AUDIO AND VIDEO SERVICE PROVISION IN DEEP-ACCESS INTEGRATED OPTICAL-WIRELESS NETWORKS

(invited paper)

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ABSTRACT

Audio and video streaming can be provided in deep-access optical-wireless networks in a cost-effective way integrating the optical access, the optical in-building network and the wireless link at customer premises. Orthogonal frequency division multiplexing (OFDM) modulation is an interesting candidate for the integrated optical-wireless provision of this service and has been selected by most of the wireless communication standards due to the high spectral efficiency and bit rate capabilities combined with its robustness to transmission channel impairments and inter-symbol interference (ISI). In this paper, the successful transmission of commercially available OFDM-based signals following different wireless standards is demonstrated and the performance of the different digital signal processing algorithms implemented in their communication stacks is analyzed. Different optical transmission media and different OFDM transmission frequency bands are evaluated experimentally including the 60 GHz band. The wireless range coverage after the integrated optical-wireless transmission is also reported from the experimental work.

***Index Terms*—** Audio and video, integrated optical-wireless, orthogonal frequency division multiplexing (OFDM)

1. INTRODUCTION

Audio and video streaming of broadcast and on-demand programs has become one of the most demanded services for telecommunication operators. In the last years, the distinctions between cable and satellite TV, and between wireless and wireline telephone systems have become less obvious, while the telecommunication operators offered more services including mostly high-speed Internet access, video-on-demand, and Internet telephony services [1]. Video broadcasting represents the bulk of capacity usage in the telecommunication market [2]. In video broadcasting provision, cable, TV-over-IP (IPTV) and fiber-to-the-x (FTTx) broadband services are still rival, as the more people watching video in a given area impacts on the quality of services for other users in the same location [2]. For instance, currently video streaming represents more than half of the downstream capacity in USA [3].

The streaming media sales increased around a 25% in each year from 2011 to 2013, resulting in a total increase in sales of $1.2 billion in 2013 [4]. The forecast indicated that total sales will reach over $16.7 billion by 2018 as consumers shift away from physical discs seeking out for unique content [4]. According to Mintel research on 2014, 46% of the online adults in the US watched video content in January 2014 using a subscription video account, increasing to 71% of all the users between 18 and 34 years old [4].

TV viewing is no longer restricted to television monitors. In the last years, video-on-demand services are requested also from other devices such as laptops, smartphones and tablets. The estimated growth in on-demand services is around 25% year on year [2]. Following the growing demand for media content distribution, ETSI is working on the development of multimedia systems (including TV and communication), investigating in media quality and the user experience for multimedia in hands-free and video phone applications [5]. Video-on-demand services can be provided in a cost-effective way integrating the optical access, the optical in-building network and the wireless network at customer premises, as depicted in Fig. 1.

Orthogonal frequency division multiplexing (OFDM) modulation is an interesting candidate for the integrated optical-wireless provision of audio and video streaming and has been selected by most of the wireless communication standards, such as ETSI terrestrial digital video broadcasting (DVB-T), 3GPP long term evolution (LTE)[6], IEEE 802.16 (WiMAX) [7] and ECMA-368 ultra-wide band (UWB)[8], between others. OFDM modulation provides high spectral efficiency and bit rate with robustness to transmission channel impairments and inter-symbol interference (ISI).

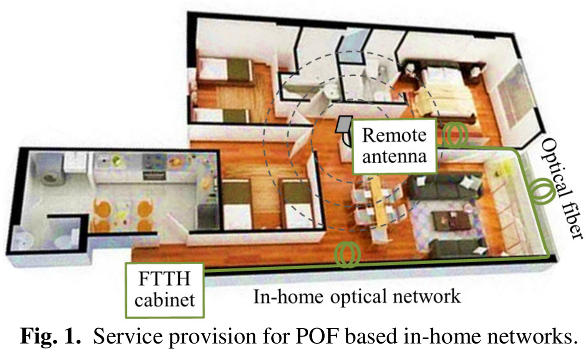

Fig. 1. Service provision for POF based in-home networks.

In order to extend the coverage, radio-over-fiber transmission was proposed for fiber-to-the-home (FTTH) network distribution [9]. The in-home distribution and further radio transmission is a straight-forward step to reach the final user as depicted in Fig. 1.

In this paper, the successful transmission of commercially available OFDM-based signals for audio and video provision following different wireless standards is demonstrated. The different digital signal processing (DSP) algorithms implemented in their communication stacks is summarized in Section 2. As the main constraint for in-home networking is the requirement for cheap and user-friendly solutions in brown-field deployment, large core plastic optical fiber (POF) fibers are currently being considered for short-range in-home links since POF enables "do-it-yourself" connectorization compared to SSMF [10]. Earlier works addressing POF transmission mostly focused on baseband transmission [11]. For longer optical link connectivity, bend-insensitive (BI) fibers such as Corning ClearCurve is preferred due to the lower optical losses from adaptation between the optical access and the in-home distribution and the higher bandwidth provided [12]. In the experimental demonstration reported in Section 3, different optical transmission media are considered including POF and BI-SMF. Also, different OFDM transmission frequency bands are evaluated including the 60 GHz band. The quality of the received video is measured in different cases and the wireless range coverage is evaluated in the experimental work. Finally, in Section 4, the main conclusions are highlighted.

2. WIRELESS COMMUNICATION STANDARDS FOR AUDIO AND VIDEO PROVISION

In order to exploit the integrated optical-wireless network capability, 3GPP LTE, IEEE 802.16 WiMAX and ECMA-368 UWB radio signals are evaluated following current standards in order to be able to use commercial devices at customer premises to receive the audio and video content.

3GPP LTE processing stack is represented in Fig. 2. The LTE frame has 10 ms duration and it is divided into 10 sub-frames with each sub-frame being 1 ms long, as shown in Fig. 2(a). Each subframe is divided into two slots (0.5 ms duration each). Each slot consists of 7 or 6 OFDM symbols, depending on the type of cyclic prefix (CP) employed (normal or extended, respectively) [6]. One sub-frame contains 100 resource blocks (RBs) for user allocation. Users are allocated a specific number of subcarriers in physical resource blocks (PRBs), which are scheduled at the LTE base station (eNodeB)[13]. The LTE downlink signal can be represented in a resource grid as shown in Fig. 2(b), where each box represents a resource element. For multiple input multiple output (MIMO) transmissions, there is a resource grid for each transmitting antenna. In Fig. 2(b) a single input single output (SISO) transmission is represented for simplicity. Unlike packet-oriented networks, LTE does not employ a PHY preamble to estimate the carrier offset or synchronize the timing. Instead, reference signals (RS) are embedded in the PRBs and transmitted during the first and fifth OFDM symbols of each slot in case of using short CP, and in the first and fourth OFDM symbols in the case of long CP. As it is observed in Fig. 2(b), the reference symbols are transmitted every sixth subcarrier. Further, reference symbols are staggered in both time and frequency. The channel response is calculated from the reference symbols and interpolation is used on the remaining subcarriers.

Fig. 2(c) shows the block diagram of a physical layer LTE system. The input bit stream is mapped to single carrier symbols using BPSK, QPSK, or 16QAM modulation, depending on the channel conditions. The serial-to-parallel (S/P) block converts the time-domain single-carrier symbols into the discrete Fourier transform (DFT) engine. The DFT output tones are mapped to specified OFDM sub-carriers. The OFDM symbol is converted to time domain and the CP is added. As it can be seen in Fig. 2(c), the receiver procedure is the opposite. The optimized LTE handover supports low-delay handovers that can support demanding applications such as VoIP and video streaming [14].

IEEE 802.16 WiMAX technology covers the frequency band between 2 GHz and 11 GHz with channels up to 20 MHz [7]. Fig. 3(a) describes WiMAX frame structure for frequency division duplexing (FDD) operation. In FDD, the downlink (DL) and uplink (UL) channels use different frequencies. Transmitting the DL in bursts as shown in Fig. 3(a) facilitates using different modulation types and allows the system to support full-duplex and half-duplex user

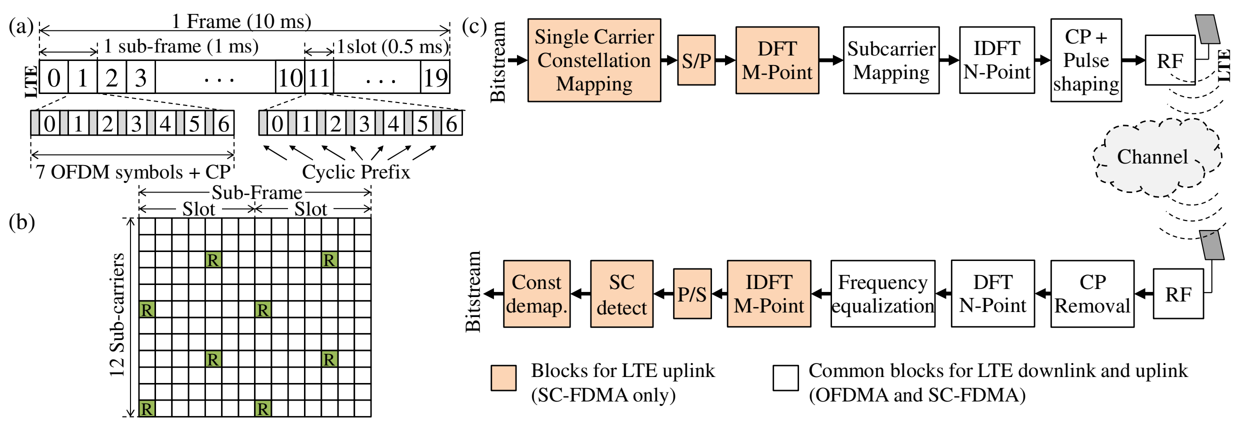

Fig. 2. (a) LTE frame structure, (b) LTE physical resource grid, and (c) LTE physical layer block diagram.

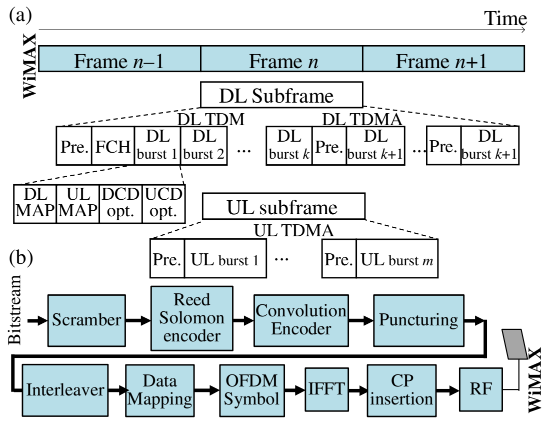

Fig. 3. (a) WiMAX FDD frame structure and (b) WiMAX physical layer block diagram.

devices. Following the block diagram represented in Fig. 3(b) raw data is converted to a WiMAX signal using a scrambler, a Reed Solomon encoder, a convolution encoder, puncturing, an interleaver, data modulation mapping, OFDM symbol former, IFFT and insertion of the CP before RF generation.

ECMA-368 UWB standard defines 12 bands of 528 MHz bandwidth each in the frequency range from 3.1 to 10.6 GHz with very low transmission power spectral density (PSD) (-41.3 dBm/MHz)[8]. The UWB frame structure is depicted in Fig. 4(a). The physical layer convergence protocol (PLCP) header includes MAC and PHY headers and it is protected by a header check sequence (HCS). The frame payload is followed by its frame check sequence (FCS). In Fig. 4(b) the block diagram of UWB transmitter is represented. As a novelty compared with LTE and WiMAX PHY, ECMA-368 UWB technology defines different time frequency codes (TFC) where the coded information is interleaved over three bands as depicted in Fig. 4(a).

Video conferencing over 4G WiMAX and LTE technology using tablets was demonstrated for the first time at GSM Association Mobile World Congress 2011 [15]. The first HD video distribution over POF was presented in [16] with the dedicated transmission of the UWB signal.

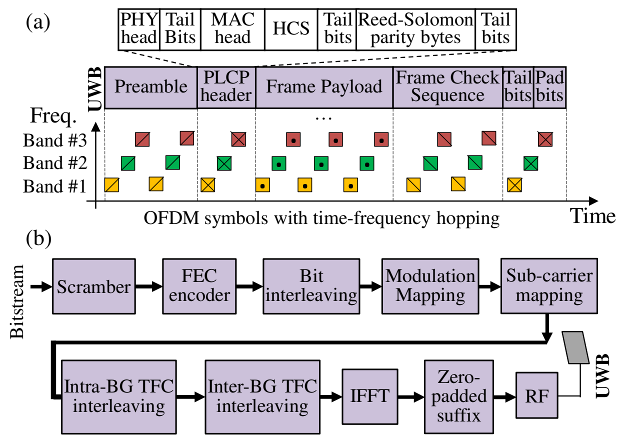

Fig. 4. (a) UWB frame structure with time-frequency code representation and (b) UWB physical layer block diagram.

To evaluate the quality of audio and video provision in integrated optical-wireless networks, we transmit LTE, WiMAX and UWB fully standard signals in their regulated wireless frequency bands using radio-over-fiber.

3. EXPERIMENTAL EVALUATION

3.1. In-home optical-wireless transmission with POF

The experimental setup used to evaluate the quality of video broadcasting using radio-over-fiber transmission in integrated optical-wireless networks is depicted in Fig. 5 for in-home optical network comprising 25 m of large core GI-POF followed by a radio link ranging from 1 to 4 m. An eye-safe broadband red vertical cavity surface emitting laser (VCSEL) diode emitting at 667 nm (Firecomms RVM 665T) was used to transmit the signals through 25 m of Optimedia PMMA GI-POF with the optical loss of 0.3 dB/m at 667 nm. Due to the bandwidth limitation of the POF system up to 1.3 GHz, the 10 MHz WiMAX signal using 16QAM is generated at 3.5 GHz and the UWB signal using the TFC6 from 3.696 to 4.224 GHz are first down-converted with a local oscillator (f_{LO}=2.94 GHz) obtaining a WiMAX signal at 0.57 GHz intermediate frequency (IF) and UWB IF from 0.757 to 1.285 GHz. These signals are combined with a 10 MHz LTE signal using 16QAM centered at 0.73 GHz and transmitted in coexistence. The optical signal after the 25 m POF link is detected by a silicon avalanche photodetector (Si-APD) of 230 μm photosensitive diameter including a 2-stage electrical amplifier. The UWB and WiMAX signals are up-converted with the same f_{LO}, filtered, amplified before wireless radiation, ensuring that UWB PSD complies with the FCC spectral mask. Fig. 6 shows the received constellations and error vector magnitude (EVM) of LTE, WiMAX and UWB signals demodulated according to Section 2 standards. The EVM values meet standard requirements confirming the correct transmission of the wireless signals ($EVM_{LTE16QAM}$ < -18 dB [6], $EVM_{WiMAX16QAM}$ < -24.43 dB [7] and $EVM_{UWBQPSK}$ < -14.5 dB [8]).

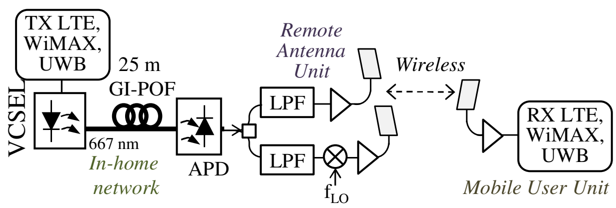

Fig. 5. Experimental setup for audio and video provision using integrated optical POF and wireless distribution.

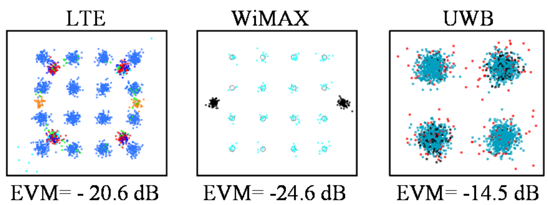

Fig. 6. Received constellations and EVM for LTE, WiMAX and UWB after 25 m POF and 2 m radio link transmission.

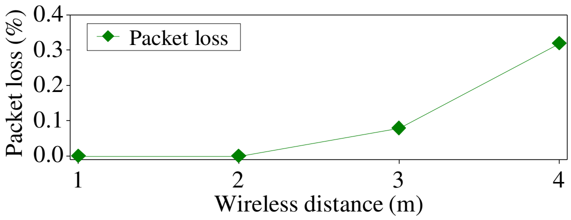

Fig. 7. Measured packet loss in UWB video transmission after integrated optical POF and wireless transmission.

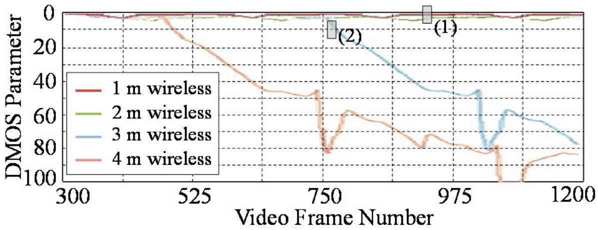

Fig. 8. DMOS video quality after POF and wireless transmission.

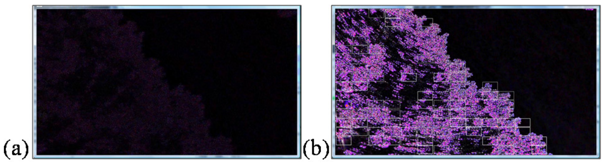

Fig. 9. Video quality analysis: (a) difference between RX and TX video for 1 m wireless –frame 927, point (1) in Fig. 8–, (b) difference for 3 m wireless –frame 758, point (2) in Fig. 8–.

Fig. 7 shows the packet loss measured after POF optical-wireless transmission of a HD video using H.264 codification and 50 fps encapsulated into UWB running at 200 Mb/s. It can be observed that for 1 and 2 m radio links there is no packet loss in the video transmission. For 3 m wireless, 0.08% packet loss is measured (20 lost from 24249 packets transmitted). For 4 m wireless, 78 packets were lost or discarded at the receiver, which leads to 0.32% packet loss.

The quality of the video is assessed using AccepTV video quality analyzer (VQA) [17]. This analyzer is based on the prediction of the mean opinion score (MOS) obtained by the observer in a subjective method. The most representative quality value is the differential mean opinion score (DMOS) curve of a video, which is mainly the subtraction of the reference and measured videos [17]. DMOS values ranges from to 0 to 100. Values close to 0 mean that the measured video is the same as the reference one (the difference between them is almost 0). On the opposite, values near 100 indicate very bad video quality as most of the frames evaluated contain differences when comparing with the reference. Fig. 8 shows the DMOS evaluation of the received video after POF transmission for different wireless links. Wireless links of 1 m and 2 m have excellent DMOS at all the video frames (values around 0). Fig. 9(a) shows an example of the difference between the received and transmitted video after 1 m wireless link. As the video is received with very good quality, the difference between the measured and the reference videos is 0 –"black screen" shown in Fig. 9(a)–. When the wireless distance increases, the DMOS gets worse. For example, at 3 m wireless, a significant drop of the quality of the received video is observed from the frame 758 –point (2) in Fig. 8–. In this case, an example of the degradation on a frame of the received video is shown in Fig. 9(b). Compared to the reference video, the received video introduced several distorted blocks in the image. This is translated in pixels if we observe the received video on the screen.

3.2. Integrated optical access and in-home distribution

Fig. 10 shows the experimental setup for the integration of the optical access (25 km SSMF), the in-home optical distribution (25 m GI-POF or 100 m ClearCurve BI-SMF) and the wireless link. As shown in Fig. 11, using POF the wireless distance is limited to a few meters before packet loss. Using BI-SMF down-conversion of the wireless signals is not needed. Fig. 12 shows the received constellations of an LTE signal at 2.1 GHz, a WiMAX signal at 3.5 GHz and a UWB signal in TFC6 transmitted using a Mach-Zehnder modulator at quadrature bias point through 25 km access network and 100 m in-home BI-SMF. The EVM values confirm the correct demodulation of the signals.

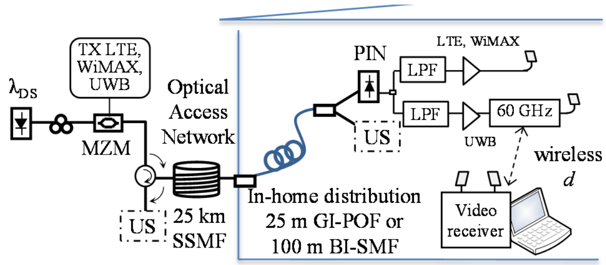

Fig. 10. Experimental setup for integrated optical access, in-home and wireless distribution of audio and video.

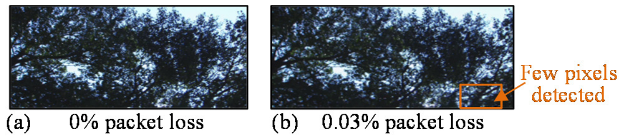

Fig. 11. Video after (a) 25 km SSMF + 25 m POF, (b) 1 m radio.

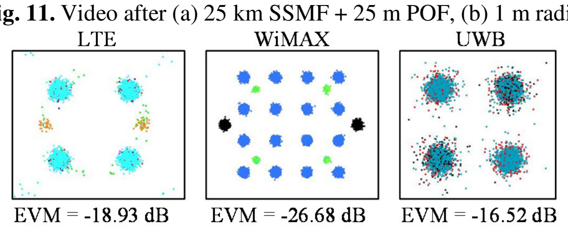

Fig. 12. Received constellations and EVM for LTE, WiMAX and UWB after 25 km SSMF and 100 m BI-SMF transmission.

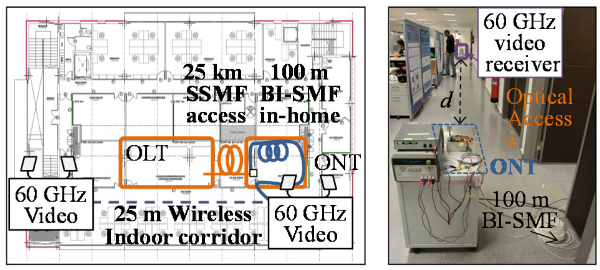

Fig. 13. Experimental demonstration of video transmission in integrated optical-wireless network in the 60 GHz band.

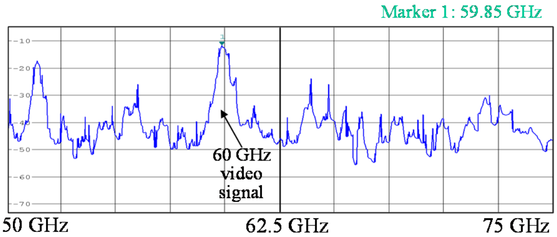

Fig. 14. 60 GHz video electrical spectrum (RBW=3 MHz).

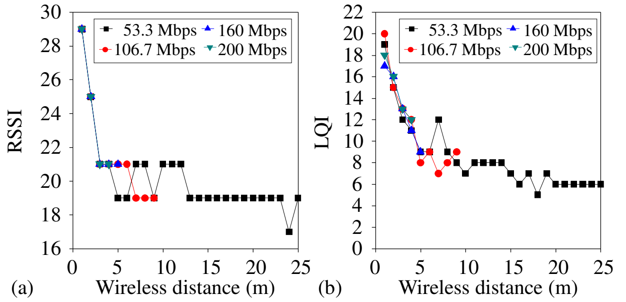

Fig. 15. Measured (a) RSSI and (b) LQI values after 25 km optical access, 100 m BI-SMF and wireless transmission at 60 GHz.

3.3. Audio and Video Transmission at 60 GHz

Following the extension to 60 GHz band depicted in Fig. 10, the UWB signal carrying the HD video broadcasting is up-converted and transmitted in a 25 m indoor corridor as depicted in Fig. 13. Fig. 14 shows the up-converted spectrum of the video signal centered at 59.85 GHz. The received video performance at 60 GHz was measured for different bitrates as Fig. 15 in terms of link quality indicator (LQI) and received signal strength indicator (RSSI). It can be observed that the quality is closely related with the received signal power. For higher wireless distances, RSSI is attenuated and some packets are lost at the receiver, which impacts on the measured LQI. The video observed and the audio heard at the receiver located at the end of the corridor in Fig. 13 had no noticeable errors after up to 10 m wireless link at 60 GHz.

4. CONCLUSION

This paper reports an overview of wireless technologies suitable for audio and video provision using OFDM modulation. The suitability of using optical-wireless networks for HD video broadcasting has been evaluated in the laboratory achieving 25 m in-home POF transmission and 2 m radius wireless distribution with excellent DMOS value and 0% packet loss. Audio and video content was received without errors on a TV screen. The coverage can be extended integrating the optical access network and using the 60 GHz wireless band. LQI values better than 10 are achieved for the transmission after 25 km SSMF, 100 m in-home BI-SMF and 10 m wireless. The received constellations of LTE, WiMAX and UWB confirm the correct wireless communication using deep-access integrated optical-wireless networks.

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