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Title: DL Coordinated Beam Switching for Interference management in LTE-Advanced
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1 Introduction

During the development of LTE, many suggestions were made on how to manage the interference level by the use of coordinated transmissions from different cells [1-2]. We, furthermore, believe that as we decrease cell sizes in an effort to improve spectral efficiency, the interference problem gets greater.

Beamforming has been promoted as a promising technique to increase cell coverage and to improve cell edge spectral efficiencies. However, one main drawback of beamforming is the so called flashlight effect where the channel quality changes between UE measurement and eNB transmission, due to the change in the beampattern of the neighbouring cells. Coordinated beamforming has been suggested as a possible solution to this problem [3, 4]. Here, we describe a relative simple method of coordinated beamswitching where the coordination information between the cells are very limited and typically changes slowly. Also, this coordination requires no additional signaling on the downlink and small increase in uplink signaling overhead.

One possible disadvantage of this method is that it assumes that all the eNB's in the cluster are doing beam switching in a predictable way, and that none of the eNB's are doing spatial multiplexing for SU-MIMO or transmit diversity. Given that an eNB with correlated antennas may do MU-MIMO, this could still be done in a predictable way by using a grid of beams, similar to what was suggested in [5]. However, it is doubtful that an eNB will do either transmit diversity or SU-MIMO with a correlated array, especially for the case it supports MU-MIMO.

2 Coordinated Beam Switching

Cell coordination can happen at many levels. At the highest level, a central scheduler has full knowledge of all radio conditions of all UE's in a cluster of cells and tries to find a global optimum selection of UE's to be served at any instant in time. This solution would unfortunately require an excessive overhead on the backhaul, and may be simply impossible to implement if we consider the fundamental delays on the backhaul transmission. This necessitates that we find a simpler, less optimal solution that would be easier and less costly to implement.

Here we propose a simple solution that requires that different eNB's be synchronised on a frame level. The basis of this solution is that since we cannot completely avoid interference all the time, our only alternative is to manage it effectively. Generally, interference fluctuations are good, as long as we know about it. This is because $E\{1/I\} > 1/E\{I\}$ for $I\sim\chi^2$. Here $E\{1/I\}$ represents that you know the interference fluctuations and you can link adapt to it, while $1/E\{I\}$ represents that you cannot link adapt to the changing interference and all you can do is link adapt to the average interference.

2.1 Illustrative Example

Consider the following example: Consider a UE that receives a constant signal power of (1W) from a serving eNB. This same UE receives a fluctuating interference power of $I(t_{1..3}) = \{1W, 0.5W, 1.5W\}$ from a neighbouring eNB. If the UE did not know about the interference fluctuation, it would simply average the interference and report an

SIR = 1/{(1+1/2+3/2)/3} = 1.

This would result in an

average channel capacity = 1bps/Hz.

However, if the UE was aware of these fluctuations, it will report

SIR's = {1,2,2/3}

with a resulting

average channel capacity = {$\log_2(1+1)$+ $\log_2(1+2)$+ $\log_2(1+2/3)$}/3 = 1.11bps/Hz,

which is a 10% increase in capacity for this example. Also, the scheduler may only schedule this UE at it's peak SIR, resulting in a peak channel capacity of 1.59bps/Hz.

2.2 Signaling for Coordinated Beam Switching

Here we propose that each eNB will beamform using a predefined beam cycling pattern. These patterns can change on a slow basis. We expect that the beam cycling pattern will be a function of the traffic distribution, and this distribution will not change faster than on the order of 100's of frames.

For example, we could imagine that all cells have 4 correlated antennas and forming beams using a DFT precoder with resulting beam patterns as shown in Figure 1. Also, in our evaluation scenarios we typically consider hexagonal sectorized cell structures as shown in Figure 2. In a 3 sectored cell we can note that sector 1 will only experience interference from sectors 2 and 3, which means that we only require a cycling pattern with 3 rows. We show an example of such a cycling pattern in Table 1.

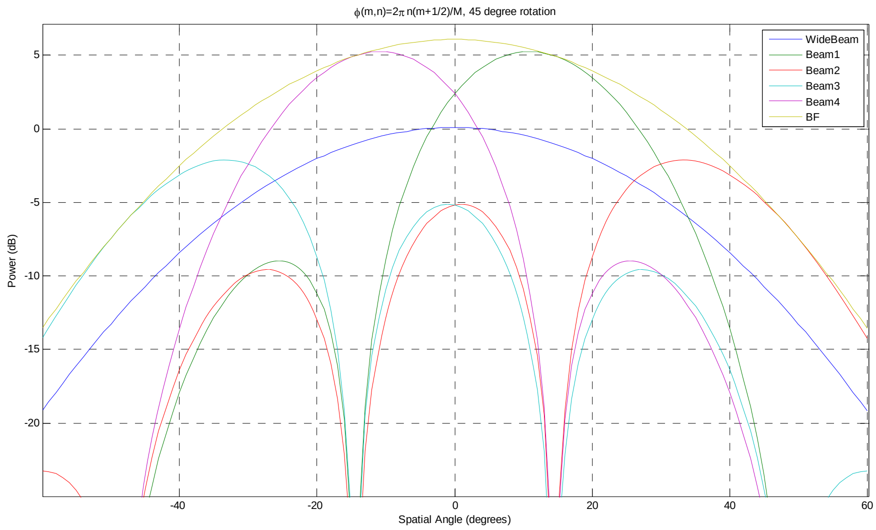

Figure 1: Beam Patterns from 4 correlated antennas using a DFT precoder

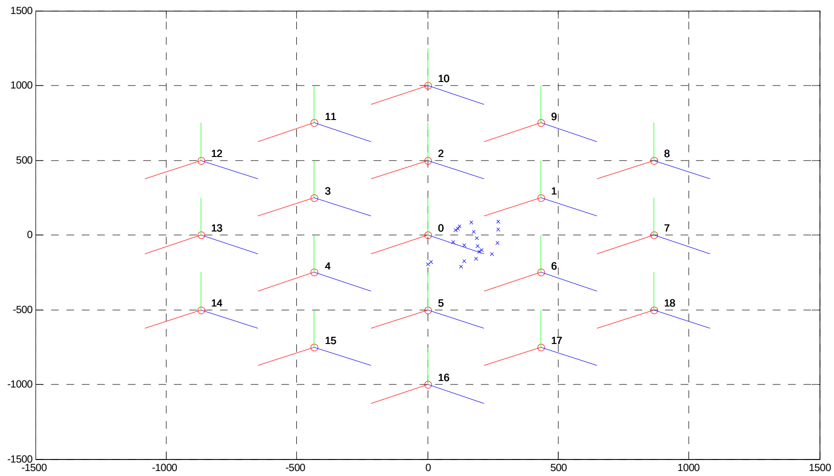

Figure 2: Hexagonal 3 sector Cell structure in our evaluation methodology. The dropped UE's (x's) will only experience interference from green and red sectors.

Table 1. Beam cycling pattern for 3 different sectors across 16 subframes (SF's). Here each Sector has a cycle period of 4 subframes.

	SF_0	SF_1	SF_2	SF_3	SF_4	SF_5	SF_6	SF_7	SF_8	SF_9	SF_{10}	SF_{11}	SF_{12}	SF_{13}	SF_{14}	SF_{15}
Sector	Period 1				Period 2				Period 3				Period 4			
1	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
2	1	2	3	4	2	3	4	1	3	4	1	2	4	1	2	3
3	1	2	3	4	3	4	1	2	1	2	3	4	3	4	1	2

In this example of coordinated beam switching we would imagine that every eNB would determine it's cycling pattern from either a predefined pattern based on its load and user distribution, and then communicate this information over the backhaul to the other eNB's in the cluster. This pattern does not need to be communicated to the UE's. We expect that the common pilots will not be beamformed due to the presence of other non beamformed traffic. Therefore the UE can do a channel estimation on both the serving eNB as well as the strongest interfering eNB. The UE can then report a CQI together with it's preferred precoder vector Index (PVI or Beam) as well as it's preferred PVI of the interfering cell and the cell index. We believe that since the cell index will change slowly, this could be a L3 message. Given this information, the serving eNB can use a look-up-table like in Table 1 to determine when will be the opportune moment to schedule that particular UE. Note that only the serving eNB needed to decode that feedback message, and this information is not relevant to other eNB's since the cycling pattern has already been determined. This is illustrated diagrammatically in Figure 3. Here consider a UE 'X" which reports a best beam (red) from serving eNB (0) and reports a best interfering beam (blue) from eNB (2). If the combination of (red,blue) does not exist in the table the eNB may substitute it for a combination (red,purple) which is in the table.

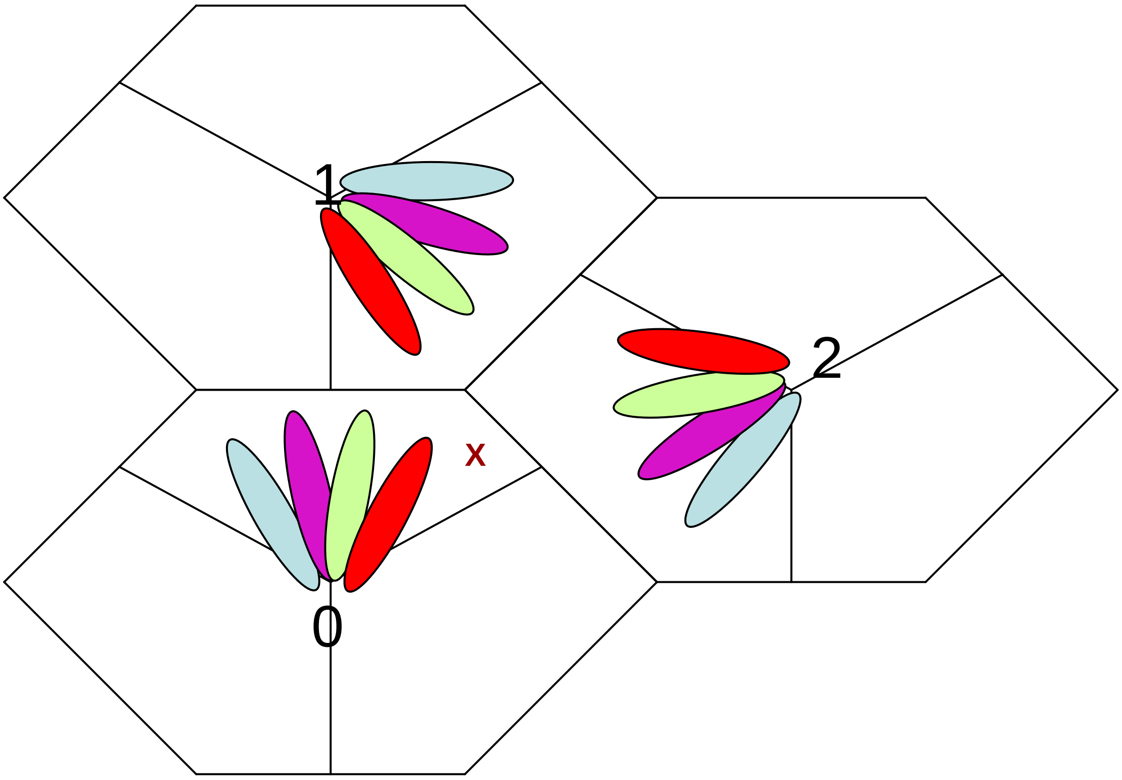

Figure 3: A UE 'X' reports a best beam (red) from serving eNB (0) and reports a best interfering beam (blue) from eNB (2). If the combination of (red,blue) does not exist in the table the eNB may substitute it for a combination (red,purple) which is in the table.

3 Numerical System evaluations

3.1 System Simulation Parameters

The following table summarizes the system simulation settings.

Table 2. System Simulation settings

Number (Tx,Rx)	(4,2)
Antenna Separation (Wavelength)	(0.5,0.5)
Channel Model	SCM
Scheduler	Proportional Fair
Users per Cell	10
Control Overhead	None
HARQ	None
Receiver Processing	MRC
FFT size, Bandwidth	512, 5MHz
STS Distance	500m
Link to System	Effective SNR/Mutual Information

Shadow Fading	8dB
Isolation	20dB
eNB Tx Power	40W
Rank Adaptation	None – only Rank 1 transmissions
Traffic type	Full Buffer
UE Speed	3km/h

3.2 Numerical results

Some experiments have been performed to compare the beam cycling method with the baseline and with PVI feedback with uncoordinated beam switching. We summarize in Table 3 the results and present the CDF of the user throughput results in Figure 4.

Table 3. Simulation Results.

	Cell AVG [bps/Hz]	Cell Edge [bps/Hz]
Base 1x2	1.4274	0.0377
Uncoordinated BeamSwitch 4x2	1.8678	0.0534
Coordinated Beamform 4x2	2.5085	0.0798
Coord Gain over 1x2	76%	112%
UnCoord Gain over 1x2	31%	42%

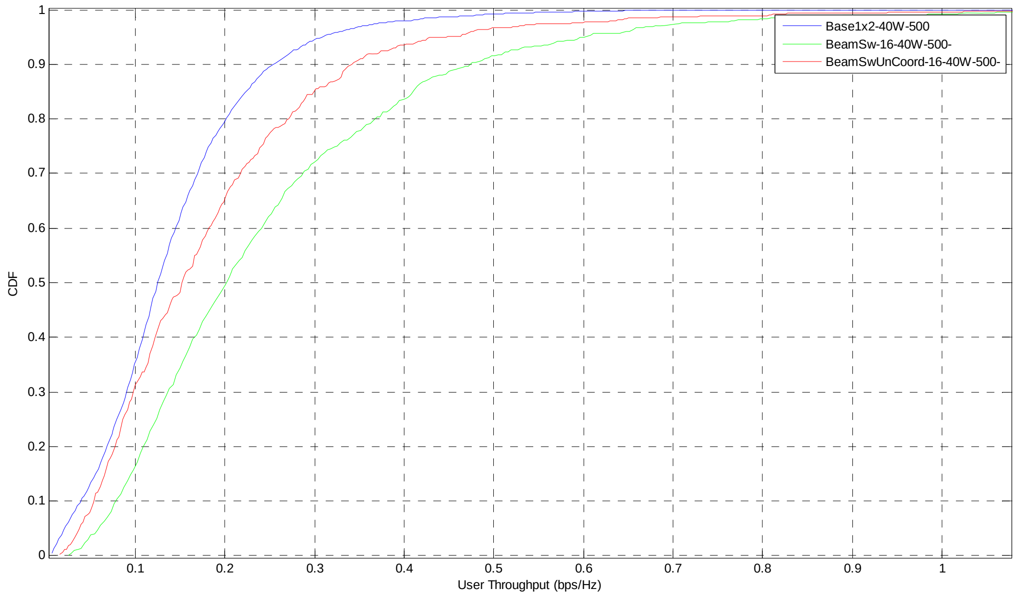

Figure 4: CDF of User Throughput

4 Conclusions

This contribution proposes a coordinated beamforming scheme to manage the interference in small cells. We propose a method to coordinate the eNB's over the backhaul such that each eNB can decide on a beam cycling pattern. This beam cycling pattern can be changed on a slow scale as the traffic density changes. The UE needs to recognize it's main interfering eNB and report this together with an acceptable beam(PVI) for the interfering eNB to its serving eNB. Even though this scheme requires additional feedback, our initial system simulations show a significant performance improvement in both cell and cell edge throughput.

References

[1] 3GPP TR25.814, Physical layer aspects for evolved Universal Terrestrial Radio Access (UTRA), v7.1.0.

[2] NTT DoCoMo, "Proposals for LTE-Advanced technologies", R1-082575, Warsaw, Poland, June 30 - July 4, 2008.

[3] Ericsson, R1-082469, "LTE-Advanced – Coordinated Multipoint transmission/reception", Warsaw, Poland, June 30 - July 4, 2008.

[4] M. Karakayali, G. Foschini, and R. Valenzuela, "Network coordination for spectrally efficient communications in cellular systems,", IEEE Wireless Communications, Vol. 13, No 4, pp 56-61, August, 2006.

[5] C80216m-08_487, Alcatel_Lucent, "Grid-of-Beams (GoB) Based Downlink Multi-User MIMO", IEEE802.16m, May 2008