Analysis of the IEEE 802.11 performances in radio-over-fiber environments with coverage overlapping

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The radio-over-fiber technology is a suitable solution to provide high bitrates and to improve the IEEE 802.11 WLAN coverage. Those systems use an optical network to distribute the radio signal from the access point to several remote antennas. As those antennas might be densely distributed, a user may be in the receiving range of more than one of them. In such a situation, an emitted packet arrives with an echoed packet to the receiver. This scenario is very uncommon in traditional wireless networks and it may result in a performance degradation. This paper discusses that issue and analyzes the 802.11 performances in radio-over-fiber environments.

Introduction

The radio-over-fiber (RoF) technique seems to be a promising solution to merge the capacity and the transparency offered by optical networks with the flexibility and the mobility of wireless access networks [1]. Figure 1 illustrates an IEEE 802.11 wireless access network using the radio-over-fiber technology: an access point (AP) uses an optical network to distribute radio signals to several remote antenna units (RAUs). Those antennas then transmit the signal on the radio channel to the mobile users. The RoF technology enables the extension of the network coverage by placing the remote antennas up to some kilometers from the AP while it limits the radio channel propagation distance between the antennas and the wireless stations.

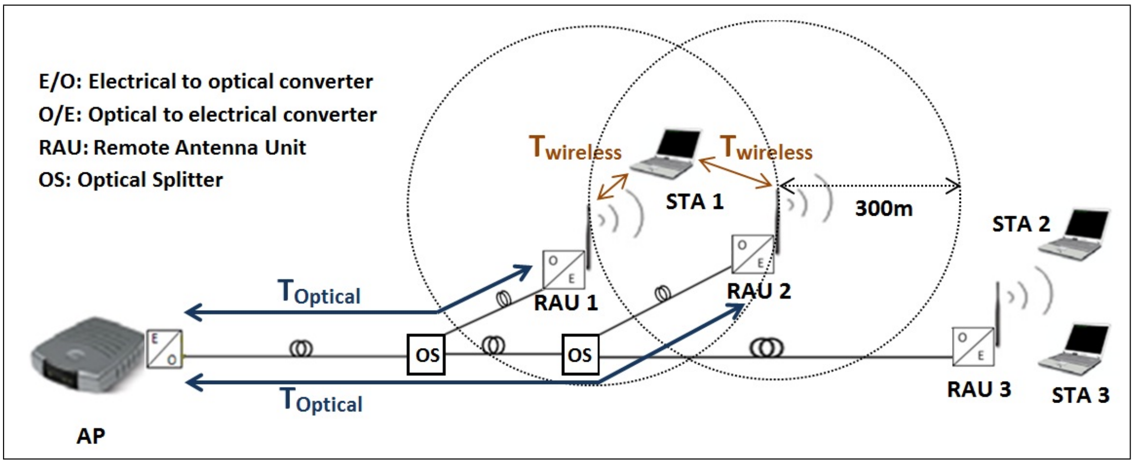


Figure 1: Illustration of an IEEE 802.11 wireless access network using the radio-over-fiber technology

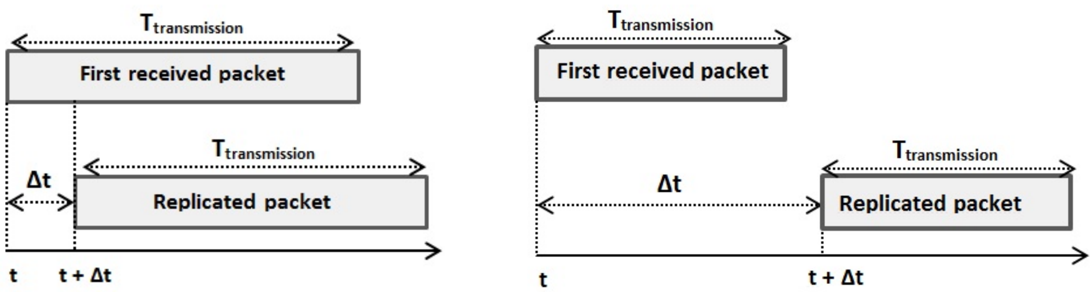
According to the RoF network topology, the remote antennas can be spaced from each other from some meters (e.g. an antenna placed in each room of a house) to some kilometers (e.g. an antenna placed in different buildings of a same manufacturer). There are

thus some scenarios where the antennas are closed from each other and a station may be in the coverage range of more than just one RAU. In that case, the same emitted packet will be received several times at the receiver side (AP), at different times and with different received power values, regarding the position of the station from each antenna. Even though that phenomenon never happens in traditionnal IEEE 802.11 networks, it needs to be analyzed in IEEE 802.11 RoF systems.
In this paper, we first discuss about that phenomenon where an emitted packet arrives with replicated ones at the receiver. Then, we investigate the performances of such RoF systems with the Network Simulator 3 [2]. Finally, the last part draws our conclusions.

Overview of RoF systems with densely distributed antennas

In radio-over-fiber systems, it is useful to dispose antennas quite close from each other to ensure connectivity everywhere (no dead spots) and to limit the propagation distance over the wireless channel. However, such a configuration may result in duplicated packets at the receiver since an emitted packet can be capted/sent by several remote antennas.
According to the delay between the arrivals of the first received packet and the replicated packet Δt, we distinguish two cases:

- $T_{Transmission} > \Delta t$ (Figure 2a): the replicated packet arrives at the receiver during the reception of the first received packet. This situation is similar to a collision between packets (handled by the 802.11 physical layer).
- $T_{Transmission} < \Delta t$ (Figure 2b): the replicated packet arrives at the receiver after the reception of the first received packet. This situation leads to duplicated data packets sent to the 802.11 medium access control layer.



(a) scenario 1: $T_{Transmission} > \Delta t$.　(b) scenario 2: $T_{Transmission} < \Delta t$.

Figure 2: We distinguish 2 scenarios according to the values of the transmission time and the delay between the arrivals of the first received packet and the replicated packet.

We first need to know which of those two scenarios is the most likely to happen. Let us first establish the expression of the Δt parameter. Using Figure 1, we observe that the delay between the first arrived packet transmitted via the RAU 1 and the replicated packet transmitted via the RAU 2 $\Delta t_{1,2}$ of a packet emitted by the station 1 is given by:

$$\Delta t_{1,2} = |(T_{wireless_1} + T_{optical_1}) - (T_{wireless_2} + T_{optical_2})| \quad (1)$$

Because of the short coverage range of IEEE 802.11 antennas (typically 300m), the wireless propagation time ($T_{wireless}$) doesn't exceed $1\mu s$. $T_{wireless}$ is thus very small compared to $T_{optical}$ ($5\mu s$ per kilometer of fiber) and equation (1) becomes:

$$\Delta t_{1,2} = |T_{optical_1} - T_{optical_2}| = \Delta t_{optical} \tag{2}$$

We will now show that the second scenario (Figure 2b) is very unlikely to happen in RoF systems. Indeed, this scenario takes place for small values of $T_{Transmission}$ and high values of Δt. A short value of $T_{Transmission}$ is obtained for short packets and high data rates. If we consider MAC protocol data unit of 100 bytes transmitted at 54Mbit/s, the transmission time is equal to $42\mu s$. We are thus in the second scenario if:

$$\Delta T_{optical} > 42\mu s \tag{3}$$

Equation (3) means that we are in the second scenario if the difference between the optical paths of the two close RAUs is at least of 8,4 km($= \frac{42\mu s}{5\mu s/km}$). Since the coverage area of IEEE 802.11 antennas is generally limited to some hundred meters, it is impossible that a station is in the receiving range of two antennas spaced from each other of 8,4 km (we obviously don't consider networks with unnecessary increased optical links). As a conclusion, we will be in the first scenario (Figure 2a) and, since Δt is generally smaller than a few microseconds, the replicated packet will always arrive to the receiver during the preamble of the first arrived packet.

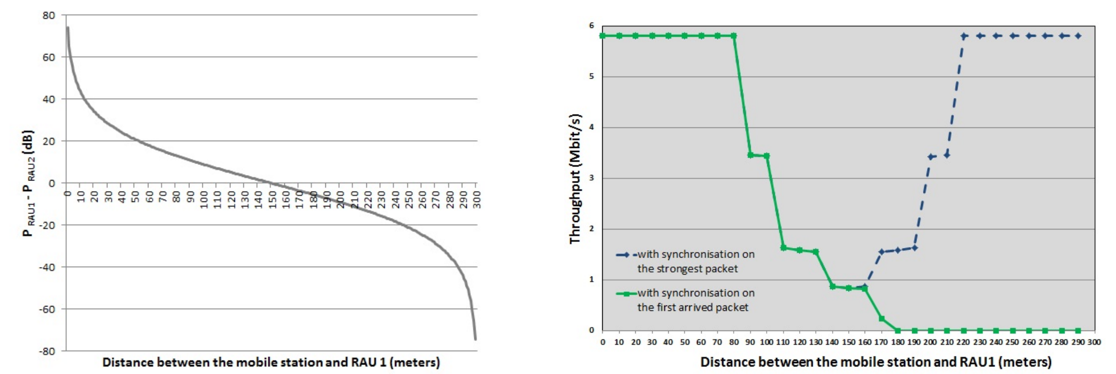
Performance analysis

In this section, we study the performances of RoF systems (Figure 1) where a station is in the receiving range of two RAUs (our analysis can be extended to more RAUs). As we explained in the previous section, this situation leads to the reception of two signals at the receiver site which is similar to a collision between two IEEE 802.11 packets. However, it has been shown [3] that a collision does not necessarily means that all the packets are lost. Depending on the relative signal power and the arrival timing of the involved frames, the frame can survive the collision and be successfully received.

If we consider the case illustrated in Figure 1, where the optical link between the AP and the RAU 1 is shorter than the link between the AP and the RAU 2, a packet transmitted via the RAU 1 will arrive at the receiver before the packet transmitted via the RAU 2 and the receiver will synchronize on the packet sent via the RAU 1. If the ratio between received power value at the RAU 1 and the received power value at the RAU 2 is sufficient, which happens when the station is located near the RAU 1, the packet will be successfully transmitted. When the station gets closer to the RAU 2, the signal strength of the replicated packet will be bigger than the signal strength of the first received packet on which the receiver is synchronized. In this case, the SNR of the useful signal becomes low and the data rate decreases as long as the station goes away from the RAU 1 to the RAU 2.

Figure 3a shows the difference between the received power at the RAU 1 and the received power at the RAU 2 when the station 1 moves between those two RAUs. According to that difference, we observe in Figure 3b (continuous line) that the emitter has to adapt its data rate in order to successfully transmit its data. The user throughput is at its maximum value when the station is near the RAU 1 and is about 5,8 Mbit/s. When the station goes away from the RAU 1 to the RAU 2, it has to progressively decrease its data rate according to the SNR. Once the station becomes too far from the RAU 1, the throughput drops to zero.

However, recent IEEE 802.11 devices allows a receiver to stop the ongoing reception of a packet if another packet with a stronger signal strength arrives within the preamble time of



(a) Difference between the received power values at the RAU 1 and at the RAU 2 (we consider the log distance propagation loss model with an exponent path loss equal to 3).

(b) Evolution of the UDP data throughput (obtained with ns-3 [2]) in the 802.11b RoF network described at Figure 1 when the station 1 moves from the RAU 1 to the RAU 2.

Figure 3

the weaker packet (capture effect mode) [3, 4]. When this mode is used, the receiver can switch its reception onto the replicated packet if it has a stronger signal strength than the first received packet. By doing so, the station can therefore transmit packets successfully at higher data rates even if the station is close to the RAU 2 (Figure 3b - dashed line).

Conclusion and acknowledgement

In this paper, we analyzed the performances of the IEEE 802.11 protocol when it is used in a radio-over-fiber system where a mobile station is in the receiving range of several remote antenna units. In this scenario, the first received packet may be followed by one or several replicated packet(s).

We showed that such a phenomenon is equivalent to a collision between IEEE 802.11 packets, where a replicated packet always arrive during the transmission of a first received packet. If the mobile station is close to the less distant RAU from the AP, the transmission of a data packet at a high data rate is possible. In the other situations, the SNR may be low, and the data rate is reduced in order to be able to transmit data packets to the receiver. Once the SNR becomes too low, the performances drop to zero. Finally, we showed that if the 802.11 capture effect mode is enabled, the receiver selects the packet with the strongest signal strength so that we can avoid poor performances and increase the area where the station is able to transmit packets at higher data rates.

The financial support for this work was provided by a FRIA grant.

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