Outline

- *Introduction: LTE-A uplink & framework;*
- *Related work;*
- *Problem statement;*
- *Virtual MIMO for small cell LTE-A;*
- *Simulation results;*
- *Conclusion.*

Introduction: LTE-A uplink & framework

Long term evolution advanced (LTE-A) and MIMO

- LTE-A is the 4th generation (4G) mobile communication aiming to increase the peak data rates both in the uplink and downlink;
- MIMO is upgraded to 8x8 and 4x4 to reach 1Gbps and 500Mbps in DL and UL, respectively;
- With MIMO, Spatial multiplexing and/or diversity gains can be achieved;
  - Spatial multiplexing → increases throughput;
  - Diversity → robust against fading channels.

Introduction: LTE-A uplink & framework

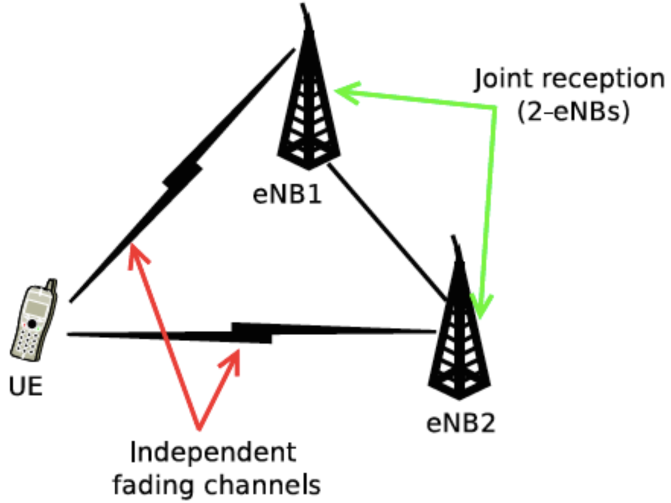
Small Cells in the framework of LTE-A

- Another means of improving throughput is to shrink cell size;
- Small cells are introduced in **3GPP Release-13** to enhance system throughput with **unit frequency reuse**;
- Spectral efficiency increases greatly with unit frequency re-use and eNBs more closer to Ues. With such configuration, cell-edge users suffer as inter-cell interference is severe;
- In DL, feedback information sent to eNBs to precode transmission for interference cancellation, whereas DM-RS signals are used in UL to remove interference **(interference cancellation should always be performed at eNBs)**;
- In multicell, cooperation between eNBs can be performed in order to mitigate intercell interference and/or to exploit diversity. This is known as virtual MIMO or network MIMO.

Introduction: LTE-A uplink & framework

Network MIMO aka Virtual MIMO

- Network MIMO or Virtual MIMO or CoMP;
- Distributed antennas at different ***cooperating*** eNBs form ***Network MIMO***;
- A concept useful for cell-edge users as transmitted power should be received at eNBs with **acceptable power**;
- **Independent fading channel** between mobile terminals and eNBs, network MIMO can introduce gains without introducing significant overhead;
- Network MIMO requires **high speed backhaul** connections among eNBs for cooperation.



Network MIMO in LTE-A uplink

Related work

- Cooperative Multipoint (CoMP) is discussed in [ZHAN13] to assess the downlink cooperative transmission with limited-capacity backhaul;
- An uplink OFDMA CoMP strategy is proposed in [MAR11] with limited capacity backhaul and imperfect channel state information (CSI);
- [ZHAN11] discusses channel dependent SC-FDMA system in cooperative relaying to improve link level performance and increase energy efficiency;
- Multi-cell cooperation is introduced in [GES10] and assesses the performance with different types of cooperation between cells;
- One such type is called MIMO cooperation [GES10] and theoretically more powerful as neighboring cells share CSI and raw received signals;
- Wireless backhaul (operating at very high frequency band) provides low delays and high capacity, as pointed out by all the above references.

Problem Statement

Objectives and advancement with respect to state-of-the-art

- A link level performance analysis is necessary that gives near to lower bound performance (i.e.: in the presence of negligible interference) for network MIMO systems. State-of-the-art works generally evaluate the theoretical capacity, rather that link Bit-Error-Rate (BER);

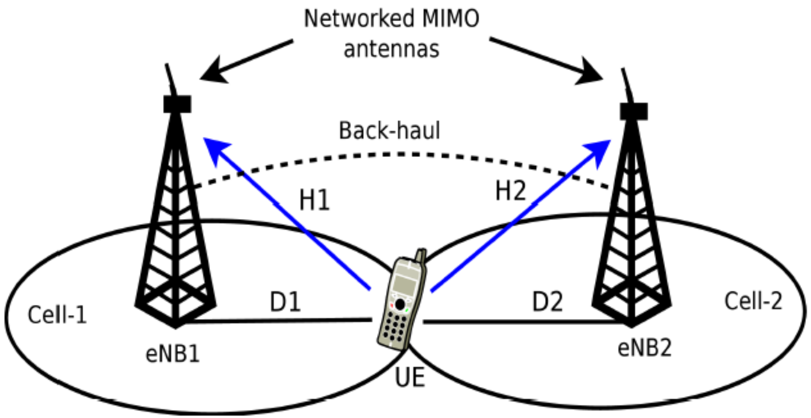
- Link performance analysis should consider the specific modulation and channel coding formats adopted by LTE-A. This is not usually dealt in the literature;

- The impact of non-ideal channel estimation on network MIMO link performance should to be assessed as well. Such an aspect is generally neglected by literature, assuming ideal channel state information availability;

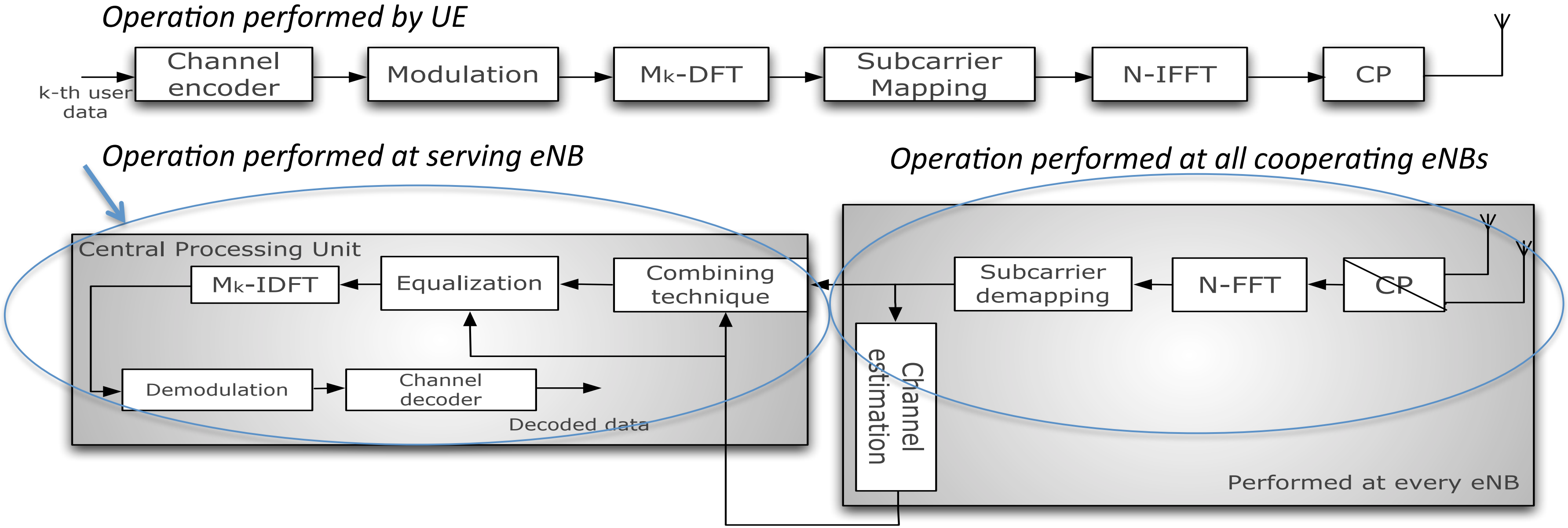
- Energy efficiency analysis has not been dealt yet for ***fixed power network MIMO*** systems in the framework of **homogeneous network**. In [ZHAN11] energy efficiency analysis is presented only for relay networks (HetNet).

System configuration

- Single-antenna UE: typical solution for cost-effective UE;
- Networked eNBs by means of transparent backhaul links (i.e.: error-free and delay-free backhaul);
- eNBs may exploit multiple antennas;
- Number of networked eNBs <=3;
- UEs are all at cell boundaries; therefore they are at equal distance with respect to the eNBs.



Virtual MIMO in Small cell LTE-A



- Serving eNBs and cooperating eNBs;
- The neighboring eNBs communicate with serving eNB over high speed wireless backhaul;
- Channel state information (CSI) is estimated for each receiving antenna element with the help of DM-RS;
- The CSIs obtained at neighboring eNBs are shared with serving eNB for coherent demodulation of information;
- With information is shared among eNBs, the performance is improved through receiver diversity (MRC combining).

Link level analysis (PHY-layer settings)

- Punctured turbo channel coding is adopted according to LTE and LTE-A standard guidelines;
- *Assumption for interference free transmission*: cell-edge users associate with same cell transmits over orthogonal frequency resources and transmissions are received at multiple spatially distributed eNBs;
- Receiver design is simpler as no multi-user detection is required thanks to orthogonality of allocated frequency resources;
- Maximal ratio combining is employed at the receiver to increase the signal-to-noise ratio (SNR) followed by zero forcing equalization in order to remove inter-sample interference due to DFT- spreading in SC-FDMA;
- Zero-forcing (ZF) equalization is performed at serving eBN. The choice of ZF is motivated by the lower complexity (no need of noise co-variance knowledge) and is in-line with LTE guidelines;
- Channel estimation is based on the Least-Square (LS) method in order to guarantee the due robustness of such a crucial operation.

Energy efficiency analysis

- With fixed transmission power the energy efficiency η is defined as: "*out of total energy transmission E_{total} , E_{useful} is the energy spent on error free transmission*":

$$\eta = \frac{E_{useful}}{E_{total}} \times 100$$

$$E_{useful} = E_{total} - E_{wasted} \qquad E_{wasted} = N_{error}\left(\frac{E_b}{N_0}\right)\frac{\sigma^2_{noise}}{R_b}$$

$$E_{total} = N_{total}\left(\frac{E_b}{N_0}\right)\frac{\sigma^2_{noise}}{R_b} \qquad N_{error} = P_{be} N_{total}$$

- Courtesy receiver diversity, greater portion of transmitted energy can be converted into useful energy;

- More independent channels will maximize energy efficiency if received power is above threshold.

Simulation setup

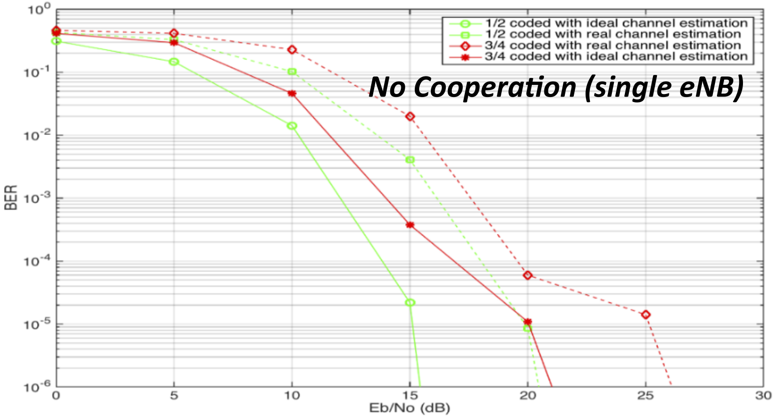
Simulation parameters and configuration

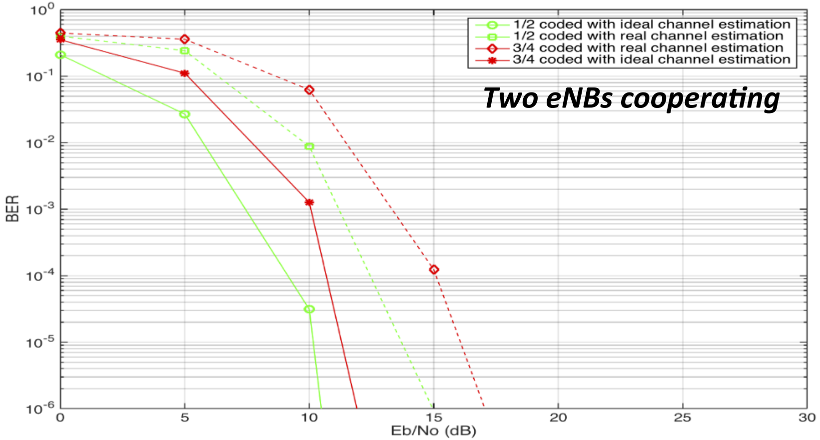
Parameter	Value
Total number of subcarriers	512
Number of resource blocks	12
Number of subcarriers per block	12
Number of users	2
Number of receive antennas (at each eNB)	2
Bandwidth	5 MHz
Punctured turbo coding rates	1/2, 3/4 (helical interleaver)
Baud-rate	3.6 Mbaud/s
Modulation constellations	QPSK, 16-QAM
Doppler frequency	5Hz
Channel model	EVA

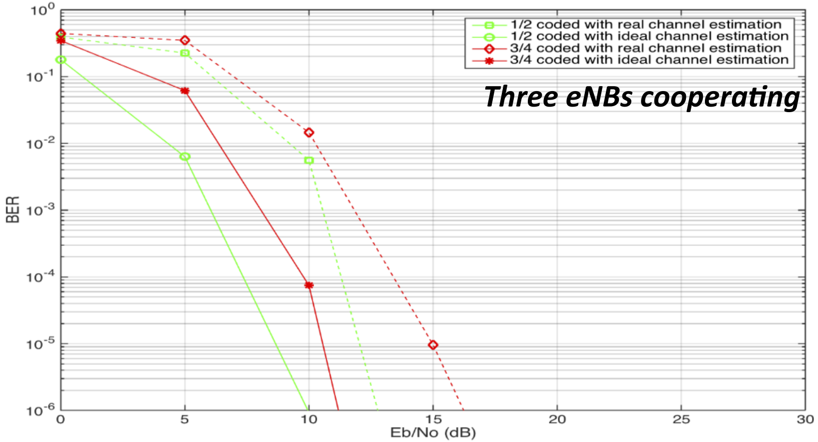
Excess tap delay (nsec.)	Relative power (dB)
0	0.0
30	–1.5
150	–1.4
310	–3.6
370	–0.6
710	–9.1
1090	–7.0
1730	–12.0
2510	–16.9

Extended Vehicular A (EVA) channel multipath profile

Simulation results (Link level performance)





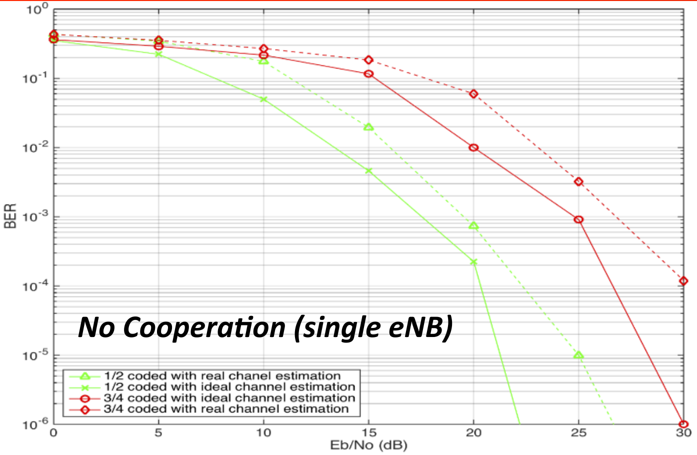


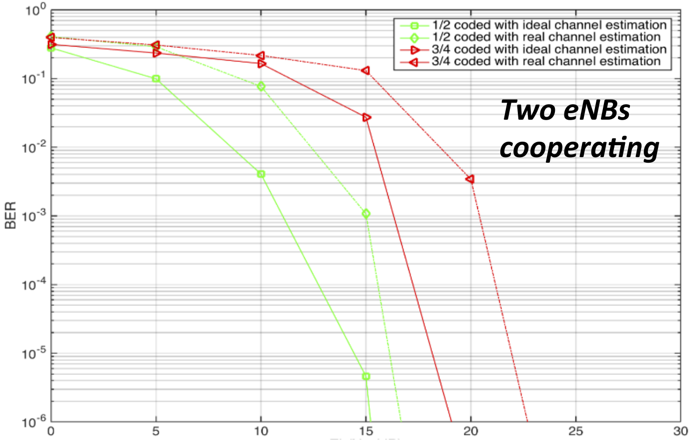
QPSK with 1/2 and 3/4 code rate in ideal and non-ideal channel estimation

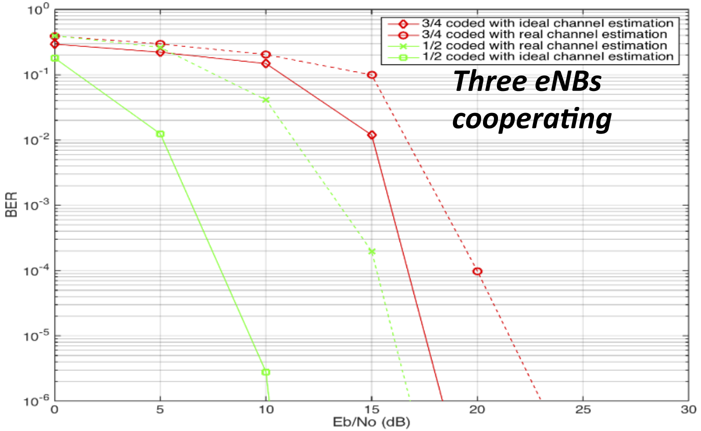
Virtual MIMO outperforms the conventional single eNB case in both ideal and non ideal channel estimation case.

Three eNBs case gives performance gains up to 8dB over conventional case.

Simulation results (Link level performance)





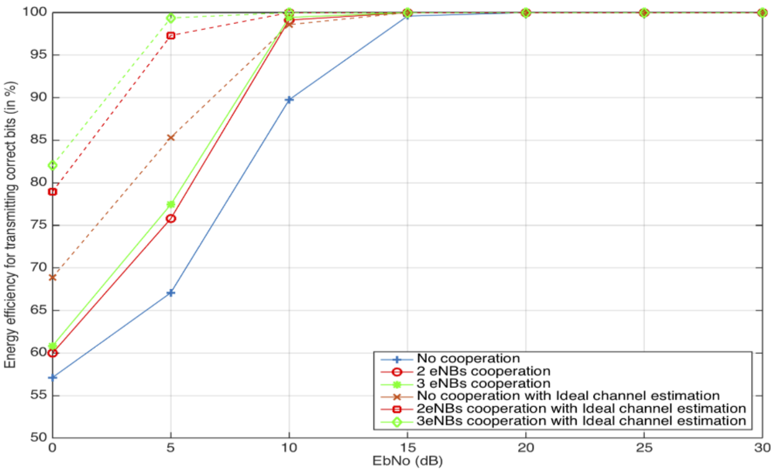


16-QAM with 1/2 and 3/4 code rate in ideal and non-ideal channel estimation

With increased spectral efficiency, a considerable gain of 12 dB is obtained with 3eNB virtual MIMO over conventional case.

Non-ideal channel estimation is more impacting on higher modulation schemes as evident in plots.

Simulation results (Energy efficiency analysis)



← *QPSK ½ code rate*

Virtual MIMO helps in converting the total energy into useful energy through receive antenna diversity.

@5dB E_b/N_0 w.r.t conventional case

Ideal channel estimation – 3eNB is approx. 23% more energy efficient.

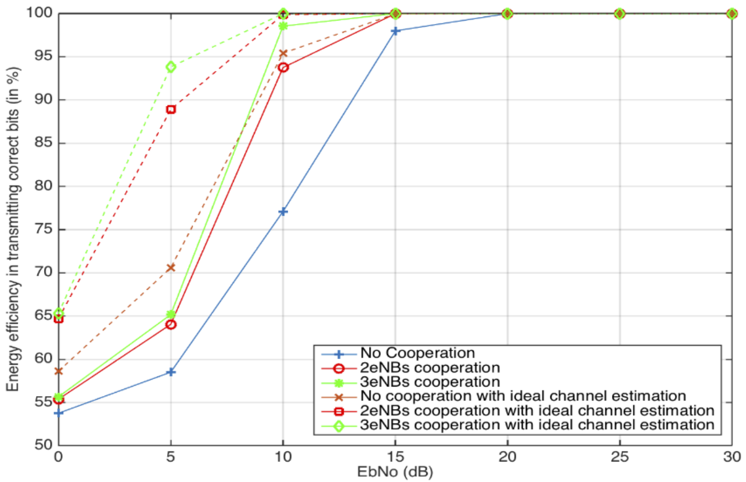
Non ideal channel estimation – 3eNB is approx. 10% more energy efficient.

QPSK ¾ code rate →

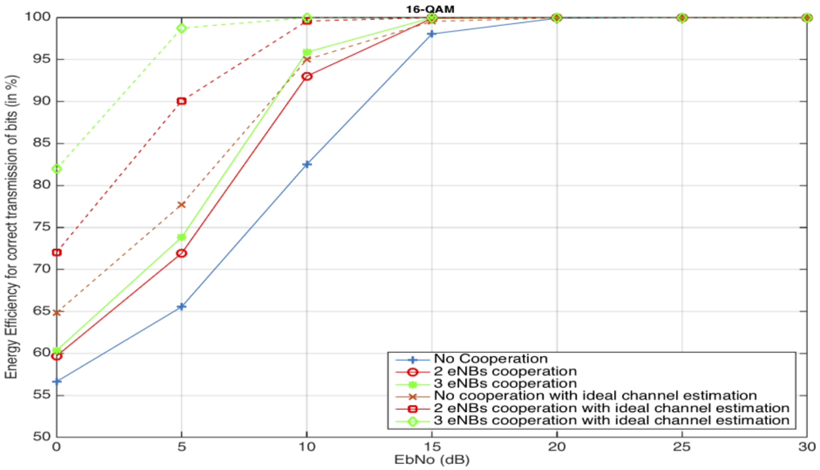
@5dB E_b/N_0 w.r.t conventional case

Ideal channel estimation – 3eNB is approx. 23% more energy efficient.

Non ideal channel estimation – 3eNB is approx. more 7% energy efficient but the gain becomes dramatic at 10dB when same achieves approx. 20% more.



Simulation results (Energy efficiency analysis)



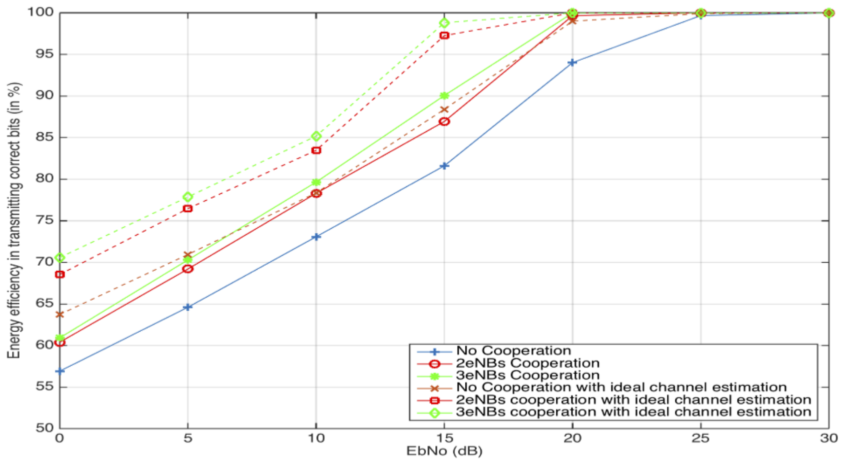
← 16QAM ½ code rate

@5dB SNR per bit w.r.t conventional case

Ideal channel estimation – 3eNB is approx. 21% more energy efficient.

Non ideal channel estimation – 3eNB is approx. 8% more energy efficient whereas it is increased to 14% more at 10dB.

16QAM ¾ code rate →



@5dB SNR per bit w.r.t conventional case

Ideal channel estimation – 3eNB is approx. 6% more energy efficient.

Non ideal channel estimation – 3eNB is approx. 5% more energy efficient.

Conclusion & Future work

- Virtual MIMO approach is applied in uplink LTE-A system for small cell system;
- Up to 3 eNBs cooperation is done in the analyses and witnessed that virtual MIMO is outperforming the conventional single eNB approach;
- Virtual MIMO provides gains at link level with the help of distributed antennas at spatially distributed eNBs, without any increase of the UE complexity (and cost);
- Energy efficient transmission is greatly improved in case of virtual MIMO due to receiver diversity;
- The impact of non-ideal channel estimation on virtual MIMO performance is generally significant and becomes even more significant for higher-order modulations achieving higher spectral efficiency;
- Multi-user interference in case of MU-MIMO with frequency reuse will be considered in future works together with large scale fading;
- This work is done under the assumption of ideal backhaul. Non-ideal backhauling analysis will be dealt in future work.

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