American Journal of Networks and Communications
2014; 3(4): 56-62
Published online October 20, 2014 (http://www.sciencepublishinggroup.com/j/ajnc)
doi: 10.11648/j.ajnc.20140304.12
ISSN: 2326-893X (Print); ISSN: 2326-8964 (Online)

Signal shaping to achieve OOK and PSK co-existence for improved optical access network performance

Yasuyuki Okumura, Maki Kato, Katsuyuki Fujii

Dept. of Science and Engineering, Nanzan University, Aichi, Japan

Email address:
yokumura@nanzan-u.ac.jp (Y. Okumura), m13sc007@ nanzan-u.ac.jp (M. Kato), fujii@ nanzan-u.ac.jp (K. Fujii)

To cite this article:
Yasuyuki Okumura, Maki Kato, Katsuyuki Fujii. Signal Shaping to Achieve OOK and PSK Co-Existence for Improved Optical Access Network Performance. *American Journal of Networks and Communications.* Vol. 3, No. 4, 2014, pp. 56-62.
doi: 10.11648/j.ajnc.20140304.12

Abstract: This paper proposes a novel symbol mapping that uses signal shaping to alleviate the BER problem in constellation sharing with the use of phase information. This mapping solves one of the most critical problems; the small Euclid distance of the PSK symbols in the constellation sharing of OOK and PSK in Passive Optical Networks (PONs). Constellation sharing enables next generation PONs to overlay existing PONs with the use of an advanced modulation format based on the Digital Signal Processing (DSP) technology that well supports migration of the access network. The modulation format of Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and Quadrature Amplitude Modulation (QAM) can co-exist with the existing PONs, which utilize On-off Keying (OOK). The proposed mapping is designed to maximize the symbol distance assuming the co-existence of OOK and PSK. This paper shows the configuration, operation principles, and performance of the proposed signal mapping for OOK and PSK. It also shows that constellation sharing improves the BER characteristics of OOK and PSK in conjunction with an existing PON and the next generation technology.

Keywords: Constellation Sharing, OOK, Optical Access, PON, PSK, Signal Shaping

1. Introduction

Passive Optical Networks (PONs) are widely used for broadband access to provide a variety of services such as Internet access, Voice over Internet Protocol (VoIP), and digital video. Their cost-effective point-to-multipoint architecture has encouraged their massive deployment in the access network. As full services are provided by PON-based access networks, operators expect improved bandwidth, flexibility in provisioning, and enhanced performance of access nodes over existing access networks. The direction of PON evolution is attracting global attention from the telecom industry [1-5].

The bandwidth improvement and enhanced allocation flexibility are the key requirements directing PON evolution. The network operators are seeking an evolution scenario from the currently deployed Giga-bit Ethernet PON (GE-PON) and Giga-bit PON (GPON) to the next generation PON. A general requirement of the next generation PON is providing higher data transmission rates than GE-PON and G-PON at reasonable cost. The other requirement is co-existence with deployed PON systems and the reuse of outside plant, since optical distribution networks account for most of the total cost in PON deployments.

There are several prospective candidate technologies for the next generation PON such as Wavelength Division Multiple Access (WDMA), Code Division Multiple Access (CDMA), and Orthogonal Frequency Division Multiple Access (OFDMA). Although these technologies can achieve large transmission capacities, they do have some weaknesses. For example, WDMA requires high cost devices such as wavelength multiplexers and de-multiplexers, and high speed signal processing devices are needed to realize the complex and real-time processing needed. To support the home use of PON systems, cost-effective technologies are required [6 - 9].

One realistic solution for overlaying the next generation PON is the use of advanced modulation formats such as Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and Quadrature Amplitude Modulation (QAM). This approach involves modulating the phase and amplitude of optical sub-carrier signals and the use of Digital Signal Processing (DSP) technology. These modulation formats can co-exist with the existing PON which utilizes On-off Keying (OOK), which allocates 1 bit to 1 symbol. Co-existence can be achieved by constellation sharing; one terminal uses the OOK format (amplitude modulation) to send one data stream while another terminal uses an advanced modulation format to sends different data streams (amplitude and phase modulation) [10, 11]. For example, one data stream is transferred by the amplitude information of the modulation format, whereas the phase information expresses the other data stream. OOK is equivalent to using just the amplitude information of the advanced modulation format.

In constellation sharing, the extinction ratio of the OOK signal must be large enough to achieve a low Bit Error Rate (BER); large extinction ratios make it difficult to discriminate the symbols via the phase information. This paper proposes a novel symbol mapping where signal shaping is used to alleviate the BER problem with phase information in consternation sharing. This mapping is designed to maximize the symbol distance even if the presence of large extinction ratios given the co-existence of OOK and PSK. This paper also shows how to improve the BER characteristics in OOK and PSK consternation sharing to allow the next generation PON to overlay the existing PON.

2. Constellation Sharing[10, 11] and Technical Problems

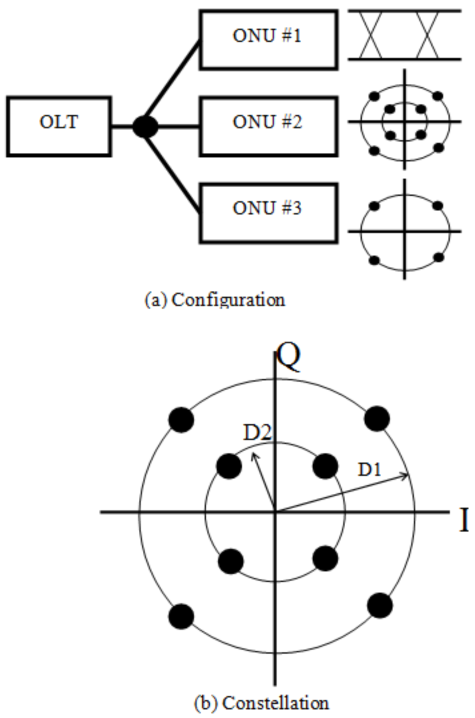


Figure 1. *Constellation sharing*

In the PON architecture, the OLT is connected to multiple ONUs via a passive optical splitter, as shown in Figure 1(a). Network evolution must consider the co-existence of different types of ONUs that use different modulation formats. Given that the OLT sends different data streams to multiple ONUs simultaneously, the data streams must avoid interfering with each other. In constellation sharing, a multilevel modulation signal such as OOK+ASK is used as the modulation format, and a number of bits allocated to a symbol differs with the ONU[10, 11]. In the example of 8-star OOK+ASK, each symbol represents 3 bits, where 1 bit is allocated to the amplitude level of the symbol, and 2 bits to the phase information, as shown in Figure 1. Constellation sharing enables the OLT to send different data streams using the amplitude levels and/or phase information. In the example of Figure 1(a), the data stream to ONU#1 is expressed by the amplitude level, which is identical to OOK; it carries 1 bit by 1 symbol. On the other hand, ONU#3 uses the phase information of each symbol to determine the data, and each symbol contains 2 bits. Each ONU separately detects the allocated data stream, assembles data frames, and determines whether the data frame contains the destination address of the ONU. If the address represents another ONU, the receiving ONU discards the data frame. In constellation sharing, the bit allocation to each ONU can change over time, which increases the capacity allocation flexibility.

If the optical signals to an ONU are modulated by OOK such as in the existing PON network, extinction ratio ε must be large enough to ensure adequate transmission quality, where ε is defined as follows,

$$\varepsilon=10\log_{10}(D1/D2)^2 \quad (1).$$

In this equation, D1 and D2 are the radius of the outer and inner circles of the constellation of Figure 1(b), respectively. Sharing reduces the Euclidean separation of the PSK symbols and degrades the BER of the PSK signals, when the symbols are OFF, as shown in Figure 1.

3. Signal Shaping[12, 13]

Signal shaping was initially developed to generate signals with the least average transmit power without increasing the BER[12, 13]. Since the average transmit power causes noise power in crosstalk-affected transmission lines, the least average power is desired. Signal shaping is an efficient algorithm for controlling the power, and employs a well-known error correcting code. Signal shaping relates to the shaping the regions of the constellation, which is divided into M regions, as shown in Figure 2. Each region is assumed to be equal in size, i.e. each one contains the same number of symbols. In this constellation, if the regions are indexed by their numbers s=0, 1, …, M-1, starting from the innermost one, the symbols in region s=0 carries the least power. Using this partition of the regions, N consecutive symbols are expressed as an N-tuple of the regions in M^N possible sequences. Given that the data frame consists of K bits, 2^K sequences with least total energy must be selected from all sequences. To do this, the symbols must be selected from the lowest possible region numbers.

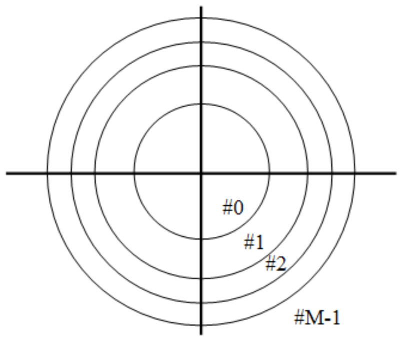


Figure 2. *Partitioning of constellation into M regions*

The principles of signal shaping are found in [14]. A block diagram of the signal shaping circuit is shown in Fig.3. Let $\boldsymbol{d}$ be a data sequence to be transmitted, it is divided into $\boldsymbol{s}$ and $\boldsymbol{b}$, where $\boldsymbol{s}$ is the Most Significant Bits (MSB) and $\boldsymbol{b}$ is the Least Significant Bits (LSB). First, the transmitter converts $\boldsymbol{s}$ into the constellation region label, as follows.

From the viewpoint of the error correcting codes, N consecutive symbols correspond to code words of length N, where the code symbols stem from an M-ary alphabet and the cardinality of the code is 2^K. In signal shaping, a data frame of K bits is mapped to a code word using the shaping algorithm. To reduce the average power, the code is selected from the innermost region possible. In the receiver, the code word is decoded to the original data of K bits. The arithmetic representation is as follows. Let $\boldsymbol{G}$ and $\boldsymbol{H}$ be the $(N\text{-}K)$xN generator matrix of the error correcting code and the KxN parity-check matrix, such that $\boldsymbol{GH}^{\mathrm{T}}=\mathbf{0}_{(N-K)\mathrm{x}K}$, where $\boldsymbol{H}^{\mathrm{T}}$ is the transpose of $\boldsymbol{H}$ and $\mathbf{0}$ is the null matrix of the given dimension. K bit data $\boldsymbol{s}$ can be viewed as a syndrome, and is mapped to a code word, $\boldsymbol{z}$, of length N as follows:

$$\boldsymbol{s}=\boldsymbol{z}\boldsymbol{H}^{\mathrm{T}} \tag{2}$$

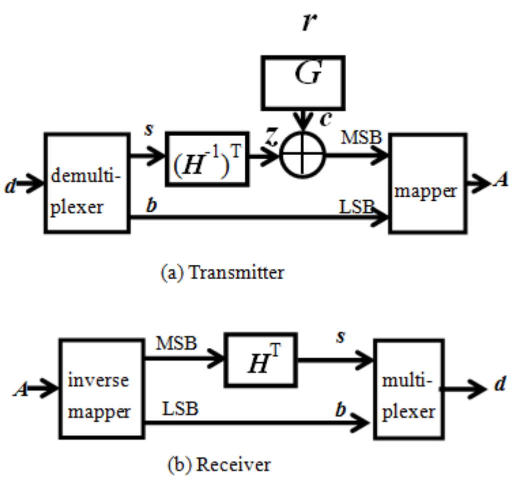


Figure 3. *Signal shaping system*

Given that the left inverse of $\boldsymbol{H}^{\mathrm{T}}$ is $(\boldsymbol{H}^{-1})^{\mathrm{T}}$, i.e. $(\boldsymbol{H}^{-1})^{\mathrm{T}}\boldsymbol{H}^{\mathrm{T}}=\mathbf{I}_{K\mathrm{x}K}$, it can be used as a coset representative generator. Given that the syndrome is $\boldsymbol{s}$, coset representative $\boldsymbol{z}$ is expressed as follows:

$$\boldsymbol{z}=\boldsymbol{s}(\boldsymbol{H}^{-1})^{\mathrm{T}}. \tag{3}$$

In addition, any codeword $\boldsymbol{c}=\boldsymbol{rG}$ can result in the all-zero syndrome, where $\boldsymbol{r}$ is a $(N\text{-}K)$bit code, since $\boldsymbol{s}=\boldsymbol{cH}^{\mathrm{T}}=\boldsymbol{rGH}^{\mathrm{T}}=\boldsymbol{r}\mathbf{0}=\mathbf{0}$. Therefore, any member of a coset is a sum of the coset representative and all possible code words. This means that syndrome $\boldsymbol{s}$ of coset representative $\boldsymbol{z}$ does not change with the addition of any possible code word, since

$$(\boldsymbol{z}+\boldsymbol{c})\boldsymbol{H}^{\mathrm{T}}=\boldsymbol{zH}^{\mathrm{T}}+\boldsymbol{cH}^{\mathrm{T}}=\boldsymbol{s}+\mathbf{0}=\boldsymbol{s}, \tag{4}$$

where + means modulo-two addition.

In signal shaping, the Binary Coded Decimal (BCD) of coset member $\boldsymbol{z}+\boldsymbol{c}$ corresponds to the region label, where the above mentioned result is used to find the desired coset member with minimum power. In many cases, the well-known Viterbi algorithm and the trellis diagram are used to find a valid code word that yields the minimum power when added to the coset representative. For example, block codes can be described as a trellis diagram, where each code word corresponds to a path in the diagram[14]. In searching for the desired code word, the algorithm uses signal power as a cost. Therefore, regarding the constellation in Fig.2, the smallest possible BCD of $\boldsymbol{z}+\boldsymbol{c}$ is selected.

4. Signal Shaping in Constellation Sharing

In a PON system with constellation sharing, the existing OLT and ONU transmit OOK signals, which require large extinction ratios such as 20 dB to realize low BER. Unfortunately, large extinction ratios complicate the discrimination of the phase information among different symbols, when the symbols are OFF. To solve this problem, this paper proposes the following signal shaping approach.

In an optical network using the constellation of Fig.2, the largest BCD of coset member $\boldsymbol{z}+\boldsymbol{c}$ is selected so that the symbols carry the largest power and thus maximize the Euclid distance among symbols. Since the optical network is connected to commercial electric power supplies, power consumption is not a critical factor. Assuming the network configuration shown in Fig.1, the signal constellation can be divided into two regions, i.e. M=2. Data sequence $\boldsymbol{d}$ is divided into $\boldsymbol{s}$ and $\boldsymbol{b}$, where $\boldsymbol{s}$ and $\boldsymbol{b}$ denote the OOK signals and the PSK signals, respectively. $\boldsymbol{s}$ is converted into $\boldsymbol{z}+\boldsymbol{c}$ with signal shaping to improve the BER of the PSK signals.

5. Simulation Results and Discussion

The simulation assumes the network configuration shown in Fig.1, where the OLT is connected to three ONUs via a 1:4 optical splitter and standard single mode fiber. The simulation is carried out using MATLAB. The modulation format is shown in Figs. 4(a) and (b). In both figures, one bit signal (MSB) is modulated using OOK and is denoted by $\boldsymbol{s}$, where the amplitude of the signal expresses the bit. On the other hand, the phase represents two bits by using 4-PSK or three bits by 8-PSK, as shown in Figs. 4(a) and (b), respectively.

Regarding the shaping code, the binary (7, 4) hamming code is adopted. Generator matrix $\boldsymbol{G}$ and the respective parity-check matrix $\boldsymbol{H}$ are given as

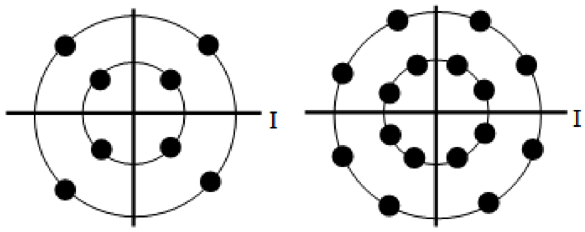
$$\boldsymbol{G}=\begin{bmatrix}1&1&0&1&0&0&0\\0&1&1&0&1&0&0\\0&0&1&1&0&1&0\\0&0&0&1&1&0&1\end{bmatrix}, \tag{5}$$

$$\boldsymbol{H}=\begin{bmatrix}1&0&1&1&1&0&0\\0&1&0&1&1&1&0\\0&0&1&0&1&1&1\end{bmatrix}. \tag{6}$$

The corresponding left inverse for $\boldsymbol{H}^{\mathrm{T}}$ is [14]

$$\left(\boldsymbol{H}^{-1}\right)^{T}=\begin{bmatrix}1&0&0&0&0&0&0\\0&1&0&0&0&0&0\\0&0&0&0&0&0&1\end{bmatrix}. \tag{7}$$

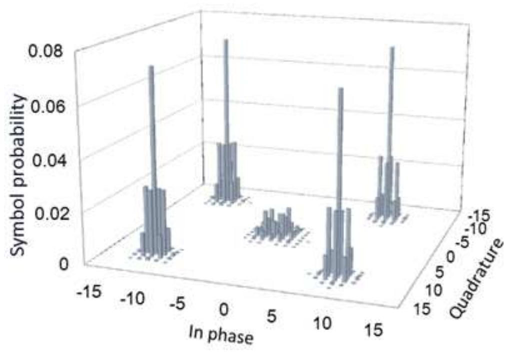
The (7, 4) Hamming code contains $2^{(7-4)}=8$ cosets, and the coset representatives are 7-bit codes. The transmitted binary information of OOK is divided into multiple sets of 3-bit data, which are expressed as $\boldsymbol{s}$, and are converted into $\boldsymbol{z}$ by equation (3). Using the shaping algorithm explained in Sections 3 and 4, $\boldsymbol{z}+\boldsymbol{c}$ is provided to the OOK modulator. Note that the data for PSK are sent to the PSK modulator without undergoing signal shaping.



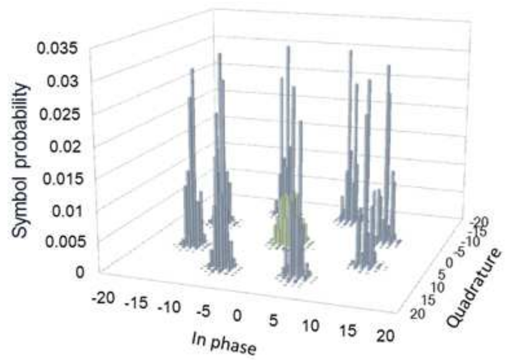
(a) OOK and 4-PSK (b) OOK and 8-PSK

Figure 4. *Constellation*

5.1. Two-Dimensional Distribution of OOK and PSK in Constellation Sharing



(a) OOK and QPSK



(b) OOK and 8-PSK

Figure 5. *Symbol probability in constellation sharing with signal shaping*

In constellation sharing for OOK and PSK signals, the MSB of the transmitted data is modulated by OOK, and undergoes signal shaping. The other bits of the data can be obtained using the PSK demodulator at the ONU's receiver circuit. The distribution of OOK and PSK in constellation sharing are shown in Figures 5(a) and (b). In these figures, the height of the rectangular bar shows the probability of each signal, where the probability of a signal in the outer region is seven times larger than that in the inner region. With uniform distribution, the probability of each signal is 1/8 and 1/16 for QPSK+OOK and 8PSK+OOK, respectively. These results indicate that if signal shaping is applied, the signals in the inner region are rarely selected.

5.2. BER Characteristics

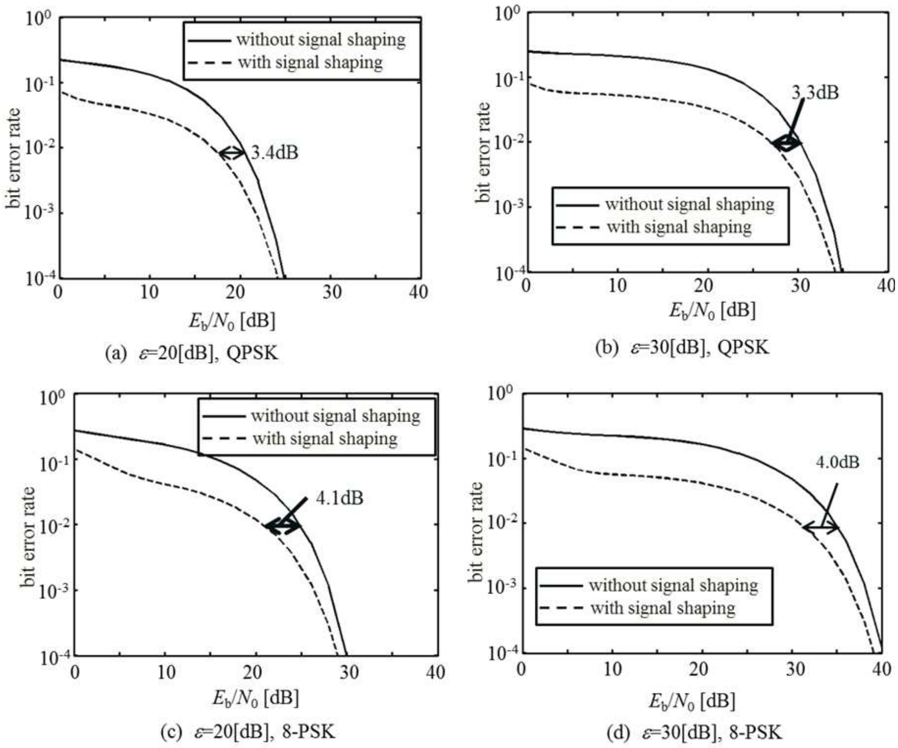


Figure 6. *BER of PSK signals in constellation sharing with OOK*

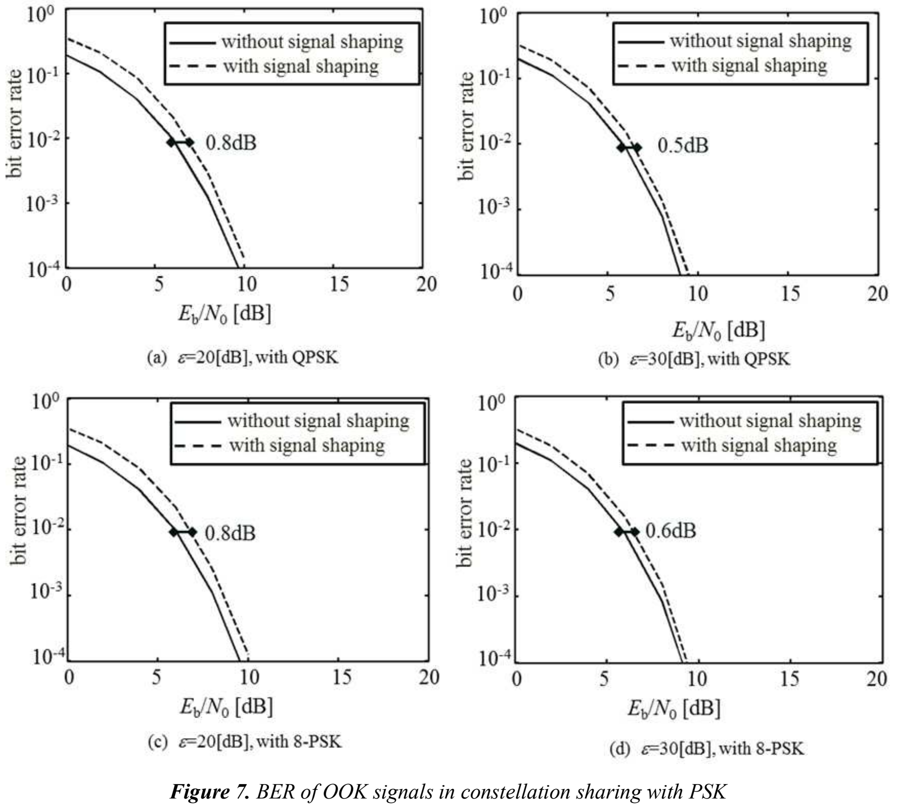


Figure 7. *BER of OOK signals in constellation sharing with PSK*

The simulation assesses the BERs of PSK signals received at an ONU under constellation sharing with QPSK+OOK and 8PSK+OOK and signal shaping. In addition, signal BER under constellation sharing without shaping is also measured as a reference. The results of QPSK+OOK with extinction ratios of 20[dB] and 30[dB] are shown in Figures 6(a) and (b), and those of 8PSK+OOK with extinction ratios of 20[dB] and 30[dB] are shown in Figures 6(c) and (d), respectively. The figures show that QPSK+OOK with signal shaping achieves SNR gain values of 3.4[dB] and 3.3[dB] at BER of 10^{-2} with the above extinction ratio values. The SNR gain values of 8PSK+OOK in these environments are 4.1[dB] and 4.0[dB]. These results show the improvement in BER possible with constellation sharing of OOK and PSK in conjunction with an existing PON and the next generation technology.

Regarding the BER of OOK signals received at an ONU, the simulation results are shown in Figures 7(a) to 7(d). Figures 7(a) and 7(b) shows the BER characteristics of OOK signals in QPSK+OOK with extinction ratios of 20[dB] and 30[dB], and Figures 7(c) and 7(d) shows those in 8PSK+OOK. The figures show that there is some slight degradation in OOK signal BER, less than 0.8[dB] at BER of 10^{-2}, when signal shaping is used. The reason is that the binary information of OOK is divided into multiple sets of 3-bit data, and each set is converted into 7-bit code by Equation (3). Under this coding algorithm, a single symbol error causes a multiple bit error, which degrades the BER characteristics of the OOK signals. The 7-bit code can be considered as a symbol and the symbol error rate is worse than the BER[15], the BER of the OOK becomes worse than that without signal shaping.

5.3 Discussion

Based on the above results, our above results clarify that the shaping algorithm achieves a larger distribution of received signals in the outer region of PSK+OOK constellation sharing. In addition, the BER results show that, with signal shaping, the BER characteristics of the PSK signals improve by about 4[dB] compared to that without shaping. On the other hand, there is slight BER degradation in OOK signals, less than 0.8[dB], when using signal shaping. Clearly the BER improvement achieved by the PSK signal is much larger than the OOK degradation. In addition, since a PSK symbol carries most of the binary data bits, the impact of the BER improvement is significant.

One of the problems of the proposed method is the code rate, which reduces the transmission capacity of the OOK signals. As an example, by using the (7, 4) hamming code for shaping, the transmitted data $\boldsymbol{s}$ of 3 bits is expanded to $\boldsymbol{z}+\boldsymbol{c}$, i.e. 7 bits, so OOK signal efficiency is 0.43. This means that signal shaping improves the BER of PSK signals at the cost of OOK signal efficiency. In constellation sharing, since PSK signals carry more bits than OOK, the latter's penalty is far outweighed by the former's improvement.

6. Conclusion

This paper introduced a novel symbol mapping that uses signal shaping to alleviate the BER problem in constellation sharing with the use of phase information. This mapping solves one of the most critical problems; the small Euclid distance of the PSK symbols in the constellation sharing of OOK and PSK. In the proposed method, the largest possible BCD representing the symbols is selected so that the symbols carry the largest power to maximize the Euclid distance among them. We detailed the configuration, operation principle, and the performance of signal shaping in constellation sharing. Computer simulations confirmed the improvement in the BER characteristics of the PSK signals in constellation sharing of OOK and PSK in conjunction of an existing PON and the next generation technology. Signal shaping increases the detection probability of the symbols, which have large Euclid separation distances, even though they have large extinction ratios, and improves the BER characteristics of the PSK signals.

Acknowledgement

This work was supported by JSPS KAKENHI Grant (C) Number 26420377, and by the Nanzan University Pache Research Subsidy I-A-2 for the 2014 Academic year, for which the authors would like to express their thanks.

References

[1] T. Koonen, “Trends in optical access and in building networks,” Proc. 2008 Eur. Conf. Opt. Commun. (ECOC), pp. 1-31, We2.A.1, 2008.

[2] D. Qian, J. Yu, J. Hu, L. Zong, L. Xu, and T. Wang, “8x11.5 Gbps OFDM transmission over 1000 km SSMF using conventional DFB lasers and direct-detection,” IEEE Electron. Lett., vol. 44, no. 3, pp. 223-225, May 2008.

[3] P. Chanclou, J. P. Lanquetin, S. Durel, F. Saliou, B. Landousies, N. Genay, and Z. Belfqih, “Investigation into optical technologies for access evolution,” Proc. 2008 IEEE/OSA Opt. Fiber Commun. Conf (OFC/NFOEC), pp. 1-3, OWH1, 2008.

[4] ITU-T Rec. G.987.2, “10-Gigabit-Capable Passive Optical Networks (XG-PON): Physical Media Dependent (PMD) Layer Specification,” Oct. 2010.

[5] N. Cvijetic et al., “Software-defined heterogeneous 100Gb/s mobile backhaul with 1000+ per-fiber cell counts,” Opto-Electronics and Commun. Cof. ’12, Technical Digest, PDP1-2, 2012.

[6] D. Qian, N. Cvijetic, J. Hu, and T. Wang, “108 Gb/s OFDMA-PON with polarization division multiplexing and direct detection,” Proc. 2009 IEEE/OSA Opt. Fiber Commun. Conf. (OFC/NFOEC), pp. 1-2, PDPD5, 2009.

[7] D. Qian, N. Cvijetic, J. Hu, and T. Wang, “108 Gb/s OFDMA-PON with polarization multiplexing and direct detection,” IEEE J. Lightw. Technol., vol. 28, no. 4, pp. 484-493, Feb. 2010.

[8] T. Duong, N. Genay, P. Chanclou, B. Charbonnier, A. Pizzinat, and R. Brenot, “Experimental demonstration of 10Gbit/s upstream transmission by remote modulation of 1 GHz RSOA using adaptively modulated optical OFDM for WDM-PON single fiber architecture,” Proc. 2008 Eur. Conf. Opt. Commun. (ECOC) , pp. 1-2, We.1.F.4, 2008.

[9] J. Armstrong, “OFDM for optical communications,” J. Lightw. Technol., vol. 27, no. 3, pp. 189-204, Jan. 2009.

[10] N. Iiyama, S. Y. Kim, T. Shimada, S. Kimura, and N. Yoshimoto, “Co-existent downstream scheme between OOK and QAM signals in an optical access network using software-defined technology,” IEEE/OSA Opt. Fiber Commun. Conf (OFC/NFOEC) 2012, OSA Technical Digest, paper JTh2A.53, 2012.

[11] N. Yoshimoto, J. Kani, S. Y. Kim, N. Iiyama, and J. Terada, “DSP-based optical access approaches for enabling NG-PON2 systems,” IEEE Commun. Magazine, vol. 51, pp. 58-64, March 2013.

[12] G. D. Forney Jr., “Trellis shaping,” IEEE Trans. Inform. Theory, vol. 38, pp. 281-300, March 1992.

[13] I. S. Morrison, “Trellis shaping applied to reducing the envelope fluctuations of MQAM and band-limited MPSK,” Proc. Int. Conf. Digital Satellite Commun. (ICDSC ’92), pp. 143-149, May 1992.

[14] R. F. H. Fischer, *Precoding and signal shaping for digital transmission,* IEEE Press, 2002.

[15] J. G. Proakis, *Digital communications,* McGraw-Hill, 2008.