Promising Technologies for 5G- A Review

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Abstract- In the past one year or so, discussion related to 5G has evolved into a full-fledged conversation. With the rapid increase in demand for Mobile Internet and Internet of Things (IOT), there is a need for higher spectral efficiency and extensive connectivity. This review paper presents some of the key technologies available for deployment of 5G. The technologies discussed include Millimeter Wave Communications, Massive MIMO, and Non-Orthogonal Multiple Access [NOMA]. Much focus is laid on some promising schemes which fall under a broad category of NOMA, including power domain NOMA, Sparse Code Multiple Access (SCMA),Pattern Division Multiple Access (PDMA), and Multi-User Shared Access (MUSA). Their future research trends and challenges are also discussed in this survey. The article also discusses basic concepts of new waveforms which include Filter-bank Multi-Carrier (FBMC), Universal Filtered Multi-Carrier (UFMC) and Generalized Frequency Division Multiplexing (GFDM). This paper summarizes some exciting developments in these technologies.

Keywords: Non-Orthogonal Multiple Access, Massive MIMO, Millimeter Wave, FBMC, GFDM, UFMC.

I. INTRODUCTION

The arrival of the fifth-generation cellular network raises an important question- Which technology would define 5G? Some of the potential candidates that will address the challenges of 5G are Massive MIMO, Millimeter Wave Communication, Ultra Dense Network and Non-Orthogonal Multiple Access [1]. Out of these, mmWave has already been standardized for short-range services; this paper discusses its potential in 5G.

Requirements of the modern day communication systems include not only higher data rate and better spectral efficiency but also low latency, energy efficiency, massive connectivity and a better user experience [2]. And these challenges are hard to meet with current communication systems. As an example, OFDM (4G) suffers from many setbacks. Some of them are:

1. No flexible use of spectrum resources in OFDM as each sub-carrier must be synchronized and be orthogonal between the sub-carriers. Also, bandwidth must be same for each sub-carrier [3].
2. In the case of lower degree of synchronization, OFDM suffers from substantial inter-carrier interference. This is because OFDM uses square wave as baseband waveform which results in larger side lobes [3], [4].
3. Also, OFDM is not spectrally efficient. The effect of the addition of a long cyclic prefix to combat intersymbol interference results in a loss in throughput of the system.

Thus, to meet the required system throughput for future mobile communication, it becomes necessary to introduce new multiple access scheme. Nevertheless, Non-Orthogonal Multiple Access appears to be a potential candidate for future mobile communications. Several NOMA techniques are discussed in this paper. These techniques are divided into two classes: power domain multiplexing and code domain multiplexing.The paper also discusses potential waveform schemes for 5G air interface which includes Filter-bank based Multicarrier(FBMC), Universal Filtered Multi-Carrier(UFMC), Generalized Frequency Division Multiplexing(GFDM).

The paper is organized as follows: Section II discusses some promising technologies for 5G other than NOMA. Section III surveys various NOMA schemes and their key challenges and solutions are also discussed. Section IV introduces novel waveform modulation schemes for 5G air interface followed by Section V concluding the paper.

II. KEY 5G TECHNOLOGIES

A. Millimeter Wave

To meet the demand for high capacity and high data rate, one of the ways is to use increased channel bandwidth. MmWave frequencies, due to their much smaller wavelength can provide this much-needed jump in bandwidth. The spectral allocations in mmWave are much homogenous as opposed to a current cellular model which employs disjointed spectrum varying widely over three octaves of frequency between 700 MHz and 2.6 GHz [5].

Although mmWavesuffers from many propagation related obstacles, these obstacles seem to be surmountable[6]. For Example- mmWave suffers from a noticeable attenuation over a long distance(15db/km in oxygen absorption band) from atmospheric and rain absorption. However, considering today's cell sizes in urban environments, this problem seems inconsequential as the spacing between

Base stations might be of the order of 200m only[5]. Moreover, the concept that higher frequencies suffer more free space propagation loss is also inconsequential in the case of mm-wave. Since, path loss not only depends on the frequency but also on the effective aperture area. So, for same antenna aperture areas, the free space path loss remains unchanged [6]. So, the propagation properties of mmWave can be exploited to be used in radio service applications. For example- use of absorption band (60Hz) for high data rate point to point systems where secured communication is desirable[7].

Increase in omnidirectional path loss can be compensated by suitable beamforming and directional transmitters[8]. But according to[8] potential millimeter wave cellular systems need to be redesigned, especially the heavy reliance on directional transmission and beamforming will bring about a reconsideration of many basic procedures such as multiple access broadcast signaling, etc.

One of the advantages of mmWave is that it fits perfectly with other available technologies. For example- Massive MIMO can use millimeter wave as the tiny wavelengths allow many antennas to be placed over a small area. On the other hand, mmWave is not energy efficient. Many component electronics like power amplifiers, antennas and particularly A/D converters are big in size and consume too much power[9]. MmWave exhibit low diffraction due to their short wavelengths. Moreover these shorter wavelengths cause the reflecting surface to appear much rougher which results in more diffusion and less specular reflection hence, resulting in less received power at the receiver. Thus, mm-waves are more sensitive to blockages and outage. About this [10], [11] propose an analytical framework to model blocking effects by using random shape theory and evaluate its impact on the performance of mmWave communication systems. [10]proposes a path loss model to capture the effects of Blockage. In [5]extensive measurements are conducted at 28 GHz and 38 GHz to gain insight on propagation characteristics and channel model in the case of mmWave frequency. Studies reveal that reliable coverage can be achieved by mmWave frequency keeping cell radius of 200m.

B. *Massive Mimo*

Massive MIMO, also known as Very Large MIMO, is a multiple antenna technology. Using spatial multiplexing, massive MIMO achieves a very high data rate and a better spectral efficiency which is required by future wireless systems. It uses a very large number of service antennas (example- hundreds of thousands), thereby bringing vast improvements in throughput and energy efficiency. This technology was proposed by Thomas L. Marzetta in the landmark paper [12]. The proposal was to equip base stations with a much larger number of antennas as compared with a number of active users. The paper proposed a time-division duplex cellular system employing base stations equipped with a large number of antennas which serve a smaller number of cheap, single- antenna terminals simultaneously through multi-user MIMO techniques.

Multi-user MIMO with an equal number of service antennas and terminals is not a scalable technology[13]. Massive MIMO overcomes this limitation. In this case, improvements in throughput and energy efficiency result because these extra service antennas help to focus the energy into a much smaller spatial region. Other benefits include: - increased robustness to interference and intentional jamming as massive MIMO provides an excess degree of freedoms that can be used to cancel signals from intentional jammers, use of low cost, low power devices and reduced latency[13], [14].

But for massive MIMO to become reality, it must first be able to overcome many challenges. Some of these difficulties are:-

1. Pilot Contamination: Massive MIMO uses the orthogonal uplink pilot sequence to facilitate cleaner channel estimates. But the number of these pilot sequences is limited by the duration of coherence interval. Thus, this necessitates reusing pilots across cells. The interference resulting from pilots in different cells leads to what is called as pilot contamination. Some methods can help deal with this issue. One is using the optimal strategy for pilot allocation. For example- by using less aggressive reuse factor for pilots[13]. Secondly, by using pilot contamination precoding [15]or by employing low rate coordination between cells during channel estimation phase[16].
2. Signal Processing: With massive MIMO, an enormous amount of data has to be processed in real time. A lot of research for designing optimal algorithms and pre-coding schemes[13]. For example- [17] proposes a novel pre-coding technique (Hermitian pre-coding).

While massive MIMO do project itself as a possible candidate for a 5G communication system, it has uncovered entirely new problems that need to be attended. For example- reducing internal power consumption to attain total energy efficiency, resource allocation for new terminals, production of low –cost, low-power components, antenna array design, reference signal definition, proper acquisition methodology for channel state information etc. Thus, a plenty of research has to be done in the field of Massive MIMO.

III. NON ORTHOGONAL MULTIPLE ACCESS

A. *Power Domain NOMA*

For Future Radio Access (FRA) NOMA presents itself with a promising downlink multiple access scheme. To understand the concept of NOMA, consider a simple model with one BS and two UEs (User Equipment) with single transmit and receive antennas. The transmitted signal is given as [18]

$$x = \sqrt{P_1}\, x_1 + \sqrt{P_2}\, x_2$$

And the received signal at UE_i is given as

$$y_i = h_i x + w_i$$

where P_1 and P2are the power allocated to UE1 and UE2 respectively and w_i is the receiver Gaussian Noise. Therefore, in a power domain NOMA, at the transmitter side, signals from different users are allocated different power levels and then these signals are linearly added or superposed and then transmitted. At the receiver side, multi-user detection is realized based on Successive Interference Cancellation (SIC)[19]. The optimal decoding order is the order of decreasing SINR i.e. at a given user, a user with highest SINR is decoded first and its interference canceled from the desired signal of the given user.

NOMA is a promising candidate for multiple access scheme because of many benefits. For example, increased performance gain as compared to OMA when the difference in channel gain is high[18]. Also, because of significant power difference, successful decoding and hence, successful cancellation can be realized at the receiver side.[18]discusses practical considerations in NOMA, the challenges they pose and their possible solutions. For example, between wide-band and sub-band scheduling, signaling overhead is more in sub-band scheduling and increases with a number of sub-bands. One possible solution for this is to use some wide-band signaling while others can remain sub-band. However, such mismatch doesn't allow full exploitation of NOMA gains and this aspect has to be considered[18].

[18]also compares the performance of NOMA and OMA. With different power allocation scheme with or without user grouping. Three power allocation schemes are considered- FSPA(Full Search Power Allocation), FTPA(Fractional Transmit Power Allocation) and FPA(Fixed per group Power Allocation). Out of these FPA is a simplified transmit power allocation scheme and has less signaling overhead and [18] shows that with FPA, a significant portion of NOMA gains can be maintained.

Foreign researchers have made some achievements about NOMA technology. [20]discusses the potential gains of NOMA over OMA by employing various link adaptation techniques such as AMC, HARQ, and scheduling. According to [20], the system level simulation shows that overall cell throughput, cell-edge throughput and the proportional fairness achieved are all superior in case of NOMA as compared to OMA. The paper attributes this performance to more degrees of freedom available to co-schedule more users in the same sub-band. [21]proposes a new optimized resource allocation scheme which is a new power allocation technique based on water-filling. It also proposes a new hybrid NOMA scheme in which adaptive switching to orthogonal signaling OS is performed if the non-orthogonal cohabitation does not achieve desired goals. [21]shows that combination of NOMA and OS performs better than exclusive NOMA. [22]investigates improved cell-edge user throughput using NOMA with SIC in cellular uplink. [22]paper shows that a higher worst user throughputis achieved with NOMA with SIC that Orthogonal access while maintaining a high total user throughput. The reason for this is that in NOMA, each user can use overall transmission bandwidth unlike that of OMA where each user is provided with restricted orthogonal subbands. Also, according to [22] when a large number of users are accommodated, enhanced user fairness is achieved by using non-orthogonal access with SIC. [23]shows NOMA with SIC in cellular MIMO downlink systems. It proposes intra beam superposition coding for multiple user signals. This is the non-orthogonal user multiplexing. OFDM signaling with a cyclic prefix is used. Different beams in a spatial domain are formed by multiple transmit antennas, and each beam exploits non-orthogonal access scheme. At the receiver side, inter-beam interference is canceled using spatial filtering and then the SIC is employed to remove intra beam interference or inter-user interference. This scheme improves spectral efficiency and achieves better sum and cell-edge user throughput[23].

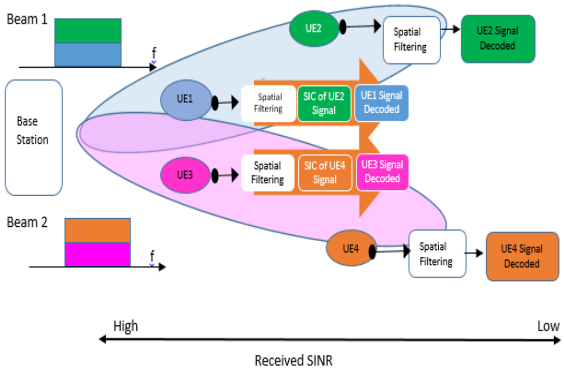

Fig 1 NOMA with MU-MIMO

A lot of research has been done to clearly clarify the advantage NOMA has over OMA. For example, [24] compares NOMA with Closed Loop (CL) SU-MIMO (Single User- Multiple Input and Multiple Output) with OMA with CL SU-MIMO. [24]explains system and signal model of NOMA with CL SU-MIMO. The article discusses two things: One is to clarify the gains of NOMA with CL SU-MIMO over OMA with CL SU-MIMO considering the practical aspects like Error Propagation (EP) and user velocity, The article introduces two different error propagation models – a worst case model and a realistic model.

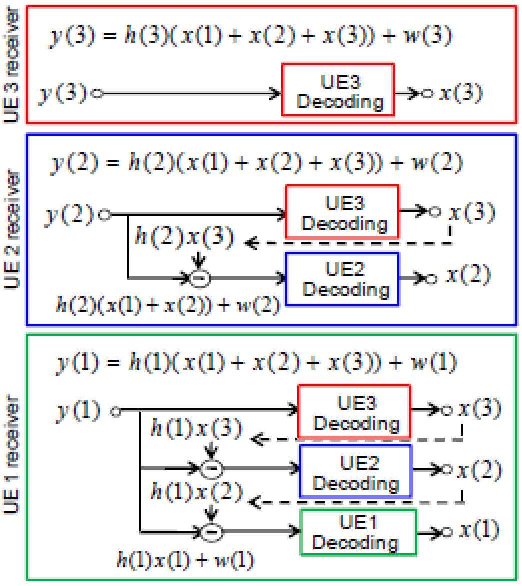

Fig 2 Illustration of UE receivers for 3-user NOMA case (Channel gain order: UE1>UE2>UE3) [20]

The cell coverage and cell edge throughputs are compared for these tw EP models. The simulation results in [24] show that NOMA with CL SU-MIMO performs better as compared to OMA with CL SU-MIMO. Also, considering the impact of user velocity, NOMA with CL SU-MIMO has much better performance gain than OMA with CL SU-MIMO and in fact, this performance gain increases with user velocity.

B. *Sparse Code Multiple Access (SCMA)*

Low-Density Signature (LDS) [25]uses a few number of non-zero elements within a large signature length and is one of the unique and novel approaches to CDMA sequence design. SCMA is a non-orthogonal code domain multiple access based on LDS-CDMA, which can improve the spectral efficiency of wireless radio access. Here, the process of the bit to QAM mapping and spreading is combined, and the incoming bits are mapped from binary domain to multi– dimensional complexdomain using a complex vector called as codeword[26]. Each layer or user is givena unique codebook which contains M codewords, and each of these M codewords are mapped to length N constellations[27].

The difference between LDS-CDMA and SCMA is that SCMA has the advantage of constellation shaping gain as it uses multi-dimensional codeword modulation technique in comparison to mere repetition of QAM symbols in LDS[26]. Similar to LDS-CDMA, SCMA takes advantage of near optimal message passing algorithm (MPA) based receiver with practically feasible complexity[26].

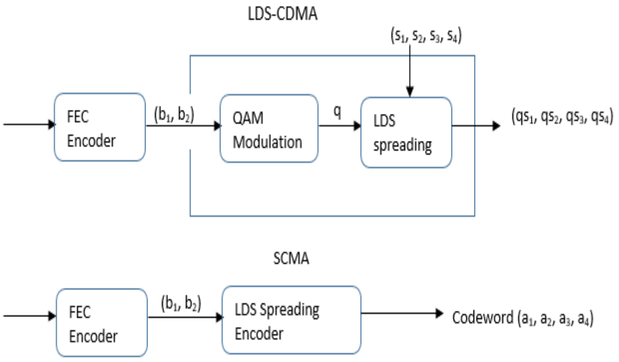

Fig 3 Merging of QAM modulator and spreading in SCMA

Because of this low complexity detection, system overloading can be realized. System overloading occurs when the number of multiplexed layers is more than the dimension of codewords. By multiplexing M codewords from codebooks over J resources, the overloading factor is defined as –

$$OF= M/J$$

By adjusting the spreading factor J and the number of non-zero entities, different levels of overloading can be achieved with a different number of codebooks[28]. [29]develops a technique to enable multi-user SCMA (MU-SCMA) to improve network throughput in the downlink. This open loop multiple access scheme is more robust to channel variations, and the problem of CSI feedback is entirely removed. [29]designs user pairing, power sharing, rate adjustment, and scheduling algorithm to improve the downlink throughput. It shows that the throughput and coverage gains of MU-SCMA over OFDMA are 28% and 36% respectively. This gainis attributed to multi-dimensional shaping gain, flexible link adaptation, and robustness of open loop MU-SCMA against channel variation.

Issues arising due to massive connectivity are- Excessive signaling overhead and latency. [28]proposes a solution to this problem. An uplink contention-based SCMA to reduce the latency and signaling overhead in uplink. Contention based data transmission can be used and thus request- grant procedure is not required but in the case of CB-OFDMA/SC-FDMA, once the load on the system increases with more active users, data transmission suffers significant performance degradation due to the non-orthogonal collision of arriving signals at the receiver. Proposed CB-SCMA addresses this issue by taking into account overloading and non-orthogonality. [28]shows that packet drop rate performance degrades much faster with load increase than SCMA. SCMA is compared with OFDMA, and the paper shows that CB-SCMA has 2.8 times gain over CB-OFDMA regarding supported users. User collision happens only if two or more users pick the same pilot sequence within a contention region. These pilot collisions can be resolved using random back-off mechanism.

In [30], an uplink SCMA system is used which employs iterative multiuser receiver. The article claims that with this proposed iterative receiver, the performance gain increases as compared to non-iterative one. The simulation results shown by the paper show that SCMA works extremely well in overloaded scenario and even at the load as high as 300%, the performance does not degrade.[30]starts with describing the system model of MU-SCMA and then followed by detailed exposition of iterative multi-user receiver. Also, simulation results show that "number of iterations leverages the tradeoff between computational complexity and system performance." [30]

[31]proposes a novel solution called blind detection in SCMA based uplink grant free multiple access to support massive connectivity. The proposed solution involves two components: a) Blind Detection of active users and b) Blind Decoding of active users without having the knowledge of active codebook set. The proposed receiver consists of two major components. A) active UE detector, to narrow down the list of potential active UEs and b) Joint Data and Active Codebook(JMPA) detection to decode active users data without no knowledge of active codebooks. The paper shows that the proposed active UE detection scheme in conjunction with blind detection capability of JMPA paves the way of designing a grant free system for massive connectivity in uplink multiple access system.

The SCMA codebook design is an involved problem as multiple layers or users are multiplexed with different codebooks. [26]and [32] propose a suboptimalmulti-stage approach for SCMA codebook design. One issue related to OFDMA is its high Peak- to- Average Power Ratio (PAPR). SCMA codewords are transmitted on OFDMA tones. Therefore, this problem of high PAPR can pass on to SCMA-OFDM transmission. By following codebook design method introduced in [32] one can achieve low PAPR in SCMA-OFDM transmission. This is comparable to low PAPR of SC-FDMA. As mentioned before, one of the important requirements of future cellular wireless communication system is how energy efficient a particular technology is. [33]analyses the energy efficiency in faded environment of SCMA scheme in uplink by proposing a unified framework. The article defines the term aggregate energy efficiency (EE) for multiple access as "sum throughput of all uplink users over total power consumption in multiple access scheme" [33]. The simulation results in this paper compare the average aggregate EE performance of SCMA over LTE systems. The results show that LTE-A performs better if the number of users in SCMA and LTE-A systems are equal, because of the orthogonal transmission in LTE-A. But, as extra users are added, the average aggregate EE improves in SCMA and is better compared to LTE-A. The article [33]also proposes a very low complexity decoding algorithm called as Logarithm-domain MPA (Message Passing Algorithm) decoding. The article points out many shortcomings of MPA algorithm used in conventional SCMA. For example, huge look up table is required in MPA for efficient computation. Also, since MPA uses exponential function, the dynamic range becomes quite high and thus complex hardware is required to incorporate such dynamic range. Moreover, as pointed out by [33] extensive multiplications are used in each message passing process, thus increasing the computational time. Therefore, the article proposes log-MPA. The results in the paper show more than 50% reduction in decoding complexity with log -MPA as log-MPA eliminates the exponent calculations and saves more than 90% multiplication and increases the number of addition operations [33]

C. Multiple User Shared Access (MUSA)

MUSA is a multiple access scheme, which was proposed by ZTE and is implemented in the code domain. It uses low cross- correlation spreading sequences to realize overloading at the transmitter. At receiver, it uses advanced SIC, particularly codeword- level SIC. SIC separates superimposed symbols on the basis of received signal to interference-plus-noise ratio (SINR) difference thereby, recovering the data of each user at receiving end. Thus, the difference between traditional CDMA and MUSA is that the spreading sequence assigned in MUSA can be non-orthogonal. Each user is assigned a new spreading sequence, and all the users share same orthogonal time-frequency resources. Also, the difference between MUSA and MC-CDMA is that MUSA doesn't need synchronization when user signals arrive at the BS. This ensures good battery life and lesser complexity of SIC receiver[34].

In the downlink, MUSA uses a newtype of superposition coding[3]. These codes are used in such a way so as to ensure Gray Mapping in combined constellation of superposed signals [34]. MUSA seems to be a potential candidate of multiple access scheme in future radio access. However, a lot of research is required in this field. A lot of key technologies used by MUSA are unanswered like pattern selection, mapping method of low correlation spreading sequences, the potential of MUSA to achieve massive connectivity etc. These are some areas which need to be researchedthoroughly, and experiments should be performed to compare MUSA with other NOMA schemes.

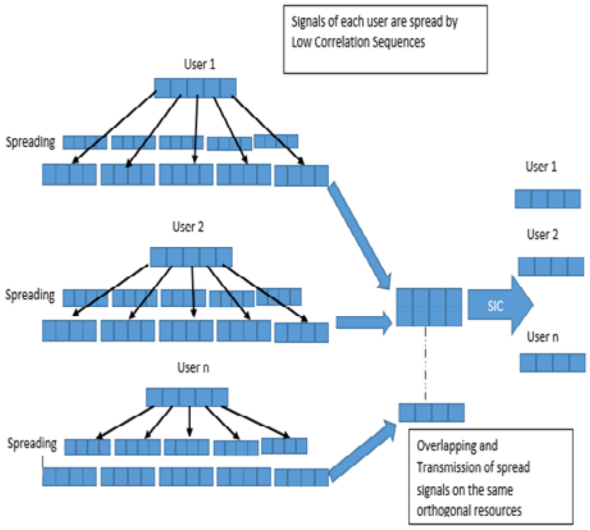

Fig 4 Multi-User Shared Access

D. Pattern Division Multiple Access (PDMA)

PDMA is a non-orthogonal multiple access technology based on total optimization of multiple user communication systems[3], [35]. It is based on joint/holistic design approach of both transmitter and receiver. At the transmitter, PDMA uses SIC amenable non-orthogonal patterns to achieve maximum diversity and minimum overlaps. At receiver, low complexity quasi-ML SIC detection technique is used, and MPA is performed for interference cancellation and separates signals from different users. At the transmitter, to achieve multiplexing, the non-orthogonal patterns can be realized either in code domain, space domain or power domain or a combination of these. This allows high flexibility for coding and decoding processing. PDMA can increase spectral efficiency above 1-2 times in system, can achieve low power consumption and is capable of reducing co-channel interference.

[36]shows the implementation of PDMA in the code domain. The paper identifies the difference between MUSA and code domain PDMA. It says that the non-zero elements in any spreading sequence are equal to 1 in code domain PDMA.

[35]presents design and optimization of PDMA in both power and spatial domain. In power domain PDMA, different proportions of powerare assigned to each user and multiple users share the whole or part of the frequency resource. In spatial domain PDMA, multiple antennas at BS are used, thus providing diversity which is preferred for macrocell deployment. Moreover, Spatial PDMA scores over MU-MIMO as no joint precoding is required in PDMA to realize spatial orthogonality and this reduces the complexity at the transmitter. The paper also shows how multi-user scheduling can be performed with PDMA and presents multi-user power allocation schemes for power domain PDMA. Of course, scheduling guidelines are to be kept in mind to ensure user fairness and systems throughput. Thus, this area is open to a lot of research. Numerical results show that the PDMA system based on SIC improves the average sum rate of users over the orthogonal system with affordable complexity[35]. PDMA still faces some key technical challenges, and they need to be researched and solved for future applications. One of such challenge is in power domain PDMA. Full Search Power Assignment(FSPA), Fixed Transmission Power Assignment, Fractional Transmission Power Assignment(FTPA) are available power allocation methods. But research is to be performed to determine the best among these which can provide maximum throughput and user fairness. Other technical areas include combining PDMA with MIMO, a proper strategy to design patterns at the transmitter so that more users are distinguished easily, practical performance of the receiver in case of PDMA and complexity evaluation of receiver.

IV. NEW WAVEFORMS

With the advent of IOT and Mobile Internet, OFDM seems to fall short in meeting their requirements. While OFDM has many excellent aspects, it faces some serious issues that render it unattractive for a future cellular communication system. This section gives a brief review of some interesting waveform candidates and the issues these face.

A. Filter Bank Multi-Carrier Modulation (FBMC)

Up until now, OFDM has been the most famous multi-carrier modulation technique of broadband communication system. FBMC, also called as Staggered Modulated Multitone (SMT) addresses some of the shortcomings of OFDM at the price of increased implementation complexity[37]. FBMC is an enhancement of OFDM with a difference that in FBMC, the IFFT block is followed by a set of digital filters (a polyphase network) while in OFDM, IFFT block is followed by a cyclic prefix module[38]. The motivation for FBMC comes from shortcomings in OFDM. One, OFDM suffers from spectral leakage because each subcarrier in OFDM is shaped using a rectangular window in time domain leading to sinc shaped subcarrier in the frequency domain and so large side lobes occur which introduce inter-carrier interference[39]. Moreover, the absence of cyclic prefix yields an improved data rate. Hence, FBMC applies filtering to each sub-carrier, thereby weakening the side lobes. Also, OFDM requires perfect frequency synchronization and a very tight time alignment. But FBMC no longer requires the subcarriers to be orthogonal and thus solves the problem of synchronization.

There is a Saltzberg method for FBMC. It says that by introducing a shift of half the symbol period between the in-phase and quadrature components of QAM symbols, it is possible to achieve baud rate spacing between adjacent sub-carrier channels and still recover the information symbol free ofintersymbol interference and intercarrier interference. Thus, each sub-carrier is modulated with an offset QAM, and the orthogonality condition is considered only in the real field. Indeed, the data rate at the receiver side is carried only by the real (or imaginary components) of the signal, and the imaginary (or real) part appear as interference terms. As far as modulation is concerned, signal separation is achieved by using the real input for a given sub-channel and the imaginary input for the neighbors or vice-versa. Then, the maximum rate is obtained by offset-QAM. While in QAM modulation, the real and the imaginary parts of a complex data element are transmitted simultaneously but in OQAM modulation, a delay of half a symbol duration is introduced between them. As a result, IFFT is simple to realize but the rate is doubled, and the two Poly Phase Network sections are needed.

For FBMC to be suitable for MIMO, [40]suggests an FBMC system based on QAM. FBMC-OQAM can protect against intrinsic interference. But this is not suitable for MIMO as it requires a complex procedure to remove the intrinsic interference. Therefore, FBMC-QAM is proposed for MIMO. The proposed system utilizes two different filters- even, and odd filters, and the problem of intrinsic interference is overcome by using orthogonality between even and odd filters. The results show that despite the advantage that this system can be easily applied to MIMO, FBMC-QAM with two filters is more sensitive to Time Offset(TO) as compared to FBMC-OQAM but is more robust to Carrier Frequency Offset(CFO) in comparison to FBMC-OQAM.

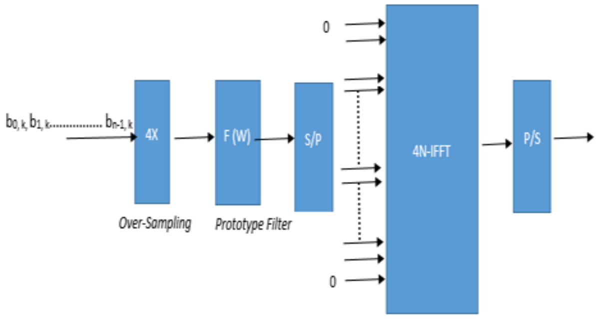

Fig 6 FBMC Waveform Synthesis [27]

[41]shows that FBMC system carries more data than OFDM in a specified burst length. [37]discusses the advantages and challenges of FBMC. While the benefits include spectrum efficiency, robustness to narrowband jammers and efficient spectrum sensing, FBMC suffers from many problems like the implementation of FBMC is complex as compared to OFDM and development of MIMO-FBMC is difficult and limited.

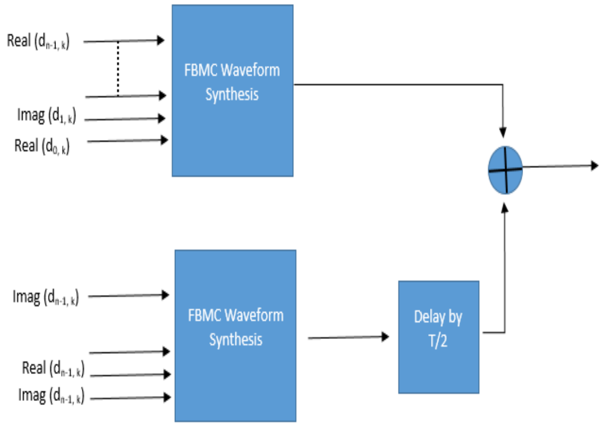

Fig 7 FBMC/OQAM Transmitter[27]

B. *Universal-Filtered Multi-Carrier (UFMC)*

[42]proposes a multi-carrier transmission scheme to overcome the inter-carrier interference problem in OFDM. The paper considers coordinated multi-point (CoMP) reception technique and examines the impact of Carrier Frequency Offset (CFO) on the performance of proposed scheme. The results indicate that UFMC outperforms OFDM and is a promising candidate for future 5G wireless systems.

In this era of IOT and machine to machine communication, relaxed synchronicity will reduce the painful overhead for a large number of devices. Additionally, since oscillator requirements will be relaxed, low-end devices can be made cheaper[43]. The drawback of FBMC is that since FBMC applies filtering on a per sub-carrier, it requires a rather tight frequency response of the filter and thus very long filter lengths. Thus, short burst emissions are inefficient due to filter ramp up and ramp down time[39], [43].

Moreover, FBMC is not compatible with all kinds of MIMO techniques due to the use of OQAM. Also, SMT (FBMC) is non-orthogonal in a complex plain. Hence, there is interference in each sub-carrier from the neighboring sub-carrier. This poses a difficulty for channel estimation. Althoughauxiliary pilot principle can be applied for this purpose, this is not an energy efficientprinciple[39]. Thus, we need to define a new waveform technique. In UFMC, few consecutive sub-carriers are packed in a group called ‘sub-band’ and filtering is applied to each sub-band i.e. block- wise filtering is used. This brings additional flexibility. Here, filters are spectrally broader than FBMC, thus are shorter in time. Hence, the short burst will be well supported in UFMC. Sidelobe suppression now works in between resource blocks. Also, UFMC is orthogonal in complex plain[39].

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[44]evaluates the performance of UFMC in scenarios of relaxed synchronization. The paper also introduces the concept of autonomous timing advance (ATA). Based on simple methods, the devices can coarsely adjust their timings improving the MSE performance of UFMC systems.

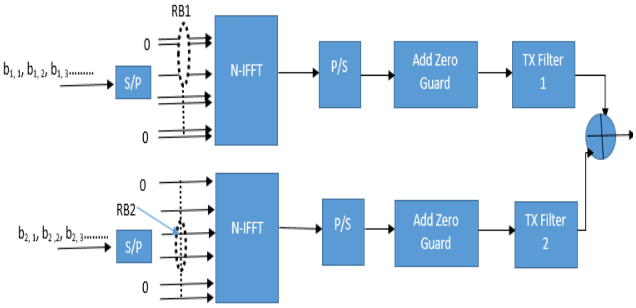

Fig 8 UFMC Transmitter[27]

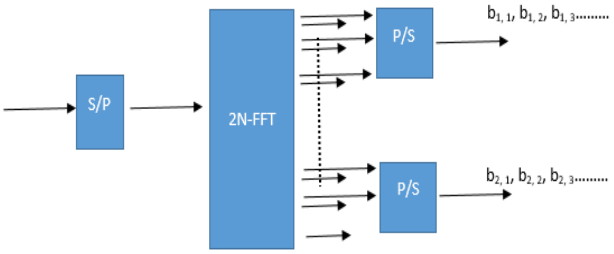

Fig 9 UFMC Receiver [27]

C. *Generalized Frequency Division Multiplexing (GFDM)*

GFDM was proposed by Vodafone Chair Mobile Communication systems. It allows flexible pulse shaping for individual sub-carriers thus, replacing linear filtering with a circular one. The flexibility is offered by ordering data in a two-dimensional time-frequency block structure[45]. Of course, this additional flexibility comes at a cost of loss of orthogonality of subcarriers which introduces self-created inter-symbol interference and inter-carrier interference. In GFDM, multiple OFDM symbols are grouped together in a block, and a Cyclic Prefix(CP) is added to this block[27]. Each OFDM symbol in a block is filtered with a prototype filter which is 'cyclic-shift' in time and frequency domain. Here, the advantage is that the overhead is small because a single CP is used for the entire block. This improves the spectral efficiency of the system.

But GFDM has some attractive features over OFDM such as low PAPR, lower out of band leakage and more suitable for cognitive radio waveform. Also, FBMC suffers from synchronization issues between the sub-carrier. GFDM overcomes this problem by introducing a tail biting cyclic prefix. Though GFDM carries many advantages, it suffers from many issues. In GFDM, simple interference cancellation cannot efficiently improve receiver performance. Complex receiver to handle ISI/ICI is required. Prototype filters requirecomplex modulation, for example- OQAM as in FBMC[27]. Also, there is no pipelining i.e. higher latency is involved in block processing.

[46]shows experimental validation of GFDM as a Cognitive Radio Waveform. The experiments conducted show that GFDM is more spectrally efficient and has improved sensing performance as compared to OFDM. [47]describes the concepts of MIMO-GFDM to achieve diversity. The paper shows how space-time coding can be effectively combined with GFDM to achieve transmit and receive diversity.

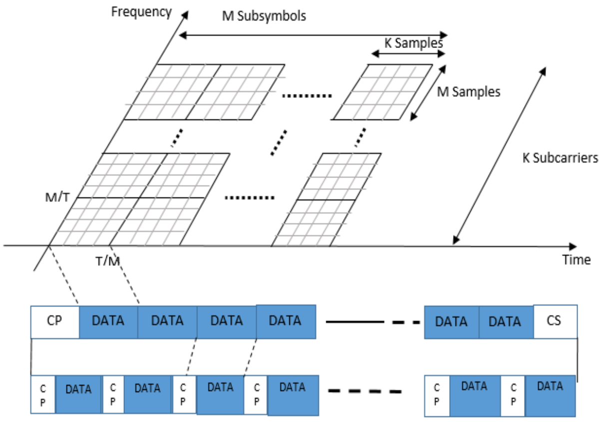

Fig 10 GFDM [27]

V. CONCLUSION

4G is reaching its maturity where the only small amount of improvements can be expected. Thus, the capabilities of future mobile communication systems must extend beyond those of the previous generation. In this paper, we discussed and compared various promising technologies available for 5th Generation Cellular Communication Systems. We analyzed how demands of massive connectivity, spectral efficiency, high data rate, low latency, energy efficiency, and high reliability can be realized by these technologies and what research areas are open so as to overcome the shortcomings of these schemes. The paper also compares new multi-carrier modulation waveforms FBMC, UFMC, and GFDM. It has been shown by various studies how these waveforms are a better option than widely recognized OFDM. As this paper has noted, there is a long road ahead towards disruptive 5G networks to become a reality.

REFERENCES

[1] F. Boccardi, A. Lozano, U. P. Fabra, T. L. Marzetta, and B. Labs, “Five disruptive technology directions for 5G,” *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 74–80, 2014.

[2] S. Chen and J. Zhao, “The Requirements , Challenges , and Technologies for 5G of Terrestrial Mobile Telecommunication,” *IEEE Commun. Mag.*, vol. 52, no. 5, pp. 36–43, 2014.

[3] Z. Z. Tao Yunzheng, Liu Long, Liu Shang, “A Survey: Several Technologies of Non-Orthogonal Transmission for 5G,” *China Commun.*, 2015.

[4] F. Schaich and T. Wild, “Waveform contenders for 5G - OFDM vs. FBMC vs. UFMC,” *ISCCSP 2014 - 2014 6th Int. Symp. Commun. Control Signal Process. Proc.*, pp. 457–460, 2014.

[5] T. S. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. N. Wong, J. K. Schulz, M. Samimi, and F. Gutierrez, “Millimeter wave mobile communications for 5G cellular: It will work!,” *IEEE Access*, vol. 1, pp. 335–349, 2013.

[6] J. G. J. G. Andrews, S. Buzzi, W. Choi, S. V. S. V. Hanly, A. Lozano, A. C. K. A. C. K. Soong, and J. C. J. C. Zhang, “What will 5G be?,” *IEEE J. Sel. Areas Commun.*, vol. 32, no. 6, pp. 1065–1082, 2014.

[7] B. Pattan and M. Marcus, “Millimeter Wave Propagation: Spectrum Management Implications,” *IEEE Microw. Mag.*, no. 70, pp. 54–62, 2005.

[8] S. Rangan, T. S. Rappaport, and E. Erkip, “Millimeter-Wave Cellular Wireless Networks: Potentials and Challenges,” *Proc. Ieee*, vol. 102, no. 3, pp. 366–385, 2014.

[9] F. K. Zhouyue Pi, “An Introduction to Millimeter-Wave Mobile Broadband Systems,” *IEEE Commun. Mag.*, vol. 49, no. June, pp. 101–107, 2011.

[10] T. Bai, R. Vaze, and R. W. Heath, “Analysis of blockage effects on urban cellular networks,” *IEEE Trans. Wirel. Commun.*, vol. 13, no. 9, pp. 5070–5083, 2014.

[11] T. Bai and R. W. Heath, “Coverage analysis for millimeter wave cellular networks with blockage effects,” in *2013 IEEE Global Conference on Signal and Information Processing, GlobalSIP 2013*, 2013, pp. 727–730.

[12] T. L. Marzetta, “Noncooperative cellular wireless with unlimited number of base station antennas,” *{IEEE} Trans. Wirel. Commununications*, vol. 9, no. 11, pp. 3590–3600, 2010.

[13] E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, “Massive MIMO for Next Generation Wireless Systems,” *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 186 – 195, 2014.

[14] “https://massivemimo.eu.” [Online]. Available: https://massivemimo.eu.

[15] A. Ashikhmin and T. Marzetta, “Pilot contamination precoding in multi-cell large scale antenna systems,” *IEEE Int. Symp. Inf. Theory - Proc.*, pp. 1137–1141, 2012.

[16] H. Yin, D. Gesbert, M. Filippou, and Y. Liu, “A coordinated approach to channel estimation in large-scale multiple-antenna systems,” *IEEE J. Sel. Areas Commun.*, vol. 31, no. 2, pp. 264–273, 2013.

[17] J. Zhang, X. Yuan, and L. Ping, “Hermitian Precoding for Distributed MIMO Systems,” *Inf. Theory Proc. (ISIT), 2012 IEEE Int. Symp.*, pp. 2281–2285, 2012.

[18] A. Benjebbour, Y. Saito, Y. Kishiyama, A. Li, A. Harada, and T. Nakamura, “Concept and Practical Considerations of Non-orthogonal Multiple Access (NOMA) for Future Radio Access,” *Intell. Signal Process. Commun. Syst. (ISPACS), 2013 Int. Symp.*, pp. 770 – 774, 2013.

[19] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li, and K. Higuchi, “Non-orthogonal multiple access (NOMA) for cellular future radio access,” *IEEE Veh. Technol. Conf.*, pp. 0–4, 2013.

[20] Y. Saito, A. Benjebbour, Y. Kishiyama, and T. Nakamura, “System-Level Performance Evaluation of Downlink Non-orthogonal Multiple Access (NOMA),” vol. 2, pp. 2–6.

[21] M. R. Hojeij, J. Farah, C. A. Nour, and C. Douillard, “Resource Allocation in Downlink Non - orthogonal Multiple Access (NOMA) for Future Radio Access,” *2015 IEEE 81st Veh. Technol. Conf. (VTC Spring)*, pp. 1–6, 2015.

[22] T. Takeda and K. Higuchi, “Enhanced User Fairness Using Non-orthogonal Access with SIC in Cellular Uplink,” pp. 3–8, 2011.

[23] K. Higuchi and Y. Kishiyama, “Non-orthogonal access with random beamforming and intra-beam SIC for cellular MIMO downlink,” *IEEE Veh. Technol. Conf.*, pp. 1–5, 2013.

[24] X. Chen, A. Benjebboui, Y. Lan, A. Li, and H. Jiang, “Considerations on Downlink Non-Orthogonal Multiple Access (NOMA) Combined with Closed- loop SU-MIMO,” *Signal Process. Commun. Syst. (ICSPCS), 2014 8th Int. Conf.*, pp. 1–5, 2014.

[25] R. Hoshyar, F. P. Wathan, and R. Tafazolli, “Novel low-density signature for synchronous CDMA systems over AWGN channel,” *IEEE Trans. Signal Process.*, vol. 56, no. 4, pp. 1616–1626, 2008.

[26] H. Nikopour and H. Baligh, “Sparse code multiple access,” *IEEE Int. Symp. Pers. Indoor Mob. Radio Commun. PIMRC*, pp. 332–336, 2013.

[27] Q. Technologies, “5G Waveform & Multiple Access Techniques,” 2015.

[28] K. Au, L. Zhang, H. Nikopour, E. Yi, and A. Bayesteh,

"Uplink Contention Based SCMA for 5G Radio Access," *2014 IEEE Globecom Work. (GC Wkshps)*, pp. 900 – 905, 2014.

[29] H. Nikopour, E. Yi, A. Bayesteh, K. Au, M. Hawryluck, H. Baligh, and J. Ma, "SCMA for downlink multiple access of 5G wireless networks," *2014 IEEE Glob. Commun. Conf. GLOBECOM 2014*, pp. 3940–3945, 2014.

[30] Y. Wu, S. Zhang, and Y. Chen, "Iterative multiuser receiver in sparse code multiple access systems," *IEEE Int. Conf. Commun.*, vol. 2015-Septe, pp. 2918–2923, 2015.

[31] A. Bayesteh, E. Yi, H. Nikopour, and H. Baligh, "Blind detection of SCMA for uplink grant-free multiple-access," *2014 11th Int. Symp. Wirel. Commun. Syst. ISWCS 2014 - Proc.*, pp. 853–857, 2014.

[32] M. Taherzadeh, H. Nikopour, A. Bayesteh, and H. Baligh, "SCMA codebook design," *IEEE Veh. Technol. Conf.*, 2014.

[33] S. Zhang, X. Xu, L. Lu, Y. Wu, G. He, and Y. Chen, "Sparse code multiple access: An energy efficient uplink approach for 5G wireless systems," in *2014 IEEE Global Communications Conference, GLOBECOM 2014*, 2014, pp. 4782–4787.

[34] L. Dai, B. Wang, Y. Yuan, S. Han, C. I, and Z. Wang, "Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends," *IEEE Commun. Mag.*, vol. 53, no. 9, pp. 74–81, 2015.

[35] J. Zeng, B. Li, X. Su, L. Rong, and R. Xing, "Pattern Division Multiple Access (PDMA) for Cellular Future Radio Access," *Wirel. Commun. Signal Process. (WCSP), 2015 Int. Conf.*, vol. 1, no. c, pp. 1–5, 2015.

[36] B. Wang, K. Wang, Z. Lu, T. Xie, and J. Quan, "Comparison Study of Non-Orthogonal Multiple Access Schemes for 5G," *2015 IEEE Int. Symp. Broadband Multimed. Syst. Broadcast.*, pp. 1–5, 2015.

[37] B. D. Tensubam, "A Review on FBMC : An Efficient Multicarrier Modulation System," vol. 98, no. 17, pp. 6–9, 2014.

[38] H. Jamal, S. A. Ghorashi, S. M.-S. Sadough, and N. Soltani, "Uplink resource allocation for cognitive radio systems: QAM-OFDM or OQAM-OFDM?," *6th Int. Symp. Telecommun.*, pp. 188–193, 2012.

[39] F. Schaich, T. Wild, and Y. Chen, "Waveform contenders for 5G - Suitability for short packet and low latency transmissions," *IEEE Veh. Technol. Conf.*, vol. 2015-Janua, no. January, 2015.

[40] W. Chung, B. Kim, M. Choi, H. Nam, H. Yu, S. Choi, and D. Hong, "Synchronization Error in QAM-Based FBMC System," *2014 IEEE Mil. Commun. Conf.*, pp. 699–705, 2014.

[41] M. Bellanger, "Efficiency of filter bank multicarrier techniques in burst radio transmission," in *GLOBECOM - IEEE Global Telecommunications Conference*, 2010, pp. 1–4.

[42] V. Vakilian, T. Wild, F. Schaich, and S. Brink, "Universal-Filtered Multi-Carrier Technique for Wireless Systems Beyond LTE," pp. 223–228, 2013.

[43] T. Wild, F. Schaich, and Y. Chen, "5G air interface design based on Universal Filtered (UF-)OFDM," *2014 19th Int. Conf. Digit. Signal Process.*, no. August, pp. 699 – 704, 2014.

[44] F. Schaich, T. Wild, and A. Ag, "Relaxed Synchronization Support of Universal Filtered Multi-Carrier including Autonomous Timing Advance," pp. 203–208, 2014.

[45] N. Michailow, R. Datta, S. Krone, M. Lentmaier, and G. Fettweis, "Generalized Frequency Division Multiplexing : A Flexible Multi-Carrier Modulation Scheme for 5th Generation Cellular Networks," *Proc. Ger. Microw. Conf.*, pp. 1–4, 2012.

[46] M. Danneberg, R. Datta, and G. Fettweis, "Experimental testbed for dynamic spectrum access and sensing of 5g GFDM waveforms," *IEEE Veh. Technol. Conf.*, pp. 1–5, 2014.

[47] N. Michailow, M. Matthé, I. S. Gaspar, A. N. Caldevilla, and L. L. Mendes, "Generalized Frequency Division Multiplexing for 5th Generation Cellular Networks," *IEEE Trans. Commun.*, vol. 62, no. 9, pp. 3045 – 3061, 2014.