LTE-Radio Network Planning with PegaPlan

The mobile communication subscribers are used to call, to send E-mails and to surf in the internet by the mobile radio network every time and everywhere. In order to ensure this accessibility, the modern mobile radio network should have a well coverage and it should be future-oriented as well as cost optimized. The planning tool PegaPlan helps the mobile radio network operators to perform the required comprehensive planning taking tasks into account realistic traffic modelling and cell load prediction.

Inter-cell interference

LTE is – like UMTS - a single frequency network in which all base stations are working on the same carrier frequency. That means, neighboured cells are not separated by different frequencies - as in GSM networks. Therefore, mobile users might be significantly disturbed from the neighbouring cells. This is called inter-cell interference. If a mobile subscriber is located at a place with high inter-cell interference the data rate in the downlink decreases. Hence, the quality of the coverage is determined particularly by inter-cell interference, which

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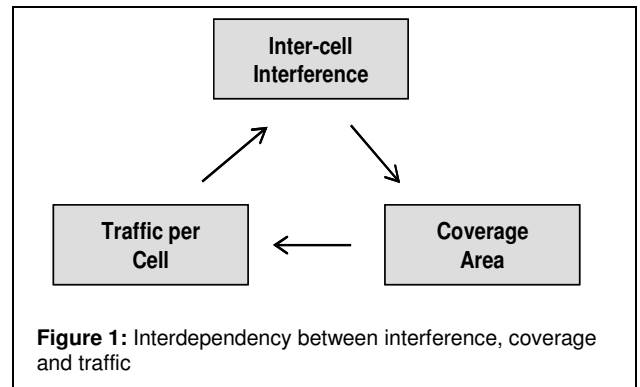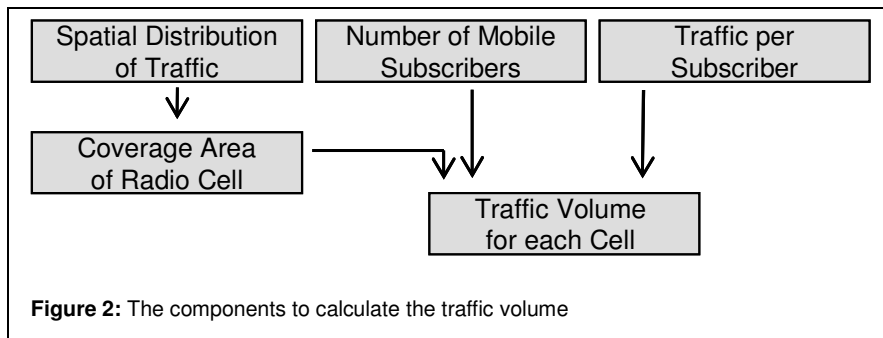
depends on the amount of traffic in the cells. The amount of traffic per cell depends on the coverage area of the cell. This interdependency is shown in figure 1. With increasing traffic of a cell their transmission power increases too leading to a higher inter-cell interference of this cell. In the downlink, the LTE-data rate is clearly reduced in areas with a high inter-cell interference – which even might lead to a call drop.

Figure 1: Interdependency between interference, coverage and traffic

Traffic data base and traffic definition in PegaPlan

The traffic data base describes the spatial distribution of the **traffic**. For this purpose the network area is divided in area elements (pixels). The traffic data base contains the offered traffic for each individual pixel. However, the offered traffic volume is not absolutely given, but as relative values. The traffic data base gives the part of traffic per pixel relative to the complete traffic in the mobile radio network. Thus, the traffic data base along with the input values given in figure 2 enable a flexible planning base in order to assess the mobile radio network for further increasing traffic. This flexible traffic definition is important if, for example, the marketing department of a network provider wish to offer low priced data tariffs, which

normally leads to an increasing data traffic. Then the radio planners have to check if the existing network is able to serve the expected increased traffic volume and - if not – they have to evaluate the number of additional required base stations for any enhancement.

The **spatial traffic distribution** is determined in PegaPlan based on traffic measurements in the mobile radio network where the traffic volume for each radio cell is continuously recorded. Based on this measured data, the traffic data base is created in PegaPlan. Besides the measured data, the predicted **coverage area** for each cell and the land usage within the cell area is considered in the calculation of spatial traffic distribution. However, further marginal conditions are taken into account: for example, a pixel of a land usage class 'Forest' in intra-city parks has more traffic than in rural forest area.

Generally, it is distinguished between real-time traffic (circuit switched traffic) and non-real-time traffic (packet switched traffic). For example Voice is real-time traffic and mobile internet surfing is non-

Figure 2: The components to calculate the traffic volume

real-time traffic (packet switched traffic). The volume of both traffic types is separately measured in the mobile radio network and the spatial distribution of both traffic types varies from each other. Therefore, separate traffic data bases are available in PegaPlan for both traffic types. Currently, there are no traffic measurements available for LTE. Therefore, the spatial traffic distribution of an existing mobile radio network is used for LTE radio network planning.

In addition to the **spatial traffic distribution** PegaPlan requires two further parameters to calculate the offered traffic volume: **the number of subscribers** in the mobile network and the expected traffic volume per subscriber. A mobile network subscriber often uses several services. Therefore, the expected traffic volume per subscriber in the busy hour is given for each individual LTE service. In the case of packet switched services, the traffic volume in the downlink is greater than in the uplink. Therefore, in PegaPlan the traffic value per subscriber is separately given for downlink and uplink.

The procedure described above to calculate the traffic volume per cell is shown in figure 2.

Calculation steps in PegaPlan

The calculation steps for the LTE-radio network planning in PegaPlan are shown in figure 3. As usual the first step in the radio network planning procedure is the calculation of the wave propagation. For this purpose, the path loss of the signal on the propagation path from the base station to the regarded pixel is computed. This result is used to calculate the received power in uplink and downlink. Different propagation models are available in PegaPlan in order to cover the wide range of requirements. E.g. if the base station antenna is below the surrounding rooftops (micro cells) an other propagation model has to be used as for the case that the base station antenna is in an exposed place (macro cells).

The interdependency between interference and traffic per cell shown in figure 1 is resolved in PegaPlan with an iterative procedure as indicated in figure 3. In

iteration step 1 a specific level of inter-cell interference is assumed. With this assumption, the traffic volume per cell is determined. This result is the basis for the iteration step 2, wherein the inter-cell interference for each pixel is calculated more precisely than in step 1. It is checked if a pixel is covered and, if yes, the traffic volume of this pixel is assigned to the serving cell. This assignment of pixel to a cell is called as cell formation in figure 3. At the end, the amount of traffic per cell is known and the cell load can be calculated. The cell load is that part of the time the cell is transmitting data. This is one basic input in order to predict the downlink interference per pixel.

Figure 3: Calculation steps for the LTE radio network planning in PegaPlan
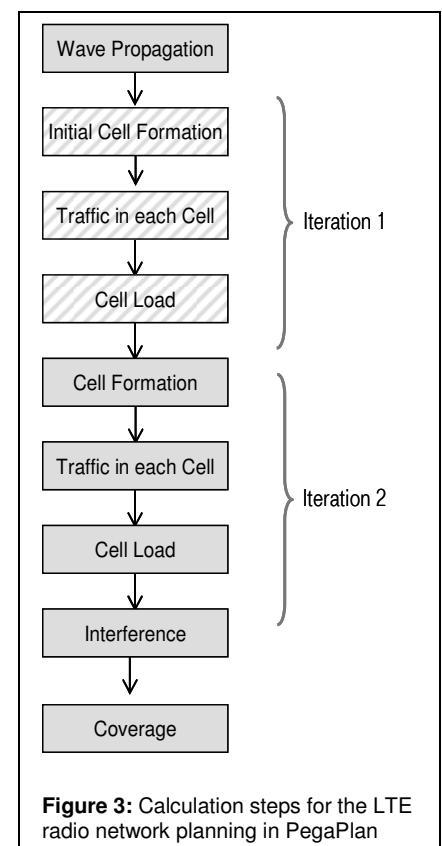
Used abbreviation	
3D	Three dimensional
GSM	Global System for Mobile Communications
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
XML	Extensible Markup Language

The interference power of the cells (second last box in figure 3) is also finally required in the coverage calculation. In the coverage calculation the location dependent interference power is used in order to compute the signal to noise ratio per pixel and, based on this, the data rate a user might achieve on this pixel. In the case of a large interference power the mobile network user will get a poor voice quality or a long download time. In different locations in a cell the user might obtain different data rates.
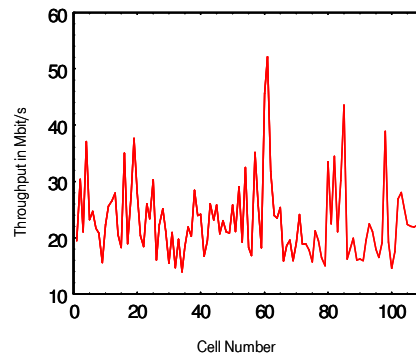

Figure 5: The achievable cell throughput in the downlink.

An application example with PegaPlan

The prediction area

For this article, some results of PegaPlan are discussed for a network in the inner city of Frankfurt (Main), Germany. The regarded prediction area has a size of about 4.6 km x 3.4 km. Figure 4 shows the radio network over the land usage in the regarded area. This radio network is not a real existing one. It is just used as an example and it was modified considerably in order to avoid any conclusion about

the actual network setup. This modified network was not further optimised.

In figure 4 the radio cells are marked by blue circle segments whose outer round sides show in the main lobe direction of the base station antenna. The network contains of 37 base stations and each base station is equipped with three radio cells.

Capacity results

In the radio network planning there are two types of results:

- Capacity results
- Coverage results

The capacity results are given per cell or per eNodeB (base station with several cells). The expected traffic volume (=offered traffic) and the amount of traffic which a cell is able to serve (=achievable cell throughput) belong to those capacity results. If the offered traffic exceeds the achievable cell throughput the cell is in overload and the offered traffic is partly blocked. The calculation of the achievable cell throughput is the first step in order to predict the cell load. From the radio network planner's point of view one goal is to maximize the achievable cell throughput.

The achievable cell throughput is affected by several components:

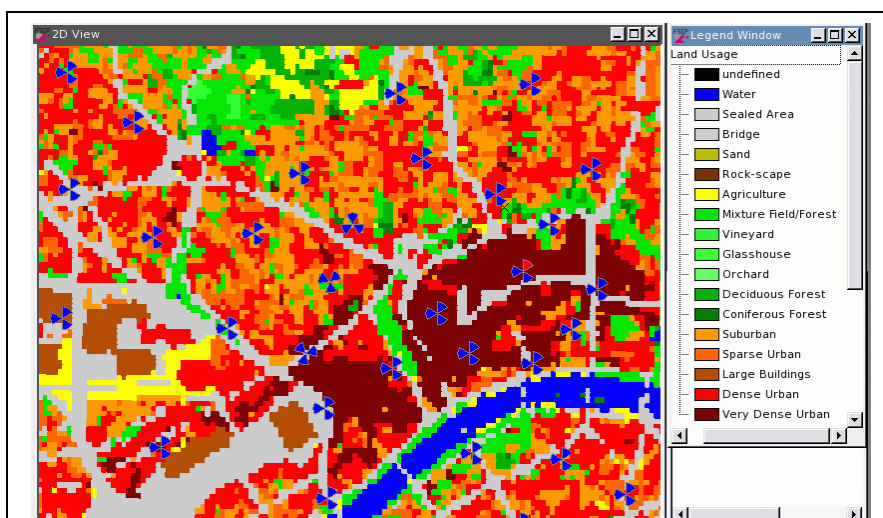- The capacity of the air interface

Figure 4: The Land usage in the regarded prediction area

- The capacity of the transmission line to the base station
- The hardware equipment of the base station

Generally, the transmission path via radio is called as **air interface**. In single frequency networks, like LTE, the capacity of the air interface is restricted by interference. Cells with large interference have a lower air interface capacity as cells with low interference.

Each base station is connected by a cable or by a radio link system to the next higher network level and the capacity of the **transmission line** represents the upper limit for the data rate over the air interface. Furthermore, the hardware of the base station is designed for a certain maximum data rate which is a further upper limit for the air interface data rate.

All three components can be considered in PegaPlan but the air interface is of particular interest in the radio network planning. Therefore, restrictions of the transmission line and of the base station hardware are not taken into account in this article. Under this assumption the achievable cell throughput equals the capacity of the air interface.

The achievable cell throughput is calculated and graphically shown in PegaPlan. The results are given for each cell and they can be exported as text- or XML-file which enables further investigations with software tools like Microsoft Excel.

The line plot in figure 5 shows the achievable cell throughput for the regarded network as a line plot predicted. This line plot, which e.g. can be easily generated with Excel, shows the high dynamic of the achievable cell throughput. Such line plots enable a quick overview of the capacity situation in a large network. However, for a detailed analysis PegaPlan provides 2D plots with cell based coloured surface.

The achievable cell throughput is also a measure for the level of inter-cell interference. Moreover, the spatial distribution of the inter-cell interference affects this result. A high level of inter-cell interference in an area with much traffic leads to a low value for the achievable cell throughput. That means, a cell with a high value for the achievable cell throughput in figure 5 has either a low inter-cell interference in general or at least low traffic in areas with high inter-cell interference.

Anyway, the values in figure 5 are noticeable. Even 'worse' cells have an achievable cell throughput of 15 Mbit/s. From this number an individual data rate per user can be estimated. Let's assume that 5 users are simultaneously downloading data from the internet in one cell. Then, on average each user will get a data rate of 3 Mbit/s.

According to figure 5 the average value for the achievable cell throughput is 23 Mbit/s. Assuming again 5 simultaneously active users per cell means a data rate of 4.6 Mbit/s per user. Such a high data rate was not possible in former mobile communication standards. The best cells in figure 5 have a achievable cell throughput of around 40 Mbit/s. If we again assume 5 active users in such a 'good' cell means that every user will get a average data rate of 8 Mbit/s. As mentioned, those numbers are averages since in a real life radio network the allocation of the data rate to the users is highly dynamic. It might happen that for a short time a user get the whole transmission capacity of the cell and, on the other side, it is possible that a user sometimes doesn't get any transmission capacity.

The average data rate per user as estimated above with some simplifying assumptions is also calculated in PegaPlan with a sophisticated algorithm.

The achievable cell throughput is one main input to compute the cell load. The other main input is the traffic volume per cell. This is the amount of traffic which is given from the spatial traffic distribution (according to the traffic data base) in the cell area together with the traffic value per subscriber. If the offered traffic of a cell exceeds the achievable cell throughput the cell
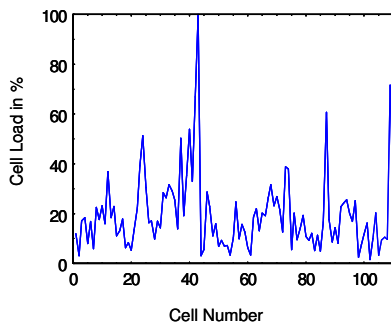
PegaPlan

Figure 6: The cell load in the downlink.

load is 100% and a part of the traffic is blocked. If the offered traffic is less than the achievable cell throughput the cell load is the ratio of the offered traffic to the achievable cell throughput. A high cell load might have the following two reasons:

- High traffic volume
- Medium traffic volume with high inter-cell interference

It is one task of the radio network planner to find the reasons for a high cell load. For this purpose PegaPlan offers further results.

Figure 6 shows the cell load of the regarded network and we realise that the cell load differs a lot whereas the ideal case is a uniformly loaded network. This is one target of further network optimisation with PegaPlan. However, according to figure 6 the cell load is below 40% for most cells which indicates that network is intended for a further increase of the traffic.

Coverage results

The coverage calculation gives location-dependent results. One coverage result is the maximum data rate which a user achieves at a certain location in a radio cell. This means in the context of radio network planning that this achievable data rate is calculated for every pixel.

At the first view this seems to be a contradiction to the average data rate per user as estimated in the previous section about the capacity results. But for this average data rate an 'imaginary' user is assumed who is distributed over the complete cell area without any specific location. On contrary, in the coverage calculation a 'user' has a real location which is a pixel in the cell – this does not mean that a 'real' user is assumed on every pixel. The achievable data rate (per pixel) is calculated assuming that only a single user is active in a cell and the complete cell capacity is available for this user. Due to that assumption this result is called 'achievable data rate'. It mainly depends on the inter-cell interference by what the results of the capacity calculation affects the coverage results.

An important topic for predicting the achievable data rate is the data rate increase due to the MIMO antenna technology. The MIMO antenna technology yields a high data rate if the different MIMO propagation paths are independent of each other (not correlated). This can, e.g., be achieved by cross polarized transmission antennas. The radio waves are affected by propagation effects such as scattering, reflection or diffraction. These effects contribute to reduce the independency of the MIMO propagation paths. The impact of these effects increases if there is no line of sight (LOS) connection to the base station. Mainly in the case of LOS a large MIMO data rate is expected. In order to consider this effect in PegaPlan comprehensive channel sounder measurements were carried out and evaluated with sophisticated numeric methods. A suited approach was found which enables a realistic prediction of the MIMO data rate in PegaPlan even without using 3D-building data.

In particular for plots with pixel based results a geographic orientation is helpful. The planning tool PegaPlan offers different options for this purpose. Often the illustration of maps is used where the scale of the planning area is automatically customized. If ,e.g., the coverage of a small state is displayed PegaPlan selects a map in the scale 1:200000, but if results for the city of Frankfurt shall be visualised a map in scale of 1:25000 is selected. Furthermore, satellite photos, street data and 3D building data can be displayed in PegaPlan. For copy right reasons the plots in this article do not contain a background map.

PegaPlan

The received power changes quickly and partly rapidly. This propagation effect is called **Fading**. It is distinguished between fast fading and slow fading. The fast fading occurs from the superposition of many signal components which are reflected close to the receiving antenna. The slow fading is caused by shadowing of building or vegetation. Generally, the fast fading is already considered in the mapping of the data rate to the signal to noise ratio. On contrary, the slow fading has do be considered in the predictions of PegaPlan. Thus, we speak about coverage probabilities or of data rates which are exceeded with a specific probability. The PegaPlan plots presented in the figures 7 to 9 show those data rates per pixel which are exceeded with a probability of 90%. That means, a user in the real world might have a greater data rate as predicted for the user location with a comparatively high probability.

Figure 7 shows the achievable data rate in the downlink assuming a 2x2-MIMO technology and that a user gets a bandwidth of 5 MHz. That means 1/4 of the maximum bandwidth is available per user (see table 1). The highest data rates of approximately 20 Mbit/s are achieved only close to the base stations. This is caused by low inter-cell interference and high MIMO data rate gain since line of
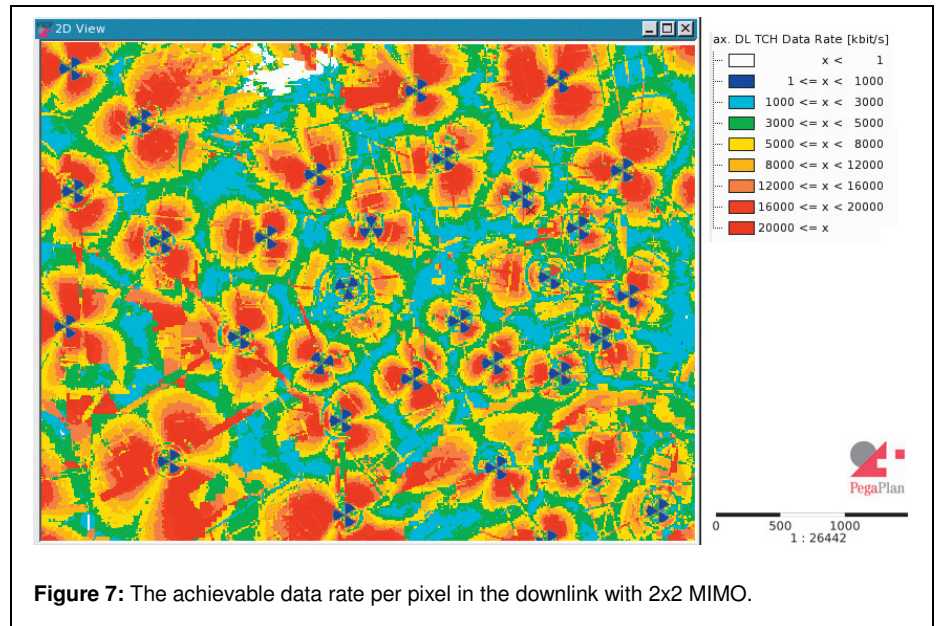

Figure 7: The achievable data rate per pixel in the downlink with 2x2 MIMO.
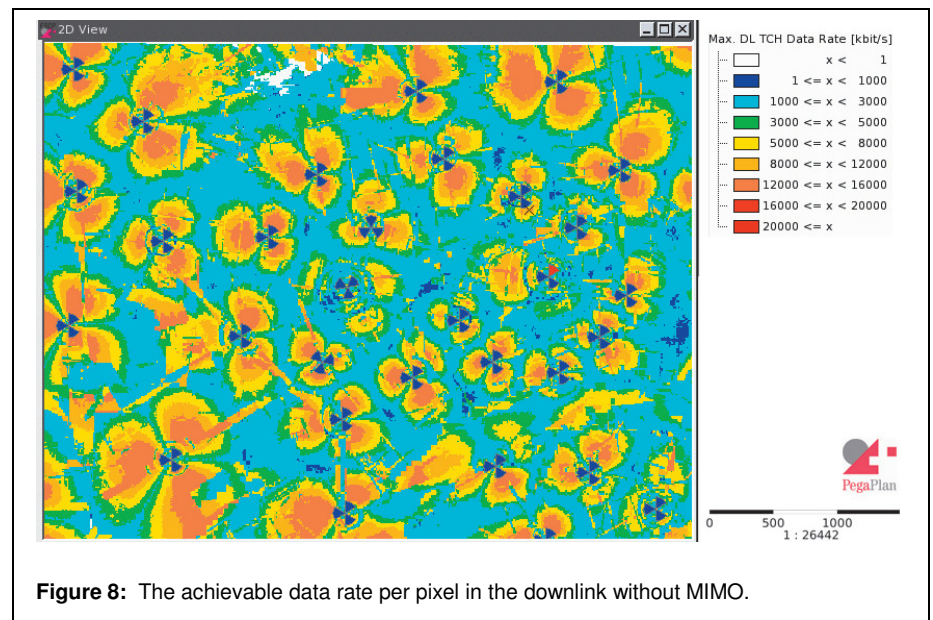

Figure 8: The achievable data rate per pixel in the downlink without MIMO.

sight is very likely close to the base station. At the cell borders the achievable data rate decreases due to the increasing inter-cell interference. But even under these bad conditions the achievable data rate is up to 1 Mbit/s. Looking more

closely we see some line structures in figure 7 where the data rate deviates a lot from that one of the surrounding pixels. This is caused by considering street data in the coverage calculation leading to a more precise identification of pixels with

Band width (MHz)	1.4	3	5	10	15	20
Max. Data Rate (Mbit/s)	10	24	40	80	118	158

Table 1: The maximum data rate which is achieved for the different LTE bandwidths

line of sight which finally improves the prediction of the MIMO data rate gain.

The impact of MIMO on the achievable data rate in the downlink is demonstrated by figure 7 in comparison with figure 8 which shows the data rate without MIMO. In the transition region between two cells the data rate is almost the same in both figures. In those areas two negative effects are coming together: Due to high inter-cell interference the data rate is generally low and - due to the large distance to the base station - the probability for a line of sight is very low leading to a low MIMO data rate gain. On contrary, close to a base station the difference of the data rate with and without MIMO is obvious. Close to a base station the probability for line of sight is quite large and, thus, MIMO gives a high data rate gain. This is true for areas coloured in red and dark red in figure 7.

For the uplink displayed in figure 9 nearly a uniform data rate is given in the entire area and also at the cell border. This significant difference to the downlink in figure 7 is to be justified with a distinguishing interference situation. In the uplink the mobile stations are the transmitters and the users do not experience an increased inter-cell interference at the cell border. The inter-cell interference occurs in uplink
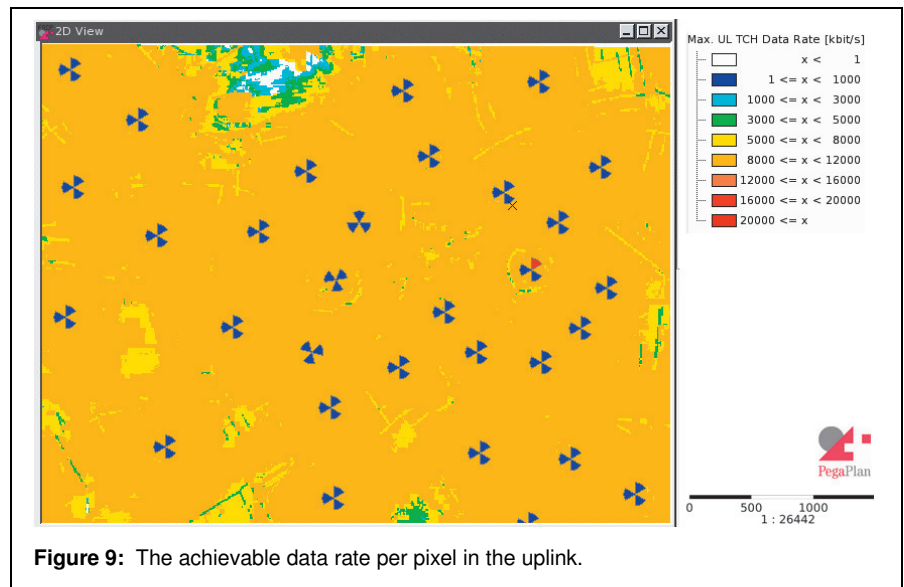

Figure 9: The achievable data rate per pixel in the uplink.

only at the base station antennas. If the uplink is frequently used in an adjacent cell the interference in the own cell increases and in order to ensure the connection the user equipment has to increase its transmission power. If the maximum power of the mobile is reached a further data transmission might be not possible and the pixel is not covered any more in the uplink. Therefore in the uplink the coverage problem is primarily discussed where as and in the downlink the interference problem is dominating. This is retrieved in figure 9 where the data rate considerable descends only at few pixels. These pixels are such far away from the base station that the transmission power of the mobile device is not sufficient to achieve the high data rates. Figure 9 in comparison with figure 7 clearly shows that the data rate is generally lower in the uplink. The main reason is that MIMO

technology is not applied in the uplink.

For LTE radio network planning the achievable data rate per pixel is the most interesting result. In PegaPlan, there are further pixel based results available which support the radio network planner and optimizer.

Summary

Although there is the vision of self organising networks (self-planning, self-configuration, self-optimisation, self-healing) it is still necessary to analyse and optimise LTE networks with the help of an interactive planning tool like PegaPlan. The availability of services in a LTE network is determined by the trade-off between coverage, inter-cell interference and capacity.

The basis for all PegaPlan analysis are the amount of traffic per cell and the prediction of the path loss with

highly sophisticated propagation models. The interdependency between coverage, interference and capacity is iteratively resolved in PegaPlan.

The radio network planner is provided with capacity results like the achievable throughput per cell, cell load and average data rate per user in the cell. A major goal in the planning process is to maximise the cell throughputs under the condition of an even cell load as possible.

The main coverage result is the achievable data rate per pixel. PegaPlan implies a sophisticated approach to predict the increase of the data rate due to the MIMO antenna technology. The situation for uplink and downlink differs significantly: in the uplink the transmission power of the mobile may limit the coverage where as in the downlink the inter-cell interference may be the dominating effect limiting the coverage area. The technical characteristics of LTE and their interdependencies may give a hint, how difficult is analysing and planning of LTE networks. The expectations in self-organising networks are very high. But for the time the planning and optimisation of LTE networks is still the domain of technical experts. PegaPlan is the best suited solution for an interactive and automatic support.

PegaPlan