GRD Journals | GRD Journal for Engineering | National Conference on Emerging Research Trend in Electrical and Electronics Engineering (ERTE'19) | May 2019
e-ISSN: 2455-5703

Recent Proposals on Photonic Generation of Millimeter wave in MMW-RoF Communication Networks: A survey

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Abstract

The emerging wireless communication networks provides many opportunities for photonics technologies to play in the realization of the next generation integrated optical/wireless networks. Millimeter wave Radio over fiber (MMw-ROF) systems has the advantages of a fiber optic link and a free space radio path. The optical network technology, which is considered as the backbone of virtually all communication networks, has evolved concurrently to the wireless networks to achieve the demands of the future generation. The emerging technology such as Radio-Over-Fiber (ROF) is one of the latest advancements in the area of optical networks and has a tremendous potential. The introduction of ROF into mobile front hauling networks divides the front haul to wireless and wired networks. ROF technology is capable of directly converting an optical signal to extremely frequency signal range by utilizing a photonic direct up-conversion scheme. Millimeter wave technology integrated with a ROF system is one of the promising technologies that could deliver high-speed radio transmission with seamless convergence between optical and radio signals. The photonic generation of the MMwave signal from ROF link is essentially considered to be a vital process that helps to keep the remote cells simple, cost-effective as well as energy efficient. This technology also guarantees a low-latency transmission for the wireless MM wave signals, thus could provide a satisfactory solution with excellent flexibility for a mobile broadband access network. Therefore, the integration of fiber and MM wave links could have a huge potential in optical network technology owing to its.

Keyword- Radio-over-Fiber, MMW-RoF, Optical, Millimeter-Wave, Fiber Bragg Grating, Frequency Quadrupling, Mach Zehnder Modulator

I. INTRODUCTION

The continual growing demand of the next generation systems to have a high data transmission rate with a latency of less than 1ms has led to the development of many advanced wireless technologies. The technologies such as Co-ordinated Multi-point Transmission, Massive MIMO, Distributed Antenna Systems, Millimeter Wave (MM wave) are few of the advanced technologies proposed to fulfil the requirements of the future generation. The overcrowded microwave band and lack of global bandwidth for global communication systems have encouraged the improvement and implementation of the Millimetre spectrum for 5G communication networks. The application of mm wave frequencies simplifies the overall design of the practical wireless mm-wave could also offer suitable terminal mobility and high capacity channels.

The optical network technology, which is considered as the backbone of virtually all communication networks, has evolved concurrently to the wireless networks to achieve the demands of the future generation. The emerging technology such as Radio-over-Fiber (RoF) is one of the latest advancements in the area of optical networks and has a tremendous potential. The introduction of ROF into mobile front hauling networks has led to its division into two primary domains that is wireless and wired networks. ROF technology is capable of directly converting an optical signal to a high frequency radio signal by utilizing a photonic direct up-conversion scheme. Millimeter wave technology integrated with a ROF system is one of the promising technologies that could deliver high-speed radio transmission with seamless convergence between optical and radio signals. The photonic generation of the MMwave signal from ROF link is essentially considered to be a vital process that helps to keep the remote cells simple, cost-effective as well as energy efficient. This technology also guarantees a low-latency transmission for the wireless MM wave signals, thus could provide a satisfactory solution with excellent flexibility for a mobile broadband access network. Therefore, the integration of fiber and MM wave links could have a huge potential in optical network technology owing to its features such as high bandwidth, high capacity and robust design.

For typical ROF systems electrical-to-optical (E/O) conversion, optical-to-electrical (O/E) conversion and high spectral-efficient transmission are important elemental technologies. The basic block diagram of RoF is as shown in Figure1.The baseband modulated signal is converted to optical signal and transmitted using an optical modulator via optical fiber link. At the receiver end, optical detectors detects the signal and converts it to electrical signal. The signal is then fed to the demodulator and further to the system terminal.

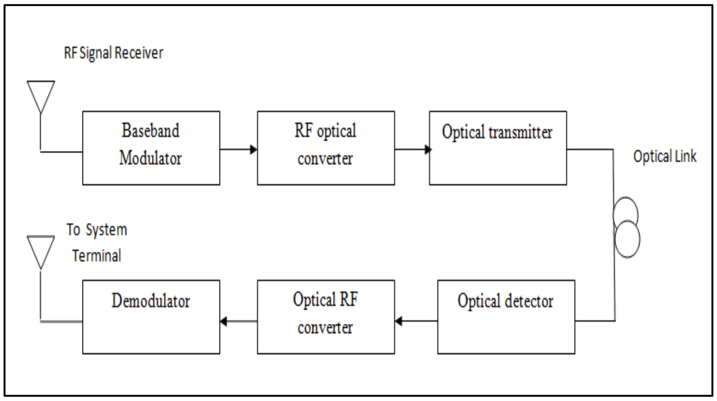

Fig. 1: The basic block diagram of RoF

The system mainly consists of transmitter, optical fiber and receiver [1]. The radio frequency modulated signal is converted to optical signal and transmitted via optical fiber link. An optical receivers detects the signal and converts it to electrical signal and is demodulated to pass to the system terminal. Figure 2 shows the RoF system topology [1].

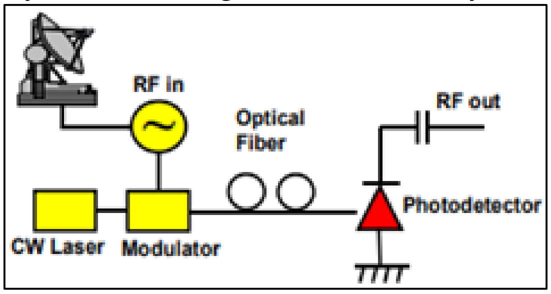

Fig. 2: RoF system topology depicted by Zin[1]

A. Radio-over-Fiber

The Radio -Over-Fiber technology (ROF) involves modulating the radio frequency (RF) subcarrier on to an optical carrier for the distribution of over a fibre network. The ROF technology proposes a cost-effective base station for the distribution of the signals. Optical fibers are an attractive option for ROF systems due to its peculiar characteristics such as high bandwidth, minimal losses, high resistance to noise and electromagnetic interferences (EMI), light-weight in design, smaller cross-sectional area, low cost and high flexibility [2]. The Radio frequency signal utilized in ROF technology is used to modulate the light and transmit it over to an optical fiber link. The primary functions utilized in ROF technology such as signal routing, processing and resource management are carried out at a central station (CS) rather than a base station (BS). Other functions such as conversion of wireless signals from optical to electrical domains are implemented in the base stations and are carried out at a higher frequency. These wireless signals are then amplified and transmitted by an antenna to the optical network. Therefore, there is no requirement to convert the high-frequency signal to a lower frequency signal at the base station which results in a simple and cost-effective method of implementing the distribution process of signals using ROF technology.

B. Selecting Millimeter Wave Spectrum

The Millimetre wave (mm-wave) consists of a spectrum of extremely high frequencies (EHF) ranging from frequency bands of 30GHz to 300 GHz [4]. A broad range of spectrum can be allotted to the MM wave band. Additionally, MM waves are able to provide high data rates up to 10 Gbps and its spectrum allocation can be co-ordinated worldwide. The MM waves are capable of generating high bit rates and have a comparatively lower complexity of implementation, lesser power consumption and lower network cost as compared to microwave ultra-wideband (UWB) technology [5]. The range of coverage does not dynamically change for MM wave signals. International harmonisation for MM waves is possible and it establishes the necessary condition for a wider application of MM wave signals. The current research is more focussed on the 28 GHz band, the 38 GHz band, the 60 GHz band and the E-band (71-76and 81-86 GHz band). Photonic generation of millimeter refers to the generation or convertion of an extremely high frequency radio signal to an optical signal.

C. Millimeter Wave RoF

The benefits of the optical fibers and the extremely high frequencies (EHF) are combined to form the Millimeter Wave frequency ROF transmission systems. The Millimeter Wave frequency ROF transmission systems are designed to build an efficient transmission system that supports high data rates.

MM wave bands have been proposed for a high capacity wireless systems employing ROF technology. According to Beans [3], the frequency around 60 GHz attracts global telecommunication's interest. This global attraction is primarily due the reason that the frequency coincides with the oxygen peak levels, i.e. the frequencies have high atmospheric attenuation exceeding 15DB/Km. High attenuation allows the reduction in the cell size and frequency reuse distance in cellular systems. Therefore, this factor increases the wireless capacity. Also, the frequency range opens the opportunity for the world-wide standardization and commercial production. In North America there is 7 GHz of unlicensed spectrum which overlaps with the unlicensed spectra of around 60 GHz in Europe, Japan and Australia. The overall performance of an ROF system must consider the performance of CS, BS and ODN.

The primary concern in the architectural design of telecommunication network is the implementation of an efficient and cost-effective network. The ROF systems essentially require to be designed with a reduced cost and lesser operational complexities of the individual subject item which is CS, BS and ODN.

II. RECENT PROPOSALS

A. Fiber Bragg Grating (FBG)

An FBG can be used to reuse the optical carrier for the uplink signal. FBG is a series of optical filters. When white light passes through FBG, it can return certain wavelengths, while allowing others to pass through. This is achieved by periodically altering the refractive index of fibers dictating which wavelengths pass and which get reflected.

Millimeter-wave photonic generation with a feasible radio over fiber system is possible using FBG [6]. The architecture becomes simpler while implementing the design using FBG. During downlink transmission the carrier frequency component is extracted at the base station using FBG. At the base station, the extracted frequency component is used for the modulation of the incoming data as the carrier during uplink.

The block diagram of a full duplex RoF link based on wavelength reuse by FBG is shown in Figure 3. By utilizing FBG for wavelength reuse, the full duplex RoF link is achieved. Thus complexity is reduced. The need for a light source is nullified with the use of FBG.

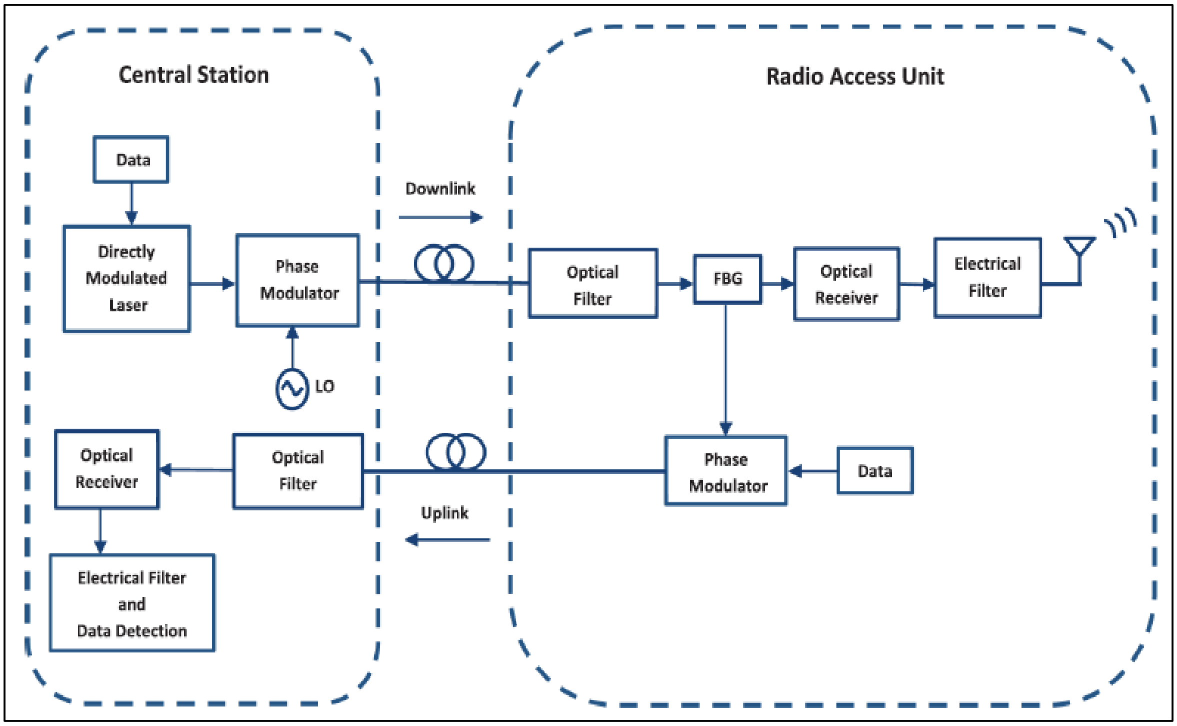

Fig. 3: A block diagram of a full-duplex RoF using FBG [6]

B. Cascaded Dual Drive Mach Zehnder Modulator (DD-MZMs)

Yang [8] proposed cascaded DD-MZMs scheme and is shown in Figure 4. Using an optical splitter into two branches. Firstt DD-MZM is used to implement frequency quadrupling. The second DD-MZM is inserted for frequency octupling. The second DD-MZM is followed by a WDM Demux to split the ±4 order optical carriers so as to enable optical single side band (OSSB) modulation. The outputs of the first DD-MZM and second DD-MZM are combined to obtain the ±4 order optical carriers from second DD-MZM and +2 order optical carrier from first DD-MZM. The cascaded DD-MZMs are all biased at the maximum transmission bias point.

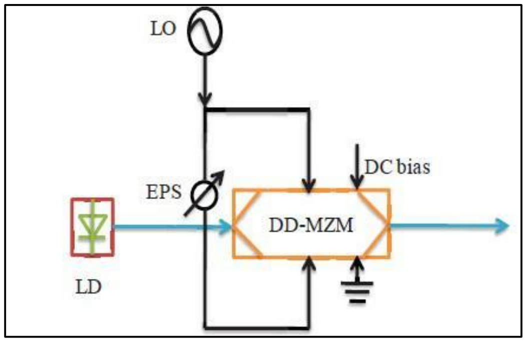

Fig. 4: Principle diagram of dual-drive Mach-Zehnder modulator (LD:laser diode; LO: local oscillator; EPS: electrical phase shifter;DC: direct current) proposed by Yang[8]

Furthermore, the proposed system can simultaneously generate two V-band MMWs (a 45GHz and a 60GHz MMWs) with a low-frequency LO (7.5GHz) simply and cost-effectively.

C. Optical Frequency Quadrupling Technique

Frequency quadrupling technique is to generate the optical mm-wave carrier with 4 times of local oscillator (LO) frequency. FBG can be used as the optical filter of the system. According to Nguyen [7] , to obtain optical mm-wave carrier with 4 times of LO frequency, the intensity modulator(IM) must be DC-biased at the top peak output power when the LO signal is suppressed. Suppose 'f' is the frequency of the radio-frequency (RF). Suppose the optical carrier is removed and the frequency spacing between the second-order sidebands is 4f. Figure 5 shows the proposed design for implementing the frequency quadrupling technique.

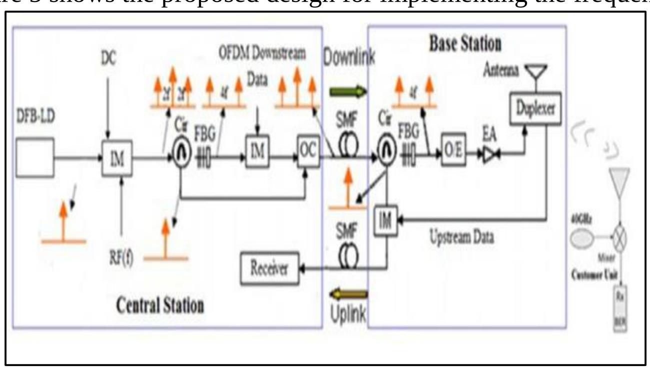

Fig. 5: Configuration of mmwave OFDM-RoF system proposed by Nguyen[7]

To suppress the optical carrier from the second-order sidebands, a circulator (Cir) and a FBG are used. Through the second intensity modulator (IM) the second-order sidebands with the OFDM analog data is carried. The optical coupler (OC) combines with the signal lightwave. The optical signals is transmitted via single mode fiber to the base station (BS) after boosting the power using Erbium-doped Fiber Amplifiers (EDFA). At BS, the second FBG is also utilized for separating the optical mm-wave signals from the optical carrier. The optical millimeter wave signals is broadcasted after optical-electrical (O/E) conversion to the system terminal of the customer. After down-converting the received signal from the antenna, the OFDM baseband signal is obtained. For uplink data transmission, the down-converted upstream data are modulated by the third IM before they are transmitted to the central office (CO).

D. Lithium Niobate Optical Modulator

Lithium niobate is an optical modulator. The modulation in Lithium niobate modulator is produced by changing the refractive index by voltage induction. The achieved modulation is very small. Large voltages or long electrode lengths are needed to achieve sufficient modulation. A figure of merit for the modulation is the product of the switching voltage and the electrode length.

In effect Lithium Niobate is a modulator with an in-built Mach Zehnder modulator. Figure 6 shows the 10 Gbps-60 GHz RoF transmission system proposed using Mach Zehnder modulator and Lithium Niobate modulator [9]. Using NRZ/RZ pulse generator, the 10 Gbps data is encoded. It is then optically modulated using MZ optical modulator. The optical carrier at 1550nm is generated using a conitinous wave laser. The encoded data is modulated again using LiNb optical modulator with 60GHz radio signal and 3 a.u direct current bias signal. Through optical fiber channel which comprises optical single mode fiber and optical amplifiers the data is transmitted over 50Km. A Guassian fiter with 60 GHz cut off bandwidth filters the received signal at the receiver end. Photodetector is used to recover the 10Gbps 60GHz millimeter from Gaussian filter output.

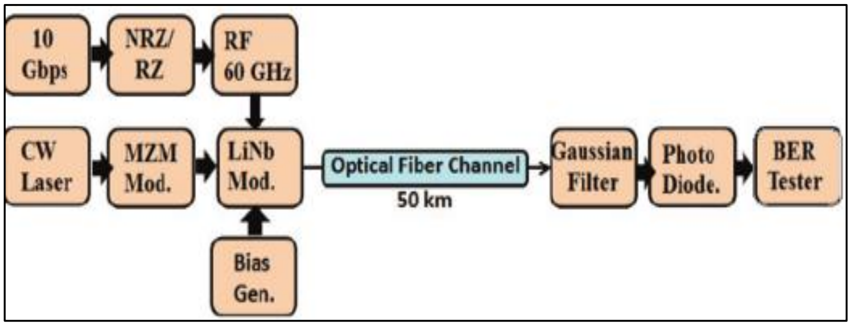

Fig. 6: RoF transmission system proposed by Chaudhary [9]

III. Conclusion

There are many challenges for the implementation of mm-wave RoF transmission system. The design of the transmission system must be less complex, feasible and cost-effective system design. The use of MMW-RoF for the next generation communication network will be surely capable of support its seamless connectivity. The design selection for the millimeter wave generation for the transmission systems design depends on the complexity, application and the cost effectiveness. It would be recommended that RoF technologies should be studied and designed after taking into account, the RoF standardization activities at international standard organizations.

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