Full DimensionalDownlink Adaptive Beamforming using Sounding Signals Information

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***Abstract*—We propose downlink Multi-User MIMO channel state information reference signal (CSI-RS) beamforming scheme,of wireless Frequency Division Duplex (FDD) system with large number of transmit antennas at base station. The developed scheme combines Uplink channel sounding information to efficiently predict the downlink channel in the CSI-RS phase. Scheme is developed to consider the practical case of different user elevations (3D coverage) for maximum received per user throughput. Results show that proposed scheme drastically reduces the user feedback overhead bits than the current LTE-A 3GPP standard dual codebook with achieving enhanced performance. It also enables the freedom of increasing BS antennas with limited DL feedback overheads.**

Keywords—LTE-A; Beamforming; CSI; MIMO; User Feedback overhead; SINR.

I. INTRODUCTION

Future wireless communication systems will providea positive response to the increasing demand ofhigher data rates and larger user and traffic capacities. Major organizations in the wireless industry are working to define what futurerequirements will be. This happens through standard committees such as 3GPP and IEEE. Expansion to current wireless standards (e.g. spectrum) and breaking limitations of existing technologies (e.g. MIMO) are popular areas where efforts are dedicated. For example, Massive MIMO or Full Dimension MIMO (FD-MIMO), where a large number of antennas is employed at the eNB, is strongly developed to become rewarding [1].

According to 3GPP standards, the future trends of research are contained mainly in user feedback overhead reduction and researching new techniques for maximum achieved throughput per user. In Frequency Division Duplex systems (FDD), users have to estimate DL channel through the transmitted reference signals in the DL path then feedback their serving BSs with standardized Channel Quality Indicator (CQI) and Precoding Matrix Indicator (PMI) feedback bits [2].When the number of antenna elements at the eNB increases, the overhead of DL reference signals and UE feedback will severely limit the system performance and exhaust DL & UL resources [3]. This will add limitations in front of the developments of future 5th Generation (5G) wireless systems. In addition, current and standard CSI-RS beamforming schemes such as the LTE-A dual codebook are only based on space division in the horizontal direction neglecting the elevation (Vertical) direction which will lead to suboptimal per user performance in such a practical case when users have different elevations.

A common trend for feedback overhead reduction and performance maximization is to divide the precoding process into two stages, training CSI-RS phase and data transmission phase [4]. The first stage is duringthe training phase where DL channel is quantized at the UE side to choose the principal direction of the DL channel per UE. The second stage is during the data transmission phase where Zero Forcing (ZF)is used for interference cancellation

Following this framework, several approacheshave been introduced and developedfor 3GPP LTE releases. For example, one approach utilizes adaptive codebooks wherean update to codebook base code words happensat the transmitter and receiver according to the channel temporalcorrelation changes [5, 6].Another approach isbased on channel reciprocity which is suboptimal for FDD systems due to the frequency gap between UL & DL channels [7]. In addition, Random beamforming (RBF), one more approach, has proven to be attractive in multi-antenna systems especially when employing large number of transmit antennas with large number of UEs [8, 9].

In this paper, we propose a novel scheme for CSI-RS transmission phase. Scheme uses the Uplink sounding information to determine and predict the Downlink channel in the 3D space with different-elevation users. Once the principal paths of DL channel per user are identified, eNB distributes group of CSI-RS beams over different elevation angles to achieve maximum received Signal to Noise Ratio (SINR) for each user. The beam architecture through elevation directions is left arbitrary and general for any other developments and to consider other Performance Key Indicators (KPI) such as the scan loss of antennas. Scheme shows enhanced performance than the standard LTE-A codebook while drastically reducing the required user feedback bits.

This paper is organized as follows: section II presents the test system model for simulations, section III discusses the new proposed 3D beamforming method in details & feedback overhead comparisons with current LTE-A dual codebook, section IV shows the performance results of the proposed scheme. Conclusion is drawn in last section.

II. SYSTEM MODELING

We used a System Level Simulator (SLS) that considers a multi-antenna downlink MU-MIMO broadcast channel over OFDM system equipped with M_{Tx} transmitting antennas at the eNB and K receivers (UEs) equipped by N_{Rx} receiving antennas each as described in *Fig. 1* similar to [10].

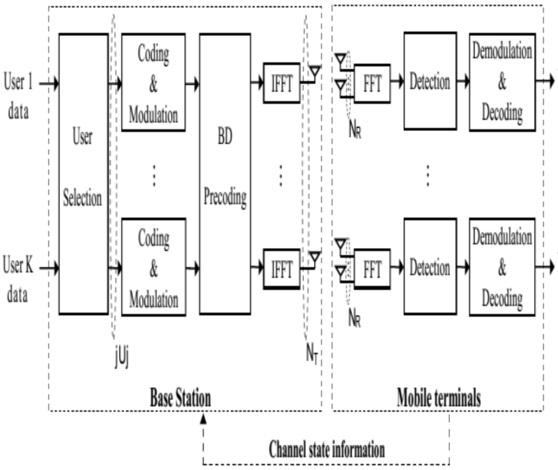

Fig.1. System block diagram

The received signal at the i-th UE, is described mathematically as in "(1),"

$$\boldsymbol{y_i(t) = h_i(t)x(t) + n_i, \quad i = 1, 2, \dots \dots k} \quad (1)$$

where$h_i(t)$ is $N_{Rx} \times M_{Tx}$ channel from the eNB to the i-th UE, $x(t)$is the transmitted signal vector and n_i ~ CN (0, N0) is additive white Gaussian noise (AWGN).

The transmitted signal vector is described as,

$$\boldsymbol{x(t) = v(t)s(t)} \quad (2)$$

Where $s(t)$the transmitted encoded data are symbols and $v(t) = [v_1(t) \quad v_2(t) \quad \dots \dots \quad v_l(t)]$ is the beamforming matrix. $l$is number of independent streams per UE which we limit to unity ($l = 1$) in order to save UE feedback and decrease control signaling overhead. Total transmitted power is divided equally among co-scheduled UEs. A perfect channel measurements (H) is assumed.

III. PROPOSED CSI-RS BEAMFORMING METHOD

A. Idea formulation

In this section we describe our proposed Multi-User downlink transmission scheme and the developments to maximize the Multi-User gain to the maximum.

According to the fact that Uplink and Downlink waves get bounced along the same set of clusters or paths to their destinations in low mobility environments, the major difference will be the carrier frequency or the frequency gap between Uplink and Downlink channels. Also sub path phases are assumed to be IID between Downlink and Uplink channel as in [11].

Idea is to estimate the Downlink channel principal directions directly from Uplink sounding signals per user. At eNB, it receives the Uplink sounding signals from users, projects the Uplink energy over a set of K Uplink DFT beams that cover the whole cell directions and estimates strongest and principal directions of the Uplink channel. In DL CSI-RS, eNB shoots 8 DL DFT beams as in *Fig. 2* towards the directions of the captured UL directions from UL channel sounding training phase. Users will feedback only 3 bits of PMI feedback each Channel State Information (CSI) period to indicate the strongest serving beam in terms of received SINR maximization.

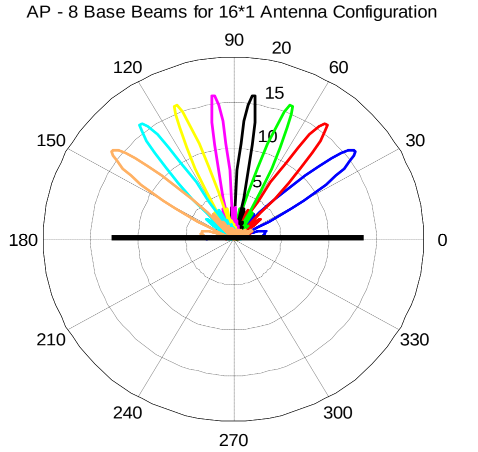

Fig.2. 2D DL CSI-RS beamforming: 8 Beams for 16x1Tx

Moreover, we developed the scheme to support beamforming in the vertical direction for best and maximum received SINR for different-elevation users. In DL CSI-RS, the horizontal directions are determined from Uplink channel sounding and vertical directions are predefined over whole vertical coverage. Hence, dividing the vertical coverage is arbitrary and can hold up some interesting architectures following pre-set rules to optimally cover the vertical space as depicted in *Fig. 3*.

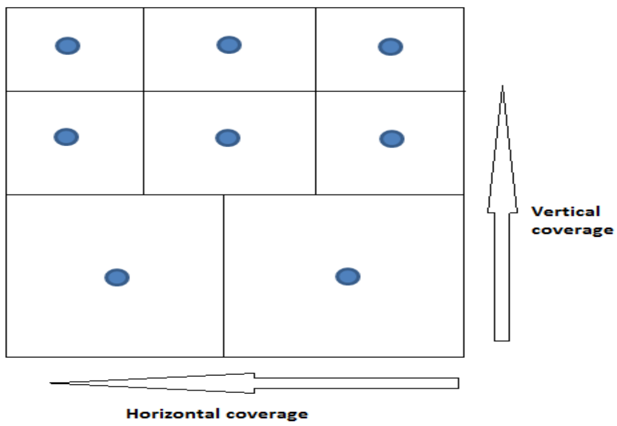

Fig.3. 3D CSI-RS beam distribution over vertical coverage

B. Comments on feedback overheads

We followed the standard CSI periodicity of 5 ms in 3GPP (every 5 subframes). Developed CSI-RS scheme showed the need for smaller PMI feedback overheads since beams are shot adaptively in estimated proximity to users hence eNB doesn't have to shoot many beams in CSI-RS phase.

In 3GPP standards, LTE-A 8-Tx codebook is divided into two separate codebooks (dual codebook) in order to divide the amount of required user feedback at each CSI instant. The UEs feedback two 4-bit indices (PMI_1 and PMI_2) to choose a precoder from each codebook (W_1 and W_2). The final precoder will be $W_1 \times W_2$. PMI_1 Captures the long term channel variations and PMI_2 captures the short term channel variations. A usual exercise of feedback overhead reduction is to increase user feedback PMI_1 periodicity interval. However, the performance suffers significant degradation in such case. Hence, different frameworks of feedback are defined in 3GPP standards such that (20, 5) ms feedback framework (20 ms per PMI1 feedback and 5ms per PMI2 feedback).

Proposed scheme requires smaller number of bits for user PMI feedback that are limited to 3 bits per CSI period since eNB shoots only 8 beams each CSIas in *TABLE I*. Searching a large number of DL CSI-RS beams as in the case of current LTE-A codebooks is replaced by adaptive codebook (set of DL CSI-RS beams) that are estimated and generated from users UL sounding.

TABLE I. FEEDBACK OVERHEADS, PROPOSED SCHEME VS. CODEBOOK

	Proposed scheme, (5) ms	8-Tx CB, CSI: (5/5) ms	8-Tx CB, CSI: (20/5) ms
PMI bits/ 5 CSI periods	15	40	28
CQI bits/ 5 CSI periods	25	25	25
Total bits	40	65	53

C. Detailed algorithm

1. Users send sounding signals over Uplink channel to serving BSs
2. BSs extracts the strongest paths of Uplink channel using general energy projection mathematical process over pool of DFT beam directions
3. Uplink and Downlink principal paths over all channel clusters get bounced similarly and strongest paths in received power diverge in degrees with increasing the frequency gap between uplink and downlink channel as in *Fig. 4*. In *Fig. 5*, a random single user is picked to show UL and DL strongest paths diversion for 100MHz frequency gap.
4. In DL CSI-RS phase, BS shoots 8 beams that are distributed horizontally from Uplink channel directions after energy projection process and vertically as an arbitrary architecture as in *Fig. 3*. Beams are formulated according to:

$$W_{m,n}(\theta,\varphi) = e^{J*2Pi\,(m*\sin(\theta)*\cos(\varphi)d_X + n*\cos(\theta)d_Z)/\lambda} \quad (3)$$

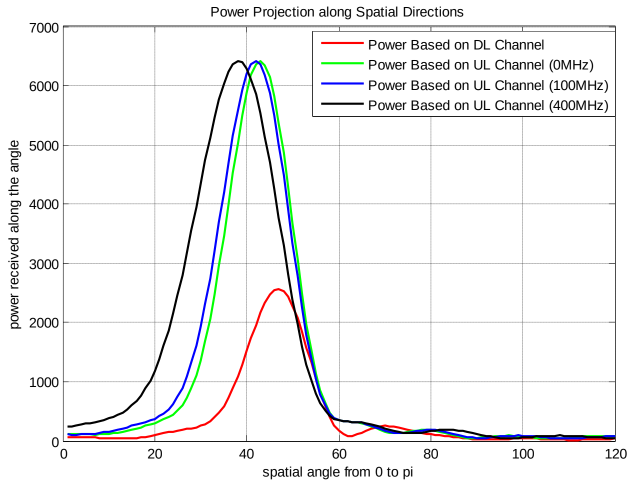

Fig. 4. UL & DL total principal paths diversion with Frequency gap

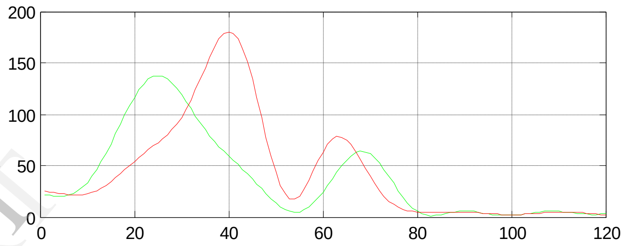

Fig. 5. UL & DL principal paths diversion for single user

Where

- m and n are the indices of antenna element horizontal and vertical placement in the array at BS.
- θ is the elevation angle (Vertical) for each UE from the antennas planar axis
- φ is the azimuth angle (Horizontal) for each UE from edge of coverage area

5. Users feedback only 3 bits to choose a beam out of the shot 8 beams compared to 8 needed bits for the LTE-A dual codebook
6. Zero Forcing beamforming is applied on top of the CSI-RS beamforming for interference cancellation in data transmission phase

IV. SIMULATION RESULTS

The major simulation parameters of our scenarios are listed in *TABLE II*. Generally, the 3GPP simulation methodology is followed.

TABLEII. MAJOR SIMULATION PARAMETERS

Parameter	Value
Channel model	3GPP 3D model [11]
Network	21 cells
DL frequency	2GHz
UL frequency	1.9GHz
UE dropping	Uniform 2D, 10 UEs/Cell
eNB antenna configurations	8
eNB antenna polarization	ULA, 0.5 λ
eNB antenna pattern	3GPP
UE antenna configuration	2
UE antenna polarization	ULA, 0.5 λ
Rank per UE	1
Channel measurement at UEs	Perfect
CQI mode	Wideband
PMI mode	Sub band
CSI feedback delay	5 sub frames
CSI feedback frequency	Every 5 sub frames
Maxim number of HARQ Retransmissions	4
Outer-loop link adaptation target packet error rate	10%
MU-MIMO rank	8
Scheduler	Proportional-Fair

As in *Fig. 6* and *TABLEIII*, proposed CSI RS scheme shows enhanced performance than the exhaustive and impractical scenario of the LTE-A codebook (CSI: [5/5] ms) and significantly improved performance than the practical scenario of the LTE-A codebook (CSI: [20/5] ms). In both cases, required user feedback bits are reduced as in TABLE I.

Proposed scheme is designed to be full dimensional CSI-RS transmission scheme by considering the vertical coverage in beamforming. As mentioned earlier, eight DL horizontal directions per user are determined from the energy projection over UL channel phase and the vertical directions are defined in a way to optimally cover the vertical space in each CSI. The horizontal directions are distributed over predefined vertical directions to achieve full dimensional beamforming and best received SINR per user. This implementation showed enhanced performance than the conventional 2D techniques of beamforming as in *Fig. 7*.

TABLEIII. PROPOSED SCHEME DEMONSTRATES HIGHER THROUGHPUT

	SVD	3D Proposed scheme, 5 ms	8-Tx CB, CSI: 5/5 ms	8-Tx CB, CSI: 20/5 ms
Average Cell Throughput (Mbps)	36.13	28.09	24.09	17.04
Cell Edge User Throughput (Kbps)	1140	690	710	410

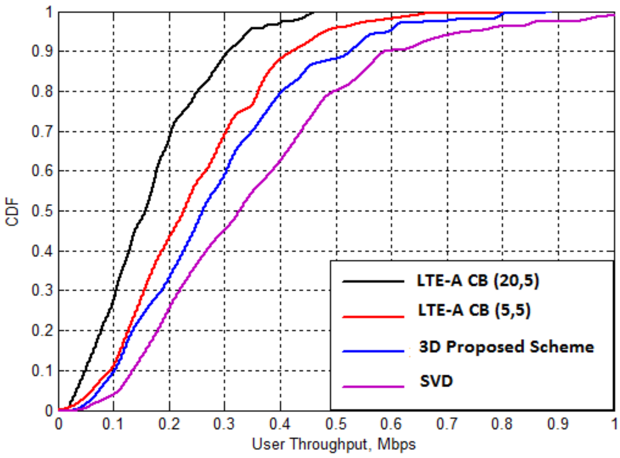

Fig. 6. Higher throughput is achieved by the new 2D method in comparison with LTE-A codebooks

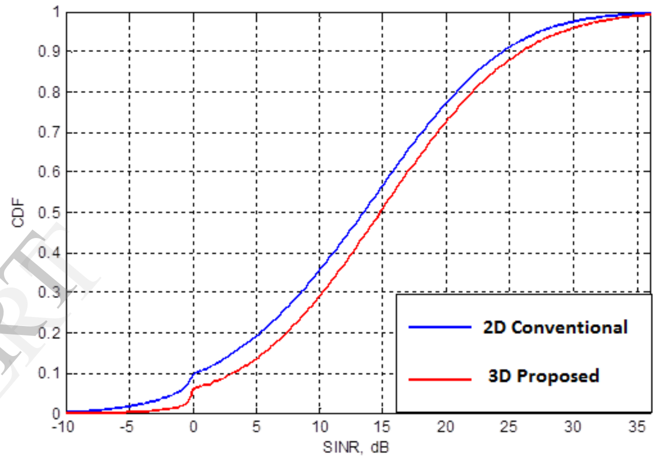

Fig. 7. Full dimensional proposed scheme demonstrates higher received SINR

V. CONCLUSION

In this paper, we introduced novel full dimensional beamforming method in the CSI-RS training phase for future wireless communication networks. Proposed scheme combines and uses the uplink sounding signals' information per user to efficiently predict and estimate the Downlink channel. Full dimension beamforming is performed to optimally cover the 3D space and for maximum received throughput for practical different elevations users. Scheme showed lower user feedback overhead bits with maintaining better performance than the standard LTE-A dual codebook since efficient beamforming is performed and targeted directly to user positions.

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