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Beamforming for 5G mm Wave Networks at Quadrature Baseband and RF using OFDM signaling

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Abstract:- This paper looks at beamforming for 5G mmWave networks at Quadrature baseband(QBB) compared to RF. Beamforming is a very key aspect of 5G networks and coupled with MIMO as it will be able to accommodate the much needed functionalities of 5G Technology which has to accommodate billions of devices. In this research a QBB beamforming approach is presented as a possible solution to this challenge. ODFM signals are used in the MatLab simulations to be able to compare results at RF versus QBB. On-going research in this area entails that it is possible to have an optimal solution to solve some of the challenges being faced as the 5G network system roll out continues.

Keywords:- *Beamforming; Quadrature Baseband, Radio Frequency, OFDM, 5G Networks;*

I. INTRODUCTION

Beamforming refers to a traffic-signaling system for cellular base stations that identifies the most efficient data-delivery route to a particular user, and it reduces interference for nearby users in the process. Depending on the situation and the technology, there are several ways to implement it in 5G networks [2]. RF beamforming has been carried out and is being used in the current roll out and test. Beamforming is considered as one of the most important enabling technologies for the fifth generation of wireless communications (i.e. 5G) and beyond networks as it compensates for the large path loss of the high frequencies in the millimeter wave (mmWave) band and the mid-band frequencies [1]. Beamforming helps massive MIMO arrays. This entails that with the use of MIMO, more services can be accommodated ad with optimal usage of the available spectrum which is a defining feature in mmWave communications. This entails highly directional and steerable beams in single- and multi-user scenarios. It will play a crucial role in the future of 5G wireless designs, because the 3GPP Release 15 specification outlines the basics of beam management [3]. mmWave 5G Technology being high frequency based entails that high-frequency waves are expected to play a key role in 5G networks, beamforming is primarily used to address a different set of problems. Quadrature baseband is a term that refers to the generation of in-phase and quadrature components of a signal at baseband. 5G Technology is expected to accommodate billions of devices [4]. In the coming years, an exponential growth of the number of connected devices is expected, as well as the volume of data traffic consumed [5]. The next section of the paper discusses related work on antenna gain and beamforming in 5G networks. In this work OFDM signaling comparisons are done for 5G mmWave networks at RF vs Quadrature baseband (QBB) beamforming. Simulations results are shown using MatLab.

II. RELATED WORKS

Several authors have researched around this topic. They have been able to come up with solutions and proposals to sort out some of the challenges in this 5G technology on a number of processes of which Beamforming is one key area.

Zhang *et'al* presented an hybrid beamforming design for millimeter-wave (mmWave) hybrid beamforming design OFDM distributed antenna system (DASs). The were able to derive a downlink transmission model that was able to consider the delay spread differences and the they proposed a cooperative hybrid beamforming method that was able to carry out digital beamforming[3].

Boroujeny *et'al* proposed the need to replace OFDM with a more effective air interface. The authors were able to come up with a common frame work but based on the OFDM principle[4].

Arshdel considered power allocation of OFDM wirelesss network locations in 5G systems. The author presented an optimization framework for ergodic and robust subcarrier power allocations, From the research results, the author was able to show that robust and ergodic power allocations do indeed provide more accurate information[5].

Lin considered the design of statistical MIMO beamforms for mmWave. The author was able to show that the optimal statistical beamformer for each sub carrier channel was an approximate linear combination of the optimal statistical beamformers[6].

Vilor [7]researched on beamforming and comes up with a 'Smart' Beamforming proposal as compared to blind beamforming. Nowadays, every aspect of society requires 'smart' practices to be able to optimize output and efficiency. Beamforming is no exception to the 'smart' approach.

Gonzalo *et'al* looked equal gain Beamforming in the RF domain for OFDM –WLAN systems. They were able to describe an alternating minimization algorithm to be able to find an approximate OFDM based solution to be used. Monte-Carlo simulations were able to demonstrate how effective the use of this new WLAN 802.11 based analog Beamforming scheme could be under coded and uncoded transmission[8].

Mossaad *et'al* proposed a new form of OFDM for Vehicle Light Communications (VLC) so as to enable the use of more power efficient drivers. In addition, authors were able to propose a scheme based on spatial optical OFDM. They also make mention that due to power issues, the use of optimization techniques to allocate power is a possibility for the subcarrier of each LED in a VLC system[9].

Pulipati *et'al* presented a 28GHz, 64QAM digital beamforming design that used 5G MIMO coupled with Beamforming applications. They proposed an extension to OFDM for physical realization at Board level[10].

Ramadan *et'al* looked at Beamforming for secrecy MISO-mmWave OFDM based systems. There were able to come up with two channels of knowledge and went on to propose two solution algorithms based on semi relaxation and gradient ascent[11].

Elvira *et'al* studied OFDM based MIMO systems which perform adaptive RF signal combining. The authors were able to address the adaptive radio frequency combining problem. They were able to come up with a linear precorder and a pair of beamformers that was able to minimize the Bit Error Rate (BER)[12].

Cuba *et'al* proposed a Hybrid Beamforming methodology using Multi-User MIMO and was able to show that throughput improved. By using Spatial Division Multiple Access(SDMA), they were able to show and prove that SDMA does greatly increase the system capacity[13].

Raji *et'al* weighed in on OFDM based wavelet transforms. The research was able to give a deep insight into Orthogonal Wavelet Division Multiplexing (OWDM) and were able to show that the two main draw backs were high memory and time cost[14].

III. LITERATURE REVIEW

In this section we look at specific literature related to the key components of our research title.

A. OFDM Signaling

OFDM (Orthogonal Frequency Division Multiplexing) has application in many of the latest wide bandwidth and high data rate wireless systems including Wi-Fi, cellular and telecommunication systems. OFDM being a multicarrier communication scheme combines a large number of low data carriers enabling the construction of a combination of a large number of low data rate carriers to construct a composite high data rate communication system which greatly diminishes inter-symbol interference.[23]. OFDM is thus preferred for 5G modulation. OFDM comes with features such as low bit rate data which implies that it is very resilient to selective fading , multipath effects and interference which in turn provides high spectral efficiency. Through its multicarrier modulation, the use of guard bands enables OFDM to be used to transmit several signals without interference. This is a fundamental requirement under 5G.
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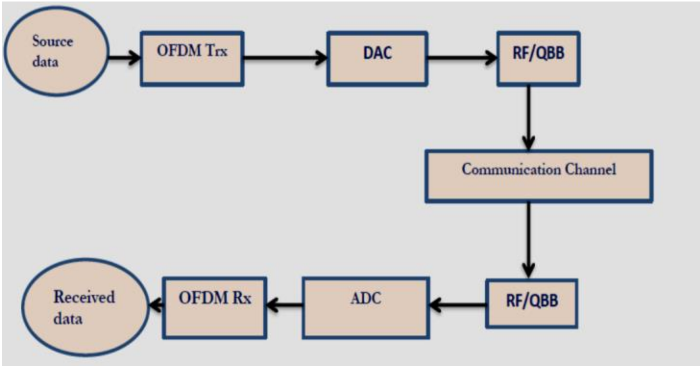

Figure 1: OFDM System

The Figure below shows ODFM with 8 sub-carriers. One key aspect of OFDM is its low complexity of implementation.

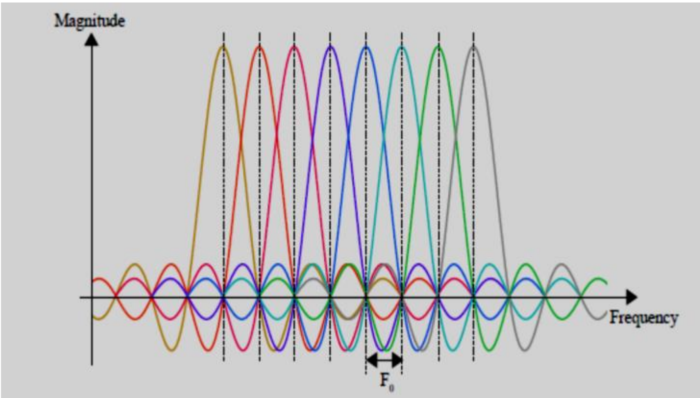

Figure 2: OFDM orthogonality with M=8 sub carriers [15]

B. Mm-Wave and 5G Networks

In the diagram below, the mm-Wave spectrum is clearly illustrated. As is known, most of the 5G mmWave is yet to be utilized since the roll out is still being carried out. This spectrum is however expected to be used once most of the roll out takes place [22].

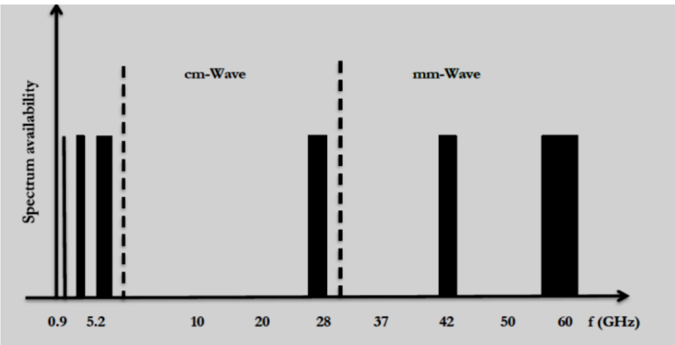

Figure 3: 5G mm-Wave Spectrum

C. Fast Fourier Transforms and signaling

The Fast Fourier Transform (FFT) is an algorithm that computes the Discrete Fourier Transform (DFT) or the Inverse DFT [16].It converts a signal from its original domain into the frequency domain and vice versa. The author in [17] described the FFT as the most important algorithm of our century hence its usage in OFDM signaling and subsequently 5G systems. The frequency domain aspect is suitable for accommodating the requirements of 5G multiple users. This is used in our QBB approach after the Lowpass filtering stage.

D. Beamforming in 5G

The importance of Beamforming in 5G systems cannot be over emphasized. This coupled with Massive Multiple Input Multiple Output (MIMO) systems is a very vital to the effective implementation of 5G Technology.

Kitao *et'al* emphasize the importance of Beamforming in 5G systems due to the fact multiple antenna technology results in increased path loss. The authors designed a system evaluation tool that was able to calculate several parameters including throughput[18].

Lin *et'al* studied a robust and secure Beamforming 5G cellular system. This system coexists with a satellite network operating at mmWave frequencies. This is illustrated in the Figure. 8 below;[19]

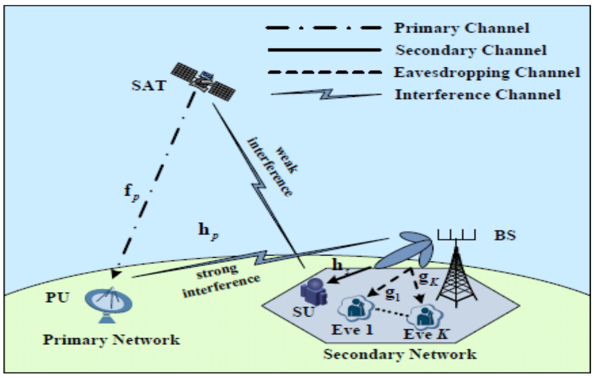

Figure 4: Scenario of 5G cellular network co-existing with a satellite network [19]

Given our proposed method to achieve beamforming at Quadrature baseband (QBB)

Lin *et'al* proposed a hybrid beamformer at RF to be able to carry out digital statistical beamforming[6]. Lin made significant research in this area and the model below is what he designed shown in Figure 5.It is seen that the hybrid consists of several blocks including the RF chain blocks leading to the beamforming output. In our case we propose QBB processes in place on the RF parts.

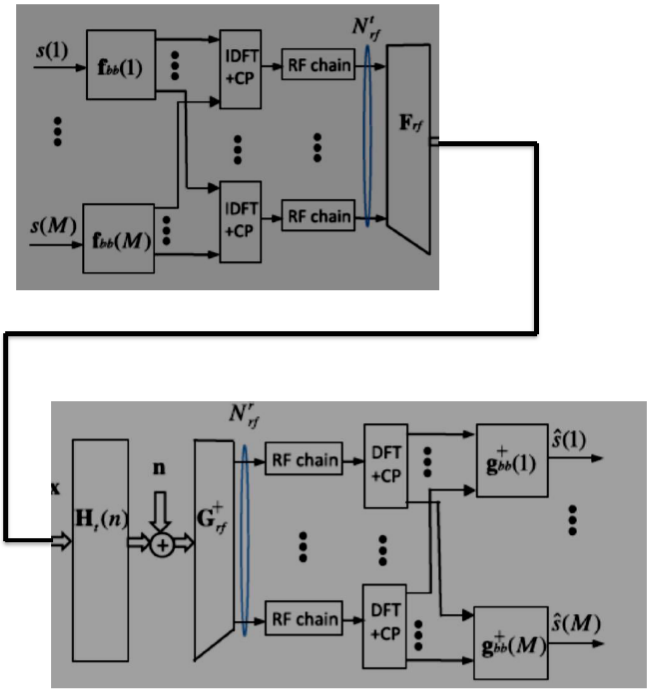

Figure 5: A Hybrid MIMO-OFDM Beamforming system[6]

In the diagram below, the signal generation process is summarized in block form. As seen from related works. OFDM signal is used because it facilitates the use of Fast Fourier Transform (FFT) based processing.

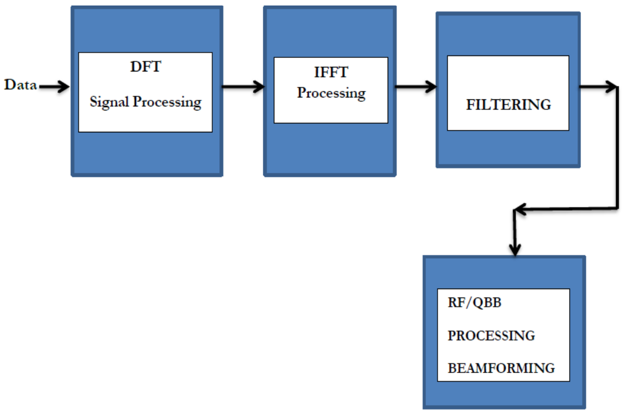

Figure 6: OFDM orthogonality with M=8 sub carriers [15]

The next section looks at how we implemented our simulations.

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IV. IMPLEMENTATION METHODOLOGY

The implementation methodology is explained and summarized in this section.

The 5G r2020b MatLab tools box generates the 5G OFDM Modulated signals that are fed into the RF and QBB algorithm system for further processing. In the diagram, it is shown that using the 5G MatLab tools box, the RF and QBB scenarios are simulated for simple OFDM signals. The Beamforming then takes place and then the beam patterns are generated [20].

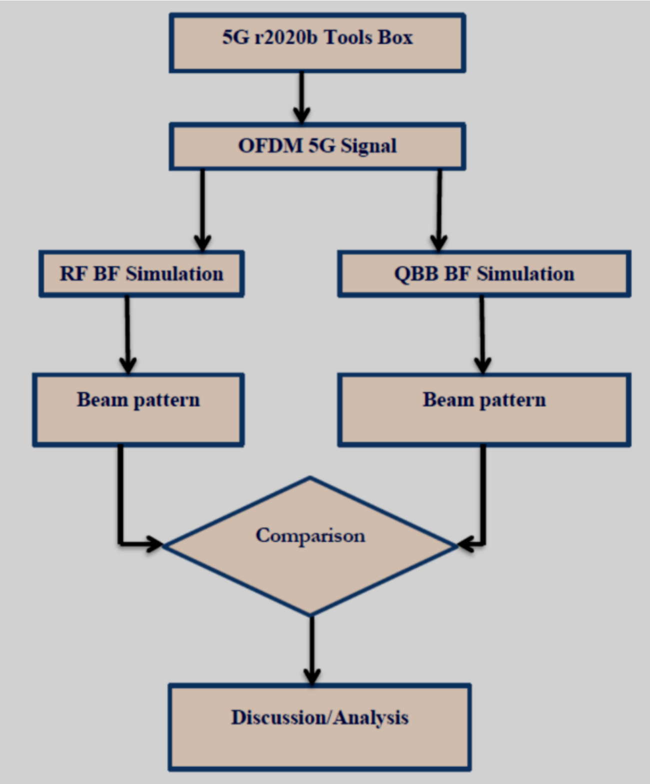

Figure 7: Beamforming 5G QBB Analysis illustration

V. SIMULATION RESULTS

After carrying out the simulations, the resulting plots are given and explained in this section. Figure 8 below shows the real part of the generated OFDM signal. This signal is the starting point in the whole process of our research so as to get the final Beamformed signals. As seen the magnitude is slightly above +/- 2 for the 4000 samples plotted. In order to carry out the Beamforming analysis using the generated OFDM signal, we used four signals with an assumption that they had slightly different magnitudes based on different times of arrival. The 4 signals are consequently shown in Figures 9, 10, 12 and 13. The different magnitudes are clearly seen. The signals all have 4000 samples represented for all the signals. The maximum and minimum peaks for the generated signals are given in Table 1.

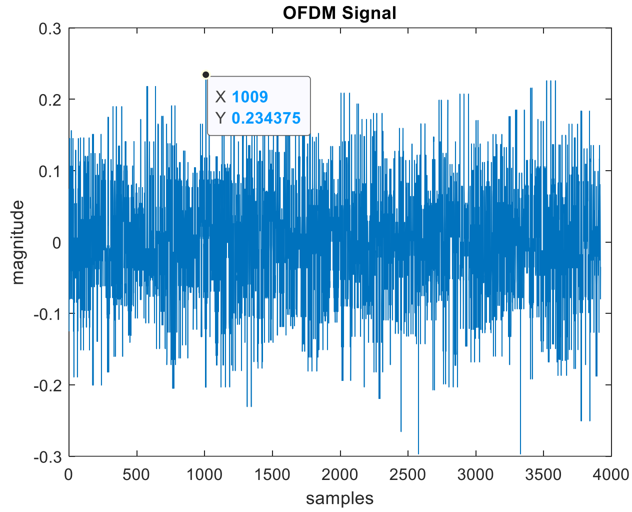

Figure 8: Real part of OFDM transmission

These play a key role in calculating other parameters like power spectral density amongst others. However that is not of main priority in our current research, but it does give us more insight into the signal properties of the four signals being Beamformed. In Figures 9, 10, 12 and 13, you can clearly see that the maximum peak points occur at the 1009[th] sample for this simulation run. This can change depending on the other parameters if changed for the next run of the simulations. What this entails is that it gives us the flexibility or enables us to vary certain parameters and thus be able to get a more varied range on inputs and outputs and understand our processes more. The minimum peaks for the signals occurred at the 2577[th] sample. In this case our focus is in seeing the resulting Beamformed signal.

Figure 8 is given below showing a maximum peak of 0.234375.

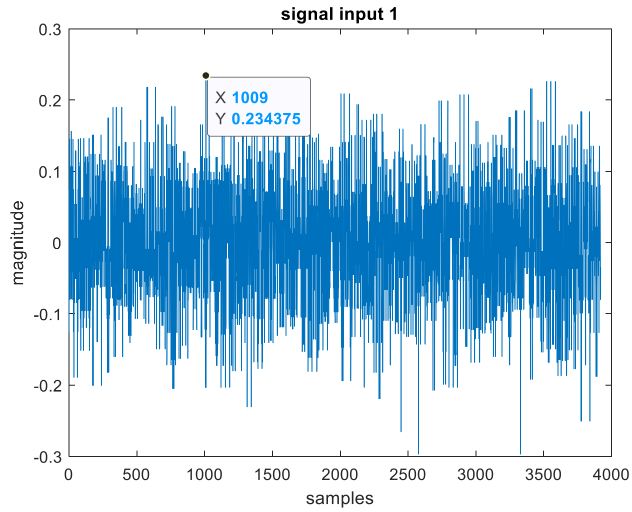

Figure 9: Signal 1 input

Figure 10 below shows signal input 2 having a maximum peak of 0.078125. This is about 3 times less than Signal 1. This is a significant very reduction in signal strength. It can be noticed that Figures 8 and 9 have minimum peaks that are equivalent to their plot boundary hence not indicated as it is straight forward.

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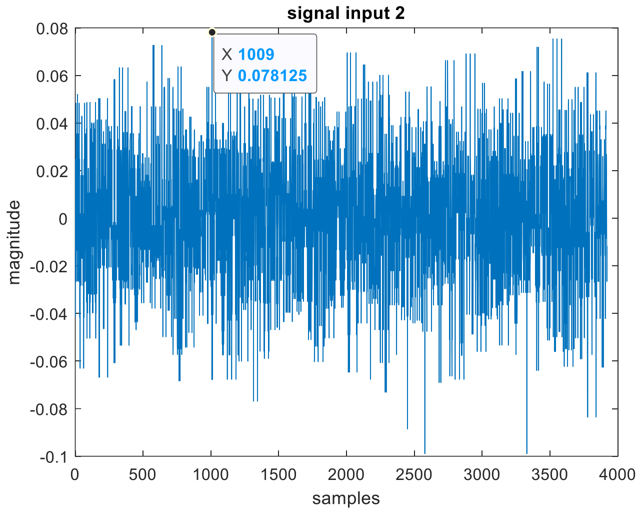

Figure 10: Signal 2 input

Figure 11 below shows the third signal input. Based on the parameters set in the simulation, signal input 3 is 33% less in amplitude than

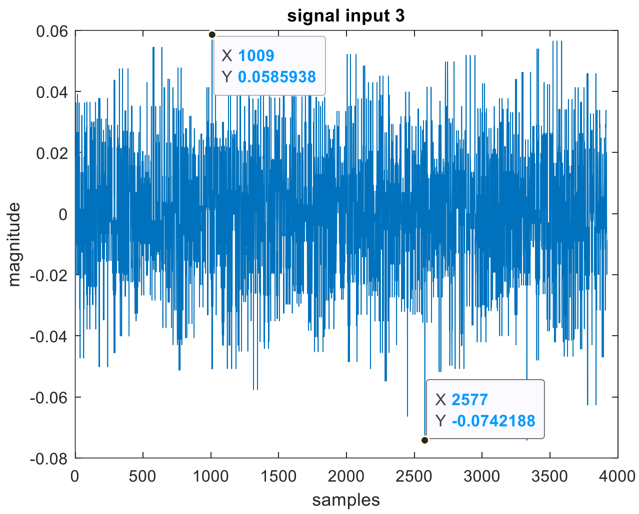

Figure 11: Signal 3 input

The simplified diagram below illustrates the general flow of the simulation plan as the coding was done for each process.

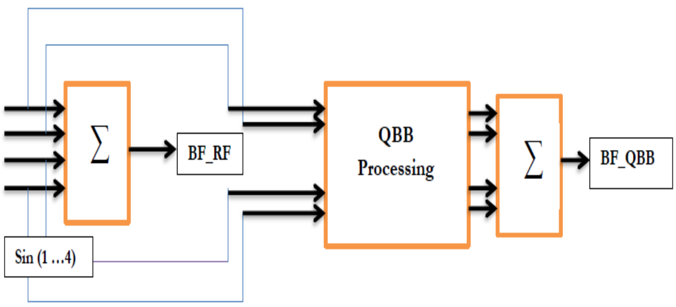

Figure 12: Simulation block illustration

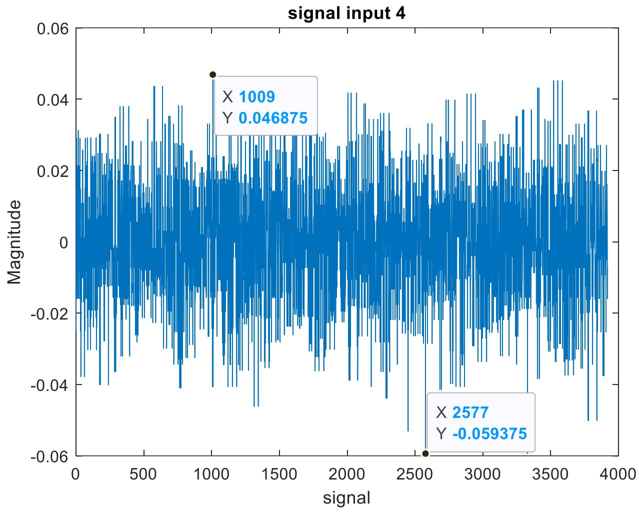

Figure 13: Signal 4 input

The 4 signals are then summed up at RF resulting in the signal below. An extract from the code is given below;

```
RF Part

%==========================================================================
%Input signals are defined
s1in=sRF;
s2in=sRF/3;
s3in=sRF/4;
s4in=sRF/5;
%==========================================================================
%Beamforming at RF is carried out here
SRFB= s1in+s2in+s3in+s4in;
%==========================================================================
```

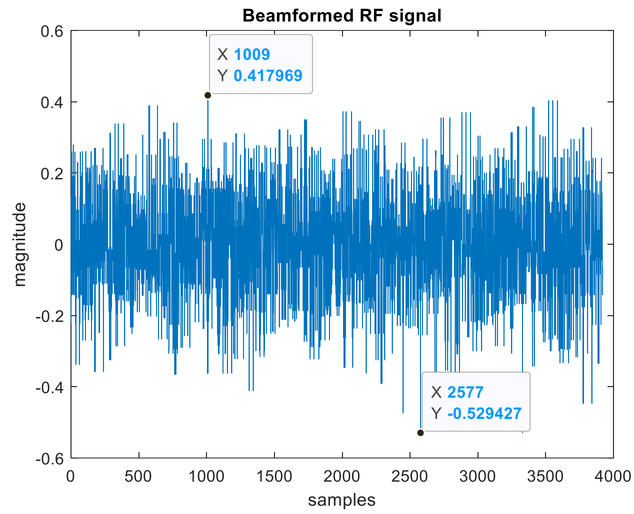

Figure 14: Summed up RF Beam formed Signal

The Table 1 below gives a gives an overview of the signal peak values and at the sample points at which they occur. From the actual plots you can see that the signals have varying peaks based on our earlier assupmtion and hence this assumption well reprensents the concept that is being propelled by our research.

	Maximum		Minimum	
	Magnitude	X(sample point)	Magnitude	X(sample point)
Input Signal	0.23458	1009	-0.30	2577
sRin1	0.23458	1009	-0.30	2577
sRin2	0.07813	1009	-0.10	2577
sRin3	0.05850	1009	-0.07	2577
sRin4	0.04687	1009	-0.59	2577
sRFB	**0.41790**	**1009**	**-0.53**	**2577**

Table 1: Signal magnitudes and sample location

The occurrence of the maximum and minimum points at the same points for the the signals shows their similarity despite their different amplitudes typicl of a simulated 5G 4 arrayed antenna environment.

From the simulations, the resulting QBB beamformed signal is given in Figure 15 below. As seen the QBB signal has real and imaginary parts plotted. The plot shows a concentration of the signal intensity in between the +/- 3 range on both the real and imaginary axis. These are critical values and areas and other parameters can be derived from the same values. Taking the absolute value of the FFT of the QBB and RF signals is able to give us the magnitude spectrums [25]for the two beamformed signals. As mentioned earlier, the size of the signal assumptions made does not in anyway affect the algorithm and method used.

Parameters once adjusted can be specific to 5G mmWave requirments.

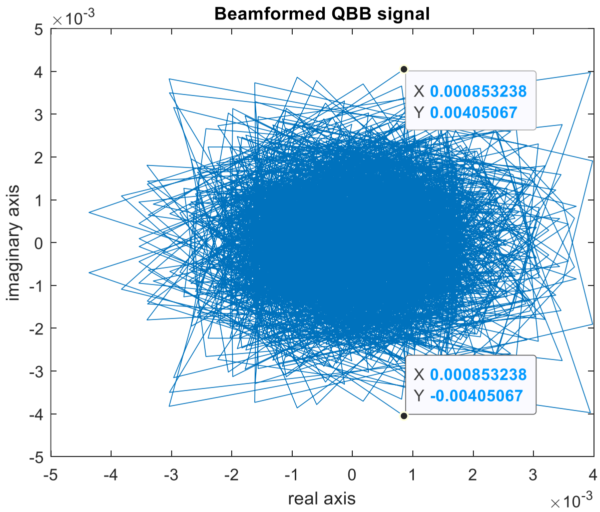

Figure 15: Beamformed QBB Signal

As mention by the authors in[20] , the QBB process involves the Lowpass filtering and other intermidiate processes all upto the final beamforming and plotting stage[24]. A code extract to achieve the process that gave the results is given below;

```
for n=1:1:N
    theta =n*2*pi/N;
for i=1:1:2000 %This function carries out the lowpass filtering.
   s1inqbb1(i)=0;
   s2inqbb1(i)=0;
   s3inqbb1(i)=0;
   s4inqbb1(i)=0;

end
%==========================================================================
    SRFQBBBa=(s1inqbb1+s2inqbb1+s3inqbb1+s4inqbb1);
%we are beamforming at QBB.
    SRFQBBB=ifft(s1inqbb1+s2inqbb1+s3inqbb1+s4inqbb1);
%we get the ifft to complete the QBB process
%==========================================================================
    angle(n)=theta;
    beamQBB(n)=max(SRFQBBBa);
    beamRF(n)=max(SRFB);
%we get the maximum value of SRFQBBB and make a polar plot.

%==========================================================================
```

As mentioned earlier, assumptions were made in the analysis on the signal inputs. Magnitude difference and not time delay is used.

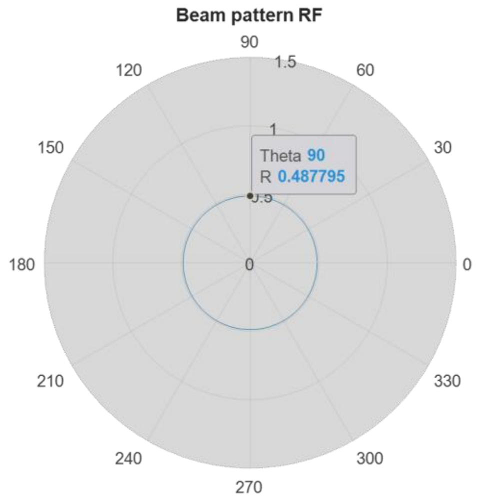

Figure 16: Polar plot of RF beamformed signal

The QBB output is given in Figure 17 below;

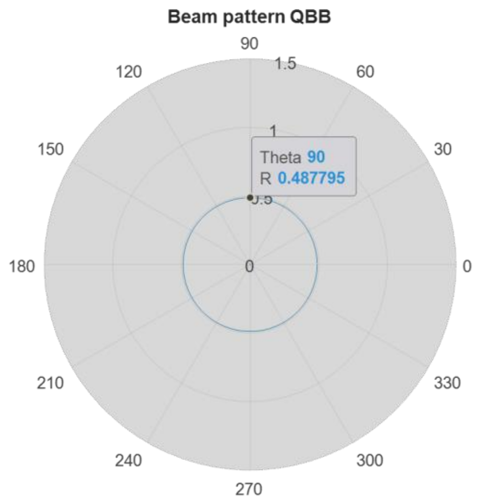

Figure 17: Polar plot of QBB beamformed signal

Given the resulting beam patterns, for the parameters used a difference plot was generated to see the difference between the two resulting patterns. The plot shows that the output was the same and hence a difference plot of zero. In future research and at difference conditions and parameters, results will be shown of how the two methods may produce different beam patterns.

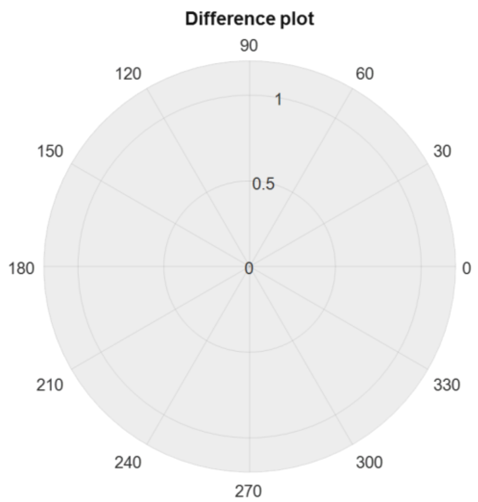

Figure 18: Difference plot

The question arises that then what is the benefit of using QBB? The answer is that QBB brings on board lower operating frequencies in terms of processing but at the same time maximizing bandwidth usage. 5G network resources are expected to be used optimally. From the results obtained other parameters like Antenna gain, throughput, and Bandwidth can be analyzed and future research suggested. From the diagram, the two different beam patterns show the difference in Beam parameters for comparisons to be made between the methods used. The applications of this enhanced 5G technology will enable Internet of Things, (IoT), Machine to Machine (M2M), and medical applications. Agro monitoring is another area that will be taken to the next. The authors in [21] proposed and designed a micro-controllers based method to monitor the environment. A MatLab based server was used. This is amongst several applications that have motivated researchers to continue to push for continuous and this 5G research to the next level.

VI. CONCLUSION

This paper looked at Beamforming using OFDM signaling and was able to show results and the benefits of carrying out analysis through the use of Quadrature baseband (QBB) beamforming in 5G mmWave Networks as an alternative to Radio Frequency (RF) beamforming. MatLab simulations are carried out using OFDM generated signals and results produced to show the benefits of working at QBB. Future works will look at this approach to enable other key parameters in 5G systems are analyzed.

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REFERENCES

[1]. M. S. Aljumaily, A. Hammoodi, L. Audah, H. Li, F. S. Shawqi, and M. M. Hamdi, "Combined Beamforming-Waveform Design using Mid-Band Frequencies for 5G and beyond Networks," *4th Int. Symp. Multidiscip. Stud. Innov. Technol. ISMSIT 2020 - Proc.*, pp. 1–5, 2020.

[2]. T. Varum, "Planar microstrip series-fed array for 5G applications with beamforming capabilities."

[3]. Y. Zhang, D. Wang, Y. Huo, X. Dong, and X. You, "Hybrid beamforming design for mmWave OFDM distributed antenna systems," *Sci. China Inf. Sci.*, vol. 63, no. 9, pp. 1–12, 2020.

[4]. B. Farhang-Boroujeny and H. Moradi, "OFDM Inspired Waveforms for 5G," *IEEE Commun. Surv. Tutorials*, vol. 18, no. 4, pp. 2474–2492, 2016.

[5]. A. Shahmansoori, "Localization with OFDM Signals in 5G Systems," p. 160, 2019.

[6]. Y. P. Lin, "Hybrid MIMO-OFDM Beamforming for Wideband mmWave Channels Without Instantaneous Feedback," *IEEE Trans. Signal Process.*, vol. 66, no. 19, pp. 5142–5151, 2018.

[7]. A. I. P, "Smart Beamforming for 5G and LTE Legacy Systems Carles D ´ Supervised by :"

[8]. Á. Gonzalo, I. Santamaría, J. Vía, F. Gholam, and R. Eickhoff, "Equal gain MIMO beamforming in the RF domain for OFDM-WLAN systems," *Lect. Notes Inst. Comput. Sci. Soc. Telecommun. Eng.*, vol. 45 LNICST, no. Vm, pp. 136–147, 2010.

[9]. M. S. A. Mossaad and S. Hranilovic, "Practical OFDM signalling for visible light communications using spatial summation," *2014 27th Bienn. Symp. Commun. QBSC 2014*, pp. 5–9, 2014.

[10]. S. Pulipati, V. Ariyarathna, U. De Silva, N. Akram, E. Alwan, and A. Madanayake, "Design of 28 GHz 64-QAM Digital Receiver," *2019 Int. Work. Antenna Technol. iWAT 2019*, pp. 193–196, 2019.

[11]. Y. R. Ramadan, A. S. Ibrahim, and M. M. Khairy, "RF beamforming for secrecy millimeter wave MISO-OFDM systems," *2016 IEEE Int. Conf. Commun. ICC 2016*, 2016.

[12]. J. Vía, V. Elvira, I. Santamaría, and R. Eickhoff, "Minimum BER beamforming in the RF domain for OFDM transmissions and linear receivers," *ICASSP, IEEE Int. Conf. Acoust. Speech Signal Process. - Proc.*, pp. 2513–2516, 2009.

[13]. G. Felipe, T. Zugno, J. Kim, M. Polese, S. Bahk, and M. Zorzi, "Full-stack Hybrid Beamforming in mmWave 5G Networks."

[14]. M. F. Raji *et al.*, "A New Approach for Enhancing the Services of the 5G Mobile Network and IOT-Related Communication Devices Using Wavelet-OFDM and Its Applications in Healthcare," vol. 2020, 2020.

[15]. A. Bazin, M. Mimo, F. O. W. Net-, and A. Bazin, "Massive MIMO for 5G Scenarios with OFDM and FBMC / OQAM Waveforms To cite this version : HAL Id : tel-01985409," 2019.

[16]. V. U. Redd, "On Fast Fourier Transform A Popular Tool for Spectrum Analysis," no. October, 1998.

[17]. G. Strang, "Wavelets The transformation of signals into a sum of small , overlapping waves offers a new method for analyzing , storing and transmitting information," vol. 82, no. 3, pp. 250–255, 2014.

[18]. K. Kitao, A. Benjebbour, T. Imai, Y. Kishiyama, M. Inomata, and Y. Okumura, "5G System Evaluation Tool," *2018 IEEE Int. Work. Electromagn. Student Innov. Compet.*, pp. 1–2, 2018.

[19]. Z. Lin, M. Lin, and J. Wang, "Robust Secure Beamforming for 5G Cellular Networks Coexisting with Satellite Networks," vol. 8716, no. c, pp. 1–13, 2018.

[20]. L. Ndovi, C. S. Lubobya, and A. Zulu, "Beamforming at Quadrature Baseband in 5G mmWave Networks and its effects on Antenna Performance."

[21]. J. Kalezhi, J. Mbale, and L. Ndovi, "Microcontroller-Based Monitoring and Controlling of Environmental Conditions in Farming," *2018 IEEE PES/IAS PowerAfrica, PowerAfrica 2018*, pp. 284–288, 2018.

[22]. https://spectrum.ieee.org/video/telecom/wireless/5g-bytes-beamforming

[23]. HTTPS://SPECTRUM.IEEE.ORG/TELECOM/WIRELESS/

[24]. L. NDOVI, "BENEFITS TO PROCESSOR LOAD FOR QUADRATURE BASEBAND VERSUS RADIO FREQUENCY DEMODULATION ALGORITHMS," NO. NOVEMBER, 2008.

[25]. HTTP://WWW.DSPLOG.COM/DB-INSTALL