Impact of Amplitude Component on HSUPA Closed Loop Transmit Diversity Performance

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Abstract— **3GPP is investigating uplink transmit diversity alternatives for High Speed Uplink Packet Access (HSUPA). This paper addresses uplink transmit diversity from the perspective of Closed Loop Beamforming (CLBF) when amplitude component is included in the beamforming codebook. This allows transmitter to divide the total transmit power unequally to transmit antennas based on the feedback from the NodeB. This study includes the investigation of the potential benefits of antenna selection and amplitude adaptation as part of the feedback. Furthermore, the focus will be on evaluating corresponding system level performance when long term antenna imbalance is assumed. The studies show that there are achievable gains and thus system performance may be enhanced by applying the amplitude component, especially when the antenna imbalance is high. However, the trends indicate that gains are mainly seen by the cell edge users, thus introducing amplitude component in the codebook increases coverage and fairness.**

Keywords: Beamforming, HSUPA, Codebook design

I. INTRODUCTION

The *Third Generation Partnership Project's (3GPP's)* Releases 5 and 6 took major steps toward enhancing packet data capabilities of cellular networks by standardizing *High Speed Downlink Packet Access (HSDPA)* and *High Speed Uplink Packet Access (HSUPA)* [1]. Following Release 6, various performance enhancements were introduced to further enhance performance which enables operators to increase the lifespan of their *third generation (3G)* networks. In 2010 a study item was opened in 3GPP to cover *Closed Loop Transmit Diversity (CLTD)* [2]. Inspired by this, a set of system level studies has been carried out to investigate the possibilities and potential performance enhancements for HSUPA using the closed loop transmit diversity.

The purpose of this paper is to introduce and benchmark the beamforming when amplitude information is included in the codebook. For that, this study will examine the performance of CLBF with three different types of amplitude schemes listed below:

1. no additional amplitude component, meaning equally divided power between the transmit antennas
2. an additional amplitude component deploying the unequal power split between the transmit antennas
3. an amplitude that allows transmitter to use only one antenna at the time, i.e. antenna switching

In addition to listed schemes, mixed scenarios are also studied. This means that the amplitude components are utilized in the way that allows beamforming with both equal and unequal power distributions between the two transmit antennas. With these assumptions, this study will deepen the earlier CLTD studies, e.g. [3], that assumes equal transmit power for each antenna branch. Moreover, the antenna switching, i.e. *Switched Antenna Transmit Diversity (SATD),* has been studied more extensively in open loop perspective, see, e.g. [4].

Simulations in this paper assume RAKE receiver and *Inter-Site Distance (ISD)* of 2800 m where *User Equipment (UE)* are more likely to get power limited. Analysis will be conducted with the help of a quasi-static time driven system level simulator using the 3GPP simulation assumptions and schemes. The rest of this document is organized as follows: in section II, the system model is presented and the basic Closed Loop Beamforming Transmit Diversity method is introduced briefly. Section III describes the simulation methods and assumptions adopted in this study and section IV summarizes the simulation results. Finally, section V concludes the paper.

II. CLOSED LOOP BEAMFORMING TRANSMIT DIVERSITY

In this paper pre-coded dual pilot beamforming scheme illustrated in Figure 1. is assumed. In the scheme, phase and amplitude adjustments are applied for the pilot as well as to the data channels. Moreover, there is a single power control loop based on the post receiver combined (across all TX and RX antennas) *Signal to Interference-plus-Noise Ratio (SINR)* at the NodeB, but the total TX power for the two antenna branches is divided in respect of the signaled amplitudes that defines the offset, e.g., 80/20 power split between antennas. Either of the antennas can have the larger portion of the power.

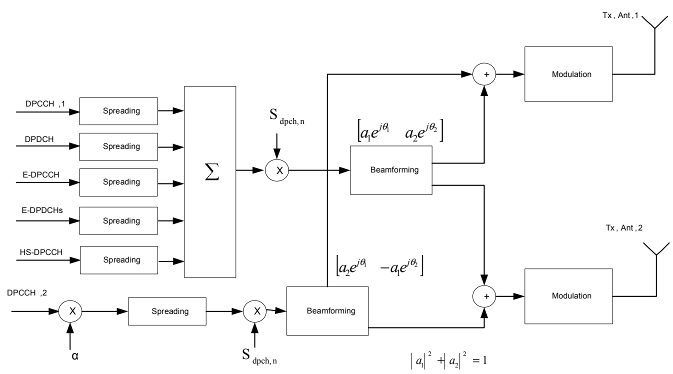

Figure 1. Dual pilot closed loop diversity transmitter [5]

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Pre-coding weight vector, a.k.a. codeword, is determined by the serving NodeB and fed back to the UE that applies the phase and amplitude shifts between antennas. To select the correct weights, the NodeB evaluates the received power with each of the weight possibilities based on the received pilots. In the NodeB receiver the beamforming weight vector (1)

$$\underline{w} = [w_1 \quad w_2]^H \tag{1}$$

is calculated to maximize the received power for the previous slot:

$$\sum_{l=1}^{L} \underline{w}^H H_l(k)^H H_l(k) \underline{w} \tag{2}$$

where $H_l(k)$ is a 2x2 matrix of channels between transmit and receive antennas for the l^{th} multipath in the k^{th} slot. The calculation in (2) is done only for the link between UE and serving NodeB and the weight resulting in the highest power is selected and applied for all links.

As presented in Figure 1. the primary pilot, DPCCH with E-DPCCH, E-DPDCH and HS-DPCCH channels are pre-coded with the primary beamforming weight vector

$$[w_1 \quad w_2] = [a_1 e^{j\theta_1} \quad a_2 e^{j\theta_2}] \tag{3}$$

where the phase $\theta_i \in \left\{0, \frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \frac{7\pi}{4}\right\}$ and amplitude a_i belong to a finite set depending on the case. The beamforming phase offset is then denoted by $\theta_2 - \theta_1$ and the relation of a_1 to a_2 reflects the selected codebook power offset.

The scaled *Secondary Pilot Channel (S-DPCCH)* is pre-coded with the orthogonal secondary beamforming weight vector (4)

$$[w_3 \quad w_4] = [a_2 e^{j\theta_1} \quad -a_1 e^{j\theta_2}]. \tag{4}$$

A. Codebook Design

Codebook (CB) defines a limited set of codewords to simplify equation (2). To study the potential benefits of having amplitude in addition to phase in the codebook, this paper will introduce various codebook combinations: codebook with only *antenna switching (AS)* codewords, codebook with phase only and codebook with phase and amplitude components. Relation between required signaling bits and codebook sizes for each schemes are shown in TABLE I.

TABLE I. CODEBOOK DESIGN

Signaling	1 bit	2 bits	3 bits		4 bits
CB size	2	4	6	8	12
Scheme	AS	4 Phases only	4 Phases + AS	4 Phases, 2 Amp	4 Phases, 3 Amp

In the phase only scheme most of the beamforming gain can be captured using a codebook size four [3], thus in this study one out of 4 possible phases presented in (5) is selected for pre-coding. The codebook is designed so that it is enough to change only the phase θ_2 while the phase θ_1 remains constant. Moreover, the signal inputs to the two antennas have equal amplitude ($a_1 = 1/\sqrt{2} = a_2$) making it unnecessary to signal amplitude feedback in downlink direction.

$$w_1 = 1/\sqrt{2}$$
$$w_2 \in \left\{\frac{1+j}{2}, \frac{1-j}{2}, \frac{-1+j}{2}, \frac{-1-j}{2}\right\} \tag{5}$$

The antenna switching codeword is special kind of amplitude component, because the phase selection becomes unnecessary. This corresponds to antenna selection where the data and control channels are transmitted on the selected antenna along with the primary pilot. However, the secondary pilot is still transmitted on the other antenna. For (3) this means that when AS is applied at the UE and primary antenna is selected for the transmission $a_1 = 1, a_2 = 0$ and both $\theta_1, \theta_2 = 0$, i.e., the included weight vectors in the codebook are [1,0] and [0,1]. These codewords can also be included in the 4 phase codebook and this case refers to a 6 entry codebook that contains 4 equal power precoding vectors with 4 different phases, as shown in (5), and 2 additional AS codewords: [1,0] and [0,1].

When amplitude component, other than AS, is included in the codebook, it will replace the equal transmit power between antenna branches. For example, if amplitude component for the 80/20 power split is used, weight selection out of 4 phases uses 2 bits and amplitude information is conveyed by an additional bit, thus 3 bits are transmitted to the UE. However, in mixed scenarios the additional amplitudes are included in the codebook in the way that reserves the equal power split, i.e., "mixed" in this case refers to scenario where UE is able to divide the total transmit power between the antennas either evenly or unevenly. For that, the equal power will need its own, explicit, amplitude. For example, if codebook contains four phases and two amplitudes (e.g. 80/20 and 20/80), the size of the codebook is 8. Now, including the 50/50 amplitude for the equal power split increases the number of amplitudes to 3 and thus codebook size to 12 that will need in total 4 bits for mapping the codewords as shown in last column of TABLE I.

III. SIMULATION METHODOLOGY AND ASSUMPTIONS

This study has been performed by using a comprehensive quasi-static time driven system simulator which simulates HSUPA with a slot resolution. The term "Quasi-static" approach means that UEs are stationary but both slow (log normal) and fast fading are explicitly modeled. Statistical confidence is reached through running multiple drops, i.e., independent simulation iterations. In each step terminal locations, fading, etc. are randomized but the statistics are gathered and averaged over all drops. The simulator has been utilized previously in various international publications, see, e.g. [3] and [4], as well as supporting 3GPP standardization work. The simulation tool enables detailed simulation of users in multiple cells with realistic call generation, propagation and fading which are adopted from [6] and updated according to 3GPP requirements.

A. Simulation Assumptions

The beamforming weights are adjusted at every slot (0.67msec) and absolute feedback from NodeB to UE is used meaning that the exact codeword is signaled to the UE. Because signaling delay is two slots and the signaled weight is calculated with the information of previous slot, total delay is three slots. The combinations of phases and amplitudes used in this study with all the main parameters used in the system simulation are summarized in TABLE II.

TABLE II. MAIN SIMULATION ASSUMPTIONS

Feature/Parameter	Value / Description
Cell Layout	Hexagonal, 19 NodeBs, 3 sectors/NodeB, wrap-around
Inter-site Distance	2800 m with 10 dB penetration loss
Channel Model	Pedestrian A 3 kmph
Log Normal Fading	Standard Deviation : 8dB Inter-NodeB Correlation: 0.5 Intra-NodeB Correlation: 1.0 Correlation Distance: 50m
NodeB Receiver	RAKE (2 antennas per cell)
UE Max. Tx Power	23 dBm
TTI Length	2 ms
Uplink HARQ	8 HARQ Processes Max. 4 HARQ Transmissions
Short Term Antenna Imbalance	Gaussian distribution: $\mu = 0$, $\sigma = 2.25$ dB
Long term Antenna Imbalance	[0, 4, 10] dB
Tx Antenna Correlation	Uncorrelated
Codebook	AS only (100/0, 0/100) 4 Ph only (50/50) 4 Ph + 2 Amp (80/20, 20/80) 4 Ph + 3 Amp (50/50, 80/20, 20/80) 4 Ph + AS (50/50, 100/0, 0/100)
Weight Feedback	Delay: 2 slots Update Interval: 1 slot Bit Error Rate: 2 %
Number of UEs per Sector	[0.25, 0.5, 1, 2, 4, 10]
UE Distribution	Uniform over the whole area
Traffic Type	Full Buffer
Scheduling algorithm	Proportional Fair, Forgetting factor: 0.01
Uplink power headroom	Averaged over 100 ms (not antenna specific)

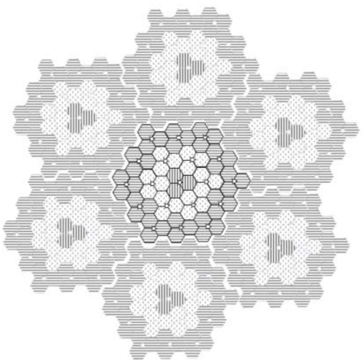

Figure 2. Wrap-around simulation scenario

For simulation scenario a wrap-around multi-cell layout, illustrated in Figure 2. is utilized. The purpose of the wrap-around is to model the interference correctly also for outer cells. This is achieved by limiting the UE placement around the actual simulation area but replicating the cell transmissions around the whole simulation area to offer more realistic interference situation throughout the scenario. In Figure 2. the actual simulation area is highlighted in the center. Statistics are collected from all cells. UEs are distributed uniformly around the simulation area which can result into some cells being more loaded than others.

B. Channel models

The fast fading model used in these simulations is based on tapped-delay line model according to the *International Telecommunication Union (ITU)* recommendations of channel models [7] that are characterized by the number of taps, the time delay relative to the first tap, the average power relative to the strongest tap and the Doppler spectrum of each tap. ITU-models are modified so that the delay and powers between paths are normalized to at least one chip-time. See [3] for more detailed information of the tap delays and powers for *Pedestrian A (PedA)* and *Vehicular A (VehA)* channels in accordance of normalized ITU recommendations.

C. Antenna Imbalance

When deploying multiple antennas to a user device it is likely that the antennas are not exactly alike. Naturally, the environment or user may cause different fading loss to other transmit antenna, but in addition to that, also the physical transmit capabilities between the antennas may differ and antenna imbalance is used to represent these transmit power differences. In this study antenna imbalance is implemented in the same fashion with [4], i.e., short and long term imbalance are used. Short term antenna imbalance models difference in slow fading conditions between the antennas caused by an object in the path of the antenna for example. Long term antenna imbalance models the difference caused by, e.g., manufacturing reasons. In terms of this study both the long and short term imbalance are fixed for the duration of the call but short term imbalance is randomized according to Gaussian distribution with 0 dB mean and standard deviation of 2.25 dB. In this study the power degradation caused by antenna imbalance is always applied on second transmit antenna called as diversity antenna.

IV. SIMULATION RESULTS

In the presented figures and tables the “Baseline” represents simulation results carrying only the basic HSUPA capable UEs utilizing one transmit antenna and all other results equal to CLBF cases. Moreover, different schemes of amplitude components are presented in tables as relative powers between antenna branches. Either of the antennas can have the larger portion of the power, e.g., 80/20 specifies general power split in which either antenna 1 or antenna 2 can have 80% of the power while the other antenna has 20% of the power. The performance is evaluated through cell and user throughputs in addition to total transmit power. All throughput values presented in tables are shown in kbps.

The amplitude component usages in respect of antenna imbalances are shown in TABLE III. Naturally, the phase only 50/50 power split is not included in the table because it does not have additional amplitude component. In general, when there is no long term imbalance between the transmit antennas, all amplitude components, other than 50/50, are equally probable and the more antenna imbalance is assumed the more UE will use the amplitude component that favors its stronger primary antenna. According to the amplitude component usages in mixed scheme including 80/20 power split, equal transmit power between the antennas is not seen as good option when compared to the unequal power split, because in this case amplitude components are used most of the time regardless of the antenna imbalance.

The mixed scenario results with AS (50/50, 100/0) shows that even if 4 dB of the transmit power send through the diversity antenna would fade away due to the antenna imbalance, the 50/50 power split is still used over 50 % of time and thus can be seen as better option than AS. However, assuming 10 dB antenna imbalance chances the situation to favor AS codewords because in this situation transmission through both antennas would lose too much transmit power.

TABLE III. AMPLITUDE COMPONENT USAGE IN RESPECT OF ANTENNA IMBALANCE

		Amplitude component usage				
Scheme		***50/50***	***80/20***	***20/80***	***100/0***	***0/100***
0 dB	***100/0***	-	-	-	50 %	50 %
	80/20	-	50 %	50 %	-	-
	50/50, 80/20	26 %	37 %	37 %	-	-
	50/50, 100/0	64 %	-	-	18 %	18 %
4 dB	***100/0***	-	-	-	79 %	21 %
	80/20	-	78 %	22 %	-	-
	50/50, 80/20	20 %	66 %	14 %	-	-
	50/50, 100/0	51 %	-	-	43 %	6 %
10 dB	***100/0***	-	-	-	96 %	4 %
	80/20	-	95 %	5 %	-	-
	50/50, 80/20	6 %	91 %	3 %	-	-
	50/50, 100/0	17 %	-	-	82 %	1 %

TABLE IV. IMPACT OF AMPLITUDE COMPONENT ON CELL THROUGHPUT

		Average number of users per cell					
Scheme		***0.25***	***0.50***	***1***	***2***	***4***	***10***
Baseline		429.2	758.7	1206.7	1656.0	1912.2	1683.6
0 dB	***100/0***	464.5	812.3	1330.6	1859.1	2116.2	1961.1
	50/50	505.6	**891.4**	**1477.7**	**2116.1**	**2508.1**	**2479.2**
	80/20	505.1	886.7	1470.8	2081.9	2440.7	2379.7
	50/50, 80/20	**506.3**	890.0	1472.9	2093.0	2458.5	2399.9
	50/50, 100/0	505.0	887.6	1467.8	2078.8	2435.7	2356.7
4 dB	***100/0***	436.9	762.4	1252.4	1769.4	2029.7	1868.2
	50/50	466.6	**826.3**	**1402.2**	**2052.6**	**2493.0**	**2476.9**
	80/20	469.4	824.3	1372.8	1990.2	2356.7	2284.6
	50/50, 80/20	**469.8**	826.2	1383.3	2001.1	2377.3	2304.7
	50/50, 100/0	465.3	817.7	1361.0	1960.4	2305.5	2215.1
10 dB	***100/0***	428.0	736.4	1196.9	1668.0	1879.4	1666.7
	50/50	422.0	745.4	**1272.5**	**1897.7**	**2314.1**	**2280.2**
	80/20	**436.7**	**762.8**	1263.6	1813.5	2120.4	1987.6
	50/50, 80/20	436.0	762.3	1266.3	1815.6	2124.8	1988.3
	50/50, 100/0	431.6	747.0	1223.2	1719.0	1961.2	1776.8

Cell throughputs in respect of different schemes and cell loads are show in TABLE IV. When comparing the phase only beamforming (50/50) with all other transmit power distributions, the phase only scheme outperforms other clearly and applying an amplitude component seems mainly to decrease the beamforming gain. In terms of cell throughput, the diversity gain is in the lowest level when the AS is used. Moreover, if antenna imbalance is raised up to 10 dB the performance with AS component drops quite close to the baseline level. This is due to the weight selection percentages shown in TABLE III. in which it could be seen that mainly the primary antenna is used for transmission and that effectively degrades UE to basic HSUPA device with no transmit diversity.

The main observation from the cell throughput results is that the overall system performance will decrease if any of the studied amplitude component is included in the CLBF codebook. However, as shown in TABLE V. applying an amplitude component can provide notable gain in terms of the 10^{th} percentile user throughput (cell edge UEs) where the results show increased performance, with and without antenna imbalance, when compared to the phase only scheme (50/50). In general, the amplitude component for 80/20 power split seems to work better than adding antenna switching codewords. Only in the case of the highest studied imbalance AS codewords can result into higher performance than other power distributions, but still mostly at lower level than the baseline.

TABLE V. IMPACT OF AMPLITUDE COMPONENT ON 10^{TH} PERCENTILE USER THROUGHPUT

		Average number of users per cell					
Scheme		***0.25***	***0.50***	***1***	***2***	***4***	***10***
Baseline		262.8	184.8	126.3	73.0	51.8	45.6
0 dB	***100/0***	364.2	301.2	198.8	95.7	78.1	72.8
	50/50	386.6	319.2	216.8	98.5	82.9	81.0
	80/20	**420.8**	**338.8**	**241.2**	111.4	**91.8**	83.7
	50/50, 80/20	415.2	338.4	220.8	**115.4**	88.4	**84.0**
	50/50, 100/0	402.4	324.8	228.8	113.0	88.8	82.8
4 dB	***100/0***	269.2	220.4	135.4	65.5	50.1	46.4
	50/50	264.8	232.2	143.7	68.2	52.2	46.0
	80/20	**300.2**	**245.2**	160.9	**75.9**	**57.6**	**53.3**
	50/50, 80/20	**300.2**	244.3	160.4	74.6	56.5	52.8
	50/50, 100/0	280.4	242.1	**167.4**	71.4	55.7	51.9
10 dB	***100/0***	**242.80**	192.60	124.27	59.60	**45.60**	**36.57**
	50/50	194.93	152.20	100.70	48.16	32.35	25.69
	80/20	234.00	**202.07**	**128.27**	**60.97**	42.60	33.82
	50/50, 80/20	236.20	190.27	122.88	57.70	43.26	34.29
	50/50, 100/0	241.20	201.20	118.52	60.60	44.40	35.56

In general, the antenna imbalance causes significant decrease on the performance of already power limited CLBF UEs. Especially with the highest loads it can cause the performance to drop below the baseline. In terms of 10^{th} percentile user throughput results, the most notable losses against baseline can be seen with phase only CLBF affected by 10 dB antenna imbalance. Some losses can also be seen with amplitude components but this is the case where the gain from including amplitude components in the codebook is most visible. In other words, this means that amplitude components can benefit the UEs in worst channel conditions regardless the antenna imbalance but it will also help UE to tolerate against it by directing more transmit power through the better antenna.

TABLE VI. summarizes the user performance in good channel conditions and shows that phase only beamforming overcomes amplitude components even with the 10 dB antenna imbalance. This is possible because even if the phase only UEs are not capable to adjust to the antenna imbalance by weighting the better antenna, they can compensate the power limitation by increasing the transmit power as shown in Figure 3. This only applies for the UEs in good channel conditions because UEs in worst channel conditions are more likely to be power limited and already transmitting with the full power.

TABLE VI. IMPACT OF AMPLTUDE COMPONENT ON 90TH PERCENTILE USER THROUGHPUT

		Average number of users per cell					
Scheme		***0.25***	***0.50***	***1***	***2***	***4***	***10***
Baseline		2946.5	2829.9	2541.2	1871.2	922.4	278.0
0 dB	***100/0***	2943.2	2839.6	2611.6	2043.2	1060.0	335.3
	50/50	**3291.3**	**3175.2**	**2915.2**	**2297.6**	**1231.6**	**416.0**
	80/20	3202.3	3091.9	2841.2	2267.2	1203.2	400.6
	50/50, 80/20	3222.5	3122.2	2855.2	2250.4	1217.6	404.6
	50/50, 100/0	3203.8	3106.7	2845.2	2245.2	1206.8	395.5
4 dB	***100/0***	2917.2	2836.5	2579.2	2017.2	1051.6	330.8
	50/50	**3261.4**	**3166.6**	**2904.6**	**2352.0**	**1305.4**	**439.0**
	80/20	3165.8	3065.2	2802.6	2239.2	1201.6	400.6
	50/50, 80/20	3173.1	3079.7	2809.2	2252.0	1218.4	404.5
	50/50, 100/0	3134.9	3046.5	2773.6	2215.2	1177.2	388.4
10 dB	***100/0***	2911.9	2810.8	2525.2	1914.6	977.6	297.0
	50/50	**3167.1**	**3076.7**	**2809.6**	**2284.4**	**1291.2**	**422.0**
	80/20	3057.8	2953.6	2691.2	2088.4	1120.3	356.3
	50/50, 80/20	3059.9	2951.9	2684.4	2103.2	1126.4	354.0
	50/50, 100/0	2947.4	2856.4	2578.7	1998.4	1020.6	313.0

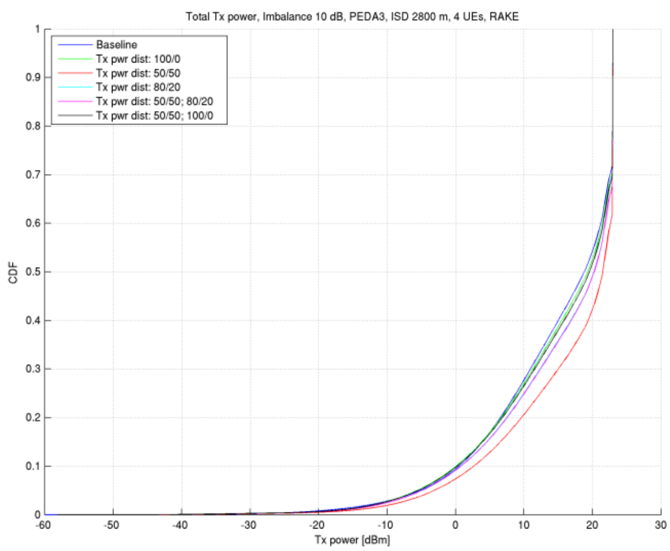

Figure 3. Total Transmit Power, 10 dB antenna imbalance, 4 UEs/cell

Moreover, if amplitude components are compared to the default 50/50 power distribution the results of 90th percentile user throughput indicate that the more antenna imbalance is assumed the lower gains can be achieved with the amplitudes. However, it was shown in TABLE V. that in the same scenarios amplitude components shows notable gains to UEs in the worst channel conditions. In other words, these cell edge UEs are able to use higher data rates TABLE V. thus consuming the higher share of the *Rise Over Thermal (RoT)* target. The outcome can be seen as an increased fairness in the user perspective but on the contrary this will decrease the system performance in terms of cell throughput as it was seen in TABLE IV.

V. CONCLUSION

When compared to the baseline performance CLBF with an amplitude component show gain in overall system in terms of cell throughput but when comparing CLBF performance with and without amplitude component, the system performance will decrease in all situations if any of the studied amplitude components are included in the CLBF codebook.

On the other hand, the benefits of transmitting amplitude information can clearly be seen in 10th percentile user throughput results which mean that the amplitude component can provide increased coverage and fairness in the system and as such can be seen useful. However, applying the amplitude component will increase the number of available beamforming weights and thus also the feedback requirements generating more signaling overhead in downlink direction.

For the cell edge UEs, it is shown that the higher the imbalance the higher is the benefit from amplitude component. With amplitude components CLBF can adapt to the power limitation caused by the long distance to the serving NodeB and also mitigate the impact of power loss caused by antenna imbalance.

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REFERENCES

[1] H. Holma, A. Toskala: "HSDPA/HSUPA for UMTS: High Speed Radio Access for Mobile Communications", John Wiley & Sons Ltd, 2006.

[2] Third Generation Partnership Project (3GPP), "Uplink Transmit Diversity for HSPA", Work Item Description, RP-101438, RAN #50.

[3] P. Eskelinen, F. Laakso, K. Aho, T. Hiltunen, I. Repo and A. Lehti, "Impact of Practical Codebook Limitations on HSUPA Closed Loop Transmit Diversity", In Proceedings of 74th IEEE Vehicular Technology Conference (VTC), San Francisco, United States, September 2011.

[4] I. Repo, K. Aho, P. Eskelinen and F. Laakso, "Switched Antenna Transmit Diversity Imperfections and Their Implications to HSUPA Performance", In Proceedings of 18th IEEE International Conference on Telecommunications (ICT), Ayia Napa, Cyprus, May 2011.

[5] Yibo Jiang, Haitong Sun, Sharad Sambhwani, Jilei Hou, "Uplink Closed Loop Transmit Diversity for HSPA", Qualcomm Incorporated, May 19, 2010.

[6] Third Generation Partnership Project (3GPP), "Selection Procedures for the Choice of Radio Transmission Technologies of the UMTS", Technical Requirement, TR 101 112 (UMTS 30.03), 1998.

[7] ITU-R, "Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000", Recommendation, ITU-R M.1225, 1997.