Enabling hybrid radio-fiber access networks

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Many studies have reported the feasibility of transporting current wireless radio signals along several km of optical fiber with very good signal quality in point-to-point scenarios. However, in a multiple users' scenario, one restriction set by the current wireless standards is their multiple access schemes and the latency of layer 2 protocols, usually adapted to the physical radio constraints only. Therefore, analyzing the impact of such a delay from a network system perspective will assist to define appropriate architectures and resource management strategies in future hybrid radio-fiber access networks.

Introduction

The current and emerging wireless systems have been conceived for operation over radio media, and thus, their specifications only consider the radio physical constraints. Since the radius of coverage in radio systems is mainly set by power constraints (maximum transmit power, propagation losses, interference and receiver sensitivity), these systems are usually built on the basis of this limitation, and it is the medium access, link control and other upper layer protocols who set the delay and timing boundaries, in order to make an optimal usage of the radio resources. When integrating a fiber feeder system to support the current and emerging wireless standards, the multiple radio access mechanisms as well as the radio duplexing schemes become a key requirement for the design of the hybrid radio-fiber distribution system, since the extra propagation delay added by the fiber path might outrun the timing boundaries of the medium access protocols and the round trip delay. In this paper, the impact of this delay in three wireless systems has been analyzed from a network system view.

Propagation delay in IEEE 802.11(a)

The WLAN standard [1] specifies a distributed medium access control (MAC) protocol called Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA), in which the medium is seized by one station during a contention period performing a backoff procedure, and then it is held by this station until the transmission of one frame (and its acknowledgement (ACK), if required) have finished (see Figure 1). According to the ACK procedure, after transmitting a frame that requires an ACK response, the source station shall wait for an ACK Timeout interval; if the ACK response does not occur during the ACK Timeout interval, the station concludes that the transmission of the frame has failed, and this station will invoke its backoff procedure upon expiration of the ACK Timeout interval. If a long fiber path is included in the access point, an extra propagation delay occurs, and it may result in the expiration of the ACK Timeout interval before any ACK response arrives at the source station, and thus, the transmission will fail. To overcome this timing limitation, three different *best effort* solutions can be proposed:
Increment the ACK Timeout interval. The simplest way to avoid the ACK timer expiration is incrementing the ACK timeout interval so that the station waits a longer period for

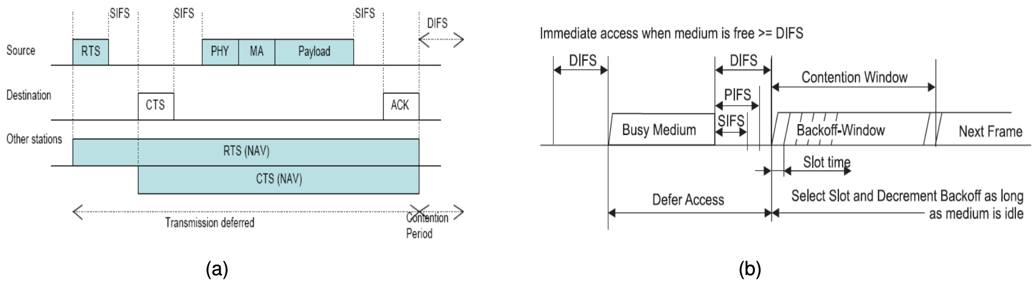

Figure 1: IEEE 802.11: (a) one-frame transmission; (b) medium access control scheme

receiving the ACK. This might work in a point-to-point scenario (one access point and one wireless terminal), however, when the radio medium is shared among several terminals, this solution yields an overall system performance degradation on the access mechanism: the access point response time is increased because of the fiber path, thus, resulting in a looseness of the slotted access emulation during the backoff procedure (only from the access point side), and consequently, in a lost of fairness together with an increment of the collision probability. According to the IEEE 802.11a PHY characteristics [2], the backoff procedure has a slotted access behavior as far as the propagation delay remains much less than the slot time ($0.1\mu s$ vs. $9\mu s$). If a fiber path of e.g. 1 km is inserted, it cannot be considered as a slotted access behavior anymore, because the total propagation delay is not much less than the slot time defined by the standard. If the fiber path is 2 km long, the access point cannot perform its backoff procedure properly, since its attempts to seize the medium will appear one slot too late for the rest of stations, and the other way around, if one station seizes the medium, the access point will be able to see the medium is "busy" one slot too late, thus, increasing the probability of collision.

PHY timing parameters. In order not to degrade the overall system performance (as in the previous case), a second solution is proposed hereafter. According to the IEEE 802.11a PHY characteristics, the standard allows certain degree of freedom in the implementation of some parameters. This fact could be used for the purpose of inserting a fiber path between the central station and the antenna site without incurring in any system degradation. However, this means that the fiber link is a part of the access point definition/implementation, thus implementation dependent for every single link, and additionally, the timing requirements for the signal processing part of the receiver become tight dependent on the fiber length inserted (the margin for processing time decreases $5ns$ per $1m$ of fiber).

Parameter AirPropagationDelay. In order to enable a standard independent hybrid radio-fiber system, to accomplish with the IEEE 802.11a requirements and to avoid any modification of the radio technology implementation, the fiber link can be introduced by sharing the specified parameter $aAirPropagationTime$ for both the delays in radio and optical domains. Assuming $aAirPropagationTime = 0.1\mu s$ (i.e. one grade of magnitude lower than the specified $aAirPropagationTime \ll 1\mu s$), the maximum coverage distance allowed in the radio interface can be easily calculated as $D = c \cdot propagation\_delay = 30m$. In the optical domain, the maximum fiber length allowed for the same propagation delay will be $D = (c/n) \cdot propagation\_delay = 20m$. Combining the usage of the maximum allowed

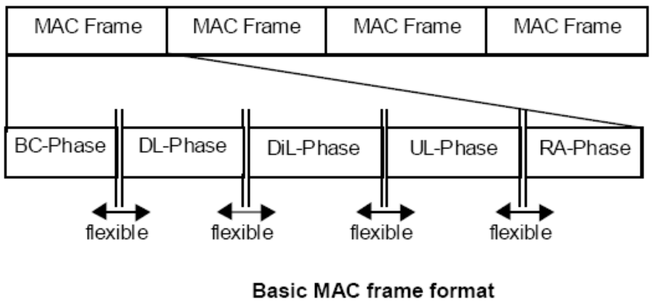

Figure 2: HiperLAN/2 basic frame format

propagation time ($0.1\mu s$) along radio and optical paths, the maximum radio distances D and fiber lengths L of $D = 3m - L = 18m$, $D = 15m - L = 10m$, etc., can be deployed (disregarding any processing time at the antenna site). Thus, although this solution keeps the standard unmodified, it yields a very limited system, which might make both the radio coverage and the fiber length too short for the envisaged networking goal.

Propagation delay in HiperLAN/2

HiperLAN/2 specifies a physical layer very similar to IEEE 802.11a in combination with a TDD/TDMA centrally scheduled scheme for the medium access control (MAC) [3]. The basic structure on the air interface consists of a sequence of MAC frames of equal length with $2ms$ duration. Each MAC frame is composed of several phases (broadcast, downlink, direct link, uplink and random access), as shown in Figure 2. This scheme allows to handle varying uplink/downlink traffic asymmetry by means of dynamically allocating resources on demand, shifting the guard time gaps between phases. Since these guard time gaps can be controlled dynamically from the central controller at the access point, HiperLAN/2 offers a greater degree of freedom for integrating an optical fiber transmission system between the central controller and the antenna site. Complying with the maximum round trip delay defined by the standard ($6\mu s$), a maximum optical path of $600m$ could be integrated (depending on radio cell radius), maintaining the maximum efficient use of resources allowed by the standard. However, longer optical paths could be easily integrated by means of defining wider guard time gaps between the MAC frame phases from the central site, in exchange of slightly degrading the spectrum utilization.

Propagation delay in IEEE 802.16

Another new emerging standard for fixed broadband wireless access is IEEE 802.16 [4]. IEEE 802.16 supports both FDD and TDD centrally scheduled schemes whose basic structure, composed of fixed frames of 0.5, 1 or $2ms$ duration, is shown in Figure 3. In FDD operation, the uplink and downlink channels are on separate frequencies. Therefore, the extra propagation delay introduced when inserting an optical path between the central controller and the antenna site will not affect the medium access control mechanism, since, as well, separated channels (e.g. separated wavelengths) could be used in the optical domain for up and downstream. Nevertheless, upper layer protocols should be

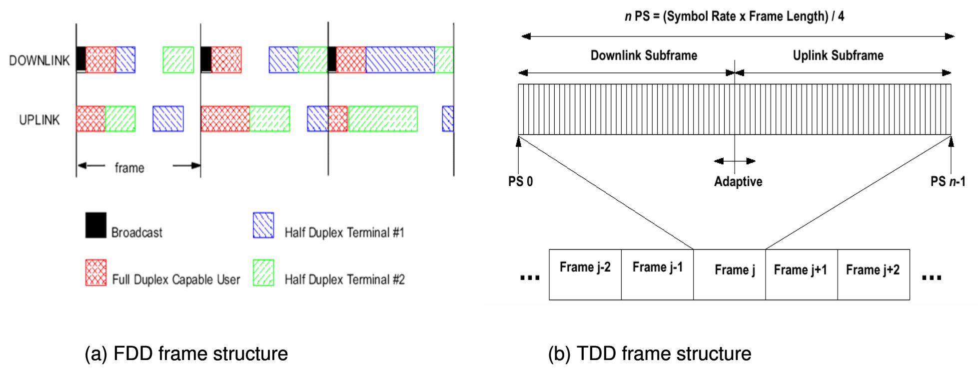

Figure 3: IEEE 802.16 frame structures: (a) FDD, (b) TDD

adjusted to consider this extra delay. In TDD operation, the uplink and downlink transmissions occur at different times and usually share the same frequency. A TDD frame also has a fixed duration and contains one downlink and one uplink subframe. The frame is divided into an integer number of physical slots (PSs). The TDD framing is adaptive in that the bandwidth allocated to the downlink versus the uplink can vary, with a granularity of one PS in the downlink, and a granularity of one minislot in the uplink . The split between uplink and downlink is a system parameter and is controlled at higher layers within the system. This RX/TX transition gaps (TG) are defined as an integer number of PSs. Thus, the integration of the optical fiber path can be very easily adjusted by increasing the number of PS assigned to the TG parameters according to the extra propagation delay added by the optical fiber, in exchange of slightly degrading the spectrum utilization.

Conclusion

Summarizing, it can be determined that the medium access control, duplexing schemes and multiple access methods of the different wireless systems establish a key requirement for the design of hybrid radio-fiber distribution networks, since the extra propagation delay inserted by the optical path has to be considered from the central controller for the support of such systems. Thus, it can also be concluded that central scheduled MAC schemes set less fiber length limitations in order to insert an optical system between central station and antenna site and also allow more flexibility for dynamically controlling the propagation delay.

References

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