WCDMA MOBILE RADIO NETWORK SIMULATOR WITH HYBRID LINK ADAPTATION

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Summary The main aim of this article is the description of the mobile radio network model, which is used for simulation of authentic conditions in mobile radio network and supports several link adaptation algorithms. Algorithms were designed to increase efficiency of data transmission between user equipment and base station (uplink). The most important property of the model is its ability to simulate several radio cells (base stations) and their mutual interactions. The model is created on the basic principles of UMTS network and takes into account parameters of real mobile radio networks.

1. INTRODUCTION

The evolution of mobile radio networks is affected by tendency to achieve as the highest data rates as it is possible. The customer wants to own the latest technology, what can be translated to common used expression “high data rate”. The condition to reach the highest data rate supports development of the new technology, which will by used in next generation of mobile networks (e.g. OFDM) [1, 9].

The most common method for delivering maximum data rate to user is the link adaptation. We are dealing only with system parameters adaptation (power and modulation). Other adaptation methods suited for CDMA systems can be found in [11].

We are looking for better performance of 3G mobile radio networks in our project. The goal of this paper is the description of the tool, which was developed during the project VEGA - 1/0140/03 (Effective radio resources management methods in next generations of mobile communication networks). The whole project is based on 3G Partnership Project (3GPP) specifications.

2. MODEL STRUCTURE

The model was created in Matlab environment with block structure. This design allows the simple addition of new blocks or algorithms. Also description of functionality is very simple. As it is shown on figure 1, the model contains five main blocks (steps):

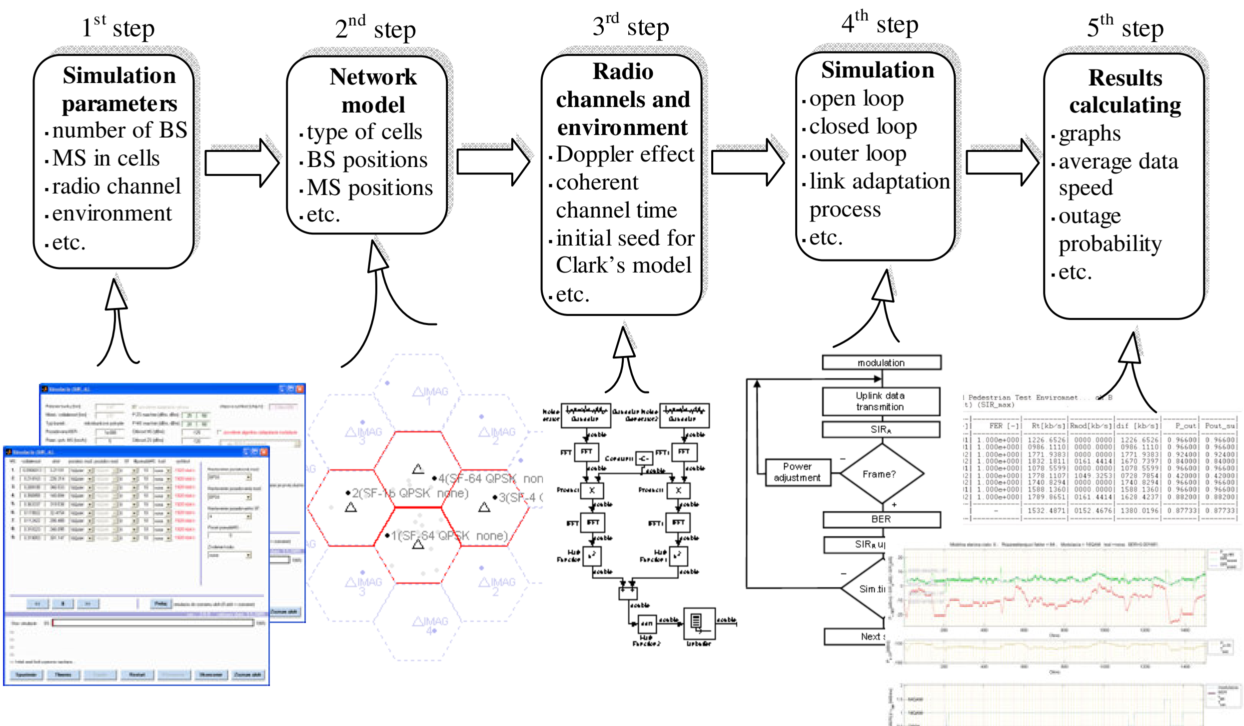

Fig. 1. Model structure.

- Input parameters processing (1st step).
- Creating model (2nd step).
- Test environment parameters and radio channels processing (3rd step).
- Simulation of uplink connections between base station (BS) and mobile station (MS), intracell and intercell interference (4th step).
- Results calculating (5th step).

The 1st step. Simulation model supports two main types of radio cells - microcells and macrocells [2]. In macrocells there are used three sectored antennas with 120° coverage. Microcells are created by one antenna in the middle of the cell with full space coverage (360°). User can set up almost all of the base stations important parameters (e.g. the highest and the lowest output power, receiver sensitivity, cable, connector and combiner losses, transmitter antenna gain, receiver antenna gain, cell radius, etc.) The example of graphical user interface (GUI) is on figure 2. The maximum allowed number of cell is 81 for microcells and 57 for macrocells.

In 3GPP specification it is also described the third type of cells: picocells [2]. Structure of these type of cells is the same as microcells, but the highest output power is lower (the main difference is in the used test environment) [3].

The next important parameter of mobile radio network simulation is the test environment. According to European Telecommunications Standards Institute (ETSI) specification, simulator supports three types of them [3]. The main difference lies in supported MS velocity and also in a different path loss model, which is used.

Types of supported test environments:

- Low Range Outdoor (Non-line of sight).
- Suburban Outdoor (Non-line of sight and line of sight).
- Rural Outdoor (Indoor office) (Line of sight).

The most important parameters of test environments are in table 1.

Radio channel model is represented by main blocks (the 3rd step):

- Long-term fading (Path loss and Shadow fading)
- Short-term fading

Environment	Maximum data rate (QPSK)	Maximum MS velocity	Model of test channel	Coverage
Rural Outdoor	144 kbit/s	500 km/h	Vehicular (A & B)	Macrocells
Suburban Outdoor	384 kbit/s	120 km/h	Outdoor to Indoor and Pedestrian (A & B)	Microcells
			Vehicular (A)	Macrocells
Low Range Outdoor	2048 kbit/s	10 km/h	Outdoor to Indoor and Pedestrian (A)	Microcells
Indoor Office	2048 kbit/s	10 km/h	Indoor (A & B)	Picocells

Tab. 1. Parameters of test environments

The path loss $L_{PATH-LOSS}$ for Low range outdoor environment is defined [3]:

$$L_{PATH-LOSS} = 40.\log10(r) + 30.\log10(f) + 49 \text{ [dB]}, \quad (1)$$

where r [km] is the distance between transmitter and receiver and f [MHz] is frequency.

$L_{PATH-LOSS}$ for Suburban outdoor environment is defined [3]:

$$L_{PATH-LOSS} = 128,1 + 37,6.\log 10(r) \text{ [dB]}. \quad (2)$$

This formula is valid for a carrier frequency of 2000 MHz and a base station antenna height of 15 meters.

$L_{PATH-LOSS}$ for Rural outdoor environment is defined [3]:

$$L_{PATH-LOSS} = -20.\log 10\left(\frac{\lambda}{4.\pi.r}\right) \text{ [dB]}, \quad (3)$$

where λ [m] is the wavelength.

Shadow fading is similar for all environments: Log-normal shadow fading with a standard deviation of 10 dB is appropriate for outdoor environments (urban and suburban areas) and 12 dB for indoor one. The building penetration loss with mean value of 12 dB with a standard deviation of 8 dB was chosen [3].

Short-term fading is represented by Clark's model for Rayleigh fading [4]. Rayleigh fading rates are generally set in the simulator by means of walk or vehicle speed (depending on used environment).

The detailed description of radio channel model is possible to find in another article in this issue.

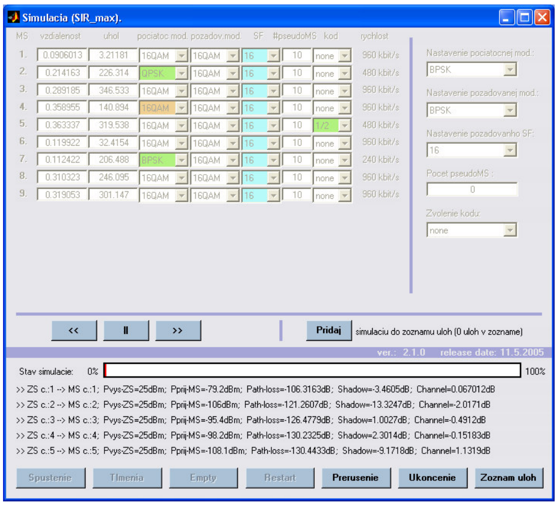

Fig. 2. The first page of GUI

The 2nd step. The position of base stations is calculated by appropriate algorithm (one is for microcell model and the other for macrocell one). Positions of the traced mobile stations (MS_T) are random, but required distance from BS is kept. Traced MS_T are highlighted on the figure 3. All traced MS_T use OVSF codes (Orthogonal Variable Spreading Factor) from the same code tree branch [5]. Other MSs use different OVFS codes (they are grey on the figure 3) and represent the intracell interference [6].

In the 2nd step there are calculated all distances among active network elements. These values are important later for the simulation, when interference level is calculated [6].

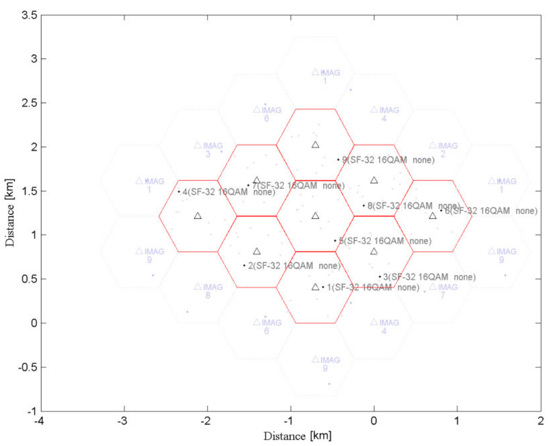

Fig. 3. Model of mobile radio network

3. SIMULATIONS

The 4th step. The process of simulation is based on algorithm used in UMTS system. This algorithm includes three power adaptation loops [1]:

- Open loop power control.
- Closed loop power control.
- Outer loop power control.

Open and Closed loops are termed together as Inner loop. In our simulation program each of these power control loops can be modified in various ways.

The main purpose of the open loop power control is to set up the initial output power for the MS transmitter to a specific value. This loop is used when MS is accessing the network [1]. There is a Dedicated Physical Control Channel DPCCH [1], which serves for this purpose. The MS measures the received power of DPCCH. The output power of transmitter has to be sufficient to overcome the various signal loss in uplink. We suppose that path-loss and shadow fading in downlink is the same as in uplink.

The initial transmitter output power P_{MS_out} is given:

$$P_{MS\_out} \geq P_{MS\_in} \qquad (4)$$

where P_{MS_in} is measured received power of DCCH, and is given:

$$P_{MS\_in} = P_{BS\_out} - L_{sun} \qquad (5)$$

where L_{sum} is the sum of all losses in the radio channel (downlink). The MS and the BS antenna gains, other losses and power reserve have to be also respected.

Closed loop power control adjusts actual transmit power of MS (P_{MS_out}) according to the selected applicable mathematic formulas. Basic algorithm of closed loop power control compares actual signal to interference ratio SIR (SIR_A) and required SIR (SIR_R):

$$\text{if } SIR_A > SIR_R \Rightarrow P_{MS\_out} - \Delta P \qquad (6)$$
$$\text{if } SIR_A < SIR_R \Rightarrow P_{MS\_out} + \Delta P \qquad (7)$$

where ΔP is the power control step. The power control step size can take several predefined values (e.g.: 0.5, 1, 1.5 or 2 dB) [1]. The value of SIR_R varies according to type of modulation (Table 2).

Modulation	SIR_R (BER = 10^{-3})
BPSK	9 dB
QPSK	11 dB
16QAM	21dB
64QAM	24dB

Tab. 2. Required SIR_R of modulations [3]

The outer loop power control adjusts value of SIR_R for used modulation. It is used to maintain the quality of communication at the level of bearer service quality requirement, while using as low power as possible [1]. At the start of the simulation the SIR_R is equal to the appropriate value from table 2, but the algorithm of outer power adaptation loop compares BER_A and BER_R and sets the value respectively:

$$\text{if } BER_A > BER_R \Rightarrow SIR_R + \Delta SIR \quad (8)$$
$$\text{if } BER_A < BER_R \Rightarrow SIR_R - \Delta SIR \quad (9)$$

where ΔSIR is SIR control step of predefined size (e.g. 1dB). The BER_R is set to 10^{-3} for speech services and 10^{-6} for data based services in our model.

The primary advantage of our model is its possibility to change modulation together with power adaptation. The UMTS system uses QPSK modulation, which has very good performance in all environments specified by 3GPP. We expected that also other higher-order modulations might be used successfully in WCDMA mobile radio networks, but with several limitations (for example the most important is SIR_A). The benefit of high-order modulation using is the higher data rate and better OVSF code utilization (Table 3) [7].

	Theoretical maximum data rate [kbit/s]						
Mod. \ SF	4	8	16	32	64	128	256
BPSK	1024	512	256	128	64	32	16
QPSK	2048	1024	512	256	128	64	32
16QAM	4096	2048	1024	512	256	128	64
64QAM	6144	4096	2048	1024	512	256	128

Tab. 3. Maximum data rate

On the figure 4 there are shown two basic adaptation algorithms, where hybrid adaptation of modulation and power is used:

- Modulation is assigned in Outer loop power control (figure 4a).
- Modulation is assigned in Closed loop power control (figure 4b).

We defined radio frame duration according to 3GPP specifications (3G UMTS). One radio frame is 10 ms long and contains of 15 time slots [1]. The MS output power is adjusted every slot (0.667 ms) and modulation scheme can be changed every 10ms in the first algorithm:

$$\text{if } SIR_A > SIR_R \Rightarrow \begin{array}{c}\text{set appropriate}\\ \text{modulation scheme}\end{array} \quad (10)$$

The second algorithm offers changes of modulation scheme and the MS output power adjustment in each slot (in 0.667 ms steps). The assignment of modulation in the Inner loop power control can cause an oscillation of switching between modulations, when boundary conditions are reached. For restriction of this behavior, the second algorithm has to include particular mechanism.

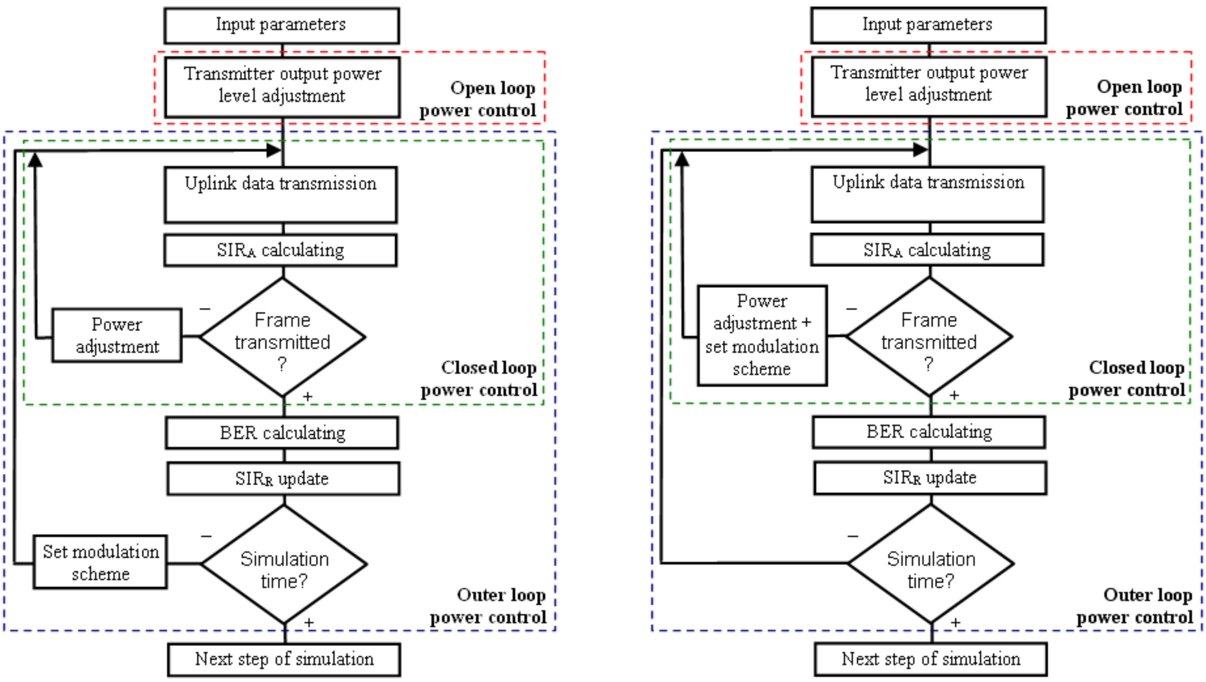

Fig. 4. Two basic types of used algorithm: a) modulation is assigned in outer loop power control b) modulation is assigned in closed loop power control

The block "Uplink data transmission" (Fig. 4) covers simplified radio transmission chain (inspired by 3GPP UMTS specifications). All elements of transmission chain (also the model of radio channel) were created in Simulink environment. Simulink environment makes possible to observe dynamic changes of transmitted signal. List of block elements:

- Data source (Bernoulli Random Binary Generator).
- PN code and OVFS code generator [8].
- Convolutional encoder and decoder.
- Spreading, scrambling and modulation blocks [5].
- Rake receiver (four fingers) [5].
- Error rate calculation and measurement block.
- Model of radio channel (6 signal paths).

4. RESULTS PROCESSING

The 5th step. Graphs of several important variables can be shown during and at the end of the simulation: SIR_R, SIR_A, P_{BS_rec}, BER, type of modulation and data rate. The bounds of channel coherence time T_{coh} and the end of transmission of UMTS frames are highlighted (Fig. 5). Graphs are generated for each traced mobile station independently or the time dependency of the same variables can be shown in one graph.

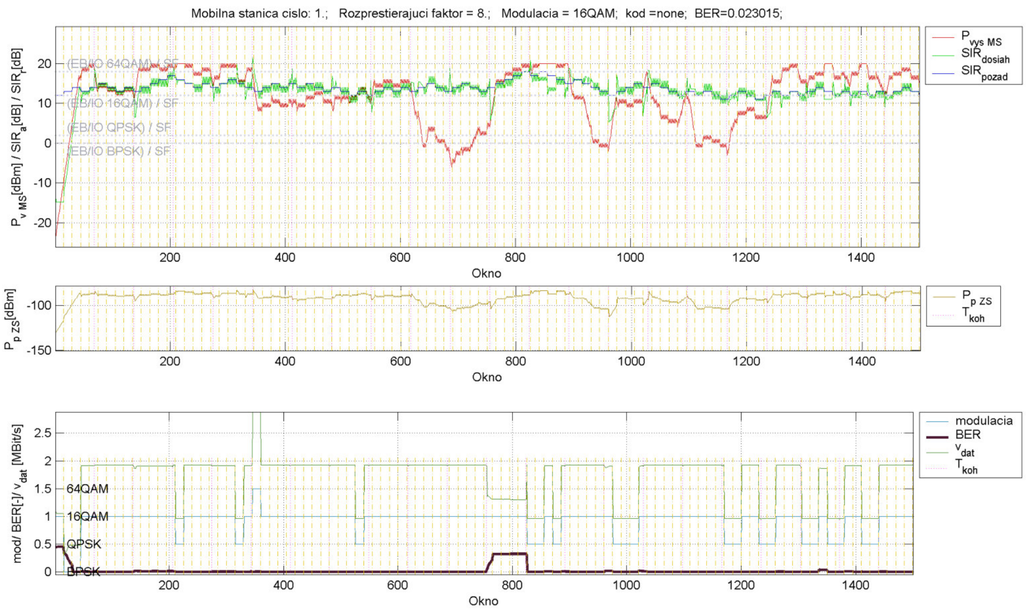

Fig. 5. Example of an output graph for one traced mobile station

At the end of the simulation (t_{sim} elapsed) BER, FER, average data rate R_t, average data rate with regard to satisfied user R_{mod}, probability of outage P_{out} and probability of outage with regard to satisfied user P_{out_su} is calculated for each traced mobile station (Fig. 4).

Average data rate R_t:

$$R_t = \frac{\sum N_b}{t_{sim}}, \qquad (11)$$

where N_b is the number of correct transferred bits and t_{sim} is duration of simulation. Average data rate with regard to satisfied user (modified data rate) R_{mod}:

$$R_{\text{mod}} = \frac{\sum N_{b\_\text{mod}}}{t_{sim}}, \qquad (12)$$

where N_{b_mod} is the number of correct transferred bits except time interval t_{err}:

$$t_{err} = \sum_{i=1}^{M} t_{0,042\_i}, \qquad (13)$$

where M is number of the time intervals $t_{0,042\_i}$. Duration of the time interval $t_{0,042\_i}$ is $0,042 t_{sim}$ and BER in it is higher than required BER_{req}.

Time interval $t_{0,042\_i}$ is set by satisfied user requirement [3], by which the user is satisfied if he is not interrupted. The session is interrupted if BER > BER_{req} during time longer than t_{dropp}

$$t_{dropp} = \max\left(5, \frac{10}{R_t \cdot \text{BER}_{\text{req}}}\right)[\text{sec}] \qquad (14)$$

We supposed (for real time services) mean session duration 120 sec [3], so t_{dropp} is 5/120 = 0.042 %.

Probability of outage P_{out}:

$$P_{out} = \frac{\sum t_{BER > BERreq}}{t_{sim}}, \qquad (14)$$

where $t_{BER>BERr}$ is time interval where BER is higher than required BER_{req}.

Finally, probability of outage with regard to satisfied user P_{out_su}:

$$P_{out\_su} = \frac{t_{err}}{t_{sim}}. \qquad (15)$$

Simulation time: 999.7 ms.
Channel model: Outdoor to Indoor and Pedestrian Test Environmet... ch.B

II.B alg. SIR-Frame-based (Forced Soft) (SIR_A) .

MS	SF	MODs	MODm	KOD	BER [-]	FER [-]	Rt [kb/s]	Rmod [kb/s]	dif [kb/s]	P_out	Pout_su
1.	32	16QAM	16QAM	none	1.0076e-002	9.0000e-002	459.46540	438.87853	20.58687	0.07994	0.04742
2.	32	QPSK	16QAM	none	1.2823e-002	5.0000e-002	223.53700	223.53700	0.00000	0.04471	0.00000
3.	32	QPSK	QPSK	none	1.3238e-005	3.0000e-002	227.80719	227.80719	0.00000	0.02032	0.00000
4.	32	QPSK	16QAM	none	4.6697e-005	3.0000e-002	297.12132	297.12132	0.00000	0.00813	0.00000
5.	32	BPSK	16QAM	none	5.6246e-002	4.4000e-001	168.68855	134.94063	33.74792	0.42271	0.33939
6.	32	16QAM	16QAM	none	8.8827e-003	1.2000e-001	448.34157	424.84559	23.49598	0.08806	0.05081
7.	32	16QAM	16QAM	none	9.4394e-003	1.6000e-001	454.04808	406.55716	47.49091	0.12871	0.09552
8.	32	QPSK	16QAM	none	3.5742e-003	9.0000e-002	225.76586	218.92250	6.84335	0.09077	0.06097
9.	32	QPSK	QPSK	none	5.0534e-005	1.0000e-002	360.31972	360.31972	0.00000	0.00881	0.00000
SUM	-	-	-	-	-	-	318.34385	303.65885	14.68500	0.09913	0.06601

Fig. 6. Example of table with simulation results

5. CONCLUSION

Simulation model of the mobile radio network is used for proposal of better algorithms for link adaptation process than is available in WCDMA networks now. Fast power adaptation process is essential for correct functionality of this kind of mobile networks. Optimization of the link adaptation algorithms together with possibility to change modulation (BPSK, QPSK, 16QAM and 64QAM) brings more efficient data transmission and saves system resources [10]. Algorithms can be designed to reach as high data rate as possible in simulated conditions or data rate is input parameter for each user and algorithm is designed to reach maximum users in each cell (combination OVSF code and modulation).

Making changes in algorithms is easy and graphs of various variables make possible to simulate and compare behaviors of each traced element of simulated mobile networks in different conditions (state of radio channel, speed of mobile user etc.).

Acknowledgement

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