Optical Code Division Multiple Access OCDMA

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24/02/2021

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1. Yang, L., Shi, S., & Zhang, W. (2018, October). Performance analysis of OCDMA-WDM-PON system with hyperchaotic sequences. In *2018 Asia Communications and Photonics Conference (ACP)* (pp. 1-3). IEEE.
2. Chih-Ta Yen, Jen-Fa Huang, and Wen-Zong Zhang. Hiding Stealth Optical CDMA Signals in Public BPSK Channels for OpticalWireless Communication. *Appl. Sci. 2018, 8, 1731; doi:10.3390/app8101731.*
3. Yeteng Tan, Tao Pu, Jilin Zheng, Hua Zhou, Guorui Su, and Haiqin Shi. Study on the Effect of System Parameters on Physical-Layer Security of Optical CDMA Systems. *International Conference on Optical Communications and Networks, 2019.*
4. Yoshioka, T., & Tsuneda, A. (2019, October). Study on Optical CDMA Communications Using Orthogonal Codes with Negative Auto-Correlation. In *2019 International Conference on Information and Communication Technology Convergence (ICTC)* (pp. 1234-1236). IEEE.

CONTENTS

1.1 Multiple Access and Multiplexing

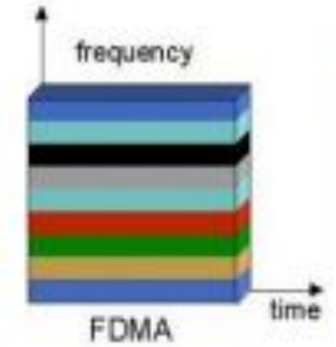
- Multiple Access is the idea of allowing several transmitters to send information simultaneously over a single communication channel and allowing several users to share a band of frequencies.
- Multiplexing is when the aggregation of channels is done before the modulation process.
- Both are employed to address growing bandwidth demands for both wireless-radio and fiber optics communication

3 Techniques

A. WDMA (Wave Division Multiple Access)
B. TDMA (Time Division Multiple Access)
C. CDMA (Code Division Multiple Access)

1.2 WDMA (Wave Division Multiple Access)

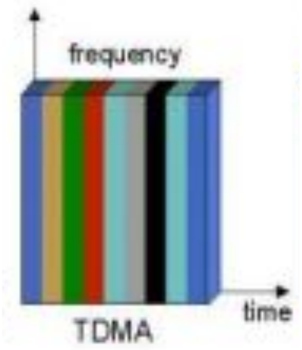
- Multiple access technique where every user are allocated different wavelength with no time limit (interralated to FDMA in the realm of radio communication)
- each channel occupies a narrow optical bandwidth (≥100 GHz)
- each channel is independent in terms of modulation format and speed for a particular wavelength.



Picture from: Rajesh Yadav1 , Dr. GurjitKaur2, Optical CDMA: Technique, Parameters and Applications, P93 or
Hongxi Yin, David J. Richardson, “OCDMA Access Communication Networks Theory and Applications”, Springer, © 2007.

1.3 TDMA (Time Division Multiple Access)

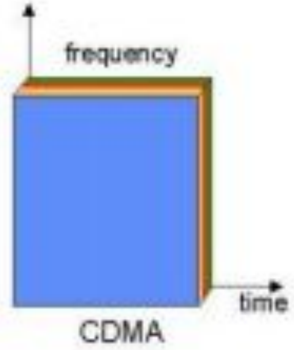
- Multiple access method where all users use the same bandwidth but are allocated a time slot during which it can transmit



Picture from: Rajesh Yadav1 , Dr. GurjitKaur2, Optical CDMA: Technique, Parameters and Applications, P93 or
Hongxi Yin, David J. Richardson, “OCDMA Access Communication Networks Theory and Applications”, Springer, © 2007.

1.4 CDMA (Code Division Multiple Access)

- Multiple access method where single channel carries all transmission simultaneously.
- We transmit multiple signals over the same frequency band, using the same modulation techniques at the same time
- Employed using spread spectrum techniques

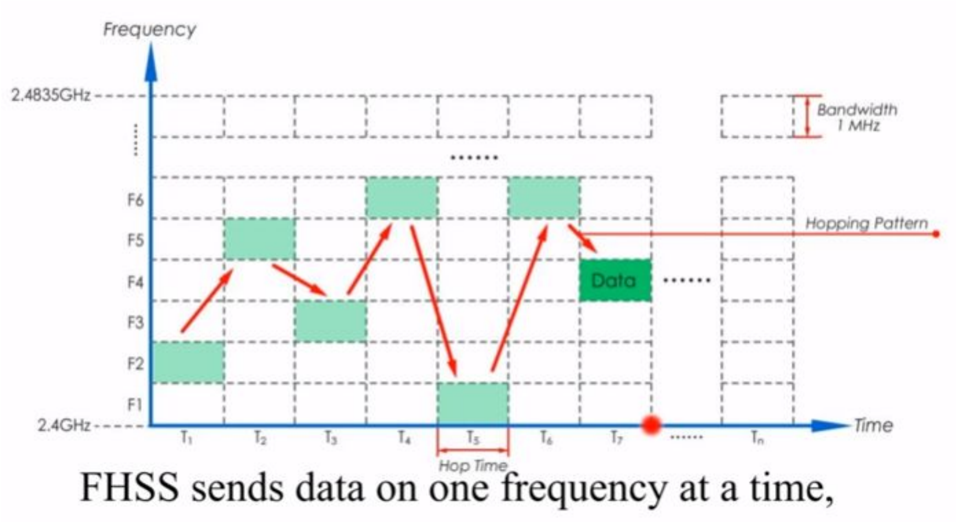


2 Spread Spectrum Techniques

A. FHSS (Frequency Hopping Spread Spectrum)
B. DSSS (Direct Sequence Spread Spectrum)

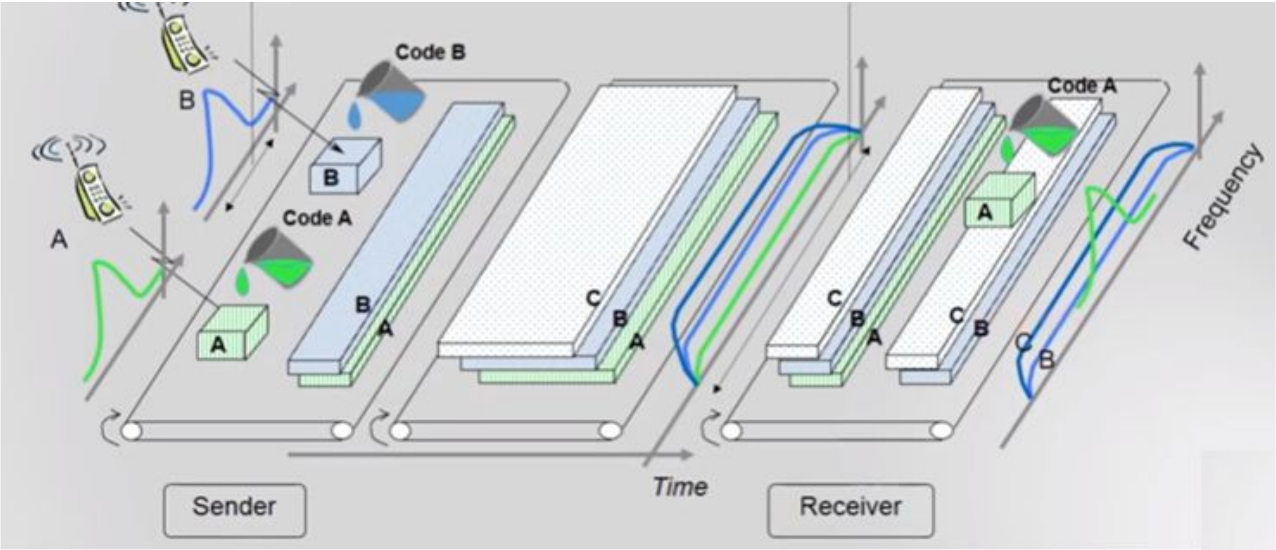
Picture from: Rajesh Yadav1 , Dr. GurjitKaur2, Optical CDMA: Technique, Parameters and Applications, P93 or
Hongxi Yin, David J. Richardson, “OCDMA Access Communication Networks Theory and Applications”, Springer, © 2007.

FHSS Working Principle



Picture from: Sunny Classroom, https://www.youtube.com/watch?v=CkhA7s5GIGc&t=35s

DSSS Working Principle



Picture from: Gurkula, https://www.youtube.com/watch?v=NjzbVxQOhvI&t=750s

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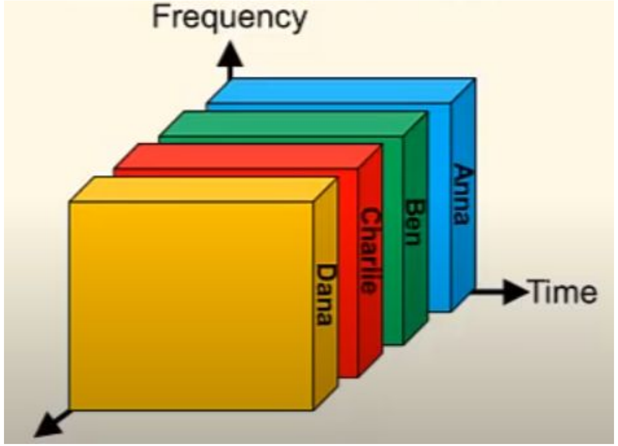
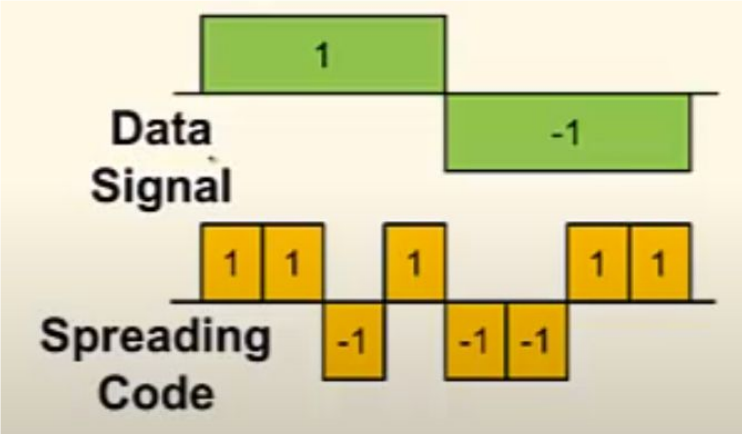
2.1 How OCDMA works?





Photos taken from Networks illustrated principles without calculus by Brinton and Chiang

How OCDMA works

The crosstalk between different users sharing the common fiber channel known as the multiple access interference

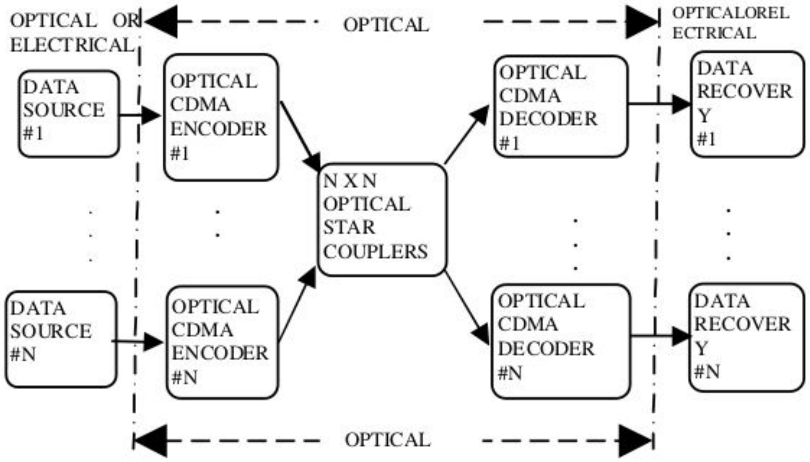


Fig. 4 Block diagram of an OCDMA communication system with a star architecture

Rajesh Yadav 1 , Dr. GurjitKaur, School of Information and Communication Technology, G.B.U., Greater Noida, India, Optical CDMA: Technique, Parameters and Applications

2.2 Coherent and Incoherent OCDMA

Incoherent OCDMA:

- intensity modulation
- direct detection
- uni-polar codes(0, 1)

Coherent OCDMA:

- phase information
- coherent receiver
- receiver more sensitive to SNR
- bipolar codes (+1, -1)

2.3 Synchronous and Asynchronous OCDMA

Synchronous:

- the bit and chip are synchronized
- receiver examines the correlator output only at one instant in the chip interval
- improved efficiency
- more complex

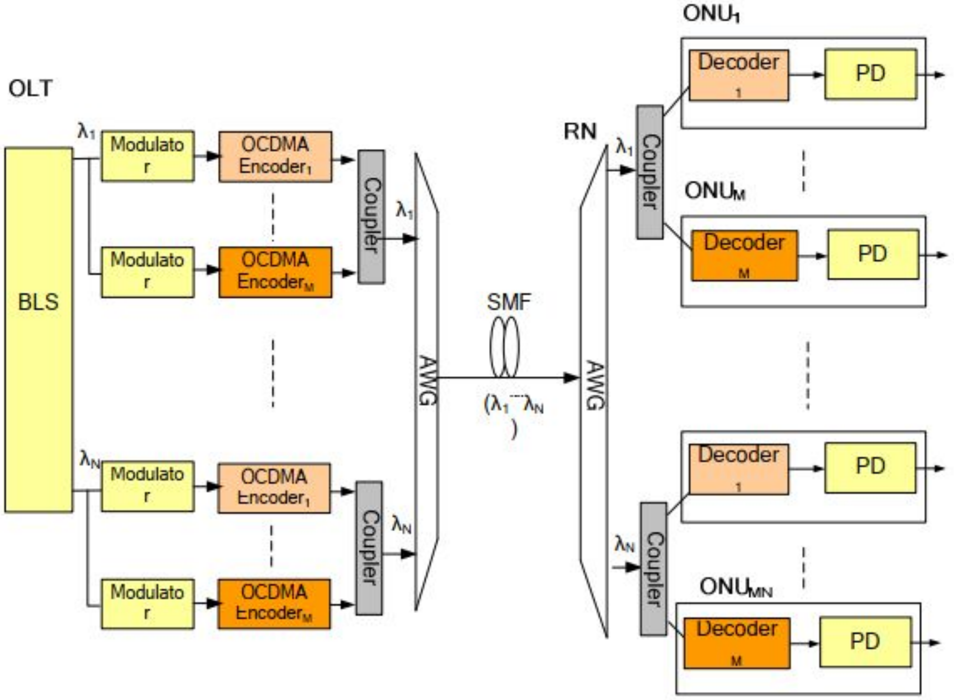
Asynchronous:

- bits not synced
- chips may be transmitted synchronously
- support limited number of users

Note: The capacity of asynchronous systems can be increased with the help of 2-D and 3-D codes. For example, it is possible to use 2-D coding schemes based on a combination of time, space, or wavelength spreading to increase the system's capacity without additional complexity. Moreover, 3-D coding can accommodate even more users by exploiting light polarization states.

CONTENTS

3.1 OCDMA-WDM-PON - Using Hyperchaotic sequences



broad-band light source (BLS)
optical line terminal (OLT)
arrayed waveguide grating (AWG)
optical network units (ONU)
Photo-Diode (PD)

Yang, L., Shi, S., & Zhang, W. (2018, October). Performance analysis of OCDMA-WDM-PON system with hyperchaotic sequences. In *2018 Asia Communications and Photonics Conference (ACP)* (pp. 1-3). IEEE.

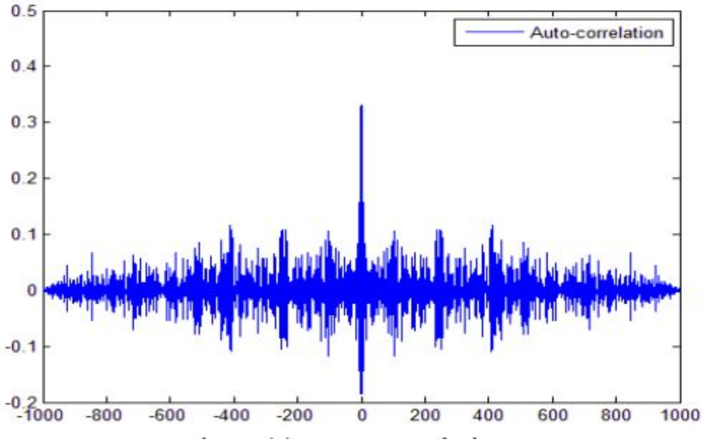
3.1 OCDMA-WDM-PON - Using Hyperchaotic sequences

To further improve the transmission efficiency - OCDMA systems need to generate powerful code sequence with:

- Good correlation properties
- Large Cardinality

E.g; **Chaotic sequences**

- Easy to generate many sequences
- High capacity
- Good transmission performance



Auto-correlation

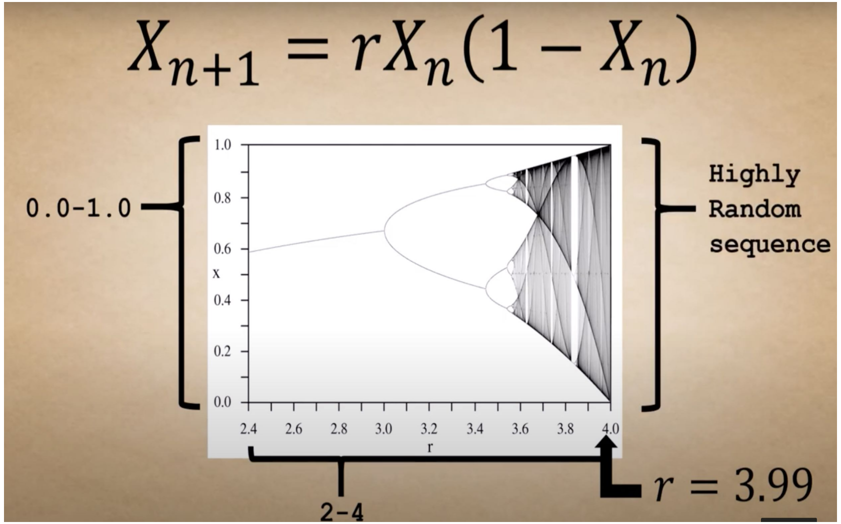
Yang, L., Shi, S., & Zhang, W. (2018, October). Performance analysis of OCDMA-WDM-PON system with hyperchaotic sequences. In *2018 Asia Communications and Photonics Conference (ACP)* (pp. 1-3). IEEE.

The design of chaotic sequences

- Logistic-map function;

  $\mathbf{x_{n+1} = \gamma x_n \,(1- \; x_n\,)}$

  where $1 < \gamma \leq 4$



Source: https://www.stsci.edu/~lbradley/seminar/logdiffeqn.html

The system performance

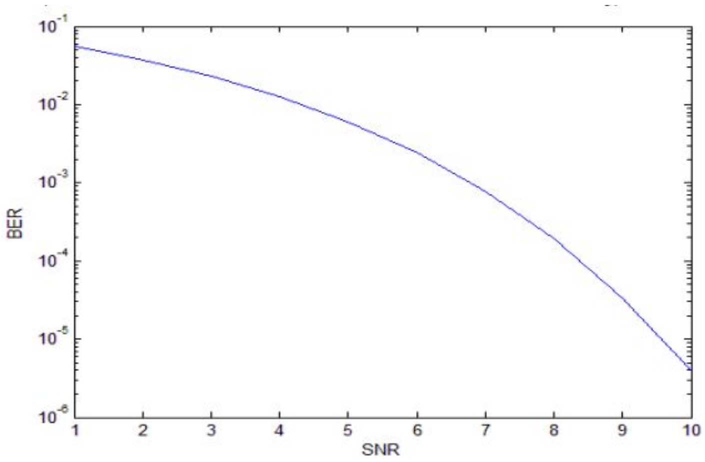
- The BER varies from 10^{-1} to 10^{-5}

when SNR changes from 1 to 10

- It can be observed that 10^{-5} BER is

obtained when SNR is near 10 dB

BER as a function of **optical received power**



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4.1 Background

- ❖ **Optical networks are an integral constituent of the physical layer of Internet.**
- ❖ **Physical layer forms the bottom layer in the open systems interconnection (OSI) model.**
- ❖ **The performance and security of the physical layer have a critical influence on the above layers.**

To enhance security in the physical layer of an optical network, several approaches have been investigated:

- ➢ Quantum Private Communication
- ➢ Optical Encryption
- ➢ Optical Steganography

4.2 Optical Encryption

OCDMA systems can directly encrypt optical transmission links at the physical layer:

- ➢ Use optical ***Encoding and Decoding technologies***
- ➢ Improve the security of communication system

- ❖ **Optical en/decoding technologies are the core technologies of OCDMA systems.**
- ❖ **The performances of optical encoder and decoder are mainly determined by the cross-correlation characteristics of the address codes.**
- ❖ **The cross-correlation characteristics is important on the physical-layer security of OCDMA systems.**

4.2 Optical Encryption System

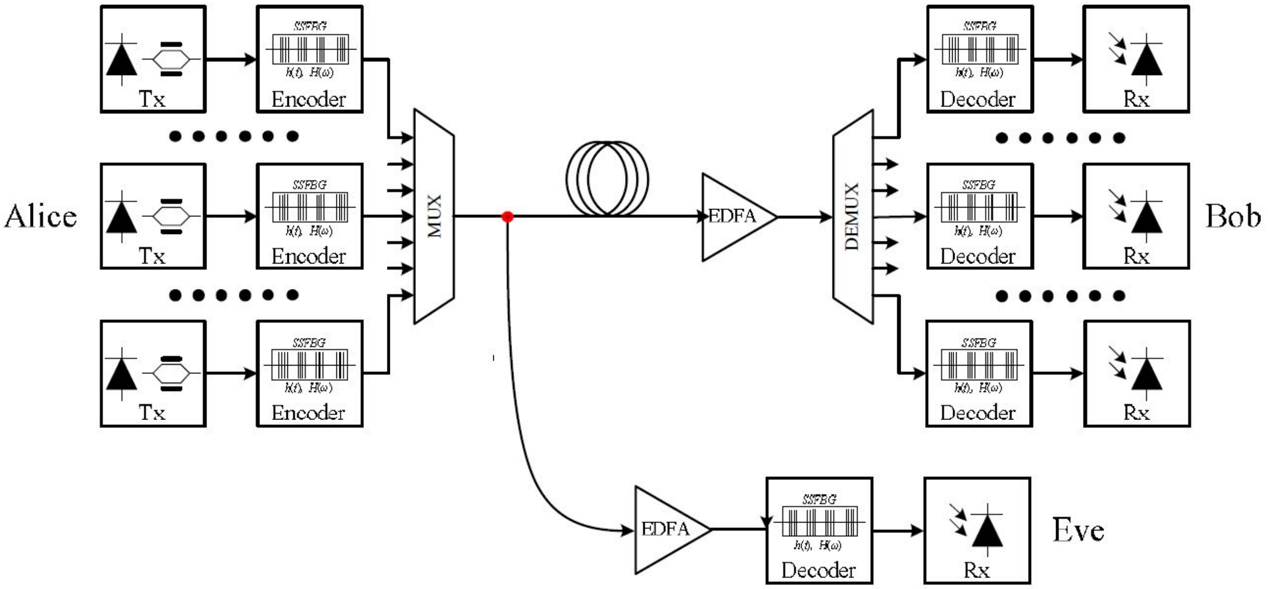

Fig 4.1 The wiretap channel model of multiuser OCDMA system

Picture from: Yeteng Tan, Tao Pu, Jilin Zheng, Hua Zhou, Guorui Su, and Haiqin Shi. Study on the Effect of System Parameters on Physical-Layer Security of Optical CDMA Systems. *International Conference on Optical Communications and Networks, 2019.*

4.2 Optical Encryption Evaluation

"Secrecy Capacity" is used to evaluate the effects of the system parameters on the physical-layer security of OCDMA systems.

- ➢ It is the largest rate at which eavesdroppers gain no information from the message.
- ➢ It can evaluate the physical-layer security of the secure communication systems quantitatively.
- ➢ Its expression can be represented as:

$$\begin{aligned} C_S &= C_M - C_W \\ &= \max_{P(x)} \{ I(X;Y) - I(X;Z) \} \\ &= [I(X;Y) - I(X;Z)]_{P(X=0)=P(X=1)=0.5} \\ &= \left[\sum_{X,Y} P(xy) \log \frac{P(y|x)}{P(y)} - \sum_{X,Z} P(xz) \log \frac{P(z|x)}{P(z)} \right]_{P(X=0)=P(X=1)=0.5} \\ &= H_2(p_m) - H_2(p_w) \end{aligned}$$

Picture from: Yeteng Tan, Tao Pu, Jilin Zheng, Hua Zhou, Guorui Su, and Haiqin Shi. Study on the Effect of System Parameters on Physical-Layer Security of Optical CDMA Systems. *International Conference on Optical Communications and Networks, 2019.*

4.2 Optical Encryption Evaluation

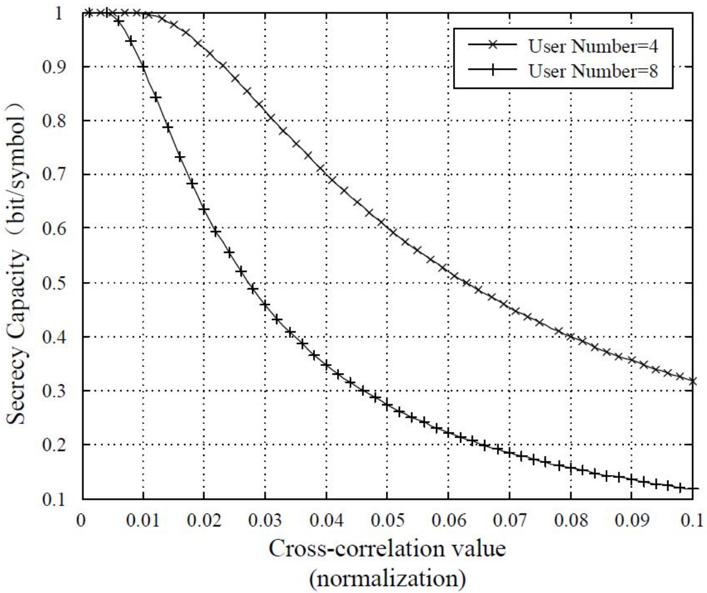

Fig4.2 Secrecy capacity vs. cross-correlation value

❖ With the increasing normalized cross-correlation value, the secrecy capacity decreases, which helps for the security of OCDMA systems to choose the code words.

❖ The main factors that cause the difference of cross correlation characteristics include:

➢ The type of codeword

➢ The length of codeword.

Picture from: Yeteng Tan, Tao Pu, Jilin Zheng, Hua Zhou, Guorui Su, and Haiqin Shi. Study on the Effect of System Parameters on Physical-Layer Security of Optical CDMA Systems. *International Conference on Optical Communications and Networks, 2019.*

4.3 Optical Steganography

The major distinction between Optical Steganography and Optical encryption.

- ❖ ***Optical Encryption*** allows a signal to be encrypted with low latency and the recipient requires a key to read the information.
  - ➢ The method cannot prevent the signal from being detected
- ❖ ***Optical Steganography*** provides an additional layer of security by hiding the data transmission underneath the steganographic medium.
  - ➢ The main goal is to hide information sufficiently well such that any unintended recipients do not suspect that the steganographic medium contains hidden data.

4.3 Optical Steganography System

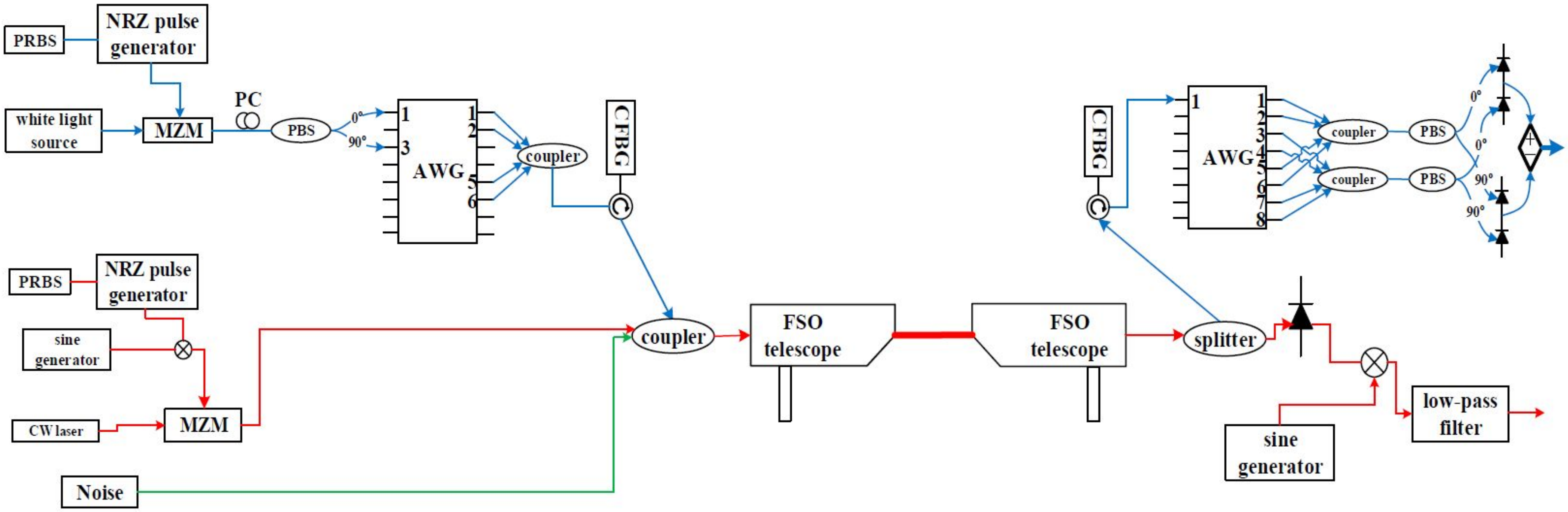

Fig4.3 Optical Steganography System Setup

Picture from: Chih-Ta Yen, Jen-Fa Huang, and Wen-Zong Zhang. Hiding Stealth Optical CDMA Signals in Public BPSK Channels for Optical Wireless Communication. *Appl. Sci. 2018, 8, 1731; doi:10.3390/app8101731.*

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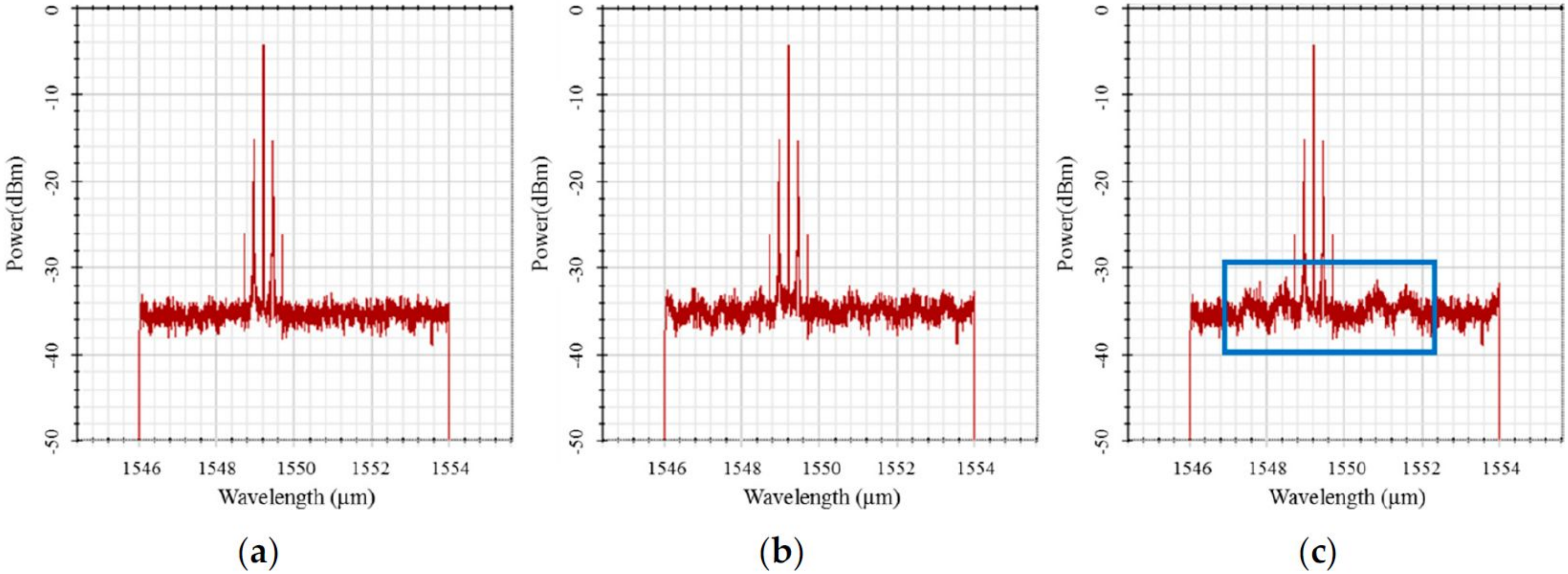

Fig4.4 Spectrum of public channel: (a) without stealth signal; (b) with SPC signal; and (c) with SAC signal

Picture from: Chih-Ta Yen, Jen-Fa Huang, and Wen-Zong Zhang. Hiding Stealth Optical CDMA Signals in Public BPSK Channels for Optical Wireless Communication. *Appl. Sci. 2018, 8, 1731; doi:10.3390/app8101731.*

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Thank you for listening!