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Radio over Fiber Communication System: Lateral Shift in Cellular Communication

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ABSTRACT: Cellular technology has progressed with a fast pace. Rolling out of cellular networks upto 4G has already been completed across the world. Research works are going on for finalizing the 5G and 6G technologies. In order to provide secure and high-speed data, Radio over Fiber (RoF) technology has been identified as one of the best means to ensure cost effective and reliable communication facilities. The major challenges is to identify correct modulation techniques, data conversion and link design with suitable components to yield optimum and cost effective solution. In this research paper, we have presented a detailed review of RoF technology, its architectures, latest updates in the field, application in various generations of cellular communication and various modulation techniques. The research gaps exist in the RoF technology have also been highlighted. This will motivate the researchers working in this field of RoF technology to undertake research to bridge the existing gaps. So that, an updated and novel RoF system could be developed and rolled out by the service providers and hard ware manufacturers for the application in cellular technology.

Keywords: Cellular Communication, MZM, Remote Antenna Unit, RoF

Abbreviations: ROF, radio over fiber; RF, radio frequency; CS, control station; RAU, radio antenna unit; BS, base station; MI, modulation index; WDM, wavelength-division multiplexing; MZM, machzehnder modulator; OPM, optical phase modulator; SPM, self-phase modulation; EDFA, erbium-doped fiber amplifier; FBG, fiber bragg grating; RZ, return-to-zero; NRZ, non-return-to-zero; FWM, four wave mixing; XPM, cross phase modulation; DM, direct modulation; EM, external modulation; EAM, electro-absorption modulator; EOM, external optical modulator; CBS, central base station; RBS, remote base station; OFDM, orthogonal frequency division multiplexing; ES, earth station; ITS, intelligent transport system; IoT, internet of things.

I. INTRODUCTION

In RoF technology, modulated RF signal is distributed through optical fiber links from Control Station (CS) to Remote Antenna Unit (RAU). The RF signals are transmitted uplink and downlink. Also, the modulated RF signal is sent from CS to Base Station (BS), and vice-versa. The RF signal processing (modulation, frequency up conversion and multiplexing) in narrow band communication is performed at BS and the applied to RAU. RoF centralizes the RF processing function at head end and further uses optical fiber which minimizes the signal loss between 0.2dB/km for 1550nm and 0.3dB/km for 1310 nm wavelength from BS to RAU. By centralizing the RF signal processing functions, the actions such as equipment sharing, dynamic resource allocation and system operation and maintenance are enabled. It results in low installation and operational cost of the system. The centralization of RF signal processing is very accommodating in broadband wireless communication systems [1-3]. Fig. 1 depicts the basic concept of RoF.

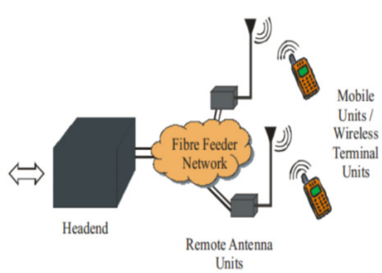

Fig. 1. Basic RoF Concept.

Nain *et al.*, (2017) have analysed Raman induced crosstalk as a function of transmission length, optical power and modulation frequency with varying Modulation Index (MI). The Crosstalk is found to be increasing with increase in MI, optical power levels and link range and declines with modulation frequency respectively. It has been concluded that the WDM RoF system performance can be optimized with appropriate selection of modulation depth [4].

Nain and Kumar (2017) have presented a simulation comparison of RoF system with external modulators MZM and OPM under the effect of Self Phase Modulation (SPM) as a function of channel power and dispersion. With increased dispersion level, MZM provides more output power while OPM on the other hand provide good SPM suppression levels with rise in input power [5]. Ahlawat *et al*., (2018) have evaluated the performance of an 8-Channel WDM system with EDFA-FBG combination. The Gaussian, Uniform and Tanh apodization functions of FBG have been analyzed with RZ and NRZ modulation formats with varying lengths of optical fiber and FBG. Among all, the Gaussian apodized FBG using RZ modulation performs superiorly with maximum reflectivity and reduced levels of side lobes [6].

Nain *et al*., (2017) have examined the performance of a WDM RoF system under the impact of Four Wave Mixing (FWM) crosstalk. For simulative comparison, the signal has been propagated through five different fibers. The Corning LEAF fiber outperforms the other four fibers in suppressing FWM crosstalk by 15-20dB [7]. Nain *et al*., (2016) have studies WDM systems for crosstalk effects due to XPM with dispersion and its higher order terms. With the rise in modulation frequency, transmission distance, walk-off parameter and dispersion, a rise in XPM-induced crosstalk has been observed. The authors concluded that performance of system can be improved by cautiously choosing the right values of dispersion pump and probe wavelength and walk-off parameters [8].

The system so far have been studied with lower data rates of upto 1Gbps, whereas now the demand is rising to 10 Gbps and beyond with the evolution of cellular technologies. In the present work, the ongoing research in RoF is described in detail. The remaining work is organized as follows. The architectures of RoF are discussed in Section II followed by the modulation techniques used in RoF in Section III. The application areas of RoF and its limitations are discussed in Section IV and Section V respectively. Section VI gives the conclusion of the paper.

II. ARCHITECTUREOF RoF SYSTEM

Frequency of the radio signal to be transmitted decides the architecture of the RoF transmission system. It has two types of architectures, which are listed below:

A. Radio Frequency-over-Fiber (RF-o-F)

In RF-O-F, the signal which carries data has frequency above 10 GHz. In downlink transmission, the laser diode at the CS is used to modulate the electrical RF signal. Then this optical signal is transmitted from BS to CS via optical fiber. These signals are then demodulated at the BS by using a PIN photodetector or any other photodiode and then as a result the electrical RF signal is recovered.Then antennas are used for propagation of RF signals into the medium. For uplink transmission, the signal is sent from RAU to headend in MU, in similar pattern as followed in the downlink. When the operating wavelength of optical carrier is chosen in the range of 1.3 µm, in that condition SMF exhibits minimum dispersion. However, in order to reduce attenuation further, the suitable operating wavelengthfound in 1.55µm window [9]. The RoF basic diagram is depicted in Fig. 2.

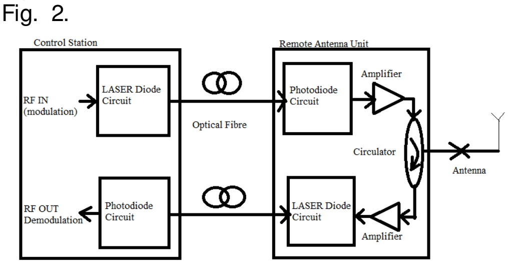

Fig. 2. Basic Block Diagram of Radio-over-Fiber System.

B. Intermediate Frequency over Fiber (IF-o-F)

In this architecture, light is modulated by intermediate frequency radio signal instead of RF and then it is transmitted through optical fiber. The frequency of radio signal used is below 10 GHz. At the BS, this signal is then up converted into the radio frequency.

III. MODULATION TECHNIQUES USEDIN RoF

In RoF, the method to implement the optical modulation is basically conversion of signals from electrical mode to optical mode. This gets executed in two ways, i.e.- Direct Modulation (DM) and External Modulation (EM). When the electrical signal is applied to the optical source and modulation takes place, the process is called DM. When an external modulator is used in the circuit to implement the modulation, the process is called EM.

In DM, current (I_{drive}) is used to drive the laser diode near the operating point to give output in form of light.When we change the value of I_{drive} because of the input RF signal the optical output power changes due to the phenomenon called DM [10]. The output power is calculated by:

$$P(t) = h(I_{drive} - I_{th})) = k(I_{bias} + I_{RF}(t) - I_{th}) \quad (1)$$

In above equation I_{th} represents the value of threshold current of laser, I_{bias} denotes the value of bias current, $I_{RF}(t)$ is used for modulating RF signal and his the proportionality constant that depends on the laser source employed.

In EM, intensity and angle of optical carrier are modulated by using external modulators.Mach-Zehnder Modulator (MZM) or an Electro-Absorption Modulator (EAM) are two type of commonly used external modulators.

MZM is broadly used as External Optical Modulator (EOM). It is also called as Mach-Zehnder Interferometer (MZI). MZM has two arms and two optical couplers of 3 dB. Fig. 3 depicts the diagram of a basic MZM.

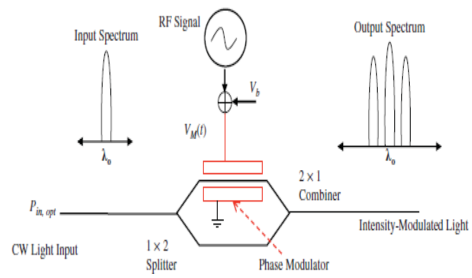

Fig. 3. Basic Mach-Zehnder Modulator.

There are two types of MZMs, i.e. single drive and dual drive. Advantages of MZM are low insertion loss and its capability to handle higher input power. Lithium niobite MZM are broadly used for this reason, but it has few limitations too. Transfer function of lithium niobate does not produce enough linearity. Engineers also find it extremely difficult to use lithium niobate and it is very difficult to mix with other semiconductors. Alternatives available, to avoid MZM and lithium niobate material is by using EAM.EAMs are becoming more popular with time. CW source in EAM needs wavelength control, unlike MZM. EAM modulates optical signal by using thesignal electric voltage. This voltage regulates absorption in EAM. The EAM however, tend to handle low optical power as compared to MZM [11].

IV. APPLICATIONS IN VARIOUS COMMUNICATION SYSTEMS

A. Cellular Networks.

Cellular networks widely use RoF technology as it can reach anywhere and everywhere efficiently and at low cost. These networks have lower installation cost, operation cost and maintenance cost. It uses mm-frequency for operations. Cell optimization and localization is handled at the Central Base Station (CBS), which results in lesser handovers in a cell. Remote Base Station (RBS) in such systems is very reliable. Optical fiber in RoF can support higher bandwidth, therefore broadband services are more feasible and available to the end users in the field. These systems are safer for human bodies too because the antennas emit low power.

Such systems consume less mobile battery and suffer from lesser crosstalk. These systems have small cells therefore propagation loss is also very low. Multiple wireless standards are supported by RoF [12, 13].

RoF in 3G: With the increase in awareness and evolution of the technologies, the consumers even at remote sites demand for higher data rates. Therefore, optical fiber is used for such communications. Cell size is also decreased for better quality and connectivity.RoF system is found to be extremely efficient in such situations. The amalgamation of high capacity of fibers and flexibility of wireless networks makes it the perfect choice. In RoF, optical fiber is used for transmission which has low propagation loss and high flexibility as compared to traditional co-axial cables. In 3G system, RoF is cheaper as compared to other technologies and base stations are deployed with almost no restrictions. RoF leads a way to develop and upgrade new technologies and makes it more feasible for outdoor usages, it also centralizes the BSs [14, 15]. Fig. 4 depicts the basic diagram for 3G system.

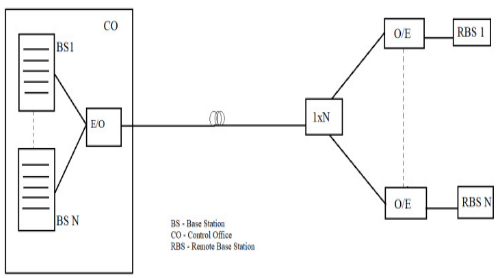

Fig. 4. Block Diagram of RoF in 3G system.

RoF in 4G: In 4G, the operational frequency band is more than 3 GHz.This results in high propagation loss during transmission which further leads to increase in power consumption in the end user mobile devices. Consumers do demand higher data rate and hence the management of large traffic and a flexible communication system becomes feasible by implementing through the RoF technology. The solutions found to the above stated problems of 4G systems are reduced cell size, improvement of flexibility of wireless resources and centralization of BS. The communication system should havemorenumber of RAUs installed in small zones. RoF is the best solution for this situation as it centralizes the BSs and reduces the cell size [16].

RoF in 5G: In the era of smart cities, smart homes, smart cars, IoT, HD multimedia etc., users expect better quality of network connectivity for their smart devices including ultra-high streaming. Characteristics of RoF that are of great use in 5G field are pico-cellular architecture and usage of mm-wave spectrum. Pico-cellular architecture and mm-wave spectrum provide higher data rates and make the 5G system more spectral efficient by consenting greater frequency reuse. Pico-cellular architecture also supports larger traffic. These are the criterions that make 5G technology much more advanced than 3G and 4G [17-19].

B. Wireless LAN.
Hi-tech transportable, compact and mobile gadgets have become a necessity for everyone these days. LAN signals with operational frequency range 2.4-5 GHz can be transmitted through optical links.

C. OFDM – RoF Systems.
High speed data transmission is achieved by amalgamation of OFDM and RoF. Wireless transmissions have a lot of drawbacks such as electrical power loss, scattering losses etc., these can be taken care of by using optical link in OFDM-RoF [20].

D. High Speed Sensing.
On high speed modes of transportation, broadbandtransmission is used for ultra fast video surveillance. It can be done through RoF.By this, electromagnetic pollution is also reduced to nearly minimum.

E. Satellite Communication.
RoF technology has two applications in Satellite Communication. The first application is remoting ofES. Better satellite visibility is achieved by using RoF, as antennas are placed many kilometres away. In other application, we remote the antennas at ES to diverse locations. Centralization of high frequency equipment is done by using small optic fiber links. These links have operational frequency range of 1-15 GHz [21, 22].

F. Vehicle Communication and Control.
RoF technology is also used inITS. For coverage of road networks, we require a large number of base stations. By using RoF systems, the given communication system can be made cost effective and easy to manage.

G. Military Application.
The radar receives the RF signals; these signals are then transmitted through optical fiber using RoF communication upto the remote end. Also it offers the system higher security. Therefore, in the event of radar strikes, there will be fewer casualties.

In the previous studies the issues of integration of IoT with RoF has not been reported. We have made an effort to highlight all the possible applications of RoF system in the present day developing environment.

V. CONCLUSION

High speed data requirements are increasing day by day. Mobility is also a concern for every user. Radio over Fiber(RoF) technology has been identified as one of the best means to do this all. In this research paper, detailed analysis of RoF technology has been presentedfor itsarchitectures both for RF-o-F and IF-o-F, application in various fields including networks and Cellular generations and various modulation techniques including internal and external modulation. Various limitations that exist in the RoF technology have also been highlighted. This will facilitate and motivate the researchers to undertake research to bridge the existing gaps of the RoF system. This will lead to evolution of novel RoF system to be rolled out for better and reliable communication system.

VI. FUTURE SCOPE

RoF technology makes use of analogue signal for transmission and data conversion. Since the SNR and signal quality has been found to be of lower order due to dispersion and scattering losses. This results in poor quality of communication. Also the link reliability is below the optimum standard. Therefore, a novel research should be under taken to overcome the above said problem, so that reliable and fail safe network could be provided.

Conflict of Interest. There is no conflict of interest with respect to this present paper.

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