A Radio-Over-Fiber Network with MAC protocol that provides intelligent and dynamic resource allocation

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Abstract We demonstrate a Radio-Over-Fiber network equipped with an intelligent Medium Transparent Access Control protocol for dynamic wavelength assignment to Remote Access Units.

Introduction

Radio-over-fiber (RoF) network architectures have mainly relied so far on static wavelength allocation schemes assigning a distinct wavelength to each RAU, requiring in this way simple filtering components in order to discriminate RAU-specific traffic[1]. This necessitates the use of a number of wavelengths at least equal to the number of RAUs. However, this requirement may often lead to inefficient bandwidth utilization, especially as wireless users have strongly differentiated traffic-load profiles than fixed network terminals.

In this article, we present for the first time a Medium Transparent Access Control Protocol that arbitrates traffic channeled through both optical and wireless media being capable of serving multiple RAUs and multiple wireless users allocating only a limited number of wavelength resources. Our scheme is based on a network architecture that employs tunable wavelength-filtering RAU configurations and remote uplink and downlink channel generation. We present simulation-based performance analysis revealing that our scheme can provide high throughput and small delay values for multiple wireless users distributed across the network even when a limited number of wavelengths is available.

Physical Layer Architecture

Fig. 1(a) depicts a Radio-over-Fiber network in bus topology with adjacent RAUs connected to the common bus via optical couplers. All uplink and downlink channels are generated at the Central Office and are considered to form n wavelength pairs, namely $\{\lambda_1, \lambda'_1\}, \{\lambda_2, \lambda'_2\}, \cdots, \{\lambda_n, \lambda'_n\}$, following a spectral arrangement as shown in the inset of Fig. (1). In each wavelength pair, λ_i is used to carry single-side-band (SSB) downlink traffic at a 60GHz subcarrier from the Central Office (CO) to the RAU, while λ'_i carries uplink traffic back to the CO. An additional wavelength pair $\{\lambda_c, \lambda'_c\}$ is used for bandwidth control operations: λ_c is used for wavelength assignment purposes informing each RAU about its allocated-specific wavelength λ_i, whereas λ'_c updates the CO about each RAU's traffic request. Fig. 1(b) shows the architecture of each RAU unit. An optical coupler arrangement allows the entire CO traffic to enter each RAU. The low-rate control channel information at λ_c is then converted to an electronic form by means of a low

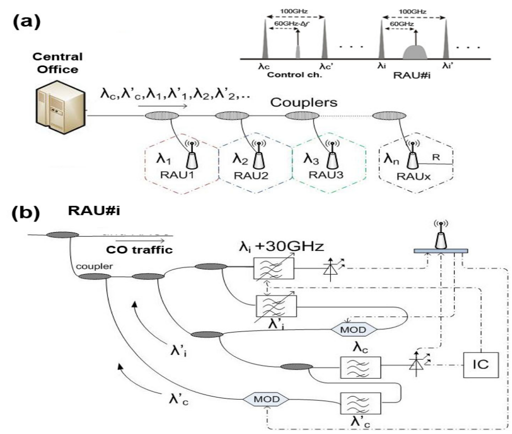

Fig.1.(a) The RoF network architecture and the spectrum allocation, (b) the RAU design.

rate photodiode being subsequently decoded by a low-rate IC microcontroller circuit, whereas λ'_c is being modulated with a beacon signal and is fed back into the network for informing the CO about the RAU's traffic requests. The RAU-specific wavelengths λ_i and λ'_i are selected by two respective optical tunable filters controlled by the IC circuit. Data at λ_i is then launched into a second photodiode prior entering the microwave antenna that feeds the 60GHz wireless signal into the air. Channel at λ'_i travels back to the CO after being modulated by RAU's uplink traffic. Control channel information is transmitted into the air at a small frequency band slightly detuned with respect to the 60GHz band delivering the wireless data signals.

Medium Access Protocol

In the wireless domain, all participating nodes are equipped with two transceivers; one utilized for the main data traffic operating at 60GHz (*Data Channel*), and a second operating at a very narrow bandwidth channel utilized for control signals (*Control Channel*). The main function of the protocol is divided into two major contention periods. During the *1st Contention Period* the CO emits a short optical pulse in the Control Channel that is then emitted into the air at every RAU unit. When the nodes detect the short pulse they respond immediately by emitting a short pulse of the same duration, thus denoting their presence and their desire to transmit data. This pulse modulates a RAU-allocated timeslot in the λ'_c channel and propagates

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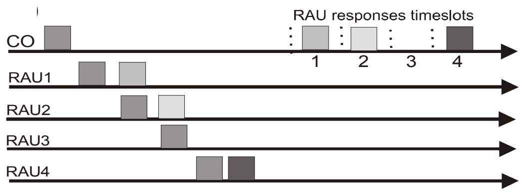

Fig. 2 The 1st Contention Period process.

towards the CO. Due to the bus architecture of the network pulses originating from the nodes will arrive at the CO in a timely fashion as depicted in Fig. (2), providing in this way the information regarding which RAUs have active clients waiting to transmit. After reception of the λ'_c, the CO assigns a data transmission wavelength pair to each RAU by transmitting a short optical bit sequence that uniquely identifies the wavelength λ where the RAU's tunable filter should tune into, ergo ending the 1st Contention Period. In high load conditions, where the number of RAUs containing active clients exceeds the number of available wavelength pairs, the CO assigns the wavelengths in a Round-Robin fashion. In this way, the available bandwidth is divided in equal portions amongst all RAUs containing active nodes without priority and consequently in a starvation-free manner.

The 2nd Contention Period takes place entirely in the Data Channel. All traffic is contained within *Superframes*. Each Superframe contains frames that can either be *Contention Frames* or *Data Frames(Fig.3)*. The duration of a Contention Frame is always equal to the duration of a data frame, and it is further divided into *slots*. At the beginning of each contention frame all the active clients randomly choose an integer value y in the interval $[1,k]$, where k is the number of total slots contained in a contention frame and y corresponds to the number of POLL packets that have to be received by the CO before responding with an ID packet. During a slot, the CO transmits a general POLL package with no receiving node specified in it. Upon correct ID packet reception, the CO responds with an ACK packet, therefore notifying the corresponding node that it has been correctly identified. The latter node will not participate in a subsequent contention frame. If two nodes however chose the same y value they will both transmit an ID packet during the same slot. The collision will render both ID packets unreadable and the CO will not respond with an ACK. The absence of ACK notifies the nodes that a collision has occurred and so they must participate in the next contention frame, after having chosen a new y value. CO continues transmitting contention frames until zero collisions occur and therefore all nodes are identified, ending in this way the 2nd contention period. Having full knowledge of the nodes that are present and active within a RAU, the CO initiates the transmission of a series of data frames, polling in each one a different station in a Round-Robin fashion. If a station remains silent for a number of data frames, it is considered to be no longer active and it is removed from the polling sequence. If all nodes within a RAU are inactive or if the Superframe has exceeded its maximum allowed

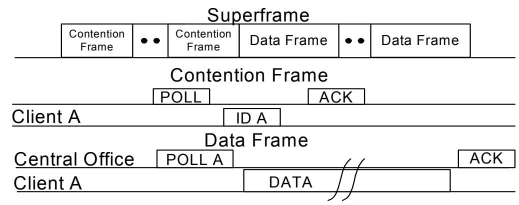

Fig. 3 Superframe, Contention and Data frame structure

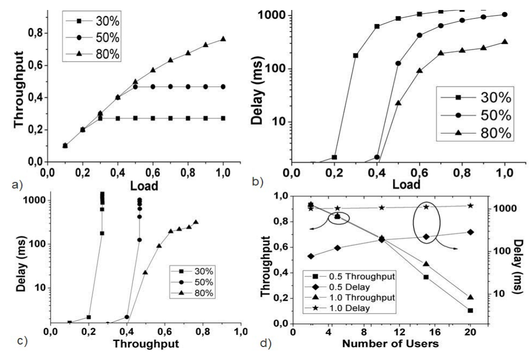

Fig. 4 Performance Evaluation

duration while other RAUs await for wavelength assignment the CO de-assigns the wavelength pair from that RAU. In parallel to the data exchange, the CO periodically reruns the 1st contention process in the control channel as to update the list of RAUs awaiting wavelength allocation. If no known active clients exist within a newly wavelength allocated RAU, the 2nd contention process is repeated.

Performance Evaluation

Fig. (4) depicts the results for the proposed protocol's performance. In Fig. (4a,4b,4c) we gradually increased the offered load from 10% to 100%, while measuring the performance for three different available wavelength pairs to number of RAUs ratios, namely 30%, 50% and 80%. In Fig. (4d) the wavelength pairs to number of RAUs ratio is kept constant to 50%, while the number of present nodes per RAU increases for two different network load conditions (50% and 100%). Throughput was measured as the packets that were correctly delivered per time slot, where a time slot equals to the time it takes for a data packet to be transmitted. As it can be observed the MAC protocol succeeds in utilizing almost all of the available bandwidth, while maintaining delay in reasonable values. More over from Fig.(4d) it can be noted that the protocol is exceptionally tolerant to an increase in the number of different users present within a RAU's range, since a 1000% increase in the number of users (from 2 to 20) leads to only a 12% decrease in throughput.

Conclusion

We have successfully demonstrated a novel Medium Transparent Control Access protocol for high-bandwidth 60GHz RoF networks.

References

[1] Saad Sari, et al: "Radio Over Fiber Networks", AccessNets '07. Second International Conference 2007