Spectrum Utilization Optimization through the use of Quadrature Baseband Processing Algorithms in 5G mmWave Networks

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Abstract:- This paper proposed a Spectrum allocation method based on Quadrature Baseband (QBB) algorithm based processing methods. Previous research has been able to show the benefits of using QBB. In this research, we analyze spectrum bands and propose a method of allocation to bidders that considers their processing methods. The financial trends in the Spectrum purchase environment are analyzed. This research was driven by the previous technical research that proved that QBB based methods coupled with other hybrid methods does increase bandwidth availability leading to financial resource usage optimization by Telecommunications companies. The results of the research will be a contribution to investment financial planning by players in the ICT sector as the roll out of 5G steps up going into 2023.

Keywords:- Bandwidth, Quadrature baseband, Spectrum, 5G, Optimization, Telecommunications

I. INTRODUCTION

Spectrum has become the pressing issue in the recent past following the stepped up deployment of 5G communication installations and roll-out. Analysts said that historically, in a spectrum scarce era with a large number of Telecommunication Companies (Telcos) scouting for limited spectrum, they have often over-spent in a bid to reserve good quality airwaves to create an edge in network quality and customer experience. "But now with merely three players in the market with only two of them looking for serious investments, and government's plan to offer spectrum through an annual schedule, there seems limited need to invest at a high price[1]. Industry executives owning Telcos and analysts said Telcos might yet again not manage to acquire certain bandwidth slot allocations on the spectrums auctioned due to the high prices and competition. Industry executives have been keen on putting across proposals for regulation of the available spectrum so as to avoid manipulation by bigger players in the market.

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 area of spectrum usage and allocation optimization in 5G technology. Our research focussed on the aspect of bandwidth optimization through the use of Quadrature Baseband processing methods. The aim of all this research is to ensure that the challenges experienced in the 5G deployment and actualization of the technology's full expectations are achieved. This research therefore, must have a positive impact on the financial aspect of business in the telecommunications sector. There is an ever increasing real-time demand for reliable, safe, high throughput, low latency connectivity in the gaming industry, betting industry, crypto currency, stock markets to mention but a few sectors. Therefore our research must not end at the technical academic input but culminate into practicality leading to the financial growth in the mobile communication sector. There has been support for research in academia with a view to ensuring the challenges emanating from the initial 5G deployment process are worked on and resolved. Other scholars proposed the use of heterogeneous networks in the deployment process and others had novel standalone solutions coupled with hybrid solutions by other scholars. In this chapter of the study, we look at the financial benefits of the methods we proposed. It must be noted that the Telecoms industry is the *fastest growing industry in the technology world* and huge investments in *billions of dollars* have been put into the sector with billions more planned. In 2022, the telecommunications industry contributed 5% to the world's Gross Domestic Product and 4.5 Trillion US Dollars in economic value[22]. Some literature reviewed in line with 5G spectrum, Telecommunication policy and business applications is as summarised below:

Kus' *et al* analysed the C-Band spectrum auctions for 5G in Europe: Achieving efficiency and fair decisions in radio spectrum management. This paper offers a detailed analysis of selected regulatory parameters used as instruments to promote efficiency with fairness for all stakeholders (in the legal sense of equity) in 5G spectrum auction [4] [5]. In [6]–[8] the research concluded that mobile network operators will need to be careful as not all new 5G service offerings may have a positive business case. Future research work should focus on studying other 5G use cases in the port area, and on examining other industrial areas beyond ports such as airports, science parks and manufacturing facilities. Medonca et al [5] presented a systematic outline of the development of 5G-related research until 2020 as revealed by over 10,000 science and technology publications. The exercise addressed the emergence, growth, and impact of this body of work and offers insights regarding disciplinary distribution, international performance, and historical dynamics. The authors in [9], [10] attempt to provide a strong foundation in the analysis of 5G policies in the EU as well as providing insights as to which areas might require further policy action.

Hilten *et al* [7] reviewed current status, opportunities and challenges for 5G agri – food. Agriculture technology collaboration across the private and public sector and ecosystem development are the first steps for all countries to make progress towards large scale uptake of 5G in agri-food. Spectrum allocation thus must take into account that smart agriculture will be heavily dependent of 5G. Beltran [8] assessed the efficiency of the first 5G spectrum auctions held in the United States in 2018 and 2019 in the 24 and 28GHz range and $700 million was raised.

III. LITERATURE REVIEW

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

A. QBB and Bandwidth Utilization optimization

Quadrature baseband is a term that refers to the generation of in-phase and quadrature components of a signal at baseband. The term Baseband is an adjective that describes signals and systems whose range of frequencies is measured from 0 to a maximum bandwidth or the highest signal frequency[8], [11]–[13].At times it is considered as a synonym to lowpass and an antonym to passband[14]–[18]. 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 whose increase is exponential. This growth of the number of connected devices will result in huge amounts of volume of data traffic consumed[16]. In the current world, frequency resources are becoming increasingly scarce with the rapid development of communication technology and billions of devices being introduced. This has resulted in some frequency bands even being reused. However, there are still issues to be solved, such as the optimization of signal waveforms, modulation and coding methods, and the development of signal forming and processing equipment in band-limited. In order to improve the spectrum utilization of the allocated frequency bands, several processing methods have been used and proposed[19]. The re-use of the same frequency bands has been done so as to optimize usage of the available resources but has disadvantages. In its simplest definition, a signal's baseband bandwidth is it's bandwidth before modulation and multiplexing, or after demultiplexing and demodulation. The figure below illustrates the difference between radio frequency and baseband.

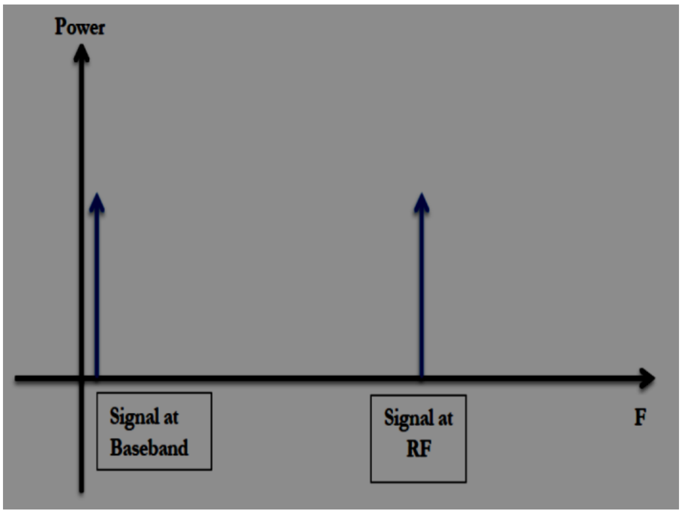

Fig 1.1: *Comparison of the baseband version and RF version of a modulated signal.*

Quadrature modulation/demodulation processes baseband signals which is basically a signal having an in-phase and quadrature phase components**.** Before undertaking the study in depth, It is necessary to define and distinguish clearly the various components of software defined radio[20]–[23] as stated by van Rooyen[24]. The conversion of an RF signal to quadrature baseband involves the down-mixing of the RF signals and then lowpass filtered[24]–[26] resulting in the quadrature baseband version of the RF signal. The real part of the lowpass filtered signal is the in phase quadrature component of the baseband signal. Mathematical analysis of a complex baseband signal shows that we are able to have the ability to modify the output signal due to the frequency domain aspect in the exponential component of the signal. Khare [27] illustrates the mathematical modelling of a complex signal and gives detailed integral illustrations which show the frequency aspect of baseband signals. In quadrature processing, by convention, the real part of the spectrum is called the in-phase component and the imaginary part of the spectrum is called the quadrature component. The signals have a real and imaginary component [27]. Real signals always have positive and negative frequency spectral components. For any real signal, the positive and negative frequency components of its in-phase (real) spectrum always have even symmetry around the zero frequency point. That is, the in-phase part's positive and negative frequency components are mirror images of each other. Conversely, the positive and negative frequency components of its quadrature (imaginary) spectrum are always negatives of each other. This conjugate symmetry is the invariant nature of real signals, and is obvious when their spectra are represented using complex notation. This means that the phase angle of any given positive quadrature frequency component is the negative of the phase angle of the corresponding quadrature negative frequency component. The complex signal is an analytic signal, which signifies that it has no negative-frequency spectral components.

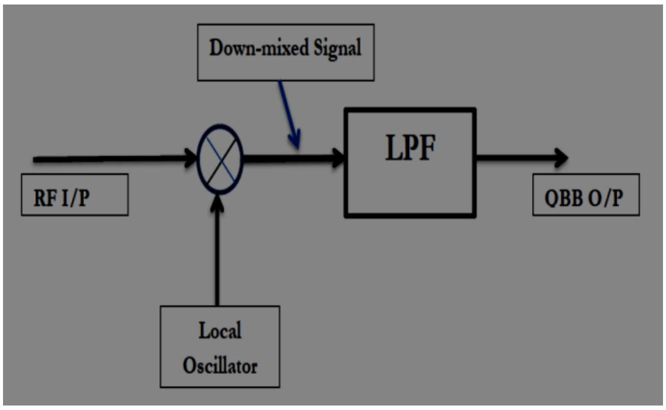

Fig 1.2: *Conversion of an RF carrier to Quadrature Baseband.*

The spectral changes resulting from the conversion to QBB are shown and discussed in figure 1.3.

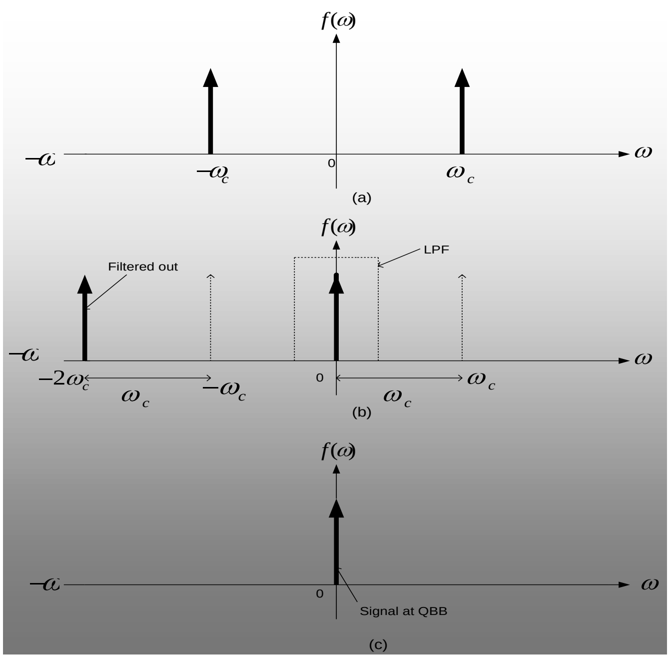

Fig 1.3: *Spectral changes* **(a)** *RF carrier spectrum* **(b)** *Spectrum of down-mixed carrier* **(c)** *Spectrum of QBB signal.*

Figure 1.3 (a) shows the RF carrier spectrum before down mixing. The down-mixing process shifts down the spectral components by ω_c as shown in figure 1.3 (b). The down-mixed signal is then low pass filtered and this eliminates the higher frequency component of the spectrum. This resulting spectrum shows the low frequency carrier component which now sits at zero IF or baseband. This use of QBB signal processing in 5G networks is to ensure optimal utilization of scarce spectrum resources given the huge demand for fast, low latency and precise communications. 5G uses OFDM signals and so our research and novelty is based on the use of QBB processing at the IFFT and FFT stages of the 5G network architecture and this achieves an output that is superior to RF because we are able to vary the parameters in the frequency domain and return to the time domain. By using QBB, we are able to optimize Spectrum usage in that more spectral space is created for other signals to be processed. This in turn should enhance the bandwidth utilization. Figure 1.4 shows a simplified summary of our approach and explains our proposed QBB algorithm based processing.

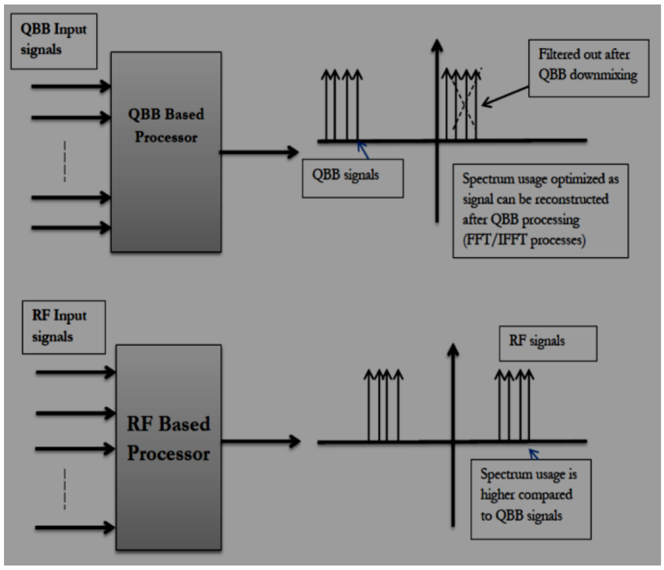

Fig 1.4: QBB vs RF processing spectral comparison

The next section looks at how we implemented our analysis.

IV. RESULTS

A. *Results – Benefits of using QBB processing on Spectrum Utilization*

Our Research approach brings the following benefits:

(i)Processing at QBB frees up bandwidth, which in turn accommodates more processing and users.
(ii) Throughput is enhanced, as expected for 5G Technology.
(iii) Accommodating more users entails that more services can be accommodated.
(iv) The Telecoms and ICT providers will be able to gain financially from their investments as a result of the astronomical increase in services due to optimal utilization of the available resources.
(v) Use of QBB based Beamforming in 5G mmWave technology will greatly enhance MIMO system Technology and more efficient Bandwidth utilization.
(vi) The use of QBB processing entails that Telcos will save on their investment costs in the sense that they can reduce on the number of sites that need to be constructed or deployed in order to manage coverage and services needed by the users. This is due to optimal bandwidth utilization by the 5G network systems.

B. *Results - Spectrum Allocations of 5G spectrum in Zambia and globally*

Table 4.1 gives the proposed spectrum allocations road map for 5G spectrum by ZICTA in 2022.

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Table 1.1 Proposed ZICTA Road Map for 5G Spectrum roll out Source ZICTA (2022) [28]

	Spectrum Band	Frequency Range	Assignable Bandwidth	Timeline
1	700 MHz	703-733MHz /758-788MHz	60MHz	Q3/2022
2	2600MHz	2550-2590MHz	40MHz	Q3/2022
3	26GHz	2403-27.5GHz	32GHz	Q4/2022
4	3300MHz	3300-3400MHz	100MHz	Q3/2023
5	C-Band	3480-3600MHz	120MHz	2024

Zambia has 3 Mobile network operators namely MTN, AIRTEL and ZAMTEL. All these currently are operating 4G communications and on the verge on commencing 5G trials leading to their eventual rollout. MTN recently launched 5G in Zambia becoming the first mobile operator in Zambia to offer 5G services commercially, after successfully running trials over the past 11 months[39],[40]. The launch of this ultra-fast communication capacity serves as a clear indication of MTN's commitment to being a major player in Zambia's digital economy. It must be noted that the roll out of 5G is going to be different based on several factors. In view of this and noting that 5G implementation and adoption is accelerating across the world, the Authority sought to consult industry stakeholders on preliminary views and plans to facilitate for appropriate packaging and timely release of frequency spectrum in harmonized bands to promote upgrade of wireless broadband networks and accelerate 5G into commercial use in Zambia. There are other players in the ICT industry like private Telcos that are also cardinal in the Zambian telecommunications industry. These Telcos are developing software and practical solutions for several sectors in the economy of Zambia ranging from e-commerce, banking, mobile applications, gaming, agriculture to name but a few. It is with this in mind that there must be swiftness in the roll-out of 5G but with caution given the expected challenges. The introduction of 5G is part of a wider network strategy for MTN Zambia. Other Programmes involve the optimization and modernization of existing 3G and 4G networks, the building of a fibre ring in Zambia with MTN GlobalConnect, as well as the extension of coverage to more rural areas. Through their rural connectivity programme, MTN Zambia and its partners plan to use cost-effective coverage alternatives to launch 45 rural sites in 2022, and another 100 in 2023[39],[40].

Equally, it should be noted that with our contribution in addition to other researchers input, optimal usage of the current 4G and 3G platforms is required so that they are utilized optimally and indirectly reducing the pressure during the 5G rollout. According to the regulator, the update to the roadmap is part of the urgent measures to improve competition in the Information and Communication Technology (ICT) sector, promote investments, and accelerate the provision of services in underserved and unserved areas, as well as improve the quality of electronic communication services for consumers in the country [28]–[30][29]. The next sections give the magnitude of investments made by Telcos in Zambia, the region and globally. It must be noted that these figures are from online publications and subject to verification.

In August, 2022, ZICTA put out a communiqué informing the general public that it has revised the 5G Spectrum Roadmap for the release of spectrum in the 700MHz and 2100MHz bands due to high demand. The regulator pushed forward the release dates for the spectrum bands, with the spectrum in the 700MHz band (703-733MHz paired with 758-788MHz) initially scheduled for release in the first quarter of 2023 being rolled out in the third quarter of 2022, while the remaining lot of 40MHz of spectrum in the 2100MHz band (2550 to 2590MHz) was also released in the third quarter of 2022. ZICTA further clarified that the spectrum in the 21 GHz band will be open for assignment on a first-come, first-served basis in the fourth quarter of 2022[9], [10], [151], [197]. Guard band regulation is also done by the authority. Different countries have adopted different guard bands depending on their particular national situation with regards to the number and location of existing[32]–[34]. In line with the Authority's objective to bridge the digital divide, the Authority proposed the view that the 700 MHz band is vital to widespread availability of broadband wireless services including 5G in Zambia. Globally the 700 MHz band is increasingly being used to support wide area 5G services and is regarded as essential for Internet of Things (IoT) applications [28], [30], [33]. Thus it is seen that processing methods that help to optimize the current available spectrum are welcome and supported. The functionality of 5G technically has not been a challenge so far, but it is the expectations and huge demand that has seen unpredicted demand call for optimal utilization of available resources. Telcos compete to buy slots on the auctioned spectra. The authority using its mandate will *ensure equitability* in the use of these resources. Following consultations with stake holders, the road map for the roll out is as shown in Table 1.2. This goes to show that this new 5G Technology still needs huge input from researchers so as to be able to meet the expectations of the users and the output parameters.

Table 1.2 Revised proposed ZICTA Road Map for 5G Spectrum roll out Source ZICTA (2022) [28]

	Spectrum Band	Frequency Range	Assignable Bandwidth	Timeline
1	2600MHz	2500-2640MHz	140MHz	Q1/2022
2	800MHz	791-801MHz /832-842MHz	20MHz	Q1/2022
3	26GHz	24.3-27.5GHz	3.2GHz	Q3/2022
4	C-Band	3300-3400MHz	100MHz	2023
5	700MHz	703-733MHz /758-788MHz	60MHz	2023
6	C-Band	3480-3600MHz	120MHz	2024

The roadmap shall be subject to updating, modification and amendment at any time as deemed necessary by the Authority.

C. *Survey Results Summary*

(i)*Investments in the 5G Technology Roll-out*

Selected are some extracts from countries and Telcos that are rolling out and carrying out preparations for massive 5G rollout.

Airtel has announced that it has purchased 10MHz of additional spectrum spread across the 800MHz and 2100MHz bands from the Zambia Information and Communications Technology Authority for a gross consideration of $29 million, payable in Zambian Kwacha. According to Airtel Zambia, the additional spectrum will support the expansion of the Telco's capability in providing mobile data and fixed wireless home broadband services, and help accelerate the 5G rollout[35].

South Africa's second-largest mobile network operator MTN has announced that it is building private 5G networks for big companies in the mining and port industries. The networks will offer dedicated capacity and guaranteed coverage as the network ramps up its superfast 5G network rollout. MTN's enterprise 5G network will also offer clients cloud computing, unified communication through integrated communication services, cyber security and machine-to-machine communications[36].

(ii) *Spectrum and the rise and growth of 5G enterprises*

The 5G spectrum acquisition race has led to the development of several small businesses being referred to as 5G enterprises. These are companies giving out the 5G experience to clients eager to access 5G services even as the roll out is yet to reach full scale. Indeed, an enterprise in the digital age can only go as far as its connectivity enables it. And like any fuel, making it more efficient and affordable will allow you to go further, faster. That is why ultra-reliable low latency communications show so much promise for the future of business [37], [38]. A number of companies have joined the spectrum acquisition race. The companies with more finances purchase more spectrum and lease to ICT providers amongst others. According to a research by Anderson[37], 5G will only make this ability to connect with others easier. But as analysts and researchers continue to assert, 5G will play a much larger role among businesses than consumers. Instead of connecting humans, we're now turning our attention to machines. By harnessing the speed, reach and scale of 5G, enterprises are at the frontier of a transformational journey to realize a simpler, controllable and more affordable way to connect the machines and devices that power mission-critical operations. In doing so, enterprises will enter the next generation of automation and efficiency fuelled by private mobile networking that knows no bounds. The connected factories that have long been the subject of wide-eyed speculations of the far-off future will become a reality in the surprisingly near term. In many ways, this transition is already underway. Industries like mining, manufacturing and energy, to name a few, are becoming increasingly more reliant on data-generating investments that provide unprecedented operational visibility and uncover new opportunities to enhance worker safety and productivity. However, without a modern, reliable and controllable connectivity foundation, enterprises will remain unable to realize the full benefit of these data-producing technologies[37]. This justifies our proposed research in that we would like to see optimized spectrum usage being appreciated by Telcos. Spectrum auctions in India have a chequered history, in large part due to some of the highest spectrum prices in the world. This time, a second look at the reserve prices and broader reforms to the telecoms market led to a clear success. A new entrant Adani Group also participated, winning some 21 GHz spectrum in certain parts of the country. With this outcome 5G is now poised to play a vital role in fulfilling the Digital India vision, and to realize benefits of at least $455 billion over the next two decades. The auction gives India's mobile operators access to plenty of mid-band spectrum[39]. Access to capacity in the 1-7 GHz range is a must for 5G to flourish. Mid-bands help power innovation in sectors such as healthcare and education, manufacturing, and public administration including smart cities. While mid-band spectrum drives the most benefits, the successful mmWave auction also bodes well. mmWave spectrum is essential for the deployment of high-capacity, low-latency 5G networks. It complements low and mid-band spectrum implementations in dense urban areas and provides fibre-like connectivity through 5G fixed wireless access (FWA) technologies.

D. Spectrum Optimal Utilization Financial benefits

The financial analysis of the 5G deployment in Zambia are best known on the aspect of equipment deployment costs. ZICTA says that although there is uncertainty regarding deployment costs and viable commercial use cases for mmWave bands in Africa, the Authority was of the view that it should promote early adoption and therefore, proposed to take all the necessary regulatory measures to make this spectrum available and encourage early trials and tests in the band to pave way for commercial use[33]. It must be noted that companies like SPACE-X are already considered having using satellite based broadband and this is in a quest to enhance Bandwidth and be able to have as much coverage as possible. In earlier research it has been highlighted that if our approach can also be considered in satellite based broadband communications processing, the financial benefits for Telcos will even be higher. Therefore, our contribution is that of ensuring that the available spectrum is optimally utilized and also the future released auctioned spectra are utilized optimally and financially benefiting costs.

V. CONCLUSION

Our research is a contribution that enables Telcos to optimize their purchased spectrum bands to the fullest. The equipment and gadget manufacturers based on agreed standards set by international IEEE standards will ensure that their financial resources are used efficiently and the savings made can be used for further site developments. Our research does not in any way recommend the doing away with RF processing but to maximize usage of QBB algorithm process so as to optimize bandwidth utilization and financially Telcos will benefits.

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