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Comparative Analysis of Analog and Digitized Radio-over-Fiber Systems

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Abstract

Due to increase in the implementation of optical access networks and surplus availability of advanced and cost-effective opto-electronic system technologies, a unified optical feeder network could provide continuous integration of both broadband optical and wireless access networks. A Radio-over-fiber (ROF) is used to transport wireless signals in optical form between the central station and the Base station . Recently Digitized radio-over-fiber(DROF) has been found to be a low-cost solution by using signal processing and sampling techniques. In this paper, we have made a performance comparison of ROF and DROF in terms of Bit Error Rate and Signal to Noise Ratio.

Keyword: Radio-over-Fiber, Digitized Radio-over-Fiber, Central office, Base station, SNR, BER.

Introduction

` There is a drastic increase in demand for broadband wired and wireless connectivity; a combined communication backbone network that integrates the wireless broadband access networks with the existing optical access network can offer meaningful benefits to network operators [1]. The user demand for higher speeds has only been constantly increasing and there are no signs of slowdown. Moreover, it has been recognized as a motive of economy to the government, thereby there is an increase in the tendency to invest in a fast deployment of broadband optical access networks [2]. When such a motive arises there is in-turn a drive for development in the long-haul optical networks necessary to withstand high data rates.

On the other hand, we also see that the user, demands for access anywhere and everywhere possible. This requires a sustained improvement in the already existing network and connectivity at high bandwidths which should be able to provide real-time applications. Furthermore, it is also important to look into the aspect of feasibility and cost-effectiveness for delivering such applications. To connect remote base stations (BSs), a higher bandwidth back haul networks are required with switching centers that connect to the central office (CO).

The transmission of microwave signals at radio frequencies and then up-converting it for radio-over-fiber transmission has been considered as a method to simplify the base station architecture, where the base stations are connected via antennas to the central office network [3-4]. The central office consists of the all the signal processing with the switching and routing. In such applications, multiple base station antennas are connected to one central office via a backhaul or feeder optical network. ROF links employing such a technique have an analog transmission through the channel. The analog signal transport suffers from inter-modulation distortions rising from the non-linearity of the microwave and optical components that exist in the network.

Furthermore, we see that the analog transport system does not hold a dynamic range of value over long distances and in turn decreases the signal power due to attenuation of the optical fiber. Keeping in mind all the above mentioned factors we need to design a long haul network that fulfill all demands, thereby we use a digital transport system over the fiber. Cost effective and high performance RF-over-fiber link for a long-haul fiber radio networks can be established using multichannel DROF technique [5-6]. DROF can maintain its high dynamic range over long distances by using fully-photonic DROF systems[7] and the non-linearity present in analog due to the components does not exist in this technique .

In this paper, we compare the analysis and discuss the advantages of DROF over the analog transport in ROF. This paper is organized as follows: Section II presents the basic description of analog and digital ROF transmission. Section III describes the simulation design. Section IV contains the corresponding results. Section V presents the discussion of challenges and future developments in DROF.

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Analog and Digital ROF Transmission

ROF refers to a technology whereby light is modulated by a radio signal and transmitted over an optical fiber link to facilitate wireless access. Although radio transmission over fiber is used for multiple purposes, such as in cable television (CATV) networks and in satellite base stations, the term ROF is usually applied when this is done for wireless access. In ROF systems, wireless signals are transported in optical form between a central station and a set of base stations before being radiated through the air. Each base station is adapted to communicate over a radio link with at least one user's mobile station located within the radio range of said base station.

Radio-Over-Fiber

ROF systems deal with the analog transmission over optical fiber of Microwave signals. Fig.1.shows the subsystems and links of ROF with single band transmission. It consists of a complex Central Office (CO) and a simpler Base Station (BS) architecture. CO holds the task of converting the input signalfrom the processor to analog or microwave signal [2]. Up-conversion techniques are used to get the desired RF signal which can sustain long-distance transmission. Most important block of CO is electrical-to-optical (E-O) conversion wherein Optical Modulators are used [6]. For low frequency signal transmission, internal modulator or directly modulated laser sufficient but for higher frequency applications external Modulators are preferred. For better performance of ROF, E-O and O-E convertors should have low loss and should be highly linear. During Multi-band frequency transmission ROF suffers from Inter-Modulation Distortion (IMD) which affects its commercial value at higher frequencies or bandwidths. This adds more complexity to the technique and reduces low cost-high efficiency criteria.

Digitized Radio-Over-Fiber

Fig.2.shows the subsystems and links of DROF with single band transmission .DROF as compared to the earlier technique directly transmits digital input to the fiber. All the signal processing and modulation schemes are applied in the BS now leaving CO to do just the digitization. Digitization of RF signal generates a sampled digital signal in serial form which can directly modulate laser source or external modulation and can be transmitted over the fiber [4]. So by using digitization scheme, non-linear effects of E-O are reduced which implies less IMD.

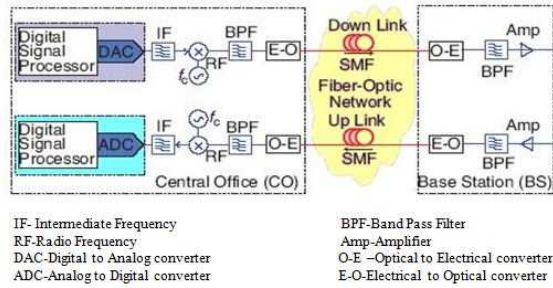

Fig.1. ROF transport of wireless signals over fiber

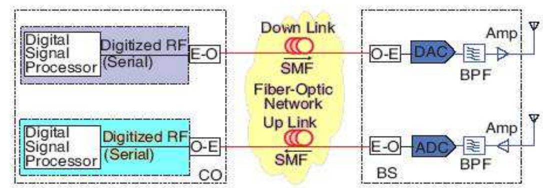

Fig.2. DROF transport of wireless signals over fiber

DROF shows high dynamic range over long distance fibers as compared to optical links. Minimum hardware components are required at the CO results in low cost digital transmitters and receivers.BS involves the conversion of received digitized signal into microwave signal which is then passed into the network through an antenna. This can be used to implement converged networks providing wired connectivity to users directly and wireless via BS. Multi-band transmission DROF can be used for GSM and WiMAX techniques to give error- free performance.

Simulation

This section briefly describes the simulation setup in Optisystem with a standard set of parameters. Firstly, the AROF system is considered. Fig.3. shows the Transmitter section of the AROF which consists of the CO subsystem that has a signal processing unit. The data signal is a Pseudo-Random Bit Sequence Generator (PRBS) where the bit rate is set at 8Gbps and a frequency of 2 GHz is initially chosen. The data is modulated using a Phase Modulator (PM). The signal is then up-converted using a sine-generator set at 10 GHz and a multiplier. The signal is modulated by the CW Laser at 1550nm by the Mach-Zender Modulator (MZM) and passed to a single mode fiber of 20km length.

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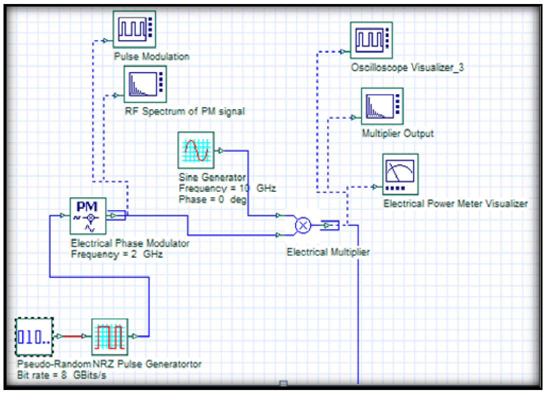

Fig.3.Transmitter of AROF

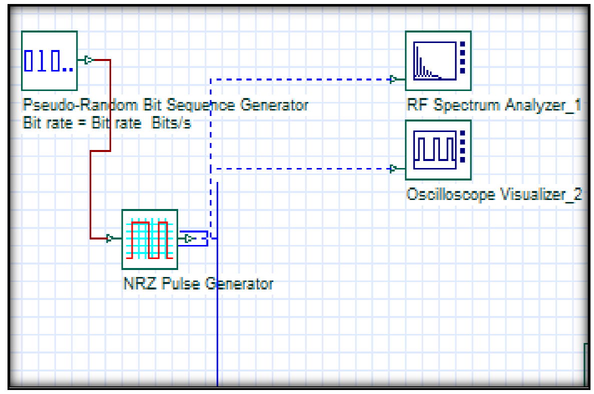

Fig.5. Transmitter of DROF

Fig.4.shows the Receiver part of AROF, where the photodetector (PD) converts the received optical into electrical signal.

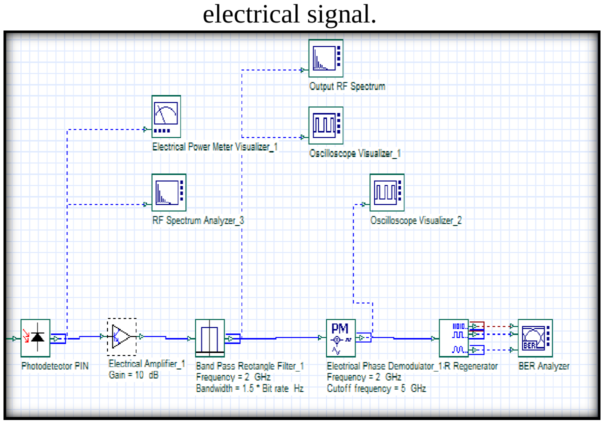

Fig.4.Receiver of AROF

The electrical signal is further amplified by 10 dB with an Electrical Amplifier. The filtered signal is obtained from a Band-pass rectangular filter and then given to a BER analyser for final results and analysis.

The transmitter part of the DROF system is shown in Fig.5. The CO directly transmits the digitized RF signal with a PRBS source producing bits at 8Gbps. The optical source, a CW laser at 1550nm is used to modulate the signal in the MZM electro-optic modulator which is passed to a single mode fiber of 20km length.

Fig.6. shows the Receiver part of the DROF transmission. In the BS, the output after photo-detection is forked. The former is used for BER analysis and the latter is filtered with a Low Pass Bessel Filter and then amplified by 24db by a Transimpedance amplifier. It is then phase modulated at 2 GHz and up-converted with a sine generator of 10GHz and a multiplier to generate the desired wireless signal for mobile applications.

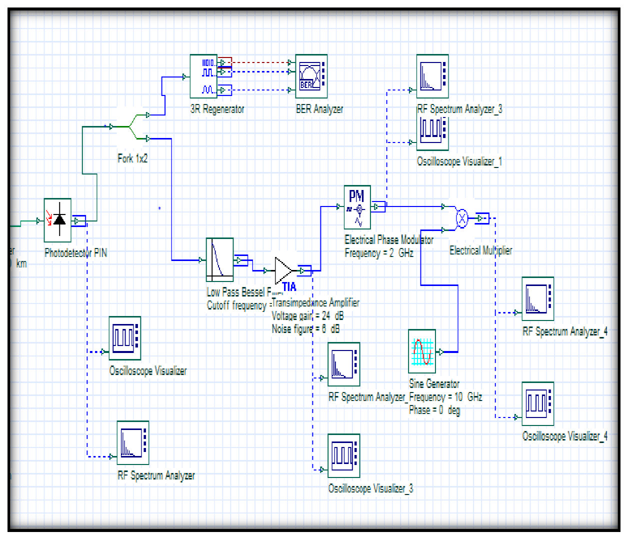

Fig.6. Receiver of DROF

Results

Based on the simulations on AROF and DROF, the analysis and outcomes have been presented. The differences between them are obtained and predictable variations are observed. Fig.7. shows the SNR (dBm) as a function of Fiber Length (km) for both the analog and digital links. It is evident that the system SNR has a significant improvement due to the DROF technique. As the fiber length increases we see that the SNR decreases due to the attenuation of the optical fiber which affects the signal power in the analog transmission adversely. The DROF shows a

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increase in SNR of 3 dBm over long distance transmission.

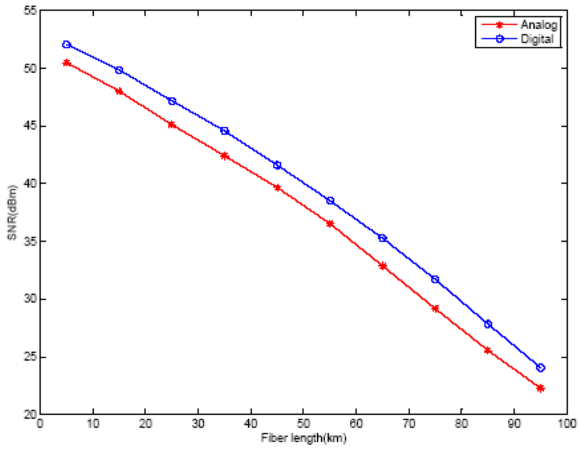

Fig.7. SNR (dBm) vs Fiber length (km) for AROF and DROF

The responsivity(R) is the input-output gain of the photodetector which measures the electrical output per optical input. It is usually expressed in units of either amperes or volts per watt of incident radiant power.

$$R = \eta \frac{q}{hf} \approx \eta \frac{\lambda_{(\mu m)}}{1.23985(\mu m \times W/A)} \quad (1)$$

Fig.8. shows the responsivity as a function of the received optical power. When responsivity increases, the signal power also increases but after a certain point it remains at an approximately constant value. This point is the maximum point wherein the photodetector can detect the input signal. The digital link performance shows an increased received signal power level of 3 dBm than the analog part. This is due to lesser noise during the (E-O) and (O-E) conversions.

Bit error rate (BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval. When the source optical power is varied, the receiver shows variations in the received optical power after the optical fiber network [7].

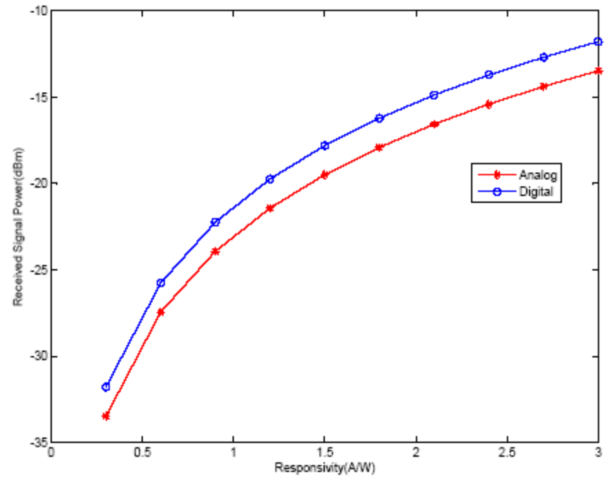

Fig.8. Received Optical Power (dBm) vs Responsivity (A/W) for both AROF and DROF

Fig.9. shows the BER as a function of the received optical power. The BER for the corresponding changes concludes that the analog link remains an almost constant value whereas the digital link is more efficient. The digital link shows a significant decrease in BER as the power is increased.

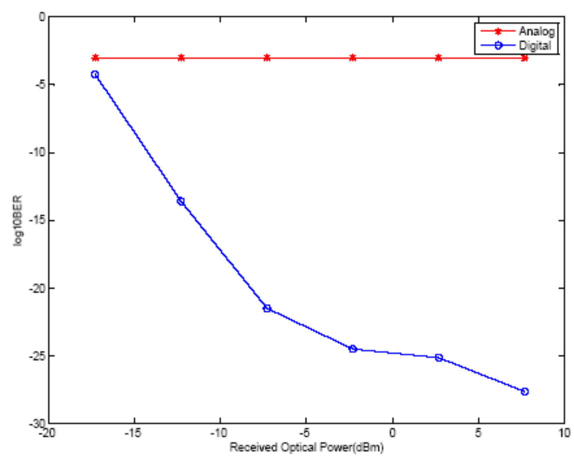

Fig.9. BER vs Received Optical Power (dBm) for both AROF and DROF

The extinction ratio(ER) is used to describe the efficiency with which the transmitted optical power is modulated over the fiber-optic transport.

ER = P1/P0 (2)

where P1 is the power used in transmitting a logic level "1" and P0 is the power used in transmitting a logic level "0" . Fig.10. gives visual representation of the effects of ER on the quality of the link. The graph clearly shows that the BER rises each time ER increases. Furthermore, only small changes in ER are required to relatively make large differences in the power in order to maintain a constant bit error rate (BER).Again it is prominent that the analog link

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shows a weaker performance and does not show any change in the BER value whereas the digital link gives a clearer outcome. A value of 30dB can be used for a constant response.

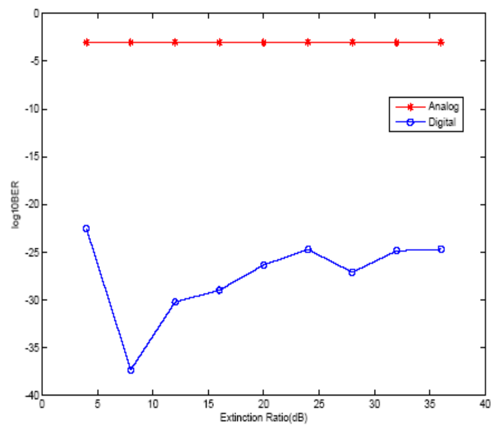

Fig.10. BER vs Extinction Ratio (dB) for both AROF and DROF

Fig.11. shows the variations of SNR with respect to fiber length and Launch power. MATLAB R2011a is used to make a 3-D plot. It is evident that,DROF technique shows a significant improvement in SNR of 3 dBm by varying the fiber length from 20 km to 100 km and optical power from -20 dBm to 20 dBm. The analog link performance is reduced due to the non-linear effects in E-O conversion that increases with the received optical power and by the attenuation which depends upon the distance.

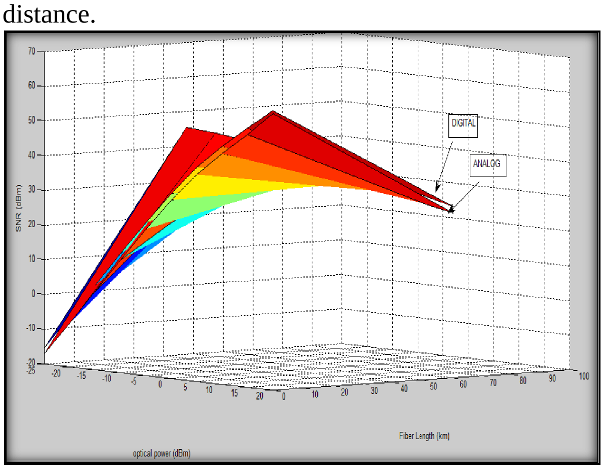

Fig.11. SNR (dBm) vs Launch Power (dBm) vs Fiber Length (km) for AROF and DROF

Conclusion

In this paper, the performance of ROF and DROF is analyzed. For performance investigation, a conventional RoF and DROF system are simulated by Optiwave-Optisystem and Matlab simulation tools for wireless signal transportation and distribution over 20 km of single mode fibre. The DROF shows an SNR improvement of 3 dBm over the analog part. The BER obtained in the DROF system is about $10^{-27.6}$ which is much better than the ROF network with BER of $10^{-4.2}$. It goes to show how these new techniques can be a superior substitute for the existing system. ROF transmission can be used for various applications in the GSM and WIMAX networks, the error-free results can be achieved. With higher bandwidth requirements and long distances of communication, the DROF system is the best suitable network.

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