HD-Video Streaming over an Inexpensive In-Building Radio-over-MMF System

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The need for indoor wireless connectivity is increasing, and conventional systems are getting congested in the radio spectrum. A promising solution is an indoor network consisting of many radio pico-cells fed via fiber. We propose a low-cost implementation by deploying Radio-over-Fiber techniques. The remote antenna contains only an optical-to-electrical conversion, and each pico-cell is fed by a residential gateway through a multi-mode fiber backbone. We characterize the physical layer and experimentally measure the Quality of Service (QoS). To evaluate its practical applicability, we assess the end-user perceived Quality of Experience (QoE) during HD-video streaming and its relation to QoS.

Introduction

The wireless LAN is world-widely deployed to connect mobile devices in the indoor environments. However, with the exponential increase in bitrate demands and number of users, a large amount of wireless access points would be required for providing the sufficient coverage as well as significant increase of the total capacity. To meet these needs, radio-over-fiber (RoF) techniques for serving smaller radio cells have been proposed as promising solutions[1, 2]. Instead of a single large wireless network, in our proposed pico-cells architecture, each remote antenna unit (RAU) only serves a few devices to reduce the congestion, but all the RAUs throughout the building are connected to a central unit by the optical fiber infrastructure. In this case, the RAU is just a simple optical-electrical interface, and the in-building optically-fed infrastructure can be potentially integrated with the fiber-to-the-home (FTTH) network without additional optical-electrical conversion[3], further reducing the Opex and Capex.
Evaluating the performance of such a network through a traditional Quality of Service (QoS) assessment is most of the time inaccurate and insufficient[4]. QoS metrics reflect the status of individual networks but do not capture the quality perceived by the end user. Thus, our network performance assessment includes a study on how the user's expectations are fulfilled, i.e., the Quality of Experience (QoE).

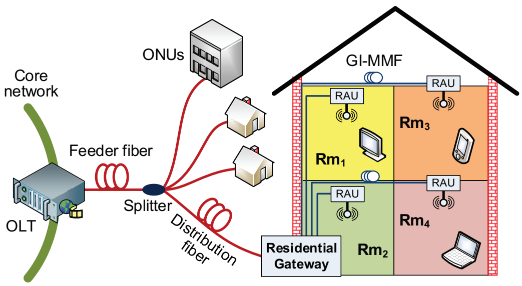

Fig. 1. Scenario of the in-door optical infrastructure terminating the FTTH network

In this paper, we propose a low-cost and commercially ready solution to terminate the access network at the residential gateway (RG), and then deliver the WLAN service over graded-index multimode fiber (GI-MMF) to each cell inside the building, as shown in Fig. 1. In the proof-of-concept experiment, we carry out the cross-layer measurement for the IP packets, as well as QoE assessment of HD video slips.

Experimental setup

Fig. 2 shows the experimental setup based on the proposed network. A computer server is used to generate IP packets and video streams. At the RG, a conventional wireless router translates the gigabit Ethernet signal to the IEEE 802.11n OFDM signal with a bandwidth of 40 MHz. In the experiment, the router is isolated in a metal-shielded box to prevent leakage of the wireless signal, and the RG and RAU are located in two different rooms. The OFDM signal is modulated by a directly modulated laser (DML) working at 1310 nm. After transmission over GI-MMF with 50 μm core diameter, the signal is detected by a multimode InGaAs photodetector (PD) and amplified by a bi-directional radio power booster (PB) at RAU. A multimode VCSEL source operating at 850 nm and GaAs PD with a multimode 62.5 μm core fiber input are used for the uplink stream, which is coupled in a single fiber by two identical multimode dual-band multiplexers. We use a laptop as the mobile device (MD) to analyze the received IP packets, as well as a QoE algorithm for qualifying the fidelity of received HD videos.

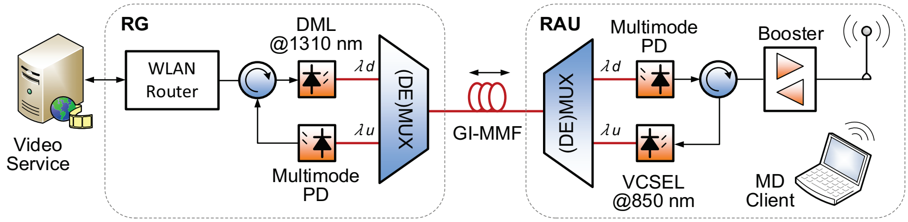

Fig. 2. Experimental setup of Radio-over-MMF system

The purpose of deploying multimode fibers for such an in-building network is to reduce the cost and complexity, because the larger core size eases connections and also allows the use of lower-cost optical devices, particularly, when numerous RAUs need to be installed. Compared to single mode fibers, multimode fibers have much lower 3 dB bandwidth mainly due to the modal dispersion, as shown in Fig. 3(a) for both downlink and uplink in our experiment. However, the modulated wireless signal at 2.422 GHz can be still accommodated even with a MMF length of 2.4 km.

Assessing Video Quality of Experience

QoE is defined as the degree of delight or annoyance of the user of an application or service[5]. As QoE is in its essence subjective, methods based on human interaction analysis are the most appropriate ones, i.e. subjective QoE[6]. However, it is not always possible to employ subjective tests, especially for applications requiring real-time feedback for services monitoring and management. Thus in this research, an objective QoE metric, in particular the structural similarity (SSIM) algorithm is employed.
The structural similarity (SSIM) metric was originally developed as a QoE objective

metric for image quality assessment (IQA), but it has been widely used for video quality assessment (VQA) as well. The SSIM metric is based on the observation that a natural image or frame in a video is highly structured. This means that there is strong neighbor dependence between the pixels. As the human visual system (HVS) is highly adapted to structural information[7], SSIM performance is better correlated with subjective QoE. Structural information is defined as the attributes that represent the structure of objects in the scene, independent of the average luminance and contrast. Hence SSIM combines comparisons in terms of luminance, contrast and structure. It can be written into the formula[7]:

$$SSIM(x,y)=\frac{(2\mu_x\mu_y+C_1)(2\sigma_{xy}+C_2)}{(\mu_x^{\ 2}+\mu_y^{\ 2}+C_1)(\sigma_x^{\ 2}+\sigma_y^{\ 2}+C_2)}$$

where μ_x, μ_y represent the mean luminance of the compared frames. σ_x, σ_y are their standard deviations and represent the base contrast of each image computed. The correlation σ_{xy} is used as a base for the structural analysis.

Analyses and Discussions

The main purpose of our evaluation is to investigate how the physical characteristic of our system would affect the network performance and ultimately the user's quality. Since multimode fiber can support many propagation modes, due to the larger core-size, the bandwidth-distance product is severely limited by modal dispersion. Thus, we assess the system performance by using fiber lengths of 200 m and 2.4 km, respectively.

We first carry out a cross-layer UDP packets analysis. During the packets transmission, we use an Agilent PXA signal analyzer to monitor the OFDM signal after photo-detection. Fig. 3(b) shows the instant electrical spectrum with the constellations of QPSK and 16-QAM formats, in which the green spots are for the pilots. The average EVM is about 2.8% through a one-minute session.

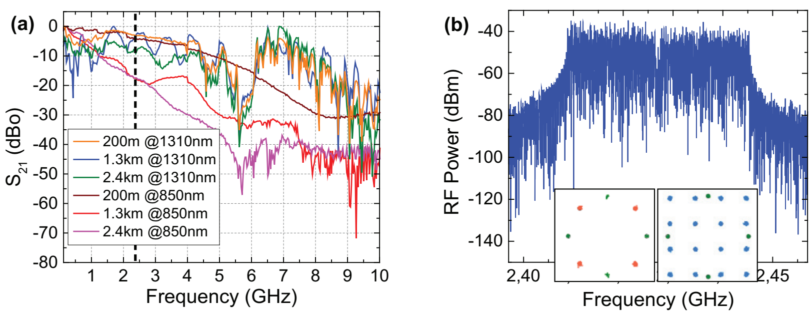

Fig. 3. (a) Measured transfer functions of GI-MMF with different lengths; (b) detected electrical spectrum of WLAN signal at RAU (inset: IQ constellations of data subcarriers and pilots)

Fig. 4(a) shows the maximum throughputs of UDP packets obtained by the mobile client. We find out that 25 Mbps and 15 Mbps are the maximum throughputs for the fiber length of 200 m and 2.4 km, respectively. The reduction of throughput is 40% in the 2.4 km link, because of the much worse channel response.

For our streaming session, we regenerate a 6-times repetition of the 10 seconds, 25 fps, 1080HD video Shields from the Live Video Database[8], 1 minute duration in total. The target video is first encoded to MP4 at 20Mbps and then streamed to the client using the Real-Time Protocol (RTP) over UDP[9].

The fiber length increase degrades the quality with about 30%, as shown in Fig. 4(b), relatively less than the degradation observed with the throughput analysis.

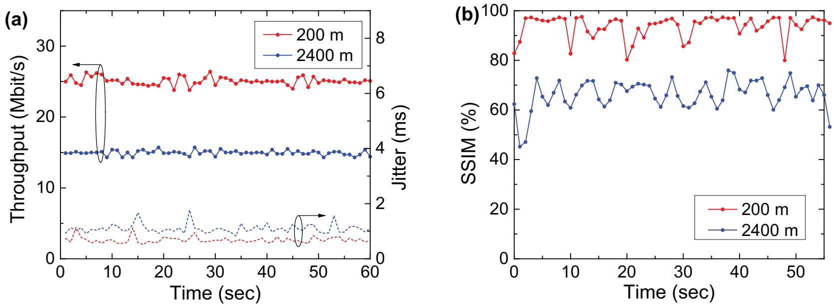

Fig. 4. (a) Measured throughput and jitter of UDP packages; (b) QoE of received HD video streams

Conclusions

We experimentally demonstrated a low-cost and simple in-building radio-over-MMF scheme. To fully assess the performance, we not only characterized the physical layer, but also evaluated the user's perceived quality of received HD-videos. We measured both QoS and QoE against different lengths of fibers. With the proposed in-building network, we are capable of extending the WLAN coverage up to 2.4 km with less QoE degradation at the mobile user side.

Acknowledgements

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