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Optimized ultra-high bit rate hybrid optical communication system design and simulation

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ABSTRACT

An optimized hybrid optical communication system for the bit rates of 160 Gbps, 100 Gbps and 40 Gbps is proposed. The system uses 1550 nm wavelength and consists of an optical fiber link for long-haul and a free space optical link for short-haul communication. For optical fiber link, the modified duo-binary return-to-zero modulation format with symmetrical dispersion compensation technique is used. For free space optical link, quadrature phase shift keying modulation technique with an atmospheric attenuation of 200 dB/km is considered. The system is also analyzed for the atmospheric fading effect of strong and weak turbulence. The performance of the proposed hybrid system is analyzed in terms of *Q*-value, bit error rate, eye opening, signal constellation diagram, etc. For a bit rate of 160 Gbps the optimized coverage distance obtained for the hybrid system is 419.93 km of fiber link and 129.34 m of free space link with strong atmospheric turbulence. To the best of author's knowledge such a high capacity and optimized hybrid system is proposed and analyzed for the first time. This system will be highly useful in optical networking and communication systems, where the front end will be a fiber link and back end will be a free space link or vice versa.

1. Introduction

Each of the current network technologies, such as twisted pair, coaxial wire, microwave radio link, wireless (fixed/mobile) and optical fiber provide different levels of mobility and specific bandwidth to each user. There are different techniques of signal generation, transmission and receptions as well as these different techniques are associated with different cost of installation, operation, energy consumption and maintenance. The major challenging task with these systems is the feasibility of cost and implementation. Recent trends reflect the continuous increase in the demand of broadband (such as "Quad-play," which refers to voice, video, internet and wireless) and mobile communications with continuous connectivity and high quality standards, pose a challenge on the network technologies that have to support these new and enhanced services, with feasibility of cost and implementation. The current networks, either wireless or wired, satisfy just a part of the new demands due to some of inherent bottlenecks of the used technologies.

Thus taking into the account of growing requirements and separately the advantages and disadvantages of the basic technologies, there comes the necessity of the implementation of a network, in which the limitations of one technology can be overcome via the coexistence with another technology, in the same network [1]. The hybrid wireless-optical broadband-access network (WOBAN) is a promising architecture for future access networks. Here, the fiber need not penetrate each end-user; hence it extends the reach of emerging optical-access solutions, such as passive optical networks (PON). It is the best solution to eliminate the wired drop to every wireless router at customer premises. Hence, this architecture also saves on network deployment cost [2].

Long-haul ultra high bit rate (>1 Gbps) optical communication can only be achieved, with the help of low-loss standard single mode fiber (SSMF) [4,24]. But the main limitation observed is the dispersion and nonlinearity of the fiber. Hence these parameters must be managed properly to achieve transmission over an appreciable distance [22,23]. Utilization of specialized fiber of opposite direction dispersion values is a key technique that keeps the total accumulated dispersion low while suppressing the non-linear effects [5,30]. Sheetal et al. designed a long-haul optical fiber dense wavelength division multiplexing (DWDM) communication system during the year 2010 and they proved that among all modulation formats modified duo-binary return-to-zero (MDRZ) is the best for tolerating dispersion and non-linearity present in the optical fiber. They also proved that among several dispersion compensation techniques, symmetric dispersion compensation technique is the best.

Free space optical (FSO) communication system uses a laser beam as a wireless connectivity between transmitter and receiver,

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free-space as propagation medium for carrying out information. Conventional FSO systems used for multicasting operate near the 800 nm spectral range, but optical devices using the 800 nm spectral ranges cannot operate above 2.5 Gbps because of the power limitations imposed for eye safety. In order to overcome this bandwidth and power limitations, 1550 nm wavelength is selected here for ultra-high bit rate FSO system. Apart from the advantage of being eye safety, it includes compatibility with existing optical fiber technology infrastructure and reduced solar background radiations [6]. By using the 1550 nm wavelength, high speed wireless transmission can be achieved due to the development of optical components e.g. erbium-doped fiber amplifier (EDFA), as well as advanced optical sources and detectors [7].

There are two types of FSO setups widely used such as line-of-sight (LOS) setup for local area networks (LAN), metropolitan area networks (MAN) and diffused link (DL) setup for home network, indoor wireless LANs [8]. The non-line-of-sight or DL setup is used for multicasting applications but LOS setup is used for point to point communication applications. DL setup solves the problem of severe shadowing and restricted mobility but have a huge loss due to multipath distortion. At the same time the LOS or directed beam setup offers excellent transmission capacity, but subjected to severe shadowing problems and restricted mobility [9]. Hence, in this paper, we have proposed fiber link for long distance communication and the DL setup for short distance communication.

For DL setup, though the intensity modulation technique that is on-off-keying (OOK) scheme is the simplest and extensively used technique, it does not offer immunity to the turbulence induced fading channels [10]. The behavior of turbulence level, which is non-predictive, produces random fluctuation of the optical intensity level, at the receiver. Hence, it requires an adaptive thresholding for optimal performance. But this adaptive thresholding is complex to implement and practically not suitable. Since the optical intensity level is get affected by scintillation affects, it is a reasonable approach to use modulation techniques that carries the information in the frequency or the phase of the carrier signal. The phase shift keying (PSK) based modulation requires no adaptive thresholding scheme, thereby offering superior performance compared to the OOK in the presence of the atmospheric turbulence induced fading channels [11]. Among all PSK techniques quadrature phase shift keying (QPSK) is proved to be the best for DL setup, as it is spectrally efficient with low probability of error and high coverage distance [12]. Hence, in QPSK modulation technique is used here for DL setup.

Fiber optic communication is suitable for only point to point communication but not for multicasting purpose. At the same time the FSO communication system with diffused link or non-line-of sight setup is suitable for multicasting purpose but suffers from severe attenuation and atmospheric turbulence. Hence, DL systems are not suitable for long-haul communication but used for multicasting purpose. Considering the advantage and disadvantage of each system, here a hybrid optical system is designed simulated and optimized which is a combination of fiber link and free space optical diffused link setup. This is an extension of our previous work published in paper [3,12]. It meets the need of practical requirement such as long-haul communication with multicasting applications. It will be highly helpful for systems, where the front end will be a fiber link and back end will be a free space link or vice versa (Ex: -WOBAN, Pico-cellular mobile systems and indoor wireless LANs, etc.) [1,2].

2. Proposed hybrid optical system setup

The schematic block diagram of hybrid optical system setup is as given in Fig. 1. It consists of fiber optic link and optical diffused

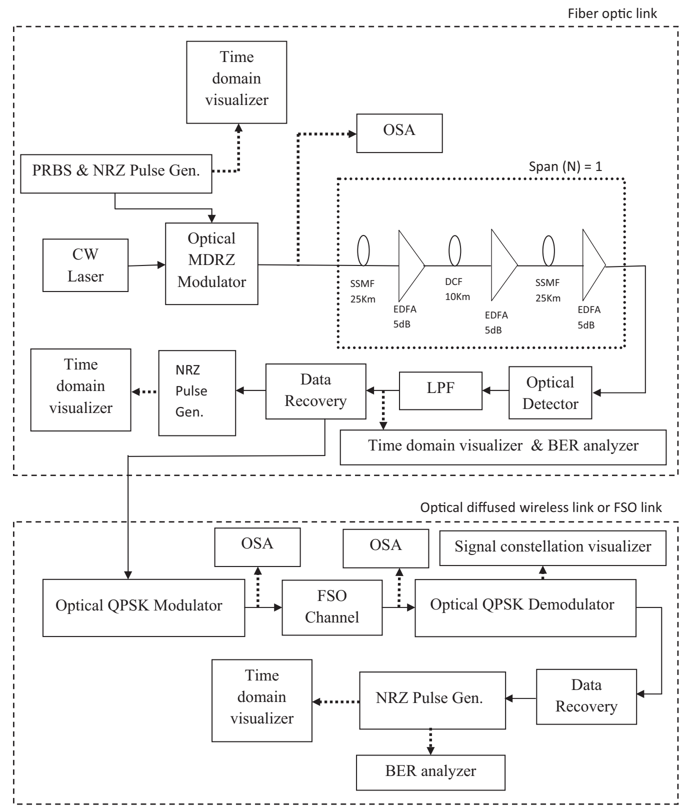

Fig. 1. Schematic block diagram of hybrid optical system.

wireless link or free space optical link. The output of optical fiber link is given to the input of the optical wireless link to achieve hybrid configuration. The system is simulated for data rates of 160 Gbps, 100 Gbps and 40 Gbps as per telecommunication standard [4,17,18].

2.1. Fiber optic link

The block diagram of fiber optic link is shown in Fig. 1. It consists of a pseudo random bit sequence generator (PRBS), which generates the random data bits (0 s and 1 s) with mark probability of 50%. Then the data is modulated with an optical carrier frequency of 193.1 THz, using MDRZ modulator [3]. The modulated optical signal passes through the fiber with symmetrical dispersion compensation configuration [4,22]. Here each fiber span consists of SSMF of 50 km and dispersion compensation fiber (DCF) of length 10 km with erbium doped fiber amplifiers (EDFA). At the receiver optical to electrical (OE) conversion is done using a PIN diode and then the signal is passed through low pass Bessel's filter for suppressing the noise. Using a data recovery circuit the information is regenerated. Optical spectrum analyzer (OSA) is used for observing the optical signal spectrum, bit error rate (BER) analyzer is used for observing the eye diagram, Q-value and BER of the system. For an optical system the BER in terms of Q-factor is given by [19],

$$\text{BER} = \frac{1}{Q\sqrt{2\pi}} \exp\left(-\frac{Q^2}{2}\right) \quad (1)$$

and the Q-factor of the system is given by [32]

$$Q = \frac{|\mu_1 - \mu_0|}{\sigma_1 - \sigma_0} \quad (2)$$

where μ_1, μ_0 are the average levels and σ_1, σ_0 are the deviation of mark (1) and space (0), respectively. The BER value acceptable is 10^{-9} to 10^{-15} for an optical link [19]. For free error correction,