PERFORMANCE ANALYSIS OF BFDM/OQAM BASED 5G IOT HEALTH CARE SYSTEM

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ABSTRACT

The latest advancements in the cellular communication technologies have enabled interconnectivity of devices through the Internet, widely identified as Internet of Things (IoT). The newer health care crisis like Covid-19 is devastating effect on the world economy by impacting every part of the society. Going forward the health care IoT devices for detection of the vital parameters of the humans and warn them before they really get sick. The requirements of the 5G cellular communications have included the low speed, low volume machine type communications along with the traditional voice, broadband information and high density video (HDV) communications. The IoT plays a major role in the creation of smarter cities, smarter health care services and other services. The IoT applications mandate low cost solutions with ultra-low power consumption, with wider coverage area. To fulfill such varied requirements, there is a need to design an innovative physical layer. In this paper, a different approach is used by tweaking the LTE accessing techniques that are defined in 3GPP for catering the requirements of sporadic traffic generated by IoT systems. An innovative bi-orthogonal frequency division multiplexing (BFDM) system with Offset-QAM (OQAM) is implemented through Matlab Software to analyze and compare with OFDM supported LTE. In this work, the performance of the proposed OQAM based BFDM system is compared with existing OFDM based LTE system along with the QAM based BFDM system under channel model conditions defined in 3GPP TR 25.943, such as Rural Area (3GPPRA), Typical Urban (3GPPTU) and Hilly Terrain (3GPP HT), which is essential part of the 5G cellular communications with IoT.

Keywords: BFDM, DPRACH, Health Care, IoT, LTE, mMTC, OFDM, OQAM, 3GPPRA, 3GPPTU, 3GPPHT, 5G.

I. INTRODUCTION

The growth of IoT technologies and penetration of its applications in our day to day life beyond our imagination invoked the interest of 5G research community to integrate these services in to 5G networks. The current health pandemic Covid-19, will fasten the growth of IoT based health care systems, to mitigate the health risks, by developing wearable smart devices that can continuously monitor the vital health parameters like temperature, pulse, oxygen levels in blood and warn based on intelligent systems. The IoT and 5G Communication growth will complement each other in the next revolution of communications. The requirements of 5G communications are mainly motivated to support the massive machine type Communication, Ultra high speed data everywhere, and the Ultra reliable low latency communication for tactile internet [1] & [2]. This kind of 5G requirements need newer variants of waveforms such as Filter Bank Multi carrier (FBMC), General Frequency Division Multiplexing (GFDM), Universal Filter Multi Carrier (UFMC) and Bi-orthogonal Frequency Division Multiplexing (BFDM) and the waveforms are discussed extensively in [3]-[9]. The growth of the 5G networks is mainly happens through the rampant use of IoT in every field of life that can span across every part of the lifestyle and business by offering the benefits of better customer services, optimum resource utilization, improved quality of connectivity, and effective continuous data acquisition through various sources [10]-[12]. The major challenge for reliable access to the 5G core networks [13], [14] is the randomness of the traffic spawned by the IoT systems, which are inactive for longer periods of time and automatic updation of trivial or incremental data needs an occasional periodic internet. In 5G networks, thousandsof interconnected IoT systems of varied nature will be a
common characteristic and managing an abnormal growth of sporadic traffic is a colossal job for the present procedures of LTE random access [15],[16]. The conventional approaches to handle the traffic of such a scaled up number of IoT devices due to the enormous amount of control messaging and synchronization requirements.

In this paper, a different approach [17],[18] has been used to handle the sporadic nature of the Machine Type Communication (MTC) for 5G, with an enhanced Physical Random Access Channel (PRACH) by accomplishing concurrent device synchronization and transmission of smaller data payloads without being connected always. In LTE, scalability of the sporadic traffic is a biggest limitation due to the use of Physical Uplink Shared Channel (PUSCH), which has lower bandwidth allocation. In Release 13 of 3GPP (R13) specifications, some of the physical layer enhancements [19] were introduced to enhance the massive Machine Type Communications (mMTC). An innovative proposal of Data-PRACH (D-PRACH) for MTC is introduced to support transmission of asynchronous data [17] by arranging a data access part in between the PRACH and synchronization PUSCH by utilizing guard bands. In this way, asynchronous sporadic data traffic will not utilize the PUSCH and the overhead of signaling reduces significantly so that the power consumption at the IoT devices also drastically reduced. The far and widely used OFDM waveform has major constraint of higher order of spectral leakage, which can be fixed with an appropriate pulse shaping technique. The general perception of increase in interference for other PUSCH users due to the usage of guard bands is well addressed with the newly designed BFDM waveform [17].

In the design of BFDM system, simple concept of replacing normal orthogonality with a twosome orthogonality of transmit and receive pulses. Due to this concept, flexibility is attained to design a prototype filter for transmit and receive side to achieve a good side lobe suppression. At the receiver for the detection of received BFDM signal, ZeroForcing (ZF) filters are used as suggested in [20]-[24], instead of matched filters. The transmission of PRACH symbols with BFDM technique is exceedingly resilient to the timing offsets and most appropriate for the transmission of sporadic data.

BFDM works with the principle of designing good localized pulse shaping at the transmitter and receiver side that are mutually bi-orthogonal [25]. A very good localization of the transmitted pulse in frequency domain makes the system immune to frequency dispersions (Doppler shift), while the receiver pulse good time-localization provide immunity to the time dispersions (multipath). However, as per the Balian-Low theorem the usage of well localized time-frequency pulses along with QAM modulation leads to lesser spectral efficiency [26]. Consequently, in this paper, to get better spectral efficiency, BFDM with OQAM is proposed due to the superior robustness for the Doppler shifts caused by the channel environment.

The proposed work is also an extension of the previously performed work in [27] by the same author, which studied the BFDM system performance under normal fading conditions for pedestrian and vehicular users. In this paper a typical, rural, urban and hilly areas are considered and compared against the OFDM based systems.

This paper is arranged in to five sections. In the section II, a brief overview of BFDM system and its design is discussed. Section III discusses about the BFDM-OQAM, Section IV talks about the BFDM and OFDM system simulation and in the section V the simulation results are discussed. Finally section VI, provides the conclusions from the simulations and future work.

II. OVERVIEW OF BFDM SYSTEM DESIGN

The PRACH message that is transmitted in the BFDM system also goes through the similar pulse shaping procedure of OFDM system. The symbols that are transmitted are nothing but shifted pulses of time and frequency domain with the lattice points \((kT,F)\), where T and F are time frequency domain shifted values respectively. As specified in [17], the reconstruction of accurate symbols can be realized only if both the transmit/receive pulses \(\{g_{kT,F}\}, \{\gamma_{kT,F}\}\) are derived from the bi-orthogonal Riesz bases. The reconstruction of perfect symbols depends on two things – one the pulse properties and the other one is the time-frequency product (TF) should be larger than one. So, the careful design of the pulse shaping is an important aspect for the BFDM system. In this paper, the time frequency product (TF) is chosen as 1.25, which is found to be optimal.

A. BFDM PRACH Transmitter

The BFDM PRACH transmitter block diagram is depicted as illustrated in the figure 1. In BFDM, pulse shaping of the PRACH requires an extra processing [21], in contrast to normal OFDM based LTE system. The B-Spline
based pulse ‘g’ is used to shape the BFDM PRACH signal. B-Spline pulses are considered for the BFDM system owing to its exceptional tail characteristics. As shown in figure 1, the data symbols are mapped to subcarriers, passed through IFFT, then stacked as a row matrix, after that mixed with the B-Spline pulse ‘g’, and get the pulse shaped PRACH signal by overlap and add operation.

![BFDM PRACH Transmitter](image)

**Figure 1** BFDM PRACH transmitter [17]

**B. BFDM PRACH Receiver**

The BFDM PRACH receiver to receive the PRACH channel is as presented in figure 2. As depicted in figure 2, the PRACH signal received is stacked, mixed with the receive pulse $\gamma$, which is a bi-orthogonal (canonical dual) of the transmitted pulse. The resultant signal is converted to frequency domain signal by applying FFT and then demapping of sub-carriers is performed to obtain the output signal at the BFDM PRACH receiver.

![BFDM PRACH Receiver](image)

**Figure 2** BFDM PRACH Receiver [17]

The design details of the BFDM pulse shaping for both transmitting and receiving side, and the overall BFDM system are discussed in [22]-[27].

**C. Overview of Pulse Design**

The careful design of the pulses ‘g’ and $\gamma$ is necessary as they play a crucial role for estimating the symbol timing offset. In the BFDM approach, the transmit the pulse ‘g’ and receive pulse $\gamma$ are designed in such a way that they are canonical dual (biorthogonal). Furthermore, the ratio of variance of the time and frequency pulse widths is approximately equal to time-frequency grid ratio, so that signal conditioning is smoothly done. In this approach, due to the bi-orthogonal pulses are used, the spectral regrowth is negligible. The details of the pulse design are discussed in [17] & [27].

**D. Offset-QAM**

In QAM, both the real and imaginary parts of a data symbol is transmitted simultaneously, whereas in the Offset-QAM, imaginary part is transmitted with a half symbol period delay after the real part is transmitted. The word “offset” is used, since real and imaginary parts of the complex data symbol are the inverse of the half the time-domain sub-channel spacing. Figure 3 shows the QAM and OQAM symbols are transmitted [27]-[29].
OFDM technique warrants a strict orthogonality and this confines the attainable time-frequency localization. So, easing of orthogonality requirement is a necessary step and OQAM based BFDM improves the localization of time-frequency considerably, which transforms to improved dispersion robustness.

E. **Bfdm System Simulation**

A representative block diagram of the simulated BFDM transceiver system is as shown in figure 4. A typical BFDM system contains a data source, an encoder, BFDM Transmitter, propagation channel, BFDM Receiver, and data decoder.

![BFDM Transmitter/Receiver block diagram](image)

F. **Channel**

The performance of the wireless communication system is determined by the channel characteristics. To estimate the received signals, modelling of the channels by considering the noise, multipath fading components, as this play a major role. Multi pathing fading is classified as two types: one is Non-Line of Sight (NLOS) and the other one is Line of Sight (LOS). These fading types are modelled with Rayleigh and Rician distribution techniques. In this work, Rayleigh distribution is used, to model the typical cellular communication cases of Rural areas, typical urban and hilly terrain fading conditions which represents Non-Line-Of-Sight type.

G. **3GPP defined Multipath Fading Channel models**

In this paper, the proposed BFDM with QAM and OQAM along with OFDM systems were tested with 3GPP defined fading models [30], that are applicable for the 5G cellular environment. The predefined fading profiles, namely Rural Area (RA), Typical Urban (TU) and Hilly Terrain (HT) are the typical demonstration of low, medium, and high delay spreads respectively and the profiles are represented in a tabular format in the Table 1.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural Area (RA)</td>
<td>Low delay spread</td>
</tr>
<tr>
<td>Typical Urban (TU)</td>
<td>Medium delay spread</td>
</tr>
<tr>
<td>Hilly Terrain (HT)</td>
<td>High delay spread</td>
</tr>
</tbody>
</table>
### III. SIMULATION OUTCOMES

The simulation of BFDM with OQAM, QAM and OFDM-QAM systems is done by using Matlab software. To evaluate the performance of the BFDM and OFDM systems under various 3GPP defined fading conditions, which are discussed in the section IV. For the simulations, the parameters set the BFDM and OFDM systems are as captured in the Table 2. As per the LTE Release 13 of 3GPP (NB-IOT feature), the carrier spacing for both the BFDM and OFDM Systems is set to 1.25KHz instead of the default 15KHz.

#### Table 2 Simulation setup parameters

<table>
<thead>
<tr>
<th>S.No</th>
<th>Variable Name</th>
<th>OFDM Normal PRACH</th>
<th>BFDM Pulse shaped PRACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Subcarrier spacing</td>
<td>1.25KHz</td>
<td>1.25KHz</td>
</tr>
<tr>
<td>2</td>
<td>OFDM symbol duration</td>
<td>800µs</td>
<td>1ms</td>
</tr>
<tr>
<td>3</td>
<td>FFT Length (N$_{FFT}$)</td>
<td>24576</td>
<td>24576</td>
</tr>
<tr>
<td>4</td>
<td>Number of subcarriers</td>
<td>839</td>
<td>839</td>
</tr>
<tr>
<td>5</td>
<td>Bandwidth</td>
<td>1.08MHz</td>
<td>1.08MHz</td>
</tr>
<tr>
<td>6</td>
<td>Sampling frequency</td>
<td>30.72MHz</td>
<td>30.72MHz</td>
</tr>
<tr>
<td>7</td>
<td>Cyclic prefix length</td>
<td>3168Ts</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Time and frequency product</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>9</td>
<td>Pulse length</td>
<td>-</td>
<td>4ms</td>
</tr>
<tr>
<td>10</td>
<td>Guard time</td>
<td>2976 Ts</td>
<td>0</td>
</tr>
</tbody>
</table>

The study of power spectral density (PSD) for BFDM (with QAM and OQAM) and OFDM system is performed and the results are depicted in figure 5. From figure 5, it can be observed that the side-lobe suppression of BFDM based systems are better than the OFDM based system. Also, it is noteworthy to see that OQAM based BFDM is better than QAM based BFDM system.

For any wireless communication system, the quality is measured through the Symbol Error Rate (SER) vs Signal to Noise Ratio (SNR) performance. So, the BFDM and OFDM systems performance is measured by calculating the SER values for different SNR values of various 3GPP defined fading channel conditions and plotted the graphs as presented in figures 6, 7 and 8.

![Figure 5 PSD analysis of BFDM (with QAM and OQAM) and OFDM Systems](image)

![Figure 6 Comparative analysis of OFDM and BFDM systems with 3GPP RA fading profile](image)
The performance of the BFDM system is superior to the OFDM based system under all the fading environments of rural, hilly terrains and urban. The other noteworthy observation is BFDM system is less vulnerable to frequency-time offsets, when compared to OFDM system. When QAM and OQAM based BFDM systems are compared for various fading conditions, OQAM based BFDM system fared well compared to QAM based BFDM system especially in urban and hilly terrain environments, which are the problem areas for cellular communications due to the higher Doppler-shift conditions.

Going forward, massive number of health care and other IoT devices will get deployed across the rural, hilly terrain and urban areas as a part of the future health care systems, where BFDM based 5G IoT systems can be deployed due to their minimum frequency and time offsets and support asynchronous short message transmission.

### IV. CONCLUSION

From the results, for the IoT kind of applications, it can be concluded that OQAM based BFDM systems can perform better than that of the OFDM based systems under various 3GPP fading conditions which covers both...
rural, urban and hilly terrains. BFDM system also provides immunity towards timing and frequency offsets of the received signals and is efficient use of spectrum as the guard bands and cyclic prefix are completely removed in PRACH design. It can be concluded that the OQAM based BFDM system is more suitable for the 5G requirement of massive machine type communications for healthcare, with lower power consumption and support for asynchronous transmission and receiving of shorter messages. To mitigate the future pandemic situations like the current Covid-19 situations, a massive deployment of smart wearable health care devices across the globe is a necessity. As a part of this drive, to make cost effective devices, the BFDM based IoT devices can be one of the solution that can be considered. The current work can be further improved by introducing other pulses like trapezoidal pulse.

REFERENCES