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Radio Network Planning for 2G and 3G

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***Abstract* – This paper deals with the procedure of how to carry out the radio network planning for 2G and 3G systems. The general steps and methods for wireless radio network planning are first addressed. Then four optimization methods used for off-the-shelf simulation based evaluations are introduced. At last the issue of radio network planning is discussed with special focus on the 2G and 3G networks, as well as a comparison between 2G and 3G radio network planning processes which is summarized at the end.**

I. INTRODUCTION

The radio access part of the wireless network is considered of essential importance as it is the direct physical radio connection between the mobile equipment and the core part of the network. In order to meet the requirements of the mobile services, the radio network must offer sufficient coverage and capacity while maintaining the lowest possible deployment costs. Because the radio network planning is a complicated subject, this paper gives a general overview of the process and the most important related issues.

II. MAIN PART

A. General Approach for Radio Network Planning

The radio network planning process can be divided into different phases. At the beginning is the Pre-planning phase. In this phase, the basic general properties of the future network are investigated, for example, what kind of mobile services will be offered by the network, what kind of requirements the different services impose on the network, the basic network configuration parameters and so on.

The second phase is the main phase. A site survey is done about the to-be-covered area, and the possible sites to set up the base stations are investigated. All the data related to the geographical properties and the estimated traffic volumes at different points of the area will be incorporated into a digital map, which consists of different pixels, each of which records all the information about this point. Based on the propagation model, the link budget is calculated, which will help to define the cell range and coverage threshold. There are some important parameters which greatly influence the link budget, for example, the sensitivity and antenna gain of the mobile equipment and the base station, the cable loss, the fade margin etc. Based on the digital map and the link budget, computer simulations will evaluate the different possibilities to build up the radio network part by using some optimization algorithms. The goal is to achieve as much coverage as possible with the optimal capacity, while reducing the costs also as much as possible. The coverage and the capacity planning are of essential importance in the whole radio network planning. The coverage planning determines the service range, and the capacity planning determines the number of to-be-used base stations and their respective capacities.

In the third phase, constant adjustment will be made to improve the network planning. Through driving tests the simulated results will be examined and refined until the best compromise between all of the facts is achieved. Then the final radio plan is ready to be deployed in the area to be covered and served. The whole process is illustrated as the figure below:

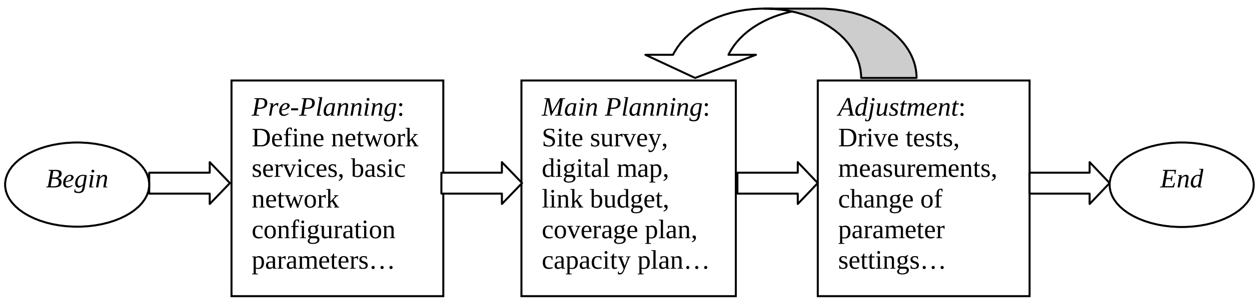

Fig.1 Radio network planning process

The base station location is a clear example of the complexity of planning radio networks. Many variables have to be taken into account, which makes the problem of network planning hard (not possible to solve in simulation time). Below we will take the uplink of UMTS as an example to show how the cost functions incorporate the degrees of freedom and are minimized.

In the digital map, possible sites for base stations form together a set of candidate sites S={1,...,m}. Each candidate site has a set of configuration parameters indicating properties like the antenna type and antenna direction. We have also a set of test points I={1,…,n}. At each test point the mobile traffic volume is investigated and the radio signal qualities must meet the demanded value here. The traffic volume can be simply related to the activity connection numbers at this point and is indicated by u_i . The P_{tar} is the minimum required power received at the base station. The g_{ij} is the propagation factor between point i and point j. So P_{tar} / g_{ij} becomes the transmission power of a mobile equipment. c_j is, in this case, the corresponding cost of setting up a base station in point j, like installation, leasing and maintenance costs. We define the following variables:

$$y_j = \begin{cases} 1 & \text{if a BS is installed in j} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

for j $\in$ S and

$$X_{ij} = \begin{cases} 1 & \text{if test point i is assigned to BS j} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

for i $\in$ I and j $\in$ S. The cost function we want to minimize is

$$\min \sum_{j=1}^{m} c_j y_j + \lambda \sum_{i=1}^{n} \sum_{j=1}^{m} u_i \frac{P_{tar}}{g_{ij}} x_{ij} \tag{3}$$

In the formula (3), the first part indicates the total costs of setting up the base locations in the chosen points, and the second part is the total mobile equipment power needed to reach the base station with an acceptable signal level in the covered area. The parameter λ is used here to adjust the weight of costs and total power in the cost function. Some operators might be in favor of reducing the number of base stations more than low transmission powers for budget reasons, while other might prefer to cover the area in a better way to reduce uplink needed power and offer more power consuming services with a better QoS to users, at the expense of setting up a more expensive network with more base stations and charging maybe higher fees to their subscribers.

There are also four constraints that should be taken into account when simulating the current layout behavior and cost function efficiency.

$$\sum_{j=1}^{m} x_{ij} = 1 \qquad i \in I \tag{4}$$

$$x_{ij} \le y_j \qquad i \in I;\ j \in S \tag{5}$$

$$x_{ij}, y_j \in \{0,1\} \quad i \in I;\ j \in S \tag{6}$$

$$\frac{P_{tar}}{g_{ij}} \le P_{\max} \tag{7}$$

The constraint (4) indicates that the test point should only be connected with one base station, with the soft handover not taken into account to plan for a relatively worst case scenario. The constraint (5) imposes that the test point is only assigned to the point where the base station is installed. The constraint (6) defines the values that could be taken by these two parameters. In the constraint (7) $P_{\max}$ is the maximum power of the mobile equipment, and the transmitted power at the mobile equipment should not exceed this value.

B. Optimization methods for solving cost functions reliably and rapidly

With the digital map, the needed data and a proper mathematical model, simulations can be conducted in order to determine the best scheme of allocation of the base stations. The computer usually searches for the optimal result step by step throughout the surrounding neighbors of an initial solution, and the neighbor is defined as the new value of the variable that has a Hamming distance of 1 from the current point. Neighboring solutions in this case are one additional base station in a possible position, or one less base station in another position. There are four methods that are frequently used here: Random Walk, Simulated Annealing, Tabu search and Genetic Algorithms.

Random Walk: The Random Walk search method generates new neighbors at each iteration. The cost function at the new neighbor is evaluated and compared to the one at the current point. If the new cost function is lower than the old one, then the neighbor will be unconditionally accepted. And if the new function is worse than the former, it will be conditionally accepted with a probability of p, with p=0 becoming the greedy search algorithm with no solution accepted unless it provides a more suitable cost function, and p=1 leading to the fully random search, thus evaluating all possible combinations of base stations at all possible places. From literature surveys, the optimal value of the probability p of choosing a worse solution than the previous one is p=0.03.

Simulated Annealing: The Simulated Annealing search is similar to the random walk. It also calculates the cost function of the generated new neighbor, and compares the result with the already obtained old result. There is also conditional and unconditional accept. The difference is that the probability of accepting conditionally is changing during the search procedure, while in random walk the probability p is fixed from the beginning to the end of one search. The change of this probability is controlled using some method, which can be analogy to the cooling procedure of annealing, so that the search becomes more and more greedy.

Tabu Search: Tabu search is defined as follows: The already selected base station positions in the last K iterations will be considered “tabu”, and so will not be taken into consideration for the generation of new neighbors. Usually K is chosen to be 1. The size of candidates for each iteration can be reset, and the larger the size of candidates, the better the final result, but also it takes longer for the simulations to converge. The best value for the candidate size can be found to be equal to 10 in the literature.

Genetic Algorithm: The idea of Genetic Algorithm comes from the phenomena of the human evolution first proposed by Darwin. From a set of parent points, the children can be generated. We select those children points, that show the best results when evaluating the cost function compared to the ones of their parents and their generation. In the Genetic Algorithm, we use a mutation operator that can be related to the definition of neighborhood. The definition of population size and generations are also similar to the candidate size and iterations mentioned before.

C. GSM planning

In GSM, the network is divided into a lot of cells, and usually a base station is planted in the center of each cell. For the sake of easy analysis, the cells are represented as neighboring hexagons, while in reality they can be of any kind of forms and overlap with each other. The size of each cell, when fixed, will usually stay stable.

There is one important feature in GSM network planning: the coverage planning and capacity planning are independent. The coverage planning depends on the received signal strength, that is to say, the covered area is nearly only limited by the minimum signal strength at the cell range, while the later capacity planning depends mainly on the frequency allocation.

The link budget is the table recording the power loss in the uplink or downlink of the network. Below is an example of the link budget from GSM 900 MHz. The link budget results can be improved by adopting some techniques like frequency hopping or using receiver diversity.

RECEIVED END		**BS**	**MS**	
RX RF-input sensitivity	dBm	-104.00	-102.00	A
Interference degrading margin	dB	3.00	3.00	B
Cable loss + connector	dB	4.00	0.00	C
Rx antenna gain	dBi	12.00	0.00	D
Isotropic power	dBm	-109.00	-99.00	E=A+B+C+D
Field strength	dBV/m	20.24	30.24	F=E+Z
				Z=77.2+20*log(freq/MHz)
TRANSMITTING END		**MS**	**BS**	
TX RF-output peak power	W	2.00	6.00	
(mean power over RF cycle)	dBm	33.00	38.00	K
Isolator + combiner + filter	dB	0.00	3.00	L
RF-peak power, combiner output	dBm	33.00	26.00	M=K-L
Cable loss + connector	dB	0.00	4.00	N
TX-antenna gain	dBi	0.00	12.00	O
Peak EIRP	W	2.00	20.00	
(EIRP = ERP + 2dB)	dBm	33.00	34.00	P=M-N+O
Path loss due to ant./body loss	dBi	9.00	9.00	Q
Isotropic path loss	dB	133.00	133.00	R=P-F-Q

Table I Link budget calculation in GSM radio network

In GSM 900 system, there are 125 channels in both uplink and downlink, and these channels span the available bandwidth of GSM 900. The frequency is a scare resource in GSM system, and the frequency must be carefully planned to be reused. The frequency reuse factor is defined as the number of base stations that can be implemented between the current base station and the ones before the same frequency is reused. The antenna height can also influence the reuse factor, since the higher the antenna is, the greater the possibility that the signal causes more interference. Frequency planning is done using one of the previously mentioned optimization algorithms, by setting an adequate cost function to maximize the capacity of the network while minimizing the number of frequency sub-bands used.

D. UMTS Planning

The main procedures of UMTS are very similar to that of GSM, and the coverage and capacity planning play also important roles in the whole radio network planning. They are both strongly related, and the coverage is a function of the capacity. Since UMTS is interference limited, a big number of users will reduce the power availability at the base station to combat interference, and therefore reduce the cell site in what is called the cell breathing effect. Here we will emphasize on the different points in which UMTS planning distinguishes itself from GSM planning.

Now let us take a look at the radio link budget of UMTS for the voice service as below:

Data rate(kb/s)		12.2	12.2
Load		50%	50%
		Uplink	**Downlink**
RECEIVING END		**Node B**	**UE**
Thermal Noise Density	dBm/Hz	-174	-174
BTS Receiver Noise Figure	dB	3.00	8.00
BTS Receiver Noise Density	dBm/Hz	-171.00	-166.00
BTS Noise Power [NoW]	dBm	-105.16	-100.16
Required Eb/No	dB	4.00	6.50
Soft handover MDC gain	dB	0.00	1.20
Processing gain	dB	24.98	24.98
Interference margin (NR)	dB	3.01	3.01
Required BTS Ec/Io [q]	dB	-17.97	-16.67
Required Signal Power [S]	dBm	-123.13	-116.83
Cable loss	dB	2.50	2.50
Body loss	dB	0.00	5.00
Antenna gain RX	dBi	18.00	0.00
Soft handover gain	dB	2.00	2.00
Power control headroom	dB	3.00	0.00
Sensitivity	dBm	-137.63	-111.33
TRANSMITTING END		**UE**	**Node B**
Power per connection	dBm	21.00	27.30
Maximum Power per connection	dBm	21.00	40.00
Cable loss	dB	0.00	3.00
Body loss	dB	5.00	0.00
Antenna gain TX	dBi	0.00	18.00
Peak EIRP	dBm	16.00	42.30
Maximum Isotropic path loss	dB	153.63	166.33
Isotropic path loss to the cell border			153.63

Table II Link budget calculation in UMTS radio network for voice service

In UMTS, the frequency reuse factor is 1, and in each cell the whole bandwidth is used. So there is no frequency assignment in UMTS. UMTS uses WCDMA as its multiplex access method, which determines that the interference plays an essential role in the coverage planning and capacity planning. The cell size in UMTS is not fixed. When the interference arises, the SIR deteriorates, which makes the mobile equipment at the old cell fringe hard to communicate with the base station. So the cell size shrinks. The resulting swinging of the cell size in UMTS due to the changing interference is called "cell breathing". The network upper capacity limit can also be easily reached when too much interference leads to the limit of the power at the base station through the mechanism of power control loop. So in UMTS the coverage planning and capacity planning cannot be independently made like in GSM, they are closely correlated. The higher the coverage, the lower is the capacity, and vice versa.

III. CONCLUSIONS

In this paper we have gone through the general process for radio network planning, the optimization methods, GSM planning and UMTS planning. The coverage planning and capacity planning are the most important ones in the radio network planning. They can be independently made in GSM system, while they are correlated to each other in UMTS system due to the significant role of interference in UMTS.

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2G and 3G Radio Network Planning

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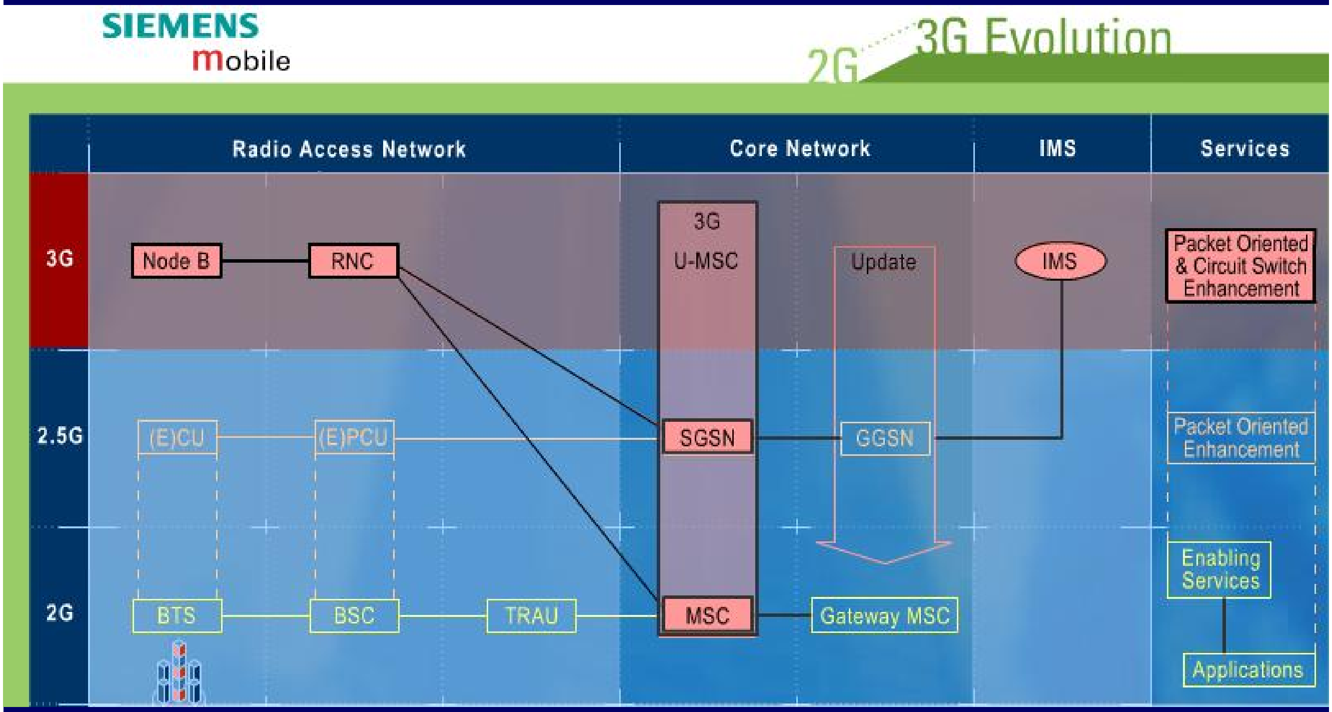
Executive Summary

- Introduction
- General Approach
- Optimization Methods
- GSM Planning
- UMTS Planning
- Summary

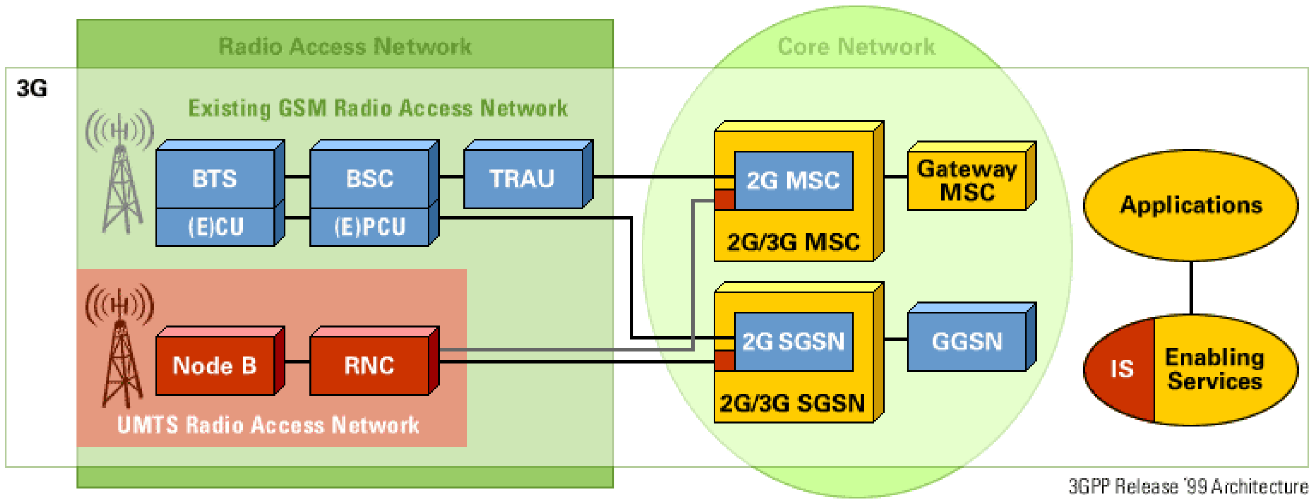
Introduction

Radio Network



Introduction

GSM to UMTS



Network elements: unchanged partly new (software/hardware upgrade, smooth migration) completely new

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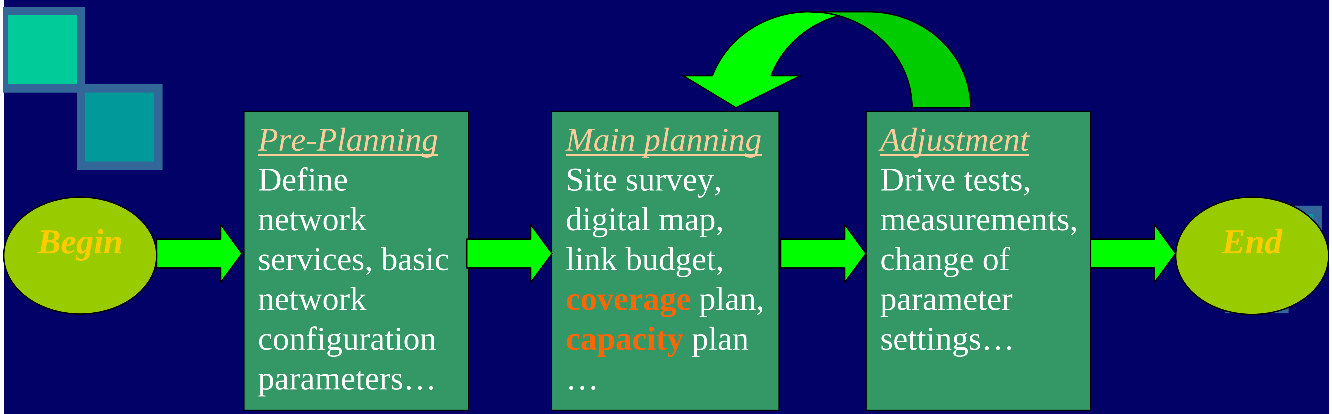
Radio Network Planning Process



General Approach

Digital Map and Pixels

- Possible sites for the base stations and configurations
- The mobile traffic volume at each point...

General Approach

Link Budget

- Link budget calculation: signal strength loss on the path between base station and mobile phone
- Help to define the cell ranges along with the coverage thresholds
- Important components: Sensitivity, Fade margin, Connector and cable losses, Antenna gain

$\min \sum_{j=1}^{m} c_j y_j + \lambda \sum_{i=1}^{n} \sum_{j=1}^{m} u_i \frac{P_{tar}}{g_{ij}} x_{ij}$

General Approach

Cost Function and Constraints

$$\min \sum_{j=1}^{m} c_j y_j + \lambda \sum_{i=1}^{n} \sum_{j=1}^{m} u_i \frac{P_{tar}}{g_{ij}} x_{ij}$$

Example of UMTS uplink

$$\sum_{j=1}^{m} x_{ij} = 1 \qquad i \in I$$

$$x_{ij} \le y_j \qquad i \in I;\ j \in S$$

$$x_{ij}, y_j \in \{0,1\} \quad i \in I;\ j \in S$$

$$\frac{P_{tar}}{g_{ij}} \le P_{\max}$$

POWER

COST

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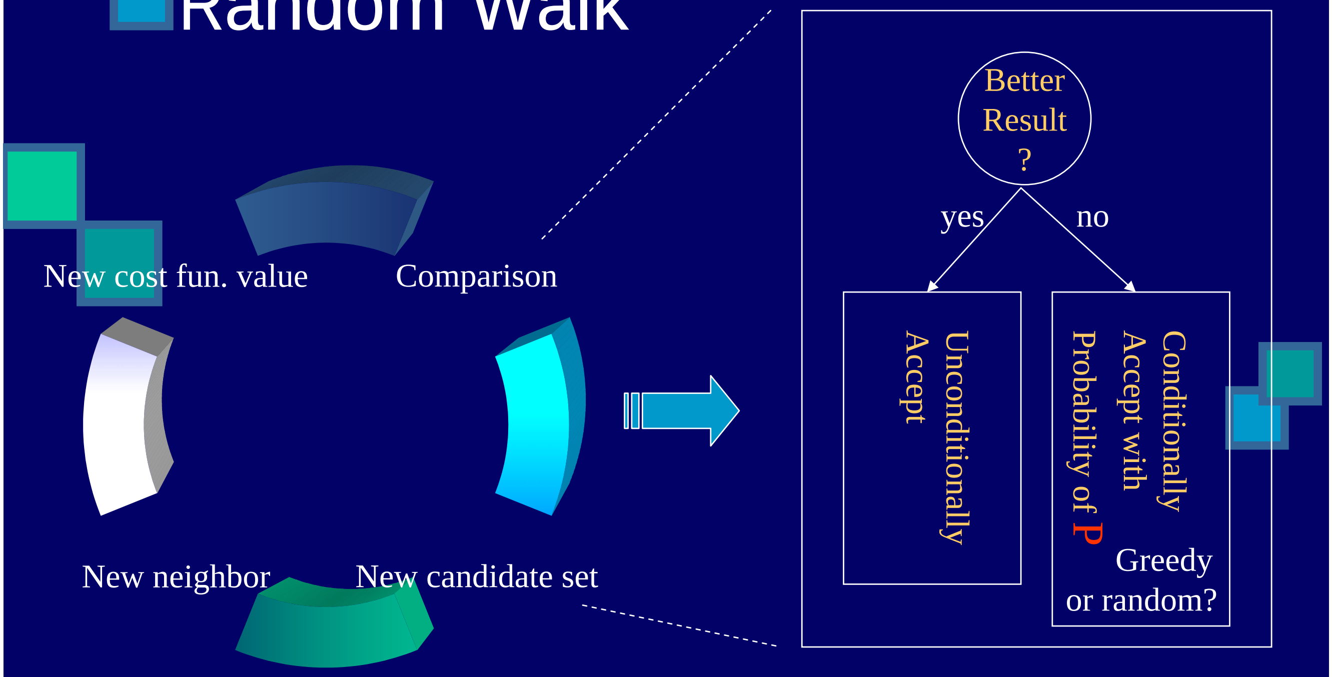
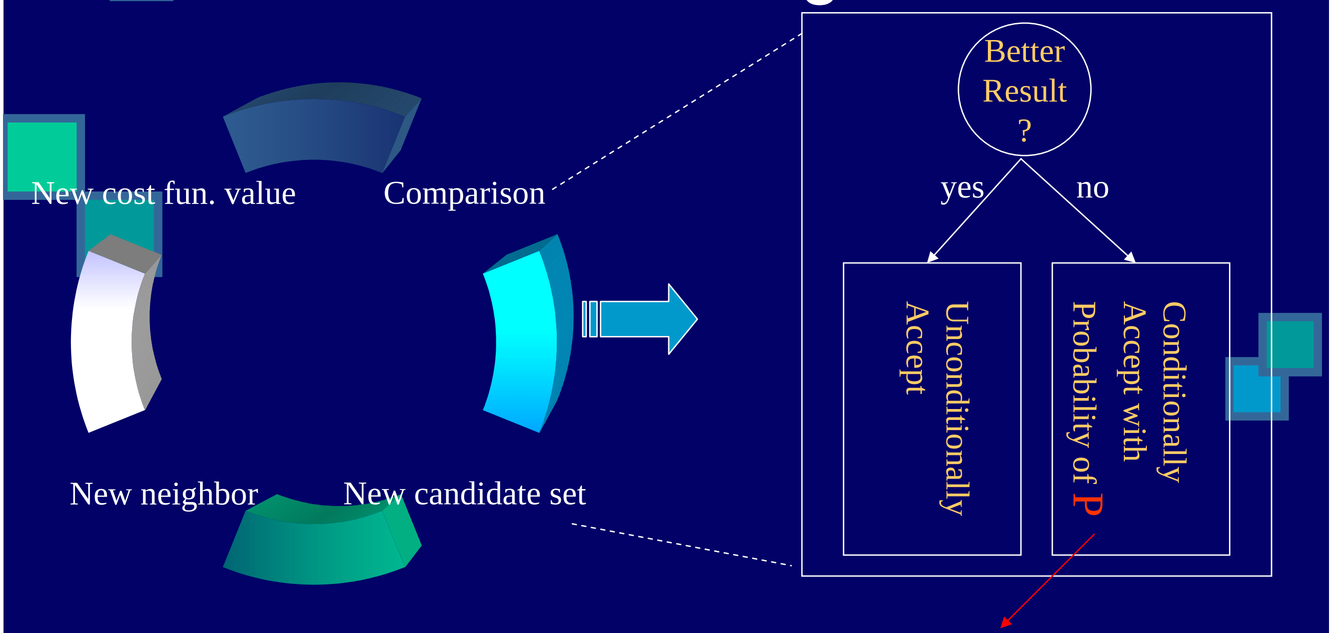
Random Walk



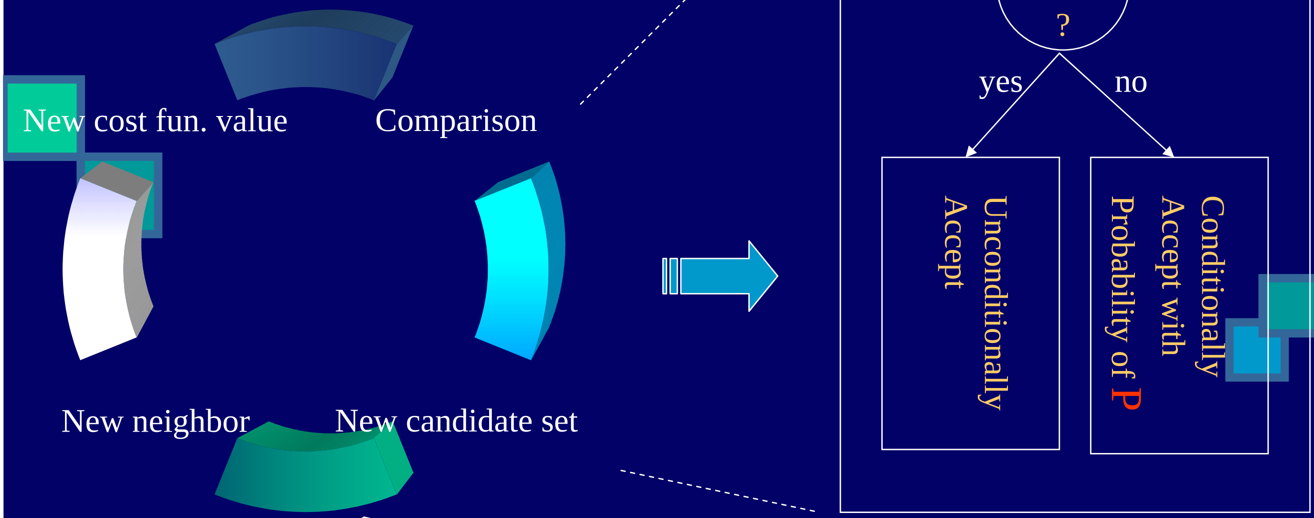
Simulated Annealing?



P is changing in each new cycle controlled by some algorithm analogy to the cooling procedure of annealing, so that the search becomes more greedy and effective.

Optimization Methods

Tabu Search

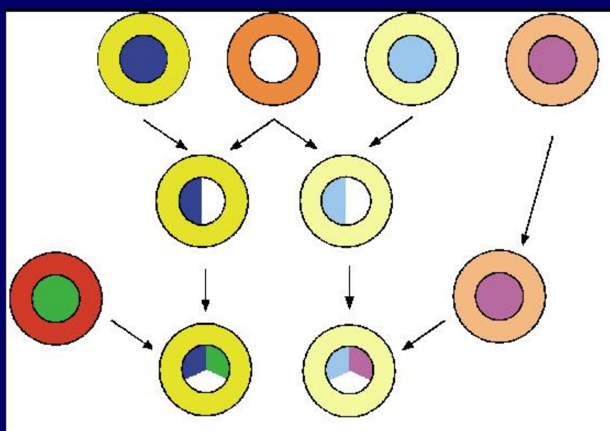


The already selected ones in the last K iterations will be considered "Tabu", and will not be taken into consideration for the generation of new neighbors

Optimization Methods

Genetic Algorithms

normal.	G.A.
Candidate sets	Parents
New neighbors	Children
Generating	Mutation
Iterations	Generations



Selection mechanisms:
Rank-based, Proportional, Tournament Selection…

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Coverage and Capacity planning independent

- Coverage and Capacity planning independent
- Coverage depends on received signal strength
- Capacity depends on frequency allocation

Budget Link

RECEIVED END		BS	MS	
RX RF-input sensitivity	dBm	-104.00	-102.00	A
Interference degrading margin	dB	3.00	3.00	B
Cable loss + connector	dB	4.00	0.00	C
Rx antenna gain	dBi	12.00	0.00	D
Isotropic power	dBm	-109.00	-99.00	E=A+B+C+D
Field strength	dBV/m	20.24	30.24	F=E+Z
				Z=77.2+20*log(freq/MHz)
TRANSMITTING END		**MS**	**BS**	
TX RF-output peak power	W	2.00	6.00	
(mean power over RF cycle)	dBm	33.00	38.00	K
Isolator + combiner + filter	dB	0.00	3.00	L
RF-peak power, combiner output	dBm	33.00	26.00	M=K-L
Cable loss + connector	dB	0.00	4.00	N
TX-antenna gain	dBi	0.00	12.00	O
Peak EIRP	W	2.00	20.00	
(EIRP = ERP + 2dB)	dBm	33.00	34.00	P=M-N+O
Path loss due to ant./body loss	dBi	9.00	9.00	Q
Isotropic path loss	dB	133.00	133.00	R=P-F-Q

Coverage Planning

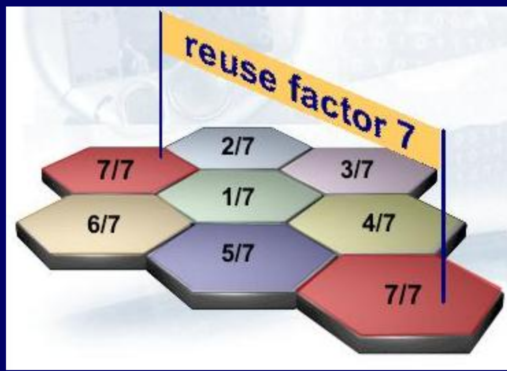
- Guarantee the signal strength in the service area
- Depending factors
  - natural: geographical aspect/propagation conditions
  - human: landscape (urban, suburban, rural)
- Methods
  - Theoretically through link budget calculation and computer simulation and optimization
  - Practically through the drive test and other measurements

Frequency/Capacity planning

- 125 number of frequencies in both down and uplink of GSM 900, each is a channel

Three essential parameters:

- Estimated traffic
- Average antenna height
- Frequency reuse factor



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Coverage and Capacity planning correlated

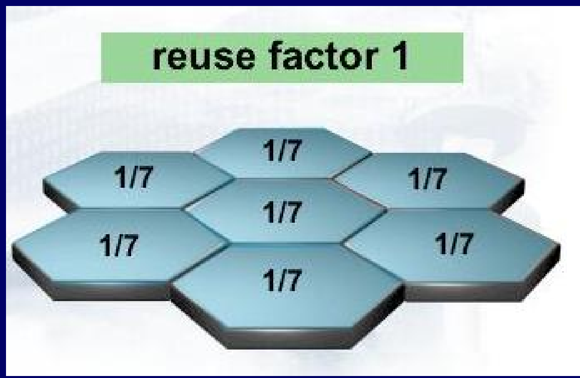
- Coverage and Capacity correlated with each other due to interference limited system
- Interference up – cell range shrinks – coverage down
- Interference up – user number down – capacity down

Budget Link

RECEIVING END		Node B	UE
Thermal Noise Density	dBm/Hz	-174	-174
BTS Receiver Noise Figure	dB	3.00	8.00
BTS Receiver Noise Density	dBm/Hz	-171.00	-166.00
BTS Noise Power [NoW]	dBm	-105.16	-100.16
Required Eb/No	dB	4.00	6.50
……	…	…	…
Cable loss	dB	2.50	2.50
Body loss	dB	0.00	5.00
Antenna gain RX	dBi	18.00	0.00
Soft handover gain	dB	2.00	2.00
Power control headroom	dB	3.00	0.00
Sensitivity	dBm	-137.63	-111.33
TRANSMITTING END		**UE**	**Node B**
Power per connection	dBm	21.00	27.30
Maximum Power per connection	dBm	21.00	40.00
Cable loss	dB	0.00	3.00
Body loss	dB	5.00	0.00
Antenna gain TX	dBi	0.00	18.00
Peak EIRP	dBm	16.00	42.30
Maximum Isotropic path loss	dB	153.63	166.33
Isotropic path loss to the cell border			153.63

Coverage and Capacity Planning

- Frequency reuse factor is 1
- Cell breathing
- Capacity is limited by interferences



Comparison with GSM

- Nearly the same as GSM
- Not suitable for UMTS
  - No actual frequency assignment
  - Traffic distribution affects heavily
- Important for UMTS

signal strength, traffic distribution, power control mechanism, power limit, quality constraint

Summary

- Radio Network planning concept
- General approaches and optimization methods
- Planning for GSM and UMTS

Thank you!