Analysis of Linear and Nonlinear Effects in Triple Play Providing WDMPON

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***Abstract*- FTTH is currently experiencing technological advance that provides enormous bandwidth and long reach offering triple play services such as data, voice and video on a single fiber. Passive Optical Network (PON) is a point to multipoint, fiber to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises, typically 16 to 128. Nowadays, the most used optical fiber access network configuration is Time Division Multiplexing Passive Optical Network (TDMPON), with Ethernet PON (EPON) and Gigabit PON (GPON) as the two important standards. However, it is quite likely that the TDMPONS today cannot support the band width exhausting multimedia services. Another attractive PON solution is the Wavelength Division Multiplexing PON (WDMPON) which offers enough bandwidth for multimedia broadband services and fully utilizes the optical fibre bandwidth. Realization of triple play providing WDMPON architecture is conducted.A detailed analysis of various important performance characteristics of WDMPON technology such as link performance characterization based on BER, linear and nonlinear fiber effects such as dispersion, polarization mode dispersion and Four Wave Mixing were conducted. Simulation model for WDMPON are developed using OPTSIM version 5.3 software.**

***Keywords:* Passive Optical Network, Bit Error Rate, Signal to Noise Ratio, Polarization Mode Dispersion, Four-Wave Mixing, Dispersion, Subcarrier Multiplexing**

I. INTRODUCTION

Fiber to the home (FTTH) is currently experiencing technological advance that provides enormous band width and long reach offering Triple Play services (data, voice, and video) on a single fiber. FTTH is being the best solution for providing add-on services such as Video on demand; Online Gaming, High definition television (HDTV) etc. The steady increase in the demand for broadband services and the consequent increase in the volume of generated traffic in our communication networks have motivated the need to implement next generation networks. Fiber To The Home (FTTH) is the end game for many service providers. As compared to other broadband access technologies such as Digital Subscriber Line (DSL), and cable/modem, Passive Optical Network (PON) technology seems to be the best solution to alleviate the bandwidth bottleneck in the access network. From a historical perspective, the first bandwidth breakthrough in the access network was the arrival of DSL and cable based solutions. They provided nearly a 1000 fold increase in data rates over traditional 'dial-up' modems. It is clear that because of the limited bandwidth of a coaxial cable, the complexity of the cable systems is expected to be higher than that of PONs. A lot of work can be done in better deployment of FTTH architectures in order to achieve large distance of transmission at high bit rates. More users can be accommodated by applying different transmission techniques in the FTTH architecture.

Several fiber access network architectures have been developed, such as point to point (P2P), active optical network (AON) and passive optical network (PON). Furthermore, there are two main types of PONs utilizing different resource sharing technologies, Time Division multiplexing (TDM) PON, Wavelength Division Multiplexing (WDM) PON. As good examples of TDMPON, Asynchronous transfer mode Passive Optical Network (APON), Broadband Passive Optical Network (BPON), Ethernet Passive Optical Network (EPON) and Gigabit Passive Optical Network (GPON) are well known broadband access network services. Another attractive PON solution is the Wavelength Division Multiplexing PON (WDMPON) which offers enough bandwidth for multimedia broadband services and fully utilizes the optical fibre bandwidth. In this work, realization of WDMPON architecture is done and various important performance characteristic parameters such as link performance characterization based on data or video signal quality, linear and nonlinear fiber effects such as dispersion, Polarization Mode Dispersion (PMD) and Four Wave Mixing (FWM) are analyzed. Subcarrier Multiplexing is also incorporated in WDMPON in order to eliminate the group delay in the video distribution. [1-5]

II. SYSTEM ARCHITECTURE

A. *Triple Play Providing WDMPON Architecture*

In today's communication service delivery market, there is more pressure than ever before to maximize revenue. Adding service offerings, decreasing the cost of doing business, and fine-tuning network efficiency are goals that top every provider's business plan. Triple play the bundled delivery of voice, video, and data services is the grand panacea. Properly planned and executed, triple play can indeed yield satisfied customers and a robust bottom line. Triple play, once a term used only in telecom trade communications, it is now a household phrase. The triple-play services riding on the network must perform perfectly all of the time. They demand service that is always available and always reliable. Customers simply will not wait for providers to get it right With respect to the networks core the majority of triple-play services will be transported via Ethernet carried over new or existing fiber based networks using WDM and SONET/SDH infrastructures. In the Access network, services will be provided to the end user via a derivative of FTTX network architecture. [6-10]

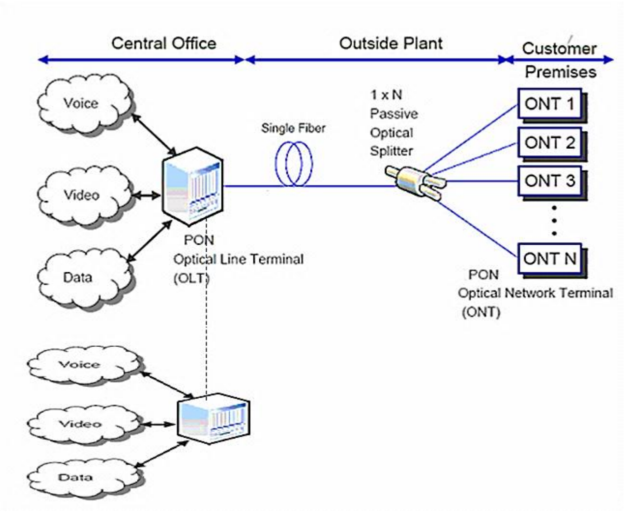

Figure 1: Triple play providing WDMPON architecture

In triple play providing WDMPON architecture data and voice can be treated as one simulation entity as Voice over Internet Protocol (VoIP) is the technique used in WDMPON. Each OLT contains data and video transmitters. The data and video of each OLT is combined. Data and video from the multiple OLTs are transmitted through the optical fiber and at the customer premises the combined data and video are splitted to 16-128 ONTs. The ONTs contain corresponding data and video receivers for the reception of data and video from the combined signal.

B. Subcarrier Multiplexing incorporated WDMPON

In signal processing, group delay is a measure of the time delay of the amplitude envelopes of the various sinusoidal components of a signal through a device under test, and is a function of frequency for each component. All frequency components of a signal are delayed when passed through a device such as an amplifier, a loudspeaker, or propagating through space or a medium, such as air. This signal delay will be different for the various frequencies. The delay variation means that signals consisting of multiple frequency components will suffer distortion because these components are not delayed by the same amount of time at the output of the device. This changes the shape of the signal in addition to any constant delay or scale change. A sufficiently large delay variation can cause problems such as poor fidelity in audio or Inter Symbol Interference (ISI) in the demodulation of digital information from an analog carrier signal. Sub Carrier Multiplexing is a technique which is used to compensate the group delay in the multiple frequency transmission. Optical Sub Carrier Multiplexing is a scheme where multiple signals are multiplexed in the Radio Frequency (RF) domain and transmitted by a single wavelength. A significant advantage of SCM is that microwave devices are more mature than optical devices; the stability of a microwave oscillator and the frequency selectivity of a microwave filter are much better than their optical counterparts. In addition, the low phase noise of RF oscillators makes coherent detection in the RF domain easier than optical coherent detection, and advanced modulation formats can be applied easily. A popular application of SCM technology in fiber optic systems is analog Cable Television (CATV) distribution. SCM has been incorporated in WDMPON in order to eliminate the group delay in multiple frequency transmission. [11]

III. SIMULATION OF TRIPLE PLAY PROVIDING WDMPON

The transmission characteristics of triple play providing WDMPON is realized using Optsim version 5.3. Figure 2 shows the simulation layout of the system.

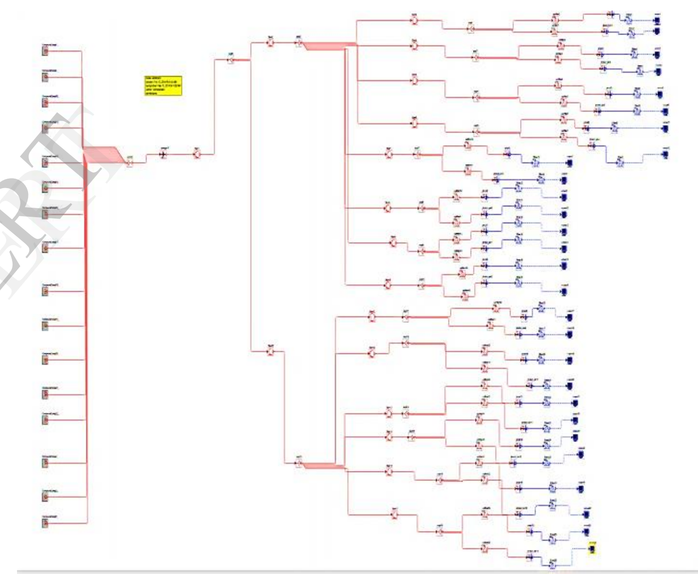

Figure 2: Simulation layout of triple play providing WDMPON

The data is transmitted at 10 Gbps. The data signal and video signal is combined by means of a combiner in each OLT and combined signal from OLTs are transmitted through ITU-T G.562 fiber of length 20 km. The splitter splits the combined signal and given to the data and video receivers at the ONTs. PIN photo detector at the receivers is a device that converts optical signals to electrical signals. In the data receiver filter is used to separate the channel information from the noise that has been added. In the video receiver individual channels are separated by Band Pass Filters (BPF), which transmit optical power within a definite wavelength only and reflect or absorb the rest. The eye diagrams for data and video signals are obtained from the 16 ONTs.

The eye diagram technique is a simple but powerful measurement method for assessing the data handling ability of a transmission system. This method has been used extensively for evaluating the performance of wire systems and can be applied to optical fiber data links. The eye pattern measurements are made in time domain and allow the effects of waveform distortions to be shown immediately on an oscilloscope. Several system performance measures can be derived by analyzing the display. If the signals are too long, too short, poorly synchronized with the system clock, too high, too low, too noisy, or too slow it will be observed from the eye diagram.

The eye diagrams obtained from the receivers gives the Q Value and Bit Error Rate which are used for the analysis.

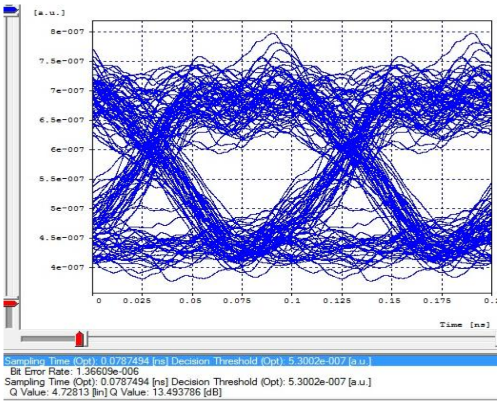

Figure 3: Eye diagram obtained for data transmission from User 1

The Q Values are obtained from the 16 users. The analysis of data transmission in WDMPON is shown in the Figure 4

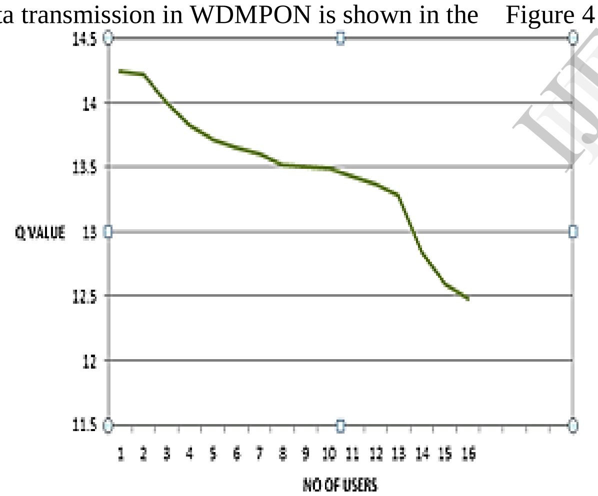

Figure 4: Graph showing the variation of Q Value with number of users in data transmission.

From the results obtained it is clear that as number of users increases, the Q Value decreases and BER increases for data transmission. The eye diagrams for video transmission are also obtained from the 16 users and at user 3 are shown in the Figure 5.

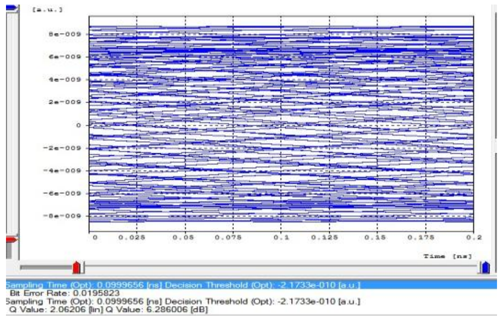

Figure 5: Eye diagram obtained for video transmission from User 3

In the video transmission also, Q values are obtained from the 16 eye diagrams at the different users. In analog video transmission also, as number of users increases the Q value decreases and BER increases.

The variation of Q Value with different number of users in video transmission is shown in the Figure 6.

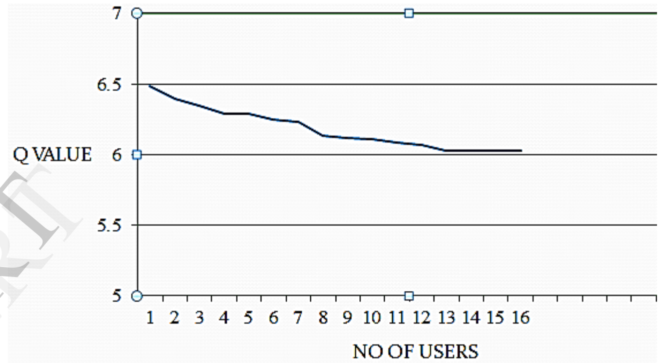

Figure 6: Graph showing the variation of Q Value with number of users in video transmission.

Dispersion is the spreading of light pulses as they travel down optical fiber. Dispersion results in distortion of the signal. The effect of dispersion is analyzed in triple play providing WDMPON. The dispersion length (L_D) is an important parameter in the analysis of dispersion.

$$L_D = \frac{T_0^{\,2}}{|\beta_2|} \qquad (1)$$

where T_0 is the initial pulse width and β_2 is the dispersion parameter and this value is taken as -20.

$$T_0 = \frac{1}{(2 \times Bit\ rate)} \qquad (2)$$

The dispersion length serves as a convenient normalizing measure for the distance 'z' in analyzing the effect of dispersion. The effect of chromatic dispersion can be neglected if z << L_D. The effect of dispersion is analyzed at 20 Gbps. From equation, the dispersion length is obtained as 31.25 km. The effect of dispersion is analyzed at different lengths of fiber such as 20 km, 25 km, 35 km and 40 km. The eye diagrams are obtained for all these lengths from the 16 ONUs. A graph is plotted by using the Q Values obtained from the 16 users at different fiber lengths. The analysis of dispersion in WDMPON is shown in the Figure 7.

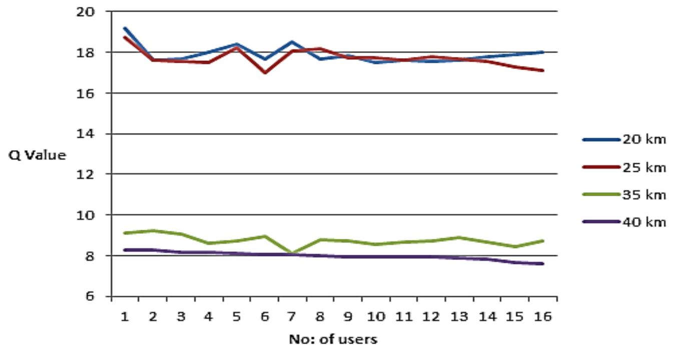

Figure 7: Graph showing the analysis of dispersion.

As the length of the fiber increases, the Q Value decreases. The effect of dispersion is analyzed at 20 Gbps. The Q Value shows high values at 20 km and it decreases slightly when the length of the fiber is increased to 25 km. The dispersion length is 31.25 km. From the results obtained it is clear that after this length, Q value shows a drastic decrease due to the effect of dispersion.

In high speed optical communication systems working at data rates of 10 Gbps and beyond, signal distortion caused by Polarization Mode Dispersion (PMD) is a major limitation of the transmission distance and this lead to the degradation of system performance. PMD is a source of pulse broadening which results from fiber birefringence and it became a limiting factor for optical fiber communications at high transmission rates. It is due to both intrinsic and extrinsic factors. For analyzing PMD, polarization mode dispersion co-efficient is varied from 0 to 180 PS/√km and eye diagrams are observed. The analysis of PMD is shown in the Figure 8.

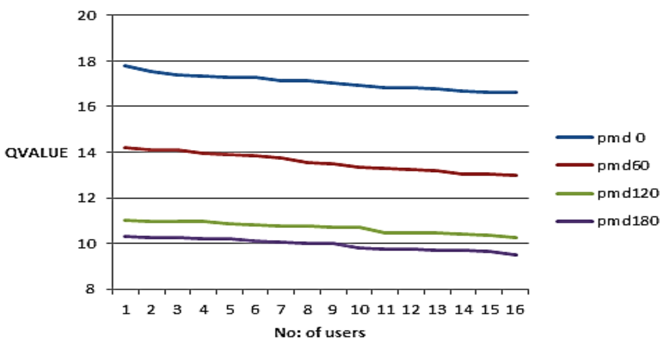

Figure 8: Graph showing the analysis of PMD

From the results obtained, it is clear that the performance of the system is getting weakened as PMD co-efficient increases from 0 to 180 PS/√km. The Q Value is maximum at 0 PS/√km and the Q Value goes on decreasing as PMD co-efficient increases. At 180 PS/√km Q Value is minimum and BER is maximum. At high bit rates it is important to consider the effect of nonlinearities. The nonlinearity length is a crucial parameter in the analysis of nonlinear effects in WDMPON.

$$L_{NL} = \frac{1}{\gamma P_0} \quad (3)$$

where γ is the nonlinear co- efficient and P_0 is the input power of the laser. The input laser power is set as 5dbm and the nonlinearity length is obtained as 66.66 km. After this length the signal gets distorted and the Q Value obtained at different ONUs was minimum of the order of 6.020600 db. The eye diagram showing the effect of nonlinearity at 67 km length is shown in Figure 9.

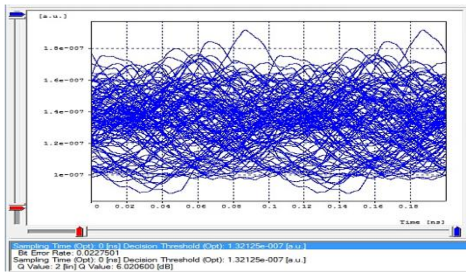

Figure 9: Eye diagram obtained at 67 km

Four Wave Mixing (FWM) is the process by which, electromagnetic fields of different frequencies, propagating simultaneously in a nonlinear medium interacts through the third order nonlinear optical susceptibility of the medium, resulting in the generation of new frequencies. Firstly, it may create new frequency components, which will reduce the power of original optical signals, and hence affect the performance of system. The optical spectrum at the input and output of the fiber at 16 dbm power is shown in the Figure 10.

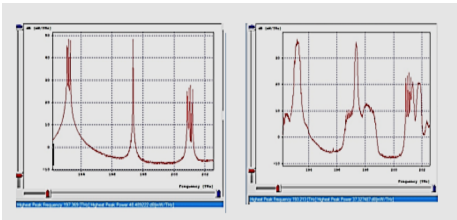

Figure 10: Optical spectrums showing the effect of four wave mixing at 16dbm.

From the Figure 10 it is clear that new frequencies are generated at the fiber output due to FWM. The optical spectrum at the input and output of the fiber at 20 dbm power is shown in the Figure 11.

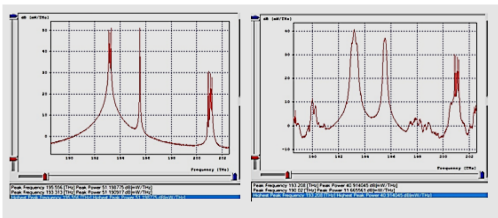

Figure 11: Optical spectrums showing the effect of four wave mixing at 20dbm

More number of new frequencies are generated at the fiber output due to FWM at 20 dbm power. The effect of FWM increases while increasing the optical power and power of the optical signals decreases due to FWM.

III. SIMULATION OF TRIPLE PLAY PROVIDING WDMPON INCORPORATING SCM

The group delay experienced in the video transmission in WDMPON was eliminated by incorporating Sub Carrier Multiplexing in WDMPON. Optical Sub Carrier Multiplexing is a scheme where multiple signals are multiplexed in the Radio Frequency (RF) domain and transmitted by a single wavelength. The transmission characteristics of Subcarrier Multiplexing incorporated triple play providing WDMPON for 4 users is realized using Optsim version 5.3 software. The eye diagrams are obtained from the 4 ONUs. Q value obtained was higher than the normal transmission in the case of data transmission which is of 29.973079 db. The simulation layout of the system is shown in the Figure 12.

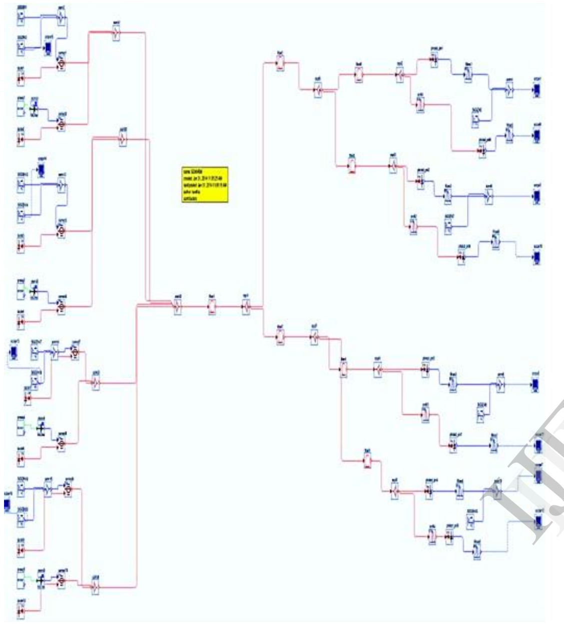

Figure 12: Simulation layout of triple play providing WDMNPON

Analog channels from 199.25 to 217.25 MHz each of 6 MHz wide are multiplexed with sub carrier of frequencies of 220 MHz to 238 MHz each of 6 MHz wide. The data and video signals are combined at each OLT by means of an optical combiner and combined signal from OLTs are transmitted through a standard single mode fiber of length 20 km. Then the optical splitter splits the combined signal and transmitted through a feeder cable of length 4.5 km. In the receiver side the data and video signals are received by the corresponding receivers. The transmitted video channel is properly retrieved from the combined video signal by using the corresponding subcarrier frequencies. In signal processing, group delay is a measure of the time delay of the amplitude envelopes of the various sinusoidal components of a signal through a device under test, and is a function of frequency for each component. The group delay introduced in the video transmission is eliminated by incorporating the technique of SCM

The comparison of outputs obtained for transmission of 199.25 MHz frequency in WDMPON and SCM incorporated WDMPON is shown in Figure 13

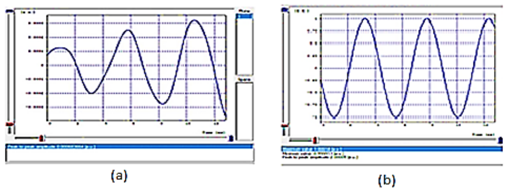

Figure 13: Comparison of the outputs of transmission 199.25 MHz frequency (a) output obtained from WDMPON (b) output obtained from SCM incorporating WDMPON

The group delay introduced in frequency transmission is eliminated by the technique of SCM.

CONCLUSION

Triple play providing WDMPON architecture with 16 users was realized. A detailed analysis of various important performance characteristics of WDMPON technology such as link performance characterization based on BER, linear and nonlinear fiber effects such as dispersion, polarization mode dispersion and four wave mixing were conducted. In data and video transmission, as number of users increases, the Q Value decreases and BER increase. The effect of dispersion is analyzed at 20 Gbps. The Q Value shows high values at 20 km and it decreases slightly when the length of the fiber is increased to 25 km. After the dispersion length, Q value shows a drastic decrease due to the effect of dispersion. In the analysis of Polarization Mode Dispersion, the performance of the system is getting weakened as PMD co-efficient increases from 0 to 180 PS/√km. The Q Value is maximum at 0 PS/√km and minimum at 180 PS/√km. The Q Value is minimum at all ONUs after the nonlinearity length. The effect of Four Wave Mixing was increased while increasing the input optical power. The subcarrier multiplexing technique is incorporated in the WDMPON in order to eliminate the effect of group delay in the video transmission.

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