Optical Fiber Technology 38 (2017) 123–129

Contents lists available at ScienceDirect

Optical Fiber Technology

journal homepage: www.elsevier.com/locate/yofte

Regular Articles

An analog mobile fronthaul based on low and high frequency hybrid network for next generation mobile system

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ARTICLE INFO

Keywords:
Hybrid network
Mobile fronthaul (MFH)
Millimeter-wave (MMW)
Radio over fiber (RoF)

ABSTRACT

We have proposed an analog mobile fronthaul (MFH) architecture for next generation mobile networks, which can simultaneously transmit 2.4 GHz, 28 GHz and 60 GHz RF signals with data rates at 100 Mbps, 1 Gbps and 10 Gbps, respectively. Low-frequency (LF) and high-frequency (HF) hybrid networking is achieved for supporting the conventional seamless telecommunication networks and emerging small cellular networks. The millimeter wave (MMW) signal at 60 GHz can be extracted by filtering and then transmitted to multiple further remote radio units (RRUs) to implement the future plug and play flexible networking in the hotspot areas. After analyzing the principle of our proposed MFH link theoretically in detail, the simulation is conducted to demonstrate the proposed MFH link. The simulation results show that the three RF signals can maintain good performance after transmitting over a 20 km standard single mode fiber (SSMF).

1. Introduction

A cost-effective radio access network (RAN) plays a key role in today's 4G mobile network, and will do more in the future 5G one. Cloud Radio Access Network(C-RAN) has been evolving as a promising architecture for 4G mobile network which partitions the base station functions into processing and control functions in baseband units (BBUs), and fundamental radio components in remote radio units (RRUs). C-RAN has emerged as a promising solution to the unprecedented traffic growth due to its potential to reduce capital and operational costs and to ease the cell association, load balancing, and interference management [1]. The Mobile Fronthaul (MFH), a new network segment that appears in C-RAN, is the link between the BBU and the RRU. The digital MFH, applied in the 4 G mobile network at present is usually based on on–off-keying (OOK) modulation and is mostly supported by the Common Public Radio Interface (CPRI) [2]. Nevertheless, CPRI may not meet the challenge of supporting the rapid increase of throughput because of digitization of samples from the radio domain. The other option, based on analog Radio over Fiber (RoF) technology, becomes attractive. Analog RoF keeps the expensive Digital-to-Analog Converters (DAC) and Analog-to-Digital Converters (ADC) inside the BBUs and simplifies the RRUs where only Optical-to-Electrical Converters (O/E) and radio components are required [3,4]. Compared to the digital MFH, the analog MFH based on RoF has a lot of advantages. The bandwidth requirement is lowered greatly, especially for the transmission of high speed millimeter-wave (MMW) signals, and the strict requirements of signal synchronization and jitter problem in CPRI method can be loosened [13,14].

Actually, the Radio Frequency (RF) signals that most MFH links actually carry are mainly concentrated in the frequencies lower than 6 GHz or only in the MMW bands [7–10]. In [1], an optical MFH link is proposed, in which the optical carrier is modulated by different intermediate frequencies (75 MHz, 175 MHz, 275 MHz and 375 MHz) with subcarrier multiplexing. Also an architecture based analog MFH, transporting LTE-A like signals with RF carrier at 3.5 GHz, is proposed in [6]. Certainly, the MMW is generated optically in MFH systems, such as an implementation employing 92.5 GHz for downlink transmission and 96 GHz for uplink direction [7], and the 60 GHz MMW link used for analog MFH in [1,5,8]. Recently, all-spectrum access is proposed to meet the broadband access bandwidth for the future 5G wireless communication. It involves low-frequency (LF) bands below 6 GHz and high-frequency (HF) bands above 6 GHz, where the former is the core bands of 5G that are used for seamless coverage, and the latter is the supplementary bands that are used to achieve high data rates in hotspot areas. Nowadays, it has been widely recognized that the high-frequency range from 6 GHz to 100 GHz can provide abundant available spectrum to achieve the ultra-high capacity and ultrahigh data rates required by 5G [15]. The main candidate bands for 5G focused by the industry include 15 GHz, 18 GHz, 28 GHz, 38 GHz, 45 GHz, 60 GHz and 72 GHz. A lot of research groups from industry and academia are making efforts

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http://dx.doi.org/10.1016/j.yofte.2017.09.007
Received 24 April 2017; Received in revised form 2 September 2017; Accepted 7 September 2017

to mine their respective advantages for applying in next generation wireless communication [11,12]. Therefore, an MFH system based on analog RoF, combining fiber and multiband transmission, can be very attractive owing to its large available bandwidths and support for all-spectrum access [9].

In this paper, we propose a novel analog MFH architecture, which can simultaneously transmit 2.4 GHz, 28 GHz and 60 GHz RF signals with data rates at 100 Mbps, 1Gbps and 10Gbps, respectively, for providing different services for users according to the data rate requirements. Also the MMW signal at 60 GHz can be sequentially transmitted over a standard single mode fiber (SSMF) serving multiple further RRUs. Cascaded RRU structure in MMW band helps MMW signals with high data rate travel longer distance, and LF and HF hybrid networking meets the requirements of seamless coverage in wide area and high data rate in hotspot areas in the next generation mobile communication.

The paper is organized as follows: in the Section 2, the proposed MHH architecture is described. In the Section 3, the operation principle is analyzed theoretically. In the Section 4, the concept-proof simulation link is built and the simulation results, including constellation diagrams and EVM curves, are given and discussed. Finally, conclusions are drawn in Section 5.

2. Proposed MFH architecture

In this section, the proposed analog MFH architecture for next generation mobile communication system is described, as shown in Fig. 1. The analog RoF enables multiband and multiservice coexistence in a shared infrastructure without extra interference. In our scheme, the RF signals at different carrier frequencies (2.4 GHz, 28 GHz and 60 GHz) with data rates at 100Mbps, 1Gbps and 10Gbps, respectively are distributed along the RoF link. Therefore, different services for users can be provided by using different frequencies or time intervals according to the client rate requirements. In the analog MFH architecture, 2.4 GHz band is utilized for wide-area seamless coverage to meet daily network requirements, 28 GHz band is supplied to meet temporary high data rate requirements such as HD movies downloading, and 60 GHz band is employed as supplementary for seamless coverage to meet ultrahigh data rate requirements in hotspot areas. Generally, we can deliver fundamental information to users by modulating lightwave with RF signals at 2.4 GHz with data rate at 100Mbps in the BBU pool; and when higher data rate access is required, the lightwave will be modulated by the RF signals at 2.4 GHz and 28 GHz for enhancing user experience. At hotspot areas, the lightwave will be modulated by the RF signals at 2.4 GHz, 28 GHz and 60 GHz simultaneously for the ultrahigh data rate requirements to ensure the quality and bandwidth of communication. Then we transmit the modulated optical signal to the RRU over an SSMF. In the RRU, the optical signal is directly detected by a photo detector (PD) to recover back to the required radio frequency signals. Then these RF signals can be delivered to users by wireless propagation in the air via antennas. To enhance the performance of the wireless propagation, many enable technologies will be adopted in the future 5 G, such as beamforming, massive MIMO and ultra-dense deployment (UDN). In the MFH architecture, beamforming will be expected to use for increasing the distance of MMW signals transmission and UDN will help the RF signal at 60 GHz to feed more users in hotspot areas. In addition, in our scheme, the 60 GHz optical MMW signal can be sequentially transmitted over an SSMF to the further RRU possibly working as a supplementary to realize the future plug and play flexible networking in the hotspot areas.

3. Operational principle

To analyze the implement of the proposed MFH architecture, the basic link is setup for describing its operational principle, as shown in Fig. 2. In the BBU, using one Mach-Zehnder modulator (MZM), the lightwave from laser diode (LD) is modulated by RF signals at different carrier frequencies based on single sideband (SSB) modulation pattern. To provide different services for users according to the data rate requirements, one selective switch is used in the link for choosing different RF signals as the RF drive signals of MZM. For the first case, only RF signal at ω_1 is carried, for the second case, the RF signals at ω_1 and ω_2 are combined together, and for the third case, the transmitted signal includes three tones at ω_1, ω_2 and ω_3. Here, we discuss the general case, where the RF signals are

$$V_{RF}(t) = K_1V_1(t)\cos[\omega_1 t + \theta_1(t)] + K_2V_2(t)\cos[\omega_2 t + \theta_2(t)] + K_3V_3(t)\cos[\omega_3 t + \theta_3(t)]. \quad (1)$$

In which, K_1, K_2 and K_3 can be realized by electrical switches with the values of 0 or 1 for selecting the signals for transmission and $V_1(t)$, $V_2(t)$ and $V_3(t)$, $\theta_1(t)$, $\theta_2(t)$ and $\theta_3(t)$ and ω_1, ω_2, and ω_3 represent the magnitudes, phases and frequencies of different RF signals, respectively. So the lightwave field at the output of MZM can be represented as

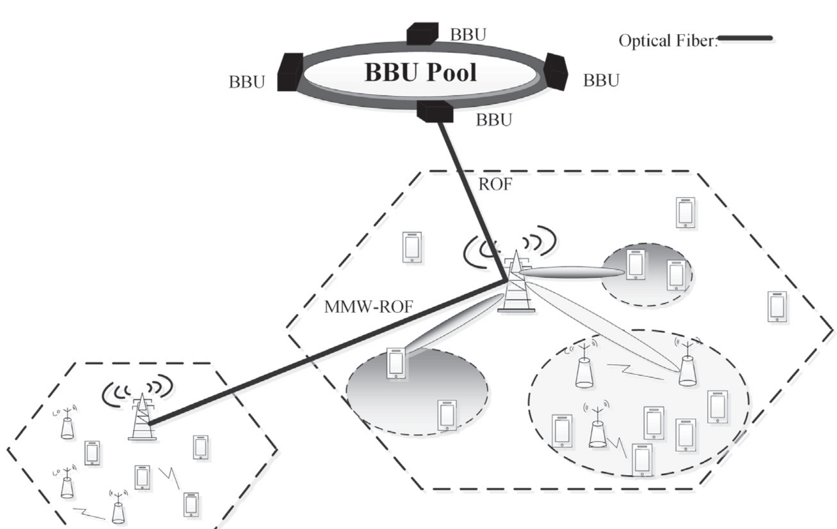

Fig. 1. The diagram of our proposed MFH architecture. BBU: baseband unit; RoF: radio over fiber; MMW: millimeter wave.