Novel wavelength-time spreading optical CDMA system using arrayed-waveguide grating

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We propose a novel two-dimensional code and transmitter/receiver structure using AWG for general multi wavelength-time optical CDMA network. We demonstrate via experiment that suggested scheme successfully performs encoding/decoding operations in addition to the possibility of incorporated dispersion compensation.
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The unique attributes of the optical code-division multiple access (CDMA) networks, such as multiple asynchronous access by independent users and enhanced information security can be achieved by assigning a codeword for a certain user and sharing a common media [1-4]. Since important system parameters, like the maximum number of supportable users and crosstalk level between channels, are directly related with the employed code family, various code families have been suggested. Recently reported temporal/wavelength two-dimensional codes outperform previous coding schemes in the number of simultaneous users at a given bit error ratio (BER) [1,2]. It also gives a notable extendibility in the design of code family with the efficient usage of both time and wavelength coordinates. To implement the encoder/decoder for such a multi wavelength-time optical CDMA network [1-3], several methods have been suggested. However, most of them use the narrowband fiber Bragg gratings (FBGs) as a wavelength-selective reflector, which makes it difficult to fabricate the accurate encoder/decoder device. Since the FBG itself has a non-zero length, it is also hard to reduce the time chip interval directly related by the distance between FBGs in physical structure. Moreover, the use of FBG requires a strict condition in the apodization of gratings [1,3].

In this report, we introduce a wavelength-time spreading two-dimensional code family and its transmitter/receiver structure using arrayed-waveguide grating (AWG), to alleviate these problems.

![Diagram](image_url)

Fig. 1. Proposed encoder/decoder structure and its experimental setup for temporal/wavelength optical CDMA network.
The case of 4-wavelength channel and code length of 15 is illustrated for example.
We constructed two-dimensional code matrices using well-known pseudo-random bit sequence as described in Lempel et. al.’s [5]. Detailed algorithm for the construction with this sequence is described in our former works [2]. For convenience, we illustrate a simple case with 4 wavelengths and 15 time chips (w=4, N=15). Starting with 15 bits PRBS, we can get code matrix in the inset of Fig. 1 after merging adjacent 4 bits (σ₄ transformation) and mapping procedure subsequently. Since the obtained sequences are optimal in Hamming correlation sense [5], two-dimensional code family has near optimal property.

<table>
<thead>
<tr>
<th>15 bits PRBS</th>
<th>0 0 0 1 0 1 1 0 1 0 1 1 1 1</th>
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<tbody>
<tr>
<td>σ₄ transformed</td>
<td>8 4 2 9 12 6 11 5 10 13 14 15 7 3 1</td>
</tr>
<tr>
<td>Mapped sequence</td>
<td>0 4 2 0 0 0 0 0 0 0 3 1</td>
</tr>
</tbody>
</table>

Using this code matrix, the pulses with wavelength λ₀ and λ₁ should be incident on the network with the delay of 7Tₐ and Tₐ, respectively. (Tₐ : chip duration, λₐ : the repeated wavelengths of the specific port of AWG.) Similarly, pulses in the wavelength λ₅ should have a time delay of pseudo-random characteristic, since the code family construction was based on the pseudo-random sequence [5]. Considering the fact that the chip duration almost corresponds to the pulse width of the optical RZ pulse, the length of delay line can be calculated easily.

Fig. 1 illustrates our novel implementation of encoder/decoder pair using AWG. In the encoder part, the AWG splits the on-off keyed broadband optical pulse in return-to-zero (RZ) format into many small pulses with different wavelengths, and the optical delay lines of various length attached to AWG make each pulse at different frequency to experience different time delay. The lengths of delay line, or the location of reflectors in each wavelength channel, are determined by employed two-dimensional wavelength-time optical CDMA code, and the decoder can discern their own codewords by performing inverse operation of the encoding process. Unlike the FBG structure, wavelengths can be repeatedly used for transmission due to the cyclic property of AWG. This makes the wasted broadband spectrum more useful for signal transmission, and enables better encryption in the wavelength domain.

The distinguished feature of this hardware implementation also includes that it can be still usable for a code family with 'multiple-pulses per wavelength'. Since pulses in different wavelength channel are processed and treated independently, it is possible to have two or more reflected optical pulses in the different wavelengths in the same time slot. This fact greatly improves the flexibility of code design and provides the way to realize the code family that has multiple pulses in the same time chip. The previous device using the array of FBGs is not suitable for 'multiple-pulses per row' code, since grating reflectors should be arranged spatially not to give a same delay time [1,3].

For the experiment, the backward amplified spontaneous emission (ASE) of erbium-doped fiber amplifier (EDFA) was used as a broadband high-power source. The waveform of input pulses and the spectrum of the encoded signals with 155 Mb/s repetition rate are shown Fig. 2 (a) and (c) respectively. After passing through an encoder, broadband pulse were shuffled in both time and wavelength domains. The time-scrambled data after encoding process are illustrated in Fig. 2 (b). As shown in example, we used 4×15 two-dimensional codeword implemented by 8-channel AWGs for the experiment. Especially, we performed this experiment using only one AWG, not with AWG pair, utilizing the symmetric property of employed code matrix. Port 1,3,5,7 of AWG were assigned for WDM channels that are arranged 3.2nm apart each other in the wavelength domain, and unused AWG ports were blocked by optical absorber to prevent unwanted power transmission. After propagating through transmission link, the encoded waveform enters the complementary decoder as described so that all the wavelength components have the same amount of time delay. Fig. 3 (a) and (b) show the intensity of the properly and improperly decoded pulses measured after decoder, respectively. When the received pulses were improperly decoded, then pulses spread by encoder remained as a pseudo-noise as shown in Fig. 3 (b), as expected. Fig. 3 (c) illustrates the spectrum of decoded pulses, such broad that making it impossible to eavesdrop signal without using a proper decoder structure.
To summarize, we have reported the novel optical CDMA system employing novel wavelength-time spreading two-dimensional code family with AWG router. The experiment results show that the proposed code family and encoding/decoding device can be used successfully in the application of secure high-speed local area network. Even though we focused on the experiment for the local access network application, long distance transmission of the suggested code set / hardware structure should be possible with the dispersion compensation procedure in the lengths of delay lines and narrow linewidth sources in each channels[2].

References