Performance Evaluations on Shared-Type Encoder/Decoder with Wavelength/Time 2-D Codes for Optical CDMA Networks

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Abstract - For large capacity optical CDMA networks, we propose a shared-type encoder/decoder based on a tunable wavelength converter (TWC) and an arrayed waveguide grating (AWG) router. Feasibility of the structure of the proposed encoder/decoder for dynamic code allocation is tested through simulations using three types of wavelength/time 2-D codes, which are the generalized multi-wavelength prime code(GMWPSC), the generalized multi-wavelength Reed-Solomon code(GMWRSC) and the matrix code.

Test results show that the proposed encoder/decoder can increase the channel efficiency not only by increasing the number of simultaneous users without any multiple-access interference but by using a relatively short length CDMA codes.

1. Introduction

In conventional 2-D optical CDMA system, each user needs a specific fixed encoder/decoder which results in very lengthy CDMA codes or huge amount of hardware for a large system. Users who share the encoder/decoder can cause collision between the users when each user transmits the same code simultaneously. We solved this problem by employing a new dynamic code allocation scheme based on the control of code wavelength by TWC.

The proposed system uses a group of encoder/decoder for many simultaneous users to share by employing AWG. Feasibility of the structure of the proposed encoder/decoder for dynamic code allocation is tested through simulations using three wavelength/time 2-D codes, which are the generalized multi-wavelength prime code (GMWPSC) [1], the generalized multi-wavelength Reed-Solomon code (GMWRSC) [1] and the matrix code [2].

2. Shared Encoder/decoder Structure

The wavelength that connects the i th input to the j th output of the N × N AWG can be expressed by

$$\lambda_i(j) = \lambda_j$$  \hspace{1cm} (1)

where the subscript j is determined by \(j = ij \mod N\) [3]. Using this AWG routing characteristics, several simultaneous users can share the encoder. The collision between users can be avoided easily by appropriate control of output wavelengths of TWC.

We now use the GMWPSC, GMWRSC and the matrix code as wavelength/time 2-D codes for our shared-type encoder/decoder. The encoder/decoder configurations for (5×5,0,1)GMWPSC is shown in Fig. 1. The encoder/decoder configurations for (7×6,0,1)GMWRSC is given in [3].

3. Simulation Results

Based on the tree network topologies of GMWPSC, GMWRSC for 5 users and matrix code for 6 users using Optsim software package, simulation results for detection of any specific user code show that the proper choosing of the threshold level at the detector gives the results that the data can be recovered back to its original values. Fig. 2 represents the detection results of C3 with bit stream of "1101010" for matrix code. Detection results for GMWPSC and GMWRSC are given in [3].

The encoder/decoder for the matrix code does not need TWC so that the system becomes simpler compared with other two cases. Compared with GMWPSC and GMWRSC, the bit error rate of the matrix code increases due to the use of more wavelengths for the same number of users. System complexities of three codes are given in Table 1.

![Diagram](image)

**Fig. 1. Configuration of the shared-type encoder/decoder with (5×5,0,1)GMWPSC.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wavelength channels</th>
<th>Code length</th>
<th>AWGs</th>
<th>TWCs</th>
<th>Error rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMWPSC</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>50</td>
<td>21</td>
</tr>
<tr>
<td>GMWRSC</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Matrix Code</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
4. Performance Analysis

The performance of encoder/decoder is determined by the bandwidth efficiency of the used optical codes which is closely related with the error probability of the code in multiple user circumstance as well as the code size dependent on the code length. To analyze the performances of GMWPC and GMWRSC codes in our encoder/decoder, we assume chip synchronization because chip synchronization results in an upper bound of the performance.

4.1 Error Probability

The probability of one of the pulses in a signature code at any time chip is assumed to be $q^{(1/2)}$, $c/L$, where $c$ is the code weight, i.e., the number of pulses in a code, $L$ is the code length, and the received data bit of 1 or 0 is equally probable. The error probability of $(p \times p, p, 0, 1)$GMWPC is given by

$$P_e = \frac{1}{2} \sum_{i=1}^{M-1} \frac{M-1}{i} q^i (1-q)^{M-1-i}$$

where $Th$ and $M$ are threshold level and total number of simultaneous users, respectively. The result in (2) can be modified to the error probability of $(p \times p, p-1, 0, 1)$GMWRSC by simply replacing $q$ by $(p-1)/p^2$.

Fig. 3 shows the error probabilities versus number of simultaneous users $M$ for GMWPC and GMWRSC for various prime number $p$ based on Eq. (2). Due to the longer code length, the GMWPC performs better than the GMWRSC.

4.2 System Capacity

When $N_c$ wavelength channels and $N_t$ time chips are used to implement the 2-D codes, we have $N_c$ for GMWPC and $N_cN_t/(N_cN_t-1)$ for GMWRSC, respectively, orthogonal codewords.

For a given $N_c$, more users can be accommodated by employing a larger number of time chips at the cost of narrower user bandwidth. In this case, however, the number of simultaneous users $M$ also decreases rapidly as the guaranteed error probability becomes lower, and thus the system capacity decreases. For the case where $N_c = p$, $N_t = p$ for GMWPC and

for GMWRSC with the same error probability of $10^{-2}$, the normalized system capacity $M/N_t$ is plotted as a function $p$ of in Fig. 4.

Fig. 3. Error probabilities vs number of simultaneous users for GMWPC and GMWRSC.

Fig. 4. Normalized system capacities for $(p \times p, p, 0, 1)$GMWPC and $(p \times (p-1), p-1, 0, 1)$GMWRSC.

We can see that as $p$ increases, the normalized system capacities increase tending to one, while the normalized user bandwidths decrease rapidly. Therefore, the system capacity and the number of users are limited by user bandwidth rather than $N_c$.

References