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Holographic Beamforming for High-Speed Network in 5G Communication

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Abstract

The 5G wireless communication system or New Radio (NR) has more features and useful for various high-end applications than 4G. This allows accessing the information and distribution of data anytime, anywhere using mmWave frequencies presenting the availability of huge bandwidths with high data rates for the next generation mobile users. But mmWave are highly prone to fast channel variations and undergo atmospheric absorption and path loss. To overcome this, user equipment (UE) and the base stations (gNB) should develop highly directional antennas so that, there is a need for accurate configuration for the receiver and transmitter beam which will improve the performance measurement. mMIMO (Massive Multiple Input Multiple Output) and mmWave will improve the network capacity and coverage but using a fully digital MIMO beamforming method requires one RF (radio frequency chain per antenna element, which is not feasible for large antenna arrays because of more power consumption and high cost. To improve this paper discuss the new dynamic beamforming technique called Holographic Beamforming (HBF) using Software Defined Antenna (SDA) with the lowest C-SWaP (Cost, Size, Weight, and Power) architecture at the base station side that reduces operator OPEX and CAPEX. The uplink-based method by holographic beamforming system to reduce power and save the cost in 5G mmWave cellular network.

Disciplinary: Communication & Information Technology.

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1 Introduction

Each mobile generation has presented lower latency, with faster data rates and new frequency bands. We are moving from the wired to the wireless world (WWWW) moving from 1st Generation (1G) which introduced analog communication system in the year 1980 to 2nd

Generation (2G) digital world in the year 1990 and the CDMA technique which was launched in the year 2000 marks the 3rd generation (3G) which leads to increase in efficiency of network the 4th Generation (4G) and 4G LTE (Long Term Evolution) provided the IP based services with higher data rate with multimedia facility introduced in the year 2010. Fifth-generation (5G) wireless networks have already been used in some parts of the world. Very soon we can see the 5G around us with considerable improvement over the 4G. 5G Network provides low response time, increased speed, greater capacity, and good quality of service (QoS) as compared to 4G. We will have new techniques and a new frequency (mmWave) of licensed and unlicensed bands. In the last ten years due to the introduction of smart devices and machine-to-machine communication, the data traffic has increased immensely and it is expected that in comparison to 2010 the mobile traffic will increase 670 times in 2030 and by the end of 2030, the mobile data traffic will go beyond 5 ZB per month as forecasted by the International Telecommunication Union (ITU) (ITU-R M.2370-0, 2015). As compared to 2010 the mobile subscription may reach 17.1 billion in 2030 as compared to 532 billion also the M2M subscription will reach 455 times in 2030 as compared to 33 times in 2020 as shown in Figure 1(a) (ITU-R SM.2352-0, 2015) and (b) (ITU-R SM.2352-0, 2015).

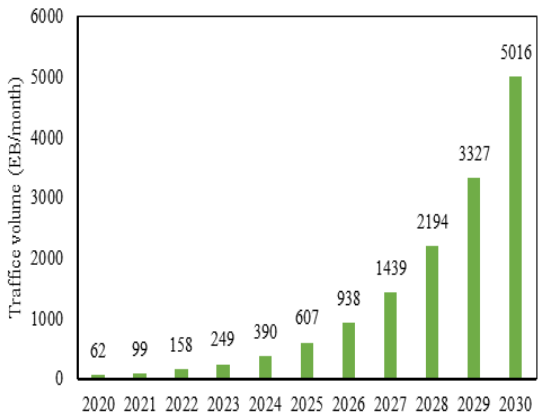


Figure 1. (a) Traffic size worldwide

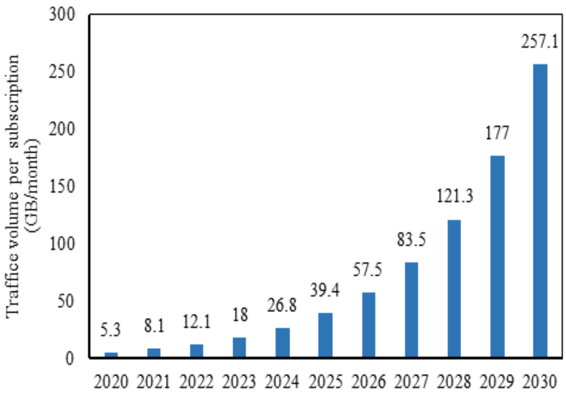
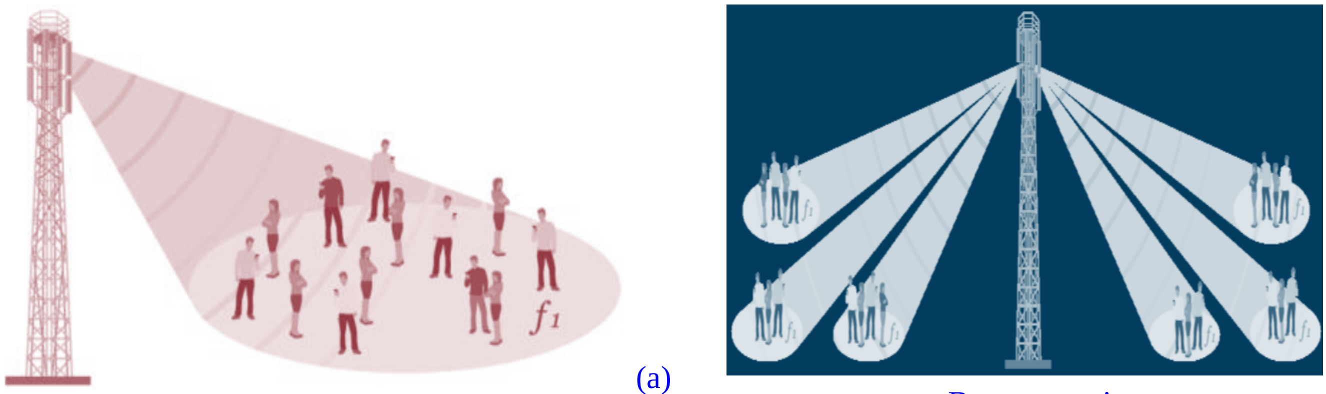


Figure 1. (b) Traffic size per subscription

For the last seven years, wireless communication industries and researchers are looking for the broad spectrum at ultra-high frequencies to meet the performance demand suggested by the international telecommunication Union, the 3rd Generation Partnership Project (3GPP) to start operating on mmWave frequencies band for 5G networks but the mmWave are extremely susceptible to a high-speed channel variation and it also suffers from atmospheric absorption and path loss due to short range.

2 Beamforming

To overcome poor propagation a highly directional and huge antenna array Multiple-Input Multiple-Output (MIMO) is required as an outcome of this is radiation that would be a beam called beamforming in a particular direction. The traditional cellular system uses antennas that broadcast energy at 60 to 90 degree and the UE listen for their code of interest. Whereas beamforming allows more focus between users (UE) and base station (gNB) and extremely dedicated beamforming that would improve SINR (signal to interference and noise ratio) of a communication channel as shown in Figures 2(a) Traditional cellular system and 2(b) Beam scanning.



(a) Traditional cellular system

(b) Beam scanning

Figure 2: Communication channels (Black, 2017).

Signal strength is improved by focusing power on the desired user. By reducing the angular field Noise the interference can be reduced. Need to track and identify the best possible receiving and transmitting pair of the beam to get a reliable connection with a high data rate. This is more severe in switching from Line-of-Sight (LOS) to Non-Line-of-Sight (NLOS) due to several obstacles. Finding the optimal beam is quick enough then the users will be disconnected from the allocated base station. In our traditional system (low frequency) a single transmission will cover many UE concurrently but in the case of the radiation beam, it is difficult to cover many UE simultaneously in a single transmission unless they are located very close to the radiator. To overcome such kind of a problem there is a need for a mechanism for managing and controlling the beam to handle all the devices in various directions in different situations. The collection of all these thoughts is identified by the 3GPP as Beam Management consisting of all beam-related mechanisms to identify the best possible beam for transmission and reception (Herranz et al., 2018). The benefit of beamforming is that you are transmitting a signal at the desired point which helps to reduce interference from other signals. One of its limitations of it can be it requires computing resources where time and power resources are used which negates its advantage. Beamforming Architecture: various types of beamforming architecture are available analog, digital and hybrid which can be used either at the base station (gNB) or at the terminal (UE). 1) Analog beamforming, a single RF (radio frequency) signal is given to the chain of antenna elements by passing through analog phase-shifters where the signal is improved and directed to the indented user. Processing is done in the analog domain, so it generates and manages transmission or receiving in unidirectional. 2) Digital beamforming: the aim of this is to correctly translate the analog signal to the digital domain by converting the RF signal at every antenna element into two streams of baseband signal where received signals amplitude and phases are recovered from every element of the chain. Every antenna consists of its own data converter and transceiver so that simultaneously many beams are generated from a single array. At the transmit end amplitude or phase difference is applied to the digital signal prior to DAC conversion. The signal received from the antenna passes through ADC and DDC converters. 3) Hybrid beamforming: To take the advantages of analog and digital beamforming both are combined to form a hybrid one called hybrid beamforming that provides the flexibility of beamforming and MIMIO which results in reducing the losses and cost incurring in beamforming unit (Molisch et.al., 2017; Busari et al., 2017). Every data stream possesses a separate analog beamforming unit with a set of antennas. Sometimes the digital beamforming unit is used to guide the direction to the main beam whereas the analog beamforming unit guides the beam to the digital domain (Ahmed et.al. 2018).

2.1 Challenges Faced by Digital Beamforming

1**)** Quantity of data generated: When higher resolution and sampling rate are demanded for increased bandwidth it's difficult to handle the amount of data that is generated. 2) Power consumption: More and more power is required for the Processors. The constraint in data bandwidth puts a limitation on the array of the element that needs waveform generators at every element. 3) Loss: Higher frequencies, mmwave communication include path loss, atmospheric absorption from rainfall and various gases present and non-line of sight (NLOS) transmission. 4) Cost: Due to the physical size of electronics instruments and more numbers of ADCs which are operating at higher frequencies are involved. As discussed the comparison is summarized in Table I

Table 1: Comparison of beamforming Techniques

Features	Analog beamforming	Digital beamforming	Hybrid (Analog - Digital) Beamforming
Number of streams	Single stream	Multi-steam	Multi-steam
Users Supported	Single user	Multi user	Multi-user
Signal control capability	Phase control only	Phase and amplitude control	Phase and amplitude control
Hardware requirement	At least; one RF chain only	Highest; the number of RF chains equals the number of transmit antennas	Intermediate; the number of RF chains less than the number of transmit antennas
Energy consumption	Least	Highest	Intermediate
Cost	Least	Highest	Intermediate
Performance	Least	Optimal	Near-Optimal
Suitability for mmwave Massive MIMIO	Unsuitable; no amplitude control, no multi-user	Impractical; prohibitive cost and high energy consumption	Practical and realistic

3 Beam Management

It comprises of 1) beam sweeping ideally which means a Base station operating with very high frequency supporting Massive MIMO would start the Synchronization process once the UE is turned on nearby it. Each UE will be able to receive the synchronization signal from the base station which transmits the beam in a particular direction at an exact time and will vary its direction slightly in the next time frame till it scans the whole area it is supposed to cover. 2) Beam Control or Measurement to determine the quality of beams. 3) Select the best quality Beam 4) finally reporting of the best quality by UE to the base station. As in currently cellular based schemes presented framework was proposed in (Giordaniy et al., 2016) and applied by Polese et.al. (2016) instead of using channel quality of the DL (downlink) signal it uses UL (uplink) based signal and with the help of a central controller (which operates at sub-6 GHz frequencies an (eNB)) it facilitates efficient measurement process. In this Uplink-based framework, a terminal (UE) search for synchronization signals from traditional 4G cells. This action is performed very fast since it is unidirectional and there no directional scanning is required. Taking into consideration that 5G mmwave are nearly timely coordinated to 4G cell and since roundtrip propagation times are small, in uplink-based transmission UE will be timely aligned to close mmwave(Marco Giordaniy et.al., 2016). As shown in Figure 3 exchanging of messages and signals during DL it consists of:

1. Beam Sweeping: Every terminal (UE) transmits the SRS (sounding reference signal) directionally in a timely manner so that it sweeps the whole angular domain space continuously.
2. Beam Measurement: Each potential serving base station (gNB) scans all its angular domain space directionally and received SRS is monitored for its strength and a report table is built accordingly based on the channel quality of receiving direction.
3. Beam determination: After finalizing the report table (RT) for each terminal (UE) from mmwave base station gNB. The information is received to LTE eNB from each mmwave cell since the report table contains the signal quality for each base station (gNB)-terminal (UE) pair and the beam with the highest quality is selected to provide maximum performance (Giordani et al., 2017).

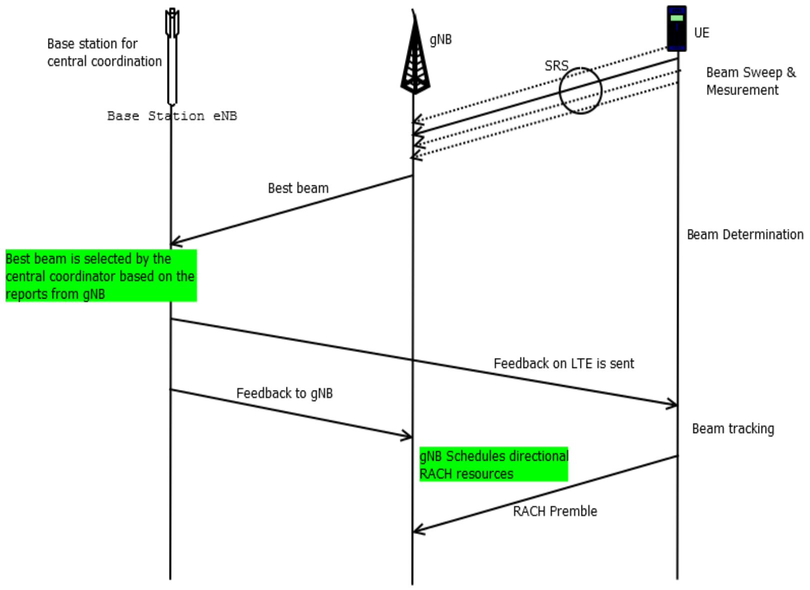


Figure 3: Beam management procedure for messages and signals exchanged during DL

Beam tracking or reporting: the central controller informs the terminal (UE) on a traditional LTE connection that which base station provides the best performance along with the best direction to which the terminal should guide its beam to connect the required cell in the best possible way. If the terminal (UE) is not able to receive the best mmwave link so to avoid the probable point of failure in the control signaling path LTE control link is tracked and since path switching is also frequently involved. Each serving UE is informed about the best direction in which to transmit data through the selected base station (gNB) through the high capacity link informed by the central controller by a high-capacity link (Giordani et al., 2019). Generally using digital beamforming and taking into account the small antenna factors. RACH allocation is completed by beam reporting which ensures minimum delay. Due to fewer demands of space constraints at the base station (gNB) as compared to the terminal (UE) so more antenna chains can be packed at the gNB which enables digital beamforming to scan more number of directions simultaneously. As previously discussed power consumption is more in fully digital or hybrid receivers and instead of implementing at the UE side so it should be implemented at gNB. To overcome the weakness of MU-MIMO, the Massive Input Multiple Output (MIMO) system is implemented which consists of multiple antennas elements at the base station (gNB) and at the terminal (UE) as compared to conventional MIMO system thousands of antennas located at base station work concurrently for the smaller number of terminals by using similar resources that increase the wireless capacity much more but large antenna array creates interference problem that can be minimized using beamforming antennas. When used in mmwave the MIMO small size antennas severely decrease the cost and power not just by employing low-power-low-cost components but also by removing expensive and large components and high-power radio frequency amplifiers.

4 Holographic Beamforming

Massive MIMO capacity increases monotonically with antenna numbers but could it be possible to have infinitely many antennas so there can be some ways it’s possible by integrating an unlimited number of antennas into a small surface area in spatial continual receiving/transmitting aperture. This requires fundamentally a new thought for analyzing and designing the antenna arrays that can be called holographic beamforming (HBF) gives higher SINR (signal to interference and noise ratio), improved coverage and throughput Emil (Björnson et al., 2019). The new method of beamforming uses a Software Defined Antenna (SDA) by using a minimum C-SWaP (Cost, Size, Weight, and Power) design and that is significantly different than the MIMO system no internal active amplification is used in HBF; it’s a passive electronically steered antenna (PESAs) for RF (radio frequencies) in mmwave band that enables symmetric transmit and receives for HBF antennas (Black, 2017). A discrete phase shifter is not used to perform steering of the beam by the antenna but performed by a hologram here holographic uses a hologram to attain beam steering by antenna whereas in an optical hologram antenna behaves like a holographic plate, at the backside center of the antenna connected to RF signal flows from radio and distribute across its front where minute elements correct the shape and beam direction as shown in Figure 4 (Black, 2017) SDA are inexpensive, size is smaller, lighter and needs less power. There are basically two steps in it as shown in Figure 5(a) first part consists of Holographic or recording whereas the second part is reconstruction shown in Figure 5(b)

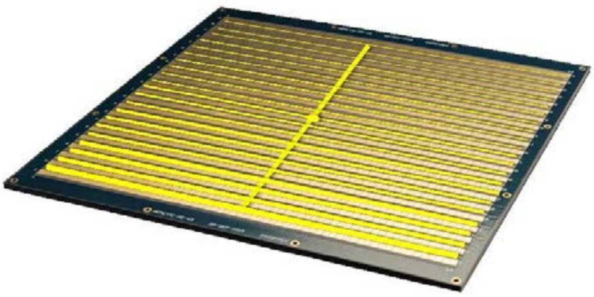


Figure 4: Reference Wave distribution network for HBF

The signal generated from the RF signal generator, a signal or source is fed to a beam splitter that spits it into two waves one is directed towards the reflecting object called an illuminated wave other parts that are not able to reach the reflecting object are mixed with the reference wave beam which then directed to photographic plate according to the signal received at the photographic plate the reference wave is converted to the required beam to the reflecting object (Chongwen Huang et.al., 2019). Commercial off-the-shelf (COTS) High-volume components are used for the construction of HBF antennas. This widespread use of extremely low-cost components in headsets brings down the cost. Since beam pointing is achieved through the large set of reverse biased varactor diodes that draws very less power by the antennas as good as USB. This avoids cooling and helps to reduce the size and weight. As discussed previously MIMO utilizes the antennas/radio pairs to accomplish the beamforming complex structure required to perform. Whereas holographic beamforming has used a simple control structure and antennas are very closely packed some of the differences are mentioned in table II.

Table 2: Difference between MIMO and HBF

Architecture	Cost	Size	Power Consumption	Challenges
Holographic beamforming (HBF)	COTS is designed so inexpensively	Thin	Less	For polarization single beam is required
MIMO	High Price since radio behind each element	Thick	High	Spectral efficiency Vs cost scales poorly

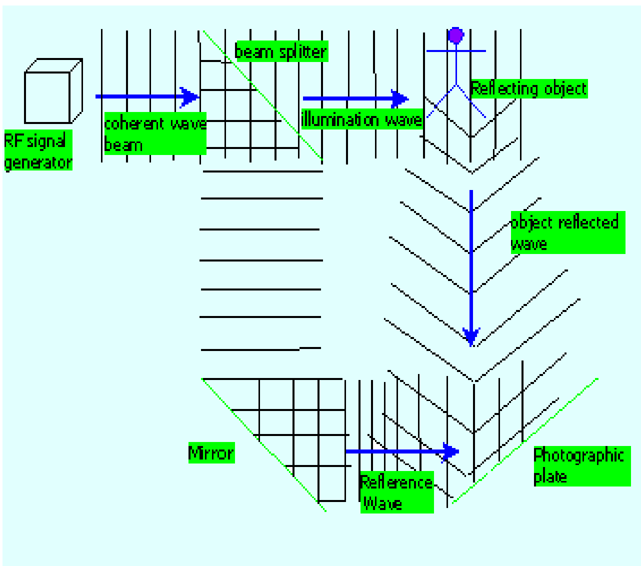


Figure 5(a) Holographic recording

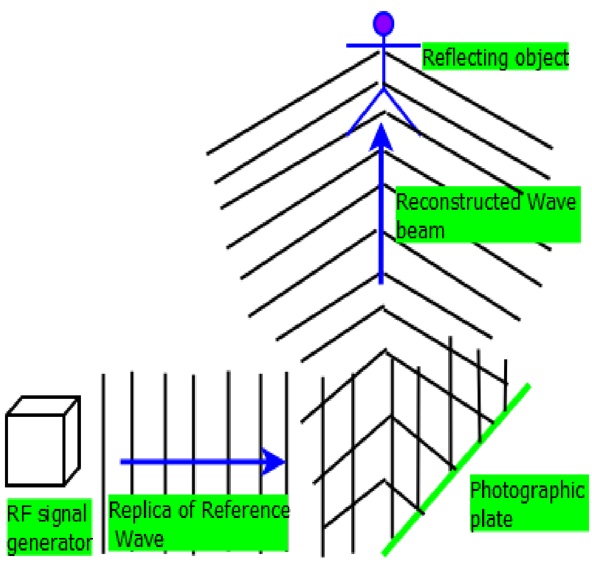


Figure 5(b) Holographic reconstruction

5 Conclusion

5G mmWave is highly vulnerable to fast channel changes which affect the mmWave environment. To cope with such a situation angular sweep in all the directions is performed that will regularly observe the directions of transmission for the possible link and adjust the beam steering after the signal drop is detected. An uplink-based measurement scheme is discussed where digital beamforming at the receiver side will get better reactiveness and helps to reduce the overhead without scarifying the accuracy. A hybrid beamforming configuration provides a trade-off between a simpler, reduce consumption transceiver design and better reactiveness. Digital beamforming architecture used at the base station (gNB) leads to higher gain with regard to the reactiveness in the Uplink-based method because the directions to be swept are more at the gNB than at the UE. One other better option can be used of HBF (holographic Beamforming) as we know that conventional cellular network (4G) signal is broadcasted in all directions as compared to software-defined MIMO antenna the signal strength from the base station is directed towards the targeted user which enables us to achieve high throughput in terms of Gigabits, SINR (Signal to Noise Ratio) is improved, reduction in transmission power and also leads to increase in the coverage area. Space Division Multiple Access (SDMA) is utilized in HBF, to optimize the overall performance MC-CMDA (Multi-Carrier Code division multiple access) can be deployed in the sub-carrier transmission of signals. It offers cheap manufacturing, is weightless, less spacious and consumes less power.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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