Interference Optimization and Mitigation for LTE Networks

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Abstract— **This paper talks about the most problematic issues brought by interferences in the New Generation Networks and their impact on the network´s data throughput with focus on the inter-cell interferences. The most important ways to avoid interferences while planning a network are mentioned. In particular frequency reuse, power control and MIMO antenna arrays. Also, interference regeneration and cancelation is mentioned and indicators of signal quality in LTE are named. In the end, a simple MATLAB simulation of the impact of interferences on the throughput is presented.**

Keywords-LTE, inter-cell interference, interference mitigation, fractional frequency reuse, fractional power control

I. INTRODUCTION

Interference mitigation has always been an important topic in cellular systems, but LTE brings some new challenges. In order to maximize the data rate, generally the whole frequency spectrum available for the network is assigned to each cell of the network. This results in higher interferences around cell borders. Also, cell density increases especially in highly populated areas. Higher cell density improves the capacity of the network and reduces power requirements, but on the other side, higher cell density results in wider area of high interferences around the cells borders. In addition to that, LTE networks require higher SNIR than any previous standard. For the optimal functionality LTE network requires SNIR higher than 20 dB [4].

LTE networks also often operate on a side of another systems using 3G, 2G or terrestrial TV broadcasting, etc., causing inter-system interferences. This paper will mainly talk about inter-cell interferences, however, some of the mentioned techniques can also be applied on inter-system interferences.

Inter-cell interferences and interferences in general, lead to malfunction of the network, call drops and decrease of data rates. All these phenomena are extremely undesirable. Therefore, improving and searching for new technologies to cope with interferences while maintaining high data rates and capacity of the network is a subject of high priority. This paper talks about technologies used to avoid interferences (Adaptive Frequency Reuse, Power Control, MIMO and Beam Forming). Further interference regeneration and cancelation method is mentioned and in the end the diminution of data throughput of the network caused by high interferences is demonstrated and visualized on a simple MATLAB simulation. Similar approach to this project can be found in master thesis [10], where coverage of LTE femtocells is simulated and interferences with overlay network are examined. This simulation provides simplified solution for attenuation introduced by buildings. Bachelor thesis [11] uses the Berg's recursive model to predict coverage of microcells

II. ADAPTIVE FRACTIONAL FREQUENCY REUSE

Original 2G cell networks were using frequency reuse patterns where cells had a pre-assigned portion of available frequency spectrum. This frequency band would be only used in spatially distant cell [2] as it is presented on Fig. 1 b. This approach is called static frequency reuse (SFR). SFR was chosen based on the request for stable service. To satisfy the increasing importance of mobile data, Next Generation Networks require a different approach. To achieve higher maximum data rate the Shannon–Hartley theorem (1) suggests widening the frequency band.

$$C = B \cdot log_2\left(1 + \frac{S}{N}\right) \; [bit/s] \qquad (1)$$

That is achieved by assigning the whole frequency spectrum to each cell (Fig.1 a). This inevitably results in higher inter-cell interferences.

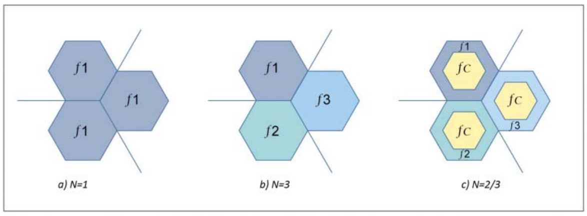

Fig. 1 Frequency reuse in special diagram [8]

The achievement of high data rates inside the cell is ruined by high inter-cell interferences and low quality of reception in the cell-border areas. This is why Adaptive Fractional Frequency Reuse (AFFR) was developed. The network can dynamically adjust

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to any situation. For example, a cell is in mode with frequency reuse N=1 (Fig.1 a). When the eNodeB receives information about mobiles located near the cell borders with low SNR on the downlink, the eNodeB changes frequency reuse scheme and gives information about it to neighborhood cells to do the same. Fractional (or soft) frequency reuse schemes (Fig. 1 c and Fig. 2 c) are often used for its efficiency. It means that the whole frequency band is used to cover the centre of the cell ensuring maximum data rate. The problematic areas around cell borders are served by a part of the frequency band, which is different in each of 3 neighborhood cells. Deployment of AFFR can increase SNIR levels in the network about up to 10 dB. [1]

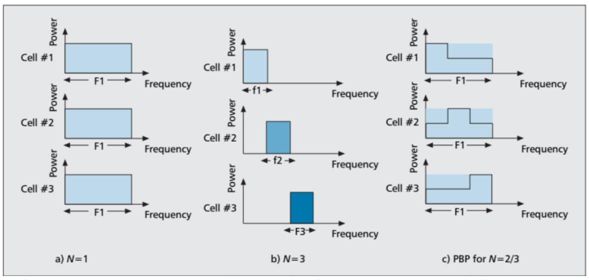

Fig. 2 Frequency reuse schemes in frequency spectral diagram [1]

III. POWER CONTROL

Power control techniques have been developed since the early generations of cell networks to save energy and prolong the battery life of the mobile devices and mainly in order to prevent interferences. In LTE there are no intra-cell interferences thanks to orthogonal character of used OFDM-based schemes. Nevertheless, inter-cell interferences are still present and in LTE they are more critical than before, as it was previously explained.

A. Opened and Closed Loop Power Control

There are two ways how to determine the transmission power of the User Unit (UE). The first is called Open Loop Power Control. In this scheme the transmission power is determined based on an algorithm implemented in UE. This algorithm takes into account various characteristics, mainly the information about the maximum transmission power and path loss of this received reference signal. Open Loop Power Control is used to determine the initial transmission power when the connection between the UE and an eNodeB is initialized. If the UE started to transmit maximum power, it could lead to massive interferences causing call drops and other malfunctions. The second way is called Closed Loop Power Control and it involves a return channel via TPC command providing personalized feedback to each active EU. Closed Loop Power Control is used when the connection between the UE and an eNodeB is established. The transmission power of the UE is determined by the eNodeB and the decision is based on the information about the SNIR of the signal. The transmission power level is updated each 20 ms via TPC command.

B. Fractional Power Control Scheme

The transmission power P_{PUSCH} (Physical Up-line Shared Channel) is given by the equation (2), where M is the number of used Physical Resource Blocks (PRBs), P_0 is the desired received power density given by network, α is the path loss compensation factor and PL is the path loss. If the path loss compensation factor is $\alpha = 1$ we talk about full compensation of path loss and the received power from all the UEs in the cell will be the same unless it is limited by the maximum transmission power.

$$P_{PUSCH} = 10 \cdot log_{10}(M) + P_0 + \alpha \times PL\ [dBm] \quad (2)$$

Spectral power density of this received power is given by equation (3), where P_n is the noise power per PRB and SNR_0 is the target signal-to-noise ratio.

$$PSD_{Rx} = P_0 = P_n + SNR_0\ [dBm/PRB] \quad (3)$$

However, full compensation is mainly used in non-orthogonal systems like for example, CDMA where equal received power helps to remove the near-far problem.

On the other hand, in systems that use orthogonal transmission scheme it is beneficial to use fractional compensation of path loss $(0 < \alpha < 0)$. In this case the spectral power density of this received power is given by equation (4).

$$PSD_{Rx} = P_0 + PL \cdot (1 - \alpha)\ [dBm/PRB] \quad (4)$$

It is apparent that the received power is decreasing with growing path loss. This diminution depends on the path loss compensation factor as it is shown on the Fig. 3. The knee point is where the UE reaches the maximum transmission power allowed. Position of this point also depends on α.

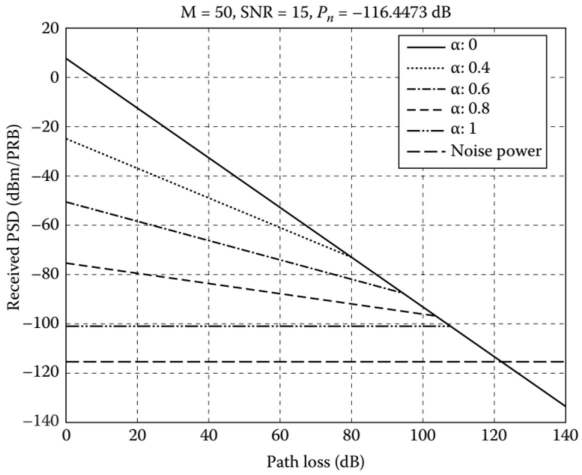

Fig. 3 Received power as a function of path loss for different values of α [2]

It has been proved, that fractional power control brings better spectral efficiency and is especially effective in small cells up to 1 km. Fractional power control scheme generally increases aggregate data rate of the cell up to 40% [2] and particularly improves the situation for users on the cell edges. These reach the maximum transmission power but do not experience such high interferences like they would, if users in adjacent cells, finding themselves before the knee, would be using the full compensation scheme. [3]

IV. DOWNLOAD CHANNEL SCHEDULING

Modern systems like LTE do not use power control in the downlink. Instead, they transmit with constant, often maximum power. That results in higher received power and therefore higher data rates. This shortens the connection time necessary to transfer given amount of data. Generated interferences are reduced via scheduling and link adaptation for the downlink channel. Each cell receives information about interferences from neighborhood cells via transmission-power indicator. This indicator provides information about frequency band, where interferences are occurring. This lets the eNodeB lower the transmission power for this frequency band or switch to another one and leave this channel free so, it is not causing interferences to any of the adjacent cells.

V. MULTIPLE-INPUT MULTIPLE-OUTPUT (MIMO)

Multiple-Input-Multiple-Output (MIMO) is another technology improving spectral efficiency and therefore helping to avoid interferences. MIMO, as the name suggests, is based on multiple antennas which are transmitting multiple different data streams using the same frequency. In LTE it can be from 2 to 8 streams. The antennas are detached, thus each signal stream has a different path. That is necessary in order to distinguish the signals on the side of receiver. Cross polarization of these streams also helps to differentiate the signals. However, MIMO still requires a lot of data processing on the side of receiver.

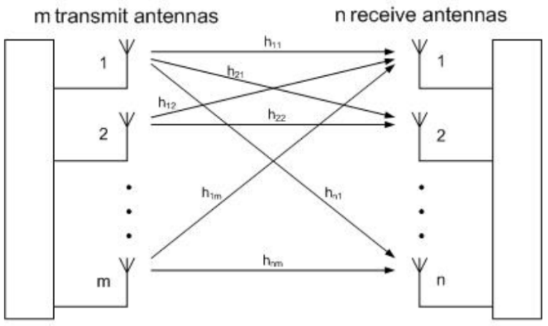

Fig 4 MIMO – scenario where multiple antena are transmiting different data streams using the same carrier but different path of propagation. [5]

There are different modes of usage of this technology. 3GPP defines eight modes. Mode MIMO-SU is when all the streams are received with one UE. This mode helps to increase date data rate for this user. On the other hand, MIMO-MU is when these data streams are received by different UE. This helps to increase the capacity and efficiency of the network. Transit diversity mode is a slightly different approach. The same data streams are transferred over different MIMO channels. This makes the transmission very resistant and improves the SINR. Complete description of the MIMO transmission modes are defined in 3GPP standard or for example in [5].

VI. BEAM FORMING

3GPP specification for LTE standard also includes beam forming as a way of improving spectral efficiency of the downlink channel. With beam forming, the UE can be directly targeted with a directive antenna characteristic with an adjustable angle. This is possible due to deployment of antenna arrays where here the antenna characteristic can be influenced by phase shift of signals arriving to each components of the antenna array (Fig. 5).

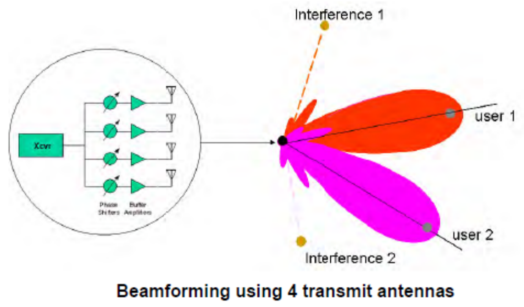

Fig. 5 Beam forming with antenna arrays [6]

The position of the UE is known to the network and therefore can be easily targeted. This technology increases the complexity of the network, but significantly improves the spectral efficiency, because another UE can be served by the same frequency band in the same cell without causing interferences. The same technology can be used also for the uplink on the side of the eNodeB due to reciprocity of antennas. Directing the beam to the UE increases the gain and decreases the influence of interfering signals arriving from different directions. [3] [5]

VII. INTERFERENCE REGENERATION AND CANCELATION

Despite deployment of any previously mentioned techniques, interferences will be still present. One possible way to repair a signal impaired by interferences is to regenerate interfering signal and subtract it from the received signal. The interfering signal is obtained from known reference symbol received with the data stream. This technique obviously requires buffer and complex signal processing. Thus, the Interference Cancelation (IC) is mainly implemented only in the base stations and used for uplink. It helps to fight not only interferences from adjacent cells, but also any other type of interferences and IC also helps with deployment of MIMO technology.

VIII. SIGNAL QUALITY VALUES AND ADAPTIVE MODULATION

The level of received power is reported by the UE using RSRP (Reference Signal Received Power). RSRP depends on the power of received reference signal from the eNodeB and it is defined in a range from -140 dBm to -44 dBm with a step of 1 dBm.

The quality of the signal is expressed by RSRQ (Reference Signal Received Quality) which is a result of formula (5), where N is the number of used resource blocks (PRBs) and RSSI (Received Signal Strength Indicator) is the overall received power by the UE including the interfering signals.

$$RSRQ = N \cdot \frac{RSRP}{RSSI} \qquad (5)$$

RSRQ is defined in the range from -3 dB to -19,5 dB. [7]

		RSRP (dBm)	RSRQ (dB)	SINR (dB)
RF Conditions	**Excellent**	>=-80	>=-10	>=20
	Good	-80 to -90	-10 to -15	13 to 20
	Mid Cell	-90 to -100	-15 to -20	0 to 13
	Cell Edge	<=-100	<-20	<=0

Fig. 6 Relation between RSRP, RSRQ and SINR and meaning of values of these indicators [9]

eNodeB chooses the order of modulation (QPSK, 16QAM, 64QAM) according to the CQI (Channel Quality Indicator) number. CQI value varies in the range from 0 to 15. CQI is estimated by the UE based on the SINR conditions and capability of the device to achieve block error rate lower than 10%. CQI=0 means out of range, up to CQI=6 QPSK is used, for CQI values from 7 to 9 16QAM is used and from CQI=10 64QAM can be used, if the UE supports it.

IX. DEMONSTRATION OF IMPACT OF INTERFERENCES ON THE DATA RATE ON A MATLAB SIMULATION

In order to demonstrate and visualize the impact of interferences on the network functionality, a simulation in MATLAB was created. The objective is to show the direct relation between the level of interferences and the network data throughput.

Fig. 7 Four eNodeBs were placed in the map in order to cover the whole area with sufficient signal

The techniques to avoid interferences presented before, power control and frequency reuse, are not applied. The whole network is using the same frequency band and we are admitting eNodeBs are transmitting maximum power the whole time.

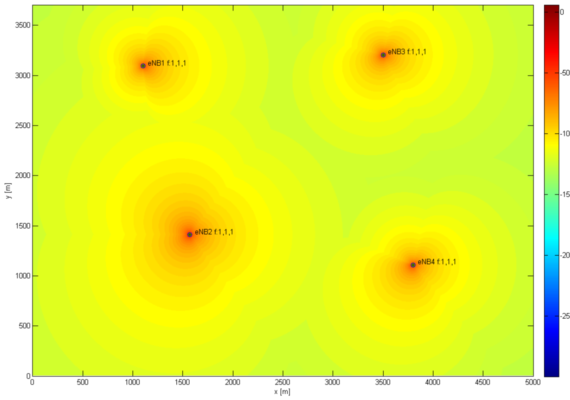

Fig. 8 The coverage was calculated using Cost-231 model

First the eNodeBs were situated in the area and emitted power was assigned to cover the whole area with sufficient signal (Fig 7). Then, the coverage of the area was calculated based on empirical model COST-231, which is described for example in [3]. In the following step the SINR ratio was calculated. Taking the strongest signal in each point as the useful signal and the second strongest as the power of interfering signal. Areas with SINR lower than 13 dB are highlighted red on Fig 8.

We can see that the area, which is not suffering major interferences and therefore, according to Fig. 6, the conditions of received signal in this area are at least good, is very limited.

Fig. 8 Are with SINR lower than 13 dB is highlighted red

These interferences have direct impact on the maximum data rate. In the Fig. 9 the maximum data rate is calculated based on previously calculated SINR assuming 15 MHz of bandwidth which means 75 Physical Resource Blocks (PRBs), each consisting of 12 subcarriers and 7 symbols per subcarrier (assuming normal cyclic prefix). Each symbol is transmitted in a 0.5 ms slot. Adaptive modulation is implemented and for SNIR < 13 dB the QPSK modulation schema is used, for 13 dB < SINR < 20 dB 16QAM is used and for areas with SINR > 20 dB 64QAM modulation is used. (These thresholds were estimated because they are not standardized and in reality the order of modulation is decided by the UE.) Also 2x2 MIMO is taken in account.

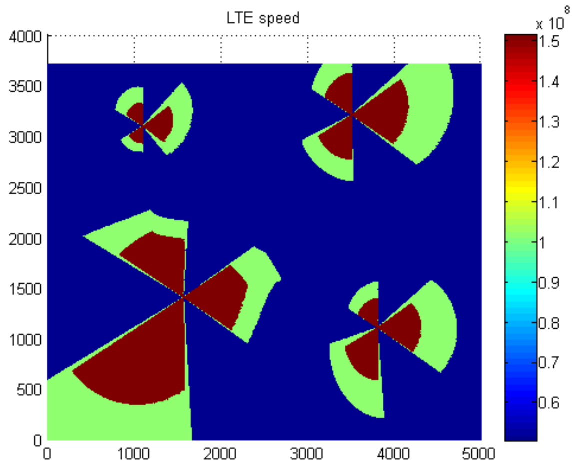

Fig. 9 Maximum data rates: 151,2 Mbit/s (red), 100,8 Mbit/s (green), 50,4 Mbit/s (blue)

Then the maximum data rate in the area with excellent reception, therefore with usage of 64QAM carrying 6 bits per symbol signal is (6):

$$75 \cdot 12 \cdot 7 \cdot 2 \cdot 6 \cdot 2 = 151200 \quad [bits \cdot ms^{-1}] \tag{6}$$

These areas with maximum data rate 151,2 Mbit/s are marked red. Areas, where 16QAM modulation carrying 4 bits per symbol is used are green. The maximum data rate there is 100,8 Mbit/s calculated respecting the same formula (6). At last the expanded blue area is where the conditions do not allow higher order than QPSK modulation caring 2 bits per symbol giving maximum data rate 50,4 Mbit/s.

X. CONCLUSIONS

This paper brings an overview of technologies improving spectral efficiency in LTE networks and brings an approach of the impact of interferences on the network functionality. On the presented simulation we can see how important network optimization and deployment of technologies capable of increasing spectral efficiency and therefore avoiding interferences are. In a purely optimized network, the whole potential of high data rates would be ruined by interferences in mayor part of the networks area. Therefore, technologies as power control and frequency reuse have been investigated, improved and deployed in LTE as partial power control and partial frequency reuse. MIMO technologies are also widely used and there are some new technologies in LTE as adaptive beam forming. Although all these technologies have been brought to maximum efficiency, it is necessary to combine various types of technologies and quality scheduling algorithm to achieve functional and efficient network with reuse pattern close to N=1 to deliver maximum throughput.

XI. ACKNOWLEDGEMENT

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