Design and Performance Evaluation of a UDWDM-Based Inter-Satellite Optical Wireless Communication System for Triple Play Services

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ABSTRACT:
In this paper a high-capacity inter-satellite Optical Wireless Communication (OWC) system designed for downstream and upstream triple play services (audio, data, video) using Ultra Dense Wavelength Division Multiplexing (UDWDM) across 16 channels. The system operates at a 20 Gbps data rate with channel spacing of 25 GHz, input power of 10 dBm, and provides coverage up to 420 km between satellites. The system utilizes DWDM Passive Optical Networks (PON), specifically using Duo binary non-return-to-zero (DBNRZ) modulation format for downstream transmission and supports triple play services for up to 16 users, with simulation analysis presented for both upstream and downstream. The optical inter-satellite link achieves high performance with a Quality factor (Q) of 6.78 and a Bit Error Rate (BER) of 5.828×e-011 for the downlink, and Q factor of 5.58 with BER 5.28× e-09 for the uplink. The analysis discusses eye diagrams, Q factor, data rate, and channel spacing graphical representations for detailed system evaluation of upstream/downstream performance. The flexible architecture, high speed, low BER values, and robust Q factors demonstrate suitability for current and future generations of optical satellite communications. Coverage and network access properties are described as excellent, making the approach highly relevant for modern satellite networks needing high data rates and reliable connectivity for multiple services. The solution is applicable for next-generation satellite constellations—where reliable, high-capacity OWC links are necessary for data-intensive triple play applications (voice, video, and internet/data). The use of modulation techniques (DBNRZ) and UDWDM enables spectrum efficiency and scalability, critical in satellite backbone applications. This research demonstrates a promising approach for efficient, scalable, and high-performance inter-satellite optical networks, addressing the needs of future broadband and data distribution in space, and proving potential for next-generation space-based triple play services.
KEYWORDS: Inter Satellite Optical Wireless Communication (IS-OWC); Passive Optical Network (PON); Ultra Dense Wavelength Division Multiplexing (UDWDM); Triple Play Services; Eye diagram; Q factor; Bit Error Rate (BER), Free Space Optics.

INTRODUCTION:

Optical transport capacities have been growing significantly in the last few years following the rapid growth of internet traffic. Communication system requires large bandwidth and large number of users. Optical Passive Networks plays an important role to meet the requirement of users [1]. The optical data transmission rate can burst up to Terabit per Second (Tb/s) [2]. Optical fiber is used support large number of users because it has large bandwidth. In optical transport system, Multi Carrier Modulation (MCM) gives better results as compare to Single Carrier Modulation (SCM) due to its ability to reduce the effect of selective fading and decreases Inter Symbol Interference (ISI).

With the rapid growth of internet data traffic and high demand of bandwidth, Passive Optical Network (PON) is the most popular and lowest cost system which enables high speed access for users [3]. Passive Optical Network is that type of technology which implements a point to multipoint network. Optical Communication systems design, which includes multiple signal channels, different modulation format, nonlinear devices, is highly complex and labor intensive. So that, advanced software tools make the design and analysis of these systems quick and more efficient. Optical Wireless technology is very attractive solution for transmission of high speed data to the short range distances. To increase the overall network capacity of Wavelength Division Multiplexing systems, high spectral efficiency modulation formats coupled with high per channel bit rates are being pursued as potential solution [4]. For the advancement of technology, Passive Optical Networks (PONs) format is used with Wavelength Division Multiplexing (WDM) system. Wavelength Division Multiplexing Passive Optical Network (WDM PON) is better technology for future broadband access network due to its feasible data delivery for network subscribers.

Ultra Dense Wavelength Division Multiplexing (UDWDM) is the most recent phenomenon for the advancement of fiber optic transmission technology. Ultra Dense Wavelength Division Multiplexing is a technology that can transmit multiple data simultaneously over the single fiber. This technology, which can fully utilize the free space bandwidth, is expected to enhance the transmission rate of a Free Space Optic (FSO) communication [7]. Free Space Optics communication system using Dense Wavelength Division Multiplexing technology is very best solution in providing high data rate transmission with very low Bit Rate Error (BER).

The simulation work on Passive Optical Network over Radio of Fiber for triple Play services proving access of Audio Data and Video to 16 Users [8]. Ultra Dense Wavelength Division Multiplexing Passive Optical Network (UDWDM PON) based on Duo binary non return to Zero (DBNRZ) format for downstream. The inter satellite link at 20 GB/s with channel spacing 25GHz and input power 20dBm, covered the distance up to 420km. To shows the good performance of the proposed system, its eye diagram, optical spectrum and Q factor are shown. The analyze system will be highly useful for present and next generation optical communication between satellite.

System set up

The growing demand for commercial software for simulation and design of optical communication system has led to the availability of a number of different software solutions. In optical communication network, software which simulates and analyzed the results of the system is opti system. With the advancement of technologies opti system 14.0 is useful and innovative optical communication system simulation tool for designing, testing and optimization of optical link.

In optic system software tool a component library is present which contains a various numbers of components. To represent these components icons are used in opti system. With the help of opti system software tool network achieves good and efficient results. The proposed 16×20Gbps ultra dense wavelength division multiplexing passive optical network optical communication system as shown in Figure 1.1 is modeled by using opti system software. Network shows full duplex communication from Optical Line Terminal (OLT) to Optical Network Unit (ONU) or vice versa.

Figure 1.1 depicts the design of ultra-dense wavelength frequency division multiplexing based passive optical network by using Triple play services. Information speed of the bidirectional latent optical system is taken as 20 Gbps for downstream and 20 Gbps in the uplink course. As a matter of first importance, so as to begin the correspondence pseudo random data generator is used which generates the binary data bits such as tributaries of 1's and 0's? Serial bits are modulated with coherent optical orthogonal division multiplexed modulation. System details are recorded in Table.1

Parameters	**Values**
Modulation	DBNRZ
Type of Signal	Video, Voice/Data
Capacity	16 Channels
Power	10dBm
Data Rate	20 GB/s
Frequency Spacing	25 GHz
Transmission Distance	420 Km
Centre Frequency	193.1 THz
Bandwidth	80 GHz
Photo Detector	APD
Wavelength Range	1550 nm
Dark Current	10Na

Table.1 Parameters of the proposed System

Radio over fiber system based on dense wavelength division multiplexing is represented by the block diagram is shown. The network consists of transmitter, receiver and free space communication channel between them. The video signal is send by two sine pulse generators and electrically adder to the power combiner. Data/Voice signal are transmitted through pseudo random bit sequence generator (PRBS) which is operated at 20 GB/s to generate a random sequence with different mode of operation. At the optical line terminal side, there are 16 distributed laser sources, followed by Duo Binary Non Return to Zero (DBNRZ) modulation scheme. Frequency starts from 193.1 THz with 25 GHz channel spacing to mitigate effects of cross talk in dense wavelength division multiplexing. Continuous wave laser is modulated by DBNRZ using 20dBm power and 20GB/s data rate to generate the desired downstream signal. The signal is multiplexed by a Wavelength Division Multiplexer ES (Equally Spaced) combines the 16 different wavelengths and transmit overall by optical spectrum analyzer for inspection.

The aggregate signal is sent over 420km long Single Mode Fiber (SMF). For downstream transmission symmetrical dispersion compensation is used because it has better contraction of pulse after 25km. The SMF which we used here has the attenuation of 0.2db/km, chromatic dispersion of 16.75ps/ (nm.km) and dispersion slope of 0.075. All the dispersion compensation fiber and amplifier are studied and implemented after calculation for optimal power and length. Whole loop is made up 7 times of 25km SMF, 10km Dispersion Compensation Fiber (DCF) and 25km SMF with 3 amplifiers of 5db gain. In the Remote Note (RN), the WDM signals are de multiplexed by DEMUX ES (Equally Spaced) where signals with various wavelengths are sent to different Optical Network Unit (ONU) with channel spacing 25GHz. Next stage is of reception after transmission of WDM multiplexed signal to realize PON. At the ONU side, an optical splitter is used having a loss of 3db. After that half of the amplitude modulated signal is fed to a DPSK balance detector for wired access network, which consists of a MZ interferometer and other is detected by amplitude demodulator for wireless access network.

The signal is fed to the Free Space Optic (FSO) channel with attenuation 0.2db/km which makes the system wireless and then it is detected by direct detection with the use of Avalanche Photo Diode (APD). For the uplink, the other half of the downstream modulated signal is modulated OOK NRZ format by Reflective Semiconductor Optical Amplifier (RSOA). The reflectivity values at input and output facets of the Reflective Semiconductor Optical Amplifier as 5×10-5 and 0.99 respectively. The re modulated signal is observed back through a MUX ES (Equally Spaced) at the Remote Node (RN) via 420km long Single Mode Fiber (SMF) to the Central Office (CO) where it is de multiplexing by a DE MUX ES and received by an Avalanche Photo Diode (APD) in the Central Office (CO). APD has very high sensitivity as compare to other diodes like PIN or other optical receivers. Erbium Doped Fiber Amplifier (EDFA) is used because it having broad bandwidth; so that thousands of channels can pass through it in single time.

Free Space Optical link which we are used in the system having major advantage that it is easy to install and purely based on optical signals. It does not require any conversion of optical signal to electrical domain

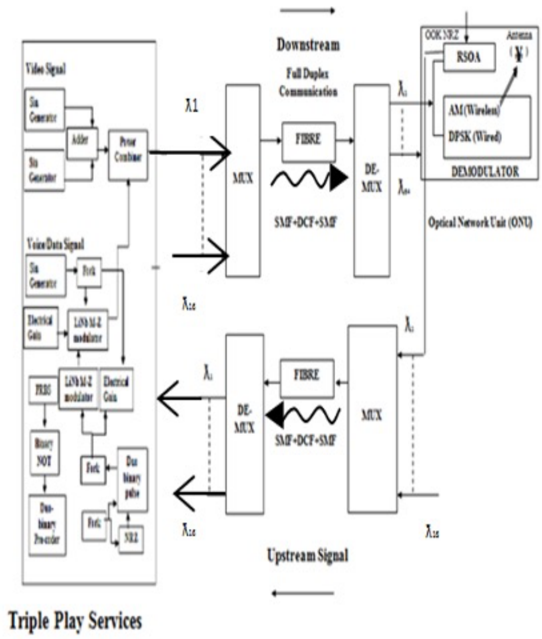

Figure.1.1 Block diagram of triple play ultra dense wavelength division multiplexing bidirectional passive optical network

In the Optical Network Unit (ONU) side, 16 users are connected which gets signals from de-multiplexer. De-multiplexer is used to separate the signal achieved from multiplexer by optical fiber. Optical splitter is used having a loss 3dB, half of the amplitude modulated signal is fed to the Differential Phase Shift Keying (DPSK) balance detector and other half is fed to Free Space Optics (FSO) channel with attenuation 0.2db/km which makes the system wireless, detected by Avalanched Photo Diode (APD) which gives better results than PIN receiver.

1. RESULTS AND DISCUSSION

The Ultra Dense Wavelength Division Multiplexing Passive Optical Network (UDWDM PON) system is simulated using opti system package from optiwave. The Bit Error Diagram of downlink at 20 GB/s of Duo Binary Non Return to Zero (DBNRZ) modulated signal with channel spacing 25 GHz are shown in Figure 1.4

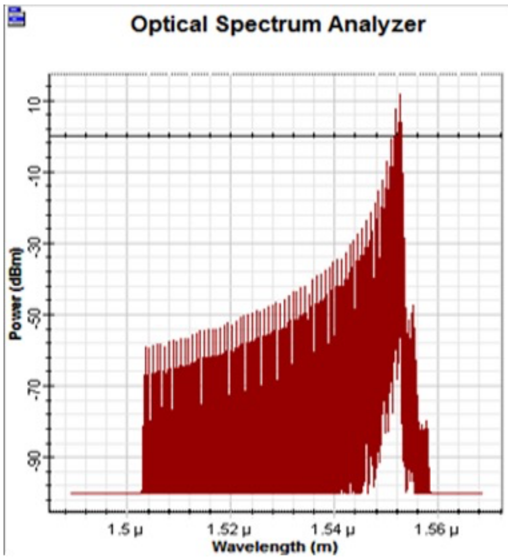

Figure 1.2 Optical Spectrum of Duo Binary NRZ modulation 16 channels by 20 Gbit/s.

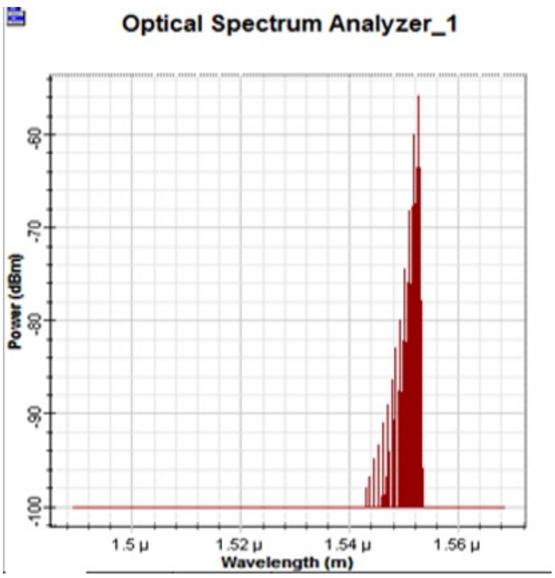

Figure 1.3 Optical Spectrum of radio over fiber modulated channels at distance of 420km.

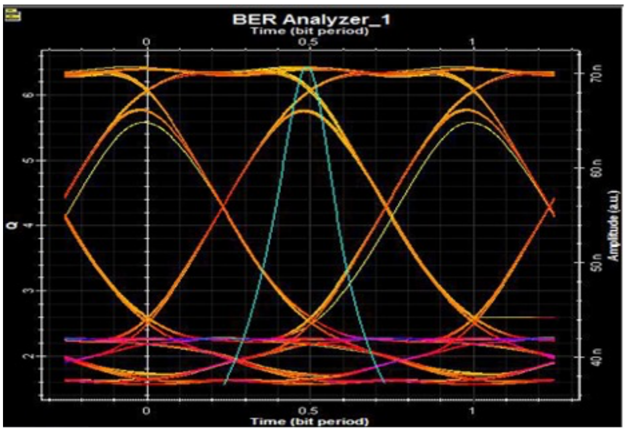

Figure 1.4 The eye graph of downstream 20Gbps modulated signal after 420km long.

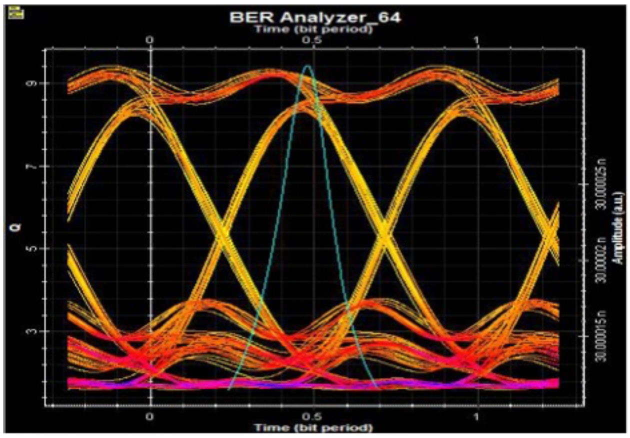

Figure 1.5 The eye graph of upstream 20Gbps modulated signal after 420km long

The OOK NRZ modulation format is used to generate the re modulation of downlink with Reflective Semiconductor Optical Amplifier (RSOA). The downlink 20Gbps signal can achieve a Bit Error Rate (BER) performance of 5.828×e-011and and Quality factor should be 6.78 and the uplink channel can achieve a Bit Error Rate (BER) performance of 5.28× e-09 and Q factor should be 5.58. The network achieves clear eye opening which means the system is error free and noise free transmission can be observed. The downstream 20Gbps signal can observe a bit error performance of and Q factor should be with Duo Binary non return to zero (DBNRZ). Results shows a clear eye opening which means system is noise free.

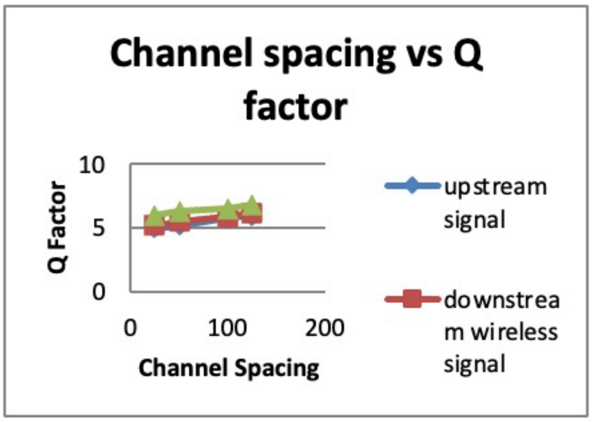

Figure 1.6 Graphical representation of system for both upstream and downstream

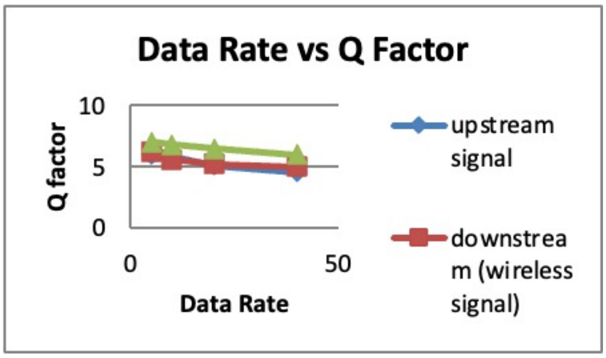

Figure 1.7 Graphical representation of system for both upstream and downstream signal

2. CONCLUSION

This proposed system is a long distance transmission up to a distance of 420 km for UDWDM system. Ultra Dense wavelength division multiplexing is very effective technique for providing high data rates with very low bit error values in optical wireless communication. Multi carrier source are based on a single laser using different wavelengths. In this work, 16 channels, each carrying 20 GB/s data are transmitted independently by using Duo Binary Non Return to Zero (DBNRZ) modulation technique for downstream signal. The performance of the design dense wavelength division multiplexing passive optical network transmission system is evaluated in terms of Q factor, Bit Error Rate (BER) and total received power and eye diagrams. We calculated the performance of the network in terms of Bit error rate, distance covered, and Q factor and observe a system with an excellent access property.

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