White Paper

The Role of Planning and Optimization Tools in SON ICIC

CelPlan International, Inc.

February 2014

The Role of Planning and Optimization Tools in SON ICIC

February, 2014

When we look at wireless networks today, we see that they are in a constant optimization cycle. It should be expected that after optimizing a network, it should stay stable for some period of time of months or years.

What causes this need for a constant optimization? The answer is that the optimization methodologies used today optimize part of the network at the expense of other parts. This means that network issues are shifted around, like a dog chasing its own tail.

1. Historical Evolution of Network Optimization

Initially network optimization was done using design and optimization tools. This method fell apart when the networks became more complex and the planning tools did not evolve sufficiently to express the network complexities. Another reason that precipitated the demise of planning tools was that the network information was not updated and trying to predict a performance with not updated information was impossible.

Instead of planning tools, operators and vendors start relying on field measurements, which were done by drive tests. This worked initially, but soon it was understood that the results were not good enough, as there was never measurements enough to characterize the network performance (as measurements were done outdoors only and at different times of the day) and nothing was provided to suggest what changes had to be done in the network and what would be the result.

A solution was then proposed to use user equipment measurements sent to the base station for handover purposes. These measurements were done very frequently by all users. The issue was that the user location was not known and it was impossible to make sense of them. Some vendors went to extreme procedures to estimate user location, but location errors were large and it was impossible to define even if a call was made indoors or outdoors. Again, nothing was provided to tell what changes had to be done in the network and what would be the result.

The location issue was resolved by distributing network probes throughout it, which would communicate the measurements. Representativeness became the issue then, as the number of probes was small and results could vary drastically from the probe location to its surroundings. Again, nothing was provided to tell what changes had to be done in the network and what would be the result.

Parallel efforts were made to use network statistics, labeled Key Parameter Indicators (KPI), to find network issues, so they could be fixed. KPIs are average values that indicate the cell performance in average, but do not tell where and why an issue is happening, so fixing it became an unsurmountable challenge.

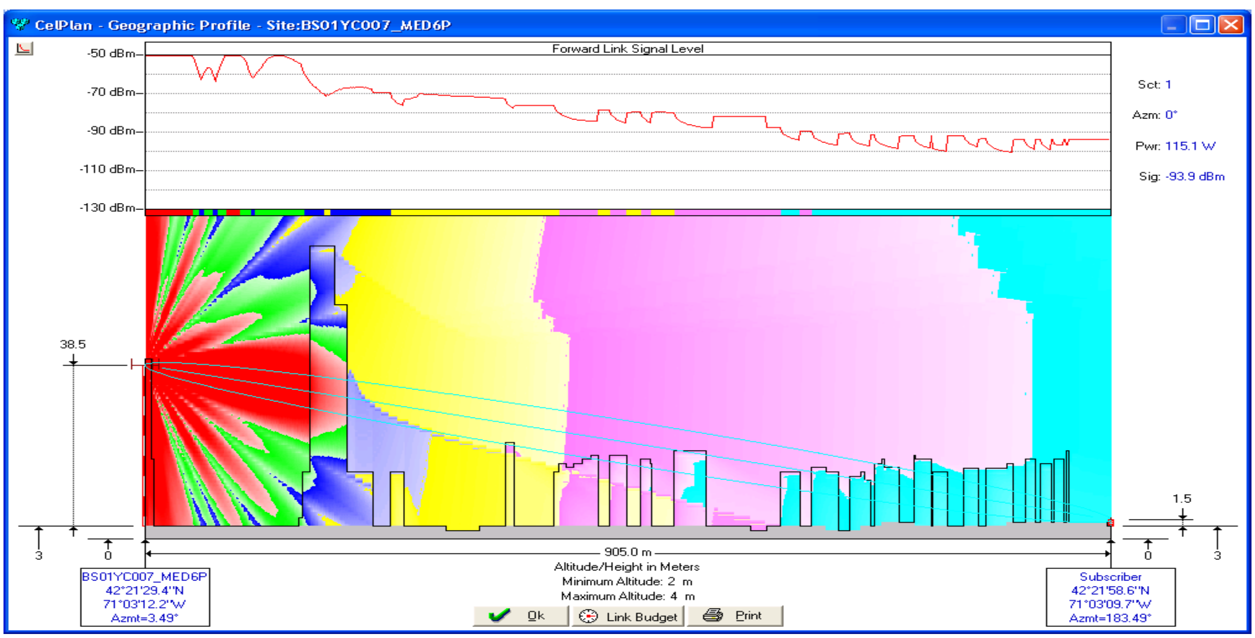
Some operators and vendors applied all the above methods at the same time, collecting an amount of data impossible to be processed meaningfully by engineers. Tools were then envisaged to automatically process this huge amount of data and try to synthesize some conclusions. Algorithms and powerful processing helped to deal with the data by discarding large chunks of it and breaking it into small regions. Considering that the data was flawed, as explained before, it could not really fix the issues. Working on a region on a time, became an issue shifting problem. Again, nothing was provided to tell what changes had to be done in the network and what would be the result.

2. How Planning and Optimization tools can do a stable and efficient Network optimization

Time came to evaluate what could be done to resolve the optimization issue. It became evident that any method to be used cannot rely only on the past and present, but must have an insight in the future. Planning and optimization tools could do it, but the issues that caused it demise had to be addressed if it would become a solution.

Networks had to be represented correctly, so technical site visits/audits were required to document the deployments. This activity "per si" pointed many network issues.

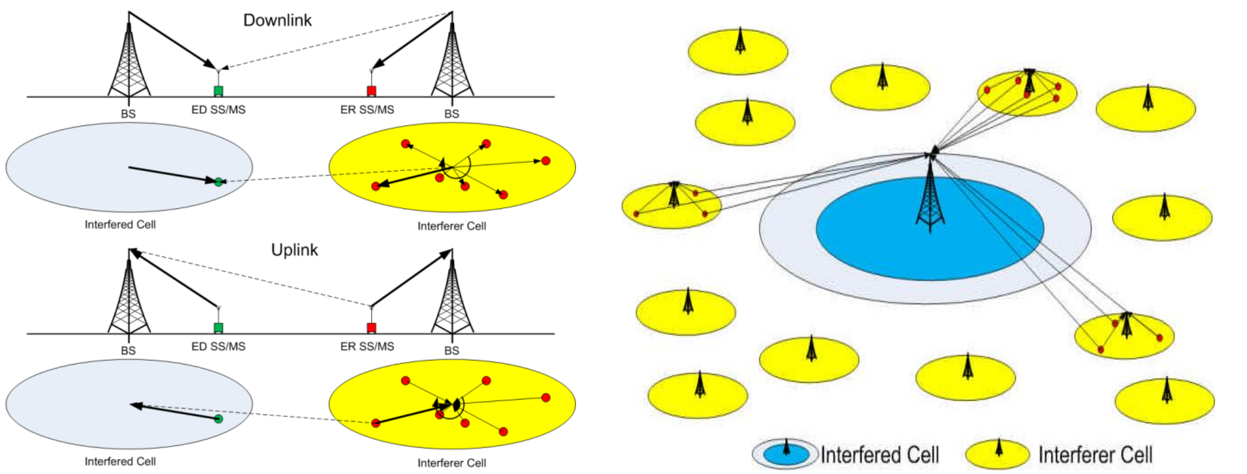
Propagation models had to be enhanced to represent path losses considering the morphologies along and around the path. This required 3D propagation models that could analyze propagation over and around morphologies, like buildings. Use of cell phones and tablets was done mainly indoor and due to this path losses should be predicted outdoors and indoors at different building levels. Propagation had to be considered not just in the vertical plane, but in the horizontal also.



The RF environment where the propagation happened had to be characterized at each location, so different fading and antenna correlation parameters could be applied. Some of this characterization became only possible very recently, as there were no equipment available to do it in the field.

Most of all, a metric was required that expressed customer experience. It is possible to relate customer experience to a certain level of SNIR. The issue is that this parameter varies significantly over time and can only be characterized statistically. Once an SNIR value is established, as related to the desired customer experience, it is possible to define the availability of this value or of a better one.

The amount of interference generated depends on the interfered user location and on the geographical distribution of the interfering users and its traffic amount. Representing this requires powerful and complex calculations that result in statistical distributions. If done correctly, this procedure can represent SNIR as a statistical variable, and not just as an average.

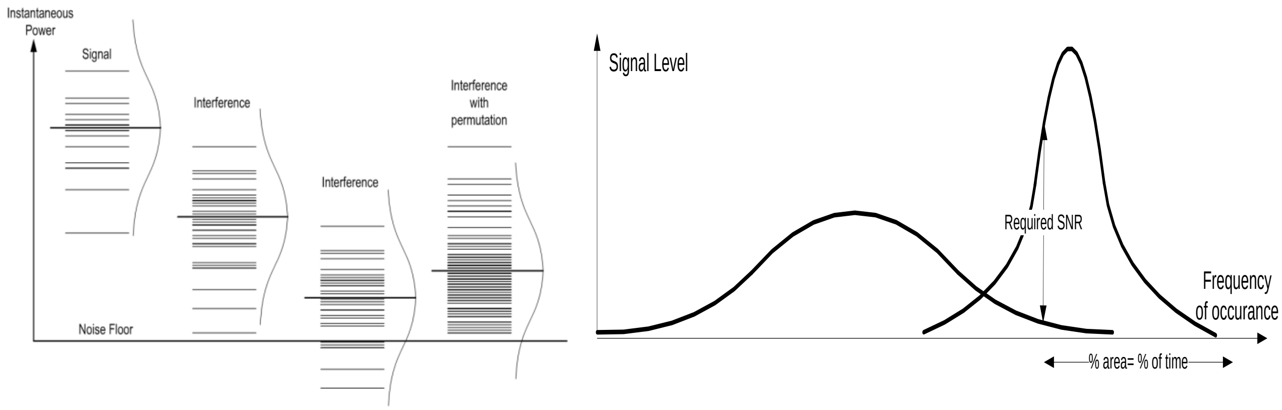


The figures on the left illustrate in the downlink that the interference depends on the traffic and user position in the interfering cell. As there are many users in the interfering cell, it is possible to calculate the average transmitted power and its statistical distribution. In the uplink the interference comes directly from the users and as each one has a different path loss to the interfered tower. This implies that the user geographical distribution and its traffic have to be considered to calculate the average and statistical distribution of the interferers. The figure on the right indicates that all neighbor cells should be considered as possible interferers.

Availability becomes the desired metric, with huge advantages. While we cannot add SNIR values, we can statistically add availability values. Availability values can be applied to time or to traffic though a simple multiplication. Now, we have a metric that can represent the customer experience at a location, at a cell or for the whole network.

Once those requirements are fulfilled we have a solution that can not only optimize the network as it is today, but it can also predict evolutions and the effect of changes.

The metric used is illustrated in the next figures. Signal and interferers are constantly varying due to fast fading, even if the UE is stationary. We know the SNIR that results in the desired customer experience for each environment. It is possible then to calculate what percentage of the time this desired SNIR is reached or surpassed. This is called the Customer Experience Availability



Networks are moving towards automation, in what is known as SON (Self Optimizing Networks). Although not strictly part of SON specifications, Inter Cell Interference Coordination (ICIC) can automate planning and resource allocation, but to do this it should rely on a stable methodology and avoid the use of measurements that are not representative, as explained above.

3. Optimization Objectives

Data usage is increasing exponentially in wireless networks, but revenues are increasing linearly, if increasing at all. This means that the deployed infrastructure should carry more information than previously thought possible, so the business plan can survive.

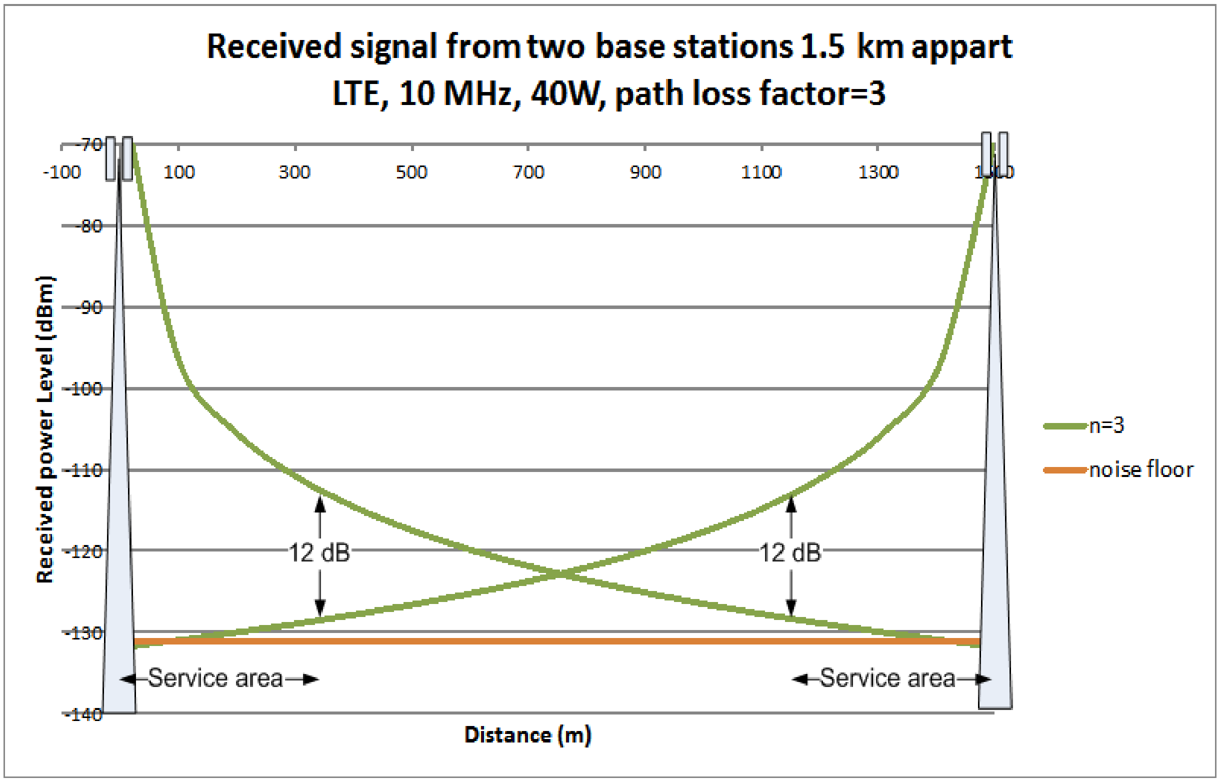
Cellular networks rely on resource reuse to increase its capacity. Tighter the reuse, higher is the capacity per area. Until recently a cell service area was considered as a single optimization entity. This meant that available resources had to be divided between neighbor cells, so each would use only a fraction of them.

More recently it was felt that not all areas of the cell had the same interference, and that the cell could be divided in Interference Regions (IR), so that one part of the cell could use more resources than another. This pivotal observation is the key to increase the reuse figure and consequently the traffic carried by each cell.

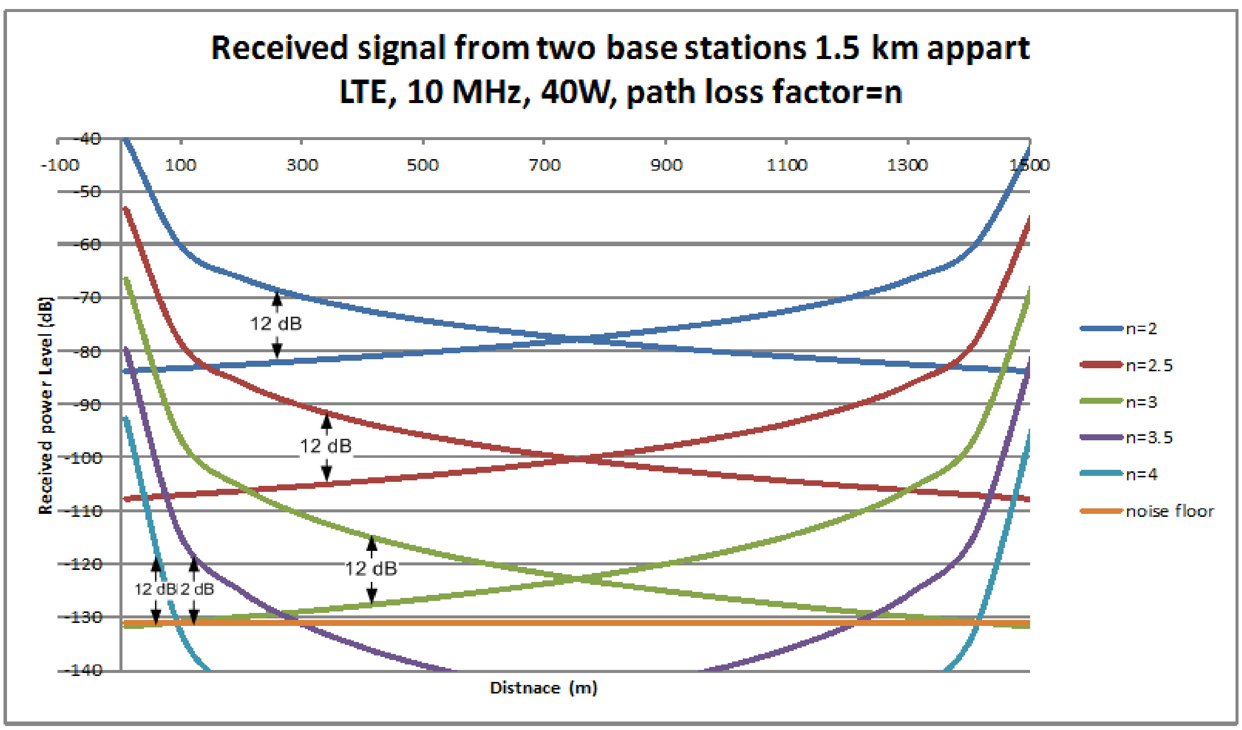
4. Resource Reuse Factor

To better understand what is involved in resource reuse we will do a short overview of the theory behind it.

Cellular architecture requires that cells be physically spaced to use the same resources. In between them other resources have to be made available. This spacing should be enough to provide the required SNIR, between the local cell and the distant cell signals.



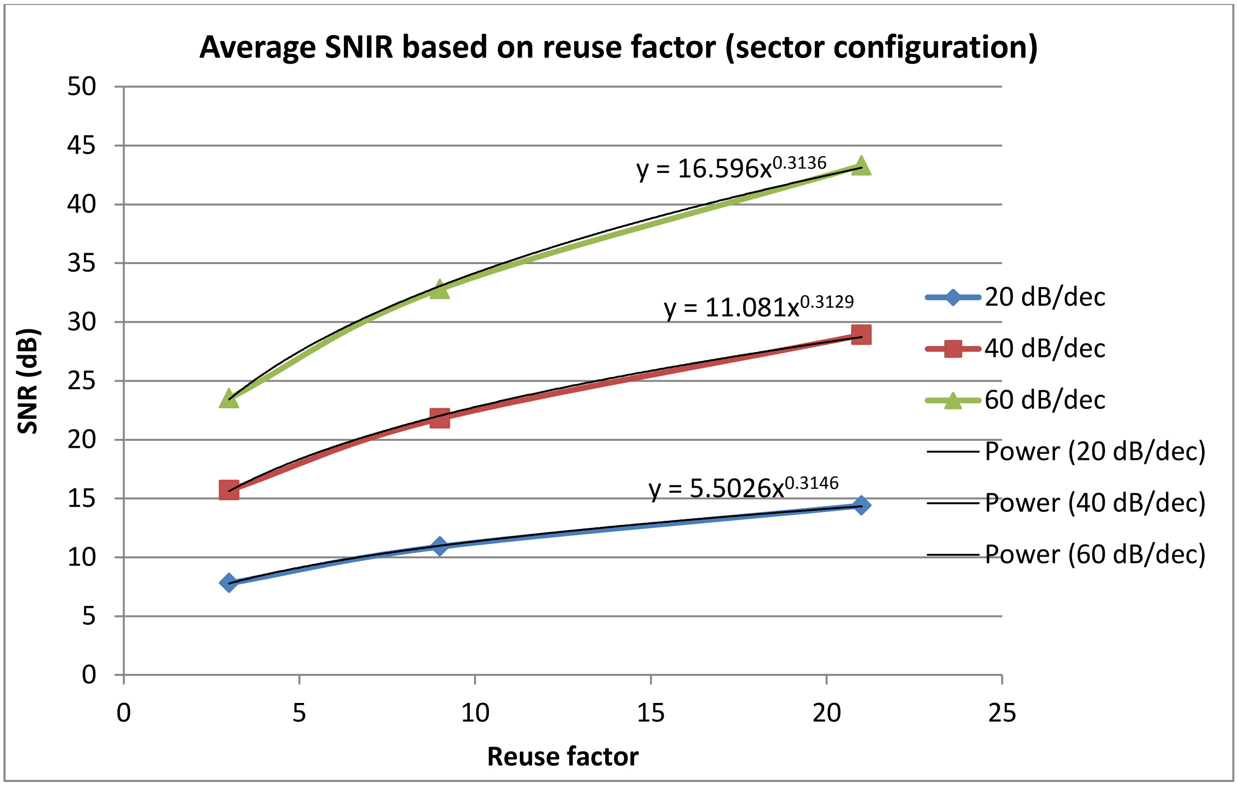
In the example, the SNIR required is 12 dB and the service areas of each cell are indicated with a gap in the middle, which has to be filled with additional resources. The extent of the service area and the gap depends on the propagation conditions. In this study we used the path loss slope as a metric.



It can be seen that the service area increases with higher path loss slopes, until the noise floor is reached, when the coverage area decreases with the path loss factor.

We developed a set of curves that tie reuse factor to SNIR requirements for different path loss slopes.

Neighbor cells that use the available resources form a reuse group. Reuse factor can be defined as the ratio between the number of resources used in each cell and the number of cells in a group.



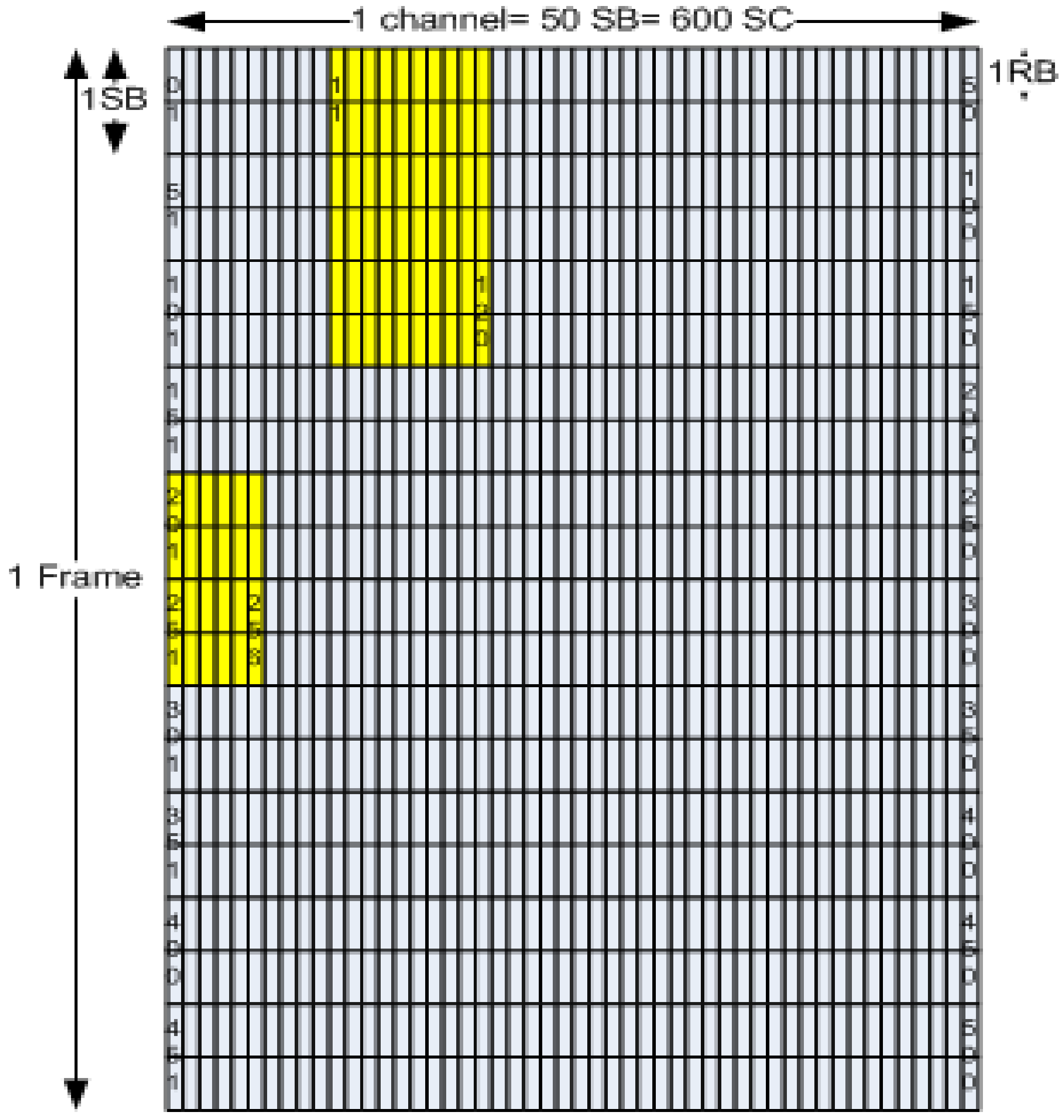
LTE uses Adaptive Modulation to maximize the amount of data transmitted. The 3GPP defined the levels to be reported by the UE that support the different modulation schemes, expressing them by a Channel Quality Indicator (CQI). The next table relates the CQI levels to a Receive Sensitivity, for a channel bandwidth of 10 MHz, error rate of 10^{-2} and a receive noise figure of 5 dB. The Receive sensitivity is shown for a Rayleigh and AWGN environments.

CQI	Modulation Scheme	Code Rate	Spectral Efficiency	Receive Sensitivity (dBm)	
				Rayleigh	AWGN
				k<1	k>10
				10^{-3}	10^{-3}
1	QPSK	0.0762	0.1524	-89.8	-101.9
2	QPSK	0.1172	0.2344	-89.2	-101.4
3	QPSK	0.1885	0.3770	-88.1	-100.5
4	QPSK	0.3008	0.6016	-86.8	-99.2
5	QPSK	0.4385	0.8770	-85.5	-97.4
6	QPSK	0.5879	1.1758	-84.7	-95.5
7	16QAM	0.3691	1.4764	-84.0	-92.1
8	16QAM	0.4785	1.9140	-81.9	-90.6
9	16QAM	0.6016	2.4064	-79.6	-88.9
10	64QAM	0.4551	2.7306	-75.9	-87.9
11	64QAM	0.5537	3.3222	-72.8	-85.8
12	64QAM	0.6504	3.9024	-70.4	-84.1
13	64QAM	0.7539	4.5234	-68.6	-82.9
14	64QAM	0.8525	5.1150	-67.5	-82.2
15	64QAM	0.9258	5.5548	-67.1	-82.1

5. LTE Resource definition

We have been using resources along this text, without specifying what the resources are. Traditionally, resources were RF channels, but with the advent of cdma, codes became also resources. In LTE the smallest resource is the Resource Element (RE) that has the bandwidth of one sub-carrier and the duration of one symbol. The next level is the Primary Resource Block (PRB or RB) that has the bandwidth of 12 sub-carriers and the duration of 1 slot (6 or 7 symbols). The smallest resource that can be allocated for data is a Scheduling Block (SB) which is composed of two PRB sequential in time.

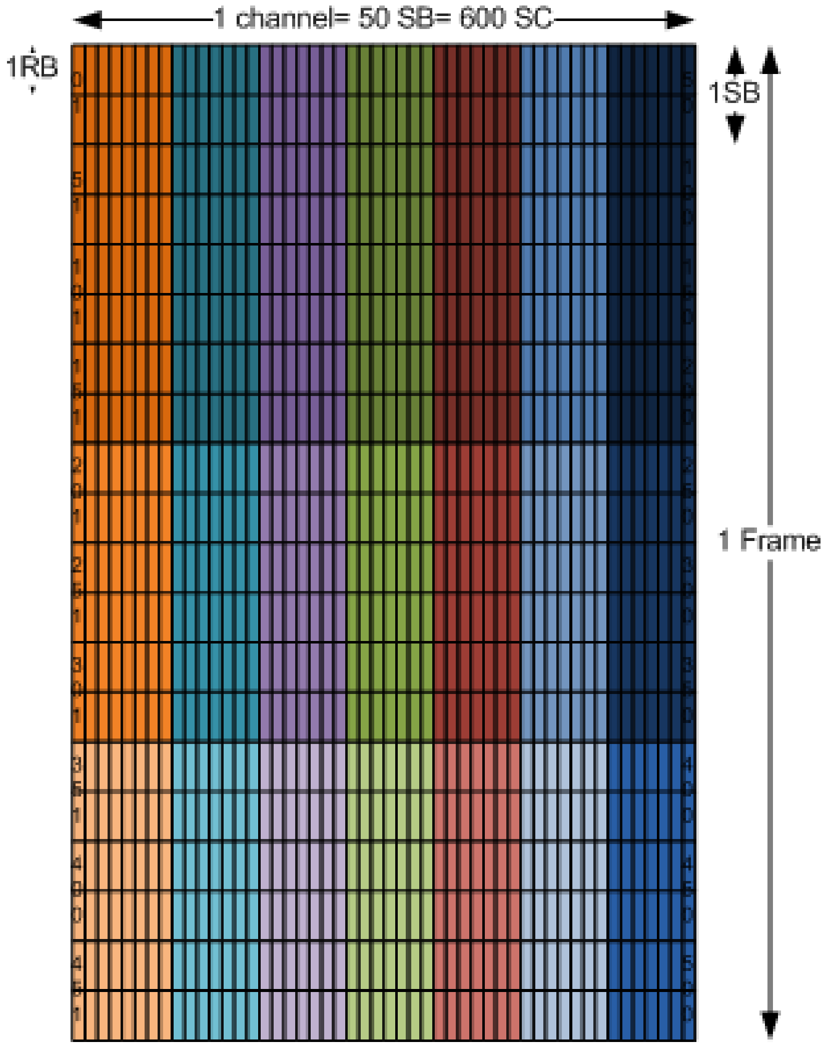
For a planning tool it is important to be able to identify the SB univocally, so a nomenclature was devised based on a numbering system, as illustrated in the figure below for a frame.



SBs are numbered in a 10MHz frame from 1 to 500. A (11,120) represents a group of 30 SBs, while (201,256) represents a group of 12 SBs and the combination (11,120; 201,256) represents a group of 42 SBs.

A cell will be allocated several SBs, so an additional concept has to be created. We borrowed from WiMAX the concept of segments and zones, but added additional flexibility. Segments are sets of contiguous sub-carriers across an entire frame, while zones are sets of contiguous sub-frames across the entire frame. Segment and zone sizes can be defined by the user and do not need to be equal in size.

Typical examples for a 10 MHz LTE channel would be 7 segments and 3 zones, as shown in the next figure. Each partition forms an Allocation Block (AB).

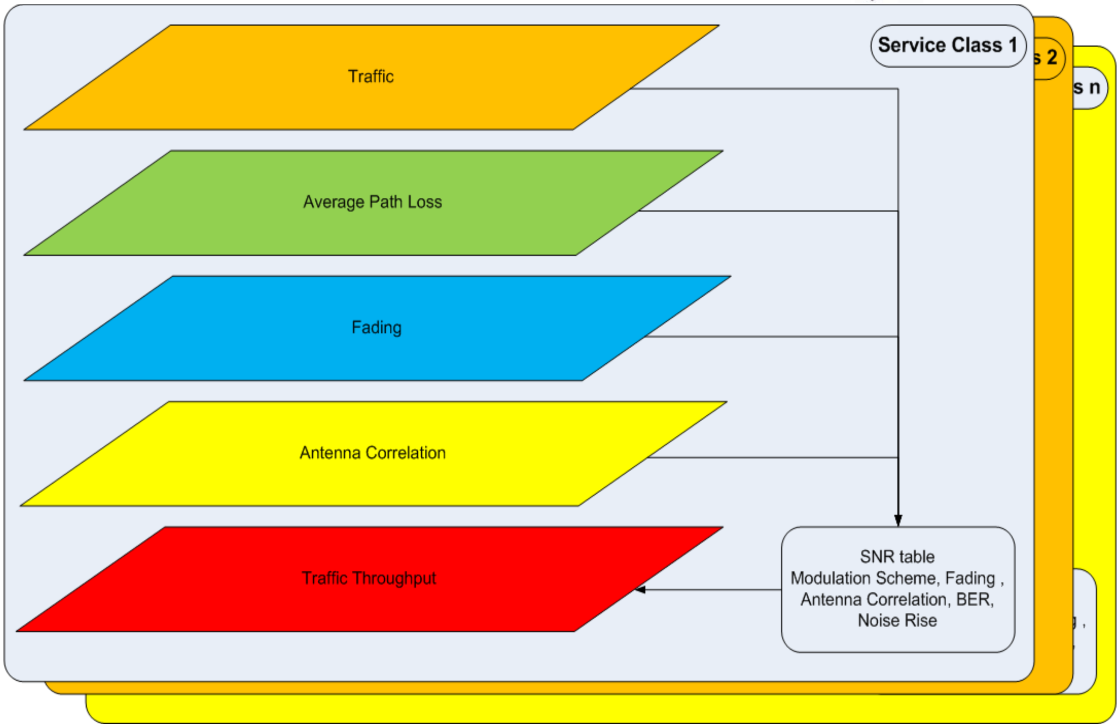


How much data can be carried by each AB, requires a complex calculation. First we need to subtract symbols used for pilots, signaling and control. What's left in an AB can carry data from several users, each one having an independent modulation scheme and an independent MIMO configuration. Besides, not all the REs will be filled with data, as rarely a packet size will coincide with the AB size.

Each prediction pixel has to be analyzed for all service classes, considering for each:

- Traffic
- Average Path Loss
- Fading
- Antenna Correlation
- MIMO/Beamforming
- SNIR required by the Adaptive Modulation scheme
- Average Reuse factor
- Average Allocation Factor

This is illustrated in the next figure.



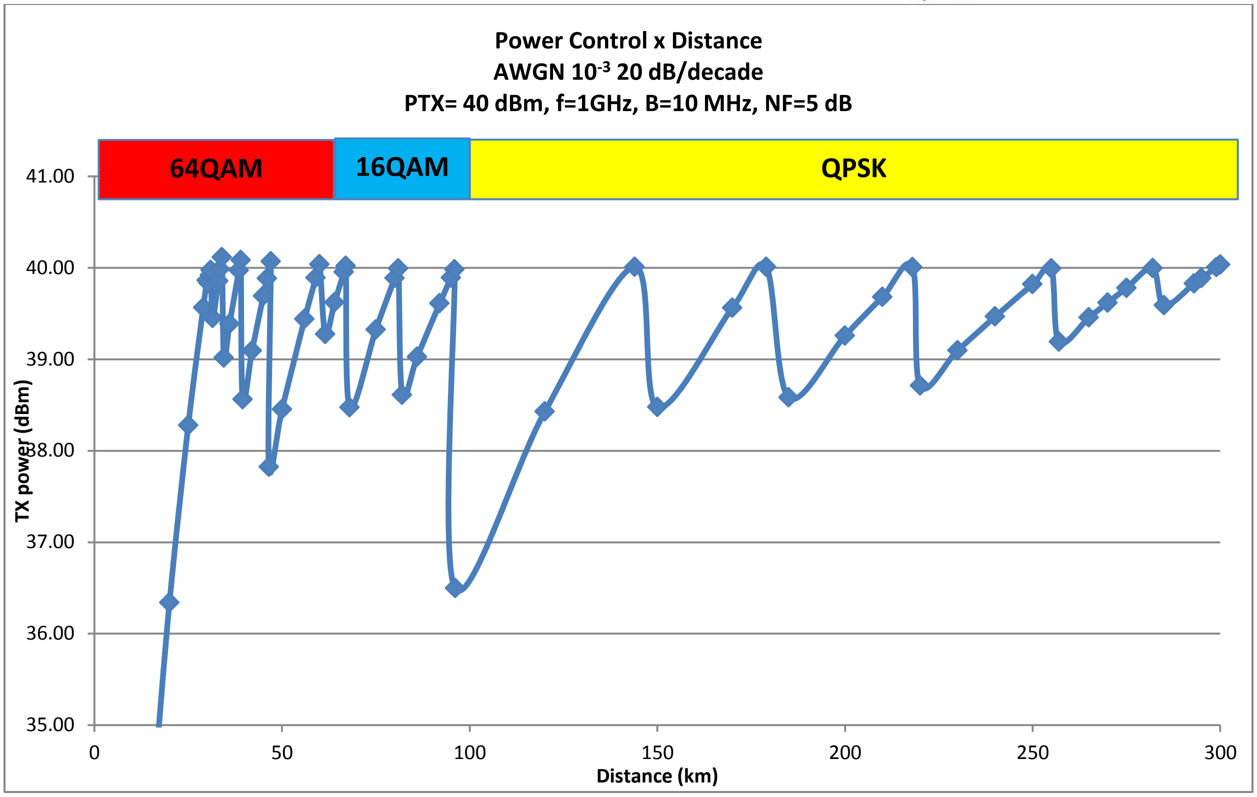
The result will be the Average Cell throughput. This throughput should be available at the Master Plan for each Interference Region

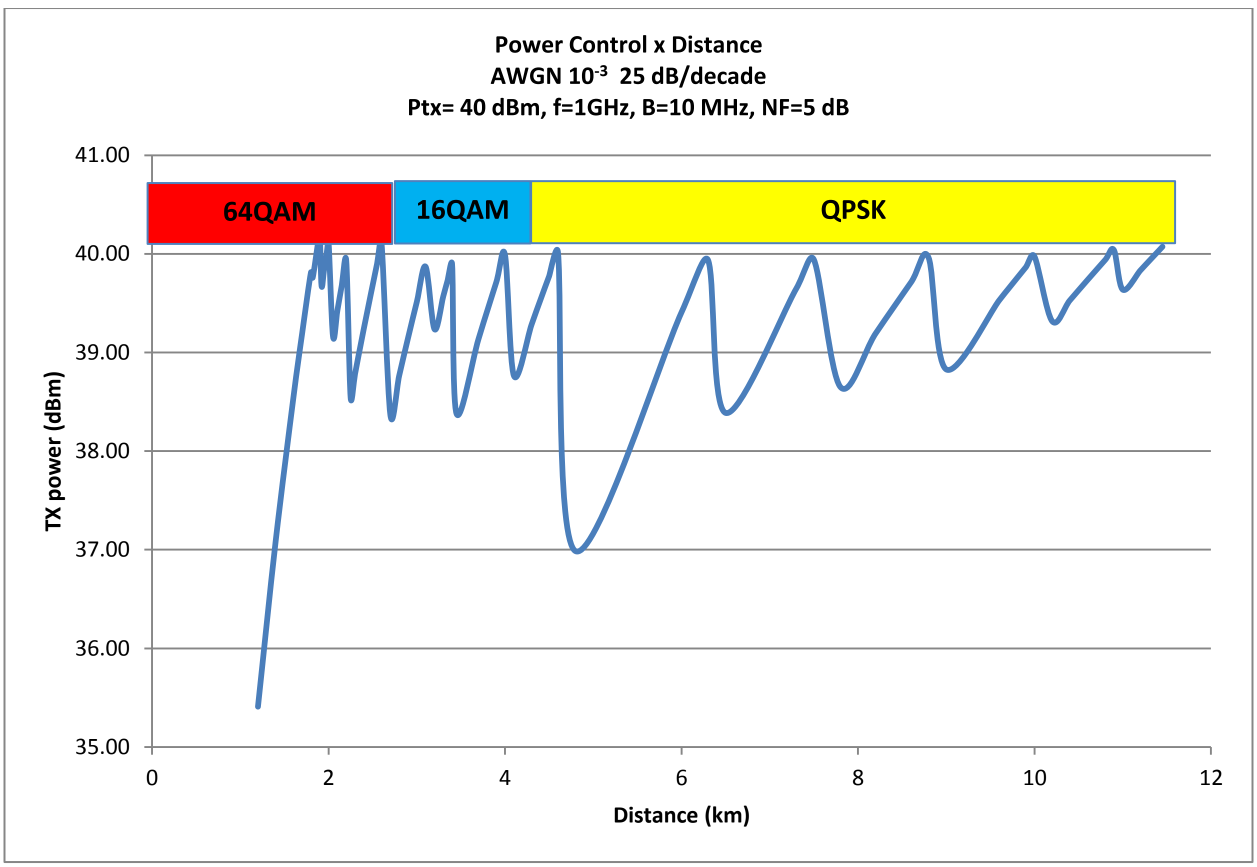
6. Interference Control Methodology

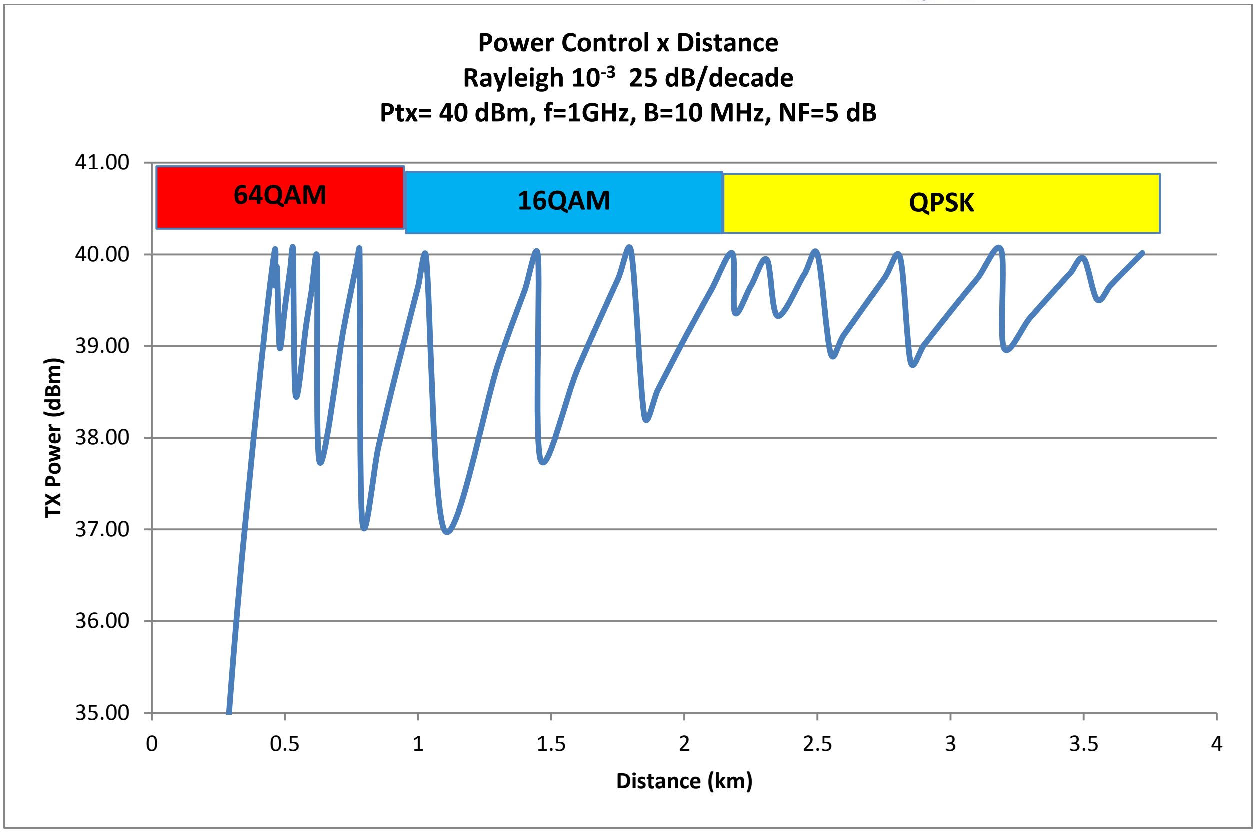
Interference can be reduced by using interference averaging and interference avoidance. Interference averaging is not contemplated in the 3GPP standard. Interference avoidance can be done by power control and selective resource reuse.

6.1. Power Control

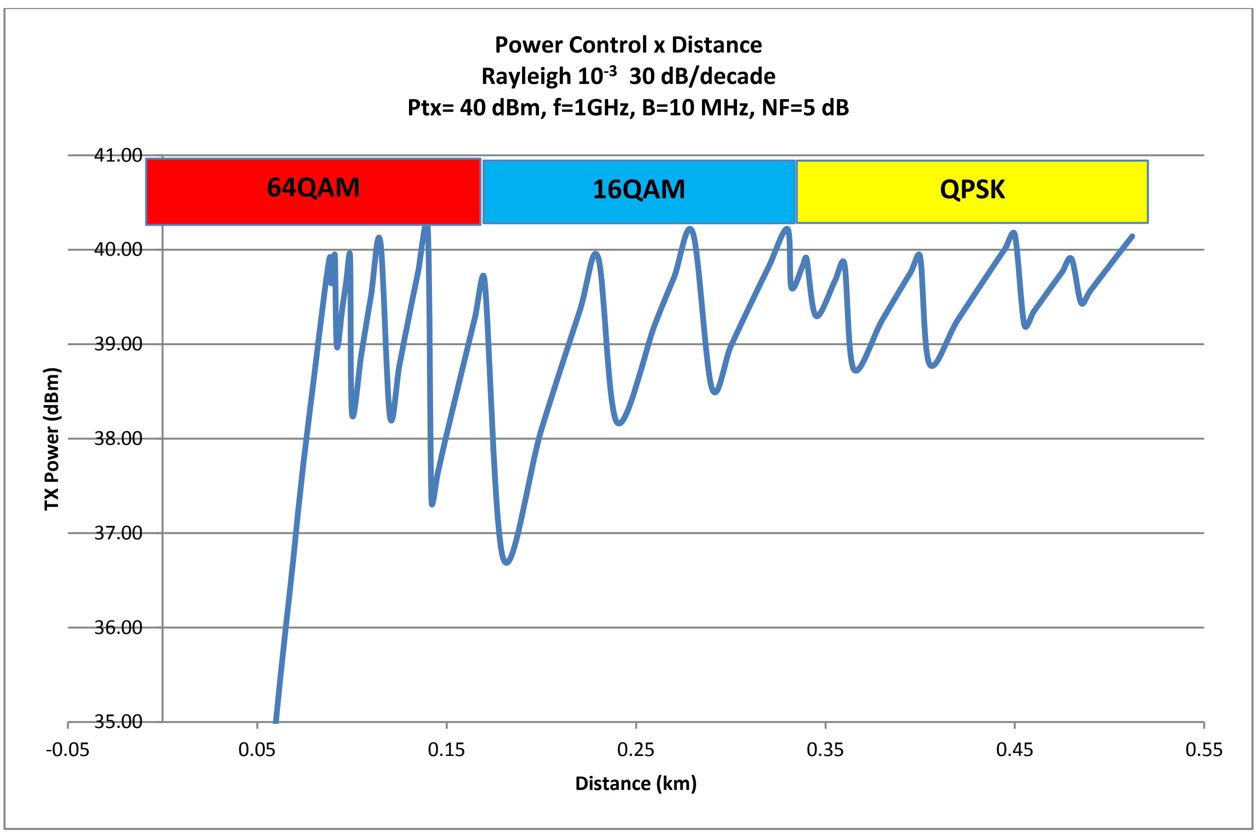
Power control plays a small influence in an adaptive modulation system; as the priority is to improve the modulation scheme, then reduce the power. We are not aware of any study that indicates the contrary. The figures above indicate the excursion of the power control in relation to the CQI values for different environments and path loss slopes.


Power Control x Distance
AWGN 10^{-3} 20 dB/decade
PTX= 40 dBm, f=1GHz, B=10 MHz, NF=5 dB
64QAM
16QAM
QPSK
TX power (dBm)
Distance (km)


Power Control x Distance
AWGN 10^{-3} 25 dB/decade
Ptx= 40 dBm, f=1GHz, B=10 MHz, NF=5 dB
64QAM
16QAM
QPSK
TX power (dBm)
Distance (km)



Power Control x Distance
Rayleigh 10-3 25 dB/decade
Ptx= 40 dBm, f=1GHz, B=10 MHz, NF=5 dB
64QAM
16QAM
QPSK
41.00
40.00
39.00
38.00
37.00
36.00
35.00
TX Power (dBm)
0
0.5
1
1.5
2
2.5
3
3.5
4
Distance (km)



Power Control x Distance
Rayleigh 10-3 30 dB/decade
Ptx= 40 dBm, f=1GHz, B=10 MHz, NF=5 dB
64QAM
16QAM
QPSK
41.00
40.00
39.00
38.00
37.00
36.00
35.00
TX Power (dBm)
-0.05
0.05
0.15
0.25
0.35
0.45
0.55
Distance (km)

6.2. **Selective Resource Reuse**

Allocation Blocks (AB) divide a frame in frequency and time blocks, which define the resources that can be shared between cells.

Before we analyze this complex setting, we will review the traditional and latest theoretical methods of distributing resources.

Neighbor cells that use all the available resources form a reuse group. Reuse factor can be defined as the ratio between the number of resources used in each cell and the number of cells in a group (e.g. 3/7).

Theoretical spectral efficiency is defined as the ratio between available resources and resources that are used in the cell. Real spectral efficiency will depend on the traffic distribution inside the cell and the size of the cell center.

The following methods have been proposed in the literature:

- Hard Resource Reuse (HRR)
- Fractional Resource Reuse (FRR)
- Soft Resource Reuse (SRR)
- Dynamic Resource Reuse (DRR)

Some of this methods use more than one reuse per cell and in this case we adopted a multiple reuse expression (e.g. 3/7, 4/7).

In the Dynamic Resource Reuse we considered that there are several areas of interference, illustrated in the figure. The number of interferers is indicated by the black numbers and is derived from a similar path loss to the area from the local site and the interfering sites. The indicated area sizes are just for reference, as the center area can be very small or even no existent.

The real reuse depends on the geographical user distribution and their traffic. When users are close to the center they will be able to use more resources, but if their concentration is on the cell border, they will be very restricted in the number of resources they can use.

We derived two parameters that can either be calculated by the prediction and optimization tool.

The Reuse Efficiency Factor (REF) that expresses the percentage of the available resources that can be effectively used, considering the allocation to other cells.

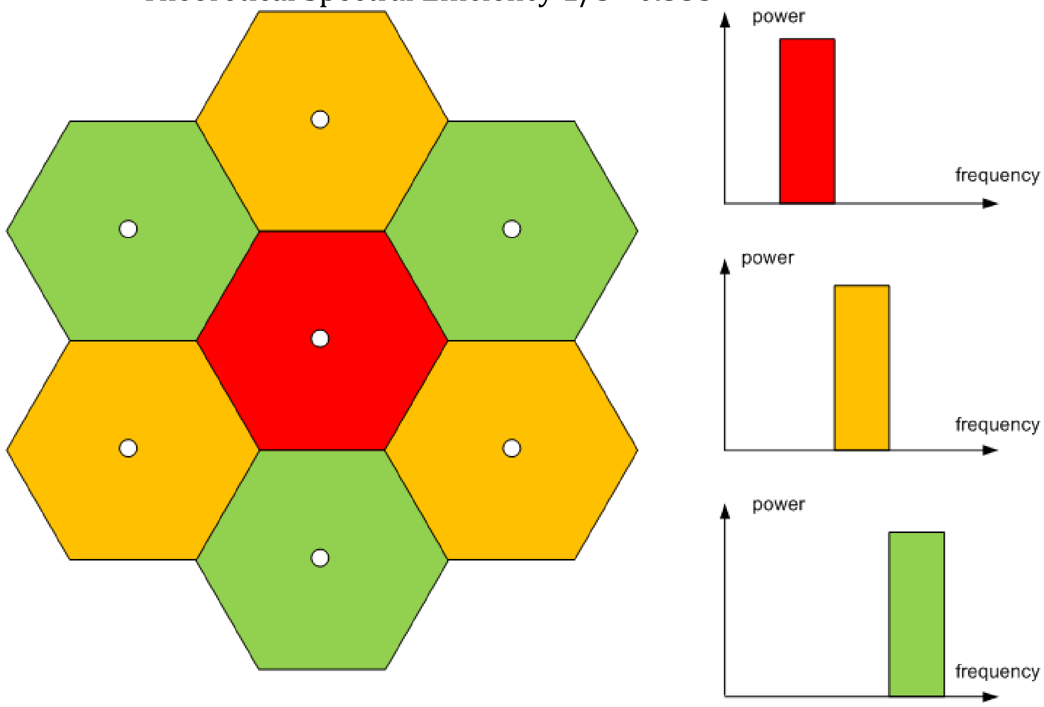
The Allocation Efficiency Factor (AEF) that expresses how efficiently data can be allocated inside each AB, as there nearly always will be a mismatch between the AB size and the data packet size, even if we consider fragmentation and aggregation.

Those methods are illustrated next.

Hard Resource Reuse (HRR)

Reuse 1/3=0.333

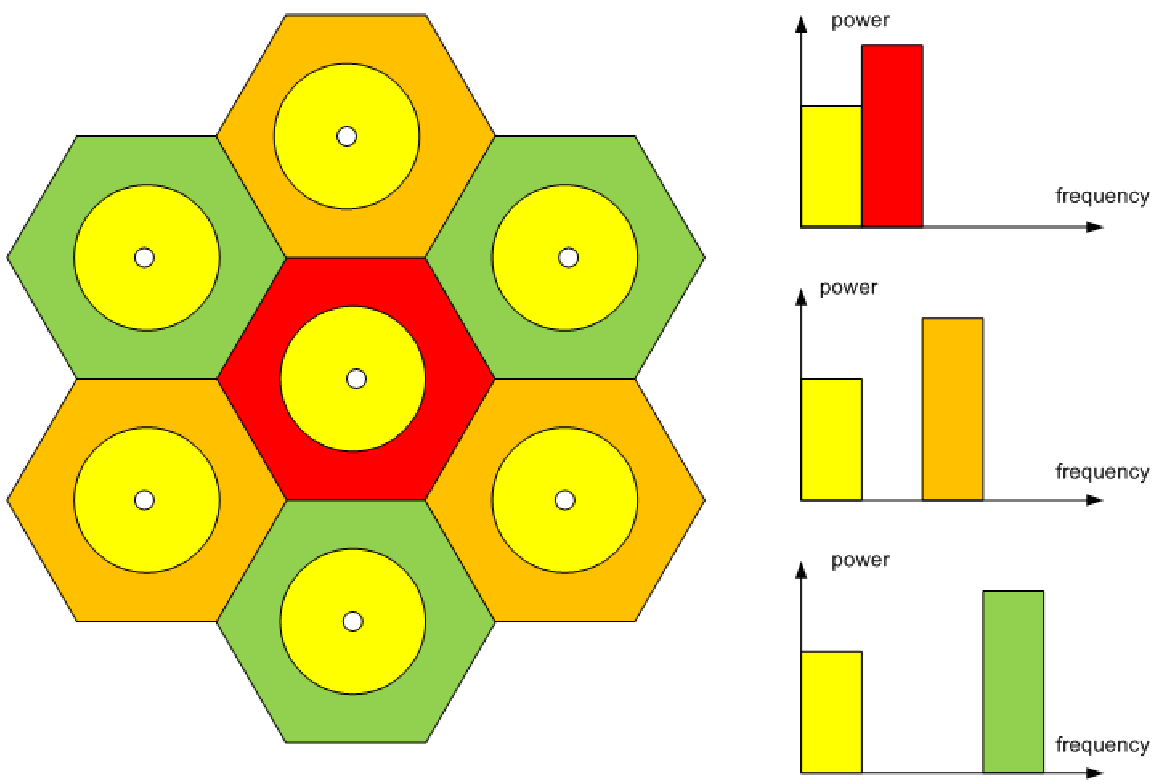
Theoretical Spectral Efficiency 1/3= 0.333



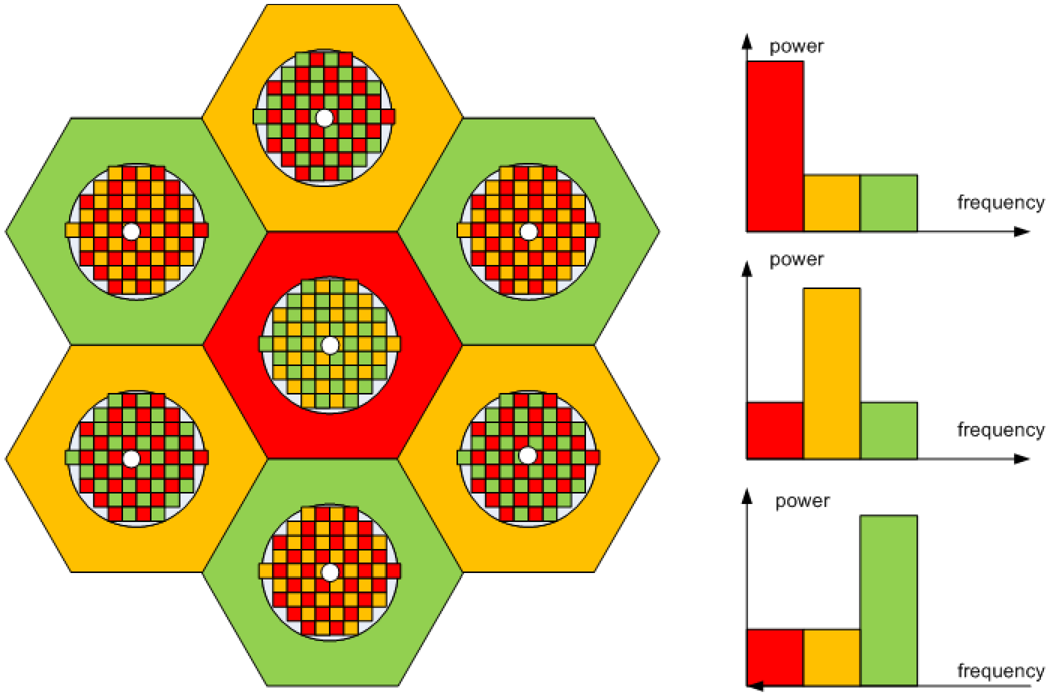
Fractional Resource Reuse (FRR)

Reuse 1/4,1/4

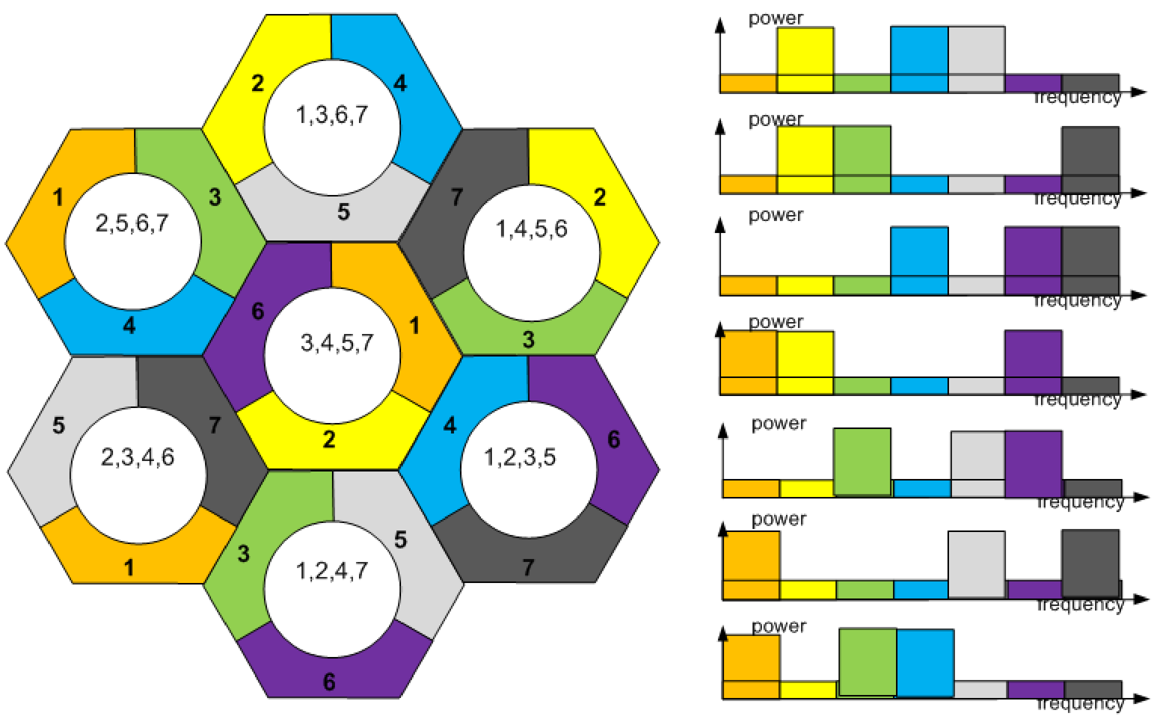
Theoretical Spectral Efficiency 1/2= 0.5



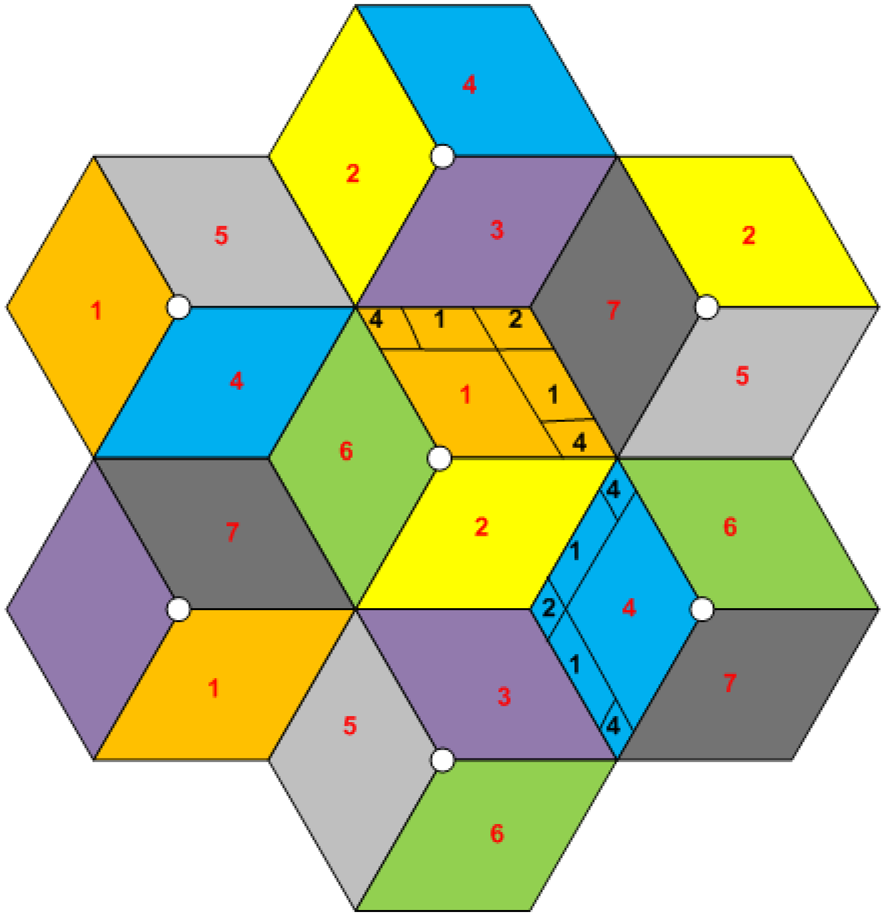
Soft Resource Reuse (SRR)
Reuse 1/3, 2/3
Theoretical Spectral Efficiency = 1



Soft Resource Reuse (SRR)
Reuse 3/7, 4/7
Theoretical Spectral Efficiency = 1



Dynamic Resource Reuse (DRR)
Reuse 1/7, 6/7
Theoretical Spectral Efficiency = 1



7. Admitting, Scheduling and Allocating Data

The process of user data allocation is done at several levels and is composed of the following processes:

- Admission Control: The eNB should only accept connections if there is resource availability to process them. As a rule new connections should not be accepted if a certain resource usage is achieved and a margin should be left for dealing with existing connections (e.g. 85%).

- Scheduling: Several algorithms are available to choose user scheduling and allocated rates (e.g. Round Robin, Max SNIR, Fairness...). Scheduling defines order and amount.

- Resource Allocation: The minimum resource allocation is a SB (Scheduling Block), which is 12 sub-carriers wide and 1 sub-frame long. It corresponds to two RB (Resource Blocks) stacked on the same sub-carriers. The number of RE (Resource Elements) available for data in each SB, depends on the CP (Cyclic Prefix) used and the amount of control and signaling

RE occupied by the system. A Resource Manager has to calculate the number of Res available for data, considering the control and signaling assignments. An SB can carry different amounts of bits depending on the Modulation Scheme and MIMO applicable to each connection

7.1. Admission Control

Admission Control process has to verify if a new UE process can be accepted. For this it has to know:

- The UE Interference Region (IR) in the cell
- The amount of Resources (SBs) available for this Region
- The applicable Adaptive Modulation Scheme
- The applicable MIMO scheme
- The required Resources (SBs) necessary
- The actual load of the Region resources (% used)

The process should only be accepted if its deployment will be inside the cell loading margin. A sound margin number would be within 80% and 90%.

7.2. Scheduling

Data transmitted on an LTE network is classified according to QoS Class Identifiers defined by 3GPP.

QCI	Resource Type	Priority	Packet Delay Budget (ms)	Packet Error Loss Rate	Service Example
1	GBR	2	100	10^{-2}	Conversational voice
2		4	150	10^{-3}	Video Live Streaming
3		3	50	10^{-3}	Real Time Gaming
4		5	300	10^{-6}	Video Buffered Streaming
5	Non-GBR	1	100	10^{-6}	IMS signalling
6		6	300	10^{-6}	Video Buffered Streaming, TCP applications
7		7	100	10^{-3}	Video Live Streaming, Interactive Gaming
8		8	300	10^{-6}	Video Buffered Streaming, TCP applications
9		9	300	10^{-6}	Video Buffered Streaming, TCP applications

GBR stands for Guaranteed Bit Rate and Non-GBR stands for Non-Guaranteed Bit Rate.

There are two types of scheduling applied to the QCI:

- Persistent Scheduling (PS) : Control overhead can be reduced by applying persistent scheduling for a certain duration. This applies to QCI 1 to 4, which use GBR (Guaranteed Bit

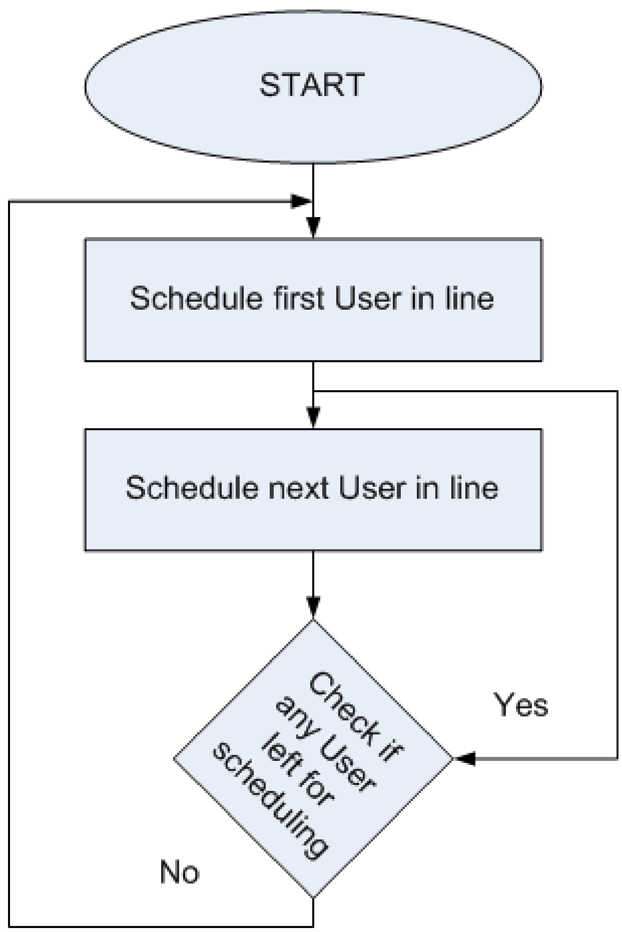
Rate). Persistent Scheduling may result in resource fragmentation and consequently lower assignment efficiency
- Dynamic Scheduling (DS): Implies in rearranging resource assignments on a frame basis. Increases control overhead, but avoids excessive fragmentation

Besides QCI, Scheduling uses Sequencing Algorithms to define which user data and how much of each to send. Many algorithms have been proposed to sequence user data, based on different criteria:

- Round Robin
- Max SNIR
- Proportional Fairness

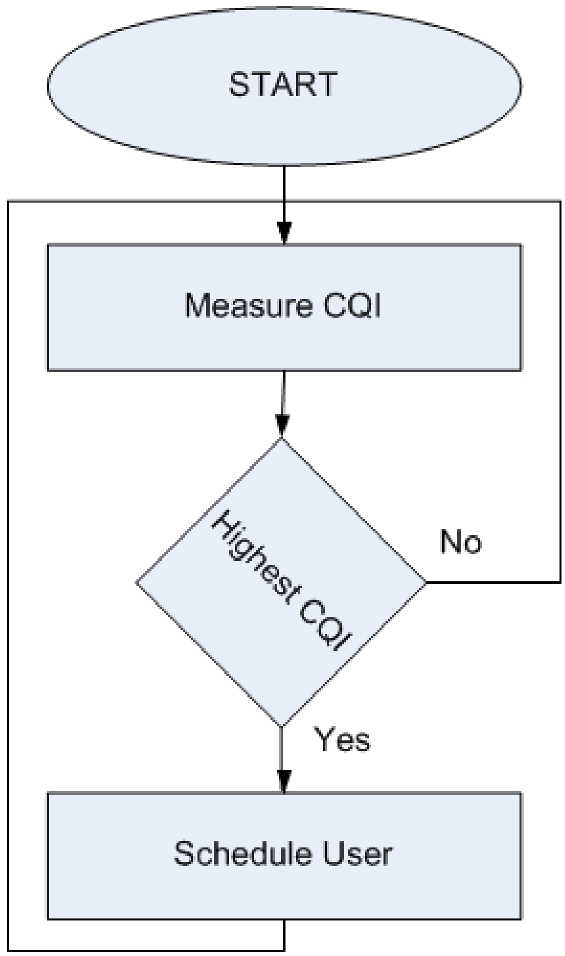
7.2.1. Round Robin (RR) Scheduling

This scheduling assigns equal number of SBs to all active UEs. The advantage of this scheduling is its simplicity and the disadvantage is that it does not take into account the CQI which will result in a lower and unequal throughput.



7.2.2. Max SNIR (MSNIR) Scheduling

In this scheduling UEs with highest CQI are assigned first. The advantage is that it increases throughput and the disadvantage is that UEs close to the edge will be badly served

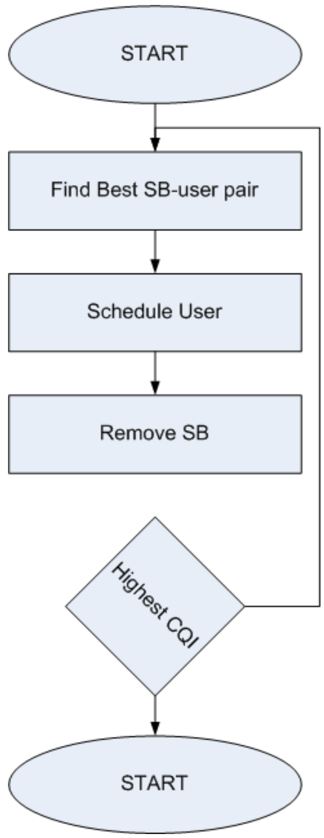


7.2.3. Proportional Fair (PF) Scheduling

There are several versions of PF algorithms, as each one considers a different fairness approach. Typical fairness considerations are:

- Equal amount of data transferred
- Smaller data packets are allocated first

It provides a compromise between throughput and UE QoS.



7.3. **Resource Allocation**

The eNB Radio Resource Manager (RRM) gets from the scheduler the allocation sequence and amount of data to be sent.

RRM gets the data for each user and verifies the available resource slots for the UE region

- RRM calculates how much bits can be sent in each available resource block
- According to the available slots, it fragments or concatenates user data
- It then assigns the data to the resource

A site will be aware of its neighbor resource allocations (SBs) according to the Master Plan.

UE will report neighbor pilot measurements. The eNB RRM can allocate resources that belong to not detected neighbors. Allocation of neighbor resources should be done in a direction opposed to the allocation of own resources.

UE may move into an area where neighbor is seen, resulting in high error rate. When this happens UE indicates high error rate and eNB proceeds to re-allocate. The eNB RRM should honor reallocation of UEs allocated to neighbor's resources.

8. Resource Allocation Optimization

CellSON™ (patent applied) methodology results in a Master Resource Allocation Plan prepared by the optimization tool.

A Cell will be divided in Interference Regions (IR) according to the number of interferers (typically six to 10 regions).

The optimization tool will define the number of IRs and its locations inside the cell.

Each IR will have assigned three types of resources

- Primary resources: Cell owned resources
- Secondary resources: Reused resources owned by other non-interfering cells
- Borrowed resources: Resources borrowed from other cells for defined periods and considered as own. This exchange will be done through the X2 interface

The outcome of the optimization is a Resource Allocation Master Plan, which accommodates the traffic and interference. Resources are optimized using SNR availability according to the desired customer experience. Customer experience has to be adjusted if there are not enough resources to provide the desired level

The Master Plan defines per cell for each Interference Region:

- Primary resources
- Secondary resources (owned by other cells, but can be used by the cell if interference is not detected). Those resources are allocated in a contrary direction then they are allocated in the cell that owns them, minimizing conflicts
- Tertiary resources: Resources that can be requested (borrowed) from neighbor cells for a certain period of time, becoming during this period own resources

A Master Plan can be generated for different periods of the day and updated according to the projected traffic in each period.

9. Het Net Resource Allocation

Almost Blank Sub-Frames (ABS) can be used to protect the control channels, as the redundant configurations are not prepared to support the expected interference levels. In some cases there may be no need to use ABS and the prediction tool can predict this

HetNets can be considered as neighbors of the cell/cells where they are located in terms of resource allocation. They can be incorporated into the Master Plan at HetNet creation in the system. HetNet should get exclusive SBs blocks.

10. Conclusion

A Dynamic Reuse methodology based on a Master Plan derived by a prediction and optimization tool (CellSON™) was presented.

SON features are accommodated by the optimization process.

ICIC considerations are the base of the proposed methodology.

A resource nomenclature was proposed.

Resource reuse was maximized and should increase significantly the overall throughput.