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Overloaded Spread Spectrum OFDMA in Outdoor Environment in the Low Interleaving Scenario

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Abstract: *The development of mobile communication technology starts with creating or modifying a Radio Access Technique (RAT) to meet user needs and increase capacity. This paper focuses on enhancing spectral efficiency and average throughput using an OFDM-based multiple access method, specifically overloaded spread spectrum OFDMA. The study found that with 24% overloading for BPSK modulation, there is approximately a 30% increase in spectral efficiency in outdoor scenarios. There is a significant improvement using higher modulation as well. This improvement highlights the potential of Overloaded Spread Spectrum OFDMA to optimize mobile communication systems, ensuring better resource utilization and system performance to handle the growing demand for data and connectivity effectively*

Keywords: overloaded; spread spectrum; outdoor; interleaving; Spreading gain (SG)

I. INTRODUCTION

The current surge in wireless communication is propelled by the growing demand for faster internet access, particularly in environments with high mobility. Although wireless data rates are approaching those of wire-line systems, they still lag behind by approximately 2 to 3 times. Moore's Law predicts a doubling of data rates every 18 months, further driving the need for faster wireless connectivity. Presently, wire-line systems achieve data rates exceeding 10 Gbps, whereas wireless devices achieve data rates exceeding 5 Gbps. It is expected that the number of mobile phone users will surpass 8 billion by the end of 2027, underscoring the urgent requirement to exceed current technological limitations and provide demanded services with optimal quality and maximum data rates. With data rate demands continually escalating, it's evident that constraints cannot be tolerated, necessitating the development of future-generation wireless systems beyond the capabilities of 5G. These advancements are crucial to ensure that users receive the high-speed, reliable connectivity essential in today's increasingly mobile-centric world.

II. SPREAD SPECTRUM OFDMA

Motivation

In Spread Spectrum-Orthogonal Frequency Division Multiple Access (SS-OFDMA), symbols are distributed across multiple carriers instead of being confined to a single carrier. This approach capitalizes on frequency diversity, enabling effective symbol decoding even in suboptimal channel conditions. SS-OFDMA amalgamates the merits of Orthogonal Frequency Division Multiple Access (OFDMA) and Code Division Multiple Access (CDMA), thereby enhancing overall system performance. The efficacy of SS-OFDMA hinges on correlation properties, which dictate system performance across diverse conditions. To mitigate potential interference and optimize performance, receivers employ multiuser detection techniques. This strategy bolsters the resilience and efficiency of data transmission, positioning SS-OFDMA as a pivotal approach for augmenting spectral efficiency and throughput in contemporary wireless communication systems. Its adaptability to varying channel conditions renders it particularly valuable in environments where signal quality fluctuates, ensuring steadfast connectivity and robust performance in dynamic operational settings.

Fundamentals of Overloaded Spread Spectrum OFDMA

One of the advantages of CDMA-based techniques is soft capacity, allowing overloading with a degradation in error probability. In cellular CDMA, each sequence of length N is typically allocated to a maximum of N users. The processing gain, $N = T/T_c$, where T is symbol duration and Tc is chip duration. In an under-loaded system, fewer than

N users are assigned, maintaining orthogonality and preserving performance. However, in an overloaded scenario where users exceed N, more sequences are assigned than the spreading factor, compromising orthogonality and increasing Multiple Access Interference (MAI). This diminishes system performance, emphasizing the importance of load management in CDMA-based communication. Maintaining the delicate balance between overloading for increased capacity and mitigating interference is crucial for optimizing the performance of CDMA systems, ensuring efficient and reliable wireless communication in various environments.

Literature presents various strategies to mitigate overloading effects and facilitate increased simultaneous user bandwidth sharing. One such method involves Multi User Detection (MUD) implementation at the base station, which, according to [14], demonstrates improved CDMA Overloading performance through an Iterative Interference Cancellation Receiver. Additionally, other approaches [15] propose leveraging Orthogonal Codes like Quasi Orthogonal Sequences (QOS) and Orthogonal Gold (OG) Codes to enhance system performance. These techniques aim to optimize spectral efficiency and throughput by managing interference more effectively and improving signal detection accuracy. By utilizing advanced signal processing algorithms and exploiting the properties of orthogonal codes, these approaches contribute to maximizing the capacity of wireless communication systems, enabling them to accommodate a larger number of users within the available bandwidth while maintaining satisfactory performance levels.

OFDMA has emerged as a dominant access technique, particularly suited for multi-path environments. However, for next-generation wireless networks, a combination of CDMA and OFDMA remains a viable consideration. An example of such a hybrid technique, utilized in the 3GPP-LTE standard, is SC-FDMA [11]. SC-FDMA employs DFT spreading, facilitating the Code Division Multiplexing of symbols. Extending the concept of overloading from CDMA to OFDM-based access techniques can potentially increase capacity. This extension may involve employing various spreading codes such as OG Codes or QOS, which should exhibit minimal performance degradation compared to underloaded systems and possess favorable correlation properties. Additionally, employing a multi-stage detector [16] for interference cancellation becomes necessary. Performance evaluation of this hybrid scheme, considering Rayleigh channel conditions in outdoor environments, involves interleaving and transmitting each user's data with low interleaving to assess its efficacy. This comprehensive approach aims to enhance system capacity and performance in next-generation wireless networks.

III. TRANSCEIVER DESCRIPTION

Overloaded OFDMA offers the advantage of increasing the capacity of an OFDM system in proportion to the amount of overload applied. By spreading symbols across carriers equivalent to the spreading gain, it also leverages diversity gain, enhancing system robustness. However, this innovative access technique faces challenges related to Peak-to-Average Power Ratio (PAPR) due to its reliance on the type of spreading sequences employed. Managing PAPR issues becomes crucial for ensuring the efficient operation of Overloaded OFDMA systems. Despite this challenge, the potential benefits of increased capacity and diversity gain make Overloaded OFDMA a promising approach for enhancing spectral efficiency and throughput in modern wireless communication systems. Efforts to address PAPR concerns through suitable spreading sequence designs and mitigation techniques are essential for realizing the full potential of Overloaded OFDMA in practical deployment scenarios [17].

In Fig.1(a), data transmission from the Base Station (BS) to individual users is depicted, while Fig. 1(b) illustrates data reception from the BS to individual users. Here, the BS spreads the data of each individual user across allocated sub-carriers. Assuming the BS has $K = U * N$ useful sub-carriers available, where N is the maximum number of sub-carriers that can be allocated to one user, and $U = K/N$ represents the total number of users supported by the system. Consequently, each user's data is transmitted solely over its allocated sub-carriers, with U users transmitting data over the entire system bandwidth. Consequently, each user maps more than N symbols ($M > N$) over the N allocated carriers, resulting in an overloaded system. Therefore, if an overloaded Spread Spectrum Orthogonal Frequency Division Multiple Access (SS-OFDMA) is utilized at the BS (transmitter), it will spread $M > N$ data symbols of each user over the allocated N carriers.

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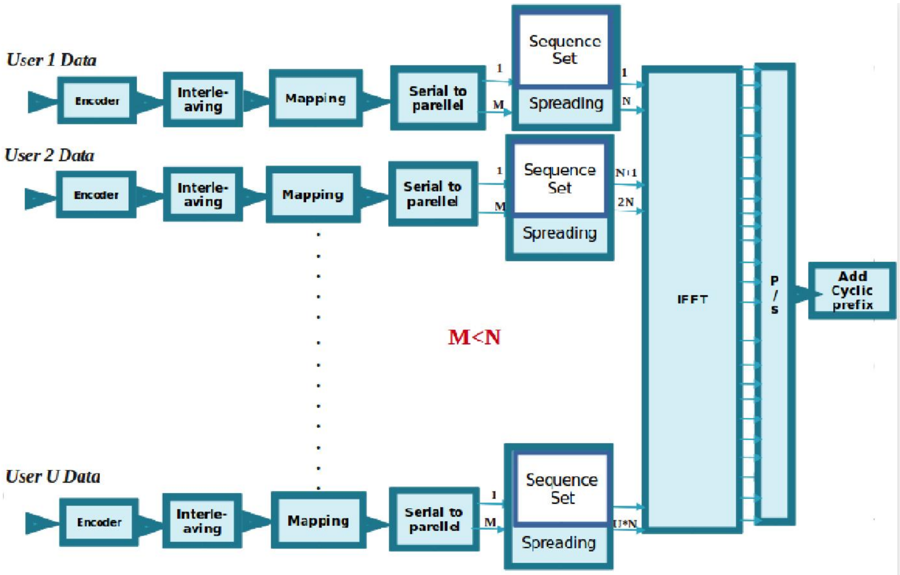

Fig. 1(a) Transmitter Block diagram

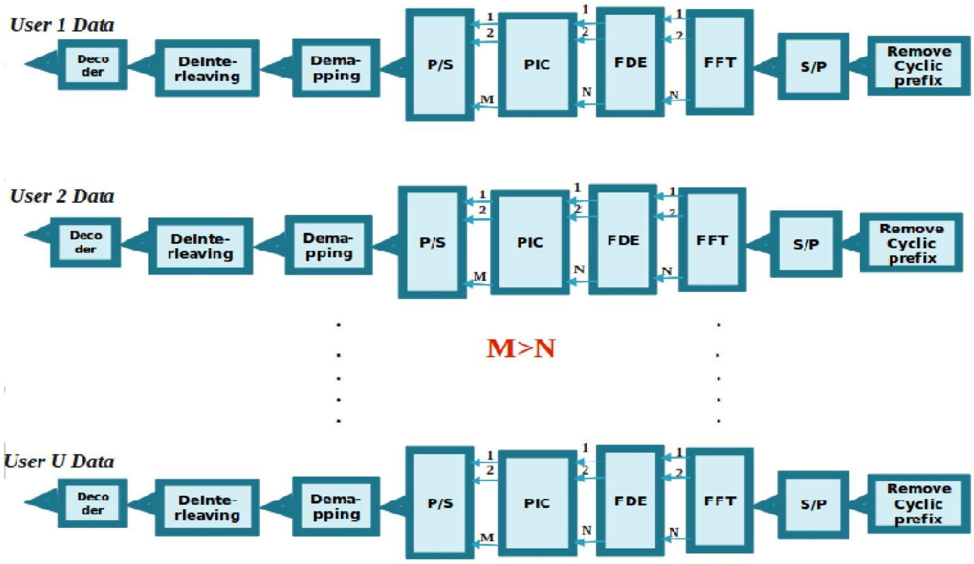

Fig. 1(b) Receiver Block diagram

Each user decodes data exclusively from the carriers allocated by the BS, optimizing decoding efforts. By focusing on allocated carriers, users efficiently extract transmitted data, enhancing system capacity proportionally to the overload. This targeted decoding strategy ensures effective data retrieval while accommodating increased system load, maximizing resource utilization, and bolstering overall system efficiency.

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IV. FINDINGS

BER performance

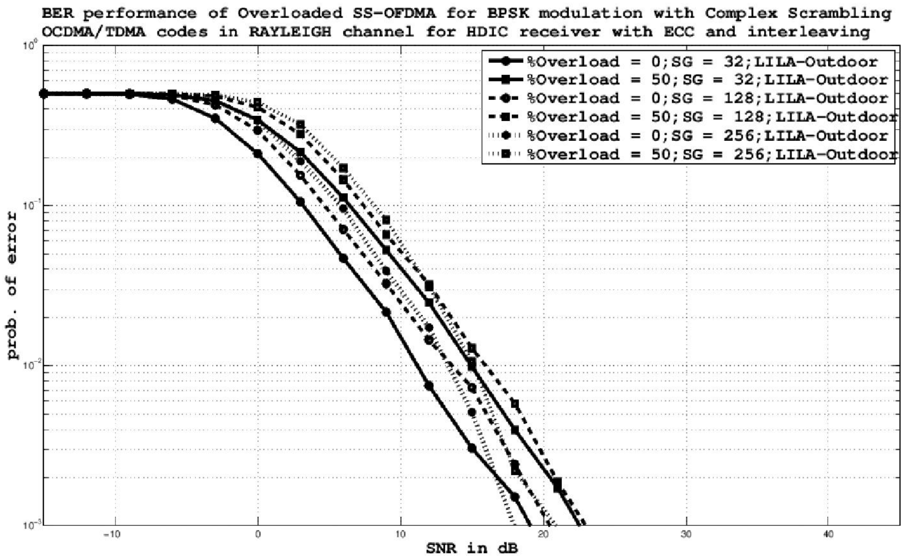

Fig. 2(a) BER performance of Overloaded Spread spectrum OFDMA for BPSK modulation

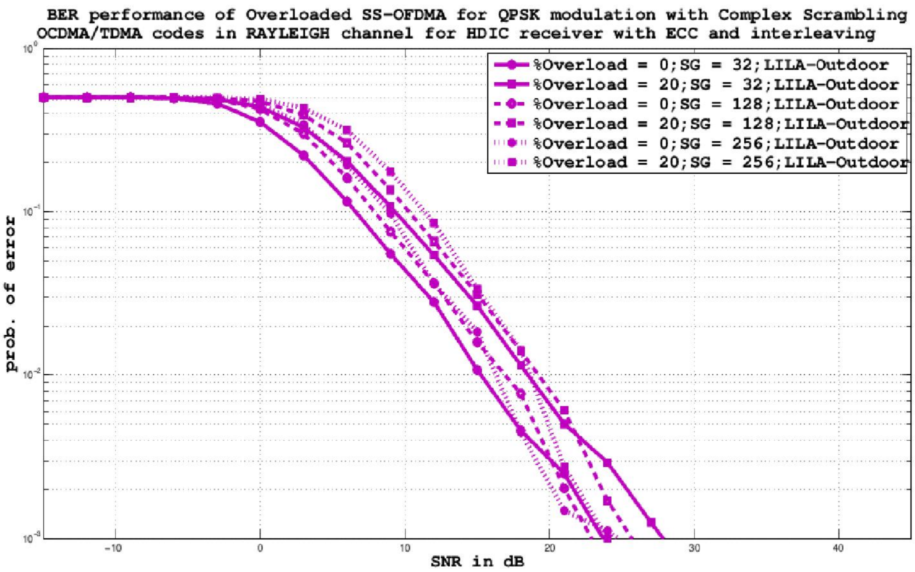

Fig. 2(b) BER performance of Overloaded Spread spectrum OFDMA for QPSK modulation

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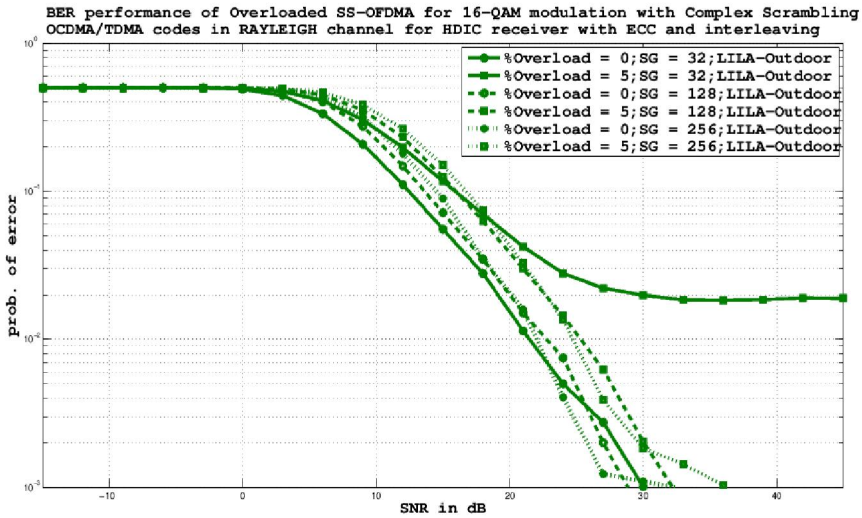

Fig. 2(c) BER performance of Overloaded Spread spectrum OFDMA for 16-QAM modulation

In Fig. 2(a), the Bit Error Rate (BER) performance of Overloaded Spread Spectrum OFDMA is depicted for BPSK modulation. Fig. 2(b) illustrates the BER performance for QPSK, while Fig. 2(c) showcases the performance for 16QAM with complex scrambling OCDMA/TDMA codes. These evaluations were conducted in a Rayleigh channel using an HDIC receiver with spreading gains of 32, 128, and 256, alongside Error Correction Coding (ECC) of 1/2, for outdoor scenarios (with FFT size = 2048).

The results indicate a degradation in Signal-to-Noise Ratio (SNR) requirement with overloading, especially pronounced for higher modulation schemes. This degradation occurs due to increased interference as the number of symbols in set-2 rises, thereby exacerbating system performance. However, performance improves with higher Spreading Gain (SG) values, as the cross-correlation decreases with increasing SG. This observation underscores the intricate relationship between system parameters, modulation schemes, and spreading gains, highlighting the trade-offs inherent in optimizing the performance of Overloaded Spread Spectrum OFDMA systems.

Analytical Model for Throughput performance

The previous section focused on improving the link between users and the base station, evaluating the probability of error for various overloading schemes. This simulation provides insight into the potential Bit Error Rate (BER) loss when transitioning from a basic OFDMA system to an overloaded scheme. However, any BER loss incurred is offset by the capacity gains of the system. To quantify the extent of this capacity improvement, throughput simulation is conducted. The normalized throughput is calculated using the following equation, which is dependent on the Signal-to-Noise Ratio (SNR) of the system:

$$\text{Throughput} = C/W = \log_2(1+\text{SNR})$$

Indeed, in the equation for normalized throughput, where C represents capacity and W signifies system bandwidth, the ratio C/W essentially quantifies the normalized throughput. This metric serves as a gauge of the number of bits per second that can be transmitted over a hertz (Hz) of bandwidth. Alternatively, it represents the number of bits that can be loaded in a symbol duration. Moreover, the Signal-to-Noise Ratio (SNR) at the receiver, denoted as SNR, plays a crucial role in determining the achievable throughput. By analyzing normalized throughput, we gain valuable insights into the efficiency and capacity utilization of the system under different operating conditions and configurations.

Certainly, the relationship between throughput and the probability of erroneously received symbols (Pe) can be expressed as follows [6]:

$$\text{Throughput} = (1-Pe)Lr(1+[\text{Percent Overload}/100])$$

Here, L represents the number of bits carried over a symbol, r denotes the rate of error control coding, and Percent Overload signifies the amount of overload applied.

For nearly zero probability of error, the throughput exceeds the case with no overload by the percentage of overload applied. Fig 3 illustrates the throughput performance of Overloaded SS-OFDMA for different modulation schemes with complex scrambling OCDMA/TDMA codes in a Rayleigh channel, employing an HDIC receiver with Low interleaving

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and Localized Access (LILA). Notably, an increase in the percentage of overload enhances spectral efficiency across various modulations such as BPSK, QPSK, and 16 QAM. This observation underscores the benefits of overloading in improving system performance and spectral efficiency in diverse modulation scenarios.

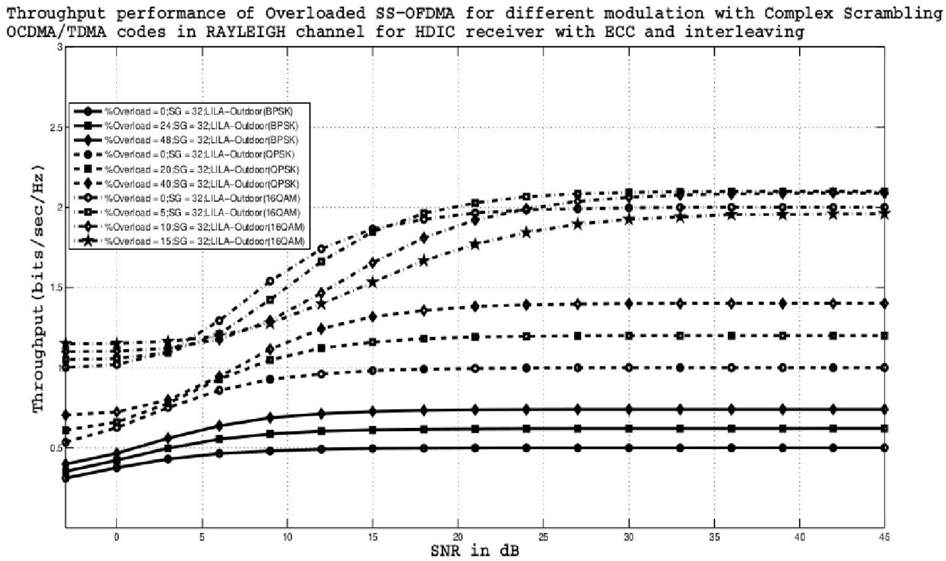

Fig. 3: Throughput performance of Overload SS-OFDMA in Outdoor environment

V. CONCLUSION

i) BER performance

Note:-with the increase in SG BER performance is becoming worse at low SNR but at high SNR BER performance improves for different modulations.

The Table I below illustrates the Signal-to-Noise Ratio (SNR) requirements, measured in decibels, needed to achieve a Bit Error Rate (BER) of 10^{-2} for various modulation schemes when using Complex Scrambling OCDMA/TDMA codes with different Spreading Gains (32, 128, and 256) and Error Correction Coding (ECC) set at 1/2.

TABLE I: SNR REQUIREMENT OF OVERLOADED SS-OFDMA FOR DIFFERENT MODULATION WITH VARIOUS SPREADING GAIN IN LILA OUTDOOR

BPSK						QPSK						16 QAM					
0% Overload			50% Overload			0% Overload			20% Overload			0% Overload			5% Overload		
32	128	256	32	128	256	32	128	256	32	128	256	32	128	256	32	128	256
14.3	15	13.7	17.2	17.4	15.5	17.1	18	16.7	20	20.4	19.6	22.6	24.2	23	25.5	26.3	24.8

ii) Throughput performance

Table II presents the Signal-to-Noise Ratio (SNR) needed to attain maximum throughput for various modulation types using Complex Scrambling OCDMA/TDMA codes, with Spreading Gain set at 32 and Error Correction Coding (ECC) at 1/2.

TABLE II: SNR REQUIREMENT OF OVERLOADED SS-OFDMA FOR DIFFERENT MODULATION TO ACHIEVE THE MAXIMUM THROUGHPUT IN LILA OUTDOOR

BPSK			QPSK			16 QAM		
0%	24%	48%	0%	20%	40%	0%	5%	10%
21.2	23.6	24	26.2	26.9	30.2	32.7	35.7	37

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