Quantum Noise with Volterra Equalizer-Aided OFDM system to Address Privacy Issues in Terahertz communication

使用量子噪聲與Volterra等化器輔助OFDM系統 解決太赫茲通信中的安全性問題

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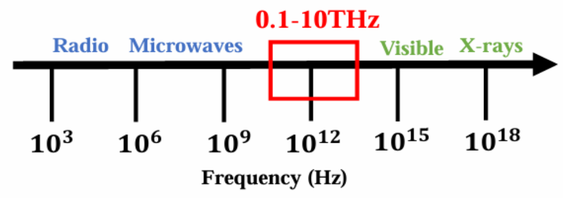
Abstract

In this report, we present a method that can implement in future 6G THz wireless communication systems. The original OFDM system was modified by using the randomness of quantum noise, adding randomly generated noise signals to the transmission to disrupt eavesdroppers and enhance data security. Moreover, a Second-ordered Volterra equalizer was implemented at the receiver to compensate for signal degradation caused by nonlinear distortion in high-frequency transmission. Therefore, simulation and experimental results showed that our system achieved at least an order-of-magnitude reduction in bit error rate (BER) below 10^{-10} with different modulation schemes (16-PSK and 16-QAM), confirming the stability and security of this approach in high-frequency Terahertz communication environments.

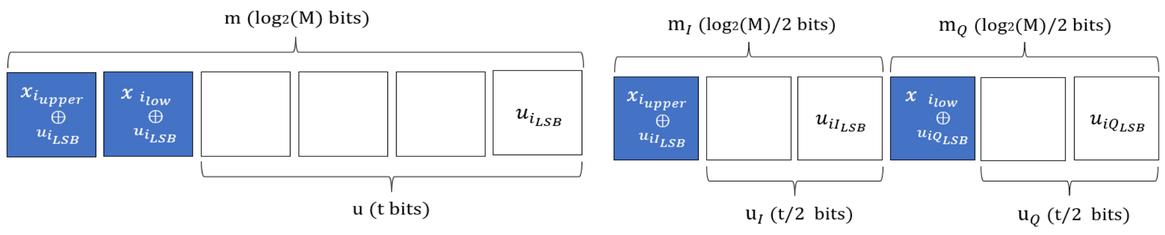
Terahertz Frequency

The Terahertz Frequency band (0.1THz-10THz), between microwaves and visible light, offers large bandwidth for high-speed 6G data transmission. Its strong directionality and interference resistance make it ideal for short-range indoor or urban 6G communication in the future .



Quantum Noise

The Y-00 protocol (Y-00 Quantum Stream Cipher) is a physical-layer encryption technology based on quantum noise, designed to enhance the security of fiber-optic communication. It converts traditional signals into high-level modulated signals and using the randomness of quantum noise to obscure the signal, making it impossible for eavesdroppers to accurately measure or decode. We also integrate OTP encryption, which creates a unique, time-sensitive key stream.

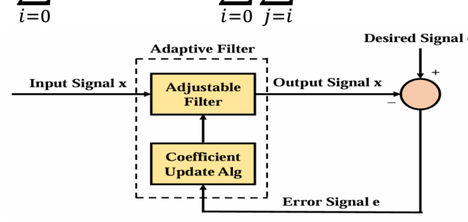


M-PSK **MQAM**

Volterra Equalizer

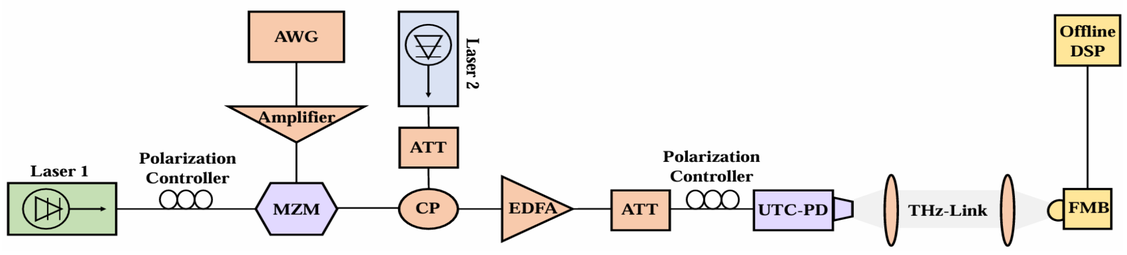
The Volterra equalizer is an adaptive filter that predicts coefficients based on input signals and updates them using the mean squared error (MSE) method to approximate the original signal. Moreover, it accounts for nonlinear effects like SSBI. It expands the signal into delayed, squared, and cross terms, estimating tap coefficients to get the original signal. Using this function, system employs the LMS algorithm to update the coefficients and enable the coefficients to converge.

$$y(n) = \sum_{i=0}^{N1} w_i\, x(n-i) + \sum_{i=0}^{N2}\sum_{j=i}^{N2} w_{i,j}\, x(n-i)x(n-j)$$



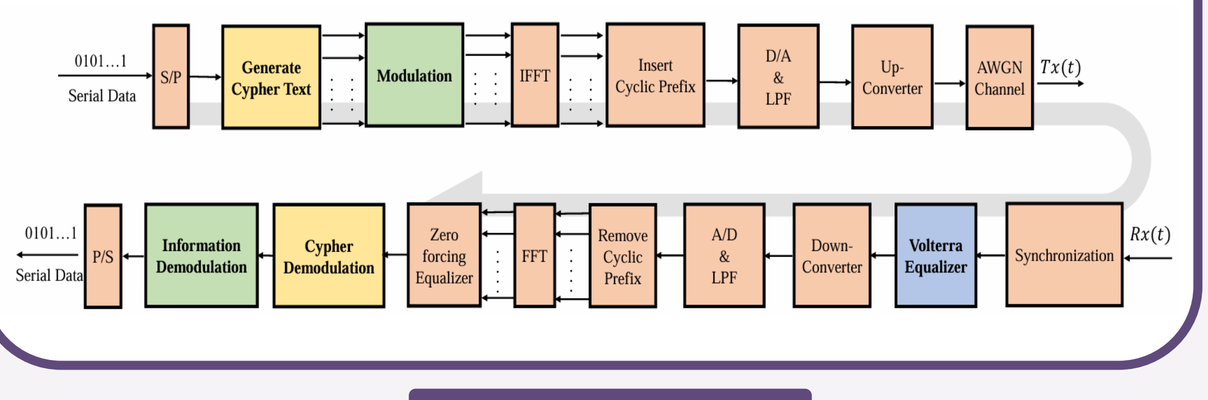
Terahertz Communication System

In this system, we use two laser to reach the Terahertz Frequency. A 1550 nm laser generates an optical signal, which is modulated and amplified. A second 1551 nm laser combines with the first laser source via an Optical Coupler (CP). Then, the UTC-PD up-converts the signal to the THz range for wireless transmission. At the receiver, a terahertz receiver (FMB) captures the transmitted terahertz waves and converts them into electrical signals. The demodulation and BER analysis are performed using MATLAB software, completing the system's functionality.



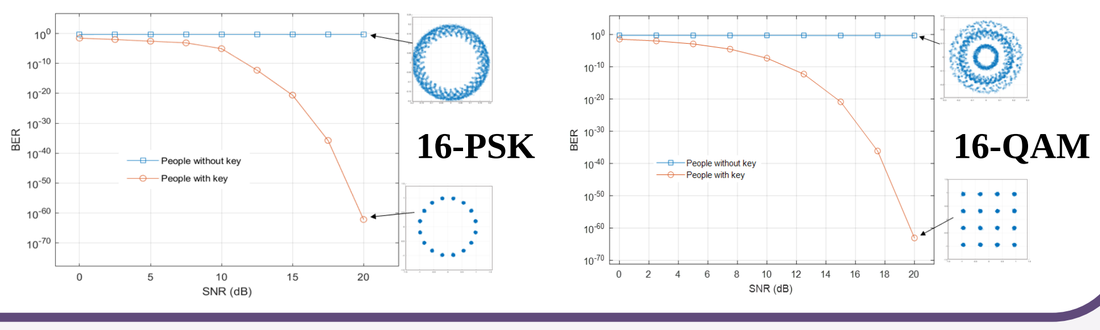
OFDM System Structure

We want to address the limitations of traditional single-carrier systems, where increasing data transmission shortens symbol duration and leads to inter symbol interference (ISI) in Line-of-Sight (LOS) environments. By adopting OFDM (Orthogonal Frequency-Division Multiplexing) , data is distributed across multiple subcarriers for parallel transmission, increasing symbol duration and maintaining orthogonality to prevent interference.
In the transmitter, a PRBS generates periodic signals, which are then modulated using QPSK to 16-PSK or 16-QAM with a quantum key. After Zero-padding, the signal is then transformed to the time domain using Inverse FFT. The Cyclic prefix are added, then the signal is upconverted for transmission.
In the receiver, the signal is synchronized, resampled, and passed through a second-order Volterra equalizer to address nonlinear distortion. After removing the CP, the signal is processed with Zero-Forcing Equalizer to eliminate interference. Finally, a demodulation algorithm is used to recover the original message.



Results

The experimental results shows that legitimate users with the key are able to successfully decrypt the signal embedded with quantum noise, while unauthorized interceptors without the key are unable to recover the original signal and experience a BER of 0.5. When comparing the performance of 16-QAM and 16-PSK, it is observed that 16-QAM slightly outperforms 16-PSK in the range of SNR from 0 to 10 dB. This is because 16-QAM utilizes the signal space more efficiently, offering better resistance to interference. Furthermore, when the SNR reaches 12.5 dB, the entire terahertz communication system achieves a BER of less than 10^{-10}, demonstrating extremely high reliability.



16-PSK

16-QAM

Conclusion

In the past 10 months (2024.2-2024-11) of this projects, we successfully simulated and experimented that quantum noise provides strong encryption in OFDM THz communication. Furthermore, with the Volterra equalizer ensuring stable, secure performance across modulation types, improving the accuracy and stability of signal reception and significantly reducing the BER, paving the way for a significant milestone in 6G THz communication.