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Optimized Eight-Dimensional Lattice Modulation Format for IM-DD 56 Gbit/s Optical Interconnections Using 850 nm VCSELs

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(Invited Paper)

Abstract—In this paper a novel eight-dimensional lattice optimized modulation format, Block Based 8-dimensional/8-level (BB8), is proposed, taking into account the trade-off between high performance and modulation simplicity. We provide an experimental performance comparison with its n-level pulse amplitude modulation (PAM-n) counterparts in a 28 Gbaud 850 nm vertical-cavity surface-emitting laser (VCSEL) based intensity-modulation direct-detection (IM-DD) system. Successful data transmission over 100 m multi-mode fiber (MMF) links of OM3 and OM4 types is demonstrated, with a power margin close to 2 dB at 100GBASE-SR4 forward error correction (FEC) threshold. A simplified bit-to-symbol mapping and corresponding symbol-to-bit de-mapping algorithms, together with a hyperspace hard-decision, are designed specifically for applications of short-reach data links. These algorithms are expected to use affordable computational resources with relatively low latency.

Index Terms—Optical fiber communication, optical interconnections, modulation, vertical cavity surface emitting lasers.
Conventional Symbol

Conventional Symbol

Fig. 1. (a) Illustration of the principle of constructing the eight-dimensional super-symbols by combining the temporally adjacent symbols. (b) The construction of two-dimensional projections by using two symbols.

experimentally investigated and compared with PAM-n in terms of BER in a 28 GBd lab setup. The performance was measured for back-to-back (BTB) and over 100 m OM3 and OM4 type MMF links. The experimental setup and methodological issues are described in Section V, and the experiment results are presented in Section VI.

II. EIGHT-DIMENSIONAL MODULATION FORMATS

A. Multi-dimensional signal space

An n-element orthogonal basis spans an n-dimensional signal space, accommodating the modulation formats of corresponding dimension. For instance, in coherent transmission systems the in-phase (I) and quadrature (Q) field components in both orthogonal polarization states (x and y), i.e. $[I_x, Q_x, I_y, Q_y]$, span a four-dimensional signal space. The orthogonal basis can also be formed using different wavelengths, independent waveforms or spatial modes. Ideally, consecutive symbol slots can also be seen as independent basis, provided the inter-symbol interference (ISI) is negligible. Alternatively, an orthogonal basis can be found in parallel optical channels, like separate fibers for the 4-lane quad small form-factor pluggable (QSFP) or 8-lane octal small form-factor pluggable (OSFP) transceivers. Such channels are inherently multi-dimensional. Furthermore, higher dimensional space can be virtually formed by adopting a hybrid scheme. For instance, links using 4.1 shortwave wavelength division multiplexing (SWDM) over 4-lane parallel channels are sixteen-dimensional. In this paper, an eight-dimensional signal space is constructed by combining eight adjacent symbols in a single channel. The resulting sequence of super-symbols is further interleaved into 8 blocks, emulating eight independent channels.

B. MD formats for IM-DD systems and optimization

Let us consider, without loss of generality, an 8-dimensional format, where eight temporally adjacent symbols in the transmitting sequence $s = [s_0, s_1, ..., s_m, ...]^T$ constitutes a super-symbol $S_n = [S_n^0, S_n^1, S_n^2, ..., S_n^7]^T$. $s_m$ indicates the m-th symbol in the transmitting sequence. $S_n^i$ is the individual symbol in the n-th super-symbol, $i = 0, 1, ..., 7$ indicates its position in $S_n$, $n = 0, 1, ...$ is the index of a super-symbol in the sequence. $S_n^i$ corresponds to the symbol $s_{8n+i}$ in s, i.e. $m = 8n + i$. Therefore, each symbol in one super-symbol gives the coordinate value of one point in 8-dimensional signal space along a specific orthogonal direction. We assume that the received super-symbols $R_n = [R_n^0, R_n^1, R_n^2, ..., R_n^7]^T$ are affected by additive white Gaussian noise (AWGN). They can be visualized as hyper-spheres expanded from the ideal format points, like $R_n = S_n + N_n$, where $N_n$ are independent and identically distributed (i.i.d.) random variables. Notice that here the channel responses are not taken into account, i.e. each super-symbol is seen as independent. In fact, the Gaussian model is not naturally guaranteed in VCSEL based IM-DD links, that leads to the noise spheres shifted from the designed locations and apart from the hyper-sphere form, becoming more irregular and anisotropic. The impact of this effect on the performance is not straightforward and depends on the specific constellation configuration. In this paper, we assume that the shift and distortion of the noise hyper-spheres are negligible and adopt a Gaussian noise model.

The modulation format can be optimized by maximizing the minimum mutual Euclidean distance (MMED), $d_{min}$, between all pairs of the format points to avoid the errors occurring in the overlap region between noise spheres. The optimal format is then achieved when the format points are chosen from the densest eight-dimensional structure, called $E_8$ lattice, can be constructed in multiple ways [28]: (i) generation matrix; (ii) seed lattice grids; (iii) analytic expression, $E_8 = \{(x_i) \in Z^8 \cup (Z + 1/2)^8 : \sum_i x_i = 0 \ (mod 2)\}$. Assuming that the VCSEL is modulated in its linear regime, the optimization equals to searching a subset of $E_8$ lattice within a fixed-size eight-dimensional hypercube. Such subset has the maximum $d_{min}$ and an optimal orientation, offering the simplest level structure in each symbol.

C. Block-based 8-dimensional/8-level format: BB8

BB8 has 8 equally probable amplitude levels. The format point set $C$ is defined as:

$$C = \left\{ (c^i) \in U_{even}^8 \cup U_{odd}^8 : \sum_i c^i \equiv 0 \ (mod 4) \right\} \quad (1)$$

where $c^i$ is the amplitude of each symbol, $i = 0, 1, \cdots, 7$ is the position of individual symbol in a super-symbol, and $U_{even} = \{ u_{even}^0, u_{even}^1, \cdots, u_{even}^7 \}$, $u_{even}^i \in \{0, 2, 4, 6\}$, $U_{odd} = \{ u_{odd}^0, u_{odd}^1, \cdots, u_{odd}^7 \}$, $u_{odd}^i \in \{1, 3, 5, 7\}$ are the sets of possible values, in which $\lambda$ indicates the dimensionality of such sets. We can use the representation of two-dimensional projections to better understand the format structure in eight-dimensional space. As shown in Fig. 1, a super-symbol forms four two-dimensional projections by artificially projecting every two symbols in one constellation diagram. Without loss of generality, we define the projections as $p_k = [c^{2k}, c^{2k+1}]^T$, $k = 0, 1, 2, 3$ with a symbol-wise sequence.
According to the expression (1), the set of format C is divided into two independent subsets, i.e. even and odd subsets, with the expression $C_{even} = \{(c^k) \in U_{even}^2 : \sum_i c^i \equiv 0 \mod(2)\}$ and $C_{odd} = \{(c^k) \in U_{odd}^2 : \sum_i c^i \equiv 0 \mod(2)\}$. Format points in each projection $p_k$ are then divided into four sub-groups (SG), as:

- $G_I = \{(c^k) \in U_{even}^2 : c^{2k} + c^{2k+1} \equiv 0 \mod(4), k = 0, 1, 2, 3\}$;
- $G_{III} = \{(c^k) \in U_{even}^2 : c^{2k} + c^{2k+1} \equiv 1 \mod(4), k = 0, 1, 2, 3\}$;
- $G_{IV} = \{(c^k) \in U_{odd}^2 : c^{2k} + c^{2k+1} \equiv 1 \mod(4), k = 0, 1, 2, 3\}$.

They are represented by points of four different colors in Fig. 2. The even subset is constructed with a conditional combination in $G_I$ and $G_{III}$, meaning $C_{even} = \{p_1 \ p_2 \ p_3 \ p_4\}^T$, $p_j \in G_I \cup G_{III}$, in which the number of pairs from $G_I$ should be 0, 2 or 4, and 2, 4, 0 or 2 from $G_{III}$, correspondingly. The odd subset is constructed with a conditional combination in $G_{II}$ and $G_{IV}$, as: $C_{odd} = \{p_1 \ p_2 \ p_3 \ p_4\}^T$, $p_j \in G_{II} \cup G_{IV}$ with similar condition as above mentioned.

BB8 carries 2 bits/symbol, the same as PAM-4. Therefore the format set C has $4^8 = 65536$ points. The MMED of neighboring points reaches $d_{min} = 2\sqrt{2}$. Theoretically, BB8 has a 0.84 dB asymptotic shaping gain compared to its PAM-n counterparts with the same maximum peak-to-peak modulation amplitude. Fig. 3 displays the aforementioned two-dimensional projection presented with experimental data, together with the histogram of the received symbols.

The proposed format is designed for independent parallel channels, where the orthogonality of the basis is inherently guaranteed. However, such assumption is not reasonable for the temporally adjacent symbols transmitted through 100 m MMF because the ISI resulting from the unavoidable inter-modal dispersion skews the basis. Hence we use a block-wise interleaving scheme to emulate the parallel channels. 64k symbols, i.e. 8k super-symbols, are fed into an interleaving matrix column-wisely. Then 8 blocks are generated row-wisely, with each block as an analogy of an independent channel. In other words, each output block contains the symbols having the same position in their original super-symbols. By doing so, the ISI becomes the signal independent noise. It is noteworthy that for keeping the consistency, we applied the same interleaving scheme on all the formats we investigate in this work.

A Monte Carlo simulation has been made based on AWGN model applied on the ideal constellations. Its results are shown in the Fig. 4. The signal-to-noise ratio is given with respect to the received electrical signal. PAM-4 and BB8 have an intersection point around the standard 7% FEC limit BER $\approx 3.8 \times 10^{-3}$. For low noise regime, BB8 outperforms PAM-4 and approaches the asymptotic gain larger than 0.8 dB.

### III. SIMPLIFIED BIT-TO-SYMBOL MAPPING AND DE-MAPPING

In spite of the theoretical benefit, the practical implementation of MD formats is not straightforward due to the indirect bit-to-symbol mapping. Look-up tables (LUTs) can be a feasible solution for MD modulations with small scale constellations in coherent transmission systems. However, it cannot be applied for the highly latency- and cost-sensitive short-reach data links. A specially designed simplified bit-to-symbol algorithm is proposed in the following section. It is expected to enable the real-time bit-to-symbol mapping, and its corresponding de-mapping.

#### A. Bit-to-symbol mapping

For the input bit block $B_n = [b_n^0 \ b_n^1 \ \cdots \ b_n^{15}]^T$ and the mapped symbol sequence $S_n = [S_n^0 \ S_n^1 \ \cdots \ S_n^{15}]^T$, a bit-to-symbol mapping is defined as, $M : \mathbb{F}_2^{16} \rightarrow \mathbb{R}^8$ and the corresponding symbol-to-bit de-mapping is $M^{-1} : \mathbb{R}^8 \rightarrow \mathbb{F}_2^{16}$. 
B. Symbol-to-bit de-mapping

The corresponding de-mapping algorithm is then written as:

\[ b_n^0 = \text{mod}(S_n^0, 2) \]  \hspace{1cm} (11)
\[ b_n^1 = \text{mod}((S_n^1 - b_n^0)/2, 2) \]  \hspace{1cm} (12)
\[ b_n^2 = \text{mod}((S_n^0 - b_n^0)/4, 2) \]  \hspace{1cm} (13)

\[ \vdots \]

\[ b_n^i = \text{mod}((S_n^i - b_n^0)/2, 2) \]  \hspace{1cm} (14)
\[ b_n^j = \text{mod}((S_n^j - b_n^0)/4, 2) \]  \hspace{1cm} (15)
\[ b_n^k = \text{mod}((S_n^k - b_n^0)/2, 2) \]  \hspace{1cm} (16)

In which, \( S_n^{0-7} \) means an arbitrary symbol from \( S_n^0 \) to \( S_n^7 \). During the de-mapping phase, a 16-bit block is recovered from one super-symbol, i.e. 8 received and aligned symbols. The first bit \( b_n^0 \) is decoded according to the parity of the subset that the received super-symbol belongs to, i.e. either even subset (when \( S_n^{0-7} \) is even, \( b_n^0 = 0 \)) or odd subset (when \( S_n^{0-7} \) is odd, \( b_n^0 = 1 \)). Then, the symbols \( S_n^{0-7} \) are shifted, i.e. subtracted by \( b_n^0 \) as described by Eq. 11-16. After doing that, \( S_n^{0-7} \) are degenerated from PAM-8 into PAM-4 signal. The remaining bits \( b_0^{1-15} \) are simply calculated from \( S_n^{0-7} \) with PAM-4 de-mapper. The parity bit \( (P_n) \) is not used during the de-mapping and therefore discarded.

IV. HYPER-SPACE BASED HARD DECISION

A maximum likelihood soft-decision (ML-SD) algorithm was used in coherent MD modulation systems. It is combined with FEC to maximize the achievable data rate [13]. However, considering the computational complexity, it is unrealistic to apply ML-SD to the eight-dimensional modulation. It would be overloaded by the number of possible states. In this work we propose a hyperspace based hard-decision (HS-HD) algorithm.

A lattice is filled with primitive cells, the smallest symmetric units. All positions inside the cell are closer to the center than to the rest of the lattice. Hence, the central lattice point in each primitive cell gives a decided symbol. All received symbols in one primitive cell have the same decision. We can separate an eight-dimensional primitive cell by determining all the perpendicular bisecting hyper-planes between the neighbors, as shown in Fig. 5. The perpendicular bisecting hyper-plane is also seen as the decision threshold hyper-plane. Generally, the \((n-1)\)-dimensional boundaries of primitive cells work as hard-decision thresholds in an \( n \)-dimensional signal space. Hence, \( 7 \)-dimensional hyper-planes \( \mathbf{H} = \{ \mathbf{x} \in \mathbb{R}^7 \mid \mathbf{a}^\mathsf{T} \mathbf{x} = d \} \), \( \mathbf{a} = (a_1, a_2, \ldots, a_7) \) divide the eight-dimensional signal space into cells of symbols. Here \( \mathbf{x} \) represents the points on the hyper-plane and \( \mathbf{a} \) is its normal vector.

We use a two-dimensional honeycomb (\( A_2 \) lattice) as the analog of the \( E_8 \) lattice to illustrate the principle of the algorithm (Fig. 5). Generally, the normal vector of the threshold plane between the \( j \)-th lattice point \( \mathbf{l}_j \in \mathbf{L} \) and its \( z \)-th neighbor \( \mathbf{l}_z \in \mathbf{L} \) is expressed as \( \mathbf{a}^2 = \mathbf{l}_z - \mathbf{l}_j \), where \( \mathbf{L} \) is
the set of the whole lattice. The unit normal vector is then
given as \( a_0^* = \mathbf{a}/d_{\text{min}} \). The perpendicular bisector of the line
connecting these two points is described as \( \mathbf{P} = \mathbf{l} + \mathbf{a}/2 \). The
hyper-plane function is written as \( (a_0^*)^T \mathbf{x} = d \), in which
\( d = (a_0^*)^T \mathbf{P} = (a_0^*)^T (l_j + \mathbf{a}/2) = D_j^2 + d_{\text{min}}/2 \). Here, \( d \)
is the characteristic number, which equals the perpendicular
distance between the decision plane and the origin of the coordinate; it consists of \( d_{\text{min}}/2 \), half of the MMED, and \( D_j^2 \), the perpendicular
distance from the origin of the coordinate to the hyper-plane containing \( l_j \). \( D_j^2 \in \mathbb{D}^2 \) is inherent for
a specific lattice structure, \( \mathbb{D}^2 = (a_0^*)^T \mathbf{L} \) is the set of all possible
\( D_j^2 \). Normally, due to the symmetry of the lattice, \( \mathbb{D}^2 \) degenerates to a smaller discrete set. It is evident that
\( \mathbb{D}^2 \) consists of identical subsets equally spaced by distance
\( d_{\text{min}} \) and expressed as \( \mathbb{D}^2 = \bigcup_{\mu = -\infty}^{\infty} \{(D^2_\mu + \mu \cdot d_{\text{min}}), \mu \in \mathbb{Z} \} \). Specifically, the number of possible direction vectors \( a_0^* \) in \( E_8 \)
reaches 120, because each \( E_8 \) lattice point is surrounded by 240 neighbors, and each direction has a conjugate counterpart, i.e. \( a_0^* = -a_0^{*\prime} \), which reduces the number by half.

We use a ‘cake-cutting’ algorithm to implement the HS-HD. \( d^2_n = (a^*_n)^T \mathbf{R}_n \) generates a characteristic number, which equals to the projection of \( \mathbf{R}_n \) along the direction \( a_0^* \). The same procedure is applied on the lattice set \( \mathbb{L} \) and generates a set of characteristic numbers, \( \mathbb{D}^2 \), as described above. By comparing the characteristic value \( d^2_n \) of the received super-
symbol with the lattice characteristic values \( D^2_\mu \in \mathbb{D}^2 \), we obtain the difference \( \delta = d^2_n - D^2_\mu \). Therefore, a hard decision selects a subset \( \mathbb{L}_\delta \) of lattice from the whole set \( \mathbb{L} \), where \( |\delta| \leq d_{\text{min}}/2 \). The selection starts from an arbitrary direction and goes through all possible 120 directions. The ergodic process stops when one element only remains in the candidate set. The procedure looks like cutting the cake (signal space) until the

The major difference between HS-HD and the conventional
hard-decision used for PAM-n are extra linear transforms required before the decision. Such operations are expected to be serialized with electrical analog circuits. As the decision can be implemented in an analog domain, ADC is dispensable, whereas it is required in the case of digital ML algorithms.

V. EXPERIMENTAL VALIDATION

The experimental setup is presented in Fig. 6. A 850 nm
multimode VCSEL, biased at 8 mA, is directly modulated by a 520 mV peak-to-peak differential electrical signal. A small-signal frequency response and an optical spectrum of the VCSEL are shown in Fig. 7 (a) and (b), respectively. The electrical
signal is generated from 28 GBaud sequences of 256K symbols by a 65 GSa/s 8-bit arbitrary waveform generator (AWG). The sequences are pre-calculated with a raised cosine (roll-off factor 0.5) pulse shaping and repeatedly transmitted. A pre-equalization on the electrical signal is included to mitigate the spectral roll-off of the AWG. The VCSEL used in this experiment had a –3 dB bandwidth of 17 GHz. The maximum output optical power from the transmitter optical sub-assembly (TOSA) reaches –0.61 dBm. A variable optical attenuator (VOA) is employed, which has the insertion loss of 0.52 dB, reducing the maximum launched optical power to –1.13 dBm. The signal was received by a commercially available VI-Systems photo-diode package which includes a trans-impedance amplifier (TIA). The detected electrical signal was improved with a low-noise amplifier (LNA) and a low-pass filter (LPF). Signal traces were captured with a 33 GHz, 80 GSa/s digital storage oscilloscope (DSO). A back-to-back BER measurements were taken for a primary characterization. Then link measurements were performed with one spool of 100 m OM3 MMF and one of OM4 MMF. They introduce the losses of 0.69 dB and 0.85 dB respectively, giving the maximum received optical power –1.82 dBm and –1.98 dBm correspondingly. For convenience of comparison, we set –2 dBm as the maximum power for BER measurements in the following experiments and treat it as the maximum achievable received optical power.

The received digital signal was processed offline. The traces were resampled from 80 GSa/s to 56 GSa/s, i.e. two samples
per symbol, processed with a T/2 fractional infinite impulse response (IIR) filter with 11 and 5 taps in the feed-forward and feed-back parts, respectively. Training sequences with an adaptive process using the least-mean-square (LMS) algorithm were applied to train the coefficients of the filter taps. The first 2048 samples of the traces were used as the training sequences. The training process was executed iteratively 10 times with different step sizes varying from 0.03 to 0.003. After the coefficients were trained during the initialization stage, they were kept constant for the whole payload. We used IIR filter instead of decision feedback equalizer (DFE) because the decision of BB8 is not straightforward, where no instant symbol-wise decision can be made. Therefore, we set the decision phase after the equalization and used the IIR filter, where no decision is required in advance. It is noteworthy that for keeping the results comparable, we apply the same signal process on all the formats studied in this work.

Data collections are treated differently in different transmission regimes. 100 traces with 2 million samples (25 µs) were stored for each transmission condition in critical regime: for the received optical power which generates BER approximately lower than $10^{-3}$ to the maximum received optical power, where the accuracy of BER is easily influenced by the number and length of the traces. 10 traces with 1 million samples (12.5 µs) were stored for the remaining power regime, because the trend was well displayed in the higher noise conditions. The value in every condition was given by the mean value of 90% confidence.

The performance criteria is often defined as the required received optical power with respect to a specific BER threshold. In optical transmission network (OTN) standard, FEC with 7% overhead (OH) is adopted and BER below $3.8 \times 10^{-3}$ is required as a criterion of successful transmission. However, it is not always reasonable to consider this BER threshold for the short-reach optical interconnects scenario because of high latency and large overhead of OTN FEC. Applications such as intra-datacenter (< 1000 m), rack-to-rack interconnects (from several meters to hundreds meters) and the board-to-board interconnects require the latency less than several hundreds nanoseconds. In addition, the high data exchange rates between datacenters are sensitive to the FEC OH. The newly accepted IEEE 802.3bm standard adopts FEC with a lower BER threshold for 100GBASE-SR4 transmission. The standard includes 2.7% OH Reed-Solomon code, RS (528, 514), with 100 ns latency. These requirements imply BER threshold at $1.42 \times 10^{-5}$ for output BER lower than $10^{-15}$ [29], [30]. A non-FEC transmission is preferred for application scenarios with extreme latency requirements, e.g. the data exchange between supercomputers. BER lower than $10^{-12}$ or even $10^{-15}$ is required. In our work the 2.7% RS (528, 514) is set as the main criteria, together with the 7% FEC limit at $3.8 \times 10^{-3}$ and non-FEC limit at $10^{-12}$ as additional references.

VI. PERFORMANCE

A. Back-to-back measurements

Fig. 8 shows the BTB BER sensitivity of BB8, PAM-4, and PAM-8. The last one is used as a reference. Substantially, BB8 and PAM-4 perform similarly at the 7% OH FEC level, predicted by simulation shown in Fig. 4. However, in the experiment BB8 has a minor degradation of 0.2 dB to PAM-4. It is reasonable that BB8 degrades faster due to the system imperfection in the low SNR regime, as it is constructed by more neighboring points. With the increase of received optical power, BB8 outperforms PAM-4 by an asymptotic gain larger than 1 dB. An apparent error floor can be observed for the PAM-4’s curve due to the limited bandwidth, relative intensity noise (RIN) and laser nonlinearities. Its new counterpart, BB8, provides a potential to achieve BER=$10^{-12}$ before reaching the maximum laser optical output power, as can be concluded from the fitted trend line in Fig. 8. It is also possible that BB8 conceals the error floor below the measurement accuracy limit at BER=$10^{-7}$. In contrast, PAM-8 displays an unsuccessful transmission with 7% FEC. BB8 gives a 2dB power margin (maximum optical power - 2 dBm) at the 2.7% OH FEC of RS (528, 514) which gives the output BER=$10^{-15}$. PAM-4 has a BER gap larger than one order of magnitude.

B. MMF links

Transmission of BB8 over 100 m OM3 and OM4 MMFs results in a < 1 dB penalty at 7% FEC as compared to the BTB scenario (100 m OM3 in Fig. 9 and 100 m OM4 in Fig. 10). PAM-4 experiences a major degradation in OM3 and OM4. Unlike the simulation analysis in Fig. 4, the receiver sensitivity for BB8 is improved as compared to PAM-4 by 0.6 dB and 1 dB for OM3 and OM4, respectively. BB8 has a successful transmission at the lower FEC threshold and an improved power margin for both 100 m OM3 and 100 m OM4, whereas for PAM-4 the error floor close to maximum received optical power makes 56 Gbit/s transmission unsuccessful. Apparently, PAM-4 degrades faster than BB8 in MMF links. We believe that it stems from the fact that BB8 has larger MMED than PAM-4, which is more tolerant to the signal distortion from the nonlinearities of components and the limited bandwidth of fiber links. It is also noteworthy that the increased gap doesn’t imply the inevitable relations with the differences in specifications between OM3 and OM4. In principle, OM4 is further optimized based on OM3, which theoretically should have the larger modal bandwidth. However, due to the different
design and implementation of vendors, batches, conservation conditions of fiber spools or even launching conditions, it is difficult to provide direct comparison of the performance with different fiber spools. Deeper analysis goes beyond the scope of this paper.

Since 100 m links are typical in commercial products, these results imply the potential of BB8 for MMF data transmission links scenarios.

VII. CONCLUSION

An 8D modulation format based on E8 lattice was proposed for short-reach data transmission links. The experimental performance shows a 2 dB power margin in BTB measurements and ~ 1.5 dB for a transmission over 100 m OM3/OM4 MMF measured at 2.7% 100BASE-SR4 FEC. It implies the potential advantages of BB8 in intra-datacenter and other short-reach applications. Due to a better asymptotic BER performance, BB8 relieves the requirement on maximum received optical power, and hence the maximum laser output power. Potential non-FEC transmission of BB8 down to BER=10^{-12} without extra redundancy can provide reduced latency and complexity of the transceivers. Moreover, it is inherently compatible with the 8-lane OSFP links. BB8 is also attractive for future modulation flexible transceivers, because of the possible smooth transition between BB8 and PAM-n provided by the simplified mapping and de-mapping schemes. Considering the requirements on capacity, power efficiency, latency, reliability and flexibility, BB8 is a possible candidate for next generation IM/DD optical interconnections.

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