Computer Communications 88 (2016) 45–56

Contents lists available at ScienceDirect

Computer Communications

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

An effective resource allocation medium access control protocol for radio-over-fiber access networks based on wavelength reuse

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ARTICLE INFO

Article history:
Received 17 July 2015
Revised 11 March 2016
Accepted 8 May 2016
Available online 10 May 2016

Keywords:
Medium access control (MAC) protocol
Simple polling adaptive protocol
Multipoint control protocol(MPCP)
Wavelength division multiplexing ethernet passive optical network (WDM-EPON)
Bottleneck
Radio-over-fiber (RoF) network
60 GHz wireless network
Best-fit algorithm

ABSTRACT

Users' rapidly increasing demands for bandwidth and mobility in conjunction with the surge of delay-sensitive applications, creates the necessity for further research and development of new energy- and cost-effective technologies such as radio-over-fiber (RoF) and radio-and-fiber (R&F). The research community is dealing with medium access control (MAC) protocol design for RoF networks, so that it can support bandwidth-demanding multimedia services such as voice over IP, video on demand, video conferencing, etc. In this work, a novel MAC protocol for RoF access networks is proposed, which is based on a modification of the multipoint control protocol (MPCP). The network's decision centre receives detailed feedback from the mobile client queues via MPCP's GATE/REPORT mechanism so as to efficiently allocate the bandwidth and the wavelength resources in a dynamic manner. The novelty of this protocol is that since wavelength reuse is achieved a single wavelength can be used by more than one remote antenna unit (RAU). The proposed MAC protocol also adapts its operation according to the clients' actual traffic demands and manages to exploit the huge capacity that the optical medium provides. Furthermore, a best-fit algorithm is applied in order to achieve further optimization. Simulation results reveal the superior performance and the better scalability of the proposed protocol compared with similar proposals reported in the literature.

1. Introduction

Lately, there has been a sharp increase in the number of Internet users [1]. This, in conjunction with the growing bandwidth demand owed to the increasing use of the new multimedia-based services, e.g. video on demand, voice over IP, etc., has led to the design and use of new and more efficient access networks. The continuous growth in the use of wireless devices like PDAs, mobile phones, and laptops combined with the growth in the use of the delay-sensitive applications [1] leads to the extended use of wireless telecommunications, resulting in demand for high wireless capacities with improved latency and throughput characteristics. Therefore, the design of new Medium Access Control protocols for networks such as hybrid wireless-optical access networks, are of significant interest to the research community. The use of such networks is intended to combine the large amount of bandwidth (in the order of Gbps) that an optical network can provide and the ubiquity and mobility of a wireless access network, in order to serve a large number of mobile users who require large amounts of bandwidth [2].

Therefore, in the present research we intend to create a MAC protocol for hybrid wireless-optical networks, in order to achieve a cost and energy-effective solution for transmitting efficiently, large amount of delay-sensitive data. This is achieved through both the use of a proper architecture for hybrid wireless-optical networks and an efficient MAC protocol. Two are the prevalent approaches in the literature: radio-over-fiber (RoF) and radio-and-fiber (R&F) [3]. In RoF networks, RF signals propagate over a fiber link from a Central Office (CO) to remote antenna units (RAUs) and then transmitted to clients through the air. RoF networks are considered as centralized, because of the procedures of data analysis and decision-making taking place in the CO. Thus the CO is considered as the network's center of intelligence while RAUs are only responsible for signal conversion. In R&F, an optical and a wireless network are combined to form a single integrated network. In those kinds of networks two different MAC protocols are used, one for accessing the optical medium and one for accessing the wireless medium. The optical line terminal (OLT) is responsible for the traffic arbitration in the optical domain and Optical network units-base stations (ONU-BS or antennas) are responsible for traffic arbitration in the wireless domain. Thus, R&F requires the use of fully functioning

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http://dx.doi.org/10.1016/j.comcom.2016.05.001

intelligent (they arbitrate traffic) along with more complex ONU-BS on the contrary to the RoF RAUs, which have simpler functionality.

From the above derives that the RoF network's components are superior in terms of cost and energy consumption compare to the R&F counterparts. This is due to that the complexity in RoF is located in the CO and therefore RAUs have simpler functionality and fewer components compared with ONU-BS. This results in lower implementation and operational costs. Moreover, the most vulnerable network elements are antennas, which are exposed to different kinds of dangers such as extreme weather conditions. Therefore, lower maintenance cost also characterizes RoF in comparison with R&F technology. Apart from the comparison of low component, fabrication and implementation cost the hybrid networks can also be used to support a wide variety of radio signals. RoF networks are more attractive in this field contrary to R&F networks, since they can provide more transparency against signal modulation techniques and are able to support various digital formats and wireless standards in a more cost-effective manner [4]. Thus, RoF technologies are considered both as a highly effective solution for bridging the ultra-fast optical buses with the increasingly utilized wireless connectivity systems [5] and as a cost effective paradigm for extended range passive optical-wireless networks.

So, in this research we conclude to deal with a RoF network which consists of a Wavelength Division Multiplexing Ethernet passive optical network (WDM E-PON) [11] and a high bit rate 60 GHz wireless network [10]. The WDM E-PON network is used because it is already known as the dominant solution for 'last mile' access [6–9] and the 60 GHz frequency range is used because it has been identified as a region for high-speed wireless data transfer [10,11]. More specific, radios operating in the license-free 60 GHz band have unique characteristics that make them significantly different than radios operating in the traditional 2.4 and 5 GHz license free bands. These qualities give 60 GHz millimeter wave band radios operational advantages not found in other wireless systems. The 60 GHz millimeter wave radio technology presents the optimal opportunity to achieve orders of magnitude higher link budgets than IEEE 802.11n and Ultra Wideband (UWB) systems, which translates into reliable and affordable gigabit-plus wireless connections. Specifically, the advantages listed below [11,12]

- Spectral availability to achieve gigabit-plus data rates
- High allowable transmit power for solid signal strength and range
- Worldwide availability and acceptance
- Narrow beam width and oxygen absorption for interference immunity and highly secure operation
- Excellent Return On Investment/ROI
- Lower fabrication and component costs due to economies of scale and widespread adoption.
- High reliability and integration level
- Readily amenable to mass production
- High efficiency which implies low-loss feed

More analytically, the WDM E-PON consists of a central office (CO) and multiple 60 GHz remote antenna units (RAUs) connected to the CO via fiber buses. The wireless network consists of the RAUs and multiple wireless users.

For the aforementioned RoF network, we design a new and effective MAC protocol to address the listed main issues:

- fiber propagation delay. This issue is mainly derived from the absence of a client recognition and contention procedure for hybrid networks. So there are two main reasons that affect the network's performance a) the contention and recognition procedure, in which a lot of packets are required to be exchanged, and b) the centralized nature of the network, in which the packets used in the above procedures have to propagate both through the optical and the wireless medium in order to be collected from the CO. So the use of the existing recognition and contention procedures have as a result the increase of the mean delay because they are not designed for hybrid networks, where the delay mainly derives from the fiber propagation delay, which is much bigger than the air propagation delay. Thus, we created a new procedure to address these issues as it is described in the following paragraphs and in Section 4.
- the unutilized optical bandwidth which is derived from the huge bandwidth difference between the optical and the wireless media. This is the main issue we came confronted with because the unutilized optical bandwidth decreases the network's throughput and increases the time that a packet takes to be served (mean delay time). More details are presented in the following paragraphs and in Section 4.

To address fiber delay issue analyzed in [2] as well as to optimally arbitrate the 60 GHz spectrum, our protocol employs a polling mechanism based on MPCP, analyzed in Section 4, that has been shown better performance than the carrier sense multiple access/collision avoidance (CSMA/CA) and time division multiple access (TDMA) schemes when operating in the millimeter-wave domain [13]. In addition, our protocol defines two distinct contention periods to optimally regulate the access to both optical and wireless media addressing the network from the RAU and end-user perspective, respectively.

To address the unutilized optical bandwidth issue, our protocol can serve multiple RAUs simultaneously in the same wavelength. This is achieved via modified multipoint control protocol (MPCP) [14], the store-and-forward technique and a best-fit algorithm. With MPCP, the CO receives detailed feedback for all clients' queues from the GATE/REPORT [14] mechanism and arbitrates traffic by allocating dynamically both the bandwidth and the limited wavelength resources depending on the exact demands of the wireless clients. So MPCP specifies point-to-multi-point communication between CO and RAUs' clients.

- Provide client timing synchronization
- Bandwidth/Timeslot assignments to clients

The store-and-forward technique is applied to the RAUs and takes advantage of the network's bottleneck by enabling the simultaneous use of wavelengths. More specifically, by inserting a small buffer in the RAUs and using the aforementioned store-and-forward technique, we artificially create an idle time space named, empty time window, in the wavelength in order to serve data packages from a client under a different RAU. The best-fit algorithm is used in order to fill better the empty time window in the optical media. In that way we can manage optimally the empty time windows in the wavelength which help us to exploit the unutilized optical bandwidth by "ejecting" data packets in these empty windows. Contrary the existing protocols consuming the same transmission time both on the optical and the wireless medium, waiting for the last bit of the packet to be transmitted in the wireless domain in order to propagate it in the optical domain. This results to unutilized optical bandwidth. Thus the existing protocols are limited to the bandwidth of the wireless medium. Simulation results reveal the superior performance of the proposed protocol compared with similar schemes.

The remainder of this work is organized as follows. Section 2 reviews related work, Section 3 describes the proposed network architecture, Section 4 presents the proposed protocol and Section 5 discusses the simulation results. Section 6 concludes the paper.