Modulation Schemes for Future 5G Cellular Networks

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Abstract-OFDM is the modulation scheme, widely employed in the current 4G LTE systems. With high spectral efficiency, immunity to external noise disturbances and low intersymbol interference, it has completely revolutionised the way the world communicates today. However with our never ending demand of increased data consumption and the upcoming IoT-Internet of things, Multiple Machine Time Communications where data is expected to grow at an exponentially sporadic rate- operating in closed synchronised networks of an LTE system leads to a painful signalling overhead, besides the usual drainage of battery. Hence, we have discussed some potential candidates for the next generation 5G spectrum.

Keywords- OFDM, modulation schemes, LTE

I. INTRODUCTION

The current 4G systems, can support Long Term Evolution (LTE) bandwidth up to 20 MHz Multiple Input Multiple Output systems have dramatically
Changed the we transfer data, with improved spectrum efficiency, and network coverages. As 5G is deployed we extend into the untapped millimetre wave range, with highly directional beamforming antennas at both the device and base station. Many theories have circulated postulating: that the mm Wave- on being subjected to atmospheric rain conditions is futile. However, considering the fact that today's cell sizes are of the order of 200m, we come to the conclusion that the mm-wave range can easily surpass this concern. Besides, mm waves have been successfully integrated in IEEE 802.11ad networks: in indoor applications, and point to point wireless communications [1].

To throw a brief limelight onto the history of communication systems: we begin with 1G; the First Generation communication scheme, based on analog frequency modulation (FDMA-Frequency Division Multiple Access). 1G evolved into 2G with the advent of digitization and TDMA (Time Division Multiple Access), though the initial FDMA was also used in conjunction with TDMA. SMS, texting- on a Nokia phone soon became a global phenomenon which set trends throughout the entire world. Within less than a decade, 2G was replaced by 3G where CDMA (Code Division Multiple Access) techniques were deployed to capture the dominant market of colourful data transfers. Our unabating thirst for data led to a surge in the number of devices now connected to the internet, as a result IEEE 802.11 and the 3GPP(The 3rd Generation Partnership Project) unanimously adopted Orthogonal Frequency Division Multiplexing as the principle behind the current 4G LTE systems.

The Paper has been divided as follows: - Section II discusses the available modulation schemes beginning from the present, evolving into the future. Section III characterizes the mm wave, outlining on its objectives' and obstacles'. Section IV acquaints the reader with the current global standards for mm wave communications- the IEEE 802.11ad and 802.15.3c.
Section V mentions the current regulations, licensing practices while Section VI eventually concludes the paper.

II. AVAILABLE MODULATION SCHEMES

A.OFDM

Orthogonal Frequency Division Multiplexing is superior modulating scheme to that of FDMA, TDMA or even CDMA, as it involves a single data-bit stream being sent over low data, orthogonally aligned subcarriers. OFDM permits the sidebands of each individual subcarrier to overlap, without the signal being distorted with ISI-Intersymbol Interference [2].

The available spectrum is divided into n subcarriers, with the serial data being fed into the encoders using N point IFFT. The symbols are then mapped into constellations such as BPSK, QPSK or QAM. Each symbol is divided into frames, with a cyclic prefix being added to the each symbol toreduce, if not eliminate ISI. An exact 25% duplicate of the cycle is copied from the back and added to the front to permit the demodulator to capture the symbol with uncertainty and still be able to deduce the information for the entire symbol period [3]. Though a CP (Cyclic Prefix) may provide system robustness: by retransmitting additional data; which can be potentially used- it takes up extra space thus deteriorating the system's performance. 10% of the bandwidth is reserved as guard bands for the signal to meet the spectrum mask [4]. The prerequisite for subcarrier orthogonality is: the integral product of their sinusoids should be zero over a given time period. [5]

Though OFDM's qualities evoke admiration; as it has been universally adopted for industry standards; drawbacks do exist in declaring it as forerunner for upcoming 5G Spectrum.

First, OFDM has a very high Peak to Average Power (PAPR) ratio. N signals of the same phase on addition produce a peak power which is N times the average power, leading to the introduction of sharp peaks which on passing through a nonlinear high power amplifier, cause a spike rise of Bit Error Rate , Out-of-Band radiation and adjacent channel interference. [6]

Secondly, OFDM is sensitive to Doppler frequency shift - frequency error offsets degrading the channel orthogonality causing Intercarrier Interference (ICI):- which is particularly not suitable for massive machine type communications (MMC), where large connections are required. To mitigate these effects, newer, improved and better variants have been developed such as: f-OFDM, w-OFDM, Universal Filtered Multi Carrier (UFMC), Filtered Band Multi Carrier (FBMC), and Generalized Frequency Division Multiplexing (GFDM).

A step ahead of its predecessor, while inheriting all its qualities: f-OFDM (filtered) and w-OFDM (window) have been employed to reduce the guard bands by limiting out-of-band data emission [8].

B. f-OFDM

F-OFDM (filtered OFDM) is a spectrally localised technique where the filter length is allowed to exceed the cyclic prefix. Subbands divided in f-OFDM are of varying lengths, with each subcarrier having its own filter and CP, thus imparting more flexibility to the subcarriers, permitting different types of service data to be carried within the same subframe. MIMO friendliness, paired asynchronous multiple access are some of the aspects of f-OFDM which give it an edge over the conventional OFDM [9].

C. w-OFDM

W-OFDM (windowed OFDM) is a most commonly used in PLC networks. A windowed OFDM is defined by symbols which are softened on the border on a roll of interval(RI). An additional stage is added after the cyclic prefix addition, where the symbols are filtered. With the implementation being quite Complex, it's less preferred over the other discussed techniques [10].

D. UFMC

Universal Filtered Multicarrier Technique (UFMC) - hasrecently appeared as a viable waveform option for 5G. A filtering operation is applied to the consecutive subcarriers to reduce out of sideband overlaps, thus minimizing ICI and asynchronous transmission between multiple users. The use of shorter filter lengths, as compared to cyclic prefix makes it more suitable for short burst transmissions [11].

E. FBMC

Filter bank carrier technique is a more evolved form of OFDM, with filter banks to address the issues of spectral selectivity, which is the main causeof degraded system performance in OFDM, where subchannels tend to overlap, causing poor signal attenuation. FBMC effectively utilizes the spectrum, as a cyclic prefix is not required so the symbol period is exploited. It can be used without the synchronisation of mobile user nodes. Filter bands can also be re-used for spectrum sensing and multi carrier transmission in cognitive radio systems [12]. However, the main concern with FBMC is the offset due to QAM modulations:its plane is restricted to only the real field orthogonality, thus suffering when it comes to imaginary interfaces as a result of which signal processing tasks become more complicated. The scope of a MIMO based FBMC system is also very limited [13].

F. GFDM

General Field Division Multiplexing: is being seen as the promising candidate for the physical layer of the upcoming 5G Spectrum, with its key feature being MIMO friendliness [14]. GFDM is a non-orthogonal block based multiband carrier technique, where each subcarrier is filtered with a circular pulse shaping filter, to reduce out-of-band emissions and the peak to power ratio (PAPR). Multiple degrees of freedom are added, as many waveforms can be covered in a single frame. The reason GFDM

Triumphs over conventional OFDM are because a single cyclic prefix is added to the entire block that contains M-symbols, instead of each symbol possessing its own CP [15].

G. SDMA

Spatial Division Multiple Access was first introduced in the 1990's and also has been integrated as a standard for IEEE 802.11ac. Unlike traditional mobile networks, which radiate the signal in all directions, in SDMA, the Base station (BS) uses high directional gain antennas to channel the radio signals to the mobile user, using phased array techniques. As a result: energy consumption is drastically reduced; and unwanted signal transmission is prevented [16].

H. NOMA

Non-orthogonal Multiple Access serves multiple users at the same time and frequency domain. Of the two given techniques, power-domain NOMA usually dominates over coded NOMA. In power domain NOMA, the incoming signal with varying degrees' of power is separated at the receiver. Although power sharing may reduce the power allocated to each user, it derives merit from the fact bandwidth can be assigned to two users according to their data usage pattern. NOMA uses superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver, thus multiplexing users in power domain. Consider the example, of two users connected to the same base station. The first user has a higher degree of data consumption then the second user. In such a case, the first user will minus the signal of the weaker user through SIC, decoding it as their own signal, whereas the weaker user shall regard the stronger incoming signal as noise, and detect its own signal directly. NOMA distributes bandwidth to users according to their data consumption fairly, thus saving up on the unused data.

Future prospects of NOMA are being enhanced by MIMO-NOMA, a novel design, where users are clustered into cells- pairwise.

Limitations exist on every new prospect- even for NOMA. The idea of bandwidth allocation may be alluring, but clustering many users at the same time into cells- to decode the signal leads to complex system design, in addition to increased power consumption. A single error during SIC might cause

A ripple effect on subsequent user information. A considerable channel gain difference is required to obtain the benefits of power division multiplexing- which, if one thinks - is not always possible [17].

I. BFDM

Currently LTE systems are played in the Physical Uplink Shared Channel (PUSCH). Studies have demonstrated the use of the further extended Physical Random Access Channel to be deployed for the future asynchronous, sporadic data transmissions. Reference [18] has designed a novel BFDM based pulse shaped Random Access waveform which is well suited for the upcoming 5G PRACH.

Many of the methods discussed so far, compromise on guard band length to improve spectral efficiency, causing increased chances of interference. In bi-orthogonal frequency division multiplexing, the spectrum is modulated with bi-orthogonal subcarriers instead of the usual orthogonal ones. BFDM is more robust to frequency offsets and responds better to the sporadic traffic as the symbols in the Physical Layer Random Access Channel are relatively longer.

III. THE mm WAVE RANGE

Seen as the next: ‘’new thing’’, on which perhaps the entire 5G architecture is based; mm waves traces back their humble origins to Calcutta, India- the home of Sir Jagadish Chandra Bose who pioneered research in radio waves, creating a millimetre wave as short as 5 mm in 1900.

Located in the range of 30 GHz to 300 GHz, the mm wave range is the next subband to exploit. The following key points demonstrating 5G, which The International Trade Union (ITU) has slated the release for IMT-2020 are: connections for at least a 100billion devices, a 10Gb/s individual user experience capable extremely low latency rates and response time at 1ms, 3 times more spectrum efficiency, greater than 100 Mbps cell edge rates all within a 10Mbit/s/km2 area traffic capacity [19].

Given the large amount of inertia in its favour, no doubt’s exist on the mm waves’ capabilities’, albeit there are few hindrances in the way, which prevent it from reaching its maximum potential [20]:

*a.Path Loss:*Millimetre Wave is more susceptible to pathloss, as they have shorter wavelengths compared to microwaves; well below the carrier frequency of 6GHz.Studies have shown the use millimetre waves up to 10 km in clean air conditions.

b. Penetration Loss: Considering indoor applications, penetration losses are relatively low for clear glass and drywalls but extremely high for tinted glass and bricks, especially as frequencies increase 28GHz onwards. Each human presence penalizes the signal by 25-30 dB [21].

c. Energy Consumption: We are cognizant of the fact, that such large bandwidths require an equally transmitted high power in to maintain the Signal to Noise Ratio. Using MIMO, highly directional beamforming antennas - if we do implement such mm waves- we realize that the block diagram of each antenna would require its own set of Power Amplifiers (PA), LNA- low/linear noise amplifiers, ADC/DAC etc. In addition to the laudable environmental concerns, it is simply not viable from a logistic, battery or cost perspective to continuously increase the power consumption. Research has been going on in the fields of alternative low-Radiofrequency architectures.

d. User Mobility: As the user moves, the distance from the transmitter and receiver varies, and the channel state varies accordingly. We know that channel state proportionate with distance, thus suitable modulation schemes need to be applied to fully utilize the mm wave spectrum. Also, the user mobility causes rapid load loss fluctuations in each Base Station Subsystem because of their small Coverage area, thus user association and handovers between different Access Points should be carried out on a smart design. The IEEE 802.11ad and IEEE 802.15.3c have adopted the Received Signal Strength Indicator (RSSI) for user association which may lead to inefficient use of resources [22]. It is known that the Handover Mechanism has a big impact on the Quality of Service Guarantee, Load Balance and network capacity.

*e. Hardware Implementation:*The next generation of smartphones, tablets, devices need to be modelled accordingly to be receptive to the incoming mm waves, as the current LTE 4 userequipment’s’ shall be deemed redundant by then. The current allocated spectrum of 700 MHz to 2.6MHz is bound to reach saturation. Implementing devices based on CMOS technology might seem as viable option to operate in the mm-wave range, where drastically high data rates can be achieved, aiming to surpass the speed 1 Gigabyte/Second.

IV. STANDARDISATION- mm WAVE RANG

A.The IEEE 802.11ad

The IEEE 802.11ad uses the 60GHz ISM band to operate on, rather than the current standard 5/2.4GHz bands. The Physical Layer of 802.11ad supports three main signals with different modulations: Control PHY (C PHY) - it provides high levels of error correction and detection, used almost exclusively for control channel messages, OFDM PHY- this signal is used for higher data throughputs and the Single Carrier PHY/Low Power Single Carrier PHY- it uses single carrier modulation techniques for lower data throughputs with the objective to minimize power consumption. As one symbol occupies the entire frequency band in SC, it’s duration is very short.

In 802.11ad, a Basic Service Set consists of designated Access Point (AP) and a non-designated AP device (DEVs). The AP is responsible for timing control and initiation, processing the traffic requests it receives from the **DEVs**.

The channel is divided into Beacon Intervals (BI), with each BI being further subdivided into beacon transmission interval **(BTI)**, association BF training **(A-BFT)**, announcement transmission interval **(ATI)**, and data transfer interval **(DTI)**. The mm-Wave beacon frames are transmitted in the BTI. The association between AP's and NAP's DEVs are performed in A-BFT. The AP allocates Contention Based Access Periods (**CBAP)** and Service Periods**(SP)** within each DTI during the ATI. An SP is a scheduled access period within the transmitter and receiver for a high gain antenna. During CBAP, all stations contend for the same channel using the hybrid TDMA Schemes. During the Data Transfer Interval, a pair of DEVs communicate. Modulations schemes such as Carrier Sensing Multiple Access/Collision Avoidance **(CSMA/CA)** are employed for intermittent traffic such as web browsing while TDMA is more suitable for high quality video streaming services [22].

Specific SPs allow battery to be saved by hibernating base stations, during the transmission data period which is not assigned to them. The Fast Session Transfer (FST) Protocol ensures the smooth transmission of data over the various channels while maintaining its compatibility, over the existing standards of 802.11a/b/g/n and also the imminent ones [23].
Reference [24], has employed space block time coding techniques to improve the range extension of 802.11 in both the PHY and MAC layers.

B.The IEEE 802.15.3c
The 802.15.3c was formed to standardize the mm WPAN. The 802.15.3c is based on the piconets, and is composed of many DEVs. The single Piconet Controller (PNC), co-ordinates, synchronises the transmission between different piconets.The time is divided into multiple super frames, which is further divided into Beacon, Contention Access Period(CAP), and Channel Time Allocation Period(CTAP). CAP is for devices to transmission requests to the PNC. CTAP is further divided into multiple Channel Time Allocations (CTAs). The

CTA is a time slot granted by the PNC, used for data communication among devices [24].

Sync frames are introduced to achieve synchronization among the DEVs using different PHY modes. Sync frames include information about the duration of superframes and timing of the CTA. Sync frames are modulated using Common mode signalling (CMS) - a low data rate single carrier modulation scheme for mitigating interferences among different PHY modes [27].

IV. LICENSING, ECONOMIC COSTS
As the current allocated spectrum becomes saturated, with each telecom operator being allocated a mere 200MHz bandwidth, we deviate from the technical tete-a-tete to focus on how licenses for operating in the mm- wave will be awarded in the future.
Firstly, we consider the exclusive license policy: where licenses are awarded for a specific band and purpose. This traditional license approach requires a great investment into the infrastructure, coupled with a high entry cost. Getting the required clearances may take years, and perhaps by that time- the technology may have become outdated.
Second, comes the unlicensed spectrum-which is made available to everyone to be used free of charge. A prime example of this is the Wi-fi which operates at the 2.4/5GHz range. A better example is the ISM (Industrial, Scientific and Medical) Band: which includes cordless phones, smartwatches, small medical devices etc.Wifi Hotspots are small cells that spatially reuse frequencies in the ISM Band. The U.S Federal Communications has commissioned forthe 57-64 GHz bandwidth to be used as unlicensed spectrum, while Japan has allocated 59-66 GHz band.
Third, Spectrum Sharing: It has been seen as possibility, albeit with limited scope.
Authorized Shared Access and Licensed Shared Access are frameworks that allow spectrum sharing.

The International Telecommunication Union (ITU) has proposed the official release of 5G named IMT-2020, so it's unlikely before then for our current smartphones to enjoy such high-speed privileges.

Nonetheless, economic costs of moving to 5G also need to be considered even if the cost of spectrum were to decrease. The major obstacles in the course road would be densification of networks and the backhaul needed to connect them to the core network. In such a case, infrastructure, active, passive sharing along with backhaul optimisation might seem as an optimistic option [1].

V. CONCLUSIONS

We have discussed the various techniques which can be potentially used for future communications as alternative waveform to the cyclic prefix based OFDM systems, on which the current 4G networks are based. The future prospect of mm waves along with its current existing IEEE standards has also been delved into for the future prospects of 5G communications. We hope, in a short passage of time, both scientific theory and fantasies will soon be seen manifested in reality.

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