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Development of 5G and 6G Using Transform Domain Precoding

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Abstract- *Due to the availability of wide bandwidth, high frequency band is promising for 5G evolution and 6G. With the increase of antenna ports and bandwidth, existing sub band-level precoding consumes high feedback overhead and restricts the precoding granularity. However, channel sparsity can be observed in transformed angular delay domain in MilliMetre Wave systems with massive antennas. In this project, to utilize the sparsity, we propose a transform domain precoding (TDP) method to design precoder and feedback. In transform domain precoding, transmitter side is fully focused to decrease the bandwidth and for performance receiver side is touched. Realistic factors including hybrid beamforming, frequency domain windowing and power allocation are analysed.*

Index Terms- *Transform Domain Precoding, Hybrid Beamforming, Channel Sparsity, MilliMetre wave.*

I. INTRODUCTION

In today's world, 5G is expected to provide new value as a basic technology supporting future industry and society, along with artificial intelligence (AI) and the Internet of Things (IoT), as well as further upgrading of the multimedia communication services with its technical features such as high speed, high capacity, low latency, and massive connectivity. High frequency bands, such as millimetre wave (mmWave) and terahertz (THz) frequencies, are promising for 5G development and 6G due to the massive accessible bandwidth [1]. This is because of the explosively expanding demand for wireless data rate. The mmWave frequency spectrum, which ranges from 24.25 GHz to 52.6 GHz, has been used for wireless transmission in 5G new radio (NR) [2]. To achieve a suitable trade-off between performance and hardware limitations in mmWave transmission, hybrid beamforming, which combines analogue beamforming and digital precoding, is used [3]. Analog radio frequency (RF) side beams are selected and fed back during beam management in 5G NR [4].

The digital precoder at the baseband (BB) side is then chosen from a codebook in the frequency domain and transmitted back during the channel state information (CSI) reporting routine [5].In 5G NR, one precoder is fed back and used for one subband consists of various continuous resource blocks (RBs), and the subband size increases with the available bandwidth [5]. This is done to achieve an acceptable feedback overhead. The performance is impacted by the subband-level precoding, which limits the precoding granularity in the frequency domain. Large subband sizes should be used in wideband systems in 5G evolution and 6G in order to maintain an acceptable feedback overhead, which will lower spectral efficiency (SE). The number of subbands would be high, resulting in substantial feedback overhead, in order to maintain acceptable SE loss. Precoding at the subband level and precoding with frequency domain feedback are therefore ineffective for wideband systems.The channel sparsity in transformed delay domain was investigated and used for the design of a digital precoder in [6] to decrease overhead and boost SE in wideband systems. Precoders for each subcarrier can be built at the base station (BS) with precoders constructed in the delay domain, enabling subcarrier-level precoding. Outcomes demonstrated that subcarrier-level precoding and delay domain precoding could both produce higher SE than subband-level precoding and frequency domain precoding under conditions of low feedback overhead. However, the precoder design in [6] does not take into account elements of real-world systems, such as power allocation, frequency domain windowing, and hybrid beamforming. Additionally, the altered angular domain's sparsity for systems with large antennas could be used further.

In this paper, to utilize the sparsity, we propose a transform domain precoding (TDP) method to design precoder and feedback. Furthermore, TDP under unequal and equal power allocation among subcarriers are both designed. Link-level simulation results show that the proposed TDP performs better than existing methods.

II. EXISTING SYSTEM

In order to provide ubiquitous, low-latency, high-speed, and high-reliability connections among mobile devices, fifth-generation (5G) new radio (NR) holds potential. New error-correcting codes for both data and control channels have been added to 5G NR compared to fourthgeneration (4G) long-Term evolution (LTE).

Each essential element in these codes has a specific function, and the corresponding operations are described. These new codes' performance and implementation benefits are contrasted with 4G LTE's. Analog beams at the radio frequency (RF) side are selected and fed back during beam management in 5G New Radio. The digital precoder at the baseband (BB) side is then chosen from a codebook in the frequency domain and sent back to preserve acceptable feedback overhead in 5G NR during the process of channel state information (CSI) reporting. one precoder is fed back and used for one sub band composed of multiple continuous resource blocks (RBs), and the sub band size increases with the allocated bandwidth.

A. OFDM Module

Consider a downlink mm Wave OFDM system with N subcarriers, where one BS equipped with M antennas serves one single-antenna user equipment (UE), i.e., multi-input single output (MISO). The mm Wave MISO channel can be described by multi-path model. For uniform linear array (ULA), the channel vector between BS and UE at the nth subcarrier is modelled as

$$hn = XL\ `=1\ \alpha`a\ H(\theta`)e\ {-j2\pi fn\tau`} \in C\ 1\times M, \ldots\ldots\ldots\ldots\ldots\ldots\ldots (\ 2.1\ )$$

where $fn = (n - 1)\Delta f$ is the frequency of n-th subcarrier, Δf is the subcarrier spacing, L denotes the number of channel paths, $\alpha`$, $\theta`$ and $\tau`$ denote the complex gain, physical spatial angle of departure (AoD) and delay of n-th channel path, respectively, $a(\theta`) = [1, e{-j2\pi\vartheta`}, ..., e{-j2\pi\vartheta`(M-1)}]\ T \in CM\times 1$ is the steering vector, $\vartheta` = d\ \lambda \sin(\theta`)$ is the normalized spatial angle, λ is the wavelength, and d is the antenna spacing. Hybrid antenna structure and beamforming are assumed for backward compatibility, where MRF RF chains are connected with $M \geq MRF$ antennas. Hybrid beamforming for n-th subcarrier is

$$wn = WRFwBB,n,$$

which is composed of an analog beamforming $WRF \in CM\times MRF$ and a digital precoderwBB,n$\in CMRF\times 1$. Fully-connected antenna structure with RF processing based on phase shifters is assumed. It should be noted that analysis under sub-connected antenna structure can be obtained with similar methods

B. Sparsity of channels in transform domains

For uniform planer array (UPA), the steering vector $a(\theta`, \varphi`)$ is a function of both azimuth angle $\theta`$ and elevation angle φ. Without loss of generality, ULA structure is considered in this paper and the extension to UPA structure is straightforward.

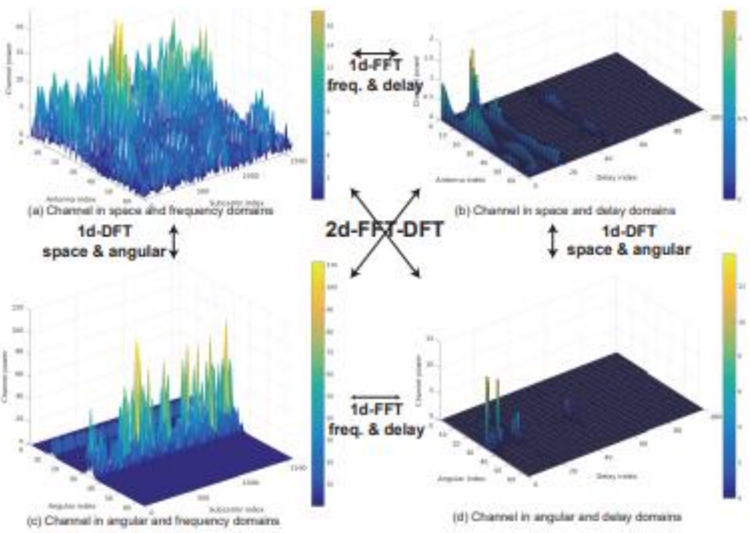


Fig. 2.1 Channels power (in linear scale) in various domains

Thanks to characteristics of multi-path channels in mm Wave massive MISO systems, large-dimensional channels in space frequency domain can be represented by 3L parameters including L delays $\tau = [\tau 1, \cdots, \tau L]$, L angles $\theta = [\theta 1, \cdots, \theta L]$ L complex gains $\alpha = [\alpha 1, \cdots, \alpha L]$……….(3.5) Due to limited scattering environments, channels in angular-delay domain are sparse, i.e., 3L MN holds in wideband massive MISO systems. Motivated by channel sparsity in transform domains, precoders should also be designed in transform domains to reduce the design complexity and feedback overhead.

C. Channel Sparsity

The acquisition of channel state information (CSI) is essential in millimeter wave (mmWave) multiple-input multiple-output (MIMO) systems. The mmWave channel exhibits sparse scattering characteristics and a meaningful low-rank structure, which can be simultaneously employed to reduce the complexity of channel estimation. In the aspect of CSI detection, Time Division Duplex (TDD) mode takes advantage of the reciprocity of the uplink and downlink link. In Frequency Division Duplex (FDD) mode where the channel reciprocity condition is no longer satisfied, the base station sends a downlink pilot signal, the mobile station receives and detects the pilot signal and then feeds back CSI to the base station. As for traditional channel estimation method, the length of pilot sequence must be proportional to the number of base station antennas, which makes it difficult to complete channel estimation within coherent time. Moreover, the uplink feedback load is high. Therefore, it is unrealistic to use traditional methods for the channel estimation of massive MIMO systems.

D. MIMO SYSTEMMultiple-input, multiple-output orthogonal frequency division multiplexing (MIMO-OFDM)

It is the dominant air interface for 4G and 5G broadband wi-fi communications. It combines multiple-input, more than oneoutput (MIMO) generation, which multiplies capacity with the aid of transmitting extraordinary signals over a couple of antennas, and orthogonal frequency-department multiplexing (OFDM), which divides a radio channel into a big variety of closely spaced sub channels to provide greater dependable communications at excessive speeds. Multi-user MIMO (MU-MIMO) improves the spectrum efficiency by using permitting a base station (BS) transmitter to speak concurrently with a couple of cellular stations (MS) receivers the usage of the identical timefrequency resources. Massive MIMO allows the wide variety of BS antenna elements to be on the order of tens or hundreds, thereby additionally increasing the number of records streams in a cellular to a large value.

E. Massive MIMO System

Here we use MIMO channel because Massive multiple input multiple output (MIMO) is one in every of the maximum auspicious technologies for the next era of wireless communication systems as it has the ability to provide gamechanging enhancements in spectral efficiency (SE) and power efficiency (EE).QPSK Modulator and Demodulator due to the fact QPSK has Very excellent noise resistance. For the identical bit error price, the bandwidth essential through QPSK is condensed to half in contrast to BPSK. Because of condensed bandwidth, the facts transmission rate of QPSK is advanced. Orthogonal space time block code (OSTBC) is used to make furthermost the benefits of MIMO channels we normally need to use area-time coding.

F.HYBRID BEAMFORMING

Hybrid beamforming systems and algorithms in the cm-wave frequency domain can in principle be used at mm-wave domain frequencies. But in practical situations, there are many factors that we need to take into account before we can infer that the cm wave systems actually work in case of mm wave systems. Factors like propagation channel and RF hardware aspects vary hugely and so a practical approach is required. At mm wave frequencies, the multipath channels suffers huge propagation loss.On the other hand, hybrid solutions become harder to implement due to the power and cost related constraints of the RF chains and hardware. Also in case of mm wave, very few spatial degrees of freedom is available due to the fact that these channel might be sparser. But this can be used for optimizing channel estimation and beam training. 5thGen (since "fifth Generation") remains the modern-day era of cellular portable communications. It thrives the 4thGen (LTE-A, WiMax), 3rdGen (UMTS, LTE) and 2ndGen (GSM) systems. 5thGen presentation marks extreme data rate, reduced latency, energy redeemable, price reduction, healthier machine capacity, and vast tool connectivity

III. PROPOSED SYSTEM

To exploit the channel sparsity in transform domains, we propose a transform domain precoding (TDP) in practical systems with hybrid beamforming and frequency domain windowing. Firstly, different from identical delays for multiple antennas in fully digital precoding, different delays are selected for multiple beams in hybrid beamforming. Secondly, quantized delays are assumed for orthogonal frequency division multiplexing (OFDM) systems. In this system, we investigate the hybrid precoder design in mmWave MIMO systems. We will adopt alternating minimization (AltMin) as the main design principle, which helps decouple the precoder design problem into two subproblems, i.e., the analog and digital precoder design. The proposed AltMin algorithms will alternately optimize the digital precoder and the analog precoder. For the fully-connected structure, we shall show that the unit modulus constraints of the analog precoder define a Riemannian manifold. We will thus propose a manifold optimization based AltMin (MO-AltMin) algorithm. This algorithm does not need any pre-determined candidate set for the analog precoder, and it is the first attempt to directly solve the hybrid precoder design problem under the unit modulus constraints. By imposing an orthogonal property of the digital precoder, we then develop an AltMin algorithm using phase extraction (PE-AltMin) as a low-complexity counterpart of the MO-AltMin algorithm, which will also be more practical for implementation. For the partially-connected structure, we propose a Random Space based AltMin (RS-AltMin) algorithm.

A. System Module

To reduce overhead and increase SE in wideband systems, channel sparsity in transformed delay domain was studied and exploited for the design of digital precoder. With precoder designed in delay domain, subcarrier-level precoding can be carried out at the base station (BS) by constructing precoders for each subcarrier. Results showed that at limited feedback overhead, precoder designed in delay domain and subcarrier-level precoding could achieve higher SE than precoder designed in frequency domain and sub bandlevel precoding.

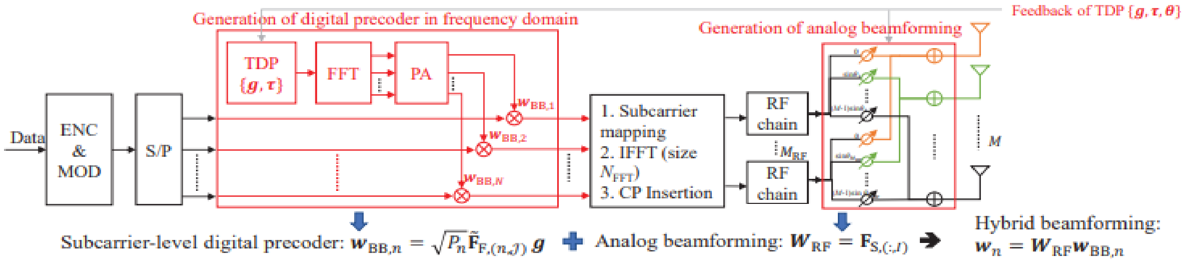


Figure 3.1 Transmitter side of TDP

However, the precoder design does not consider factors of practical systems, e.g., hybrid beamforming, frequency domain windowing and power allocation. Besides, for systems with massive antennas, the sparsity in transformed angular domain could be further exploited. In this system, to exploit the channel sparsity in transform domains, we propose a transform domain precoding (TDP) in practical systems with hybrid beamforming and frequency domain windowing. Firstly, different from identical delays for multiple antennas in fully digital precoding, different delays are selected for multiple beams in hybrid beamforming. Secondly, quantized delays are assumed for orthogonal frequency division multiplexing (OFDM) systems.

Then, frequency domain windowing caused by smaller number of allocated subcarriers than the size of fast Fourier transform (FFT) will affect the observed channel sparsity in delay domain. To cope with frequency domain windowing and optimization problem on quantized delays, compressive sensing (CS) algorithm is used to design delays of TDP. Furthermore, TDP under unequal and equal power allocation among subcarriers are both designed. Link-level simulation results show that the proposed TDP performs better than existing methods in terms of both feedback overhead and SE.

B.HYBRID PRECODING

Hybrid precoding introduces phase shifters in the analog domain to process the transmitted signal. Since the phase shifter can only adjust the phase of the signal and cannot adjust the amplitude of the signal, the nonzero terms in the analog precoding matrix need to have the same modulus. A is used to represent the set of A matrices that satisfy the constant modulus constraint. To reduce overhead and increase SE in wideband systems, channel sparsity in transformed delay domain was studied and exploited for the design of digital precoder. With precoder designed in delay domain, subcarrier-level precoding can be carried out at the base station (BS) by constructing precoders for each subcarrier. Here exist both Analog and Digital precoding in this hybrid precoding.

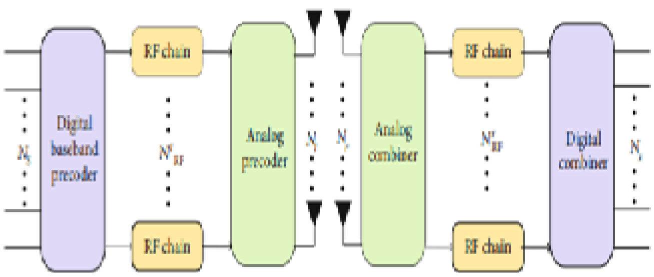


Figure 3.2 Block diagram of Hybrid Precoding

The Euclidean distance is used to make the optimal mixed precoding as close as possible to the unconstrained optimal digital precoding. It is shown in reference that the objective function in the minimization problem can maximize the spectral efficiency. The optimal mixed precoding matrix in the problem can be obtained by singular value decomposition of the channel matrix. The channel matrix singular value decomposition is represented by

H = UΣVH, …………………………(4.1)

and the unconstrained optimal precoding matrix Fopt consists of the first Ns columns of the right singular matrix. The spectrum efficiency of the receiver and the mutual information of the transmitter have similar structures, so the analog receiver and the digital receiver can be designed in the same way as the transmitter. Results showed that at limited feedback overhead, precoder designed in delay domain and subcarrier-level precoding could achieve higher SE than precoder designed in frequency domain and sub band-level precoding.

C. HYBRID BEAMFORMING WITH CHANNEL SPARSITY

The simplest form of implementation of hybrid beamforming in SUMIMO is to exploit the channel's sparsity This focuses the array gains to a limited number of RF multipath chains while allocating powers in the baseband and multiplexing the data streams at the same time. The asymptotic nature of the hybrid architecture makes it ideal for large antenna arrays. For systems with practical array sizes, hybrid beamforming is highly beneficial. In addition to this, what makes this model more desirable is the reduction of hardware components and reduction of computational complexity. For all these reasons, a number of methods have been proposed. Some of them are discussed below.

Use of codebook The codebook-based beamforming Performs downlink training using already defined beams and the only feeds back these selected beam's IDs to the transmitter, instead of directly estimating the large CSI matrix at the receiver. A codebook for full complexity hybrid architecture can be made to use the sparsity of mm wave channels. This would reduce the complexity and feedback overhead for large antenna systems. Each codeword is constructed uniquely based on the algorithm of Orthogonal

Spatially sparse precoding This method finds the approximation of the unconstrained (i.e., fully digital) beamformer electrically large arrays. We can safely approximate close to the optimal precoder using the correct number of antenna elements in the 35 antenna array. The multipath sparsity restricts the proper setting up of array response vectors by the analog precoders. It also hinders the setting up of baseband precoder optimization. The solution then can be obtained by using OMP. Fig. 5 compares the Spectral Efficiency with unconstrained fully digital beamforming with perfect transmit CSI.

Antenna selection In general the structure for mm wave beamforming channel is the same as the one for cm-waves. But mm wave channels are sparse and fast. Hybrid antenna selection can perform better than a sparse hybrid combiner with roughly quantized phase shifters when comparing in terms of power consumption. Both have the same SE performance, but there is still a huge gap in SE between the hybrid combiner with switches and fully-digital one with ideal phase shifters.

Beam selection Using continuous Aperture Phased MIMO transceivers is another hybrid beam forming solution. Instead of phase shifters or switches, it uses lens antennas to realize the Beam space MIMO (B-MIMO). An antenna array beneath the lens electrically excited the large lens antenna setup. The antenna produces high gain beams that point to different angles depending upon the antenna feed, hence the feed array is called a beam selector. The CAP-MIMO can select a couple of feed antennas using a limited number of RF chains like that in spatially sparse coding. By doing this, they can efficiently utilize the low dimensional gain beam space of the multipath channel which is very high.

Impact of transceiver imperfections The SE is degraded in different ways due to the imperfections in the transceiver e.g., If the beamformer gain is high, it becomes difficult to get accurate transmit; the instantaneous channel gain (therefore the SNR) determines the nonlinear distortion at the receiving end. As suggested by previous studies of the cm wave beamforming The SE performance achieved by the hybrid structures is the same as that of a full digital beamforming given that the number of data streams is half the number of RF chains at each end The transceiver being imperfect and these imperfections being more noticeable at the mm level, the delay and SNR of hybrid precoders doesn't match with that of the RF Chains. The comparison of TFD hybrid precoding, including RF imperfections, with that from hybrid beam forming. The roughly quantized phase shifters and the transceivers' imperfections especially at the mm waves level significantly degrade the SE.

IV. SIMULATION RESULTS

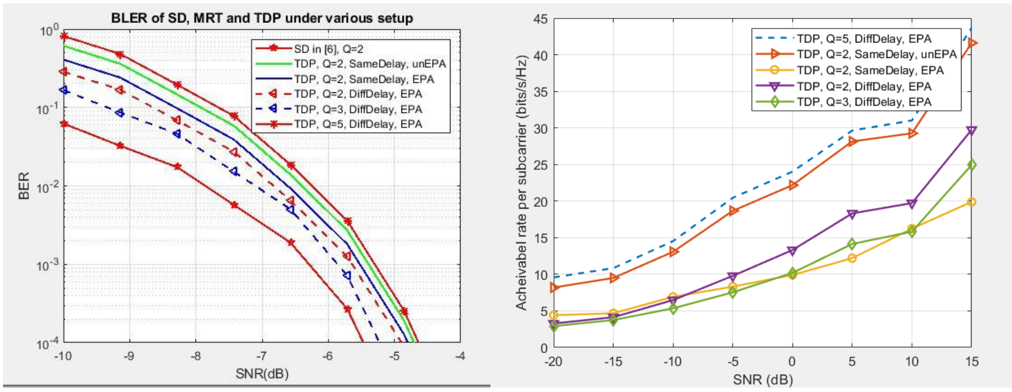
In this section, performance of TDP is evaluated by link level simulations. For comparison, hybrid beamforming with sub band-level digital precoder in 5G NR, space-delay (SD) precoder and maximum ratio transmission (MRT) are also evaluated. The evaluation assumptions are listed in the below Table. Here, block-error-rate (BLER) of TDP and SD at limited feedback and MRT at infinite feedback are evaluated.

Table 4.1 Evaluation Assumptions

Parameters	Assumptions
Carrier frequency	28 GHz
Subcarrier spacing	120 kHz
BS and UE bandwidth	400 MHz (264 RBs), 144 MHz (100 RBs)
FFT size	4096
Channel model	CDL-C with rms delay spread 300ns [11]
Antenna number	64 antennas, 2 RF chains
Code rate, modulation	500/1024, 64QAM
Quantization	Vector quantization with Type I codebook (CB) [5] for subband feedback; Scalar quantization by 64QAM for TDP and SD

Table 4.2 Overhead Reduction of TDP at Same Performance

UE Bandwidth	50 RBs	100 RBs	150 RBs
Gain over CB with flexible SBs [5]	68%	84%	89%
Gain over SD with flexible Q [6]	60%	60%	60%



(a) (b)

Fig. 4.1 BLER outputs

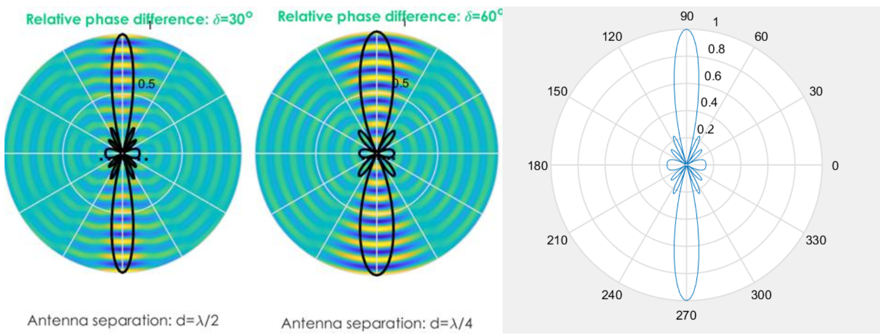
Fig 4.1 (a)BLER of SD, MRT and TDP under various setups, (b) BLER using TDP and Hybrid Beamforming The results show that TDP achieves 60~89% overhead reduction than existing schemes. This is because with same number of delays, SD with identical delays for all RF chains will consume less overhead for τ than TDP with different delays.

From the given table, at same feedback overhead of 16 bits, SE gains of TDP with Q = 2 over CB with 8 sub bands and SD with Q = 2 are provided.

Table 4.3 SE Gain of TDP With Q = 2 At Same Overhead (16 Bits)

SNR	-20dB	-10dB	0dB	10dB
Gain over CB with 8 subbands [5]	21%	14.3%	8.46%	4.06%
Gain over SD with $Q = 2$ [6]	8.13%	5.55%	3.73%	2.38%

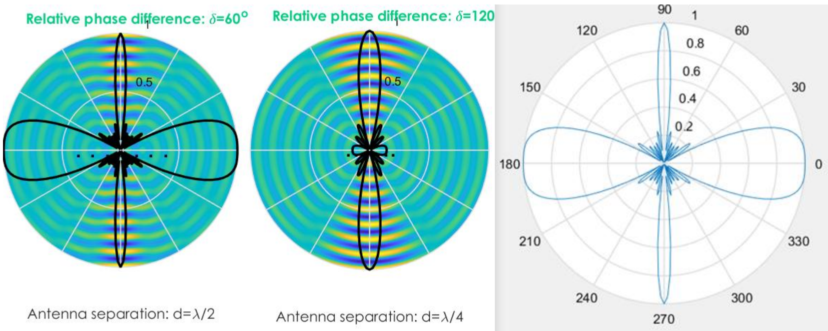
The results show that at same overhead, proposed TDP achieves 4.06%~21% and 2.38%~8.13% higher SE than sub band-level CB precoding and subcarrier-level SD precoding, respectively.



(a) (b)

Fig. 4.2 (a) Relative phase difference level -1, (b) Channel allocation level -1

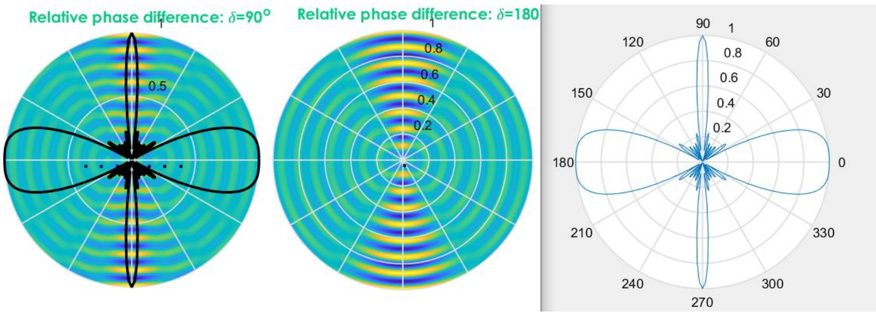
Here, the relative phase difference at angle 30 with antenna separation, d=λ/2 and the relative phase difference at angle 60 with antenna separation, d=λ/4 is stimulated using the hybrid beamforming. Here, the relative phase difference at angle 60 with antenna separation, d=λ/2 and the relative phase difference at angle 120 with antenna separation, d=λ/4 is stimulated using the hybrid beamforming.



(a) (b)

Fig. 4.3 (a) Relative phase difference level -2, (b) Channel allocation level -2

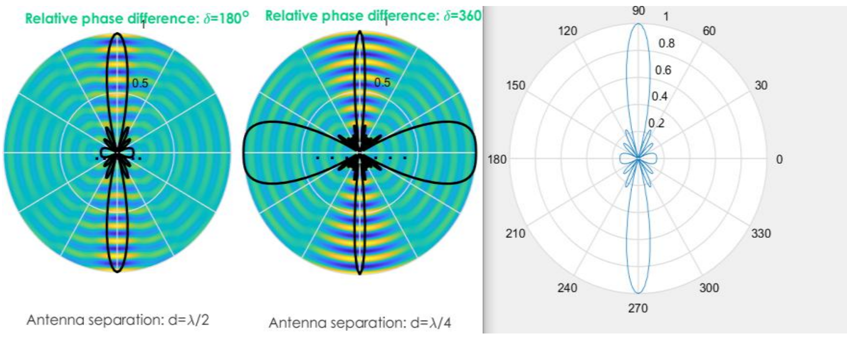
Here, the relative phase difference at angle 90 with antenna separation, d=λ/2 and the relative phase difference at angle 180 with antenna separation, d=λ/4 is stimulated using the hybrid beamforming.



(a) (b)

Fig. 4.4(a) Relative phase difference level -3, (b) Channel allocation level -3

Here, the relative phase difference at angle 180 with antenna separation, d=λ/2 and the relative phase difference at angle 360 with antenna separation, d=λ/4 is stimulated using the hybrid beamforming.



(a) (b)

Fig. 4.5 (a) Relative phase difference level -4, (b) Channel allocation level -4

This simulation results shows the phase shifted patterns of the antenna at different levels of phase angle and channel sparsity towards the transceiver.

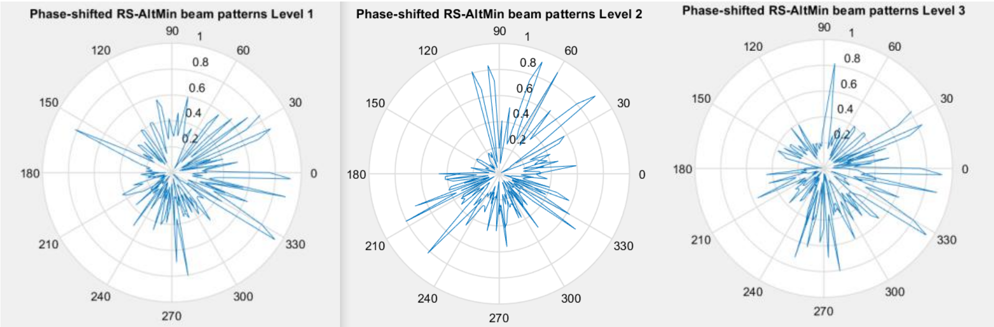


Fig. 4.6 Phase shifted patterns at different levels

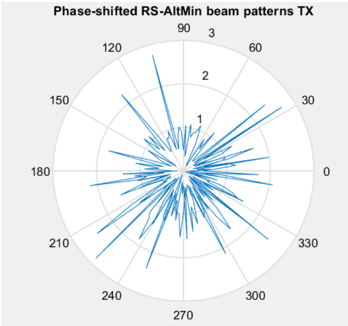
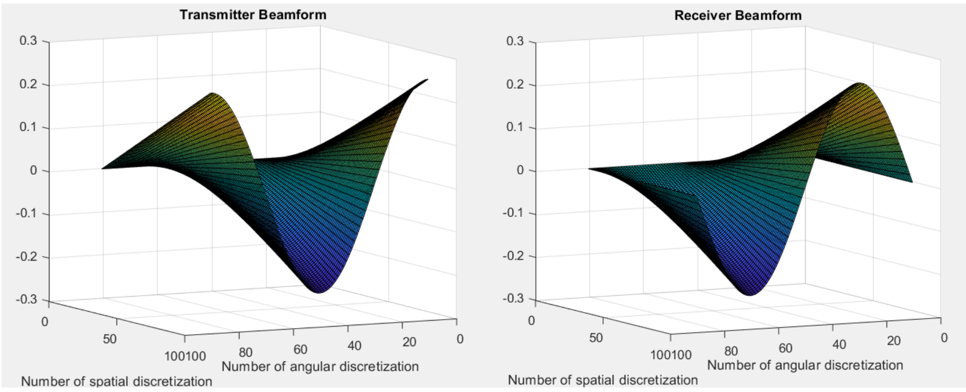


Fig 4.7 Phase shifted beam pattern at Transmitter

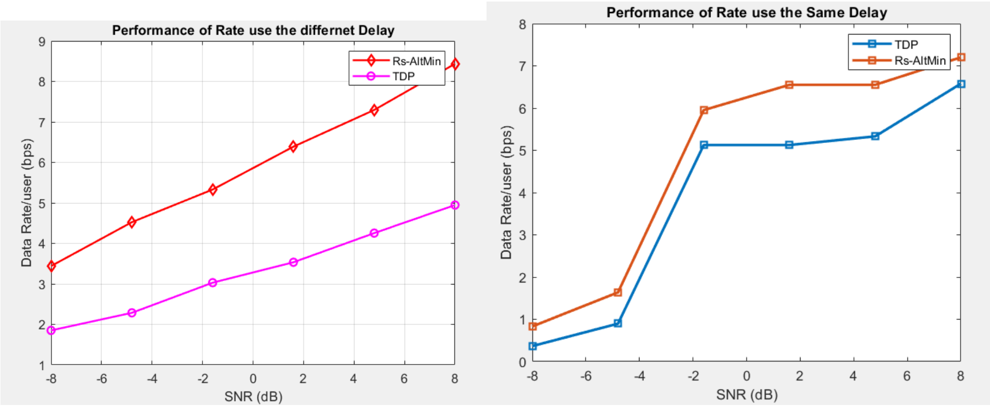
By simulation with the help of angular discretization and spatial discretization, beamforming is done in the transmitter side at beam pattern levels



(a) (b)

Fig. 4.8 (a) Beamforming at Transmitter, (b) Beamforming at Receiver

By simulation with the help of angular discretization and spatial discretization, beamforming is done in the receiver side at beam pattern levels.The performance of data rate has been stimulated using the same delay in both the RS and TDP with SNR value is generated.



(a) (b)

Fig. 4.9 (a) Performance rate at same delay, (b) Performance rate at different delay

The transceiver being imperfect and these imperfections being more noticeable at the mm level, the delay and SNR of hybrid precoders doesn't match with that of the RF Chains. The comparison of TDP hybrid precoding, including RF imperfections, with that from hybrid beam forming. The roughly quantized phase shifters and the transceivers' imperfections especially at the mm waves level significantly degrade the SE.

V. CONCLUSION

A new transform domain precoder to maximize the SE with limited feedback overhead. To utilize channel sparsity, here transform domain precoding (TDP) method to design precoder and feedback is implemented. In transform domain precoding, transmitter side is fully focused to decrease the bandwidth and for performance receiver side is touched. Realistic factors such as hybrid beamforming, frequency domain windowing and power allocation were taken into account, which makes TDP a practical solution. Results of link-level simulations show that proposed TDP outperforms existing methods in terms of feedback overhead and SE, which is promising for 5G evolution and 6G. The SE is degraded in different ways due to the imperfections in the transceiver e.g., If the beamformer gain is high, it becomes difficult to get accurate transmit; the instantaneous channel gain (therefore the SNR) determines the nonlinear distortion at the receiving end. As suggested by previous studies of the mm wave beamforming The SE performance achieved by the hybrid structures is the same as that of a full digital beamforming given that the number of data streams is half the number of RF chains at each end. The transceiver being imperfect and these imperfections being more noticeable at the mm level, the delay and SNR of hybrid precoders doesn't match with that of the RF Chains. The comparison of TDP hybrid precoding, including RF imperfections, with that from hybrid beam forming. The roughly quantized phase shifters and the transceivers' imperfections especially at the mm waves level significantly degrade the SE. Hence, it is important to know about the transceiver imperfections as it is a detrimental factor in the 61 understanding of the SE in MIMO system. Results of link-level simulations show that proposed TDP outperforms existing methods in terms of feedback overhead and SE, which is promising for 5G evolution and 6G.

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