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Performance Analysis of Modulation Formats for Next Generation Passive Optical Networks

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Abstract-In this research paper comparison of efficient binary modulation formats like Chirped-NRZ, Chirped-RZ, RZ-50 %, Duobinary and AMI is carried out for GPON networks. Their performance is evaluated in terms of bit rates versus fiber link length. Chirped-NRZ comes out to be optimal modulation format for high speed and long reach optical communication. Quality of the received signal is analyzed by considering parameters like Q-factor and BER. Three different data rates i.e. 10 Gbps, 40 Gbps and 100 Gbps are selected to evaluate the performance of optical communication system whereas optical fiber length is varied from 40 km to 140 km. Simulations are performed on licensed version of Optisystem v.14.

Keywords-Optical Fiber Communication, Intensity Modulation, Modulation Formats, Bit Error Rate, Passive Optical Networks

I. INTRODUCTION

In current scenario optical networks are gaining immense attention of the researchers due to their high bandwidth, high data rates and increased reliability. With the surge in demand of high bandwidth each customer would require data rate in Gbps for triple play services (video, audio and data transfer). The services like high definition TV and video on demand require high bandwidth with high speed internet access (HSI). Optical fibers to subscribers (FTTx) provide the most optimum solution to cope with all these demands. Most of the FTTx models are designed on the fashion of passive optical networks (PON). Gigabit PON (GPON) is the most emerging architecture in next generation networks (NGN). For long haul optical transmission many optical modulation formats have been proposed [i-ii]. Appropriate type of digital modulation is the significant part of optical communication system. Higher spectral efficiency can be achieved by selecting most suitable modulation format in PON. In this paper comparison of various modulation formats is investigated for different data rates and transmission distances. PON is a cost-effective approach consuming less energy per bit. It is point-to-multipoint topology having splitter based optical distribution network (ODN) [iii-iv]. The PON optical line terminal (OLT) at the central office (CO) is linked with numerous optical network units (ONUs) placed at far end through one or more passive optical splitters [v-vi].

The Next Generation Networks necessitates the exploration of the optimum schemes for increased capacity and spectral efficiency (b/s/Hz) using different modulation formats. To improve the system performance, telecom networks and communication systems require the exploitation/implementation of advanced modulation formats to diminish the impact of degradation sources [vii]. The selection of optimum modulation format depends upon various factors like fiber types, channels spacing, per channel data rates etc [viii-ix]. Direct modulation or Intensity modulation is the simplest way to perform optical modulation. Here, binary data is modulated with the laser drive current using basic On-off keying (OOK) modulation technique. Classification of different intensity modulation formats is shown in Fig. 1. Intensity modulation formats like non-return to zero (NRZ), chirped-NRZ, vestigial side band (VSB) NRZ, return to zero (RZ) 33 %, RZ-50 %, RZ-67 %, chirped-RZ, alternate chirped-RZ,carrier suppressed-RZ (CSRZ), duobinary (DB) and alternate mark inversion (AMI) are investigated for different data rates and different fiber lengths.

NRZ is considered to be the dominant modulation format in intensity modulated optical communication system. From the transmitter and receiver point of view it requires lower electrical bandwidth as compared to the RZ modulation format. It is less sensitive to laser phase noise as compared to phase shift keying (PSK). NRZ modulated optical signal has the most compact spectrum as compared to the other modulation formats [ix]. On the other side NRZ scheme is not reliable for high capacity optical systems like Dense wavelength division multiplexing (DWDM) systems. NRZ has poor tolerance against cross-phase modulation and residual chromatic dispersion in overall DWDM system [x].

RZ modulation format has wider spectrum than the NRZ. Dispersion causes to broaden the RZ pulses more rapidly. But this behavior comes out to be advantageous because as pulse broadens, its peak decreases. This makes RZ modulation format more robust against the non-linear effects. Infect the non-linear effect is directly proportional to the signal intensity [xi-xii]. Both RZ and NRZ modulation formats can be implemented through dual-port Mach-Zehnder modulator (MZM). MZM transforms the incoming binary coded electrical signal into OOK optical signal. Different modulation formats can be formed depending on the drive conditions of this modulator. By changing the bias voltage of MZM different RZ modulation formats with duty cycle 33%, 50 % and 67 % can be achieved [xiii].

Duobinary signal format is sub-class of correlative coding format shown in Fig. 1 in which inter symbol interference (ISI) is intentionally introduced into the transmitted signal to achieve the required Nyquist rate. At the receiver decoding is performed to remove the effect of ISI [xiv-xv]. Duobinary modulation format is more robust against chromatic dispersion as compared to other modulation formats [xvi]. But its tolerance against non-linear effects is the same as RZ and NRZ modulation formats. So, it can be applied to systems having weaker non-linear effects. For data rates higher than 40Gbps, DB modulation is preferred as compared to OOK modulation [xvii-xviii].

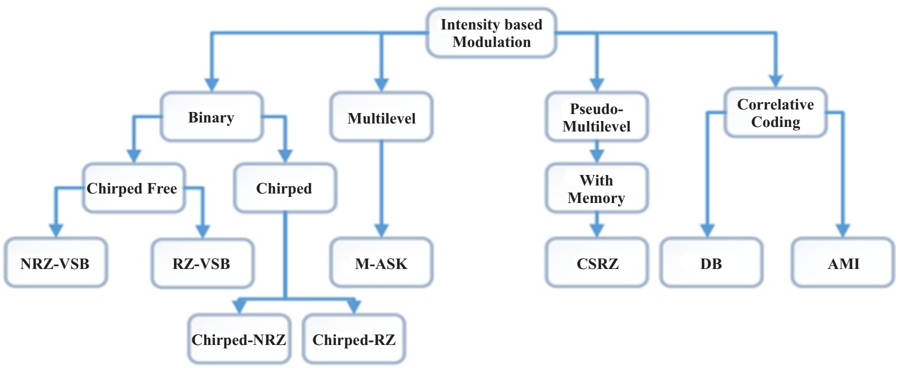

Fig. 1. Classification of different intensity modulation formats

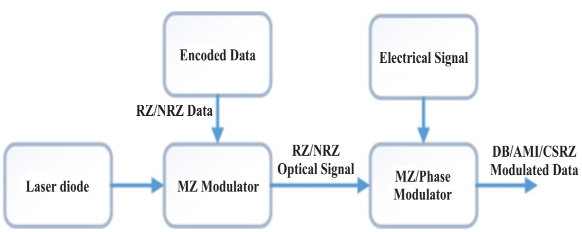

Fig. 2. Generation of RZ, NRZ, CSRZ, DB and AMI optical signals

In CSRZ modulation format the phase of the optical carrier is changed for each bit interval. In CSRZ half of the bits have positive phase and the others have negative phase. Due to alternate phase change high power components in signal spectrum does not exist. For data rates, higher than 40 Gbps CSRZ shows superior tolerance against non-linearity. Two MZ intensity modulators are needed to generate CSRZ optical signal as shown in Fig. 2.

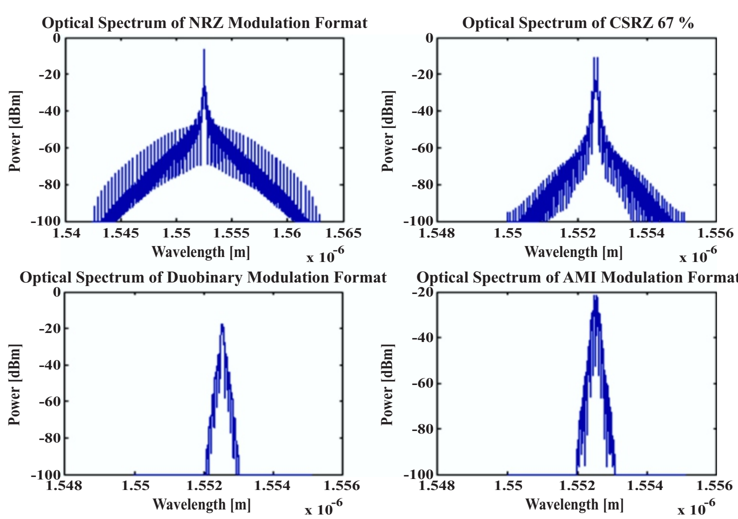

Fig. 3. Optical spectrum of different modulation formats

Non-chirped RZ optical signal is generated by the first modulator. Second modulator is used to produce 180-degree optical phase shift between adjacent bits. Fig. 3 shows the optical spectrum of different modulation formats. The baseband complex envelope of the transmitted optical duobinary signal can be written mathematically as [xix-xx].

$$E_D(\tau) = \sum_m O_m g(\tau - mT_b) \quad (1)$$

In (1), O_m represents the transmitted binary data which is either +1 or -1, having equal probability of occurrence. The term $g(\tau)$ can be written as

$$g(\tau) = \frac{1}{2}[h(\tau) + h(\tau - T_b)] \quad (2)$$

In (2), h(τ) is the transmitted pulse shape. From (1) and (2) it can be shown that Power Spectral Density (PSD) of the optical duobinary signal $E_D(\tau)$ is given by

$$P_D(f) = |H(f)|^2 cos^2(\pi f T_b) \quad (3)$$

Here in (3), H(f) is the Fourier transform of a time limited pulse $h(\tau)$.

Major difference between duobinary and AMI modulation formats is the encoding process. An inverter is not needed in case of AMI modulation format which makes it cost efficient. AMI is less susceptible to dispersion and nonlinearities. The equation for the baseband complex envelope of the transmitted AMI optical signal is similar to (1). But the equation for $g(\tau)$ in case of AMI is given by

$$g(\tau) = \frac{1}{2}[h(\tau) - h(\tau - T_b)] \quad (4)$$

From (1) and (4), the expression for PSD of the AMI signal can be written as

$$P_D(f) = |H(f)|^2 sin^2(\pi f T_b) \quad (5)$$

II. Simulation Model

Basic working model of GPON network is shown in Fig. 4. The GPON model consists of N number of ONUs connected to the OLT via propagation medium. N may be 32, 64 or 128 depending upon the user density. Performance of different modulation scheme is investigated from OLT to remote node (RN). At OLT, light signal is modulated with binary encoded data either RZ, NRZ, DB or AMI through MZ modulator. Further the modulated optical signal is transmitted over optical single mode fiber. To compensate dispersion losses dispersion compensating fiber (DCF) is employed. The compensated signal is boosted up through EDFA amplifier to reduce attenuation [xxi]. At the remote node, photodetector (PD) is used to receive the incoming optical signal and converts into electrical signal for further processing. Eye-diagram analyzer is used to analyze the quality of the signal via quality factor and Bit error rate. The parameters used for different components are listed in Table I.

III. Results and Discussion

Based on the above system prototype, comparison of different types of modulation formats including NRZ, RZ, DB and AMI is done and their behavior is examined for different fiber lengths and data rates. In Fig. 5 comparison of different NRZ modulation formats like non-chirped NRZ, VSB-NRZ and chirped-NRZ is analyzed at 10 Gbps of data rate. The graph is plotted between fiber length varying from 40 km to 140 km and quality factor values ranging from 0 to 140. The purpose here is to select the best NRZ modulation scheme for further comparison with other modulation formats in GPONs. It can be seen from the graph that chirped NRZ outperforms the rest of the NRZ schemes.

TABLE I
System Parameters

Parameter	Value
Laser power	10 dBm
Channel wavelength	1550 nm
Modulator extinction ratio	20 dB
DCF attenuation	0.6 dB/km
DCF dispersion	-80.75ps/nm/km
Amplifier gain	0-16 dB
Noise figure	4.5 dB
Responsivity of receiver	1 A/W

In Fig. 6, comparison of different RZ modulation formats i.e VSB-CSRZ, Chirped-RZ, CSRZ-67%, RZ-33%, and RZ-50% and Alternate Chirp-RZ, is presented for data rate of 10 Gbps. Graph shows different behavior of RZ schemes for different range of fiber length. RZ-50% shows better performance than CSRZ-67% from 40 km to 140 km and then onwards CSRZ-67% shows comparable resultsto that of RZ-50%but at this point the Q-factor became too low. As a whole performance of RZ-50% outperforms all other RZ modulation formats from 40 km to 140 km.

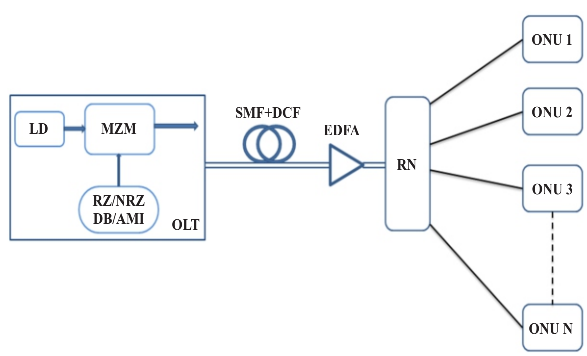

Fig. 4. Basic model of proposed gigabit passive optical network

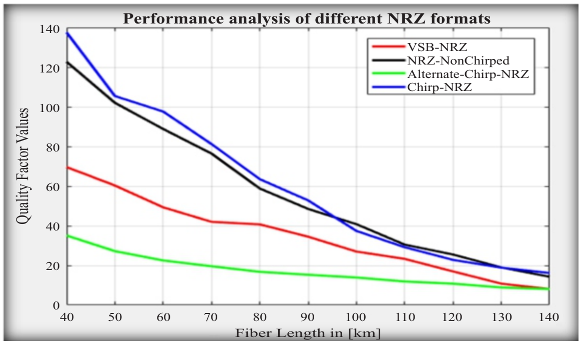

Fig. 5. Performance analysis of different NRZ formats

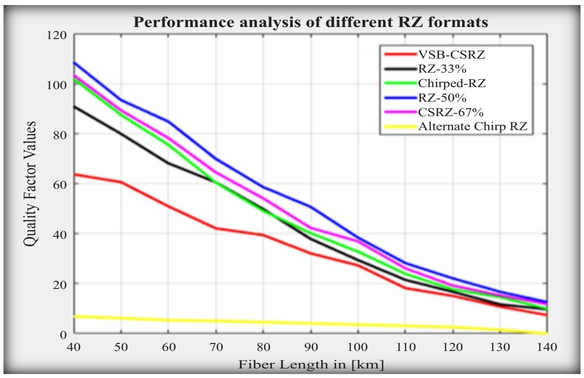

Fig. 6. Performance analysis of different RZ formats

In Fig. 7 performance of different modulation formats is shown by varying fiber length at data rate of 10 Gbps. Chirped-NRZ and RZ-50 % modulation formats which shows excellent performance in Fig. 5 and Fig. 6 are further tested and compared with DB and AMI schemes.

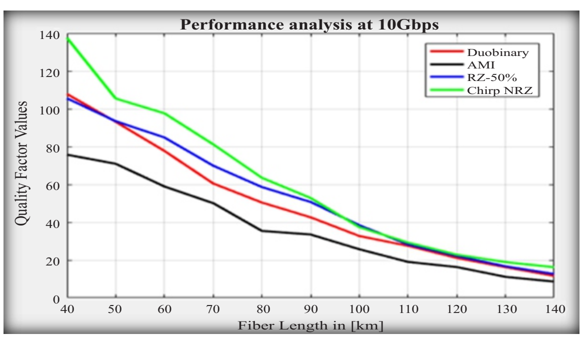

Fig. 7. Performance analysisat 10 Gbps

Our aim is to select the best modulation format for reliable and successful communication for GPON. It is clear from the graph that Chirped-NRZ has better tolerance against dispersion and nonlinearities and results in better eye opening and quality factor values. It means during the transmission from ONU to OLT Chirped-NRZ results in good quality signal and minimum Bit Error Rate (BER). Further the above described modulation formats are tested and analyzed for data rates of 40 Gbps and 100 Gbps in Fig. 8 and Fig. 9. Again, Chirped-NRZ shows acceptable values of quality factor.At40Gbps a drastic decrease in performance of all modulation formats is observed at higher lengths of fiber. At same data rate DB format shows better result till 60 km of fiber length but than AMI dominates DB modulation format. When the data rate is increased upto 100 Gbps as shown in Fig. 9, the quality factor found degraded reaching zero values for all the three selected modulation formats.

At 100 Gbps of data rate, nonlinearities and residual dispersion degrades further quality of the signal and results in high BER and low-quality factor values. In Fig. 10, the effect of BER on different modulation formats is shown. BER shows the ratio between the effected bits and transmitted bits. According to [xx], for telecommunication systems it should be in range of 10^{-9} to 10^{-12}. It is clear from the graph that for the case of DB, AMI and RZ-50 % modulation schemes the value of BER increases gradually with the increase in fiber length in GPON. Upto 90 km Chirped-NRZ and RZ-50 %modulation formats have lower BER but at the same length DB and AMI have high values of BER. Among all the modulation formats Chirped-NRZ shows the best BER values while AMI has the worst BER results.

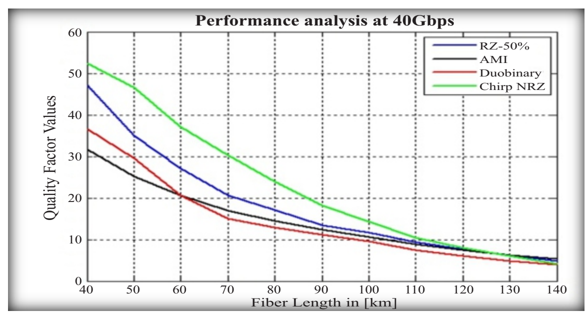

Fig. 8. Performance analysis at 40 Gbps

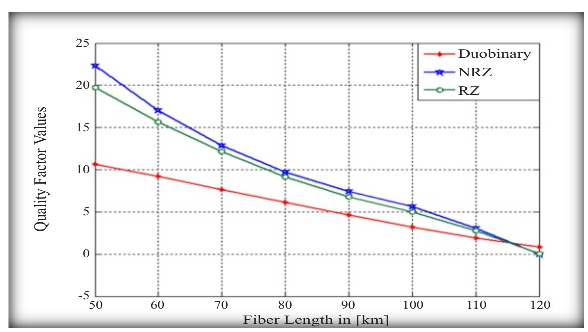

Fig. 9. Performance analysis at 100Gbps

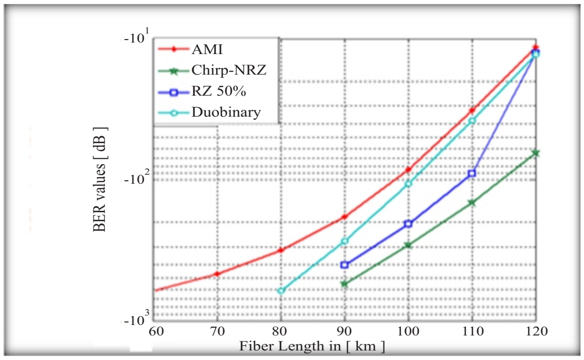

Fig. 10. BER analysis at 10 Gbps

IV. CONCLUSION

The comparison & analysis of different modulation formats for next generation passive optical networks like non-chirped NRZ, VSB-NRZ and Chirped-NRZ based on their Q- factor values & BER shows that Chirped-NRZ outperforms all the other NRZ modulation formats. The detailed comparison of different RZ modulation formats like RZ-33 %, RZ-50%, RZ-67%, Chirped-RZ, Alternate Chirp-RZ, and VSB-CSRZ, shows that RZ-50 % is best among all the RZ modulation formats. Further RZ-50 %, Chirped-NRZ, DB and AMI are analyzed at 10 Gbps, 40 Gbps and 100 Gbps of data rates by varying different fiber lengths which shows that Chirped-NRZ performs best in terms of low BER and higher quality factor whereas AMI shows highest BER among all. For selected fiber lengths i.e. 40 km to 140 km, different Q-factors are observed ranging from 0 to 140. Also, significant decrease in Q-factor alongwith higher BER observed at higher fiber lengths (above 120 km) where the recovery of received signal is difficult in all the modulation schemes due to poor quality signal suffered by greater linear and non-linear impairments.

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