

Reconfigurable Optical CDMA Network Codecs Structured over M-Signed Waveguide-Gratings

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Abstract—In views of optical CDMA confidentiality, this paper proposes a signature reconfiguration scheme over the network coder/decoders (codecs) design. By exclusively assigning to each network user a set of pseudo-orthogonal M-signature codes and randomly selecting one among them to represent each user's signature. A central node station is assumed to monitor network traffic condition and to signal transceiver coder-decoder pair to perform signature codes changing. We structure the detailed M-signature codecs design over arrayed-waveguide grating devices.

Keywords—Optical code division multiple access (CDMA), Spectral amplitude coding, Arrayed-waveguide-grating router, FSR (free spectral range), Balanced photo-detector.

I. INTRODUCTION

Optical code-division multiple-access (OCDMA) is an attractive technology due to its robust performance, asynchronous network access capability, flexibility. However, as pointed out by Shake [1], OCDMA techniques suffer from inherent security disadvantages. In order to overcome the security problem we propose a code reconfiguration scheme.

The code reconfiguration [2] is governed by a central node to signal transceiver pair to change their signatures in a random way. Relatively prime-length maximal-length sequence (M-sequence) codes are adopted to illustrate the signatures assignment and reconfiguration. They are simply called 'M-signatures' in this paper [3][4]. The M-signatures possess well-defined correlation functions and are nearly orthogonal among the signature codes families [5].

In this paper, we illustrate an OCDMA network codecs design governed by changing user's M-signature codes in a random way. The result shows that the eavesdropper processes codes detection more difficult, thus network confidentiality could be significantly increased.

II. WAVEGUIDE-GRATING-BASED M-SIGNATURES

An AWG provides a fixed routing of an optical signal from a give it input port to a given output port, based on the wavelength of the signal. Signals of different wavelengths coming into an input port will each be routed to a different output port. Similarly, different signals of the same wavelength may be directed to different input ports, and they shall be routed to different output ports. Figure 1 show the AWG wavelengths routing property. The input wavelengths λ_M more than the AWG input port N ($M > N$) then the output

wavelengths characteristics based on FSR (free spectral range) property. For example if input wavelengths $\lambda_1 \sim \lambda_{21}$ the output port 2 wavelengths are $\lambda_2, \lambda_2 + \text{FSR}, \lambda_2 + 2\text{FSR}, \lambda_2 + 3\text{FSR}$ so we can adjust FSR to get a given wavelengths in output port.

The output ports of AWG router are placed mirrors according to the signature sequence. If signature sequence has cyclically property so that the mirror didn't change its place. In this way the optical circulator also can output particular signature codes, then the optical circulator output change the code assigned by the optical switch. Features mentioned above can be known by Fig. 1.

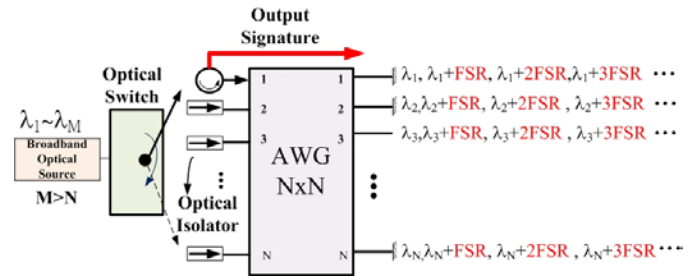


Figure 1. M-signature codes reconfiguration over AWGs' periodic routing and FSR characteristics.

Two nodes codec users are assumed in the following optical code-division multiple-access (OCDMA) network codecs design. In such two nodes OCDMA network, binary code vectors $T^i \mathbf{X}_1$ and $T^j \mathbf{X}_2$ of code periods n_1 and n_2 are assigned to the 1st and the 2nd users, respectively. Here T^i is an operator that shift $\mathbf{X}_1$ cyclically to the left by i chips, $0 < i < n_1$. Also, T^j is an operator that shift $\mathbf{X}_2$ cyclically to the left by j chips, $0 < j < n_2$.

In the reconfigurable OCDMA network, user #1 can be assigned with n_1 possible signature codes $\{\mathbf{X}_1, T\mathbf{X}_1, T^2\mathbf{X}_1, \dots, T^{n_1-1}\mathbf{X}_1\}$, each of code period n_1 . Also, user #2 can be assigned with n_2 possible signature codes $\{\mathbf{X}_2, T\mathbf{X}_2, T^2\mathbf{X}_2, \dots, T^{n_2-1}\mathbf{X}_2\}$, each of code period n_2 . For code periods n_1 and n_2 being relatively prime, signature $T^i \mathbf{X}_1$ assigned for user #1, $0 \leq i \leq n_1 - 1$, can repeat its code vector n_2 times to result in a signature sequence $(T^i \mathbf{X}_1)^{n_2}$ of length $n = n_1 n_2$. Similarly, signature $T^j \mathbf{X}_2$ assigned for user #2, $0 \leq j \leq n_2 - 1$, can repeat its code vector n_1 times to result in a signature sequence $(T^j \mathbf{X}_2)^{n_1}$ of the same length $n = n_1 n_2$. When the information signal is bit "1", either users #1 and #2 will send their signature chips $(T^i \mathbf{X}_1)^{n_2}$ and $(T^j \mathbf{X}_2)^{n_1}$. Conversely, when the information signal is bit "0", all

zero chips ($\mathbf{0}$)ⁿ of length n will be sent by the corresponding network user.

Following the above coding processes, the coded spectral signals are combined in the $N \times N$ channel coupler and broadcast to each receiver. For bipolar coding scheme, signature sequence ($\mathbf{X}_k$)ⁿ and complementary signature sequence ($\bar{\mathbf{X}}_k$)ⁿ are respectively coded for logic “1” and logic “0” data bits of the k -th user. The received spectral signal ($\mathbf{Y}$)ⁿ is the summation of all users’ transmitted signal spectra: ($\mathbf{Y}$)ⁿ = $\sum_{k=1}^N [d_k (\mathbf{X}_k)^n + (1-d_k)(\bar{\mathbf{X}}_k)^n]$, where $d_k \in \{0, 1\}$ is the k -th user’s data bit, N is the maximal number of network users. In this paper, we assume unipolar coding scheme for simplicity. That is, when $d_k=1$, signature sequence ($\mathbf{X}_k$)ⁿ is encoded and transmitted; when $d_k = 0$, all zeros signature sequence ($\mathbf{0}$)ⁿ is assumed. The composite spectral signal then becomes ($\mathbf{Y}$)ⁿ = $\sum_{k=1}^N [d_k (\mathbf{X}_k)^n]$.

III. STRUCTURING M-SIGNATURE ENCODERS

Figure 2 shows the proposed arrayed-waveguide grating (AWG)-based transmit-encoders. In each transmitter, the spectrum of broadband sources are filtered within one free spectral range (FSR) of the AWG router and the output ports of AWG routers are placed mirrors (e.g., output port # i is placed reflective mirror when signature chip x_{i1} in code vector $\mathbf{X}_1$ is 1).

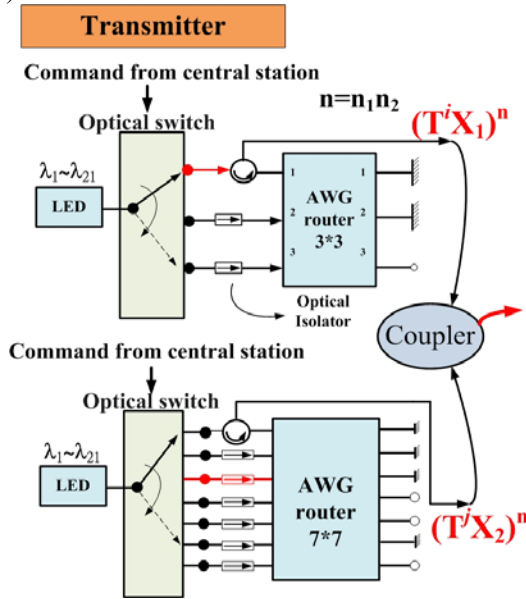


Figure 2. Reconfigurable transmitter encoders with signature codes $\mathbf{X}_1 = (110)$ and $T^2 \mathbf{X}_2 = (1011100)$.

For signature encoder of transmitter #1, an illustration is drawn in the upper part of Fig. 2 with M-signature code pattern $\mathbf{X}_1 = (110)$. The reflective mirrors corresponding to signature $\mathbf{X}_1 = (110)$ are normally placed at the output ports #1, and #2 of the 3x3 AWG router, but leaves open in the output port #3. If information bit to be transmitted is “1”, the reconfiguration switch will direct the ‘light signal’ to the first input port of the AWG router. The wavelengths $\lambda_1 \lambda_2$, $\lambda_4 \lambda_5$, $\lambda_7 \lambda_8$, $\lambda_{10} \lambda_{11}$, $\lambda_{13} \lambda_{14}$, $\lambda_{16} \lambda_{17}$, $\lambda_{19} \lambda_{20}$ will be reflected, corresponding to sequence chips ($\mathbf{X}_1$)ⁿ = ($\lambda_1 \lambda_2 0$, $\lambda_4 \lambda_5 0$, $\lambda_7 \lambda_8 0$, $\lambda_{10} \lambda_{11} 0$, $\lambda_{13} \lambda_{14} 0$, $\lambda_{16} \lambda_{17} 0$, $\lambda_{19} \lambda_{20} 0$) being coded and transmitted.

Conversely, when the information signal is bit “0”, all zero chips ($\mathbf{X}_1$)ⁿ = ($\mathbf{0}$)ⁿ of length $n = 21$ will be sent by the transmitter #1.

As for signature encoder of transmitter #2, an illustration is drawn in the lower part of Fig. 2 with M-signature code pattern $T^2 \mathbf{X}_2 = (1011100)$. Reflective mirrors corresponding to signature $\mathbf{X}_2 = (1110010)$ are normally placed at the output ports #1, #2, #3, #6 of the 7x7 AWG router, while leaves open the output ports #4, #5, and #7. If signal light to be transmitted is “1”, the reconfiguration switch will direct the ‘light signal’ to the third input port of AWG router. The wavelengths $\lambda_3 \lambda_4 \lambda_5 \lambda_1$, $\lambda_{10} \lambda_{11} \lambda_{12} \lambda_8$, $\lambda_{17} \lambda_{18} \lambda_{19} \lambda_{15}$ will be reflected, corresponding to sequence chips ($T^2 \mathbf{X}_2$)ⁿ = ($\lambda_1 0 \lambda_3 \lambda_4 \lambda_5 0 0$, $\lambda_8 0 \lambda_{10} \lambda_{11} \lambda_{12} 0 0$, $\lambda_{15} 0 \lambda_{17} \lambda_{18} \lambda_{19} 0 0$) being coded and transmitted. Conversely, when the information signal is bit “0”, all zero chips ($T^2 \mathbf{X}_2$)ⁿ = ($\mathbf{0}$)ⁿ of length $n = 21$ will be sent by the transmitter #2.

Following the above coding process, the coded spectral signals are combined in a 2x2 optical coupler and broadcast to each receiver in the network. The composite spectral signal assumes spectral amplitudes summation of the individual spectral signal chips from either of transmitters #1 and #2. For information bits in transmitters #1 and #2 being both of logic “0”, the composite signal will surely be ($\mathbf{Y}$)ⁿ = ($\mathbf{0}$)ⁿ. For information bits in one transmitter being of logic “1” while in another transmitter being of logic “0”, the composite spectral signal will be the signature sequence ($\mathbf{Y}$)ⁿ = ($\mathbf{X}_1$)ⁿ + ($\mathbf{0}$)ⁿ = (λ_1 , λ_2 , 0, λ_4 , λ_5 , 0, λ_7 , λ_8 , 0, λ_{10} , λ_{11} , 0, λ_{13} , λ_{14} , 0, λ_{16} , λ_{17} , 0, λ_{19} , λ_{20} , 0), or the signature sequence ($\mathbf{Y}$)ⁿ = ($\mathbf{0}$)ⁿ + ($T^2 \mathbf{X}_2$)ⁿ = (λ_1 , 0, λ_3 , λ_4 , λ_5 , 0, 0, λ_8 , 0, λ_{10} , λ_{11} , λ_{12} , 0, 0, λ_{15} , 0, λ_{17} , λ_{18} , λ_{19} , 0, 0). However, for information bits in transmitters #1 and #2 being both of logic “1”, the resultant composite signal will be ($\mathbf{Y}$)ⁿ = ($\mathbf{X}_1$)ⁿ + ($T^2 \mathbf{X}_2$)ⁿ = ($2\lambda_1$, λ_2 , λ_3 , $2\lambda_4$, $2\lambda_5$, 0, λ_7 , $2\lambda_8$, 0, $2\lambda_{10}$, $2\lambda_{11}$, λ_{12} , λ_{13} , λ_{14} , λ_{15} , λ_{16} , $2\lambda_{17}$, λ_{18} , $2\lambda_{19}$, λ_{20} , 0). These composite spectral signals will correspondingly transmit over optical fiber channel to each receiver in the OCDMA network.

TABLE I. Composite signal under different data bits combination; (a). with initial $\mathbf{X}_1$ and $T^2 \mathbf{X}_2$ signatures assignment; (b). with $T^2 \mathbf{X}_2 \rightarrow \mathbf{X}_2$ signature reconfiguration.

(a)	Assigned address sequence	Data bit	Transmitted signal $\lambda_1 \sim \lambda_{21}$	composite signal
User #1	($\mathbf{X}_1$) ⁿ	1	110110110110110110110	211220120221111121210
User #2	($T^2 \mathbf{X}_2$) ⁿ	1	111100101110010111001	
User #1	($\mathbf{X}_1$) ⁿ	1	110110110110110110110	110110110110110110110
User #2	0	0	000000000000000000000	
User #1	0	0	000000000000000000000	101110010111001011100
User #2	($T^2 \mathbf{X}_2$) ⁿ	1	101110010111001011100	
User #1	0	0	000000000000000000000	000000000000000000000
User #2	0	0	000000000000000000000	

(b)	Assigned address sequence	Data bit	Transmitted signal $\lambda_1 \sim \lambda_{21}$	composite signal
User #1	($\mathbf{X}_1$) ⁿ	1	110110110110110110110	221111121210211220120
User #2	($\mathbf{X}_2$) ⁿ	1	111001011100101110010	
User #1	($\mathbf{X}_1$) ⁿ	1	110110110110110110110	110110110110110110110
User #2	0	0	000000000000000000000	
User #1	0	0	000000000000000000000	111001011100101110010
User #2	($\mathbf{X}_2$) ⁿ	1	111001011100101110010	
User #1	0	0	000000000000000000000	000000000000000000000
User #2	0	0	000000000000000000000	

Following from the above initial signature assignments of $\mathbf{X}_1 = (110)$ and $T^2\mathbf{X}_2 = (1011100)$, Table 1(a) illustrates the transmitted composite signal sequences under different combinations of the transmitted information bits from transmitter users #1 and #2.

On M-signatures reconfiguration, suppose the signature code assigned for transmitter #2 is now changed from $T^2\mathbf{X}_2 = (1011100)$ to $\mathbf{X}_2 = (1110010)$ while the signature code for transmitter #1 remains at $\mathbf{X}_1 = (110)$. This happens when central node station senses transmitter #2 been eavesdropped and sends reconfiguration command to the communicating transceiver pair, say transmitter user #2 and receiver user #2', to change their signatures accordingly.

The reflective mirrors corresponding to signatures $\mathbf{X}_1$ and $\mathbf{X}_2$ are placed unchanged. The 'light signal' in transmitter #2 is now directed to the first input port instead of the third input port of the bottom AWG encoder in Fig. 2. For information bits being of logic "1", the signature chips sequence $(\mathbf{X}_2)^n = (\lambda_1\lambda_2\lambda_3 00\lambda_6 0, \lambda_8\lambda_9\lambda_{10} 00\lambda_{13} 0, \lambda_{15}\lambda_{16}\lambda_{17} 00\lambda_{20} 0)$ will be coded and transmitted in transmitter #2. Combined with the signature chips sequence $(\mathbf{X}_1)^n = (\lambda_1\lambda_2 0, \lambda_4\lambda_5 0, \lambda_7\lambda_8 0, \lambda_{10}\lambda_{11} 0, \lambda_{13}\lambda_{14} 0, \lambda_{16}\lambda_{17} 0, \lambda_{19}\lambda_{20} 0)$ from transmitter #1, the resultant composite signal appears to be $(\mathbf{Y})^n = (\mathbf{X}_1)^n + (\mathbf{X}_2)^n = (2\lambda_1, 2\lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, 2\lambda_8, \lambda_9, 2\lambda_{10}, \lambda_{11}, 0, 2\lambda_{13}, \lambda_{14}, \lambda_{15}, 2\lambda_{16}, 2\lambda_{17}, 0, \lambda_{19}, 2\lambda_{20}, 0)$. This composite spectral signal will then transmit over optical fiber channel to each receiver in the OCDMA network.

For the above reconfiguration signature assignments of $\mathbf{X}_1 = (110)$ and $\mathbf{X}_2 = (1110010)$, Table 1(b) illustrates the numerical result for the composite signal sequences under different combinations of the transmitted information bits from transmitter users #1 and #2.

IV. STRUCTURING M-SIGNATURE DECODERS

The proposed AWG receiver decoder is shown in Fig. 3. The signature codes at the AWG decoders are the same as those adopted at the corresponding AWG encoders for the communicating transceiver pair.

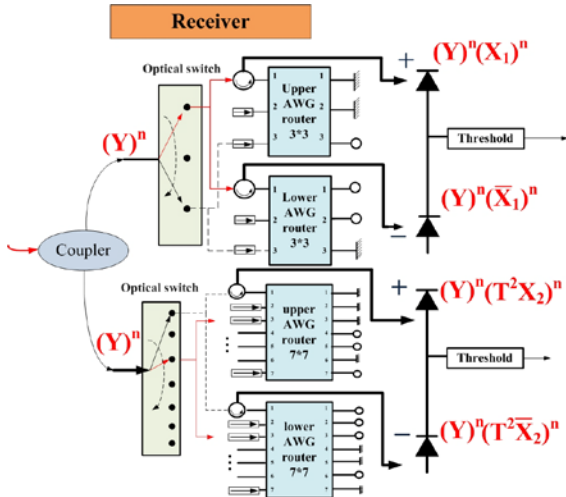


Figure 3. The proposed AWG receiver decoders with M-signatures reconfiguration.

For the receiver user #1', as shown in the top part of Fig. 3, a pair of AWGs with output reflective mirrors placed in accordance with signature codes $\mathbf{X}_1$ and $\bar{\mathbf{X}}_1$ are adopted for the first user's receiver decoder. The received composite signal $(\mathbf{Y})^n$ from the fiber channel is directed to the upper and the lower branches of the top AWG decoders arranged respectively with signature $\mathbf{X}_1$ and complementary signature $\bar{\mathbf{X}}_1$. Correlation values $(\mathbf{Y})^n(\mathbf{X}_1)^n$ and $(\mathbf{Y})^n(\bar{\mathbf{X}}_1)^n$ will be obtained at the upper and the lower photodiodes of the balanced detector.

Correlation subtraction of $(\mathbf{Y})^n(\mathbf{X}_1)^n - (\mathbf{Y})^n(\bar{\mathbf{X}}_1)^n$ is intuitively performed in the balanced photo-detector. Based on the subtracted correlation energy passing through a threshold decision device, the corresponding data bit of "1" or "0" received from transmitter #1 can be accordingly deduced. In our example, the correlation subtraction $(\mathbf{Y})^n(\mathbf{X}_1)^n - (\mathbf{Y})^n(\bar{\mathbf{X}}_1)^n$ is 18 units of power, and receiver #1' will decide that logic "1" is transmitted from transmitter #1.

For the receiver user #2', as shown in the bottom part of Fig. 3, another pair of AWGs with output reflective mirrors placed in accordance with signature codes $T^2\mathbf{X}_2$ and $T^2\bar{\mathbf{X}}_2$ are adopted for the second user's receiver decoder. The received composite signal $(\mathbf{Y})^n$ is directed to the upper and the lower branches of the bottom AWG decoders. Correlation values of $(\mathbf{Y})^n(T^2\mathbf{X}_2)^n$ and $(\mathbf{Y})^n(T^2\bar{\mathbf{X}}_2)^n$ will be obtained at the upper and the lower photodiodes of the balanced photo-detector. Based on the subtracted correlation energy of $(\mathbf{Y})^n(T^2\mathbf{X}_2)^n$ and $(\mathbf{Y})^n(T^2\bar{\mathbf{X}}_2)^n$, the corresponding data bit of "1" or "0" received from transmitter #2 can be deduced.

Corresponding to the logic "1" combination in the first row case of Table 1(a), the subtracted correlation energy of $(\mathbf{Y})^n(T^2\mathbf{X}_2)^n - (\mathbf{Y})^n(T^2\bar{\mathbf{X}}_2)^n$ is of "22-4=18" units power so that receiver user #2' assumes a logic "1" data bit from the communicating partner. Similarly, corresponding to the logic "0" combination in the third row case of Table 1(a), the subtracted correlation energy of $(\mathbf{Y})^n(T^2\mathbf{X}_2)^n - (\mathbf{Y})^n(T^2\bar{\mathbf{X}}_2)^n$ is of "0 units" power so that receiver user #2' assumes a logic "0" data bit transmitted from the transmitter #2.

On M-signatures reconfiguration illustrated in Table 2(b), let us examine the situation when signature code assigned for receiver #2' is synchronously switched with the communicating transmitter #2 into $\mathbf{X}_2 = (1110010)$. As before, in the bottom part of Fig. 3, the pair of AWG decoders are arranged with output reflective mirrors placed in accordance with signature codes $\mathbf{X}_2$ and $\bar{\mathbf{X}}_2$. But the reconfiguration switch will now direct the received composite signal $(\mathbf{Y})^n$ to the first input port, instead of the third input port, of the upper and the lower AWG decoders. Correlation values of $(\mathbf{Y})^n(\mathbf{X}_2)^n$ and $(\mathbf{Y})^n(\bar{\mathbf{X}}_2)^n$ will be obtained at the upper and the lower photodiodes of the balanced photo-detector. Based on the subtracted correlation energy of $(\mathbf{Y})^n(\mathbf{X}_2)^n - (\mathbf{Y})^n(\bar{\mathbf{X}}_2)^n$, the corresponding data bit of "1" or "0" received from reconfigured transmitter #2 can be deduced.

As illustrated on the reconfigured transmitter encoders, we recall that, corresponding to the logic "1" combination in

the first row of Table 1(b), the subtracted correlation energy of $(Y)^n(X_2)^n - (Y)^n(\bar{X}_2)^n$ is of “20-6=14” units power so that receiver user #2’ assumes a logic “1” data bit from the communicating partner. Similarly, corresponding to the logic “0” combination in the third row of Table 1(b), the subtracted correlation energy of $(Y)^n(X_2)^n - (Y)^n(\bar{X}_2)^n$ is of “0” units power so that receiver user #2’ assumes a logic “0” data bit transmitted from the transmitter #2.

TABLE II Composite signal under different data bits combination; (a). with initial X_1 and T^2X_2 signatures assignment; (b). with $T^2X_2 \rightarrow X_2$ signature reconfiguration.

(a)

Received Signal	User 1 balanced photo-detector	User 1 data bit
	User 2 balanced photo-detector	User 2 data bit
$(Y)^n = (X_1)^n + (T^2X_2)^n$	$(Y)^n(X_1)^n - (Y)^n(\bar{X}_1)^n = 22-4$	18>TH User #1 data bit “1”
	$(Y)^n(T^2X_2)^n - (Y)^n(\bar{T}^2X_2)^n = 20-6$	14>TH User #2 data bit “1”
$(Y)^n = (X_1)^n + 0$	$(Y)^n(X_1)^n - (Y)^n(\bar{X}_1)^n = 14-0$	14>TH User #1 data bit “1”
	$(Y)^n(T^2X_2)^n - (Y)^n(\bar{T}^2X_2)^n = 8-6$	2<TH User #2 data bit “0”
$(Y)^n = 0 + (T^2X_2)^n$	$(Y)^n(X_1)^n - (Y)^n(\bar{X}_1)^n = 8-4$	4<TH User #1 data bit “0”
	$(Y)^n(T^2X_2)^n - (Y)^n(\bar{T}^2X_2)^n = 12$	12>TH User #2 data bit “1”
$(Y)^n = 0 + 0$	$(Y)^n(X_1)^n - (Y)^n(\bar{X}_1)^n = 0$	0<TH User #1 data bit “0”
	$(Y)^n(T^2X_2)^n - (Y)^n(\bar{T}^2X_2)^n = 0$	0<TH User #2 data bit “0”

(b)

$(Y)^n = (X_1)^n + (X_2)^n$	$(Y)^n(X_1)^n - (Y)^n(\bar{X}_1)^n = 22-4$	18>TH User #1 data bit “1”
	$(Y)^n(X_2)^n - (Y)^n(\bar{X}_2)^n = 20-6$	14>TH User #2 data bit “1”
$(Y)^n = (X_1)^n + 0$	$(Y)^n(X_1)^n - (Y)^n(\bar{X}_1)^n = 14-0$	14>TH User #1 data bit “1”
	$(Y)^n(X_2)^n - (Y)^n(\bar{X}_2)^n = 8-6$	2<TH User #2 data bit “0”
$(Y)^n = 0 + (X_2)^n$	$(Y)^n(X_1)^n - (Y)^n(\bar{X}_1)^n = 8-4$	4<TH User #1 data bit “0”
	$(Y)^n(X_2)^n - (Y)^n(\bar{X}_2)^n = 12$	12>TH User #2 data bit “1”
$(Y)^n = 0 + 0$	$(Y)^n(X_1)^n - (Y)^n(\bar{X}_1)^n = 0$	0<TH User #1 data bit “0”
	$(Y)^n(X_2)^n - (Y)^n(\bar{X}_2)^n = 0$	0<TH User #2 data bit “0”

V. CONCLUSIONS

We have devised a network codec to combat eavesdropping based on signatures reconfiguration of OCDMA networks. In the proposed scheme, each user is initially assigned one set of M-signature codes, with code periods relatively prime to other user’s signature codes. It then dynamically changes its signature code upon reconfiguration command from central monitoring station in the OCDMA network.

The proposed scheme has a number of attractive features such as asynchronous network coordination, reduced transceiver encoder/decoders, and enhanced system confidentiality. When number of signature codes increases and the eavesdropper’s codeword detection becomes more difficult, thus network confidentiality is significantly

increased the two-code keying is a good alternative way for security enhancement. The proposed scheme shows an immunity of the OCDMA system against eavesdropping without affecting the received signal.

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