Multi Point Transmission with Channel Conditioned Spatial/Frequency Domain Processing

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***Abstract*—In this paper, we propose a simple transmission measurement method for multi-point transmission system operating above 6GHz. By evaluating the channel condition, the system can acquire diversity order or boost SNR gain with limited feedback from mobile station. Simulation results show that the proposed transmission mode selection criteria and its feedback method can suggest coordinated multiple TRP based transmission scheme for better system efficiency.**

***Index Terms*—Multi-point transmission, diversity, URLLC.**

I. Introduction

RECENTLY, the use of massive antenna elements for hybrid beamforming enabling sufficient transmit power in a spatially sparse channel (frequency range 2: FR2) has been proposed [1]–[3], and it is implemented in practice for the 5G new radio (NR) newtork. Along with hybrid beamforming, multi-point transmission (MPT) has been introduced in celluar systems, which dates back to LTE system with the feature called Coordinated Multi-Point transmission/reception (COMP) in release 10. This feature offers diversity and reliability in link level. In order to apply MPT for FR2, consideration of transmit and receive beamforming with relative beam width must be taken in consideration. Such combination of hybrid beamforming and MPT under channel environment caused by physical placement of transmitter and receiver may be considered for URLLC scenarios, where stringent requirements suggested by codeword block error rate (BLER) of 10^{-9} and less than 1ms end-to-end latency [4].

In this letter, we suggest selective layered processing scheme for multi-point transmission based on channel condition. In addition, we also suggest limited feedback based channel condition measurement for low complexity. Simulation results show that based on measured received power after transmitter/receiver beamforming between the base station's (BS) transmission/reception points (TRPs) and mobile station (MS), channel power difference from TRPs and limitation of simultaneous signal reception from multiple TRP sources due to receiver beam width leads to adaptation of suitable MPT transmit modes in layer processing for optimizing link performance.

II. Selective layered Processing based on channel condition

In order to increase diversity order and SNR gain by adapting MPT, channel condition number is one of several crucial factors to decide, whether spatial multiplexing, spatially redundant addition, or dominant path full power allocation is appropriate. To measure the channel condition, the proposed transmitter receives channel state information (CSI) from the mobile station to assess/evaluate the channel condition number from participating TRPs. As an example, Fig. 1 shows two participating MPT TRPs. The content of CSI could be optimal if the MS can send many complex channel frequency response (CFR) for the entire system bandwidth. However, such relatively large feedback information could be prohibitive for a power limited MS, especially when number of TRPs involved with MPT is large. Thus, we propose scalar power level as a feedback component for evaluating the channel condition number. In fact the proposed feedback content does not necessarily need to be estimated during the connected state, but it can rather be acquired as early as during the beam sweeping state in random access stage. In addition, the power level need not to be presented as a absolute value, but rather a relative value among participating TRPs' layers. This will be explained in the later part of the current section.

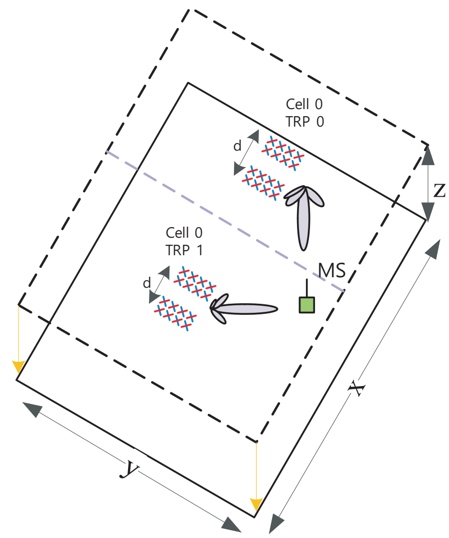

Fig. 1. An example of indoor 2 TRP multi-point transmission scenario

The multi-point transmission situation can be generally considered as a MIMO channel in the baseband perspective with typically high number of transmission layers, and the performance gain coming from MIMO channel depends on

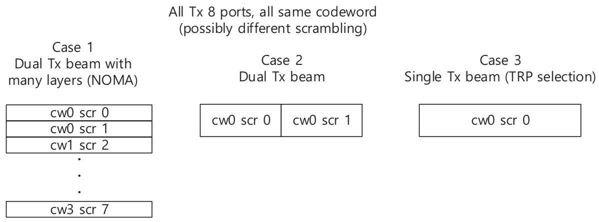

Fig. 2. Proposed three transmission modes based on channel condition number for MPT

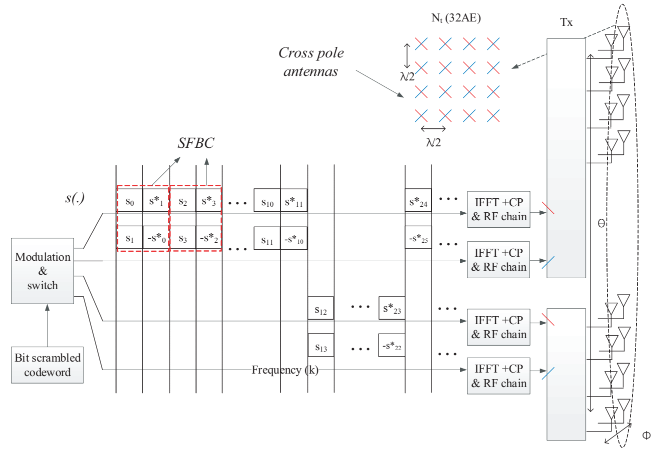

Fig. 3. Frequency separated SFBC transmitter structure for mode 2 and 3

the condition number of the channel matrix, just like the conventional point-to-point MIMO situation. Let s be the transmission signals from all TRPs participating multi-point transmission. Then the subcarrier-wise MIMO channel is considered, which yields a received signal

$$\mathbf{y} = \mathbf{Hs} + \mathbf{n} \tag{1}$$

where $\mathbf{y}$ is the N_r x 1 received vector, $\mathbf{H}$ is the N_r x N_t channel matrix, and $\mathbf{n}$ is the vector of additive Gasussian noise with i.i.distribution $\mathcal{CN}(0, N_0)$. Thus, we can assume N_T transmission layers are participating in the MPT mode.

We propose three types of transmission modes for MPT utilizing channel condition number. For the sake of clarity, two TRPs, as illustrated in Fig. 1, are involved for the proposed MPT modes.

As described in Fig. 2, the first transmission mode is case 1 spatial multiplexing mode that the transmitter layers are assigned with same or different codewords where the layers sharing the same codeword have different bit/symbol level scrambling applied. This effectively increases the throughput, while diversity could be obtained by layers transmitting a common codeword such that experienced statistically different fading channels. The spatial multiplexing gain and diversity would be obtained if the given channel condition number exceeds a certain threshold.

The second transmission mode is an diversity mode of case 2. In the channel condition aspect for a given allocated frequency band region, the condition number would be high such that it is analyzed to be a non suitable channel for spatial multiplexing. However, assuming two different RX beamforming weight vectors can be processed simultaneously (i.e. frequency separated method) and the received power at the MS from both TRPs are in similar range, the receiver can combine the beams simultaneously. Note that the transmission signals from two separate TRPs use the same codeword but different bit/symbol level scrambling for diversity combining. Thus, when two frequency separate RX beam weights are aligned, case 1 MPT mode can be selected whereas case 2 is chosen if two frequency separated RX beam weight are totally out of phase. Unlike transmission mode 1, frequency separated group SFBC [6] is formed in the baseband with physically separated beam groups, as shown in Fig. 2. The transmission signal $\mathbf{s} = [s(k)\ \ s'(k)]$ that enables diversity combining is done by forming the baseband signal as

$$\begin{aligned} s'(k) =& z(k) \cdot \Big[s_{re}\big(k + z(k)\big) - j \cdot s_{im}\big(k + z(k)\big) \Big] \\ z =& (-1)^k, \quad k = 0, 1, ...C/Q - 1, \end{aligned} \tag{2}$$

that two consecutive N_s x 1 symbol vector $\mathbf{s} = [s(k), s'(k)]^T$ in frequency domain (i.e., [$\mathbf{s}_k$, $\mathbf{s}_{k+1}$]) forms space frequency block code (SFBC) unit. s_{re} and s_{im} means real and imaginary part of symbol $s(\cdot)$, respectively. C refers to codeword length and Q is the modulation order.

The third transmission mode is also a selection diversity mode with dominant TRP selection. For the environment in Fig. 1, case, the condition for selective TRP transmission occurs when there is a significant received power gap between the TRPs, despite even after frequency separated RX as well as TX beamforming is applied. It is clear that the condition number of the MIMO channel would be very high, and clearly joint transmission would not be a optimal solution. In this case, it is more beneficial to allocate the total transmission power to the dominant TRP. Just like the applied baseband configuration proposed in mode 2, the frequency separated beamforming group transmission

The condition number of a channel matrix $\mathbf{H}$ is defined as

$$c_{\mathbf{H}} \triangleq \frac{\sigma_{max}}{\sigma_{min}} \tag{3}$$

where σ_{max} and σ_{min} are the largest and the smallest singular value of $\mathbf{H}$, respectively. Obviously, value closer to 1 would be ideal for spatial multiplexing and a value larger than 2 would be unsuitable. When the value exceeds a certain threshold, for example $c_{\mathbf{H}} \geq 2$, the transmitter look for suitability of mode 2, otherwise mode 3 is chosen. Considering the relatively large MIMO channel matrix size usually formed in MPT circumstances, the complexity of finding dominant Eigen value would be immensely high, so in order to reduce the computational burden and latency, the mobile station can feedback the channel power only, which can be represented by received reference signals received power (RSRP), to the base station for practical channel measurement. In fact,

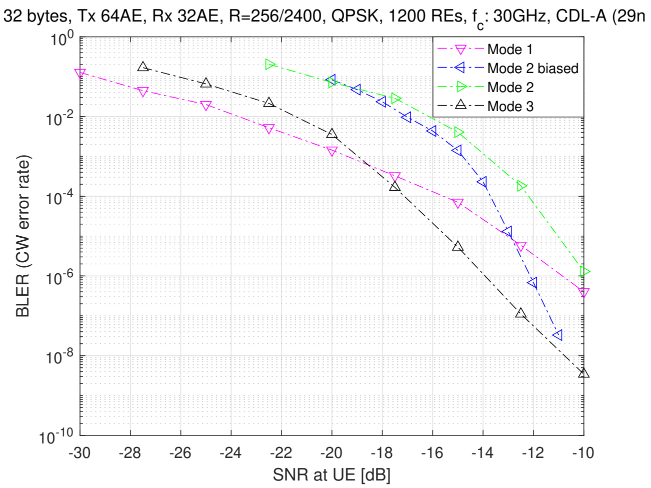

Fig. 4. Performance comparisons of MPT modes in Fig.1 indoor environment

modern mobile stations sends CSI, which contains channel quality indicator (CQI), rank indication (RI), precoding matrix indicator (PMI), to the base station regularly for long term channel measurement. Thus, for channel matrix for Fig. 1 case could be simplified as

$$\mathbf{H} \approx \begin{bmatrix} p_1 & 0 \\ 0 & p_2 \end{bmatrix}, \tag{4}$$

where p_1 and p_2 are estimated scalar value received power from TRP 1 and TRP 2, respectively. This could be especially beneficial for cellular mobile systems that feedback content maybe limited due to scarce uplink capacity. Thus, we suggest estimating channel condition number only with CQI or RSRP.

III. Numerical Results

In this section, we compare link level simulation results under cluster delay line channel (CDL) model [5] with various transmit mode configurations. The evaluation channel environment and physical layer numerology assumptions and parameters are summarized in Table 1. Although perfect channel estimation is assumed, front-loaded demodulation reference signal (DMRS) of one OFDM symbol is occupied, and, thus, the other OFDM symbol is used for payload transmission. NR LDPC base graph 2 is applied for channel coding. CDL-A channel model with average delay spread of 29ns is configured.

For mode 1 case when the channel condition is evaluated to be good enough for spatial multiplexing, SNR gain at low SNR operating region is observed, as shown in Fig. 4. It is analyzed that multiple codeword soft LLR combining is in effect, but diversity order is lowered due to mixing of soft bit LLRs. In mode 2 case, we distinguished two sub cases to figure out the effect of UE's statistical location to link performance. First sub case (biased) usually happens to occur when UE lies at the border between two TRPs shown in Fig. 1. This could possibly let the UE combine transmit signal from each TRPs with high probability of statistically independent channel fading coefficients with similar received power. Second sub case is the case when the UE having unrestricted location. This situation could be thought as ”forced” soft LLR combining scheme despite having a received power difference. In situations where a single TRP is selected due to high received power disparity, mode 3 is chosen. Diversity order by frequency separated group beamforming described in Eq. (2) is observed. It can also take advantage of full transmit power allocation to a single TRP for improved high BLER region SNR gain. It can be analyzed that for relatively high BLER targets, which is expected most frequently, shall utilize mode 1 if channel conditions are allowed. On the other hand, in practical situations, mode 3 should be utilized for low BLER target.

TABLE I
Link-level fading channel simulation assumptions.

Parameters	Assumptions
Carrier frequency	30GHz
System bandwidth	10MHz (100 PRBs)
Subcarrier spacing	15kHz
Simulated number of OFDM symbols	1
Channel model	3GPP TDL-A (DS: 29ns)
Antenna set up (CRS ports)	4-Tx & 2-Rx
Channel estimation	Perfect

IV. Conclusion

A simple transmission measurement method for multi-point transmission system operating above 6GHz was proposed. By evaluating the channel condition with simplified matrix composition, the system can acquire and boost throughput, receive SNR or diversity order, with limited feedback from mobile station.

Acknowledgments

This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government(MSIT) (No.2018-0-00218, Speciality Laboratory for Wireless Backhaul Communications based on Very High Frequency).

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