AN EFFICIENT 5G NETWORK USING RADIO OVER FIBER

Lalit Sahu[1], Prof.(Dr.) Neena Gupta[2]
[1]P.G Scholar, ECE Dept., Punjab Engineering College (Deemed to be University), Chandigarh, India
[2]Professor, ECE Dept., Punjab Engineering College (Deemed to be University), Chandigarh, India
[1]lalitsahu2093@gmail.com, [2]neenagupta@pec.ac.in

Abstract— Radio-over-fibre (RoF) is a cutting-edge technology which merges RF communication system and optical fibre communication system. Orthogonal Frequency Division Multiplexing (OFDM) technology promises to be an essential technique for achieving high data rate when it is incorporated with RoF. Generally, Quadrature Amplitude Modulation (QAM) is generally implemented in optical OFDM communication system. This paper investigates the combination of OFDM with RoF for realising high data rates and the transmission of the signal over long haul optical fibre with QAM as the modulation in OFDM based RoF System. The performance of the system is analyzed in terms of Symbol-Error-Rate (SER) and Constellation diagram.

Keywords— *Radio-over-Fiber, millimeter-waves, Microwave photonics, QAM, OFDM, CW Laser, PIN photo diode*

I. INTRODUCTION

Microwave photonics is being encouraged largely in the recent years. The interest is developed in generation, processing, control and distribution of microwave and millimetre waves. Nowadays, microwave photonics is being used in the applications like radar, passive optical networks, satellite communication, sensor networks and military systems.

A. Radio-Over-Fiber (RoF): The principle application of microwave photonic technology nowadays is to transport and distribute radio signals via optical fiber. This wireless and optical integration would be reliable and cost effective, that will support future demands for higher bit rates and better services [1].

The basic idea of Radio over Fiber (RoF) is to transport data via optical fiber after modulating the radio signal with the light. A single central station (CS) is associated to multiple base stations (BSs) via an optical fiber in this system.

Firstly, microwave signal is transformed into optical signal at the CS, and then transported to the nearby connected BSs via optical fiber, which provides low attenuation characteristics and wide bandwidth. The processing part comprising modulation, demodulation, coding and routing are executed at the CS. BS's core function is to translate optical signal into wireless one and vice-versa.

B. Need of RoF: To utilize the advantages of both wireless and wired expertise, service providers are keenly looking for an integrated network architecture which will provide numerous services to both mobile and fixed customers. In this aspect, RoF technology based wireless network is a lot effective solution to increase the capacity, bandwidth and coverage.

Optical fiber offers reduced amount of signal attenuation i.e. 0.5 dB/km for 1310 nm and 0.3 dB/km for 1550 nm wavelengths. RoF centralizes the RF signal processing functions in one shared location (head end), and then to use optical fiber to distribute the RF signals to the BSs.

The optoelectronic conversion and amplification functions are executed by BS, which simplifies its architecture. The RF signal processing functions are centralized, and this helps in dynamic allocation of resources, maintenance, equipment sharing and simplified system operation [2].

RoF technology has the following central features:
(1) Support multiple wired and wireless standards.
(2) Centralized operation is possible.
(3) Small and simple base stations.
(4) Low power consumption.
(5) Transparent to modulation techniques.

These features can transform into operational savings and system installation majorly in widespread coverage broadband wireless communication systems.

But this system has the many challenges such as fiber dispersion, optical communication component's non-linearity, and fiber optic network implementation cost [3].

C. QAM: Quadrature amplitude modulation (QAM) is a type of modulation scheme, which transports two digital bit streams, or two analog message signals, by varying (modulating) the amplitudes of two carrier waves, using the amplitude modulation (AM) i.e. analog modulation scheme or amplitude-shift keying (ASK) i.e. digital modulation scheme. The two carrier waves, usually sinusoids are of the same frequency but out of phase by 90° with each other and are hence called quadrature carriers or quadrature components — thus the name of the scheme. In the end, the modulated waves are summed, and the ultimate waveform is a combination of both phase-shift keying (PSK) and amplitude-shift keying (ASK), in case of digital modulation, or combination of phase modulation (PM) and amplitude modulation (AM), in case of analog modulation.

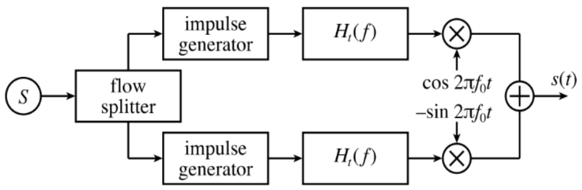

Figure 1: QAM Transmitter

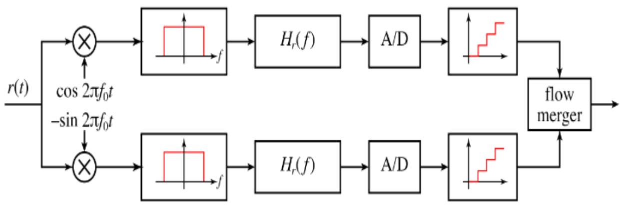

Figure 2: QAM Receiver

D. OFDM: Orthogonal frequency division multiplexing (OFDM) is a type of multiplexing technology, which is used for satisfying the increasing demand of high data rate and large capacity of the system [4].

Fig. 2 shows the OFDM modulation and demodulation process. A bit sequence with rate R, each with a different frequency, is parallelized into N different channels. Whole bit rate is divided into a bit rate of R/N for each single channel. The data in each channel denotes an information symbol, gets multiplied by its corresponding frequency. These parallel information symbols get added, resulting in one OFDM symbol. There is a separation of 1/Ts between every subcarrier. Hence, the orthogonality condition gets satisfied, resulting in remarkable spectral efficiency for the communication is attained. This technique helps in recovering the subcarriers at the receiver end without any significant inter-carrier interference (ICI) regardless of intense signal spectral overlapping, by means of the orthogonality condition as

$$\int_{-T/2}^{T/2} \cos\left(\frac{2\Pi mt}{T}\right) * \cos\left(\frac{2\Pi nt}{T}\right) dt = 0, m \neq n \qquad (1)$$

The transmitted signal of an OFDM system for one OFDM symbol period as a following form

$$s(t) = Re\left\{\sum a_n h(t) \exp(j2\Pi f_n t + \Phi\right\} \qquad (2)$$

where,

a_n: denote the transmitted data symbol for the n^{th} subcarrier;

h(t): denote the pulse shaping filter response;

f_n: denote the n^{th} subcarrier frequency and $f_n = f_c + n\Delta f$.

However, the OFDM modulator and demodulator can be realized easily using the Inverse Fast Fourier transform (IFFT) and Fast Fourier transform (FFT) respectively [5]. The time domain coefficients C_m can be computed by IFFT as

$$C_m = \frac{1}{\sqrt{N}} \sum_{N=0}^{N-1} a_n \exp\left(-\frac{j2\Pi nm}{N}\right) \qquad (3)$$

where:

a_n: denote the input of the IFFT block which is the data symbol for n^{th} subcarrier;

c_m: denotes the m^{th} output of the IFFT block.

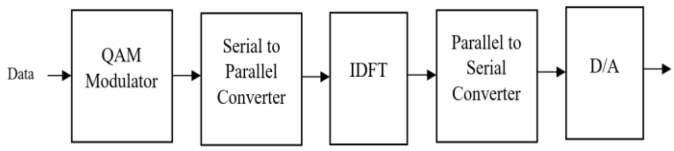

Figure 3: A block diagram of an OFDM transmitter

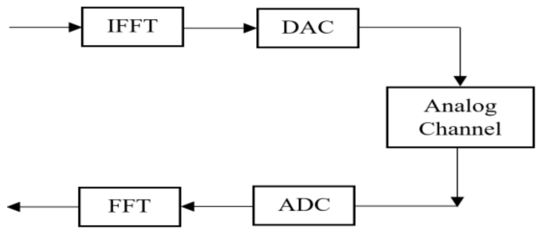

Figure 4: A block diagram of IFFT/FFT

II. APPLICATIONS OF RoF

Owing to the many advantages and quality of signal provided by RoF system, it has numerous applications, some most common are discussed below [6][7].

A. Video Distribution Systems (VDSs): The large bandwidth provided by the RoF system is a key factor to VDs. A typical example of VDSs is the Common-Antenna (cable) Television (CATV) networks that have used historically electrical communication techniques. The replacement of low bandwidth coaxial cables by the optical fiber provides better quality of service in terms of number of users. For instance the coaxial cable bandwidth cannot exceed 1GHz whereas the optical fiber easily exceeds this value.

B. Satellite Control: The control of a remote antenna located at satellite earth station can be done via optical fiber. The CO/CS can be centralized at a specific location in order to service many remote satellite earth stations. The choice of deploying the optical fiber between the CO/CS and the satellite earth station is the best choice since the satellite earth stations require high bandwidth in order to manage the efficient working of the satellites. This is a cost-effective method since it saves the number of CO/CS required.

C. Cellular Networks: Cellular networks have become more attractive nowadays and all mobile network service providers are deploying their resources to cope with the increase in capacity needs. Talking about the capacity, we automatically understand that the RoF system is the best option since the optical fiber relayed between CO/CS and BS has a large capacity. Therefore with increase in capacity, more services, such 5G-based services, can be provided in the broadband network.

D. Vehicle Communication: The RoF system can be to control the traffic of vehicle by deploying several BSs along the roads. These BSs communicate with the vehicles moving in the road via the microwave signal while the BSs are connected to the centralized CO/CS. Due to the tracking of fast moving vehicles, the high frequency signal is a necessity. Thus the RoF system is well suited for this purpose.

E. Wireless LANs (WLAN): The current WLAN provides maximum capacity of 11 Mbps per carrier. The next generation capacity is expected to provide 54 Mbps which requires the high frequency carrier. The RoF system come as a solution in this regard since copper cables have shown to be inefficient at higher frequencies.

F. Mobile Broadband Services: The fast growing of the mobile broadband services requires definitely large bandwidth. The typical example is the 4G services which use the bit rate in several MBs. Thus, the RoF system is the best choice to deal with the need of large bandwidth to support more users. Moreover, The RoF will help to provide good quality signal as the losses, reflection and other impairments are minimized.

III. EVOLUTION OF WIRELESS TECHNOLOGY

Wireless communication got started in the early 1970s. Subsequently, even the mobile wireless technology got evolved from First Generation (1G) to Fourth Generation (4G). The next breakthrough would be Fifth Generation (5G). This innovation is due to the rapid rise in telecom users and their bandwidth demanding video, voice and data services [8][9].

Table 1: Mobile Technology Comparison

Technology Features	1G	2G	3G	4G	5G
Deployment	1970-1980	1990-2004	2004-2010	Present	Expected by 2020
Data Bandwidth	2 kbps	64 kbps	2 mbps	1 Gbps	10 Gbps
Technology	Analog	Digital	CDMA 2000, UMTS, EDGE	WiMax, LTE, WiFi	WWWW (Wireless World Wide Web)
Service	Mobile Telephony	Digital Voice, SMS, Higher capacity packetized data	Integrated high quality audio, video and data	Dynamic Information access, Wearable devices	Dynamic Information access, Wearable devices with AI Capabilities
Multiplexing	FDMA	TDMA, CDMA	CDMA	CDMA	OFDM (probably)
Switching	Circuit	Circuit, Packet	Packet	All Packet	All Packet
Core Network	PSTN	PSTN	Packet Network	Internet	Internet

IV. FEATURES OF 5G TECHNOLOGY

(1) Bi-directional widespread bandwidth modelling and high resolution.
(2) Technology providing a unified global standard for all networks to converge all on one platform.
(3) 5G is expected to provide large distribution of data in Gigabit which sustains almost 65,000 connections.
(4) 5G technology also provides subscriber's supervision tools for faster action.
(5) It supports pervasive connectivity, wide variety of applications, very extraordinary capacity.
(6) 5G technology will propose a transporter class gateway with unmatchable consistency
(7) Remote diagnostic is also a remarkable feature of 5G technology.
(8) 5G technology also sustain virtual private network.

V. 5G ARCHITECTURE

The architecture of 5G is highly advanced; terminals and network components are dynamically upgraded to new situation. Network operators use the upgradability to introduce value-added services more easily. Upgradability is based upon cognitive radio. Cognitive radio technology includes various significant features such as ability of devices to determine the location's temperature, weather, etc., sensing the spectrum which is used by neighbouring devices, adjust output power, change frequency, and even change transmission parameters and characteristics [10].

Cognitive radio technology acts as a transceiver (beam) that is able to catch and respond radio signals in its operating environment. Thus, cognitive radio is an intelligent system that looks for mobile devices and networks which are aware of their environment, including radio resources and related communications to explore user communication needs and provide wireless services, be appropriate to those needs.

Hence, it promptly distinguishes the changes in its environment and hence respond accordingly to provide uninterrupted quality service [11].

VI. PROPOSED MODEL

The simulation setup is shown in Figure 5 and system parameters are listed in Table 1.

An OFDM uplink system of bit rate 10 Gb/s is designed and simulated. At transmitter side i.e. at CO, data is generated by a pseudo random binary sequence (PRBS) generator which is then mapped using a quadrature amplitude modulation (QAM) encoder. Information stream is parsed into 64 data subcarriers and then is processed by inverse fast fourier transform (IFFT) processor. To ensure correct data recovery, a cyclic prefix (CP) of 12.5 % is added. This generated electrical QAM

OFDM signal is then modulated using a Mach Zehnder modulator (MZM) in combination of CW laser. Laser has linewidth of 1 MHz and average power of 5 mW. The wavelength of carrier wave is 1550 nm.

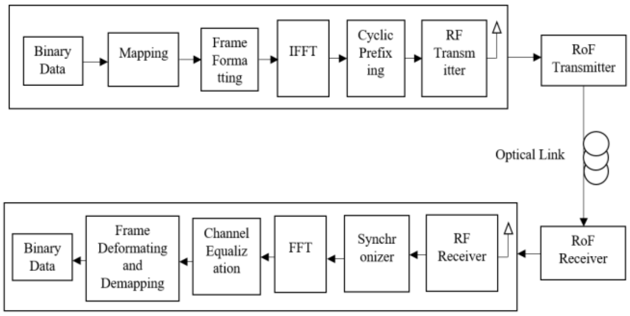

Figure 5: Downlink OFDM model for Radio Over Fiber Network

Optical channel consists of 5 repeated sections, where each section consists of a 1:8 splitter followed by 5 km of single mode fiber (SMF) and 1 km of Dispersion Compensated Fiber (DCF). Hence the maximum outreach of the fiber would be 30 km as the average radius of the city. Likewise total number of BSs for a particular CO would be 8^5=32,768.

The receiver side i.e. at BS, consists of a photo detector to convert optical signal to electrical signal. After removing CP from received signal, it is passed through FFT module. Processed signal is then passed through QAM decoder and then constellation diagram is plotted and EVM is calculated to evaluate system performance.

VII. RESULTS AND DISCUSSION

For the downstream link, first the operators transmit their own radio spectrums and these spectrums get added over the whole channel bandwidth. Each electrical spectrum has a bandwidth of 1GHz. The centre frequency for each operator is 2.5GHz, 5GHz, 7.5GHz and 10GHz respectively so as to avoid interference between the spectrums as shown in Figure 6. Then it is converted into optical domain using a laser having power 5mW via MZI having extinction ratio as 20. The electrical spectrum of each operators gets added before modulating via laser in order to save the transmitting power.

The maximum outreach for an optical fiber used to transmit the modulated signal for a particular CO is 30Kms, which is assumed to be as average radius of a city. The spectrum transmitted over a bidirectional optical fiber is shown in Figure 7. The BS acts a termination end to this network just before antenna, which transmits signal into the air. At the BS, photo receiver is used to reconvert the signal into electrical domain, and the spectrum is shown in Figure 8. This is later demodulated by using 256-QAM, in order to study the quality of the received signals using electrical constellation visualizer.

The SER is also calculated at 30Km as shown in Figure 9. The 256-QAM constellation diagram at 30Km is more clearly arranged, and the stars are separated as shown in Figure 10. Likewise the upstream link is also demonstrated.

Table 2: System parameters

Parameters	**Values**	**Unit**
Number of subcarriers	64	-
Laser Wavelength	1550	nm
Average Power	5	mW
Cyclic Prefix	12.5	%
Bit rate	10	Gbps
Coding	256 QAM	-
Dispersion	17	ps/nm/km
Dispersion Slope	0.08	$ps/km/nm^2$
Kerr non-linearity coefficient	2.6×10^{-20}	m^2/W
Fiber attenuation	0.2	dB/km
Photodetector	PIN	-
ADC/DAC quantization bits	10	-

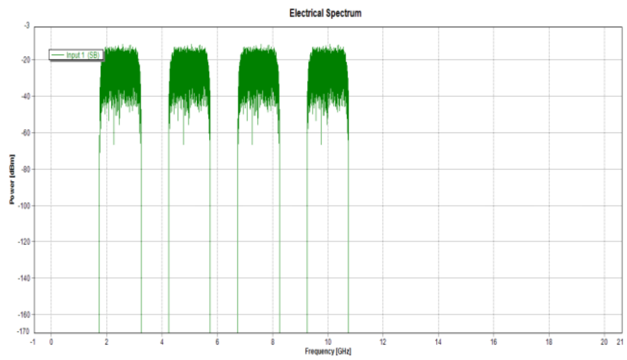

Figure 6: Electrical spectrum of 4 different operators at CO

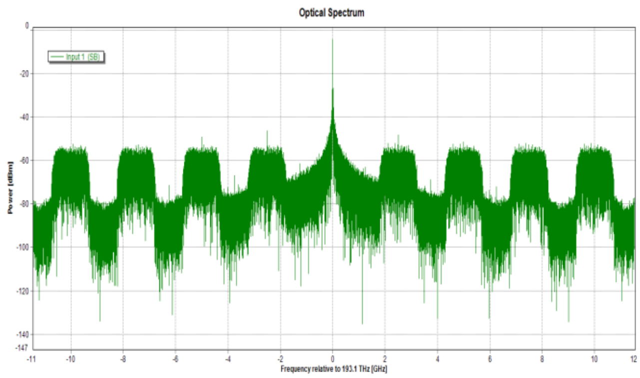

Figure 7: Electrical spectrum of 4 different operators transmitted via optical fiber

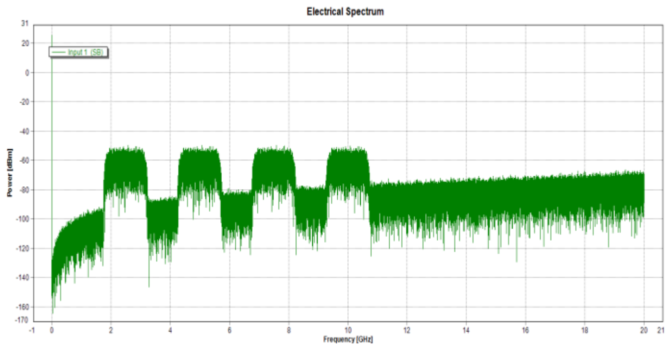

Figure 8: Electrical spectrum of 4 different operators at BS

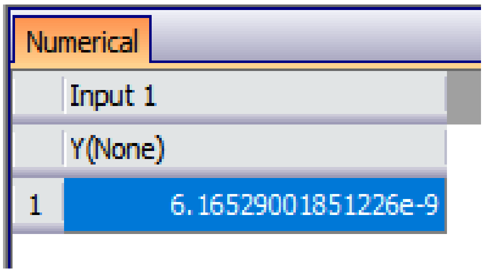

Figure 9: SER at 30 km

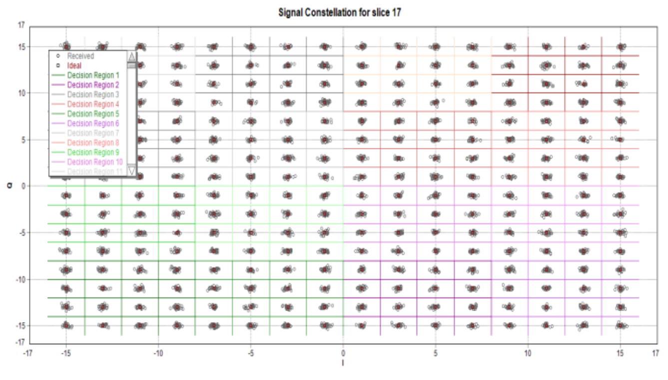

Figure 10: Received 256-QAM constellation diagram at 30 Km

VII. CONCLUSION

In this paper we have demonstrated how to transmit signals via bidirectional SMF with length of 30 km by using OFDM, which is modulated by 256QAM in both downstream and upstream link. The received signals were studied by using an electrical constellation visualizer, which helps to show the constellation of the symbols at the receiver's end [12].

This would minimize number of CO for a particular area but the number of BSs would drastically increase, like it should be due to millimetre waves. The use of optical fibers would increase and due to this fact, the received signal attenuation would severely decrease. The laying of optical fiber would change the geography of the city technically.

References

[1] P. Hartmann, Xin Qian, A. Wonfor, R.V. Penty, I.H. White, *"1-20 GHz Directly Modulated Radio over MMF Link,"* Microwave Photonics (MWP) 2005 International Topical Meeting on , vol., no., pp.95,98, 1214 Oct. 2007

[2] M.J. Crisp, Sheng Li, A. Watt, R.V. Penty, I.H. White, "*Uplink and Downlink Coverage Improvement of 802.11g Signals Using a Distributed Antenna Network*", Journal of Lightwave Technology, Vol.25, Issue 11, Nov. 2009 p3388-3395.

[3] A. Nirmalathas, P.A. Gamage, C. Lim, D. Novak, R. Waterhouse, Y. Yang, "*Digitized RF transmission over fiber*", Microwave Magazine, IEEE , vol.10, no.4, pp.75,81, June 2010

[4] D. Wake, A. Nkansah, N.J. Gomes, "*Radio Over Fiber Link Design for Next Generation Wireless Systems*", Lightwave Technology, Journal of , vol.28, no.16, pp.2456,2464, Aug.15, 2012

[5] A. Haddad, M. Gagnaire, "*Radio-over-Fiber (RoF) for mobile backhaul: A technical and economic comparison between analog and digitized RoF*", Optical Network Design and Modeling, 2014 International Conference on , vol., no., pp.132,137, 19-22 May 2016

[6] A. Saadani, M. El Tabach, A. Pizzinat, M. Nahas, P. Pagnoux, S. Purge, Y. Bao, "*Digital radio over fiber for LTE-advanced: Opportunities and challenges*", Optical Network Design and Modeling (ONDM), 2013 17th International Conference on , vol., no., pp.194,199, 16-19 April 2015

[7] T. Li, M. Crisp, R.V. Penty, I.H. White, "*Low Bit Rate Digital Radio over Fibre System*", Microwave Photonics, 2009. MWP '09.International Topical Meeting on , vol., no., pp.1,4, 14-16 Oct. 2011

[8] T. Li, M. Crisp, R.V. Penty, I.H. White, "*Digital Radio Distribution System over Multiple Cabling Types*", Microwave Photonics (MWP), 2013 International Topical Meeting on , vol., no., pp.214,217, 28-31 Oct. 2015

[9] CPRI Specification, V 4.2, November 2012.

[10] 3GPP TS 36.101 V12.6.0, Evolved Universal Terrestrial Radio Access (E-UTRA) User Equipment (UE) Radio Transmission and Reception (Release 12), December 2016

[11] 3GPP TS 36.141 V12.6.0, E-UTRA Base Station Conformance Testing (Release 12), December 2016

[12] DE4 User Manual, V1.2, Terasic Technologies, Hsinchu City, Taiwan, March 2014

Lalit Sahu, pursuing M.Tech in Electronics at Punjab Engineering College (Deemed to be university) Chandigarh, India.

Neena Gupta is the Professor in the Department of Electronics and Communication Engineering at Punjab Engineering college (Deemed to be university) Chandigarh, India. Her research interests include Communication Engg, Optical Communication, and Wireless communication. She is a B.E, M.E and PhD graduate. She has done 2 projects since 2012 at Punjab Engineering College (Deemed to be university). She has a lifetime membership in Fellow, Institution of Electronics & Telecommunication Engineers (FIETE), member, Institution of Electrical & Electronics Engineers (IEEE).