response can also explain the imperfection in the link dispersion compensation and part of the penalty. Effort has been made to modify the grating fabrication facilities to improve this. Much improved gratings have been made recently and will be reported elsewhere. The source laser had large wavelength jitters (which can be as much as a few nanometres in the worst case), and this would give much of the penalty in conjunction with the wavelength dependence. Indeed, the expected excessive noise as result of this can be seen in the eye diagram. An improved future result will come from gratings with better controlled dispersion characteristics. A broadband timing (several nanometres) is possible if third-order dispersion compensation can be written in the same grating. Nevertheless, we have demonstrated, for the first time, transmission over 27 times the dispersion limit using chirped fibre gratings.

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References

Asynchronous multirate optical wireless PPM-CDMA in an indoor non-directed diffuse channel

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Indexing terms: Optical communication, Code division multiple access

Asynchronous multirate pulse position modulation-code division multiple access (PPM-CDMA) is proposed for an indoor optical wireless time dispersive channel. As a signature sequence for CDMA, an optical orthogonal code (OOC) is used. The optical PPM-CDMA has advantages in that it is power efficient and provides multirate services by simply varying the modulation level for the fixed chip rate at the transmitter and sampling time at the receiver.

Introduction: Owing to increasing demand for wireless services, wireless communication requires a new frequency spectrum. As a solution to this problem, an optical wireless channel is considered for indoor wireless communication [1]. Since the channel has practically unlimited resources for bandwidth, it can accommodate wireless multimedia communications. As a multiple access scheme, code division multiple access (CDMA) is preferable to the optical communication systems, because of the large bandwidth offered by an optical channel [2]. There has been research on optical wireless CDMA employing on-off keying (OOK) in an indoor non-directed diffuse channel [2]. Since power efficiency is more important than bandwidth efficiency for an optical wireless system, pulse position modulation (PPM)-CDMA is proposed to OOK-CDMA [3]. The optical PPM-CDMA exploits both the power efficiency and the large bandwidth provided by an optical channel and it provides the multirate services by varying the level of PPM for the fixed chip rate at the transmitter and sampling time at the receiver. In this Letter, the bit error rate is analysed for the asynchronous multirate optical wireless PPM-CDMA.

System and channel models: Suppose that there are N users in an optical wireless PPM-CDMA system. The PPM encoder converts the binary source bits into a symbol vector with a rate of log₂M per M. The M-PPM symbol vector of the kth user is represented as s_k,n which has all zeros except for one at position n, n ∈ {0, 1, ..., M - 1}. The PPM symbol vector is parallel-to-serial converted into the sequences s_k,n at time i. The PPM encoded sequence waveform is represented as s_k(t) =
\( \Sigma_{\tau} P(t - \tau) \). Here, \( \tau \) is the pulse duration and \( P(t) \) is a rectangular pulse with duration \( \tau \). In an optical CDMA system, an optical orthogonal code (OOC) is used as a signature sequence which is the sequence of 0s and 1s. We suppose that each user has a distinct \( (F, K, \lambda_0, \lambda) \) OOC which is characterised by length \( F \), weight \( K \), autocorrelation constraint \( \lambda_0 \), and cross correlation constraint \( \lambda \) \[4\]. We suppose also that each pulse of the PPM signal is divided into \( F \) chips with duration \( \tau \), then \( \tau = F \tau' \). Let the signature sequence of the \( k \)th user be denoted by \( (c_{k,0}, ..., c_{k,F-1}) \), where \( c_{k,j} \in \{0, 1\} \), \( j = 0, 1, ..., F - 1 \). Then, the signature sequence waveform for the \( k \)th user is represented as \( c_k(t) = \sum_{j=0}^{F-1} c_{k,j} P_j(t - j \tau') \). Here, \( c_{k,j} = c_j \) for any integer \( j \) and \( P_j(t) \) is the rectangular pulse duration with width \( \tau \). Finally, the transmitted optical signal of the \( k \)th user is represented as \( u_k(t) = (FMP/k)c_k(t)\delta(t) \) for the average power of a transmitted optical signal \( P \).

To provide the multirate services in optical wireless PPM-CDMA systems with fixed pulse duration, the chirp rate and sampling time do not change for each transmission rate. In Fig. 1, the multiuser PPM CDMA signaling is shown with fixed pulse duration. The pulse duration is fixed for each PPM level and one chip period is multiplied to one pulse duration. The bit rate of the \( M \)-PPM-CDMA is represented as \( R_{\text{bit}} = \log_2(M/F) \). The total received signal from \( N \) users is given by

\[
 r(t) = \sum_{k=1}^{N} u(k)(t - \Delta_k) * h_k(t) + z(t) \tag{1}
\]

where * denotes convolution, \( \Delta_k \) is a relative delay for the signal from the \( k \)th user to the desired user, \( h_k(t) \) is the channel impulse response given in \([1]\) and \( z(t) \) is an additive white gaussian noise with power spectral density \( N_0 \). Here, the delay is represented as \( \Delta_k = \frac{j}{2} \tau + \rho \) \( \forall k \); \( \rho \) is the discrete random variable which takes the one value out of \([0, 1, 2, ..., F - 1]\) and \( \rho \) is the random variable uniformly distributed over \([0, 1]\).

The received signal is multiplied with the signature sequence waveform of the \( k \)th user and integrated over each pulse duration \( \tau \) and sampled, before being serial-to-parallel converted into the received symbol vector \( \mathbf{e}_k \). For the largest PPM level \( M_{\text{max}} \), the size of the received symbol vector is \( 1 \times M_{\text{max}} \). The received symbol vector consists of a desired signal vector, a self-interference vector, a multiuser interference vector and a noise vector. Out of the desired signal, the component where the pulse is located is given by

\[
 x_k = \frac{1}{T_C} \int_{0}^{T_C} u_k(t) * h_k(t) \, dt \tag{2}
\]

where \( \mathbf{h}_k = [h_k(0), h_k(1), ..., h_k(T_C)] \) and \( \mathbf{l}_o \) is the self-interference term. The desired signal vector of the \( k \)th user is represented as \( \mathbf{d}_k = [d_k(0), d_k(1), ..., d_k(T_C)] \). To represent the interference vector of the \( k \)th user, we define a signature sequence vector of the \( k \)th user: \( \mathbf{c}_k = [c_k(0), c_k(1), ..., c_k(T_C)] \), where \( c_k(i) \in \{0, 1, \ldots, F - 1\} \) and \( i = 0, 1, ..., F - 1 \). The \( M_{\text{max}} \times F_{\text{max}} \) signature sequence matrix is given by

\[
 \mathbf{C}_{k,F} = \begin{bmatrix}
 c_k & 0 & \cdots & 0 \\
 \vdots & \ddots & \ddots & \vdots \\
 0 & \cdots & \cdots & 0 \\
 0 & \cdots & 0 & c_k
\end{bmatrix} \tag{3}
\]

where \( 0 \) is the \( 1 \times F \) zero row vector. Using the signature sequence matrix, the self-interference vector is given by

\[
 \mathbf{l}_o = \sum_{k=1}^{N} \mathbf{l}_{o,k} = \sum_{k=1}^{N} \mathbf{c}_k \mathbf{c}_k^T + \mathbf{z}_k \tag{4}
\]

where \( \mathbf{S}_k^{-1}, \mathbf{S}_k^{(0)} \) are the two symbol vector groups of the \( k \)th user and \( \mathbf{C}_{k,F} \) is the signature sequence matrix column-wise shifted by \( n \) times on the right side for positive \( n \) and on the left side for negative \( n \). For example, to get \( \mathbf{C}_{k,F} \), each column of \( \mathbf{C}_{k,F} \) is shifted once to the right side and a zero column vector is inserted in the first column.

The multiuser interference vector of the \( k \)th user is given by

\[
 \mathbf{l}_{o,k} = \sum_{n=1}^{N} \sum_{x \neq k} \mathbf{c}_n (S_n^{-1}) \mathbf{c}_n + (1 - \rho) \mathbf{C}_{n,F} \mathbf{C}_{n,F}^T \tag{5}
\]

where \( \rho \) is the discrete random variable which takes the one value out of \([0, 1, 2, ..., N - 1]\) and \( \rho \) is the random variable uniformly distributed over \([0, 1]\). The received symbol vector is divided into \( M_{\text{max}}(M) \) vectors and each vector is the input to the decision device. The decision device has the rule to choose the largest component out of the \( M \) component. The decided PPM symbol vector is decoded into the binary sequence.

**Probability of error**: The method to get the BER of the PPM signal is given in \([1]\). Considering the interferences of the other users, the BER of a PPM-CDMA system for the \( k \)th user is given by

\[
 p_{\text{err}}^k = \frac{M}{M-1} \left[ 1 - \sum_{m=2}^{M} \left( 1 - Q \left( \frac{W_k^m - W_k^m}{\sqrt{2\sigma^2}} \right) \right) \right] \tag{6}
\]

where \( W_k^m \) and \( W_k^m \) are the first and the \( m \)th components of \( W_k \), respectively, and \( Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-t^2/2} \, dt \). Then, the expectation is taken for independent and uniformly distributed symbol vector groups \( \mathbf{S}_k^{(0)}, \mathbf{S}_k^{(0)} \) and \( \beta_0, \rho_0 \).

**Fig. 2 BER of PPM-CDMA**

Data rate of 4-PPM is 2 Mbit/s and that of 16-PPM is 1 Mbit/s

**Conclusions**: In this Letter, the BER of multirate optical wireless PPM-CDMA is analysed. As the level of PPM signal increases, the data rate gets slower and the power efficiency improves. There is a trade off between the data rate and the power efficiency as the level of PPM varies providing users with a choice.

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**References**

Benefits of wavelength translation in datagram all-optical networks

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Indexing term: Optical communication

It is shown that wavelength translation mitigates the blocking of cells substantially in cross-connected networks. By increasing the number of wavelengths and employing wavelength translation, the probability of deflection can be reduced, which in turn leads to a significant improvement in the teletraffic performance of the network.

Introduction: One of the major problems in multi-wavelength, two connected mesh networks is the blocking of cells at the nodes. Blocking occurs when two competing cells at the input of the node desire the same output. Store and forward, deflection routing and wavelength translation are some techniques which can be used to resolve the conflicts. The teletraffic performance of circuit-switched all-optical and electronic (regenerative) wavelength translation has recently been reported [1, 2]. However, the benefits of using wavelength translation in cell-switched cross-connected networks with deflection routing have not been reported yet. This Letter compares Manhattan Street (MS) and ShuffleNet (SN) networks under wavelength translation in terms of average propagation delay and throughput. We present the limit of operation based on a uniform traffic scenario. It is shown that wavelength translation significantly solves the blocking of cells. Results indicate that the probability of deflection can be reduced substantially by increasing the number of wavelengths and employing wavelength translation which, in turn, significantly improves the teletraffic performance of the network.

Fig. 1 Architecture of wavelength translation node

All submodules are interconnected and there is a central control unit which decides transmission operations

Principle of operation: The node under consideration is composed of a stack of submodules, one per wavelength as shown in Fig. 1. All the submodules are interconnected and there is a central control unit which decides the routing operations. The wavelengths from the input fibres are spatially demultiplexed and sent to the appropriate submodule. Cells from the submodules are finally remultiplexed onto the output fibres. The logical flow of submodule operations is absorption, translation of flow-through cells, electronic translation/injection of new generated cells, and routing [3]. The absorption operation removes cells destined for the node. It is assumed that there is one receiver per input wavelength, so that all cells destined for the node can be removed. The wavelength translation operation has the task of rearranging the cells on the various wavelengths so as to eliminate as many wavelength conflicts as possible at its output. Wavelength translation priority is given to cells in transit in order to minimise deflections of flow-through cells. Then, electronic wavelength translation and injection of newly generated cells occurs. Finally, the routing operation is performed by 2x2 switches, one per wavelength, that routes cells out with a simple hot-potato, random contention-resolution algorithm.

Basically, slots can be empty (E), or they can carry a cell for the node (FN), or a cell that cares to exit at output 1 (C1) or at output 2 (C2), or they can carry a don’t care (DC) cell. A conflict occurs in a submodule when there are two care cells with the same output preference, for example (C1, C1) or (C2, C2). A conflict selected at random from the pool of conflicts is resolved by taking one of the cells and translating it to a suitable non-conflictive empty or non-empty slot of a neighbouring submodule randomly selected. Therefore, there are many possibilities to resolve a conflict [3], but the most important is that which resolves conflict of kind (C1, C1) in one submodule by using another conflict of kind (C2, C2) in another submodule, possibly as a result of the translation (C1, C2) and (C1, C2). In the case of a local conflict, where there are no alternative available slots, one of the cells in conflict is randomly chosen for deflection.

The decision for transmission is taken after the absorption operation; then, a new cell per submodule will be injected into the network if there is at least one empty slot and a cell ready for transmission. If there is a conflict between the newly generated cell and the cell in transit, the new cell migrates randomly to a submodule where there is an available non-conflictive empty slot, and is then transmitted by the corresponding submodule. If the new cell cannot find an empty non-conflictive slot, then it is transmitted even though a deflection will occur. Something could be gained by using a hold-up technique [4]; i.e. avoid injecting a new cell whenever such injection causes a deflection.

Results and discussion: Monte Carlo simulation results are presented to validate the accuracy of an analytical model [5] using uniform traffic according to the routing method for regular cross-connected networks presented in [6], which have been extended to wavelength translation. Fig. 2 shows propagation delay H in number of hops against number of channels n for hot-potato, single-buffer, store-and-forward (SandF) and wavelength translation at p = 1

Results are for ShuffleNet (SN64) and Manhattan Street (MS64) networks with 64 nodes.

* MS simulation, O SN simulation

--- MS theory, · · · · · · SN theory

Fig. 2 Results of average propagation delay H in number of hops against number of channels n for hot-potato, single-buffer, store-and-forward (SandF) and wavelength translation at p = 1

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