APPENDIX II

Basics of Radio Network Design, Planning & Optimization
Submitted by LIME in CD 2009-1 (8 April 2009)

RADIO NETWORK DESIGN&PLANNING PROCESS

The main aim of radio network planning is to provide a cost-effective solution for the radio network in terms of coverage, capacity and quality. The network planning process and design criteria vary from region to region depending upon the dominating factor, which could be capacity or coverage. The design process itself is not the only process in the whole network design, and has to work in close coordination with the planning processes of the core and especially the transmission network. But for ease of explanation, a simplified process just for radio network planning is shown in figure below.

Network Requirements- Capacity, Quality, etc → Pre-Planning Coverage & Capacity Plan → Site Survey & Site Selection → C/I Analysis Frequency Plan → Parameter Planning → **Radio Network Plan**

The process of radio network planning starts with collection of the input parameters such as the network requirements of capacity, coverage and quality. These inputs are then used to make the theoretical coverage and capacity plans.

Definition of coverage would include defining the coverage areas, service probability and related signal strength.

Definition of capacity would include the subscriber and traffic profile in the region and whole area, availability of the frequency bands, frequency planning methods, and other information such as guard band and frequency band division. The radio planner also needs information on the radio access system and the antenna system performance associated with it.

The pre-planning process results in theoretical coverage and capacity plans. There are coverage-driven areas and capacity-driven areas in a given network region. The average cell capacity requirement per service area is estimated for each phase of network design, to identify the cut-over phase where network design will change from a coverage-driven to a capacity-driven process. While the objective of coverage planning in the coverage-driven areas is to find the minimum number of sites for producing the required coverage, radio planners often have to experiment with both coverage and capacity, as the capacity requirements may have to increase the number of sites, resulting in a more effective frequency usage and minimal interference.

Candidate sites are then searched for, and one of these is selected based on the inputs from the transmission planning and installation engineers. Civil engineers are also needed to do a feasibility study of constructing the base station at that site.

After site selection, assignment of the frequency channel for each cell is done in a manner that causes minimal interference and maintains the desired quality. Frequency allocation is based on the cell-to-cell channel to interference (C/I) ratio. The frequency plans need to be fine-tuned based on drive test results and network management statistics.

Parameter plans are drawn up for each of the cell sites. There is a parameter set for each cell that is used for network launch and expansion. This set may include cell service area definitions, channel configurations, handover and power control, adjacency definitions, and network-specific parameters.

The final radio plan consists of the coverage plans, capacity estimations, interference plans, power budget calculations, parameter set plans, frequency plans, etc.

Dimensioning

APPENDIX II

Basics of Radio Network Design, Planning & Optimization
Submitted by LIME in CD 2009-1 (8 April 2009)

The dimensioning exercise is to identify the equipment and the network type (i.e. technology employed) required in order to cater for the coverage and quality requirements, apart from seeing that capacity needs are fulfilled for the next few years (generally 3–5 years). The more accurate the dimensioning is, the more efficient will be network rollout. In practice, network rollout very closely follows the output of network dimensioning/planning. For an efficient network rollout, the equipment has to be ordered well before the planning starts (i.e. after dimensioning), as the equipment orders are placed based on the dimensioning results.

Planning engineers should try to do very realistic/accurate dimensioning for each cell site.

The inputs that are required for the dimensioning excercise include:

- the geographical area to be covered
- the estimated traffic in each region
- minimum requirements of power in each region and blocking criteria
- path loss
- the frequency band to be used and frequency re-use.

With the above parameters, can be predicted the number of base stations that will be required for coverage in the specified area to meet the individual quality targets, and to meet the expected increase in traffic in the next few years.

Capacity and Quality

The major target of the radio planner is to increase the coverage area of a cell and decrease the amount of equipment needed in the network, so obtaining the maximum coverage at minimum cost. Maximum coverage means that the mobile is connected to a given cell at a maximum possible distance. This is possible if there is a minimum signal to noise ratio at both the BTS and MS. Another factor attributing to the path length between the two antennas (BTS and MS) is the propagation loss due to environmental conditions.

Capacity can be understood in simplest terms as the number of mobile subscribers a BTS can cater for at a given time. The greater the capacity, the more mobile subscribers can be connected to the BTS at a given time, thereby reducing the amount of base stations in a given network. This reduction would lead to an increase in the operation efficiency and thereby profits for the network operator. As the number of frequency channels in the GSM bands is constant, the re-use of these frequencies determines the number of mobile subscribers who can be connected to a base station. So, efficient frequency planning which includes the assignment of given frequencies and their re-use plays an important part in increasing the capacity of the radio network.

The quality of the network is quite dependent upon the parameter settings. Most of these are implemented during the rollout of the network, just before the launch. In some cases these values are fixed, and in some other cases they are based on measurements done on existing networks. With the first GSM network to be launched in a given region/country, these values should be planned beforehand for the initial network launch before they have the first measurement results. Once there are some measurements available from the initial launch of the network, these parameters then can be fine-tuned. This process becomes a part of the optimisation of the radio network.

Site Survey and Site Selection

When the pre-planning phase is nearing completion, the site search process starts. Based on the coverage plans, specific areas should be identified for prospective sites.

There are some points to remember during the process of site selection:

- The process of site selection, from identifying the site to site acquisition, is very long and slow, which may result in a delay of network launch.
- The sites are a long-term investment and usually cost a lot of money.

Therefore, radio planners in conjunction with the transmission planners, installation engineers and civil engineers should try to make this process faster by inspecting the site candidates according to their criteria and coming to a collective decision on whether the candidate site can be used as a cell site or not.

Result of the Site Survey Process

There are two types of report that are generated in the site survey process. One is at the beginning of the search and the other at the end, which is a report on the site selected. Both reports are very important and should have the desired information clearly given. The site survey request report should stipulate the area where the site candidates should be searched for. The report may contain more specific information such as the primary candidate for search and secondary site candidates – thereby giving the site selection team more specific information on where to put their priorities. Also, this report should contain addresses, maps, and particular information. The report made after site selection should have more detailed information. This may contain the height of the building/green-field, coordinates, antenna configuration (location, tilt, azimuth, etc.), maps, and a top view of the site with exact location of the base station and the antennas (both radio and transmission).

RADIO NETWORK DETAILED PLANNING

The Link (or Power) Budget

The detailed radio network plan can be sub-divided into three sub-plans:

(1) link budget calculation,

(2) coverage, capacity planning and spectrum efficiency,

(3) parameter planning.

Link budget calculations give the loss in the signal strength on the path between the mobile station antenna and base station antenna. These calculations help in defining the cell ranges along with the coverage thresholds. Coverage threshold is a downlink power budget that gives the signal strength at the cell edge (border of the cell) for a given location probability.

As the link budget calculations basically include the power transmission between the base station (including the RF antenna) and the mobile station antenna, we shall look into the characteristics of these two pieces of equipment from the link budget perspective.

Link budget calculations are done for both the uplink and downlink. As the power transmitted by the mobile station antenna is less than the power transmitted by the base station antenna, the uplink power budget is more critical than the downlink power budget.

Thus, the sensitivity of the base station in the uplink direction becomes one of the critical factors as it is related to reception of the power transmitted by the mobile station antenna.

Basics of Radio Network Design, Planning & Optimization
Submitted by LIME in CD 2009-1 (8 April 2009)

In the downlink direction, transmitted power and the gains of the antennas are important parameters. In terms of losses in the equipment, the combiner loss and the cable loss are to be considered. Combiner loss comes only in the downlink calculations while the cable loss has to be incorporated in both directions.

For the other equipment (i.e. the MS), the transmitted power in the uplink direction is very important. To receive the signal transmitted from the BTS antenna even in remote areas, the sensitivity of the MS comes into play. The transmitting and the receiving antenna gains and the cable loss parameters are to be considered on the BTS side.

Frequency Hopping

Frequency hopping (FH) is a technique that basically improves the channel to interference (C/I) ratio by utilizing many frequency channels. Employment of the FH technique also improves the link budget due to its effects: frequency diversity and interference diversity.

The frequency diversity technique improves the signal level.

If the number of frequency channels increases in the radio network, the number of frequencies used increases in the network, so reducing the interference effect at the mobile station. This leads to an increase in signal level, and an improvement in the power budget.

Equipment Enhancements

Receiver Diversity

Diversity is the most common way to improve the reception power of the receiving antenna.

Major diversity techniques are space diversity, frequency diversity, and polarization diversity. Frequency diversity is also known as frequency hopping.

Space diversity involves installing another antenna at the base station. This means that there are two antennas receiving the signal at the base station instead of one and are separated in *space* by some distance. There is no fixed distance of separation between the antennas, which depends upon the propagation environment. Depending on the environmental conditions, the distance between the main and the diversity antenna can vary from 1 to 15 wavelengths.

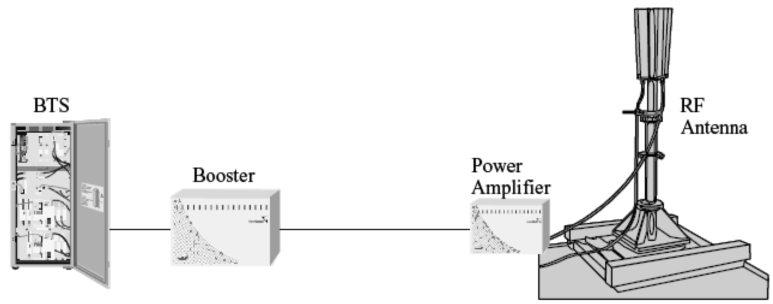
Polarization diversity means that the signals are received using two polarizations that are orthogonal to each other. It can be either vertical–horizontal polarization or it can be ±45-degree slated polarization.

Low-noise Amplifiers (LNA)

Where the received power is limited by the use of long cables, low-noise amplifiers can be used to boost the link budget results. As the name suggest, a LNA has a low noise value and can amplify a signal. The LNA is placed at the receiving end. When diversity is being used, the LNAs should be used on both the main and the diversity antennas, thereby improving the diversity reception. As stated above, this is used for improvement of the uplink power budget.

Power Boosters

Power in the downlink direction can be increased by the use of power amplifiers and power boosters. If the losses are reduced before the transmission by the use of amplifiers, which in turn increases the power, then the configuration is called a power amplifier. However, when the transmission power is increased, then it is done by using the booster. Power amplifiers are located near the transmission antennas while the boosters are located near the base station as shown in figure below.



Cell and Network Coverage

The cell and network coverage depend mainly on natural factors such as geographical aspect/propagation conditions, and on human factors such as the landscape (urban, suburban, rural), subscriber behavior etc. The ultimate quality of the coverage in the mobile network is measured in terms of *location probability*. For that, the radio propagation conditions have to be predicted as accurately as possible for the region.

There are two ways in which radio planners can use propagation models. They can either create their own propagation models for different areas in a cellular network, or they can use the existing standard models, which are generic in nature and are used for a whole area.

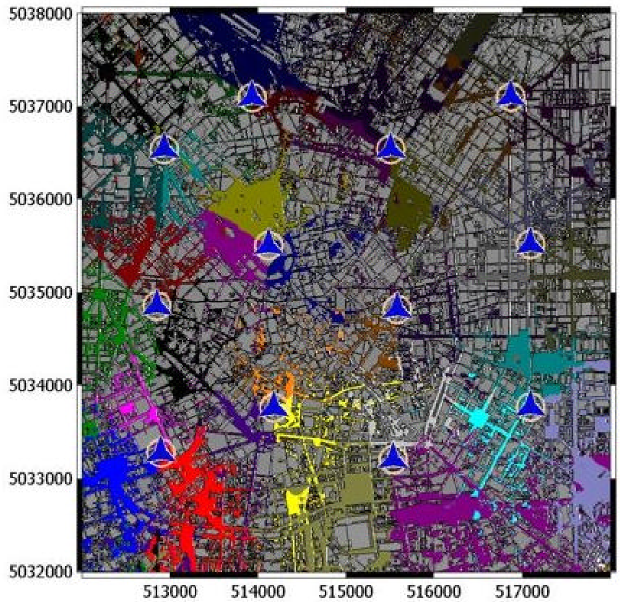
The advantage of using their own model is that it will be more accurate, but it will also be immensely time-consuming to construct. Usage of the standard models is economical from the time and money perspective, but these models have limited accuracy. Of course, there is a middle way out: the use of multiple generic models for urban, suburban and rural environments in terms of macro-cell or micro-cell structure.

Planned Coverage Area

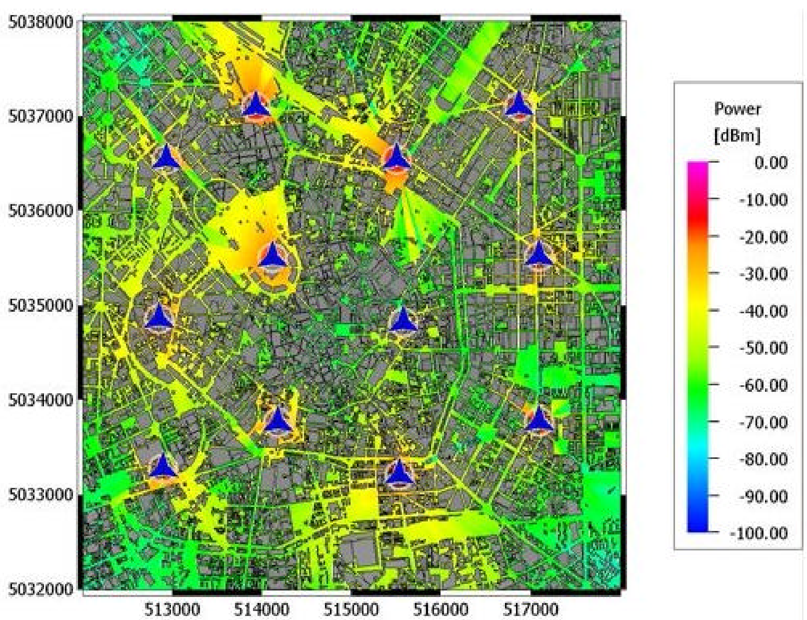
Based on propagation models, drive tests and correction factors, prediction of coverage areas is done. The sites are located according to the requirements of the network, and the coverage predictions are done as shown in figures below. Usually some radio network planning tools are used for such exercise.

APPENDIX II

<u>Basics of Radio Network Design, Planning & Optimization</u>
Submitted by LIME in CD 2009-1 (8 April 2009)



Service Area plot



Best Server coverage plot

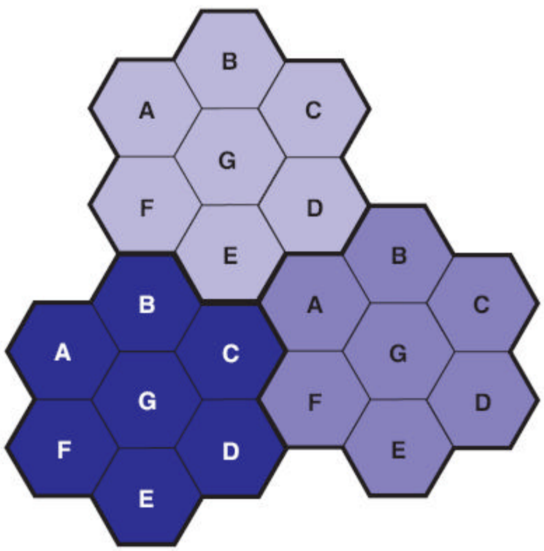
Capacity Planning

APPENDIX II

Basics of Radio Network Design, Planning & Optimization
Submitted by LIME in CD 2009-1 (8 April 2009)

Capacity planning is a very important process in the network rollout as it defines the number of base stations required and their respective capacities. Capacity plans are made in the preplanning phase for initial estimations, as well as later in a detailed manner.

The number of base stations required in an area comes from the coverage planning, and the number of transceivers required is derived from capacity planning as it is directly associated with the frequency re-use factor. The frequency re-use factor is defined as the number of base stations that can be implemented before the frequency can be re-used. An example of frequency re-use is shown in the figure below.



Each of the frequencies is called a channel. The minimum frequency re-use factor calculation is based on the C/I ratio. As soon as the C/I ratio decreases, the signal strength starts deteriorating, thereby reducing the frequency re-use factor.

Another factor to keep in mind is the antenna height at the base station. If the antenna height is too high then the signal has to travel a greater distance, so the probability that the signal causes interference becomes greater. The average antenna height should be such that the number of base stations (fully utilized in terms of their individual capacities) is enough for the needed capacity of the network. Of course, as seen above, this depends heavily on the frequency re-use factor.

There are three essential parameters required for capacity planning: estimated traffic, average antenna height, and frequency usage.

Traffic Estimates

Traffic estimation or modeling is based on theoretical estimates or assumptions, and on studies of existing networks (i.e. experience). Traffic in the network is dependent on the user communication rate and user movement in the network. The user communication rate means how much traffic is generated by the subscriber and for how long. The user movement is an estimate of the user's use of the network in static mode and dynamic mode.

APPENDIX II

Basics of Radio Network Design, Planning & Optimization
Submitted by LIME in CD 2009-1 (8 April 2009)

Traffic estimation in the network is given in terms of 'erlangs'. One erlang (1 Erl) is defined as the amount of traffic generated by the user when he or she uses one traffic channel for one hour (this one hour is usually the busy hour of the network). Another term that is frequently used in network planning is 'blocking'. Blocking describes the situation when a user is trying to make a call and is not able to reach a dialed subscriber owing to lack of resources.

Frequency Planning

Capacity and frequency planning do of course go hand-in-hand. A good frequency plan ensures that frequency channels are used in such a way that the capacity and coverage criteria are met without any interference. This is because the total capacity in a radio network in terms of the number of sites is dependent upon two factors: transmission power and interference.

Power Control

The power that is transmitted both from the mobile equipment and from the base station has a far-reaching effect on efficient usage of the spectrum. Power control is an essential feature in mobile networks, in both the uplink and downlink directions. When a mobile transmits high power, there is enough fade margin in the critical uplink direction, but it can cause interference to other subscriber connections. The power should be kept to a level that the signal is received by the base station antenna above the required threshold without causing interference to other mobiles. Mobile stations thus have a feature such that their power of transmission can be controlled. This feature is generally controlled by the BSS. This control is based on an algorithm that computes the power received by the base station and, based on its assessment, it increases or decreases the power transmitted by the mobile station.

Discontinuous Transmission

Discontinuous transmission (DTX) is a feature that controls the power of the transmission when the mobile is in 'silent' mode. When the subscriber is not speaking on the mobile, a voice detector in the equipment detects this and sends a burst of transmission bits to the BSS, indicating this inactivity. This function of the mobile is called voice-activity detection (VAD). On receiving this stream of bits indicating DTX, the BSS asks the mobile to reduce its power for that period of time, thereby reducing interference in the network and improving the efficiency of the network.

APPENDIX II

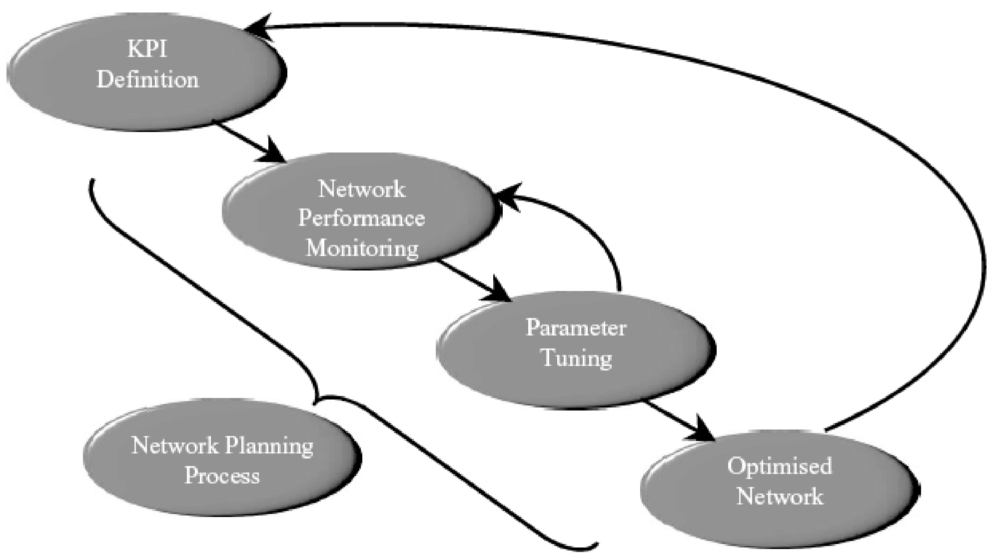
Basics of Radio Network Design, Planning & Optimization
Submitted by LIME in CD 2009-1 (8 April 2009)

BASICS OF RADIO NETWORK OPTIMISATION

Optimization involves monitoring, verifying and improving the performance of the radio network. It starts somewhere near the last phase of radio network planning, i.e. during parameter planning. A cellular network covers a large area and provides capacity to many people, so there are lots of parameters involved that are variable and have to be continuously monitored and corrected. Apart from this, the network is always growing through increasing subscriber numbers and increases in traffic. This means that the optimisation process should be on-going, to increase the efficiency of the network leading to revenue generation from the network.

As we have seen, radio network planners first focus on three main areas: coverage, capacity and frequency planning. Then follows site selection, parameter planning, etc. In the optimisation process the same issues are addressed, with the difference that sites are already selected and antenna locations are fixed, but subscribers are as mobile as ever, with continuous growth taking place. Optimisation tasks become more and more difficult as time passes.

Once a radio network is designed and operational, its performance is monitored. The performance is compared against chosen key performance indicators (KPIs). After fine-tuning, the results (parameters) are then applied to the network to get the desired performance. Optimisation can be considered to be a separate process or as a part of the network planning process, see figure below.



The primary purpose of optimisation is to verify and improve the actual radio plan by taking into account the radio network evolution as:

- subscriber growth
- radio interface traffic
- coverage demands (indoor/outdoor coverage)
- radio quality
- overall radio network functionality.

APPENDIX II

Basics of Radio Network Design, Planning & Optimization
Submitted by LIME in CD 2009-1 (8 April 2009)

There is a verification and tuning phase for the radio network configuration to adjust and achieve radio system planning targets. The network tuning contains the final problem solving actions like:

- to change the base station site configurations
- to tilt antennas, to turn antenna direction, to change antennas
- to change the radio parameters
- to build higher or lower antenna masts
- to move antenna locations
- to move base stations

in order to change the base station coverage or dominance areas to balance the traffic (to improve the usage) or to improve the quality or handovers and thus overall call success rate. The required actions have to be clarified step by step by trying always to avoid moving base stations or building new base stations which may in the worst case be the only possible solutions to improve the radio network quality.

In order to be able to perform successful optimisation work some essential optimisation tools are needed. These optimisation tools can be divided into three categories like:

- database tools
- radio planning tools
- measurement tools.

Database tools are required to manage the base station site configurations. The essential radio planning parameters for coverage planning are the antenna height, antenna type, antenna direction, antenna tilt, cable length and type, diversity technique, LNA parameters, combiner type and BTS transmission RF peak power. These parameters can not automatically be found from the same database and there is considerable work ahead in the optimisation phase if these base station site configurations have not been managed properly.

Radio planning tools are, of course, needed to calculate the base station coverage or dominance areas and especially for the coverage plan post-processing to predict interference and to allocate frequencies to the base station sites. In some cases the advanced radio network simulators could also be useful if they work properly.

Measurement tools are required to analyze the base station traffic, coverage, speech quality and handovers to the neighbour base stations in the downlink and uplink directions. There are several tools on the market available to fulfill these requirements and a set of these tools have to be selected based on the available functions.

Key Performance Indicators

APPENDIX II

Basics of Radio Network Design, Planning & Optimization
Submitted by LIME in CD 2009-1 (8 April 2009)

For radio network optimisation (or for that matter any other network optimisation), it is necessary to have decided on key performance indicators. These KPIs are parameters that are to be observed closely when the network monitoring process is going on.

The performance of the radio network is measured in terms of KPIs related to voice quality, based on statistics generated from the radio network. Drive tests and network management systems are the best methods for generating these performance statistics.

One of the most important of these from the operator's perspective is the DCR (dropped call rate).

The dropped call rate, as the name suggests, is a measure of the calls dropped in the network. A dropped call can be defined as one that gets terminated on its own after being established. As the DCR gives a quick overview of network quality and revenues lost, this easily makes it one of the most important parameters in network optimisation. Both the drive test results and the NMS statistics are used to evaluate this parameter. There is some relation between the number of dropped calls and voice quality. If the voice quality were not a limiting factor, perhaps the dropped call rate would be very low in the network. Calls can drop in the network due to quality degradation, which may be due to many factors such as capacity limitations, interference, unfavorable propagation conditions, blocking, etc. The DCR is related to the call success rate (CSR) and the handover success rate. The CSR indicates the proportion of calls that were completed after being generated, while the handover rate indicates the quality of the mobility management/RRM in the radio network.

Some of the performance indicators are listed below:

- Drop Call Rate
- Call Success Rate
- Amount of traffic and blocking
- Resource availability and access
- Handovers (same cell/adjacent cell, success and failure)
- Receiver level and quality

Network Performance Monitoring

The whole process of network performance monitoring consists of two steps: monitoring the performance of the key parameters, and assessment of the performance of these parameters with respect to capacity and coverage.

The KPIs are collected along with field measurements such as drive tests. For the field measurements, the tools used are ones that can analyze the traffic, capacity, and quality of the calls, and the network as a whole. For drive testing, a test mobile is used. This test mobile keeps on making calls in a moving vehicle that goes around in the various parts of the network. Based on the DCR, CSR, HO, etc., parameters, the quality of the network can then be analyzed. Apart from drive testing, the measurements can also be generated by the network management system. And finally, when 'faulty' parameters have been identified and correct values are determined, the radio planner puts them in his network planning tool to analyze the change before these parameters are actually changed/implemented in the field.

Drive Testing

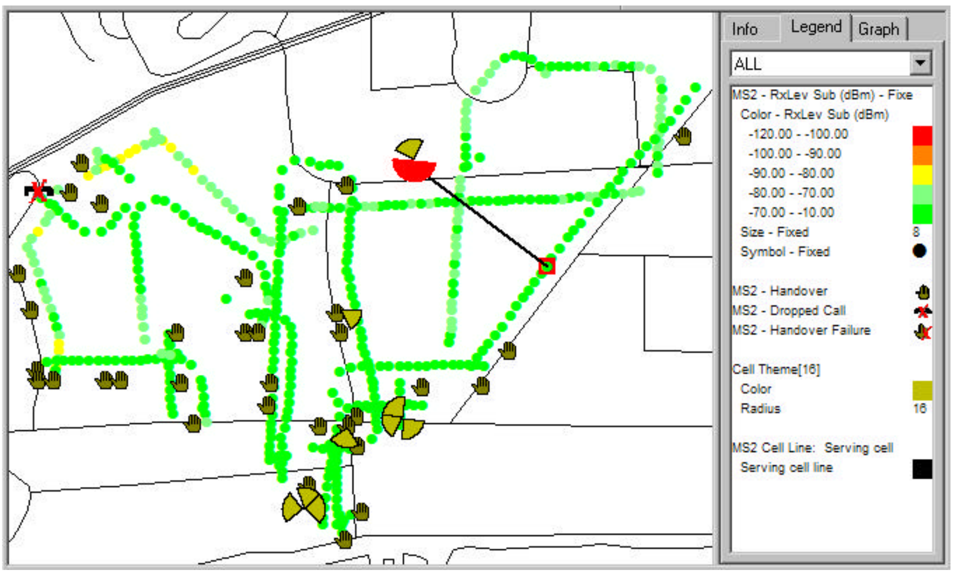
APPENDIX II

<u>Basics of Radio Network Design, Planning & Optimization</u>
Submitted by LIME in CD 2009-1 (8 April 2009)

The quality of the network is ultimately determined by the satisfaction of the users of the network, the subscribers. Drive tests give the 'feel' of the designed network as it is experienced in the field. The testing process starts with selection of the 'live' region of the network where the tests need to be performed, and the drive testing path. Before starting the tests the engineer should have the appropriate kits that include mobile equipment (usually three mobiles), drive testing software (on a laptop), and a GPS (global positioning system) unit.

When the drive testing starts, two mobiles are used to generate calls with a gap of few seconds (usually 15–20 s). The third mobile is usually used for testing the coverage. It makes one continuous call, and if this call drops it will attempt another call. The purpose of this testing to collect enough samples at a reasonable speed and in a reasonable time. If there are lots of dropped calls, the problem is analyzed to find a solution for it and to propose changes.

An example of a drive test plan is shown in figure below.



Drive test result analysis showing handovers (HO) and dropped call (DC) on the path.

Network Management System Statistics

After the launch of the network, drive tests are performed periodically. In contrast, the statistics are monitored on the NMS daily with the help of counters. The NMS usually measures the functionalities such as call setup failures, dropped calls, and handovers (successes and failures). It also gives data related to traffic and blocking in the radio network. An example of KPI statistics is shown in figure below.

APPENDIX II

Basics of Radio Network Design, Planning & Optimization
Submitted by LIME in CD 2009-1 (8 April 2009)

Time	TCH Failed Assignment rate (%)	TCH Drop rate (%)	TCH Congestion Rate (%)	SDCCH Failed Ass rate(%)	SDCCH Drop rate (%)	Incoming Handover Failure rate (%)	Total Traffic (Erlangs)
19/03/2009	0.15	0.45	0.19	0	2	1.6	5016.25
20/03/2009	0.2	0.33	0.23	0	2.46	1.51	5135.73
21/03/2009	0.06	0.38	0.06	0.01	1.85	1.49	5904.53
22/03/2009	0.06	0.45	0.06	0	1.73	1.67	5694.32
23/03/2009	0.36	0.42	0.52	0.01	3.5	1.77	4875.47
24/03/2009	0.26	0.42	0.3	0	1.92	1.66	5843.93
25/03/2009	0.31	0.38	0.4	0	2.82	1.6	3862.51
26/03/2009	0.11	0.41	0.19	0	3.07	1.57	5299.71
27/03/2009	0.22	0.39	0.24	0	1.75	1.51	5944.64
28/03/2009	0.09	0.38	0.11	0	2.33	1.75	5143.31
29/03/2009	0.04	0.47	0.06	0	1.44	1.55	5763.3
30/03/2009	0.2	0.4	0.23	0	1.55	1.51	6180.49
31/03/2009	0.17	0.39	0.21	0	1.92	1.54	5314.16

Coverage

Drive test results will give the penetration level of signals in different regions of the network. These results can then be compared with the plans made before the network launch. In urban areas, coverage is generally found to be less at the farthest parts of the network, in the areas behind high buildings and inside buildings. These issues become serious when important areas and buildings are not having the desired level of signal even when care has been taken during the network planning phase. This leads to an immediate scrutiny of the antenna locations, heights and tilt. The problems are usually sorted out by moving the antenna locations and altering the tilting of the antennas. If optimisation is being done after a long time, new sites can also be added.

Coverage also becomes critical in rural areas, where the capacity of the cell sites is already low. Populated areas and highways usually constitute the regions that should have the desired level of coverage. A factor that may lower the signal level could be propagation conditions, so study of link budget calculations along with the terrain profile becomes a critical part of the rural optimisation. For highway coverage, additions of new sites may be one of the solutions.

Capacity

Data collected from the network management system is usually used to assess the capacity of the network. As coverage and capacity are interrelated, data collected from drive tests is also used for capacity assessment. The two aspects of this assessment are dropped calls and congestion. Generally, capacity-related problems arise when the network optimisation is taking place after a long period of time. Radio network optimisation also includes providing new capacity to new hot-spots, or enhancing indoor coverage. Once the regional/area coverage is planned and executed in the normal planning phase, optimisation should take into consideration the provision of as much coverage as possible to the places that would expect high traffic, such as inside office buildings, inside shopping malls, tunnels, etc.

Quality

The quality of the radio network is dependent on its coverage, capacity and frequency allocation. Most of the severe problems in a radio network can be attributed to signal interference. When interference exists in the network; the source needs to be found. The entire frequency plan is checked again to determine whether the source is internal or external. The problems may be caused by flaws in the frequency plan, in the configuration plans (e.g. antenna tilts), inaccurate correction factors used in propagation models, etc.

APPENDIX II

<u>Basics of Radio Network Design, Planning & Optimization</u>
Submitted by LIME in CD 2009-1 (8 April 2009)

Parameter Tuning

The ending of the assessment process sees the beginning of the complex process of fine-tuning of parameters. The main parameters that are fine-tuned are signaling parameters, radio resource parameters, handover parameters and power control parameters. Expected KPI values should be achieved after the process is complete.

The major complexity of this process is the inhomogeneity of the radio network. During network deployment, some more measurements are made and the parameters are fine-tuned again. Once the network goes 'live', the drive test and NMS statistics help in further fine-tuning of the parameters, and it is at this point that a set of default parameters is created for the whole network. However, as the network is inhomogeneous, these default parameters may not be sufficiently accurate in all regions, thereby bringing down the overall network quality – and leading to a reduction in revenue for the network operator.

Radio network optimization must be a continuous process that begins during the prelaunch phase and continues throughout the existence of the network.

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