Simulation and Comparison of Advanced Modulation Formats for Wavelength Reuse in High-Speed WDM-PON System

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Abstract. In recent years, the innovation in devices and schemes of physical layer plays an important role in promoting the development of WDM-PON (Wavelength Division Multiplexing Passive Optical Network). Among the key technologies adopted in the WDM-PON system, advanced modulation formats at downstream and remodulations at upstream attract the most attention. DPSK (Differential Phase Shift Keying Modulation), FSK (Frequency-Shift Keying), IRZ (Inverted Return-to-Zero) and Manchester are four of the most common formats and each of them was studied before, but, however, nobody compared and analyzed them together. So, we will do the job by numerical simulation in this paper. During our simulation, the 40-Gbit/s FSK is generated through the demodulation of two DPSK signals and 40-Gbit/s Manchester signal bases of employing a delay interferometer (DI) and an optical delay line as format conversion device to convert RZ-DPSK (Return to Zero-Differential Phase Shift Keying Modulation) coding to Manchester coding, both of the two format generation schemes are novel. Meanwhile, this paper emphasizes the input optical power and dispersion tolerance, which both related to the sensitivity of the system. Analyze the sensitivity with DPSK, FSK, IRZ and Manchester, and then compare the four advanced modulation formats.

1. Introduction
In the 21th century, with the popularity of the Internet worldwide and the rapid development of the Microscale Integrated Manufacturing Technology, the High-bandwidth multimedia applications which use video signal as the major data load, including the three-dimensional video games, the network TV, the Multi-point video conference system and so on, are gradually become the main content of the network communications. At the same time, due to the optical properties of low-loss window and high bandwidth, the transmission system based on fiber has already stooded out and becomes irreplaceable technology in the
Information transmission system, especially in the high-speed, large-capacity, long-distance transmission system. So, the facts that whether the network can meet the transmission requirements of ultra-high speed and large capacity or not, will inevitably become the important development symbol of the next generation Optical Network in the future. In addition, with the continuous expansion and in depth of business forms, the requirements of network bandwidth and signal processing will be constantly strengthened.

In the Optical fiber transmission system, the common factors causing signal injury include: loss, the ASE of amplifiers, the nonlinear effects of fiber, the Chromatic dispersion, the Membrane polarization dispersion, the filter cascade, the crosstalk caused by multiplex channel bifurcation in DWDM, and so on. With the transmission speed less than 10Gb/s, these factors can be easily overcome. However, when the transmission speed goes above 40Gb/s or even 100Gb/s, the traditional modulation formats has been unable to resist the transmission loss caused by the signal rate increase. Therefore, advanced modulation formats with good nonlinear resistance, high chromatic dispersion tolerance, high polarizing coating chromatic dispersion tolerance and high frequency spectrum utilization rate has been presented and deeply studied which had overcome many transmission limitations caused by transmission speed enhancement and channel narrowing, and it has been one of the revolutionary technologies which propelled the optical network transmission speed enhance quickly. The research objectives are as follows: firstly, obtain high optical spectrum efficiency, cut down unit bit transmission cost and can adjust to the new environment when the intervals between channels narrow down. Secondly, reduce the impact caused by the system loss (like chromatic dispersion, polarizing coating chromatic dispersion, optical fiber nonlinear and channel interference etc.). Lastly, support special user requirements (confidential transmission etc.). What’s more, use advanced modulation format can update the transmission speed and tolerance without changing the original optical transmission link during practical applications, this will reduce the cost to a large extent.

With the growth of the correspondence demand of people, meanwhile, the FTTx has developed very fast. The FTTx technology based on the PON has widely spread all over the world in many different shapes. Moreover, with the combination of service operation and network in our country, high-bandwidth applications, such as video conferences, real-time games and IPTV, are emerging unceasingly, which not only set even higher demand on the bandwidth of the access network, but also impel the new FTTx technologies to emerge one after another continuously. Besides, some new technologies, like the integration of telecommunications networks, cable TV networks and the internet, the Internet of things, the cloud computing, the mobile network and the FMC, will also improve the applications of high-bandwidth and the related network. As a result, the FTTx technology will develop in the direction of higher speed, more transmission wavelengths, broader covering scope in the future. Thanks to its ability of full use of fiber resources, completely transparent speed and service, high security, easy management, long transmitting distance and good extension, the WDM-PON system is able to save the cost of branch optical fiber and other light-attribute-network largely, while it can also expand user covering scope and the quantity of the users, and WDM-PON system has provided an ideal solution for the operating agencies to build a new-light-network with bigger capacity, higher transmission speed and facing entire service operation.
In summary, either advanced modulation formats or WDM-PON system is the most potential technology in the future; therefore, this paper aims to the applications of four advanced modulation formats (DPSK, FSK, IRZ and Manchester) in high-speed WDM-PON access network system is meaningful. Firstly, introduce schemes of the four advanced modulation formats. Then, give system simulation chart and results, which focus mainly on the input optical-fiber power influence and chromatic dispersion management, and then, compare and analyze their transmission performances. Lastly, summarize the job.

2. Numeral simulation

In this section, we will describe our scheme of WDM-PON system based on RSOA adopted in the numeral simulation and the schemes we take to generate the advanced modulation formats.

2.1. Scheme of WDM-PON system based on RSOA

The scheme adopted in our simulation is presented in Figure 1.

![Figure 1. Construction of simulation system](image)

In our system, the downstream bit rate is 40-Gbit/s, and the upstream is 2.5-Gbit/s; the four advanced modulation formats mentioned are used to modulate our downstream signals because of their constant power during transmission, and RSOA is employed to remodulate signals because of its advantage of modulating upstream signals and amplifying the power simultaneously. During our simulations for different formats, we remain all the parameters of the system the same value.

For one advanced format, the corresponding transmitters generate signals, which are carried by different wavelengths carriers. Firstly, the three channels are combined by the multiplexer, and then enter into EDFA to amplify the power in the Central Office (CO) before getting to the fiber network. The optical fiber adopted in our simulation contains two parts: 20km SMF and 5km DCF, which aims to offset the chromatic dispersion phenomenon. After finishing the fiber travel, signals arrive at demultiplexer, where signals are separated respectively and sent into corresponding channel. Following the channel, they get to the ONU, where the signal are divided into two parts, one is received as the downstream signal from CO; meanwhile, the other flows into RSOA, which remodulate the downstream signals with 2.5-Gbit/s NRZ electrical signals to generate upstream signal. So, the upstream travel begins.
Similarly, the three channels enter into the multiplexer first, then the optical fiber, then the demultiplexer, and the receiver of the CO at last. In this paper, we make the intermediate channel as our study object.

We need to note that: the typical WDM-PON structure is a single bi-directional fiber, the whole transmission will be done with the help of circulators. However, considering the scheme cannot avoid signal degradation caused by the parasitic reflection radically, we take the solution of two-fiber bi-directional. Moreover, the cost of optical fiber is low, and the two-fiber scheme may be more suitable for WDM-PON system.

2.2. schemes of advanced modulation formats

The four advanced modulation formats generation schemes are introduced in this section, meanwhile, as both of the FSK’s and Manchester’s are novel, we will emphasize to describe them.

2.2.1. DPSK scheme

NRZ (nonreturn-to-zero) data is differentiated by the encoder firstly, and then modulate the continuous wave generated by the laser source in a phase modulator, and the DPSK signal is generated.\(^4,5\)

2.2.2. FSK scheme

Utilizing MZM suppressed carrier modulation to obtain the two waves needed by the 40Gb/s FSK, and the advantage of making use of single light source is the avoidance of wave and power’s precise control of the two light sources. Besides, suppressed carrier modulation can be operated in multi-channel at the same time. It helps to save cost in the WDM system. MZ modulator works in the push-pull state, setting the DC bias at the “zero” spot of the transmission curve, the RF driving voltage amplitude was one half of the half-wave voltage(NR/2), and at this time, we can realize the suppressed carrier modulation, the interval between the two generated frequencies is the double of RF signal frequency. Then, through the phase modulator, 40Gb/s data signal was modulated into this two carrier frequency so as to generate this two NRZ-DPSK signals and was sent to a 1-bit time-lapse demodulator. When this two carrier frequencies locate at the maximum and minimum value of the DI transmission spectrum, we can get two different signals with same amplitude but reverse logic, namely NRZ-FSK signal. And the interval between the two carrier frequencies can be modified by modulating the RF signal. When receiving, we can add a band pass filter which can make a frequency discrimination to the new FSK signal (Figure 2).\(^6\)

![Figure 2. Scheme of FSK transmitter](image)

2.2.3. IRZ scheme
The RZ data electrical signal will be reversed by a reversor firstly, and then, drive the amplify modulator so as to generate the IRZ signal by making it consistent with the continuous optical carrier wave generated by the light source.

2.2.4. Manchester scheme

In fact, Manchester encoding is a kind of redunance encoding, utilizing 1-bit signal from high level to low level and from low level to high level to signify binary character “1” and “0”. Since the bit stream contains clock and data, the clock signal can be extracted easily. We can differential demodulate the RZ-DPSK signal to generate the phase-aided Manchester signal: the center frequency of the signal was setted at 193.1 THZ, the two cascaded MZM were drived by the 40Gb/s differential encoding data and 20GHz sinusoidal clock, making phase modulation to input optical signal, and then, generate RZ-DPSK signal with 4040Gb/s and 50%’s duty cycle. A DI with one bit delay will differentiate and demodulate the amplified RZ-DPSK signal, then get two-way RZ signal with reversed logic at the output terminal. One optical chronotron with 0.5 bit delay will be connected to one of the DI output terminal, And then, combine the delayed optical signal with the other one via a 3dB coupler and then, obtain the phase-aided Manchester signal consequently (Figure 3)[7,8].

![Figure 3. Scheme of Manchester’s experimental system](image)

3. Comparisons of simulation results

In this section, we will mainly compare the simulation results obtained in the schemes mentioned above. The comparisons emphasize two parts: input optical power and dispersion tolerance.

3.1. Effects from the input optical power

Retained DCF in the situation of well proper compensation to 20kmSMF; meanwhile, changed the value of input optical power of the WDM-PON system, and then we got the sensitivity curves of the four advanced modulation formats as follows (Figure4,Figure5.):

What we have to point out is that the values of power-into-fiber in the figure were measured after getting through EDFA, the power amplified before flowing into the optical fiber.
During the downstream transmission, DPSK holds the highest sensitivity, which is nearly 3 dBm higher than that of the other three advanced modulation formats. While FSK, IRZ and Manchester go in a similar trace, that is they hold the nearly same sensitivity.

During the upstream transmission, differences among the four modulation formats are little. All of them possess the sensitivity at about 21.8 dBm.

3.2. Effects from dispersion
Keep the input optical-fiber power constant and change the length of DCF, the chromatic dispersion managements of the four advanced modulation formats are displayed as follows (Figure 6, Figure 7):
Figure 6. Measured sensitivity to dispersion curves of the four advanced modulation formats for upstream in WDM-PON system based on RSOA.

During the downstream transmission, for the four advanced modulation formats, we can easily see that effects from dispersion are close to that from input power. DPSK also holds the highest sensitivity, and the other three ones share the nearly same sensitivity. However, for the chromatic dispersion management, Manchester’s dynamic range is much smaller than the others.

Figure 7. Measured sensitivity to dispersion curves of the four advanced modulation formats for upstream in WDM-PON system based on RSOA.

During the upstream transmission, the sensitivity of DPSK modulation format is lower than the other three formats, about 1.5dBm. In comparison, the dynamic range of Manchester is...
very small, which is corresponding with its downstream transmission. As for the IRZ and FSK code, they perform equally with each other.

3.3. Analysis and discussion

For the downstream, due to their characteristic of constant power, NPR-DPSK, FSK, IRZ and Manchester possess the abilities of tolerance of nonlinearity. Therefore, the dynamic range of input power corresponding to the 1-dB receivers’ sensitivity is large. However, since the IRZ with 50% duty-cycle, FSK and Manchester is not actually power constant after all, when the value of input power keeps increased, NRZ-DPSK holds the lowest peak power for the equal power. So, DPSK performs better than the other ones at tolerance of nonlinearity.

With regard to the chromatic dispersion, for the same transmission speed, DPSK holds the narrowest optical spectrum; therefore, the chromatic dispersion affects DPSK lest. While, IRZ, FSK and Manchester signal are affected by dispersion easily because of their large bandwidth. Especially is FSK affected, due to the special generation scheme of FSK adopted in this paper, the frequency interval reaches 60GHz. Additionally, considering that the generation of IRZ signal has no phase characteristic; whereas, either FSK or Manchester is generated by demodulating the DPSK signals, and consequently, their data has some phase characteristic, we can explain that although optical spectrum of FSK and Manchester signal is large relatively, the difference of the results between them and IRZ signal is very little. And it’s the fact that the transmission speed of Manchester signal was doubled, which is Manchester signal at 40Gb/s transmit at 80Gb/s actually, that’s why its dynamic range of chromatic dispersion tolerance is much narrower.

For the upstream, when the power entering into the network fiber becomes lower, the power entering into reflective SOA becomes lower, too, which results in not good remodulation of signals. On the other hand, if the power is too high, reflective SOA will be in gain saturation, which cannot modulate well. Both of these will consequently lead to wave distortion, meanwhile, the recovery time of carrier also effect the wave. Due to the large differences between the higher rate entering into reflective SOA and carriers’ recovery time, Manchester signals go to bad quickly with its power being higher.

When it comes to upstream dispersion, actually, it makes a little impact on 2.5Gb/s NRZ signals with 20km transmission distance. And considering about affect from phase, undulation is natural.

4. Conclusion

In summary, in the system of WDM-PON based on RSOA, among the four advanced modulation formats, IRZ and FSK performs equally, whatever in the situation of input power influence or chromatic dispersion management, either for the 40Gb/s downstream transmission or for the 2.5Gb/s upstream transmission. With regard to Manchester, its sensitivity is close to IRZ and FSK’s in any situation, while its dynamic range is much smaller than the other three modulation formats. During the downstream transmission, DPSK’s performance is the best.

On the whole, due to their own good characteristics, the advanced modulation formats have been regarded as one of the most potential technology in future fiber-optic communication systems. At the same time, WDM-PON system is regarded as the most promising plan for the passive optical-network access scheme. Only select the proper scheme according to specific project in practical operation, can we meet the requirements from all sides. The job this paper
finished may be a good piece of material.

5. References

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