Computer Networks 57 (2013) 3511–3521

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Efficiency-driven selection of bandwidth request mechanism in broadband wireless access networks

Ce-Kuen Shieh [a,1], Chia-Yu Yu [a,*], Cheng-Han Lin [a,1], J. Morris Chang [b,2]

[a] Institute of Computer and Communication Engineering, Department of Electrical Engineering, National Cheng Kung University, EE Department Building, No. 1, Da-Xue Rd., Tainan 701, Taiwan, ROC

[b] Department of Electrical and Computer Engineering, Iowa State University, 391A, Durham Center, Ames, IA 50011, USA

A R T I C L E I N F O

Article history:
Received 18 June 2012
Received in revised form 26 June 2013
Accepted 3 August 2013
Available online 15 August 2013

Keywords:
BWA
WiMAX
BR
Unicast polling
Contention request

A B S T R A C T

To avoid collisions in WiMAX networks, the connections in Subscriber Stations (SSs) use a request–grant process to acquire transmission resources from the Base Station (BS). In accordance with the IEEE 802.16 standard, the request–grant process is accomplished using either a unicast polling method or a contention request method. In WiMAX systems, the number of bandwidth-request (BR) slots per frame is limited. Thus, to enhance the network performance, the BR slots must be used in the most efficient manner possible. In practical WiMAX systems, the offered network load varies over time, and thus the strict use of either the unicast polling method or the contention request method results in a poor utilization efficiency of the BR slots. Accordingly, the present study proposes a scheme designated as Efficiency-Driven Selection of Bandwidth Request (EDSBR), in which the request–grant mechanism is adjusted dynamically on a frame-by-frame basis in accordance with the network conditions. The performance of the proposed scheme is evaluated by simulations. The results show that EDSBR achieves a more efficient utilization of the BR slots than the unicast polling scheme or the contention request scheme, and therefore yields an improved network performance.

1. Introduction

Wireless local area networks, generally referred to as WiFi networks [1,2], provide a convenient means of accessing the Internet via stationary or mobile devices. However, such networks have insufficient bandwidth to adequately support multimedia services with large bandwidth requirements such as Youtube [3] or Netflix [4]. In addition, WiFi is impractical for outdoor use due to its narrow transmission range. As a result, various Broadband Wireless Access (BWA) technologies have been proposed to support higher data rates and a wider transmission range [5–7]. The IEEE 802.16 set of standards [8,9], referred to conventionally as Worldwide Interoperability for Microwave Access (WiMAX), define the MAC and PHY specifications of the air interface and provide various mechanisms for guaranteeing the Quality of Service (QoS) [10] in terms of the required bandwidth [11] or delay [12]. WiMAX is one of the most widely used BWA technologies around the world and is regarded as a promising solution for the realization of next-generation networks.

In WiMAX, the MAC layer is connection-oriented, i.e. every traffic flow is associated with a particular connection. Furthermore, each connection is associated with a particular service flow, where this flow is characterized by a particular set of QoS parameters. The IEEE 802.16 standards define five different service types, namely Unsolicited Grant Service (UGS), real-time Polling Service (rtPS),

* Corresponding author. Tel.: +886 62757575x62359; fax: +886 62345486.

E-mail addresses: shieh@ee.ncku.edu.tw (C.-K. Shieh), frankyu0326@gmail.com (C.-Y. Yu), jhlin5@hpds.ee.ncku.edu.tw (C.-H. Lin), morris@iastate.edu (J.M. Chang).

[1] Tel.: +886 62757575x62359; fax: +886 62345486.

[2] Tel.: +1 5152947618; fax: +1 5152948432.

1389-1286/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.comnet.2013.08.004

extended real-time Polling Service (ertPS), non-real-time Polling Service (nrtPS), and Best Effort (BE) service. To meet the QoS requirements of these different service types, and to avoid collisions during transmission, WiMAX employs a request–grant process [13] to request transmission resources. Specifically, when a connection of Subscriber Station (SS) has data to transmit, it first sends a bandwidth-request (BR) to the Base Station (BS). If sufficient transmission resources are available, the BS grants the requested resource to the connection of SS, which then uses this resource to transmit its data. In WiMAX, the request–grant process is performed using one of two different mechanisms, namely unicast polling [14] or contention request [15]. In unicast polling mechanism, the BS would poll each connection and each connection is assigned a specific time slot within which to transmit its BR to the BS; thereby avoiding contention. By contrast, in the contention request mechanism, the connections transmit their BRs using a random access scheme, and thus the BRs contend for the BR slots. In WiMAX networks, the number of BR slots per frame is strictly limited. Thus, the slots must be used in the most efficient manner possible if the system performance is to be enhanced.

Oh and Kim [16] proposed a mechanism for improving the performance of WiMAX systems by determining the optimal number of BR slots required to support the contention request mechanism. However, the proposed scheme did not consider the efficiency with which the BR slots were actually used, and thus the performance improvement was inevitably constrained. Lu et al. [17] presented a method for determining the optimal size of the backoff window used in the contention request mechanism based on the number of active SSs (i.e. the number of SSs intending to transmit a BR). In theory, the optimal backoff value reduces the risk of collision, and therefore increases the likelihood of the BR being successfully received. However, the method proposed in [17] does not consider the optimal number of BR slots per frame and takes no account of their utilization efficiency. As a result, an overflow problem may occur and the utilization efficiency of the BR slots is reduced.

In practice, the contention-request mechanism results in a more efficient use of the BR slots in networks with fewer active connections (i.e., connections intending to transmit a BR), whereas the unicast polling mechanism achieves a higher utilization efficiency of the BR slots in networks with a greater number of active connections. However, in real-world WiMAX systems, the network conditions would vary over time. As a result, the strict use of either the contention-request method or the unicast polling method fails to make the most efficient use of the BR slots. Thus, the ability of the BS to allocate the bandwidth in an optimal manner is constrained. To resolve this problem, the present study proposes a scheme designated as Efficiency-Driven Selection of Bandwidth Request (EDSBR), in which the request–grant mechanism is adjusted adaptively in accordance with the current network conditions. Specifically, the contention request mechanism is employed when the active rate of the connections is less than a certain threshold value (E_{peak_m}), and the unicast polling mechanism is applied otherwise. The performance of the proposed scheme is evaluated both analytically and numerically. It is shown that EDSBR achieves a higher utilization efficiency of the BR slots than the contention request scheme or the unicast polling scheme, and yields an improved system performance as a result.

The remainder of this paper is organized as follows: Section 2 describes the basic principles of WiMAX networks and discusses the unicast polling and contention request mechanisms. Section 3 reviews the related literature in the field. Section 4 introduces the EDSBR scheme proposed in this study. Section 5 presents and discusses the analytical and numerical results. Finally, Section 6 provides some brief concluding remarks.

2. Background

The IEEE 802.16 standards define two operation modes for WiMAX networks, namely the point-to-multipoint (PMP) mode and the mesh mode. In the PMP mode, the SSs transmit their data to the BS and the BS then forwards the data to the destination (see Fig. 1). In other words, all of the data transmissions are processed by the BS and the SSs do not communicate directly with one another. By contrast, in the mesh mode, the SSs are able to transmit their data to the destination directly.

In WiMAX systems, transmissions occur in two different directions, namely from the BS to the SSs (i.e. the downlink direction) and from the SSs to the BS (i.e. the uplink direction) [18,19]. In the downlink direction, the BS is the sole transmitter and the data are transmitted via broadcasting. By contrast, in the uplink direction, all of the SSs are potential transmitters. If multiple SSs transmit their data simultaneously, traffic collisions would occur at the uplink and the system performance would be reduced. Therefore, the WiMAX prescribes the use of a request–grant process to reserve resources in such a way as to avoid collisions. Specifically, when a connection of SS wishes to transmit its data, it first sends a BR message to the BS. If sufficient bandwidth is available, the BS grants the requested resource to the connection of SS and the connection then uses this resource to transmit its data. As described in the previous section, the request–grant process is implemented using one of two different mechanisms, namely unicast polling or contention request.

2.1. Unicast polling

The BS would poll each connection. Thus each connection is assigned a particular time slot in which to transmit its BR to the BS. In other words, unicast polling is contention-free.

2.2. Contention request

The connections use a random access scheme to transmit their BRs to the BS within a specific interval of the uplink subframe, called contention period. Since a random access scheme is used to access the uplink bandwidth, collisions may occur, and thus some form of resolution procedure is required [20–22].