ensure the satisfaction of the QoS requirement of the MSSs.

Most related studies have considered single MSS for scheduling; even if they have considered multiple MSSs, the QoS requirement of the MSSs was not satisfied after scheduling. Therefore, we propose a scheduling scheme for assigning time slots used by multiple MSSs with UGS connection so that the QoS requirement of each connection can be satisfied after scheduling.

The rest of this paper is organized as follows. Section 2 explains the scheduling scheme for multiple MSSs. Section 3 presents the simulation results, and Section 4 concludes this paper.

2. Scheduling algorithm for multiple MSSs

In IEEE 802.16e networks, one BS may serve several MSSs simultaneously. However, in a particular time slot, the BS can serve only one MSS (Chakchai et al., 2009). If two or more MSSs are scheduled for data transmission in the same time slot, the BS side incurs interference. Therefore, an efficient scheduling algorithm that can avoid the potential interference between the MSSs and satisfy the QoS requirements of all the MSSs is required. Table 1 lists some of the notations used in this paper. The proposed scheduling scheme is presented subsequently.

Fig. 1 shows the scheduling algorithm for multiple MSSs. Initially, set *U* contains all the connections that are waiting to be scheduled. The first step of the proposed scheduling algorithm is to select a maximum-weight connection from set *U* as the target connection (*t*) for scheduling. Subsequently, we inspect if sufficient empty slots are present to meet the bandwidth requirement of the target connection. If empty slots are not present, we remove the target connection from *U* because its bandwidth requirement cannot be fulfilled during this round of scheduling; however, it is assigned a higher priority for selection in the next round. Next, we inspect if the target connection requires modification. If the target connection is modified, we must verify whether the delay constraint requirement is satisfied after modification. If the target connection is not modified, it cannot be scheduled in this round. Connection modification may produce surplus connections, which are scheduled only after all the connections in set *U* have been scheduled. Nevertheless, we must reserve the time slots used to schedule these additional connections after connection modification. We then determine the start time of the target connection and separate the connection if required. Finally, we schedule the target connection according to its start time, grant a transmit interval, and remove the target connection from set *U*.

Table 1
Notations.

U	*Set of connections waiting for transmission.*
T	*The repeat cycle length.*
G_i	*Grant transmit interval of connection* i.
I_i	*Idle interval of connection* i.
ST_i	*Start time of connection* i.
C_i	*Cycle of connection* i, *equals to* G_i+I_i.
W_i	*Weight of connection* i.
ω_i	Waiting time of connection *i*.
ω_{max}	*Maximum waiting time of all the connections.*
d_i	*Delay constraint of connection* i.
t	*Target connection.*

```
Algorithm: Scheduling algorithm for multiple MSSs
 1: for all the connections in set U
 2:     Select a connection with maximum weight
        from U as target connection t.
 3:     if the remaining slots are not enough
 4:         goto step 16.
 5:     endif
 6:     if the target connection needs to be modified
 7:         Perform connection modification.
 8:         if the delay constraint is not satisfied
 9:             goto step 16.
10:         endif
11:         Reserve timeslots for scheduling
            additional connections.
12:     endif
13:     Determine the start time of the target connection.
14:     Perform connection separation if needed.
15:     Schedule the target connection.
16:     Remove target connection from set U.
17: endfor
18: Schedule the additional connections resulted from
    connection modification.
```

Fig. 1. Scheduling algorithm for multiple MSSs.

2.1. Weight of a connection

$$W_i = \frac{\frac{\omega_i}{\omega_{\max}} + \frac{I_i}{d_i}}{C_i} \tag{1}$$

The weight formula is shown in Eq. (1). The weight of connection i (W_i) is associated with a waiting ratio (ω_i/ω_{max}), delay constraint ratio (I_i/d_i), and cycle length (C_i). The weight of the connection increases with the waiting ratio because a connection with longer waiting time must be served earlier. Similarly, a high delay constraint ratio indicates that the connection has a stringent delay constraint; therefore, it must be assigned higher priority for scheduling. The cycle length (C_i) is inversely proportional to the weight because a shorter cycle indicates a higher probability that the selected connection can be scheduled without any modification. The connection modification is described in the following subsection.

2.2. Connection modification

For scheduling, we must verify whether the target connection encounters interference with any of the already scheduled connections. If it encounters interference, then the target connection must be modified. We transform the target connection into another UGS connection with different grant transmit and idle intervals to avoid interference with the already scheduled connections.

As shown in Fig. 2, assume that a connection i has already been scheduled; therefore, the repeat cycle length T is equal to the length of the cycle (C_i) of connection i, which is 4 in this case. Next, we aspire to schedule the target connection t. If the length of the cycle of the target connection (C_t) is a multiple of T, t does not interfere with the already scheduled connections and can therefore be scheduled without any modification. Moreover, the new repeated cycle equals C_t, and the grant transmit and idle intervals of the target connection remain unchanged.

If C_t is not a multiple of C_i, the target connection may or may not overlap with the already scheduled connections. As shown in