FPGA Based Register Access and Memory Control for 5G Beamforming Processing

Rakshitha M[1*], Shivaputra[2], Girish Prabhu[3], Chooppakatla Venkata Naveen Kumar[4]

Abstract

The Evolution of radio communication during the last decades has brought major improvements in exploring new types of architecture and technologies to meet the growing demands of the consumer. A fifth generation (5G) network, actively standardized by 3GPP under Release 15, exploits the millimeter wave frequencies to dramtically increase the network bandwidth. Typically, in 5G communication such high frequencies is carried out by newer frequency bands with a wider bandwidth. Besides continous improvements in terms of data capcity, a technique called beamforming is brought up which is distinguishable feature from the previous generations. In the current approach, we design 4T8R macro O-RU to implement beamforming which extracts the beam weights generated by O-DU and sent via C-plane packets, and the address calculation to store the beam weights is calculated with respect to the beam ID. O-RU needs to fetch the beam weights associated with that beam ID from the internal memory. The beam ID serves as a pointer to read from beam weight memory and performs complex multiplication and addition of those to indicate which beam to be applied for further processing. The proposed design is carried out using Verilog HDL and delivered using the Xilinx Vivado Tool and this design is tested on the Xilinx Zynq ZCU102 board which demonstrates that our implementation achieves the IQ data extracted from the C-plane packets and obtains the high gain beam intended for the specific user.

KeyWords: Beamforming, beam ID, beam weights, mmWaves

DOI Number: 10.14704/NQ.2022.20.12.NQ77305 **NeuroQuantology2022;20(12): 3058-3064**

Introduction

The development of wireless communication began in the 1970s that had a continuous growth from analog signals to Long-Term Evolution (LTE). Fourth generation networks were composed of cells divided into sectors that requireimmense power cell towers to fan out signals to cover long range and used the lower-frequency band spectrum. Considering this as the foundation for 5G, signals are transmitted at high-band millimeter waves 24GHz up to 54GHz that rely upon to generate high speeds, as signals are transmitted through abundance of multiple small cells.

The research on 5G led to setting a benchmark not only in terms of communication intended to the consumer market but also sketched to interconnect user devices, machinery objects and automation industry. 5G delivers bettermet in network throughput over the existing 4G classes, besides having data rates with high peak values that is approximately 30 times fatser with more than 10Gbps and connection densities of up to 1000 devices per sqm, up to 100 times more than 4G. Intending to accommodate such communication for 5G, the existing technologies and architecture are not satisfactory.Hence, with incorporating beamforming techniques that constitutes as the essential fundamental that will vouchsafe 5G to meet the demarcated requirements. Beamforming focuses the signal in a narrow beam to the intended receiver which nullifies the interference in the high-density environment rather than broadcasting in uniform directions which is basically a signal processing technique. This approach with advancement in time has progressed as a vital part of communication which introduces a simplified communication interference between the O-RAN

Corresponding author: Rakshitha M
Address: [1]Dr Ambedkar Institute of Technology, [2]VVDN Technologies Pvt. Ltd
E-mail: rakshithagowda077@gmail.com, girish.prabhu@vvdntech.in

units, especially in front-haul, where the C-plane communication carries the beamforming data in several beamforming methods. Directionality of the beam appears by fine tuning theantenna vectors as far as a maximum gain is acquired.
The foremost goal of this design is to transfer the extracted beam weights from DU to RU where every set of beam weights is assigned with beam ID. RU is expected to store the beam weight for a particular beam ID in the memory to save the throughput and perform beamforming. Remarkable improvements and evaluation of the proposed design and performance results to be used as prime technique for 5G systems. On top of that, visualization outcome provides a piece of appropriate knowledge of the examined beamforming behavior.
The outline of this paper is categorized as follows, Segment 2 provides the Literature Survey, Segment 3 confers the concept of Beamforming, Segment 4 Proposed Design and Segment 5 yields the Simulation framework. Lastly, Segment 6 outlines the conclusion of this paper

Literature Review

Mondal et al., [11] provided an overview of wireless communication advancements from the 1970's and the significant breakthroughs and enhancements in each milestone. The first generation was most popular in 1980's where the centre of attention was only voice signals, while the second generation introduced a newdigital technology known as Global System for Mobile communication which set a base standard for further developments. The next era, 3G became chart-topping across the globe by the invention of smartphones. It has been specially designed to broadcast data at higher speeds. Then came the next evolution, 4G which provided internet speed up to 1Gbps. 5G's goal is to provide advanced features that the users have not in the least have experienced before with high data speed and very high bandwidth which sets it as a powerful technology in near future.
LaxmikantBansod et al., [12] in this write up the author talks about the various proposals used for designing a smart antenna. One of the most significant factors that need to be considered in wireless communication. Smart antennas provide a beam pattern in the desired direction by applying a suitable signal processing algorithm with the binary data received from each antenna element. By selectively choosing the algorithm, the system is allowed to sweep the beam with maximum radiation pattern toward the receiver and by rejecting the undesired signals.
Mustafa Mohsin et al., [1] researched on challenges of implementing beamforming in O-RAN while meeting the requirements of low-latency. They started with O-RAN construction and the interfaces between the O-RAN units and also presented the various split options specified by 3GPP standard addressing the challenges to achieve higher flexibility in dense traffic communication environments while reducing the interference caused by the other sources.
Gordana Barb et al.,[2] this paper consisted of a study on beamforming and its types that make 5G mobile communication more efficient. A detailed explanation of digital beamforming was made using massive MIMO technology embedded in it. The analogy of two approaches on digital beamforming techniques- EBB and GoB Beamforming. Results were achieved using Nokia's internal simulator, 5GMax, in terms of BER and throughput.
Marco Giordani et al., [7] provided an overview of beam management and mobility management techniques in mmWave networks, and briefs the insight of how mmWave demands for the exertion of directional transmission accomplished by beamforming techniques. Control procedures for initial access are updated and the optimal beam with which communication is established should be tracked. A brief report on frame structure and reference signals in 3GPP NR, concentrating on frequencies above 6 GHz. Also, they have marked out various beam management procedures for both standalone and non-standalone architectures and evaluated their performance.

Beamforming

Beamforming is fundamentally a special type of technology to form a beam that lays a radiation pattern for a set of antenna systems. In 5G systems, beamforming is used to steer the signal in an angular direction from the base station to the intendedBeamforming
Beamforming is fundamentally a special type of technology to form a beam that lays a radiation pattern for a set of antenna systems. In 5G systems, beamforming is used to steer the signal in an angular direction from the base station to the intended

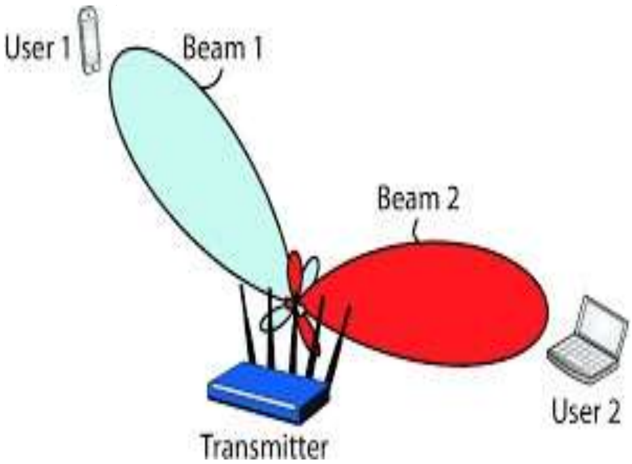

Fig 1. Typical Beamforming Scenario for End Users

Accompanying, the antenna array elements are designed in such a manner that side lobes are nullified. At the receiver, each antenna element's response is coherently combined to get the required signal to maximize the optimal gain. Beamforming has a set of procedures for the management of beams which include beam steering, beam selection, beam measurement, and beam reporting. Figure 2, for the generated condition the intended beam is steered to the desired user and at the coexistent moment null is generated for the interferer in order to provide directionality to the user with high throughput

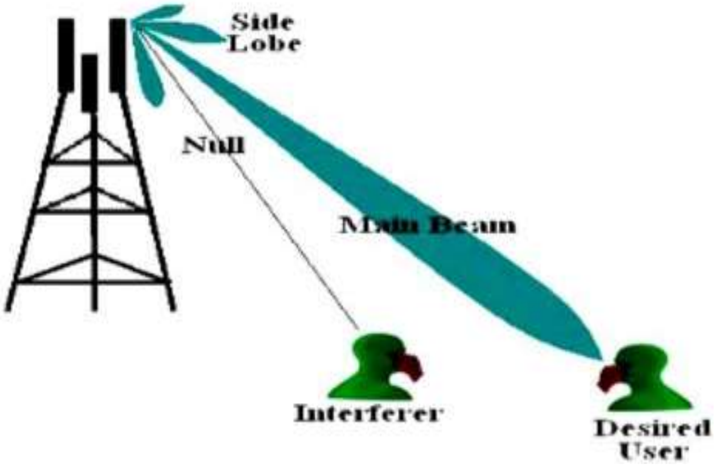

Fig 2. Main Beam towards desired users and null toward interferer

3GPP standard has introduced the split options so that designers achieve greater flexibility along with increased performance. Open RAN has adopted split option 7-2x in the fronthaul interface which has never been used before which simplified communication interference, especially in front-haul, where beamforming can be implemented O-DU and O-RU based on Category A or Category B. In our implementation, we focus on Category B where each RU interference carries the beamforming matrices through the C-plane channel and generates a precoding beam in O-RU where precoding weights are embedded in beam weights. In our design, we use the combination of both Predefined beam forming and Weight Based Dynamic Beamforming to transfer beam weights to RU.

Analog Beamforming

This is the simplest method, where the signals received from multiple antennas are sent to the phase shifters with the phase being changed in the analogue domain. For implementing designs with a key factor of low cost then its preferable to consider analog beamforming. Each signal path that arises from individual antennas is totalized prior to Analog-to-Digital Converter (ADC) at the receiver end.

Digital Beamforming

In this, the amplitude and phase of the beam signal is controlled by making use of RF chains and determined baseband where each signal is precoded in baseband processing before transmission. In our design, we focus on the implementation of digital beamforming.

Hybrid Beamforming

It is a combination of analog beamforming executed in the analogue domain and digital beamforming in the baseband domain which offers a trade-off between the flexibility of digital beamforming and low power consumption and low cost of analog beamforming.

Proposed Work

Predefined beam forming and Weight Based Dynamic Beam forming respectively are implemented in the design. The DU uses a combination of above-mentioned beamforming techniques to transfer beam weights to RU. Control logic receives the C-plane extracted information from front-haul IP AXI Register Configuration (S-plane) configures the corresponding registers in beamforming register space and generates the write operation to strobe the Beam ID in Beam ID memory and Beam weight memory. Mux is used to select either C-plane extracted data or S-plane to populate in the Beam ID or Beam weight memories. FIFO used to store the write request and FSM generates the writes into the memories based on the information. BRAMS are used for BID memory.

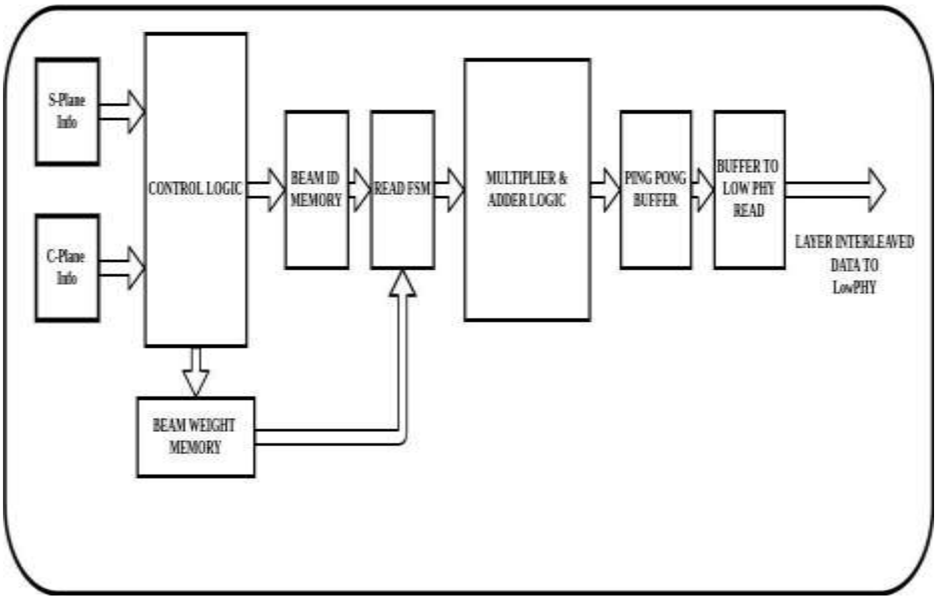

Fig 3. Proposed Block Design for Beamforming

The memory is reset during initialization and all valid bits are set to 0. The valid bit is to distinguish the user allocated PRBs from the zero padded PRBs. During every write cycle, the valid bit is set to 1. The number of REs for which a beam ID is valid is calculated using num PRB, i.e., the beam ID is valid for num PRB * 12 cycles. The beam weights for a particular antenna are segregated together in one memory. Thus, 8 such memory locations are present to store beam weights for all 8 antenna channels. In this way, the beam ID can be directly used as the address location to write the beam weights.

Beam weight FSM reads the beam weights from the memory. The beam IDs are fetched in a sequential manner from the beam ID memory. While reading the beam ID, the FSM will extend beam weight for the required active cycles of the PRB if the bit is valid, else for invalid PRBs 12 cycles of 0's will be streamed out and address would be incremented by 1. Based on the beam ID, the corresponding address location which stores the Beam Weights for 8 antenna channels are read.

The numprbc field indicates the number of cycles

for which the beam weight should be held active in the bus.
The DL read module reads the IQ Buffer data do complex multiplication and addition operation. Complex multiplication operation is performed by Xilinx Complex multiplier IP. A complex multiplier is instantiated to process data in all 4 spatial layers. The output of these complex multipliers is added to generate input for one antenna channel. The Buffer to lowPHY read module reads the data in a layer interleaved manner to the lowPHY module.

Simulation Results

In this section, we present the results obtained for our design using Xilinx Vivado Tool. In our work, we implement beamforming as a 4X8 matrix where there are 4 spatial layers and 8 antenna channels per carrier in downlink. The total number of beam weights assigned to a beam ID is equivalent to the number of antenna channels * number of spatial layers. The purpose of C-plane messages is to exchange the scheduling information and beamforming commands required for processing between O-DU and O-RU. The C-plane frame format consists of various parameters; the transmitter should fill the data in the corresponding sections to minimize the traffic and also to ensure successful transmission of packets. The commands required for transmission from O-DU to O-RU are: Data_direction bit, indicating whether it is an uplink or downlink transmission. eAxC, indicates to which antenna port the data has to be mapped. Frame_ID command, acts as a counter for the frames each of 10ms. Subframe_ID, this section gives the description of the counter value which consists of subframes inside a frame. Slot_ID, this parameter provides the numbers to the slot in the sub frame and counter running from 0 to N slot-1. parallel as 4 AXI streams in order to multiply with the beam weights. Each sample data will be held for 4 cycles to Start_symbolid, this field provides the information of the first symbol to which the message is applied. Section_ID, this field is required to map the C-plane data to the corresponding U-plane data section. StartPRB, indicates the starting of the physical resource block. NumPRB, this field indicates the number of continuous PRB for which the beam ID will be the same. StartPRB and NumPRB should not overlap. Beam ID, this field provides the information for RU to select the correct beam weight from the memory to build a beam.
The beamforming module receives the C-plane data which is of 128 bits since it
carries 4 layers of data. Each layer consists of 32 bits of data consisting of 16 bytes of in phase data and 16 bytes of quadrature phase data. With the help of AXI Stream protocol the incoming data is monitored. Bfo_dl_data [127:0] is the data signal of 128 bits width. We consider keeping the incoming data as valid by keeping the valid bit high. Valid bit with the value FFFFh indicates that all the 32 bits are valid.
Frame_tick is high after every frame data. After receiving every slot in a frame slot_tick is made high. The axi_tsuer is a 4-bit signal that represents the spatial layers.
Upon receiving this field information, write logic starts to generate the write
address to store the corresponding beam ID and RU fetches the beam weights associated with the beam ID from the memory and each sample data will be held for 4 cycles to do complex multiplication and addition operation passes these corresponding data to the low PHY module.

Fig 4. Simulation of Beamforming Top Module.

Fig 5. Complex Multiplier and Adder

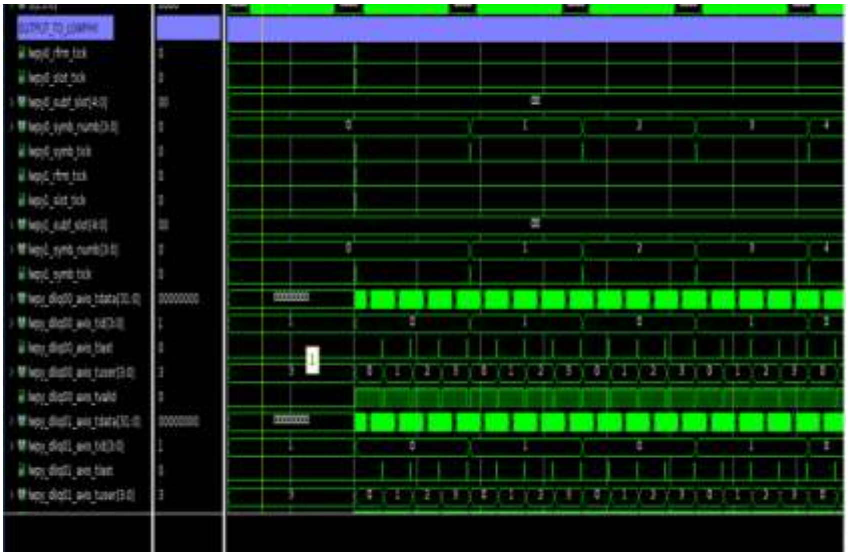

Fig 6. Output to LowPHY Module

Conclusion

A challenge for the 5G cellular systems operating at mm Waves is the need to sustain a high dense environment and its essential to produce a high directional beam between the communication endpoints. İn the light of this, the design and implementation of initial access for beamforming and beam tracking procedures able to systematically pick out the effective beam pair with which communication is established is prominent. İn this paper, we implemented beamforming using a suitable type of digital beamforming where the Distributed Unit sends the beam weights generated in sync with the beam Id value associated with the weights with respect to the user location to the Radio Unit. The simulation results tell us how beamformed samples for 4 antenna channels are generated using a single beamforming block having 4 complex multipliers. İn conclusion, we observe that by implementing beamforming that corresponds to an increase in the antenna gain and directivity which forefronts 5G communication as superior when compared to the previous cellular.

References

Mustafa Mohsin, Jordi MongayBatalla, EvangelosPallis, George Mastorakis, Evangelos

K. Marakakis and Constandinos X. Mavromoustakis, "On Analyzing Beamforming Implementation in O-RAN 5G," Article

Gordana Barb, Marius Otesteanu, Florin Alexa, Ana Ghiulai, "Digital Beamforming Techniques for Future Communication Systems," 2020 12th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP).

Irfan Ahmed, HediKhammari, Adnan Shahid, Ahmed Musa, K wang Soon Kim, Eli De Poorter, Ingrid Moermrcan, “A Survey on Hybrid Beamforming Techniques in 5G: Architecture and System Model Perspectives,” IEEE Communications and Surveys, 2019.

Joyce AyoolaAdebusola, Adebiyi Marion Olubunmi, Adebiyi Ayodele Ariyo, Okesola Olatunji Julius, “An Overview of 5G Technology,” IEEE Journals, 2020.

Marco Giordani, Michele Polese, Arnab Roy, Douglas Castor, Michele Zorzi, “Standalone and Non-Standalone Beam Management for 3GPP NR at mmWaves,” IEEE Journals, 2019.

Dariusz Wypior, MiroslawKlinkowski, “Open RAN- Radio Access Network Evolution, Benefits and Market Trends,” Article in Applied Sciences, January 2022.

R Thandaiah Prabhu, M. Benisha, Dr. V. Thulasi Bai, V. Yokesh, “Millimeter Wave for 5G Mobile Communication Application,” International Conference on Advances in Electrical, Electronics, Information, Communication and Bioinformatics (AEEICB 16), 2016.

3GPP, “NR - Physical layer measurements - Rel. 15,” TS 38.215, 2017.