International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Multiple Access Schemes for Wireless Cellular Networks: Survey

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ABSTRACT

The achievement of future development goals in 5G is dependent on the implementation of ITU-published usage scenarios, enhanced Mobile Broadband (eMBB), massive Machine Type Communication (mMTC), and Ultra-reliable Low Latency Communication (URLLC). To support these usage scenarios, an efficient multiple access scheme must be implemented, as classical multiple access schemes used in previous generations will not. Non-orthogonal multiple access schemes are the answer to today's needs for high spectrum efficiency, low latency, accommodating a larger number of users, and providing justice to users who are far from the base station. This survey's condensed overview of various orthogonal and non-orthogonal multiple access schemes is expected to assist researchers in developing new multiple access schemes for 5G and beyond.

Keywords: 5G, Non-Orthogonal Multiple Access (NOMA), Orthogonal Frequency Division Multiple Access (OFDMA), Code Division Multiple Access (CDMA), Sparse Code Multiple Access (SCMA), MultiUser Shared Access (MUSA)

INDEX TERMS

5G, Non-Orthogonal Multiple Access (NOMA), Orthogonal Frequency Division Multiple Access (OFDMA), Code Division Multiple Access (CDMA), Sparse Code Multiple Access (SCMA), MultiUser Shared Access (MUSA)

NOMENCLATURE

5G	Fifth Generation
MA	Multiple Access
NR	New Radio
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
CDMA	Code division Multiple Access
NOMA	Non-Orthogonal Multiple Access
eMBB	enhanced Mobile Broadband
mMTC	massive Machine Type Communication
URLLC	Ultra-reliable Low Latency Communication
ITU	International Telecommunications Union
SCMA	Sparse Code Multiple Access
TDMA	Time Division Multiple Access

OMA	Orthogonal Multiple Access
PD-NOMA	Power Domain Non-Orthogonal Multiple Access
CD-NOMA	Code Domain Non-Orthogonal Multiple Access
LDS-CDMA	Low density spreading code division multiple access
LDS-OFDM	Low density spreading Orthogonal Frequency-Division Multiplexing
MUSA	Multiuser Shared Access
SAMA	Sparse Code Multiple Access
PSMA	Power Domain Sparse Code Multiple Access
FDMA	Frequency Division Multiple Access
TDMA	Time Division Multiple Access
MC-DS-CDMA	Direct-Sequence Code-Division Multiple Access
MT – CDMA	Multitone CDMA
RU	Resource Unit
MAI	Multi Access Interference
ICI	Inter-carrier Interference

I. INTRODUCTION

Achieving the objectives of future development in 5G, depends on implementation of usage scenarios published by ITU, enhanced Mobile Broadband (eMBB), massive Machine Type Communication (mMTC) and Ultra-reliable Low Latency Communication (URLLC). Classical multiple access schemes used in earlier generations will not support these use cases so an efficient multiple access scheme to be chosen or new multiple access scheme to be developed. Non orthogonal multiple access scheme (NOMA) is recommended to be used for 5G. In this paper condensed survey on different multiple access schemes of NOMA are presented. Since NOMA is combination of orthogonal frequency division multiple access (OFDMA) and code division multiple access (CDMA) so brief of Orthogonal multiple access (OMA) is presented first. Following figure fig.1, shows different existing multiple access schemes are shown and will be presented in following sections.

This paper is organized as follows. Second section will present background of OFDMA and CDMA, section 3 will detail about different NOMA schemes available. Section four will conclude our paper.

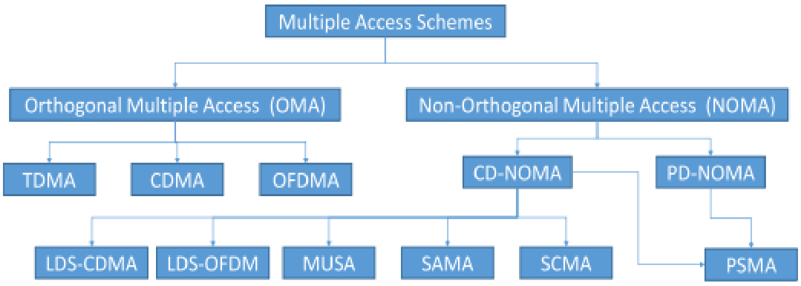


Fig.1. Existing Multiple Access Schemes [1]

2. Orthogonal Multiple Access

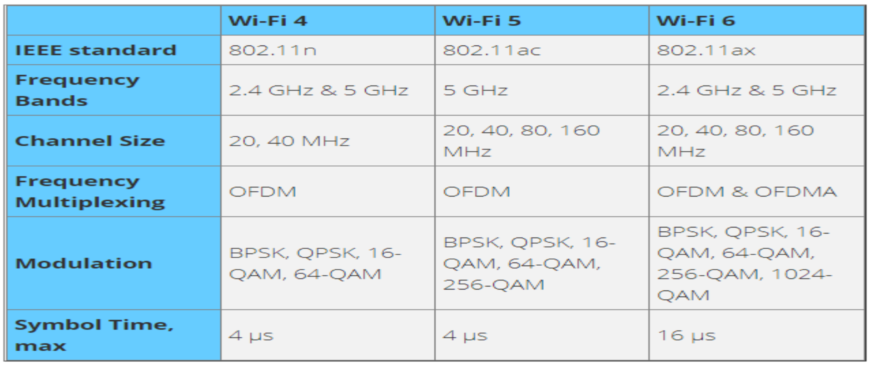
Orthogonal multiple access (OMA) techniques harmonize the access of multiple users to the network, thus preventing the collision of transmissions from different users. Preserving the orthogonality between transmissions can be achieved in the frequency domain MA, time domain MA, and code domain MA techniques that have been used in 2G and 3G. A more robust technique, known as orthogonal frequency division MA, combines time and frequency domains and has been incorporated to LTE (Long Term Evolution). For 5G New Radio, the adoption of Orthogonal Frequency Division Multiplexing (OFDM)-based MA implies significant differences related, among others, to the fact that NR supports different numerologies according to the selected subcarrier spacing [13], described in next section.

A Orthogonal Frequency Division Multiple Access (OFDMA)

The most successful technique used in 4G and recommended for 5G. OFDM is an effective way to achieve high data rates and OFDMA is a further enhancement to OFDM in which multiple devices share the same wireless channel. OFDMA is now used in 5G and the latest wifi - 6 standard **IEEE 802.11ax** uses OFDMA for both uplink and downlink data transmission and is also compatible with earlier wifi versions. 2.4GHZ and 5GHZ unlicensed bands are used in wifi - 6 and according to FCC announcement 1200MHZ unlicensed spectrum is available in 6GHZ band and this new band is called wifi - 6E. Adding high speed 1024 QAM modulation to wifi – 6, improved channel efficiency and maximized capacity through OFDMA.

A Wifi network has one Access Point (AP), serving multiple client devices. In OFDM, the channel is shared by multiple devices, one device transmitting in given time slot. The CSMA protocol minimises and manages collisions in the channel. It is used by each device to sense the channel, whether its freely available, then the device transmits the data assuming that no other device is transmitting at the same time. After the data transmission, the device waits for an acknowledgement to know that the data packet has been received, otherwise it will repeat the transmission. The disadvantage of this system is that when congested, more collisions occur, resulting in poor network performance and each device uses all the bandwidth whether it needs it or not. OFDMA overcomes these problems. OFDMA provides dynamic allocation of channel bandwidth to multiple users.

Table 1 Comparison of last 3 generations of wifi



	Wi-Fi 4	Wi-Fi 5	Wi-Fi 6
IEEE standard	802.11n	802.11ac	802.11ax
Frequency Bands	2.4 GHz & 5 GHz	5 GHz	2.4 GHz & 5 GHz
Channel Size	20, 40 MHz	20, 40, 80, 160 MHz	20, 40, 80, 160 MHz
Frequency Multiplexing	OFDM	OFDM	OFDM & OFDMA
Modulation	BPSK, QPSK, 16-QAM, 64-QAM	BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM	BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM, 1024-QAM
Symbol Time, max	4 µs	4 µs	16 µs

Channels are divided into sub-channels called Resource Units (RU). Resource Unit (RU) is a unit in OFDMA terminology used in 802.11ax WLAN to denote a group of 78.125 kHz bandwidth subcarriers (tones) used in both DownLink (DL) and UpLink (UL) transmissions. In each time slot the access point allocates resource units to individual devices according to their bandwidth needs. This process is dynamic, meaning that different resource units are allocated to devices in each time slot.

As RUs are allocated on uplink and downlink. On the downlink, AP transmits over the entire channel and client devices know which RUs are assigned to them. On the uplink, all client devices transmit simultaneously over their assigned RUs.

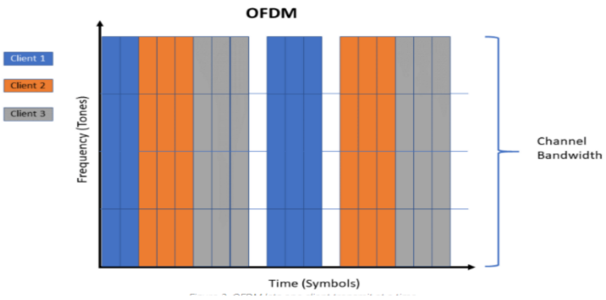


Fig.2. OFDM usage of Bandwidth by different Channels in wifi

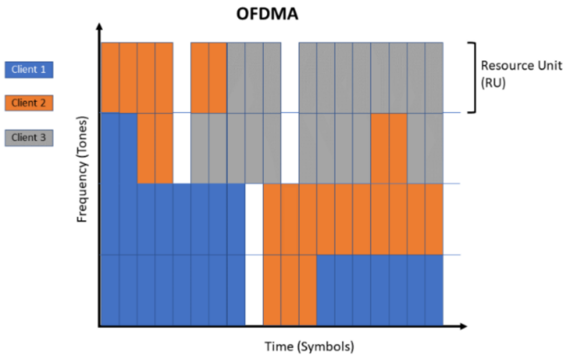


Fig.2. OFDMA provides multiple devices using channel simultaneously.

RU type	20 MHz BW	40 MHz BW	80 MHz BW	80+80/160 MHz BW
26-tone RU	9	18	37	74
52-tone RU	4	8	16	32
106-tone RU	2	4	8	16
242-tone RU	1	2	4	8
484-tone RU	N/A	1	2	4
996-tone RU	N/A	N/A	1	2
2x996-tone RU	N/A	N/A	N/A	1

Fig.3. OFDMA Sub-carriers in RU, Bandwidth and users

OFDMA Transmitter and Receiver System: Orthogonal Frequency-Division Multiple Access (OFDMA) is a multi-user version of the digital modulation scheme Orthogonal Frequency-Division Multiplexing (OFDM). OFDM is a modulation technique that employs a large number of closely spaced sub-carriers modulated with low-rate data. The key principle in OFDM is the use of orthogonal subcarriers to send multiple data symbols in parallel, resulting in improved spectral efficiency and simpler equalization methods at the receiver. The samples of the transmitted OFDM signal are obtained by performing an IFFT operation on the group of data symbols to be sent on orthogonal subcarriers. The data symbols are recovered from the orthogonal sub-carriers by performing a Fast Fourier Transform (FFT) operation on a block of received samples. As a result, the wideband wireless radio channel with frequency-selective fading is converted into a set of narrowband channels (subcarriers) with flat fading. Each data symbol is then sent on a single subcarrier, making it resistant to multipath propagation. These carrier signals would normally be expected to interfere with each other, but by making the subcarriers orthogonal to each other, mutual interference is avoided. This is accomplished by making the carrier spacing equal to the symbol period's reciprocal. OFDMA functions similarly to OFDM, with the main difference being that instead of allocating all available subcarriers to each user, the base station allocates a subset of carriers to each user in order to accommodate multiple transmissions at the same time. Because it assigns users to subcarriers, subcarrier mapping is critical in implementing OFDMA [44].

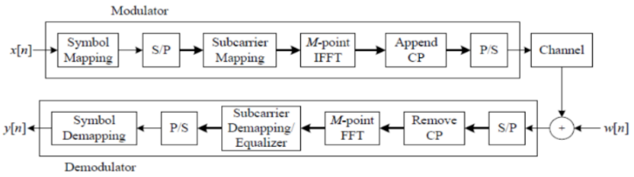


Fig.4 OFDMA System [44]

B Code Division Multiple Access (CDMA)

CDMA is a channel access method used in 3G radio communications and its more advanced versions built are cdmaOne, CDMA2000, and WCDMA. Groups of users shared the same code. Many codes occupy the same channel, but only those with the same code can communicate. CDMA is based on spread spectrum technique. The main feature is that each channel uses the entire bandwidth. Individual conversations are encoded with pseudo random bit sequence and then transmitted over a wider range of frequencies. It provides better capacity over conventional access techniques TDMA and FDMA for voice and data communications and allows more subscribers to connect at any given time. The ITU defined the standards IMT 2000 defined the standards for accessing voice, data, Internet, and multimedia services anytime and anywhere, and formed the basis for third generation (3G) wireless systems.

Key features of IMT 2000 are specified below. [2]

- high degree of commonality of design worldwide
- compatibility of services within IMT-2000 and with the fixed networks
- high quality
- small terminal for worldwide use
- worldwide roaming capability
- capability for multimedia applications and a wide range of services and terminals.

CDMA allows up to 61 concurrent users in a 1.2288 MHz channel by processing each voice packet with two PN codes. There are 64 Walsh codes available to distinguish between calls and theoretical limits. Operational constraints and quality issues will reduce the maximum number of calls somewhat below this value. The band used in CDMA ranges from 824 MHz to 894 MHz (50 MHz + 20 MHz separation). 1.25 MHz of the FDMA channel is divided into 64 code channels. Since CDMA is a spread spectrum technique. Each data bit is spread by a code sequence. This means, that the energy per bit is also increased. The gain is calculated as follows.

P (gain) = 10log (W/R)

W is Spread Rate

R is Data Rate

CDMA has 100% frequency reuse. Using the same frequency in the surrounding cells causes additional interference.

The RAKE receiver is used in CDMA-based (Code Division Multiple Access) systems and can combine multipath components, that are time-delayed versions of the original signal transmission. The combination is performed to improve the signal to noise ratio at the receiver. [6]

CDMA – Spread Spectrum Technique: In this technique many users can use the same bandwidth simultaneously without interfering with each other. The transmitted signal bandwidth is greater than the minimum information bandwidth, required to successfully transmit the signal. There are two types of spread spectrum techniques: Direct Sequence and Frequency Hopping. Direct Sequence is adopted by CDMA and is the focus here. Direct Sequence Code Division Multiple Access (DS-CDMA) is a technique for multiplexing users by different codes. In this technique, the same bandwidth is used by different users. Each user is assigned its own spreading code. These code sets are divided into two classes − Orthogonal Codes and Non-Orthogonal Codes. Walsh code belongs to the category of orthogonal codes and PN, Gold belong to non-orthogonal codes [6]. DS-CDMA is further elaborated as follows.

DS-CDMA: The signal, which has a spread spectrum, can only be demodulated by a code used for transmission. In this way, each user's transmission signal can be identified by the separate code when it receives the signal. In synchronous CDMA system orthogonal codes (Walsh codes) are used, it is called synchronous DS-CDMA and in asynchronous CDMA system PN or Gold codes are used, it is called asynchronous DS-CDMA. Synchronous DS CDMA is used for Point to Multi-point Systems. For example, forward link/downlink (base station to mobile station) in cell phones. In asynchronous DS CDMA system, unlike the signal from base station, the signal from mobile station to base station, that is reverse link/uplink, becomes asynchronous system and orthogonal codes have poor cross correlation and mutual interference increases, but other codes like PN code or Gold code or Kasami codes are used. [6].

DS-CDMA Transmitter and Receiver:

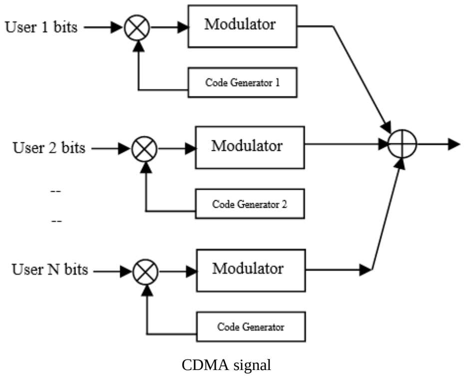


Fig.5. Block diagram of multiple user CDMA transmitters

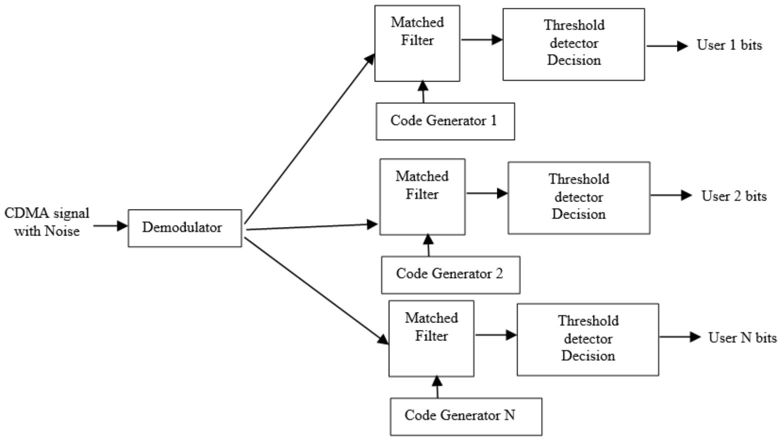


Fig.6. Block diagram of multiple user CDMA receivers

Three types of multiple access techniques based on OFDMA have been proposed: Multi Carrier CDMA (MC-CDMA) also known as OFDM/CDMA, multi carrier DS – CDMA (MC DS - CDMA) and multi tone CDMA (MT CDMA) [4]. Previously MC-CDMA was used to describe 0the variant in which spreading is performed in the frequency-domain only. CDMA, which spreads a given symbol in the time domain was called multicarrier direct-sequence code-division multiple access (MC-DS-CDMA). In Multi-Tone CDMA (MT-CDMA), signal spreading is performed on the OFDM signal. Finally, Spread-Spectrum Multicarrier Multiple Access (SS-MC-MA) refers to a multiple access method in which different user signals are transmitted on different carriers, and code-division multiplexing (CDM) is used on each carrier. [5]

MC - CDMA: In the MC-CDMA technique, the original data stream is first multiplied by the spreading sequence and then modulated onto the orthogonal carriers, as shown in Figure 7: Since the chips belonging to the same symbol are modulated onto different carriers, the spreading occurs in the frequency domain [7], [8], [10].

Fig. 9 shows the MC-CDMA receiver of the scheme, assuming that the jth user receives. In fig. 9, MC-CDMA receiver also receives the transmitted signal as a sum of j users. It first demodulates the received signal and then dispread the signals using the specific codes given by the receiver code generator. Again, the code for jth user must be same in both the transmitter and the receiver. Next, a low pass filter restricts the high frequency portion of the signal. Finally, the P/S converter outputs the actual digital data signal. Since each chip is given different orthogonal frequency, this system can support more users with better performance compared to DS-CDMA and MT-CDMA. Multi Access Interference (MAI) and Inter-carrier Interference (ICI) can be minimized by using orthogonal code and orthogonal sub-carriers, respectively. In accumulation, the system provides non-frequency selective fading channel [7], [8], [9].

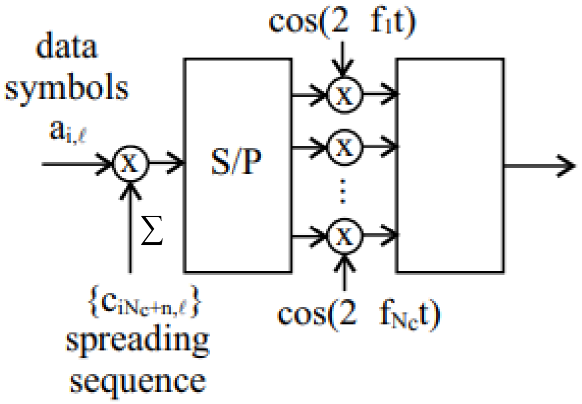


Fig.7. MC-CDMA transmitter [10]

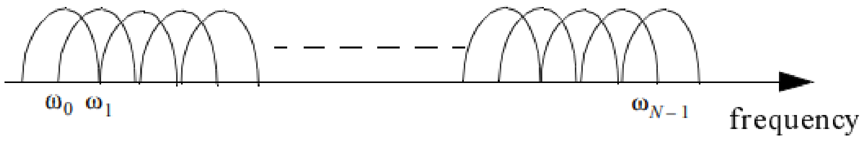


Fig.8. Power Spectrum of transmitted signal [8]

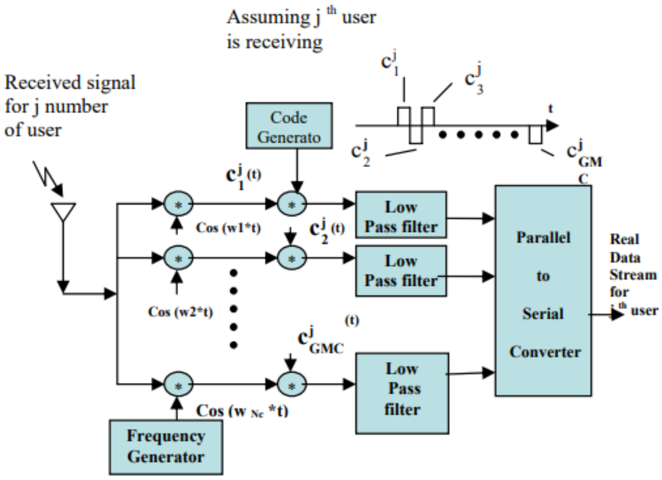


Fig.9. MC-CDMA receiver [7]

MC - DS - CDMA: In the MC-DS-CDMA technique, the serial to-parallel converted data stream is multiplied by the spreading sequence and then the chips belonging to the same symbol modulate the same carrier, as shown in Figure 10. The spreading occurs in the time domain. MC-DS-CDMA receivers, usually, consisting of a set of normal coherent (non-Rake) receivers, since it is crucial to have frequency non-selective fading over each sub carrier so with no forward error correction (FEC) among subcarriers and this scheme does not achieve frequency diversity gain [3].

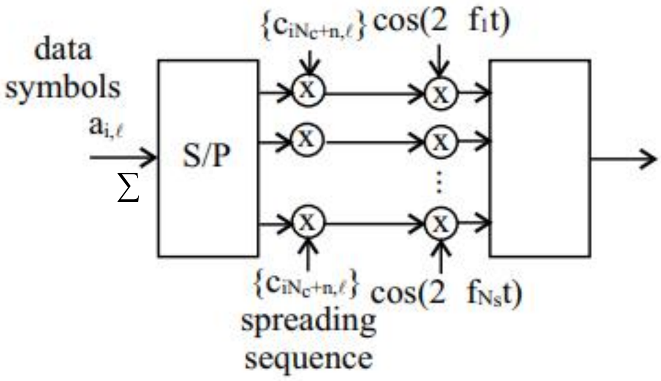


Fig.10 MC-DS-CDMA transmitter [10]

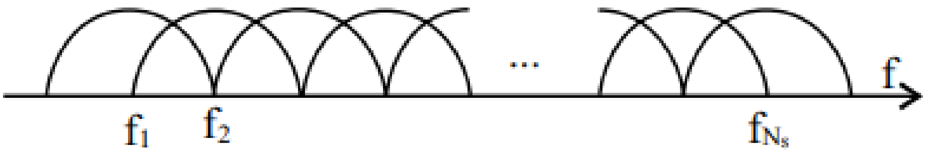


Fig.11. Power Spectrum of transmitted signal

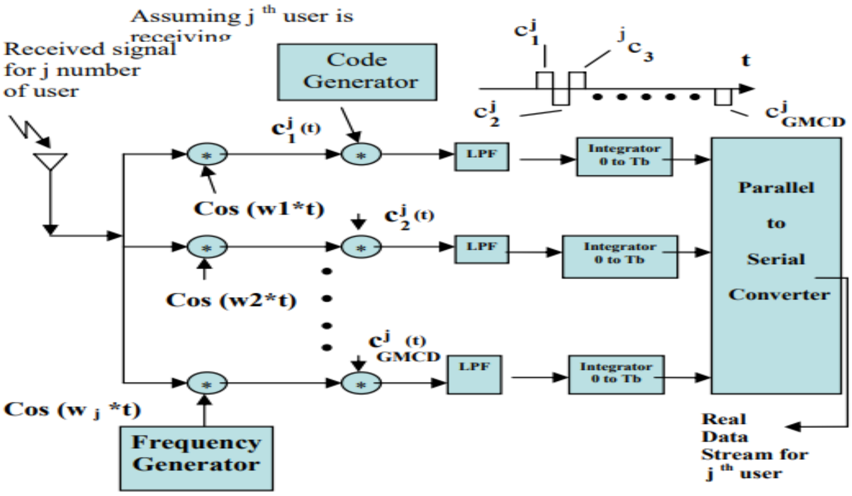


Fig.12. MC-DS-CDMA receiver [7]

MT – CDMA: In general, the number of subcarriers is equal to the length of the spreading code in MC-CDMA, multicarrier DS-CDMA schemes, while MT-CDMA system uses much fewer subcarriers than the length of the spreading code. This strategy simplifies the receiver structure. On the other hand, after spreading the spectrum, each subcarrier no longer satisfies the orthogonality condition, even without multipath propagation and Doppler frequency shift, and consequently the inter-subcarrier interference is introduced. Operation of MT – CDMA transmitter and receiver is presented here.

MT – CDMA Transmitter: Fig.14, is the transmitter of the jth user in the MT-CDMA scheme, assuming jth user is transmitting. In this figure, the MT-CDMA transmitter spreads the serial to parallel (S/P) converted data streams using a specific spreading code in the time domain. The Code Generator generate unique codes for each user. It then, it modulates the data signal using various sub-carriers. The modulation technique here is Quadrature Phase Shift Keying (QPSK) and the sub-carriers are spawned by the transmitter frequency generator. The MT-CDMA scheme uses longer spreading codes relative to the number of sub carrier (Nc= number of sub carriers), as compared to normal (single carrier) DS-CDMA scheme. Consecutively each two chips are given separate subcarriers in this analysis (shown in fig.12). Then a Combiner merges the modulated signals, and a CDMA antenna transmits the signals over wireless media. The Power spectrum is shown in figure 13.

MT – CDMA Receiver: Fig. 14 is the receiver of the jth user in the MT-CDMA scheme, assuming that jth user is receiving. In this figure, the MT-CDMA receiver receives the transmitted signal as a sum of j users. First, the CDMA antenna receives the signals. Then, the demodulator demodulates the received signals with a Nc number of sub-carriers. After that, the data signal is routed with GMT number of rake combiners. The rake combiners acquire the signals in the time domain. The Rake combiner checks the data signals according to Tc, 2Tc….GMT Tc and selects suitable paths for data signals. The Rake Combiner Block contains a code generator (shown in fig. 14). The code generator generates specific code for jth user for dispreading. The code is same as it was given by the transmitter code generator. Otherwise the original user’s digital data signal cannot be retrieved. The Rake Combiner Block also has low pass filters as shown in fig. 14, that limit the high frequency portion of the data signal. It also has GMT number of integrators to minimize the multi-access interference (MAI) term using the cross-correlation characteristic. Afterward a P/S converter provides the original digital data for the jth user.

Since each consecutive two chips are given different sub-carrier, the effect of frequency selective multi-path fading in MT-CDMA is less compared to in DS-CDMA, but some still remains. Therefore, the system can accommodate more users than the DS-CDMA scheme. The MT-CDMA scheme suffers from inter-carrier interference (ICI), while the ability to use longer spreading codes results in the reduction of the ISI (inter-symbol interference) and MAI (multi-access interference), as compared to the spreading codes assigned to a normal DS-CDMA scheme. MT-CDMA is found the most secure communication system among the other systems as it modulates different sub-carriers onto specific number of chips at both transmitter and receiver.

Security can be maintained by making undisclosed of the order of modulated chips. Then, that secret order of activating group chips can then only be maintained by the proper destination receiver [7].

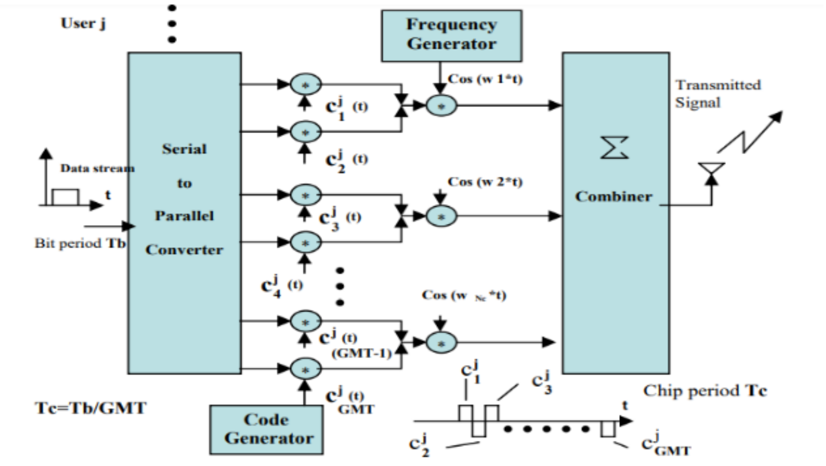


Fig.13. MT-CDMA transmitter [7]

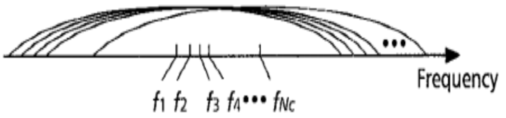


Fig.14. MT-CDMA Power Spectrum [3]

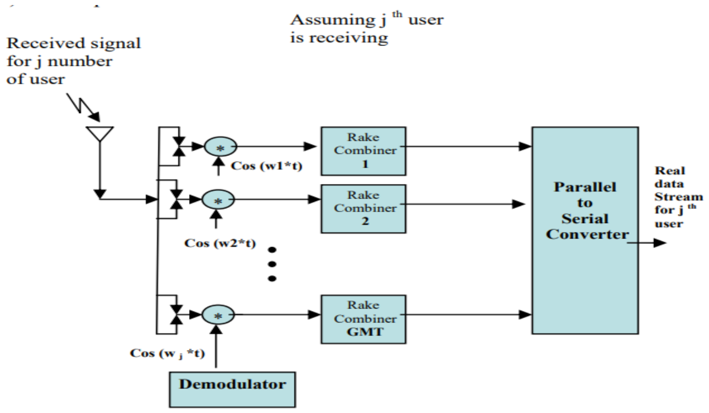


Fig.15. MT-CDMA receiver [7]

3. Non-Orthogonal Multiple Access

One of the most promising radio access techniques for next-generation wireless communications is non-orthogonal multiple access (NOMA). In comparison to the current standard orthogonal multiple access (OMA) technique, orthogonal frequency division multiple access (OFDMA), NOMA offers a number of desirable potential advantages, including improved spectrum efficiency, lower latency with high reliability, and massive connectivity. The basic idea behind NOMA is to provide the same resource to multiple users in terms of time, frequency, and space [18]. In conventional 4G networks, information for each user is assigned to a subset of subcarriers using OFDMA. In NOMA, on the other hand, each user can use all of the subcarriers, and this applies to both downlink and uplink transmission [44].

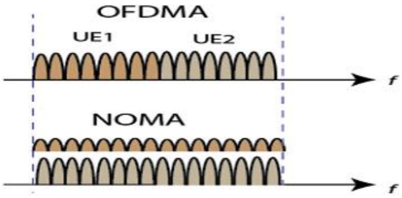


Fig.16 Spectrum sharing in OFDMA and NOMA for two users [44]

NOMA intentionally introduces intercell and/or intracell interference on the transmitter side, allowing it to use non-orthogonal transmission. The successive interference cancellation technique (SIC) is used on the receiver side to decode the desired signal [14]. The following section goes into detail about downlink and uplink transmission in a NOMA network.

Downlink NOMA network: The BS transmits the combined signal, which is a superposition of the desired signals of multiple users with different allocated power coefficients, to all mobile users on the transmitter side of the downlink NOMA network. The SIC process is assumed to be performed sequentially at each user's receiver until the user's signal is recovered. Users' power coefficients are assigned in an inversely proportional manner based on their channel conditions. The user with a poor channel condition receives more transmission power than the user with a good channel condition. As a result, because the user with the highest transmission power regards the signals of other users as noise, it recovers its signal without performing any SIC process. Other users, on the other hand, must carry out SIC processes. However, other users need to perform SIC processes. In SIC, each user's receiver detects signals that are stronger than the user's desired signal first. Following that, those signals are subtracted from the received signal, and the process is repeated until the related user's own signal is determined. Finally, each user decodes its own signal by treating lower power coefficient users as noise [45], [46].

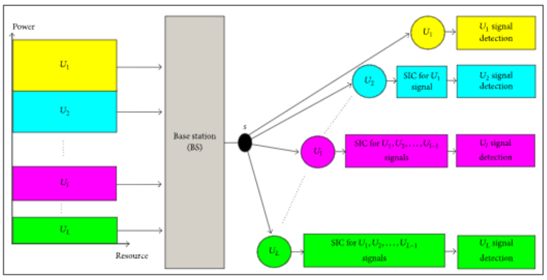


Fig.16 Downlink NOMA Network [46]

Uplink NOMA network: Each mobile user transmits its signal to the BS in an uplink NOMA network. SIC iterations are performed at the BS in order to detect mobile user signals. The BS transmits power allocation coefficients to mobile users by assuming that the downlink and uplink channels are reciprocal [46].

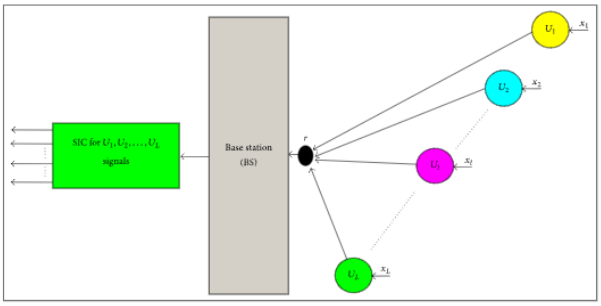


Fig.17 UPLINK NOMA Network [46]

Energy harvesting NOMA system for downlink and uplink presented in [47] where authors demonstrated bases station can serve more number of users at downlink and their energy harvesting protocol benefit both downlink and uplink in wireless system.

NOMA techniques are classified into two types: power-domain NOMA and code-domain NOMA. The code-domain NOMA can be further subdivided into various multiple access techniques based on low-density spreading and sparse code multiple access, as shown in Figure.1. Other closely related multiple access methods in this context are Interleave division multiple access (IDMA), Lattice-Partition Multiple Access (LPMA) and Pattern-Division Multiple Access will also be discussed.

Power Domain NOMA: PD-NOMA provides flexibility in radio resources to improve user access performance. Multiple users share the same radio resources in PD-NOMA, which can achieve better spectrum efficiency [17]. Power domain technology is used in the PD-NOMA multiplexing technique. The PD-NOMA system with a SIC computing unit is shown in Figure 15. User Equipment (UE) is uniformly distributed in every cell. The base station (BS) performs downlink transmission for numerous users simultaneously using the varying transmission powers of multiple users in each sub-band. By applying the Proportional Fair (PF) scheduling technique at BS in the PD-NOMA system, multiple individual users can be scheduled for the same sub-band at the same time. First, BS chooses a group of users known as "NOMA candidate user sets," with a maximum number of users of Nmax. The number of feasible user combinations within a single cell is used to build the selected user set. Second, BS uses a power allocation scheme to allocate transmission power to each user set. The power allocation ratio is used to estimate the scheduling metric for the corresponding user set. Third, the planner determines which user groups in each sub-band are eligible for data transmission using the maximum scheduling metric. Finally, the scheduler estimates the equivalent signal-to-interference-plus-noise ratios (SINRs) for each individual scheduled user for each allocated sub-band. The SNR for each user is determined by the Coding and Modulation Scheme (CMS). Advantage of Power domain NOMA is that it also supports existing OMA systems, such as TDMA and FDMA, are also supported by NOMA; existing wireless networks can be easily adopted [36]. The disadvantage of this system is that if a user error occurs due to SIC, the decoding of the user's information will be incorrect.

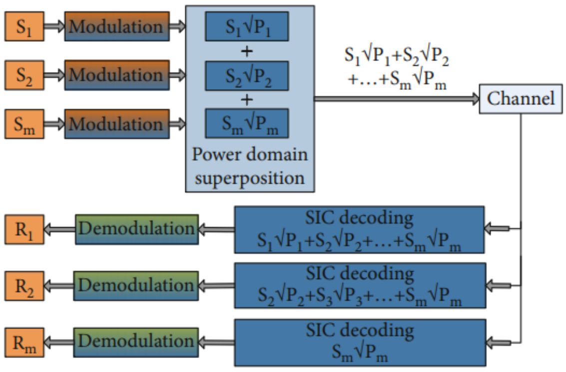


Fig.18. PD – NOMA system with SIC [14]

Code Domain NOMA: In traditional CDMA, users can share a common channel at the same time. Separating users is accomplished by assigning codes or spreading signatures to each individual user. However, as a result of this channel sharing, ISI is unavoidable in CDMA-based systems. This limitation is mitigated by CD-NOMA, which employs spreading codes with low density signatures (LDS) and interleave sequences [19]. Some of the CD – NOMA categories are discussed here.

Low Density Spreading CDMA (LDS – CDMA): A sparse spreading sequence is used instead of dense spreading as in conventional CDMA to reduce interference among multiple users and achieve overloading, resulting in improved system performance compared to CDMA. Figure 19 depicts the Uplink LDS-CDMA system model.

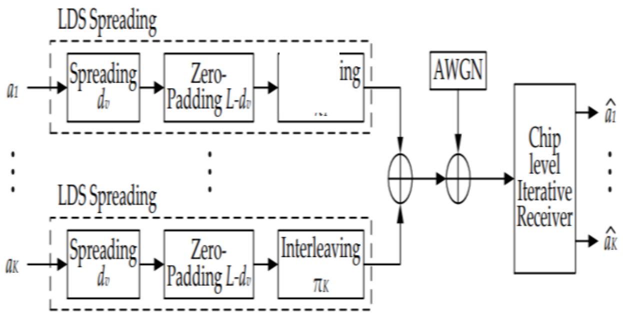
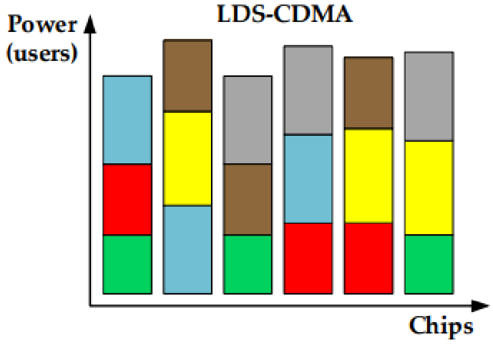


Fig.19 Uplink LDS-CDMA [21]

The benefits of LDS-CDMA are as follows: A higher chip-level Signal to Interference-plus-Noise Ratio (SINR) could be achieved, resulting in a more accurate detection process. Because a user will have a relatively small number of interferers at each received chip, the search-space should be smaller and, as a result, more affordable detection techniques can be used, and each user will see an interference coming from different users at different chips, resulting in interference diversity by avoiding strong interferers from corrupting all of a user's chips. [20], [21].



(a) LDS-CDMA structure

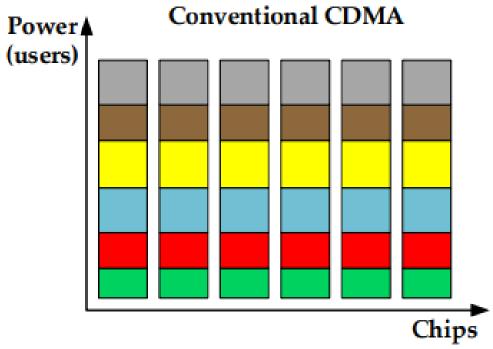


Fig.20 Structure of LDS-CDMA and conventional CDMA. [21]

CDMA. Let dv and dc represent the number of chips over which a single user will spread its data and the maximum number of users that are allowed to interfere within a single chip, respectively. The new spreading sequences will have a maximum of dv non-zero values and Ldv zero values for each user. Each user will experience interference from dc 1 users at each chip. The interference level in LDS-CDMA varies depending on the chip. In conventional CDMA, each user is spread across all L chips, so each user sees interference from K 1 users. The LDS structure enables the use of near-optimal chip-level Multi User Detection (MUD) based on the Message Passing Algorithm (MPA) [21].

In our study, we discovered that LDS-CDMA has the disadvantage of high multiuser detection complexity and does not fully exploit channel state information, and researchers are working to address this issue. For example, in [37], authors proposed a novel low-complexity multiuser detection scheme based on dynamic factor graph.

Low-Density Spreading OFDM (LDS – OFDM): It is a hybrid of LDS-CDMA and OFDM, with the chips acting as subcarriers of OFDM to combat multipath fading. The transmitted symbols in LDS-OFDM are first mapped to specific LDS sequences before being transmitted on different OFDM subcarriers. The number of symbols can be greater than the number of subcarriers, allowing for overloading to improve spectral efficiency. MPA is also employed in LDS-OFDM [22]. Despite being an efficient multiple access technique, high Peak to Average Power Ratio (PAPR) is a significant impediment to multicarrier communication systems. To address this issue, the authors [38] proposed two methods for PAPR reduction: Newman phases and DFT pre-coding.

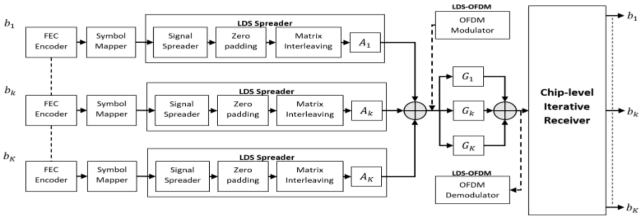


Fig.21 LDS-OFDM [20]

Multi User Shared Access (MUSA): It employs good spreading sequences as well as an advanced SIC (Successive Interference Cancelation) mechanism. Each user's data is spread by special short length spreading sequences, and user data is overlapped and transmitted. At the receiver, advanced SIC receivers demodulate and recover the data. Unlike in 4G, where orthogonal methods are used to distinguish users at different times, sub-carriers, or spaces to avoid overlapping, MUSA assigns a different spreading sequence for each user, which is non orthogonal, and these users are assigned at the same time, sub-carrier, or space. Unlike 4G, which sacrifices the capacity of the remote user from the base station, MUSA ensures greater system capacity and maintains balance among all users [23].

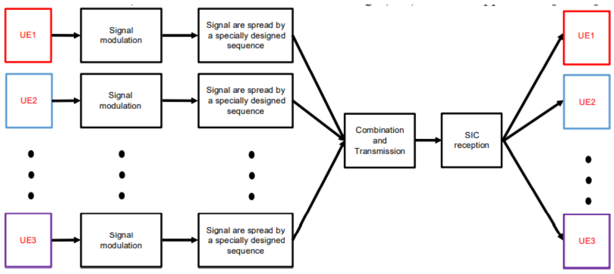


Fig.22 MUSA Operation [23]

Non-binary complex spreading codes are used to support higher user overloading factors and to provide free transmission. Allowing free access reduces signaling overhead, transmission latency, and device power consumption [23], [24]. Because MUSA reduces device power consumption, it is recommended for uplink transmission [40]. MUSA employs a receiver based on successive interference cancelation (SIC). When there is a SINR difference between the received signals, it works well. When the difference is small, however, there will be some performance loss due to error propagation. While there is an inherent SINR difference in mMTC due to free power control, it is not a major issue for MUSA signal detection. Because the SINR difference is small, it can be resolved by employing a more sophisticated receiver, such as a joint detection and decoding scheme [41]. The authors clarified that MUSA has the best channel capacity due to non-zero code spreading, and that the benefits of MUSA are most strongly demonstrated in scenarios of high SNR and many-user transmission. As a result, MUSA is suitable for 5G mMTC [39].

Successive Interference Cancellation Aided Multiple Access (SAMA): A SAMA scheme is presented [25], which is based on the joint design of the system signature matrix and the SIC-based iterative message-passing algorithm. The symbols of the different users are of judiciously designed diversity orders in the frequency domain in this scheme, which can be effectively exploited by the successive interference cancelation based iterative message-passing algorithm to cancel multi-user interference as well as obtain diversity gain. The authors demonstrated that NOMA based on SAMA with a message passing algorithm achieves better performance while requiring less computational complexity. If we take K as the number of users and N as the number of resource elements, and K is set to K = $2^N - 1$ That is, the system will invariably be overloaded [26]. The factor graph [25] is shown here for K = 7 and N = 3.

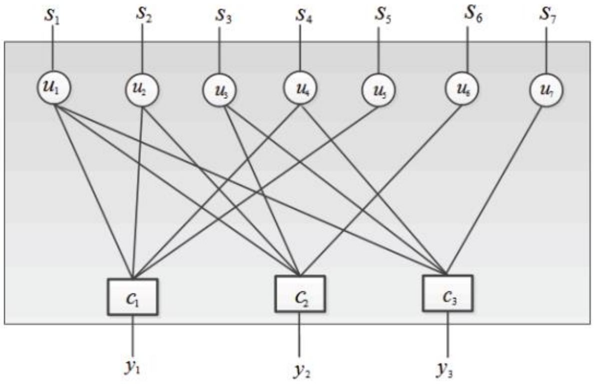


Fig.23 Factor graph for K = 7 and N = 3

Sparse Code Multiple Access (SCMA): Sparse Code Multiple Access (SCMA) is a scheme that is commonly recommended for 5G networks and is a popular research topic among researchers.

Sparse code multiple access (SCMA) technique is based on sparse structure codebooks, and SCMA system consists of two parts: SCMA encoder and SCMA decoder. A SCMA encoder is a mapping from log2(M) bits to a K-dimensional codeword of size M chosen from a predefined codebook. K orthogonal tones, such as OFDMA subcarriers, correspond to K dimensions. A K-dimensional codeword is a vector with N K nonzero entries. Users are unable to transmit data over the subcarriers represented by the remaining N K zero entries. In theory, each user can be assigned to more than one codebook, and each codebook can be used by multiple users.

Figure 24 depicts an SCMA encoder with six layered codebooks (variable nodes) and four subcarriers (function nodes). Each row represents a dimension, and each column represents a four-dimensional codeword. The constellation size in each codebook is four, which means that four different codewords can be selected. In the codebooks, white entries represent zero elements and colored entries represent non-zero elements. In Codebook 1, for example, the entries in the first row are colored, while the entries in the third row are white, indicating that the first dimension is non-zero and the third dimension is zero. Each codebook contains two non-zero dimensions with colored lattice. The signal received in the base station in an AWGN channel is a superposition of the codewords chosen from the codebooks. The design of the codebook is the most important aspect of the SCMA encoder.

SCMA code is designed in three stages. 1) The Mapping Matrix determines the number of layers interfering at each subcarrier, indicating the complexity of Message Passing Algorithm (MPA) detection. 2) Design of Constellation Points and Multi-dimensional Mother Constellation 3) Constellation Function Operator, which includes operators such as complex conjugate, phase rotation, and dimensional permutation, aims to create distinct codebooks for collision layers. SCMA decoders typically use MPA detection or a better version of MPA detection. The conventional MPA detection process consists of three steps: 1) Initialize the conditional probability. 2) Iterative message passing through variable nodes and function nodes. 3) Log-Likelihood-Rate (LLR) calculation [27]. Authors in [43] presented, number of promising directions associated with SCMA for faster, more reliable, and more efficient multiple access in future 6G communication networks.

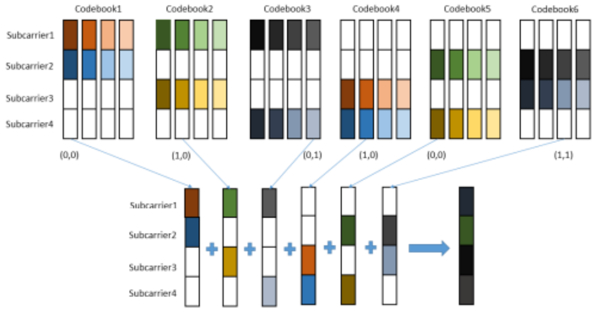


Fig.24 SCMA Encoder [27]

Power Domain Sparse Code Multiple Access (PSMA): The basic idea behind PSMA is to use SCMA's ability to remove inference using MPA while allowing users to use the codebooks non-exclusively, i.e., each codebook is assigned to more than one user. After applying the MPA, the SIC method is used to remove the interference caused by non-exclusive use of the codebooks [28]. The authors proposed the PSMA system, which assumes that each codebook can be assigned to more than one user in a BS at the same time. Using the SC method, each codebook is assigned to more than one user using this new approach. MPA and SIC are used on the receiver side to detect user signals. According to the PSMA approach, each user can detect and remove the signals of users with lower average channel gain by using MPA and SIC, while the signals of users with higher average channel gain are considered noise [28].

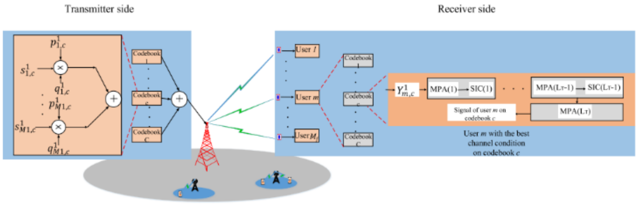


Fig.25 PSMA based System [28]

4. Other multiple Access methods

Other multiple access methods closely related to NOMA are Interleave division multiple access (IDMA), Lattice-Partition Multiple Access (LPMA) and Pattern-Division Multiple (PDMA, will be briefly discussed here.

Interleave division multiple access (IDMA): It’s a potential candidate in the code domain NOMA. It can be thought of as a subset of code division multiple access direct sequences. Instead of code division multiple access, specific sequences are not used to distinguish users in IDMA. Instead, the entire bandwidth is dedicated to forwarding error correction code, resulting in a lower code rate than code division multiple access systems. Furthermore, user-specific interleavers are used as a distinct feature in IDMA to separate users [36].

IDMA Transmitter and Receiver Structure:

The upper half of Fig. 22 depicts the transmitter structure of the multiple access scheme under consideration with K concurrent users. The user-k input data sequence dk is encoded using a low-rate code C, resulting in a coded sequence ck $[c_k(1),\ldots, c_k(j),\ldots, c_k(J)]^T$, where J is the frame length. Coded bits are the elements in ck. Then, using an interleaver k, ck is permutated, yielding x_k $[x_k(1),...,x_k(j),...,x_k(J)]^T$. x_k's elements are referred to as "chips" in accordance with the CDMA convention. Users are identified solely by their interleavers, thus the name interleave-division multiple-access (IDMA). A suboptimal receiver structure, as shown in Fig. 22, is used, consisting of an elementary signal estimator (ESE) and K single user a posteriori probability (APP) decoder (DECs) [42].

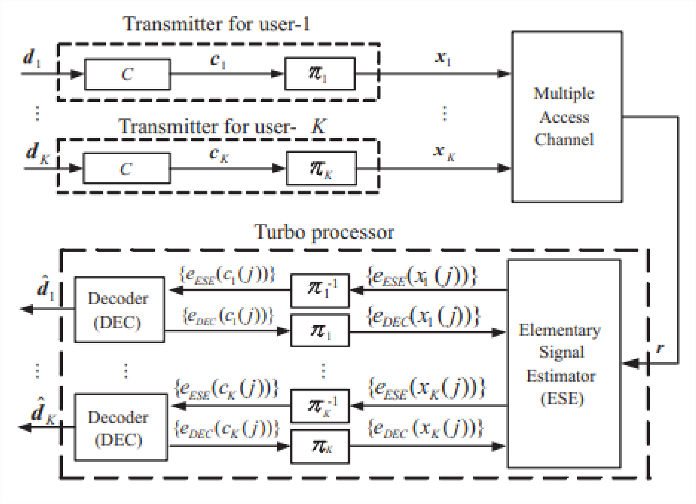


Fig.26 IDMA Transmitter and Receiver [42]

Lattice-Partition Multiple Access (LPMA): In scenarios where users have similar channel conditions, the performance gain of NOMA over OMA may be reduced. To address this issue, the authors [32] proposed lattice partition multiple access, a new downlink superposition transmission scheme based on multilevel lattice codes (LPMA). LPMA takes advantage of the structural property of lattice codes to harness user co-channel interference. LPMA can multiplex users by assigning them different lattice partitions which are isomorphic to the same finite field.

The BS encodes multiuser signals into different lattice code levels, and each UE extracts their desired signal via a modulo lattice operation and SIC/PIC (successive interference cancellation/parallel interference cancellation) decoding [32]. The advantage of LPMA is that it can avoid the PD-NOMA impediment. LPMA requires more encoding and decoding complexity than PD NOMA [33].

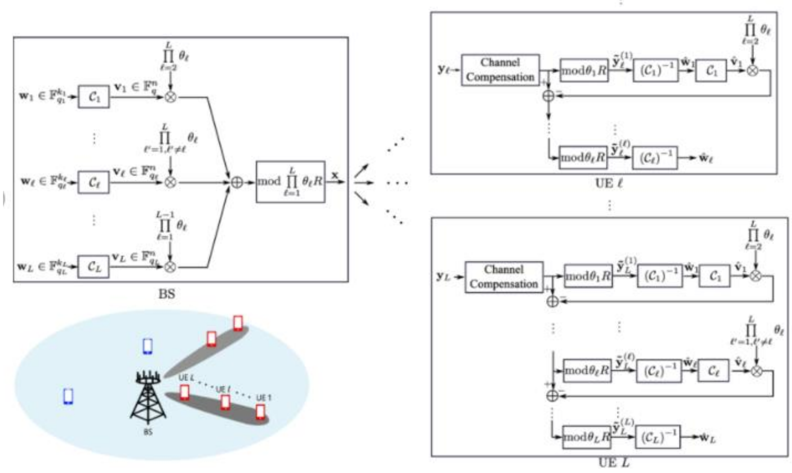


Fig.27 Lattice-Partition Multiple Access (LPMA) [33]

Pattern Division Multiple Access (PDMA): Pattern Division Multiple Access (PDMA): PDMA evolved from SAMA and employs successive interference cancellation (SIC) detection in the receiver. A joint transmitter-receiver design is a good solution to the SIC error propagation problem. This is the key feature of the PDMA scheme, which includes a joint transmitter and receiver design that enables low-complexity successive interference cancellation (SIC)-based multi-user detection with significantly improved performance over traditional OMA schemes. It has been demonstrated and proven by authors, that PDMA is a promising multiple access technology for 5G, with low signaling overhead, low latency, and massive connectivity support. The PDMA scheme's design philosophy is that user signals are wisely allocated in a specific physical resource space (frequency, code, or spatial domain) at the transmitter, which can then be effectively used to improve the performance of SIC-based detectors at the receiver. More specifically, different users' data should exhibit appropriate diversity disparity at the symbol level and power disparity at the physical resource element level. Such disparities are expected to introduce a convergence-amenable property that the SIC-based detector can fully exploit in eliminating multi-user interference as well as retrieving transmit diversity at the receiver [34].

PDMA based Transmitter Receiver system for Uplink: At the transmitting end, the system completes signal processing by using multiple user data forward error correction channel coding, PDMA code modulation, PDMA subcarrier resource mapping, and OFDM modulation. At the receiving end, the base station performs the inverse process, in which the system obtains the transmitting data of each terminal via OFDM demodulation and general SIC type detection such as belief propagation iterative detection and decoding (BP-IDD). The symbol level mapping and frequency domain spread spectrum are achieved concurrently during the PDMA modulation and coding process [35].

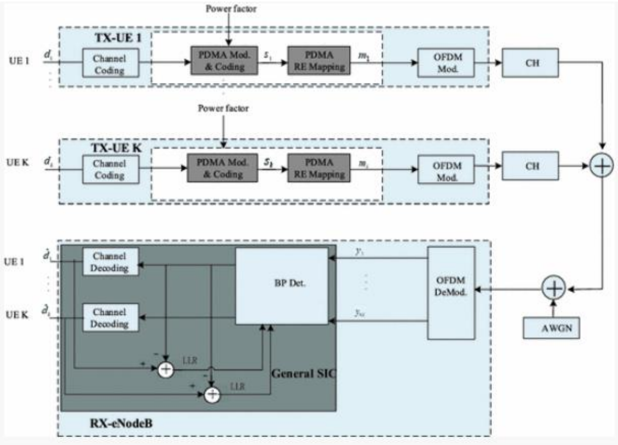


Fig.28 PDMA Transmitter and Receiver Scheme for Uplink [35]

PDMA based Transmitter Receiver system for Downlink:

The base station performs data forward error correction channel coding for multiple users at the transmitting end of the downlink PDMA system, such as PDMA code modulation, PDMA subcarrier resource mapping, and OFDM modulation. Each user performs the opposite process at the receiving end of the downlink PDMA system, including OFDM demodulation and general SIC type detection, such as BP-IDD [35].

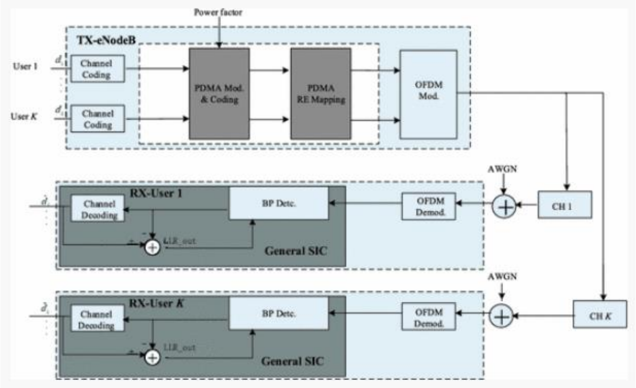


Fig. 29 PDMA based transmitter and receiver scheme for Downlink [35]

PDMA can be used in 5G scenarios such as eMBB, URLLC, and mMTC to improve spectrum efficiency, increase connections, and decrease latency [35].

5. Conclusion

A condensed survey on multiple access techniques orthogonal and non-orthogonal is presented in this paper. Non-orthogonal multiple access schemes that can support all defined use cases are presented, and our research found that combining different schemes can support better in terms of spectrum efficiency, latency, and accommodating a greater number of users, which will be the focus of our future work.

REFERENCES

1. Manel Rebhi1, Kais Hassan, Kosai Raoof, and Pascal Chargé, “Sparse Code Multiple Access: Potentials and Challenges”, IEE COMSOC, Date of publication 17 May 2021, Date of publication 17 May 2021, VOLUME 2, 2021, PP 1205 – 1238.
2. https://www.itu.int/dms_pub/itu-r/opb/hdb/R-HDB-60-2003-PDF-E.pdf
3. Shinsuke Hara and Ramjee Prasad, “Overview of Multicarrier CDMA”, IEEE Communications Magazine December 1997, 0163-6804/97/$10.00 0 1997 IEEE
4. Sari H. (2002) A Review of Multicarrier CDMA. In: Fazel K., Kaiser S. (eds) Multi-Carrier Spread-Spectrum & Related Topics. Springer, Boston, MA. https://doi.org/10.1007/978-1-4757-3569-7_1
5. Jean-François Hélard, Jean-Yves Baudais, Jean-Michel Auffray. Multicarrier CDMA: A very promising multiple access scheme for future wideband wireless networks. European Workshop on Integrated Radio Communication Systems, May 2002, Angers, France. ffhal-00283645f.
6. https://www.tutorialspoint.com/cdma/cdma_useful_resources.htm
7. Saimoon Ara Amin, Md.Mahbubul Alam Rafe, Satya Majumder, “Performance Analysis of Multi-carrier DS-CDMA Wireless Communication Systems”, DOI: 10.1109/EMS.2009.95 · Source: IEEE Xplore.
8. Yucong Gu, Domng Ming Chuang, “Multi Carrier CDMA Communication System Design”, University of Texas Austin documents, may 1998
9. Yu-Chieh Cheng, Chin-Kuo Jao, and Shyue-Win Wei, “Spreading Code Allocation for Downlink MC-CDMA”, 978-1-4244-2075-9/08/$25.00 ©2008 IEEE
10. Heidi Steendam and Marc Moeneclaey, “Comparison of the sensitivities of MC-CDMA and MC-DS-CDMA to carrier frequency offset”, February 2000, DOI: 10.1109/SCVT.2000.923358 · Source: IEEE Xplore

11. Chang-Yi Yang and Bor-Sen Chen, “Robust MC-CDMA Channel Tracking for Fast Time-Varying Multipath Fading Channel”, IEEE transactions on vehicular technology, vol. 59, NO. 9, November 2010, 0018-9545/$26.00 © 2010 IEEE.
12. Wei Yang, Junying Liu1, Junshi Chen, Zhenhui Tan1andShixin Cheng, “Performance Analysis of MT-CDMA System with Antenna Arrayin a Multipath Fading Channel”, Wireless Personal Communications (2007) 41:427–446DOI 10.1007/s11277-006-9151-5.
13. José J. Escudero-Garzás, Máximo M. Céspedes, “Orthogonal Multiple Access”, Orthogonal Multiple Access, Wiley Online Library, January 2021.
14. Muhammad Hussain and Haroon Rasheed, “Nonorthogonal Multiple Access for Next-Generation Mobile Networks: A Technical Aspect for Research Direction”, Hindawi Wireless Communications and Mobile Computing Volume 2020, Article ID 8845371, 17 pages.
15. Rukhsana Ruby, Derrick Wing Kwan Ng, Victor C.M. Leung and Taneli Riihonen, “Non-Orthogonal Multiple Access Techniques in Emerging Wireless Systems”, Springer Open.
16. Quazi Mehbubar Rahman, and Abu B. Sesay, “Performance of MT-CDMA System with Post-Detection Diversity Reception over Rician Fading Channel”, academia.edu.
17. Kassir, R. A. Dziyauddin, H. M. Kaidi and M. A. Mohd Izhar, "Power Domain Non Orthogonal Multiple Access: A Review," *2018 2nd International Conference on Telematics and Future Generation Networks (TAFGEN)*, 2018, pp. 66-71, doi: 10.1109/TAFGEN.2018.8580477.
18. Mahrukh Liaqat, Kamarul Ariffin Noordin, Tarik Abdul Latef & Kaharudin Dimyati, “Power-domain non orthogonal multiple access (PD-NOMA) in cooperative networks: an overview”, Springer, July 30, 2018.
19. Zeyad Elsaraf, Faheem Khan, and Qasim Ahmed,” Performance Analysis of Code-Domain NOMA in 5G Communication Systems”, Emerging Technology Conference, ISBN (Print) 9780993342646, 11 Apr 2019.
20. Elsaraf, Zeyad & Khan, Faheem & Ahmed, Qasim. (2019). Performance Analysis of Code-Domain NOMA in 5G Communication Systems, Proceedings of the 2019 EMerging Technology Conference (EMiT 2019), ISBN: 9780993342646, 11 Apr 2019.
21. Al-Imari, M. and Imran, M. A. (2018) Low density spreading multiple access. In: Vaezi, M., Ding, Z. and Poor, H. V. (eds.) Multiple Access Techniques for 5G Wireless Networks and Beyond. Springer: Cham, pp. 493- Ibikunle 514. ISBN 9783319920894 (doi:10.1007/978-3-319-92090-0_15)
22. Linglong Dai, Bichai Wang, Yifei Yuan, Shuangfeng Han, Chih-Lin I, and Zhaocheng Wang, “Non-Orthogonal Multiple Access for 5G: Solutions, Challenges, Opportunities, and Future Research Trends”, 0163-6804/15/$25.00 © 2015 IEEE IEEE Communications Magazine • September 2015
23. Tao Yunzheng, Liu Long, Liu Shang, Zhang Zhi1,” A Survey: Several Technologies of Non-orthogonal Transmission for 5G, China Communications · October 2015 DOI: 10.1109/CC.2015.7315054
24. Yuan, Zhifeng, et al. "Multi-user shared access for internet of things." 2016 IEEE 83rd Vehicular Technology Conference (VTC Spring). IEEE, 2016.*
25. Dai, Xiaoming & Chen, Shanzhi & Sun, Shaohui & Kang, Shaoli & Wang, Yinmin & Shen, Zukang & Xu, Jin. (2015). Successive interference cancelation amenable multiple access (SAMA) for future wireless communications. 2014 IEEE International Conference on Communication Systems, IEEE ICCS 2014. 222-226. 10.1109/ICCS.2014.7024798.

26. Mai T. P. Le, Guido Carlo Ferrante, Giuseppe Caso, Luca De Nardis, Maria-Gabriella Di Benedetto," On information-theoretic limits of codedomain NOMA for 5G", IET Communications Special Issue: Recent Advances on 5G Communications, n 13th August 2018 doi: 10.1049/iet-com.2018.5241, ISSN 1751-8628
27. Ziyang Li and Wen Chen," Sparse Code Multiple Access", https://wnt.sjtu.edu.cn/papers/liziyang-scma.pdf
28. Moltafet, Mohammad, et al. "A new multiple access technique for 5G: Power domain sparse code multiple access (PSMA)." IEEE Access 6 (2017): 747-759.
29. Liaqat, Mahrukh, et al. "Power-domain non orthogonal multiple access (PD-NOMA) in cooperative networks: an overview." Wireless Networks 26.1 (2020): 181-203.
30. Mathur, Harshita, and T. Deepa. "A Survey on Advanced Multiple Access Techniques for 5G and Beyond Wireless Communications." Wireless Personal Communications 118.2 (2021): 1775-1792.
31. Nguyen, Hieu V., et al. "A survey on non-orthogonal multiple access: from the perspective of spectral efficiency and energy efficiency." Energies 13.16 (2020): 4106.
32. Fang, Dong, et al. "Lattice partition multiple access: A new method of downlink non-orthogonal multiuser transmissions." 2016 IEEE global communications conference (GLOBECOM). IEEE, 2016.
33. Mathur, Harshita, and T. Deepa. "A Survey on Advanced Multiple Access Techniques for 5G and Beyond Wireless Communications." *Wireless Personal Communications* 118.2 (2021): 1775-1792.
34. Dai, Xiaoming, et al. "Pattern division multiple access: A new multiple access technology for 5G." IEEE Wireless Communications 25.2 (2018): 54-60.
35. Chen S., Sun S., Kang S., Ren B. (2019) Pattern Division Multiple Access (PDMA). In: Vaezi M., Ding Z., Poor H. (eds) Multiple Access Techniques for 5G Wireless Networks and Beyond. Springer, Cham. https://doi.org/10.1007/978-3-319-92090-0_14
36. Shah, AFM Shahen, et al. "Survey and performance evaluation of multiple access schemes for next-generation wireless communication systems." IEEE Access 9 (2021): 113428-113442.
37. Y. Du, B. Dong, P. Gao, Z. Chen, J. Fang and S. Wang, "Low-Complexity LDS-CDMA Detection Based on Dynamic Factor Graph," 2016 IEEE Globecom Workshops (GC Wkshps), 2016, pp. 1-6, doi: 10.1109/GLOCOMW.2016.7848955.
38. Al-Imari, Mohammed, and Reza Hoshyar. "Reducing the peak to average power ratio of LDS-OFDM signals." 2010 7th International Symposium on Wireless Communication Systems. IEEE, 2010.
39. Okamoto, Eiji, Manabu Mikami, and Hitoshi Yoshino. "Performance comparison of multi-user shared multiple access scheme in uplink channels." IEICE Transactions on Communications 102.8 (2019): 1458-1466.
40. Le, Mai TP, et al. "On information-theoretic limits of code-domain NOMA for 5G." IET Communications 12.15 (2018): 1864-1871.
41. YAN Chunlin, YUAN Zhifeng, LI Weimin, YUAN Yifei. Non-Orthogonal Multiple Access Schemes for 5G[J]. ZTE Communications, 2016, 14(4): 11-16.
42. Ping, Li, et al. "Interleave division multiple-access." IEEE transactions on wireless communications 5.4 (2006): 938-947.
43. Yu, Lisu, et al. "Sparse code multiple access for 6G wireless communication networks: recent advances and future directions." IEEE Communications Standards Magazine (2021).

44. Frank, & Ike, Dike & Jimi, Ajayi & Kayode, Onasoga. (2013). Multiple-Access Technology of Choice In 3GPP LTE. Indonesian Journal of Electrical Engineering and Informatics (IJEEI). 1. 10.11591/ijeei.v1i3.70.
45. Kizilirmak, Refik, "Non-Orthogonal Multiple Access (NOMA) for 5G Networks" In Towards 5G Wireless Networks: A Physical Layer Perspective, edited by Hossein Bizaki. London: IntechOpen, 2016. 10.5772/66048
46. Mahmoud Aldababsa, Mesut Toka, Selahattin Gökçeli, Güneş Karabulut Kurt, Oğuz Kucur, "A Tutorial on Nonorthogonal Multiple Access for 5G and Beyond", Wireless Communications and MobileComputing, vol. 2018, ArticleID 9713450,24 pages, 2018. https://doi.org/10.1155/2018/9713450
47. Duong Hien Thuan, Nhat-Tien Nguyen, Xuan Tien Nguyen, Nguyen Thi Hau, Bui Vu Minh & Tan N. Nguyen (2023) Uplink and downlink of energy harvesting NOMA system: performance analysis, Journal of Information and Telecommunication, DOI: 10.1080/24751839.2023.2260230