

Performance Comparison of Radio over Fiber System Using WDM and OADM with Various Digital Modulation Formats

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Abstract: Radio over Fiber (RoF) is a technology where light is modulated with radio frequency signals and transmitted over the optical fiber to facilitate wireless access and transmission. The convergence of wired and wireless networks is a promising solution for the increasing demand of transmission capacity and flexibility, as well as offering economic advantages due to its broad bandwidth and low attenuation characteristics. The full duplex transmission of RoF is accomplished by means of Wavelength Division Multiplexing (WDM) and Optical Add Drop Multiplexer (OADM), where WDM enables transmission of different signals through a single mode fiber over large distance and OADM permits transmission of both down-link and uplink data via the same single-mode fiber. The performance analysis of RoF system employing various line coding techniques and digital modulation formats has also been done. The simulation and performance comparison of RoF was done using Optisystem 12.0.

Keywords: Radio over Fiber, Wavelength Division Multiplexing, Optical Add/Drop Multiplexing, Differential Phase Shift Keying, Offset Quadrature Phase Shift Keying, Minimum Shift Keying, Continuous Phase Frequency Shift Keying.

1. Introduction

For the future provision of broadband, interactive and multimedia services over wireless media, current trends in cellular networks are (1) Reduction in cell size to accommodate more users and (2) Operation in microwave/millimeter wave (mm-wave) frequency bands to avoid spectral congestion in lower frequency bands. It demands a large number of Base Stations (BSs) to cover a service area, thus a key to success is to make BS cost effective. This requirement has led to the development of system architecture where functions such as signal routing/processing, handover and frequency allocation are carried out at a Central Station (CS), rather than at the BS. Furthermore, such a centralized configuration allows sensitive equipment to be located in safer environment and enables the cost of expensive components to be shared among several BSs.

An attractive alternative for linking a CS with BSs in such a radio network is via an optical fiber because it has broad bandwidth, low loss and immunity to Electromagnetic Interference (EMI). The transmission of radio signals over fiber, with simple optical to electrical conversion, followed by radiation at remote antennas, which are connected to a central CS, has been proposed as a method of minimizing costs. The reduction in cost can be brought about in two ways. Firstly, the remote antenna BS or radio distribution point needs to perform only simple functions, and it is small in size and low in cost. Secondly, the resources provided by the CS can be shared among many antenna BSs. This technique of modulating the Radio Frequency (RF) subcarrier onto an optical carrier for distribution over a fiber network is known as Radio over Fiber (RoF) technology [6]. The basic radio over fiber system is depicted in Figure 1.

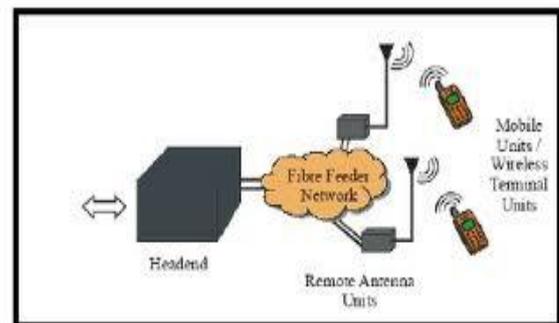


Figure1: Radio over Fiber System Concept

There exists several methods to accomplish full duplex transmission in radio over fiber system, but all these methods utilize wavelength re-use technique where downlink data is power splitted and a part is remodulated as uplink data. It restricts the simultaneous transmission of multiple wavelengths over RoF system. Wavelength Division Multiplexing (WDM) is a technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths of laser light to carry different signals. An Optical Add Drop Multiplexer (OADM) is a device used in WDM systems for multiplexing and routing different channels of light into or out of an optical network. The combination of WDM and OADM technologies with RoF enables multi-wavelength transmission over a large transmission distance and simultaneous transmission of downlink and uplink data via same single mode fiber. To enable high frequency transmission several digital modulation formats can also be employed in RoF system.

2. Digital Modulation Formats

Modulation is the process of varying some parameter of a periodic waveform in order to use that signal to convey a

message. Normally a high-frequency sinusoidal waveform is used as carrier signal. If the variation in the parameter of the carrier is continuous in accordance to the input analog signal the modulation technique is termed as analog modulation and if the variation is discrete then it is termed as Digital Modulation.

2.1 Differential Phase Shift Keying (DPSK)

For the perfect detection of a phase modulated signal, it become evident that the receiver needs a coherent reference signal but if differential encoding and phase shift keying are incorporated together at the transmitter then the digital modulation technique evolved is termed as Differential Phase Shift Keying. For the transmission of a symbol 0, the phase is unchanged whereas for transmission of symbol 1, the phase of the signal is advanced by 180°. The track of the phase change information which becomes essential in determining the relative phase change between the symbols transmitted.

2.2 Offset Quadrature Phase Shift Keying (OQPSK)

OQPSK is a variant of phase shift keying using four different values of the phase to transmit. Taking four values of the phase at a time to construct a QPSK symbol can allow the phase of the signal to jump as much as 180° at a time. When this signal is low pass filtered, these phase shifts result in large amplitude fluctuations, an undesirable quality in communication systems. By offsetting the timing of odd and even bits by one bit period, the in-phase and quadrature components will never change at the same time, i.e, it will limit the phase shift to no more than 90° at a time which yields much lower amplitude fluctuations.

2.3 Minimum Shift Keying (MSK)

Minimum Shift Keying (MSK) is a modified form of continuous phase FSK. Here, in this case, the spacing between the two carrier frequencies is equal to half of the bit rate which is the minimum spacing that allows the two frequencies states to be orthogonal.

An MSK signal can said to be derived from either an OQPSK signal by replacing a square pulse by 1/2 cosinusoidal pulse. The information capacity of an MSK signal is equal to that of QPSK signal but due to the 1/2 cosine pulse shaping the bandwidth requirement is lesser than that required by QPSK. It achieved smooth phase transitions thus providing a constant envelope.

2.4 Continuous Phase Frequency Shift Keying (CPFSK)

Continuous Phase Frequency Shift Keying (CPFSK) is a commonly used variation of Frequency Shift Keying (FSK), which is itself a special case of analog frequency modulation. FSK is a method of modulating digital data onto a sinusoidal carrier wave, encoding the information present in the data to variations in the carrier's instantaneous frequency between one of two frequencies (referred to as the space frequency and mark frequency). In general, a standard FSK signal does not have continuous phase, as the modulated waveform switches instantaneously between two sinusoids with

different frequencies. As the name suggests, the phase of a CPFSK is in fact continuous; this attribute is desirable for signals that are to be transmitted over a band-limited channel, as discontinuities in a signal introduce wide band frequency components.

If a finitely valued digital signal to be transmitted (the message) is $m(t)$, then the corresponding CPFSK signal is $m(t) = A_c \cos(2\pi f_c t + D_f \int_{-\infty}^t m(\alpha) d\alpha)$ (1)

where A_c represents the amplitude of the CPFSK signal, f_c is the base carrier frequency and D_f is a parameter that controls the frequency deviation of the modulated signal. The integral located inside of the cosine's argument is what gives the CPFSK signal its continuous phase; an integral over any finitely valued function (which $m(t)$ is assumed to be) will not contain any discontinuities [3].

3. System Design

In transmitter side, two Continuous Wave (CW) lasers at 0.1 dBm power emit light at frequencies 193.1 THz and 193.2 THz. A MZM modulates optical carrier from CW laser by an electrical signal of data rate 5 Gbps coming from NRZ pulse generator. The modulated signals from both channels are multiplexed using a WDM multiplexer and then the multiplexed signal is fed to a single mode fiber.

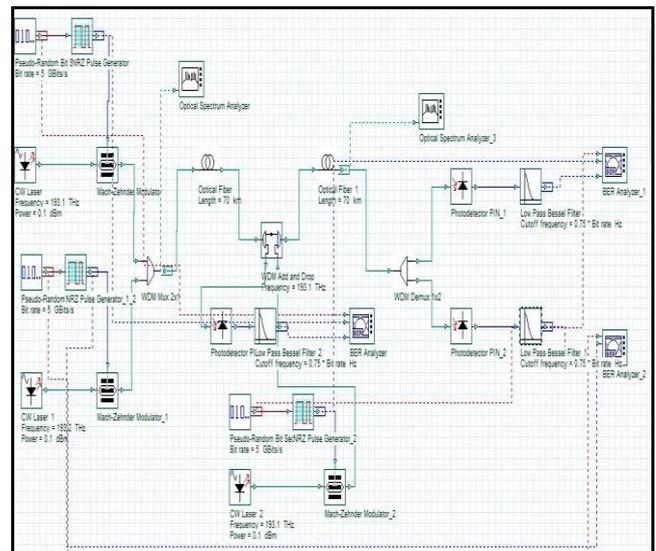


Figure 2: Simulation layout of full duplex RoF system using WDM and OADM.

After transmitting the multiplexed signal up to BS, appropriate frequency (193.1 THz) is dropped by the OADM. This downlink data signal is passed through a PIN detector of responsivity 1 A/W and a Bessel low pass filter. The resulting electrical signal is then given to a BER tester for analyzing the downlink signal. At the same time, another optical carrier of same frequency 193.1 THz modulated by baseband signal of data rate 5 Gbps is added from BS to fiber backbone, as uplink data, by OADM. Now the multiplexed signal which contains carrier frequency (193.2 THz) other than that dropped at the BS along with the uplink data of frequency 193.1 THz added from base station is transmitted towards CS.

At the central station, a WDM demultiplexer separates the signal and fed to corresponding detectors. The resulting electrical signals are then passed through low pass filters and given to BER analyzer through which the Q factor and BER of the signal is analyzed. The entire simulation is shown in Figure 2.

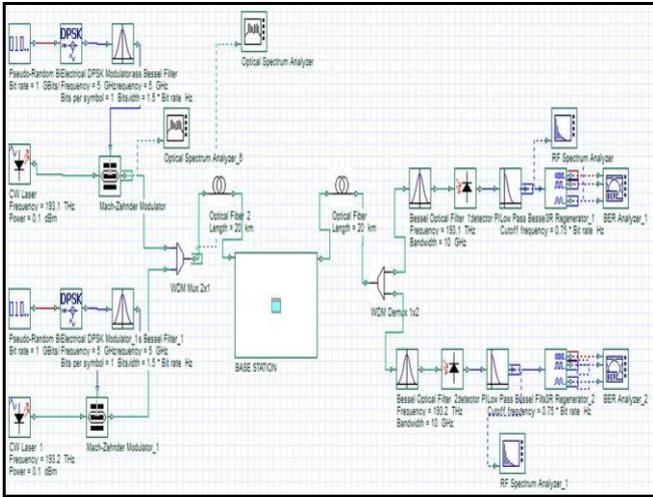


Figure 3: Full duplex RoF system with DPSK modulation.

Figure 3 shows RoF employing DPSK modulation. The optical carriers of frequencies 193.1 THz and 193.2 THz are emitted by two CW lasers. The digital data of bit rate 1Gb/s from PRBS generator is given to a DPSK modulator, which has an inbuilt carrier of frequency 5 GHz. The modulated optical carriers from two channels are multiplexed by WDM multiplexer and given to SMF through which it reaches the BS, addressed to a frequency of 193.1 THz.

At the BS, signal with frequency 193.1 THz is simultaneously added and dropped as uplink and downlink data respectively. The dropped signal is first passed through an optical Bessel filter of frequency 193.1 THz and bandwidth 10 GHz. Then the signal is detected using a PIN detector, filtered using a low pass Bessel filter and fed to a BER analyzer for the analysis of Q factor and BER of downlink. The multiplexed signal having frequency 193.2 THz along with uplink data of 193.1 THz, added from BS, is transmitted to CS via SMF of attenuation 0.2 dB/Km. At CS, the signal is demultiplexed, optically filtered using an optical Bessel filter and detected using a PIN detector of responsivity 1 A/W and dark current of 10 nA. The recovered electrical signal is filtered using a low pass Bessel filter and given to a BER analyzer for the analysis of uplink data. To analyze the performance of RoF system with other three digital modulations (OQPSK, MSK and CPFSK), DPSK modulator is replaced by corresponding digital modulators.

4. Results and Discussions

4.1 Relationship of Q factor and BER with Fiber Length

The Q factor and BER observed by varying the fiber length is plotted in Figure 4. The fiber length was varied from 10 km to 100 km at a transmitter power of 0.1 dBm and input bit

rate of 5 Gbps. From the graph, it is observed that with increase in fiber length, Q factor decreases and BER increases.

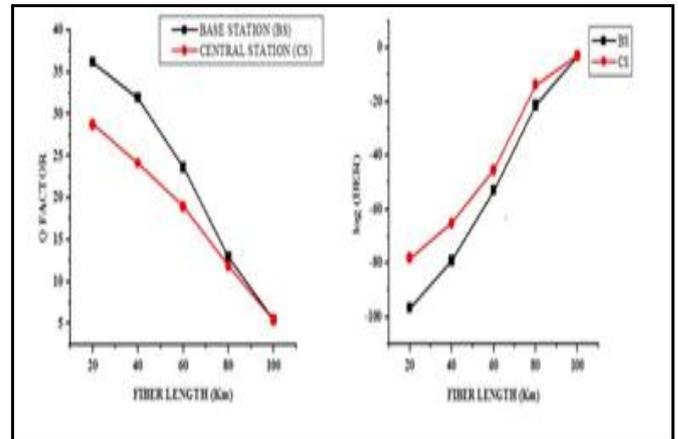


Figure 4: Variation of (a) Q factor Vs fiber length (b) log(BER) Vs fiber length.

4.2 Relationship of Q factor and BER with bit rate

The variation of Q factor and BER with bit rate is shown in Figure 5. Both Q factor and BER are analyzed for bit rates 5 Gbps and 10 Gbps. Here input power and fiber length are kept constant at 0.1 dBm and 20 Km respectively. From the analysis, it is clear that as bit rate increases, Q factor decreases and BER increases.

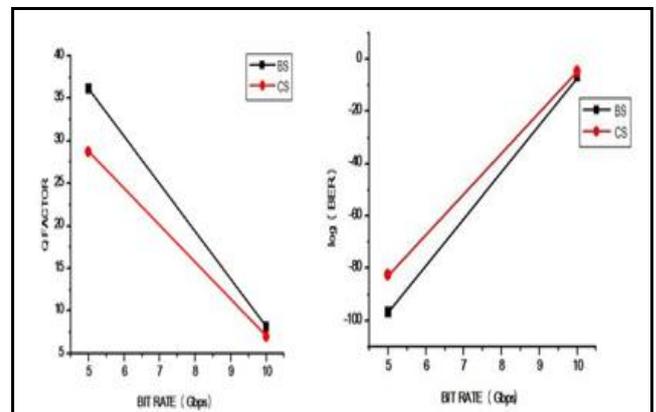


Figure 5: Variation of (a) Q factor Vs bit rate (b) log(BER) Vs bit rate.

4.3 Comparison of various digital modulation formats

Table 1: Q factor and BER values for various digital modulations

Modulation	Max. Q Factor		Min. BER	
	BS	CS	BS	CS
DPSK	20.57	15.06	$2.17e^{-94}$	$1.117e^{-51}$
OQPSK	5.65	5.39	$1.24e^{-8}$	$2.91e^{-8}$
MSK	15.28	12.54	$2.32e^{-53}$	$1.57e^{-36}$
CPFSK	10.9	8.86	$2.19e^{-17}$	$3.19e^{-28}$

The performance of digital modulation formats are analyzed strictly on the basis of Q factor and BER. The CW laser power, bit rate and fiber length are kept constant at 0.1 dBm, 1 Gbps and 20 Km respectively. Table 1 shows Q factor and BER values obtained from BS and CS respectively, for various digital modulations. From the analysis, it is observed that DPSK modulation provides better Q factor and low BER.

5. Conclusion

A full duplex radio over fiber system employing WDM and OADM techniques is simulated using optisystem 12.0. WDM enables transmission of multiple signals through a single fiber over large distance whereas OADM permits simultaneous transmission of downlink and uplink data via same single mode fiber. The performance of RoF system with various digital modulation formats is analysed. Better Q factor and low BER is achieved for all the simulations, which implies better performance of the system. RoF system with DPSK modulation not only results in high performance but also brings reduction in electronic components and elimination of electrical demodulation.

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