

A Survey on Hybrid Beamforming in MmWave Massive MIMO System

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Abstract: The escalating demand for wireless data traffic has prompted the need to explore the area of spectrum suitable for meeting the expected requirement. Sub 6 GHz is highly occupied so the researchers are moving towards mm-wave where a spectrum range from 30-300 GHz is available. Channel modeling and hybrid beam-forming has become integral part to realize a system in mmwave frequency band. In this paper we trace the advances in hybrid beam-forming for mm-wave Massive MIMO communication in the context of hybrid beam-forming architectures, and pre-coding techniques in different channel environment. We have also compared the spectral efficiency of different pre-coding techniques employing different antenna array size at the Base Station.

Index Terms: Phase Shifter, Precoding, NOMA, RF Chain, Channel State Information (CSI), Analog/Digital Beamforming.

I. INTRODUCTION

The communication system must be designed in such a way that they travel most efficiently from the transmitter to the receiver unit in a mobile cellular infrastructure. MIMO is an enabling technology to scales up the data rate and encounter the escalating use of inflated rate of data, SE and bandwidth in future communication (Tyagi, 2019). MIMO refer to the deployment of many antenna elements at a Tx and Rx of communication link. Spectral efficiency can be improved either by the simultaneous communication of base station with the different user in the same available resources or by the multiple parallel transmission of data to the users.

The use of DB in Massive MIMO increases spectral efficiency; however the discrete RF chain of each antenna element causes an addition in the hardware cost and the power expenditure (Arora, 2019). Relative to a small number of antennas at BS, analog or digital beamforming is appropriate but due to the huge antenna array in Massive MIMO, a combination of DB and AB is used to develop HB to have a decrement in the RF chains

required (Tyagi, 2019). In digital domain, beam-forming can be achieved at the baseband frequency while in analog dominion beam-forming is developed using low cost PS.

A. Massive MIMO

The massive MIMO is a scheme in which the number of BS antenna array is hefty than the user antenna array. The motive of this technology is to maximize the benefits of traditional MIMO systems and it acts as a driver for added power efficient, safe and long lasting systems. The potential of large MIMO systems depends greatly on the accessibility of CSI. In MIMO system, for the base station to have CSI, it is preferably accepted that the system functions in TDD and exploits the uplink/downlink reciprocity. In TDD, time-frequency plane is chopped off into small channel coherence interval. Every such coherence interval is divided in to uplink and downlink part. All UE send pilots and payload data in the same coherence interval. The BS evaluates the channel parameter during the uplink and uses the same for downlink transmission. In massive MIMO the channel reciprocity is preferred below sub 6 GHz because signal can penetrate through different objects, walls and also can bend around corners providing a long coherence interval in high mobility. The channel evaluation time increases in FDD based Massive MIMO system due to the utilization of huge antenna array. In addition, users retransmit the estimated channel to the BS, which increases feedback costs (Adhikary, 2013). The Massive MIMO HB method that supports many UEs provides advantages over methods that support only one UE or one set of UEs. In (Zhu, 2016) states some of the HB methods assign the whole band to a single UE but the scheduling of these users has imperfect flexibility. A minor number of UEs are scheduled per scheduling period which causes data latency in UEs and also resource efficiency is very low because few UEs may not need to be serviced by the entire band.

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Table I: Summary of Abbreviations

Symbols	Description
AB	Analog Beamforming
ADC	Analog to Digital Convertor
AoA	Angle of Arrival
BD	Block Diagonalization
BER	Bit Error Rate
BS	Base Station
CEE	Channel Estimation Error
CmWAVE	Centimeter Wave
CSI	Channel State Information
DAC	Digital to Analog Convertor
DB	Digital Beamforming
DFT	Discrete Fourier Transform
EB	Eigen Beamforming
EE	Energy Efficiency
FC	Full Complexity
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
HB	Hybrid Beamforming
JSDM	Joint Spatial Division Multiplex
LNA	Low Noise Amplifier
LOS	Line Of Sight
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
MMSE	Minimum Mean Squared Error
MS	Mobile Station
MU-MIMO	Multi User MIMO
MmWave	Milli Meter Wave
MU-MISO	Multi-User Multiple Input Single Output
NLOS	Non Line of Sight
NOMA	Non Orthogonal Multiple Access
OFDM	Orthogonal Frequency Division Multiplex
OMP	Orthogonal Matching Pursuit
PS	Phase Shifter
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
Rx	Receiver
SCM	Spatial Covariance Matrix
SE	Spectral Efficiency
SNR	Signal to Noise Ratio
SP4T	An Analog Switch
SU-MIMO	Single-User MIMO
SVD	Singular Value Decomposition
TDD	Time Division Duplex
Tx	Transmitter
UE	User Equipment
ULA	Uniform Linear Array
URA	Uniform Rectangular Array
ZF	Zero Forcing
N_p	Number of Phase Shifters
N_u	Number Of Users
N_t^{RF}	Number of RF Chain at Transmitter
N_r^{RF}	Number of RF Chain at Receiver
N_t	Number of Transmitting Antenna At BS
N_r	Number of Receiving antenna per User
r_t	Rank of Digital Precoder
V_D	Digital/Baseband Precoder
V_{RF}	Analog/RF Precoder
V_{opt}	Optimal Precoder
N_s	Number of Data Stream
W_{RF}	RF Combiner
W_{DB}	Baseband Combiner
5G	Fifth Generation

B. Beamforming

Beam-formation is defined as a type of spatial filtering method which uses the spatial characteristics of signals. Beam-generation is done by making some modification in phase and amplitude of the signals from each sensor and these signals get added productively to form beam. In standard MIMO systems, each antenna element is connected to the baseband processor which requires a distinct mixer, ADC/DAC, filters and amplifiers for each antenna. RF chains connect the antennas to the baseband. Hence, pre-coding and baseband consolidation can be performed with DB procedure where there is complete control of the angle and magnitude of the signals of each antenna. The increasing number of antenna elements lead the channel matrix tends to favorable conditions and provides large multiplexing gain. Moreover, the total transmission capacity can be reduced while providing significant gains in beam formation. However, RF chains are expensive and consume a great deal of power, especially in mmWave systems. The hard and soft antenna selection is used to minimize N_t^{RF} in large MIMO system. A network of switches is used to establish the connection between the antennas and RF chains. Based on performance parameters different joint optimizations are performed for selection of suited set of antenna. The joint optimization results in large mathematical complexity due to which suboptimal approaches are preferred. Hard antenna selection has a disadvantage of low beam-forming gain when the N_t is greater than N_t^{RF} . In soft antenna selection a PS network is used to connect the antennas and the RF chains. The beam forming process is split-up into digital beam-formation and RF beam formation. The RF beam-formation is accomplished by varying the signal phase and using analog circuits so the term RF beam-forming or the analog beam-forming is used in the literature. Each phase component of analog pre-coder matrix is adjusted to obtain an increment in SNR and interference reduction of the intended user. Analog beam-former has been favorable for mm-Wave such as IEEE 802.15 where short range connection is established. Phase shifter used in RF beam-former imposes a constraint of constant modulus, this problem become more difficult and poses large arithmetic operation when the practical realization is performed to have a quantized resolution PS.

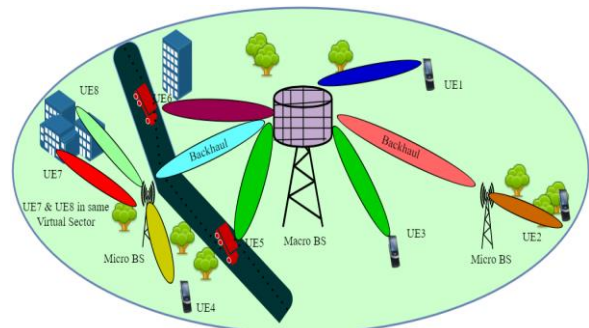


Fig 1. Virtual Sectorization in mmWave, UE7 & UE8 forms a group due to their similar Covariance Matrix & exist in same Virtual Sector

C. Hybrid Beamforming

When the technology will move to next generation 5G, there will be some new challenges. Today most cell-phone network around the world work in the frequency range above 600 MHz to 2.7 GHz but in the future 5G network frequency ranges will start at 3 or 3.5 GHz. With the use of high frequency arises some new interesting challenges. This challenge is rain fade and scattering of gases, at this high frequency signals get highly attenuated by rain. To get around this problem is the mm-Wave Massive MIMO where more advanced beam-forming techniques are used to punch the signal through but if there are heavy scatterers between cell phone and BS then even advanced beam-forming is not enough to penetrate the scatterers. Mm-wave has already been used in some standards like IEEE 802.15.3.c and IEEE 802.11ad. In mm-Wave Massive MIMO different types of small cells are deployed to increase the network capacity. The full capacity of a massive MIMO transceiver is achieved when both side links are fully digitally equipped and full CSI is available, however it requires a distinct RF chain per antenna which increases the complexity. Digital Beam-former provides freedom of higher degree and better performance than analog Beam-former. The hardware complexity of RF beam-former is acceptable but has very poor spectral efficiency as only few or single RF chain is used. Hybrid beam-former is intended to overcome the limitation of RF beam-forming and baseband beam-forming. In hybrid beam-forming structure the number of phase shifters, RF chain and other expensive components such as mixers, ADC/DAC are reduced which further reduces the power consumption and hardware complexity (Sohrabi, 2016). The sub-connected structure has lower complexity and provide near optimal performance with respect to fully digital beam-forming. The two major objectives that hybrid Beam-forming performs is the channel estimation and the beam generation. Taking system parameter (coherence time/bandwidth, total transmit power, transmit power per sub-carrier in case of OFDM) in to consideration an efficient channel estimation algorithm is applied. The beam-former generates the beam to transmit data streams achieving advanced SE. Overall, HB act as driver for enabling Mm-wave based Massive MIMO communication, reduces hardware cost and complexity and provide a spectral as well as energy efficient architecture which can be deployed in the realization of practical system. With HB in Massive MIMO, the number of base station antennas can be increased up to 256 which can beam-form for individual devices and also can track high speed moving devices. Currently most systems can deploy beam-form only in horizontal direction but it provides more flexibility where not only horizontal but vertical beam-forming can be generated which gives a look of 3D-beam-forming as in Fig 5. where 3D beam pattern of a Massive MIMO system for different number of users is shown.

II. LITERATURE REVIEW ON HYBRID BEAMFORMING

In (Morsali, 2019), proposed a three novel hybrid beam-forming schemes to implement SCRA. Advantage of using SCRA is that it requires single RF chain and is implemented with same hardware and production cost as that of any conventional hybrid beam-forming. Second is the implementation of SCRA based on analog constellation (AC). RF chain is used to generate analog pre-coder while AC module is used to generate symbol matrix. The AC block is designed based on the constellation and has fixed number of PS and switches. Third is the implementation of SCRA using RF multipliers. These three novel architectures are realized in SU and MU scenario considering the sparse scattering channel model.

In (Chen, 2018), a hybrid beam-form structure is proposed which consists of four components of 90° phase array to cover the entire service angle of 360°. Each 4x4 arrays has 16 antennas with horizontal feeding ports. SP4T RF switches are used to switch the antenna ports during the beam-forming process.

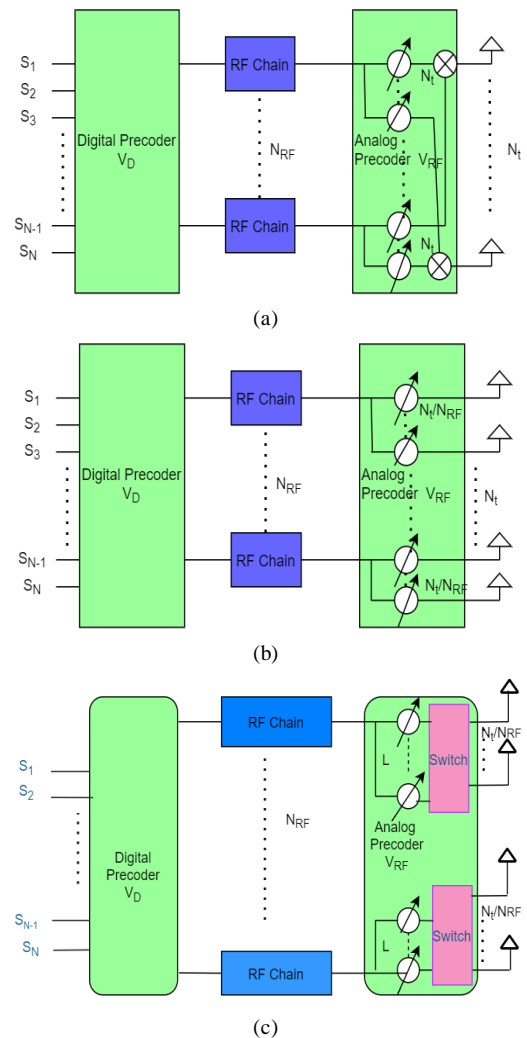


Fig 2. Block Diagram of Hybrid Beamforming Structure: (a) Fully-Connected HB structure (Morsali, 2017), (b) Sub-Connected HB Structure, (c) Sub-connected HB Structure with Fully Connected Switch Network (Tyagi, 2019)

In (Liu, 2018), two methods have been proposed to obtain the digital and analog pre-coder at the base station assuming no hybrid structure on the user side. The Near optimal hybrid beam-forming, the digital pre-coder V_D and the analog pre-coder V_{RF} are tuned to approximate the optimal pre-coder V_{opt} .

In (Kim, 2017), the fact is taken into account that when number of cluster/sectors is increased which reduces the feedback overhead but UEs groups need not be orthogonal. The mutual optimization of RF pre-coder and baseband pre-coder is complex, so the separate optimization is performed by designing analog beam-former to reduce interference between groups and baseband combiner is designed to increase the rate of data per user. For the given analog beam-former, the digital pre-coder is optimized in term of linear MMSE to maximize the net data rate.

In (Payami, 2018) two RF beam-former structure, sub-connected PS network with FC switch network and sub-connected PS network with sub-connected switch network in hybrid beam-forming architecture is investigated for low cost and power consumption. The power expenditure of switches are insignificant as compared to PS so the FC structure has better performance however due to simpler circuit of sub-connected structure it is practically used.

In (Tyagi, 2019), two AB structures is proposed, Sub-PS where individual RF chain is linked to a subunit of antenna to reduce complexity and Sub-FCS where each RF chain is connected to subunit of antennas where PS is replaced with switch based network. To increase the overall energy efficiency of the structure by 50% Sub-FCS is used in sub-connected switch network. ZF technique is applied for the estimation of transmitted symbol exploiting the effect of CEE under perfect and imperfect CSI.

In (Morsali, 2017) first a generalized architecture of HB is developed; further an algorithm is presented to explore the minimum number of RF chains required to realize any FD in HB. All the elements of AB is assumed to have unit norm. If the output of DB is same for all RF chain than min number of RF chain required is one while if it is non-unique than min number of RF chain is two, and hence a degree of freedom in designing is obtained as the optimal solution is not unique.

In (Zhu, 2016) the variation in Spatial channel matrix is slower than the instantaneous full CSI so using SCM a novel SC algorithm is proposed for Sub 6 GHz. Due to the large antenna at BS, SCM is still challenging in Massive MIMO framework. In SC partial CSI is required to estimate SCM using adequate number of RF chain to approximate the behavior to DB. The presented algorithm can be applied to single user and multiple users find its application in both TDD and FDD system, can be used in single carrier frequency and multiple carrier frequency and in LOS and NLOS channel.

In (Bogale, 2016) considers the downlink transmission and present scheduling of user and subcarrier power allotment algorithm for Massive MIMO in frequency selective channel.

The $N_p = 2 N_t^{RF} (N_t - N_t^{RF} + 1)$ where $N_t^{RF} < N_t$ is required for the presented HB to reach the performance of DB. Secondly a novel approach is used to realize HB by using N_t^{RF} RF chain and less than N_p constant PS. The formulated problem is solved by three approaches -1) Antenna selection beam-forming (ASB) it selects N_a antenna from available N antenna. 2) Proposed Hybrid Beam-forming approach where ZF pre-coding is combined with proposed algorithm to schedule user and subcarrier power allocation.3) Digital Beam-forming approach has N_t number of RF chain.

In (Sohrabi, 2016) introduces a nearly optimal HB architecture for massive antenna system, in which the N_t^{RF} required is greater than or twice the total number of stream of data used to obtain FD performance. If this condition is not satisfied than the two algorithms are presented for p-to p MIMO and MU-MISO for the maximization of SE. For large p-to-p MIMO system two cases are considered to design HB algorithm first is $N_t^{RF} = N_s$ with infinite resolution phase shifter and other is $N_s < N_t^{RF} < 2N_s$ with finite resolution phase shifters. For $N_t^{RF} = N_s$, the algorithm approximate to maximum capacity.

In (Adhikary, 2013), JSDM scheme with FDD system is introduced to obtain high throughput gain and to simplify the system operation. Channel vector from BS to MS are correlated forming covariance matrix. This property is used to form the group of MS having similar covariance matrix to reduce the number of feedback required. A DFT based pre-beam-forming matrix that relies on second order statistics of channel is used to reduce the inter group interferences.

In (Noh, 2015), a framework to reduce the dimension of pilot sequence and transmit pre-coding matrix is proposed and further this method is applied in HB for large scale antenna array system to enable a low complexity system.

In (Wei, 2018), a Full Duplex mm-wave MIMO system is explored with HB to enhance the sum rate in uplink and downlink by mutually optimizing the system at the BS using HB as well as at the UE using digital beam-former.

In (Kwon, 2018) a RF beam-former is developed to reduce the overhead in forward and backward case of MIMO system. The beam-former is codebook based to reduce the user scheduling overhead and to lower the inter beam-interference. There is an increment in sum rate with the increment in user number.

In (Bai, 2017), a HB method in which the one column of AB pre-coder and the corresponding row of DB pre-coder is updated iteratively. AB column is updated by Lagrange Multiplier and DB row is updated by LS method.

In (Haider, 2019), an analysis is performed in the relation between EE and SE using hybrid beam-forming technique at 60 GHz for small antenna array. Increase in interference results in degradation of SE.

In (Sun, 2018), different HB methods are compared to for multicell system in CoMP and non-CoMP environment. The analytical SINR and SE have good accuracy.

Table II
SUMMARY OF REVIEW PAPERS ON HYBRID BEAMFORMING

Paper	MIMO System and RF chain	Hybrid Beamform Methodology	Phase Shifters & RF chains	Application Area, FDD/TDD	Channel Type	Effects on Performance Metric
Liang, 2014	$T_x=128, N_u=4$ $N_{RF} = N_u =4$	Phased Zero Forcing for MU-MIMO system	Fewer number of RF chain i.e. $N_{RF}=N_u,$	Mm wave Massive MIMO TDD	Rayleigh Fading & Sparsely Scattered mm wave Channels	Low complexity RF hardware, SE is 1dB less than full complexity ZF precoding, Reduced power Consumption as compared to FC-ZF
Bogale, 2016	$N_i=64, N_u=16,$ Single Antenna User	A novel HB approach is proposed to reduce the N_i^{RF} and PS. A scheduling algorithm is presented for $N_i^{RF} < r_i,$	$N_i^{RF}=r_i,$ $N_p=20-40$	Microwave as well as Mm Wave	Frequency selective & Rayleigh fading channel model	Convenient for practical application & performance better than existing HB's in both frequency selective and flat fading channel
Demir, 2016	$T_x=32,64,$ $N_u=12$ $N_{RF}=1,2,4,8,16,32,64$	A HB optimization problem is solved iteratively instead of SDR	$N_i^{RF} N_p=$ constant for $N_p =1,2,4,8,16,32,64$ PS=2 bit resolution	Massive MIMO as well MmWave Systems	Gaussian Channel Model	Performace is close to full digital beamformer with less number of RF chain, As N_{RF} increases transmitted power decreases
Sohrabi, 2016	64x16 MIMO system, RF chain=6	Three HB algorithm for P-to-P & MU-MISO. For P-to-P $N_{RF} >= 2N_s$. If first condition is not satisfied then, $N_{RF}=N_s$ with infinite resolution PS and $N_s < N_{RF} < 2N_s$ with finite resolution PS	Infinite and finite PS is used. $N_{RF}=2N_s$	Large Point to point MIMO & MU-MISO, TDD is used	Geometric Channel	Coverage capacity and Spectral efficiency approximate to fully DB
Zhu, 2016	16x16 UPA, 256x1 ULA, $N_i^{RF}=64$	A novel HB and SC algorithm is proposed	Reduced PS $N_i^{RF}=64$	Massive MIMO-OFDM in sub 6 GHz frequency band, MmWave Systems Both TDD & FDD	3D Geometrically Statistical Channel Model	Can serve multiple group of users, Highly directive Beamforming, Low power consumption
Morsali, 2017	64x8 MIMO System $N_{RF}=1$	Any FD can be realized in single RF extended HB architecture.	Single RF with two PS	Massive MIMO, TDD	Directional Vector Channel Model	Match the performance of optimal FDP
Wang, 2018	64x64 MIMO System with $N_{RF}=4,6,8,8x8$ MIMO system with $N_{RF}=1$	Joint Optimization of codebook based HB using low resolution PSs	For p-to-p MIMO $N_{RF}=N_s$, For MU-MIMO N_{RF} =Number of users	Point to Point Mm wave MIMO System, MU-MIMO System TDD	Geometric Channel Model	Improves SE, Low power consumption due to low resolution PSs, Polynomial Complexity
Xiao, 2018	$T_x=128, N_u=4,$ $N_{RF}=4$	A fully digital precoder is partitioned in to two matrices by QR decomposition	$N_i^{RF}=4,$ each entry of AB is defined as sum rate of two PS	Massive MIMO, TDD	Rayleigh Fading & Practical channel model	Measurably perform close to full digital with less RF chain
Osman, 2019	$T_x=16,32,64,128,$ $N_u =4,8,16,32,$ $N_{RF}= N_u$	Phased zero forcing for MU MIMO to exploit maximum capacity with low complexity	$N_i^{RF}=N_u$	In 5G frequency Band TDD	Rayleigh, Rician, Nakagami-m Channel Model	Low computational and implementation complexity, Nakagami achieves highest SE
Tyagi, 2019	$T_x=128, N_u=4,$ $N_{RF}=4$	Two sub-connected structure Sub-PS and Sub-FCS is designed, Sum Rate and SE is analyzed under the impact of CEE for perfect and imperfect CSI	50% Reduction in PS in Sub-FCS	Massive MIMO TDD	Rayleigh Fading Channel Model	SE of Sub-FCS is better than Sub-PS in perfect CSI due to CEE, As switches are used which consume less Power.

III. HYBRID BEAMFORMING ARCHITECTURE

Based on phase shifter networks the hybrid beamforming is classified into two architecture naming fully connected architecture and subconnected architecture. The signal transmitted on digital transceivers passes through the N_t RF path and is summarized before they are connected to each antenna. Fully connected structure is linked to all antennas which require a massive number of PS increasing its hardware complexity; however it provides full array gain. Sub-connected structure also called as partially connected structure each RF chain is linked to a sub unit of antennas. It gives a uncomplicated circuit but the SE is reduced as compared to fully connected structure. Constant modulus of RF beam-forming results in a non convex optimization problem which increases unnecessarily computational complexity so generally fully connected structures are used for research purpose while sub-connected is used in real life implementation. Similar to PS switches can also have fully connected and sub-connected network architecture because the switches has find its place as the best alternative PS in term of power efficient. Due to high equipment complexity in fully connected structure lead to insertion loss and crosstalks. A number of HB architecture is designed for SU-Massive MIMO and MU-Massive MIMO to reduce the cost and power expenditure. The main difference between the SU structure and MU structure is, in SU to reduce the cost the RF beamformer is designed by phase shifters having same amplitude for each element. In MU scenario, each user has a unique digital component while the analog component of each user is same.

A. Hybrid Beamforming for Perfect and Impefect CSI

Channel evaluation is very difficult task in TDD as well FDD. In TDD mode coherence channel is assumed to be large enough so that channel remain invariable during uplink and downlink. In TDD data transmission and channel estimation takes place in same frequency resource only a fine tuning between Tx and Rx is required. The channel estimation time increases at Rx due to the huge antenna arrays in Massive MIMO. User need to send the estimated channel to the transmitter which results in feedback overhead, so in high mobility using TDD is more feasible. Since in HB $N_t^{RF} < N_t$ so the amount of resources used to estimate the channel is limited which can result in erroneous channel estimation further deteriorating the HB performance. The purpose of designing a HB is reducing the signaling overhead, reducing the channel estimation delay in case of large antenna system and increasing the received SNR. Channel estimation can be either in close loop or open loop. In closed loop a dedicated link is required from the receiver to the transmitter, the receiver choose the suitable eigen vector from a pre-set beam-forming code book and fed back to transmitter. But in this approach high resolution phase shifters are required. In (Kim, 2017) a hybrid beam-forming scheme is presented for multiuser transmission in mm-wave communication. The

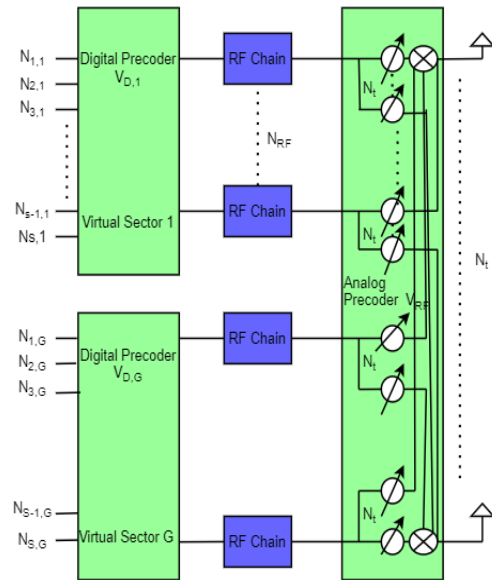


Fig 3. A fully Connected Structure in which the AB forms Virtual Sectorization. It forms the group of alike channel covariance matrix users and serve them with same DB (Molisch, 2017)

combination of RF pre-coder and baseband pre-coder requires a large feedback information so a HB with joint scheduling scheme having two stage CSI restricted feedback is presented to scale up the sum rate. In the first stage BS chooses $N_B \ll N$ RF beam-forming vectors with largest signal power and best channel quality. In the second stage scheduling is performed on the selected vectors. In (Tyagi, 2019) two HB structure has been proposed for downlink narrowband single cell multiuser case employing perfect and imperfect CSI to reduce channel estimation error assuming uncorrelated Rayleigh fading channel. With imperfect CSI the performance loss of SubFCS is less than 5bit/Hz/s as compared to SubPS.

B. Number of RF Chain & PS in Hybrid Beamforming

When HB structure is employed at both the Tx and Rx than full DB realization of HB can be achieved by using $N_t^{RF} = N_t$ at the Tx and $N_r^{RF} = N_r$ at the Rx. However, this structure increases hardware complexity, power consumption and lowers down energy efficiency. With reduced N_t^{RF} in hybrid structure a near optimal FD performance can be obtained. Since it is already known that if the data stream number is one then the number of RF chain required is twice the data stream number i.e. $N_t^{RF} \leq 2N_s$. The validity of this condition can be fulfilled by a specific property of the column of digital precoder. A transmitted data stream has two identical digital gains in digital precoding matrix due to this only single data symbol realization is required and can be used twice. So FD can be realized by $2N_s$ RF chains and $2N_s N_t$ PS. DB design approach is acceptable for few antennas at the Tx and Rx, however hybrid beam-forming is used in case of Mm-wave Massive MIMO system where a massive amount of antennas are deployed at the two end links.

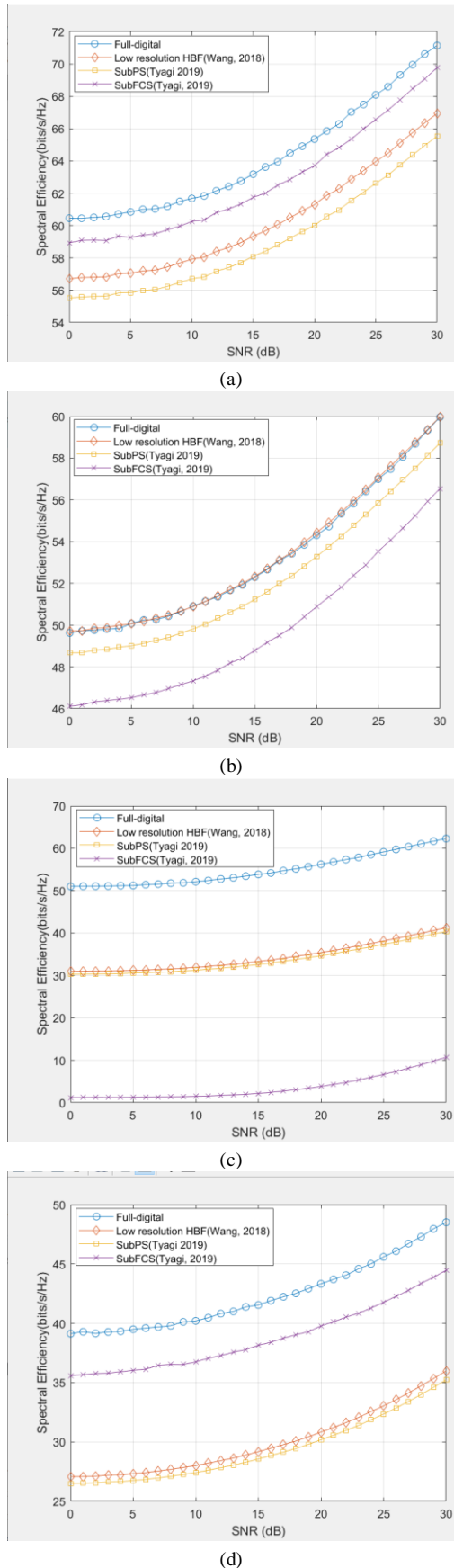


Fig 4. Spectral efficiency of different HB techniques for different number of user, (a) SE for $N_t=32, N_u=2, N_s=2$ per user using 64QAM, (b) SE for $N_t=64, N_u=4, N_s=2$ per user using 16QAM, (c) SE for $N_t=128, N_u=8, N_s=2$ per user using 16QAM, (d) SE for $N_t=64, N_u=16, N_s=1$ per user using 4QAM.

In (Wang, 2018) an efficient iterative algorithm is presented which mutually design the analog and digital pre-coder pair. The major drawback of existing HB algorithms is that they assume infinite resolution phase shifter which is practically not possible. Proposed system assumes low resolution phase shifters minimizing the performance loss while maintaining a low complexity structure. In (Demir, 2016) a 2 bit RF PS based HB is presented with low hardware cost, simpler circuit and a joint optimization is performed on the beam-forming weight. The rank constraint is converted into quadratic problem which is then used in objective function where it is solved iteratively with guaranteed convergence of the optimal equations. This optimization problem can also be solved by semi-definite relaxation but its performance degraded as the variables increases.

C. Hybrid Beamforming in THz

The hybrid beam-forming technology is attractive for THz communication to offset the tremendous path loss and have the benefits of lower hardware complexity and acceptable power expenditure (Yan, 2019). At THz band the wavelength is very small which enables the ultra Massive MIMO system and provides large gain. In THz frequency fully connected architecture can provide high SE but at a cost of very high power consumption, sub-array structure can lower power consumption but with poor SE. SE and power consumption in tera-hertz is balanced by dynamic array of sub-array structure. In dynamic architecture antennas are divided in to sub-array and each RF is connected to only a subset of sub-array dynamically. Many challenges are associated with THz beam-forming that need to be addressed for future perspective. I) Although many low complexity hybrid beam-forming algorithms have been developed but their computational complexity is still too high to implement. Recently machine learning techniques have found its place in solving the large non convex problems of hybrid beam-forming algorithms. II) In THz, the number of Tx and Rx antennas are huge which the makes channel matrix unaffordably high and this creates difficulties in obtaining CSI. III) Till now DAoSA is considered as a feasible architecture for UM-MIMO, still it uses excessive phase shifters. PS can be replaced by lens based and transducer based architecture to reduce instrument complexity. Low resolution ADCs/DACs should be used to lessen the hardware complexity and the power expenditure.

IV. HYBRID BEAMFORMING SYSTEM OUTLOOK

In hybrid beam-forming Massive MIMO downlink scenario the BS is equipped with N_t transmitting antennas and N_t^{RF} transmit RF chains serving N_u users. Each user can be single antenna user or can be equipped with multiple antennas. In the two stage digital and analog hybrid pre-coding first the data symbol is modified at the baseband and then up-converted to carrier frequency by RF pre-coder. Analog pre-coder consists of

RF chain which is designed by using phase shifters or switches. In Phase shifters based analog pre-coder only the phase constraint changes while keeping the amplitude constraint constant for all elements. In switch based analog pre-coder generally binary switches are considered to simplify the hybrid structure. For a given digital pre-coder V_D , RF pre-coder V_{RF} , and the transmitted data symbol vector s , the received signal for user k can be modeled as (Sohrabi, 2016):

$$y_k = H_k V_{RF} V_D s_k + \sum_{l \neq k}^K V_{RF} V_{Dl} s_l + z_k \quad (1)$$

Where z is i.i.d AWGN vector of size $N_r \times 1$ modeled as $z \sim CN(0, \sigma^2)$. Let the analog and digital combiner at the receiver be denoted as W_{DB} and W_{RF} , the combiner output at the receiver can be modeled as (Sohrabi, 2016):

$$y_k = H_k W_{RF}^H W_{DB}^H V_{RF} V_D s_k + H_k W_{RF}^H W_{DB}^H \sum_{l \neq k}^K V_{RF} V_{Dl} s_l + W_{RF}^H W_{DB}^H z_k \quad (2)$$

where s_k is column matrix of N_s data streams, $V(=V_{RF}V_D)$ is a pre-coding weight matrix of $N_s \times N_t$, $W(=W_{RF}W_{DB})$ is combining weight matrix of size $N_r \times N_s$, y_k is $1 \times N_s$ column matrix of received data streams. In this paper, we have investigated different HB techniques for mm-wave massive MIMO system. In this paper a single cell downlink mmwave OFDMA system is operating at frequency f_c (28GHz) is considered to compare the SE of different existing hybrid pre-coding techniques in Massive MIMO scenario where multiple antennas are equipped at the BS as well as at the user side. It is assumed that if the ratio N_t/N_s is 1 then each Base station and user employs ULA otherwise URA. Phased scattering channel model is used and it is assumed that all UEs are within 1000m of BS. The SE of low resolution based PS(Wang, 2018), Sub-PS and Sub-FCS(Tyagi, 2019) is compared with full digital hybrid beam-forming technique. The simulation is performed assuming perfect CSI and employing no hybrid architecture at the receiver. From Fig 4 we can conclude that as the number of antenna and SNR is increasing Sub-FC performance reaches to FD beam-forming technique.

V. HYBRID BEAMFORMING IN MMWAVE

The remarkable shift that took place in the history of telecommunications a year ago, that is, from the narrow band to the extremely high frequency band, and for further refinement, has set an idea for researchers that communication theory needs to be re-examined. Microwave communication had a long period and now due to the requirement of high data rate and low latency services, technology is moving towards mmwave communication. In mm-wave communication the spacing between antennas is reduced due to which huge antennas arrays can be incorporated in a compact space and so mm-wave become key driver of Massive MIMO. Massive MIMO works in

collaboration with mm-Wave because there is very high frequency in mm-wave and lambda value diminishes, so there is possibility that really a system can be build up where massive MIMO antenna can be really fabricated over a small area. Mm-wave band cover an ample of spectrum range (30-300GHz) and so can come up to fulfill the 5G requirements of high data rate. In mm-wave, the way propagation happens or actually the way the wireless channel changes gives challenges to the researchers to model the channel at such a high frequency. 3GPP channel model which up to some extent could get some shape but this is not the exhaustive one. Beam-forming is the heart of this key technology that is coming up for 5G and above. Mm-wave in 5G needs to have beam-forming, very strong beam-tracking, beam-refinement technology, without this mm-wave technology is not possible.

Wireless communication has many popular applications like Bluetooth, Wifi, Wireless LAN but Bluetooth can support a data range of some kbps, Wifi wireless LAN data rate has increased to mbps. For the requirement of Gbps data rate the only option is to increase carrier frequency to mm-wave. Not only that high resolution radar, high resolution imaging, augment reality, virtual reality are also possible by using mm-wave. In mm-wave the number of antennas increases and so the signal processing complexity, the hybrid beam-forming leverage the benefit in terms of system cost and power expenditure. The advantages which the hybrid beam-forming provide for mm-wave communication is 1) It Enables mm-Wave Massive MIMO communication and mm-wave enables a boost of 1000x of system capacity. In mm-wave Massive MIMO, hybrid beam-forming reduces cost and complexity, intergroup interferences and provide precise and narrow beam-forming. 2) hybrid beam-forming provide an improvement in energy efficiency by coherent combining of signal in uplink and downlink. 3) hybrid beam-forming reduces the operational expense by employing low cost RF amplifiers.

Hybrid beam-forming architecture of mm-wave can be similar to that of microwave frequency or cm-wave frequency architecture however it differs from them in aspect of RF hardware and channel propagation model. First challenge at mm-wave frequency band is a major amount of power is carried by LOS because there is huge attenuation upon hitting a particular surface. MPCs in mm-wave encounter a heavy propagation attenuation which is being compensated by increasing the beam-forming gain by employing huge antennas arrays at the Tx and Rx. In mm-wave scenario, different hybrid beam-forming techniques have been realized based on codebook, spatially sparse channel model, antenna selection and beam-space MIMO. The Rx computes CSI based on preexisting beam codebook and then feedback the relevant beam IDs to the transmitter. For SU MIMO system OMP algorithm is used to design the codeword to minimize the error. The spatially sparse channel model represents a limited number of scatterers and provides

correlation between different antenna array at mm-wave. The joint optimization of the spatially sparse channel model and hybrid pre-coder provides a simple pre-coding explanation and a near optimal performance. Second challenge is LTE-A uses time – frequency base resource block however mm-wave uses time-frequency-space based resource block. To optimize the performance in 3D system requires full CSI at Tx and Rx which increases the feedback overhead and also the channel estimation time. Hybrid beam-forming make it possible by using low dimensional baseband pre-coder and a high dimensional RF pre-coder. Device packing hardware limitations at mm-wave frequency make the implementation of devices like power amplifier, ADCs/DACs and LNA difficult. Table III shows the power consumption range of different devices taken from several papers.

Low resolution devices such as ADC/DAC can be an alternative of HB mmwave system specially the case of 1 bit resolution of ADC. At a very sampling rate 1 bit ADC/DAC consume approximately 10 mW.

A. Single-User & Multi-User HB in Mmwave

In FDD channel reciprocity cannot be exploited, so using FDD in Massive MIMO causes a large feedback overhead. JSDM is a multiuser MIMO downlink approach that enables to use huge antenna arrays at the BS while requiring limited CSI. In a cellular configuration, the channel covariance matrix from base station to users is random and depends on the scattering geometry. Fading statistics and the multipath propagation environment is modeled as the “one ring” model (Adhikary, 2013). In JSDM UE’s are split up into categories based on roughly the same channel covariance matrix and consider the fact that UEs in the one group are nearly collocated and sufficient angular separation between different groups. The downlink beam-forming is partitioned into pre-beam-forming matrix and MU-MIMO beam-forming. The pre-beam-forming matrix relies on the channel covariance matrix and reduces the inter-group interference. The optimization condition can be met by using DFT based pre-beam-forming matrix which requires a little knowledge of AoA distribution of each user, without requiring an exact estimation of the channel covariance matrix. The MU-MIMO beam-forming matrix is a classical linear or nonlinear pre-coding matrix that relies on the instantaneous CSI realization. In JSDM fixed UEs are selected to form sets based on uniform channel covariance matrix. Estimate and feedback for the entire channel is usually very costly so a more practical is to feedback the diagonal blocks of each groups. This approach is known is PGP (per group processing). Block diagonalization is one of the popular linear pre-coding methods. BD is performed in two stages using two pre-coding filters. First filter eliminate the multiuser interference with noise, and second pre-coding filter parallelize each data stream. The second pre-coding matrix is obtained after decomposing MU-MIMO channel matrix into

SU-MIMO followed by SVD. The collection of groups is partitioned into separate set called pattern. In JSDM these groups satisfy tall unitary condition and finally they are scheduled to serve the users simultaneously on the same time-frequency slots with orthogonal frequency slots assigned to different users.

OMP (Orthogonal Matching Pursuit) based pre-coding method is used for the single user downlink transmission. In mm-Wave, to find the joint optimization solution for the four matrix variable of hybrid pre-coding i.e. V_{RF} , V_D , W_{RF} , W_{DB} increases a lot of computational complexity, so the pre-coder and combiner are optimized separately. Due to high path loss and compact antenna arrays in mm-wave propagation environment spatially sparse scattering channel model is suitable in which the limited number of scatterers are used which further reduces the fading statistics. In spatially sparse channel, the optimization problem is to maximize the mutual information achieved by analog pre-coder and digital precoder and than minimizing the distance between $V_{RF}V_D$ and V_{opt} (V_{opt} -unconstrained pre-coder). SVD decomposition, some mathematical manipulation and few approximations are considered to minimize the distance between $V_{RF}V_D$ and V_{opt} , and then V_{opt} is simplified to a single variable problem.

B. NOMA in HB based Mmwave System

The standard procedure in OFDMA based LTE is to provide different subcarriers or set of subcarriers to each user while in NOMA the whole idea is to give a particular subcarrier or set of subcarrier to more than one user. NOMA is fundamental phenomenon and is not multiple antennas dependent technique but it can be employed with MIMO system in case of multiple users. Multiple level of allocation is done in NOMA like different amount of power allocated to different band, different number of users allocated to different band, different number of power allocated to each user in a band. In (Nain, 2017) NOMA performs superior to OFDMA system and as the number user increases, per user throughput drops but sum throughput keeps on increasing.

In (Zhu, 2019), user grouping is performed based on high channel correlation and low channel correlation to mitigate the inter-channel interference. Then a mutually optimized HB and power allocation is applied to maximize the sum rate and energy efficiency in mmwave system.

The physical layer latency in NOMA is ignored because it does not cause feedback overhead for channel estimation. SIC is used at the receiver for decoding and demodulation.

Table III
Power Expenditure Range of Different Front End Devices

Device	Number of Device	Power Expenditure per device (mW)
ADC/DAC	$N_t^{RF}(N_r^{RF})$	15-800
PS	$N_t(N_r) \times N_t^{RF}(N_r^{RF})$	15-115
Power Amplifier	$N_t(N_r)$	45-250
LNA	$N_t(N_r)$	5-90

VI. CONCLUSION AND FUTURE RESEARCH ASPECT

This work demonstrates a comprehensive study of hybrid beam-forming Massive MIMO scenario. Specifically this paper discusses about present state of the research and obstacles which people are facing in the implementation of hybrid beam-forming in mm-wave Massive MIMO system and realizing it in real life environment. This paper provides a comparative study of different existing HB technique in term of SE. Apart from different advancements in hybrid pre-coding technique a further investigation is required for the improvement in number of RF chain and errors in CSI. Another research area can be the call handover, scheduling and mobility management especially in small dense cells where call handover occur frequently. Another important issue that 5G researchers are working towards is developing mechanism by which NOMA can be enabled to operate with MIMO system. 5G community is expecting a higher data rate using NOMA scheme.

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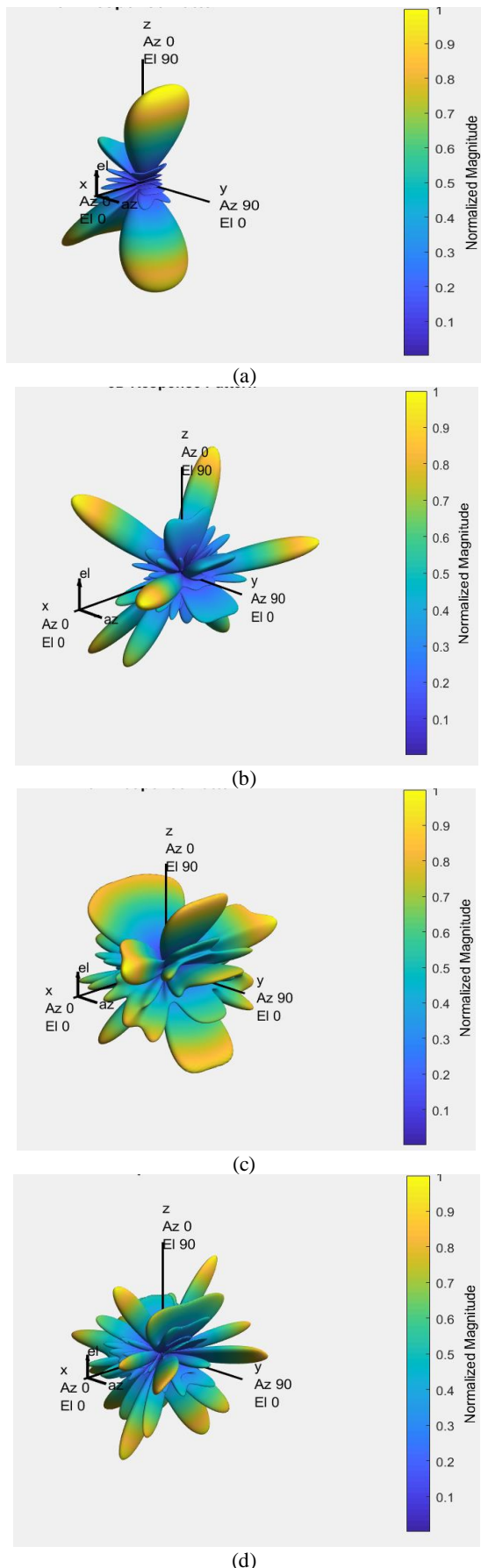


Fig 5. 3D Beam Pattern for different number of users, (a) $N_u=2$, (b) $N_u=4$, (c) $N_u=8$, (d) $N_u=16$

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