Paper

Modelling of CDMA systems

Piotr Gajewski and Jarosław Krygier

Abstract — This paper describes a model of a system with wideband CDMA that is a proposal of user access for future UMTS. This model has been implemented using OPNET tool. The model enables network architecture, radio interface, mobile station motion, call generation, signalling, etc. The examples of simulation results of call and handover blocking probability are also presented in this paper.

Keywords — OPNET, DS-CDMA, cellular systems, network simulation.

1. Introduction

The commercial proliferation of cellular voice and limited data service has created a great demand for mobile communication and computing. Third generation systems, such as UMTS in Europe, CDMA-2000 in US and TTA I in Korea, are based on combination of integrated fixed and wireless mobile services that form a global personal communication network [11]. Each of them is proposed as a IMT-2000 (international mobile telecommunication) system. Wideband code division multiple-access (WCDMA) has been chosen as the basic radio access technology for such systems. Comparing to the narrow-band CDMA, the WCDMA radio interface offers significant improvement, especially for higher rate and multimedia services.

Recently, different components of CDMA systems as well as theirs behaviour and particular performance have been described in many papers [1, 2, 10, 11]. Most of them have used simulation models as a basic way to resolve many complex problems. There are two approaches to simulate the overall performance of DS-WCDMA system [4]. One is a combined approach where the link level and cellular network level simulations are combined into one package. Another approach is to separate the link and system level simulations to reduce the complexity of the simulators. In both cases specialised simulators are needed.

In this paper, the model of WCDMA system with direct sequence spreading scheme is presented. It was elaborated using MIL-3 OPNET radio-modeller tool. The model consists of network architecture, radio interface, subscribes mobility, traffic generation, channel allocation, handover, signalling, etc. It enables the comprehensive analysis of the influence of many WCDMA system components on the quality of service (QoS). Results of such analysis can be utilised to solve the questions concerning base stations deployment in a given area, optimisation of channel allocation and handover procedures in urban and suburban environments, etc.

2. Simulation tool characteristic

Taking into account the growing interest for WCDMA system modelling, we decided to elaborate our model using MIL-3 OPNET. Optimised network engineering tool (OPNET) is an example of commercial software package that is capable of simulation of large communications networks with detailed protocol modelling and performance analysis. It consists of specialised modules for creation of network and node models, elaboration of models processing, simulation executing, and simulation data analysis as well as output data edition.

OPNET simulation bases on a discrete-event modelling approach, where the progression of the model over simulation time is decomposed into separated time points in which the system state can change.

3. Network architecture

The cellular network is a complex system that includes architecture, procedures and services both on user, network and management levels. The network architecture consists of the mobile stations (MS), base stations (BS), base station controllers (BSC), mobile switching centres (MSC), management centre, and exterior public switching telecommunication network (PSTN) (Fig. 1). These elements are interconnected by transmission links – wired or wireless.

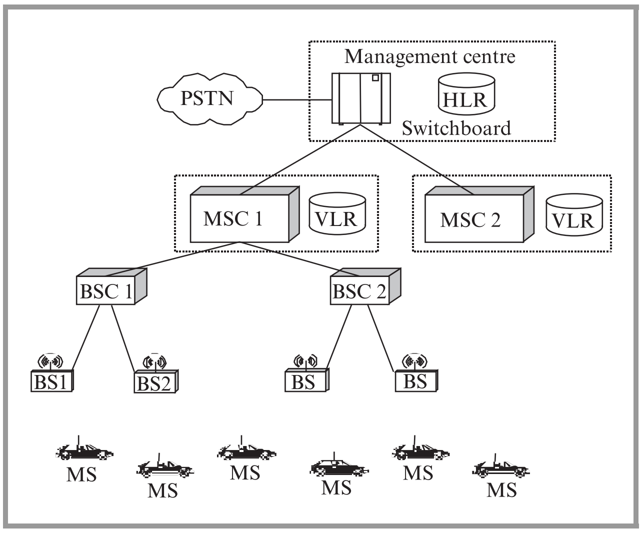

Fig. 1. Cellular network architecture.

The radio link is the duplex communication channel from the base station to each mobile user and from user to base station.

4. Simulation model structure

General simulation model structure is displayed in Fig. 2. The model consists of five basic levels:

- input data setting,
- net (configuration, cell sizes, dimension of switching regions),
- user's behaviour (generation of calls, mobility, soft handover effect),
- call service (allocation and reallocation of channels, transfers, supervising of connections),
- collecting simulation effects.

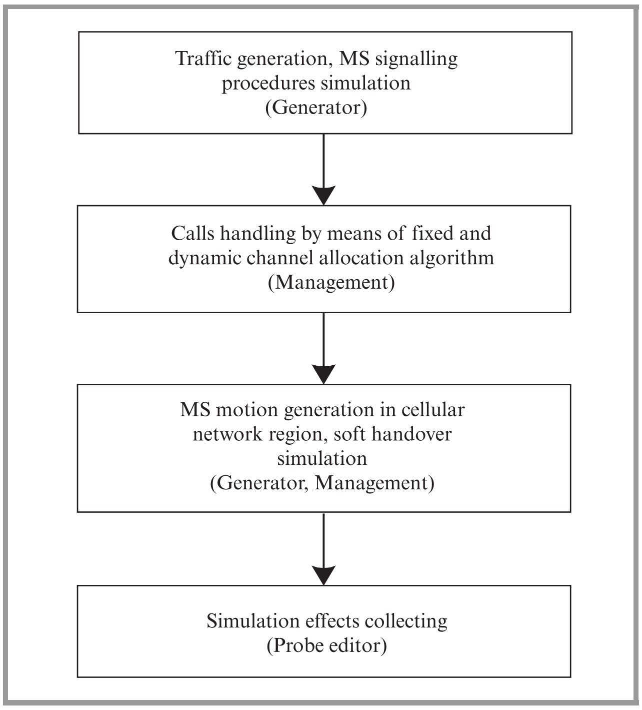

Fig. 2. Simulation program structure.

The following parameters can be determined in the input data set:

- mean number of mobile station users for one cell,
- general amount of duplex channels for speaking,
- amount of fixed and dynamic channels for one cell,
- number of channels reserved for switched calls,
- channel holding mean time,
- mean interval time for successive calls coming from any free subscriber,
- probability of outer subscriber's inaccessibility,
- mean value and standard deviation of mobile velocity,
- cellular network modulus and switching region radius.

5. Real-time services traffic model

In the real-time services case the traffic model is a traditional birth-death process. Speech users arrive to the system according to simple Poisson process with intensity λ:

$$P(k,t) = \frac{(\lambda t)^k}{k!} e^{-\lambda t},$$

where: $P(k,t)$ – probability that there k calls take place during period of time $(0,t)$, t – time, k – number of calls during period of time $(0,t)$.

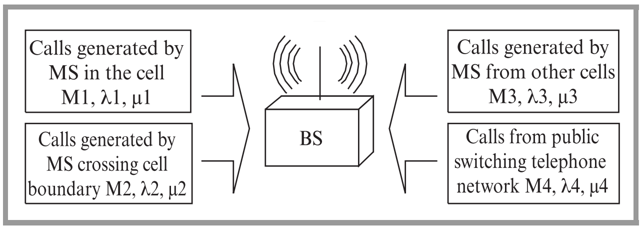

Fig. 3. Types of calls directed to the cell (M1, 2, 3, 4 – number of users, λ1, 2, 3, 4 – calls intensity, μ1, 2, 3, 4 – service intensity).

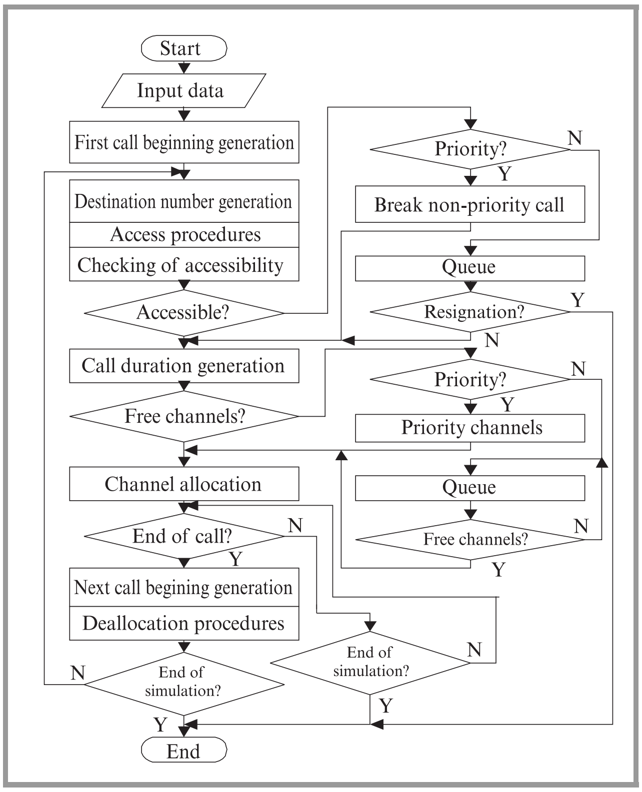

Fig. 4. Traffic generation and calls service algorithm.

The call generators as well as communications traffic procedures were elaborated in presented model. The traffic in each cell consists of four kinds of calls (Fig. 3). They are:

- intra-cell calls generated by MS in the cell that are directed to the other MS in the same cell,
- calls incoming from other cells,
- calls incoming from PSTN,
- calls handovered from neighbouring cells.

Number of users M, calls intensity λ and service intensity μ are the basic parameters of each part of traffic that should be serviced in each cell. Call duration and time between calls are exponential random variables that finally define the traffic intensity generated in cell. Moreover, we assume a number of call priorities in our model.
In case of inter-call, two traffic channels have to be assigned for it. In the other cases, one channel is used for connection. Simplified algorithm of mobile traffic generation is shown in Fig. 4.
It should be noticed, that a call handovered from neighbouring cell has the highest level of priority and that a call generated by PSTN is directed to the cell in which MS is being in a given moment.
The remaining, non real-time services are not taken into consideration in this paper since their models are being elaborated. Channel allocation and deallocation model mention in Fig. 4 is based on modified dynamic channel MDCA allocation policy described in [6].

6. Mobility model

Mobility modelling is involved with the analysis aspects related to location management (location area planning, paging strategies), radio resource management (access technique, channel allocation strategies, handover rates), network signalling loads and propagation (handover decision). Different purposes require different types of mobility models. In vehicular outdoor area, there should be used different mobility model then in indoor environment. Let assume outdoor pedestrian environment, where deployment area is a regular grid of streets and buildings. In this connection the mobile station mobility can be model as fourth-directional motion with the same probability each one. There can be defined motion attributes such as: mean mobile velocity, mean way length, mean time to point of direction change and PDF of applied random variables. The mobile's position is updated every specific time that is dependent on its speed. In such points, remaining call time is checked according to drawn channel holding time.

7. Mobility management model

Mobility management contains two components: handover management and location management [11]. Handover management enables the network to maintain a user's connection as the mobile station to move and change its access point to the network. Handover management includes

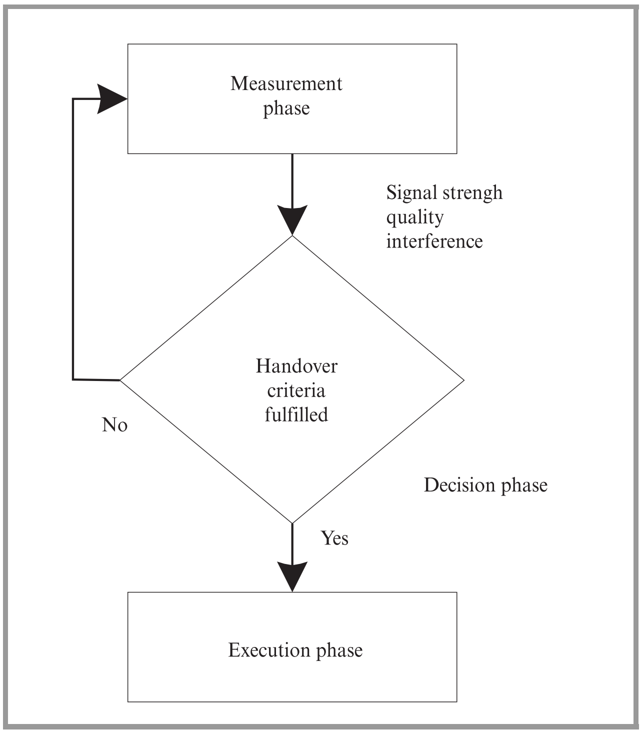

Fig. 5. Handover phases.

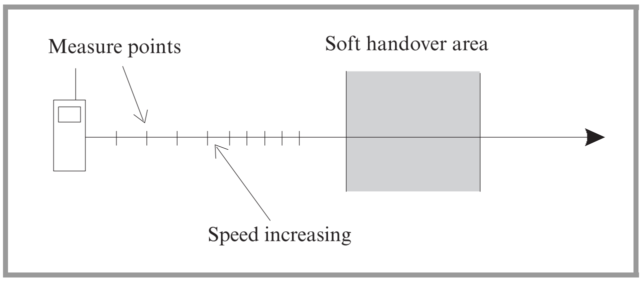

Fig. 6. Measure points and soft handover area.

two conditions intercell and intracell handover. Let assume that we deal with omni directional antennas and only intercell handover will be taken into consideration. A handover procedure in such case can be divided into three phases: measurement, decision and execution phase, as illustrated in Fig. 5 [4].
Due to specific properties of CDMA system connected with the possibility of using the same frequency band in the whole network, the soft handover is often utilised. It means that two or more BS supervise the quality of radio connection in case of the mobile station moving inside the so-called soft handover range and choose the most convenient base station through which useful information exchange is carried on. In wideband CDMA system with asymmetric traffic, at least the following parameters can be identified:

- distance attenuation,
- uplink interference,
- downlink interference.

Built handover model takes into account distance attenuation. The same measures as in mobility model are needed to gather information for a handover decision in such situation. The averaging period for the measurement results depends on the mobile speed and is updated more frequently when the speed of the mobile increases (Fig. 6).

Location management is a two-stage process that enables the network to discover the current attachment point of the mobile user for call delivery. The thirst stage is location registration (location update) and the second one is call delivery. In the location update stage the mobile periodically notifies the network of its place of stay.

The model of location management consists of the way of location area LA as well as base stations distinguishing. All indispensable data are stored in home location register (HLR) and visitor location registers (VLR). BSs, BSCs, MSCs and PLMN are addressed by means of their nametags specified directly in network editor.

They are next converted on ISDN numbers as follows: 10000000*PLMN nametag + 100000*MSC nametag + + 1000*BSC nametag + BS nametag.

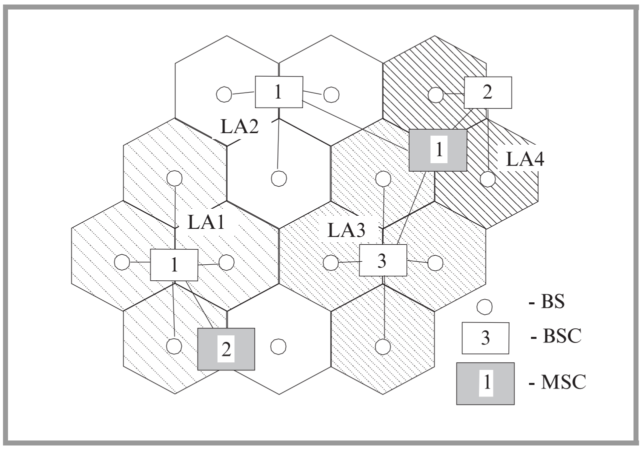

Fig. 7. Modelled location areas.

So the last three digits represent adequate BS, next four digits – BSC and MSC and the last one – PLMN. For example 10302001 is a number of BS with nametag amount to 1, which is connected to BSC with nametag amount to 2, while MSC nametag is amount to 3. VLRs are connected to MSCs, so the number of MSC unambiguously identifies them. Whole network is divided into location areas that are recognised by the BSC number. Such situation is shown in Fig. 7. Therefore, 10201000 is an address of the LA1 location area, 10101000 – LA2, 10103000 – LA3 and 10102000 – LA4.

Home location register is a some kind of data base storing information about registered MSs. On the beginning of the simulation there is created configuration file describing each mobile station. During simulation there are created working files representing VLRs. They are updated according to mobility and handover model.

8. Example of signalling model

When the user of a MS originates a call, he first enters the called number and possibly additional information with the MS keypad and then depresses the send button. Figure 8

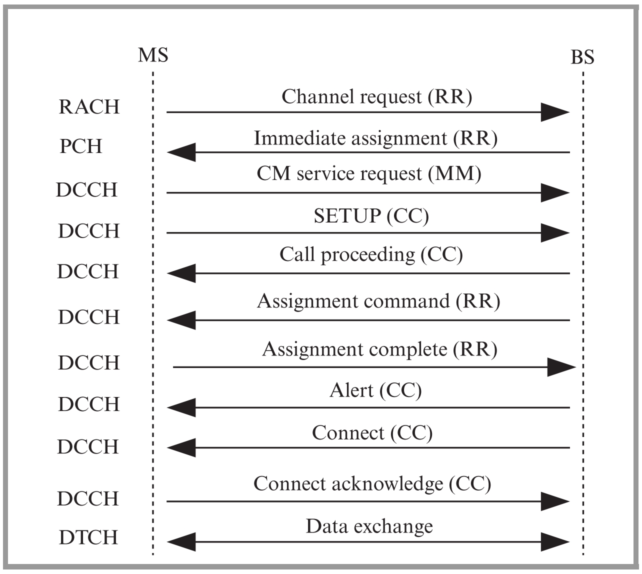

Fig. 8. Signalling for the set-up of the call originated by MS.

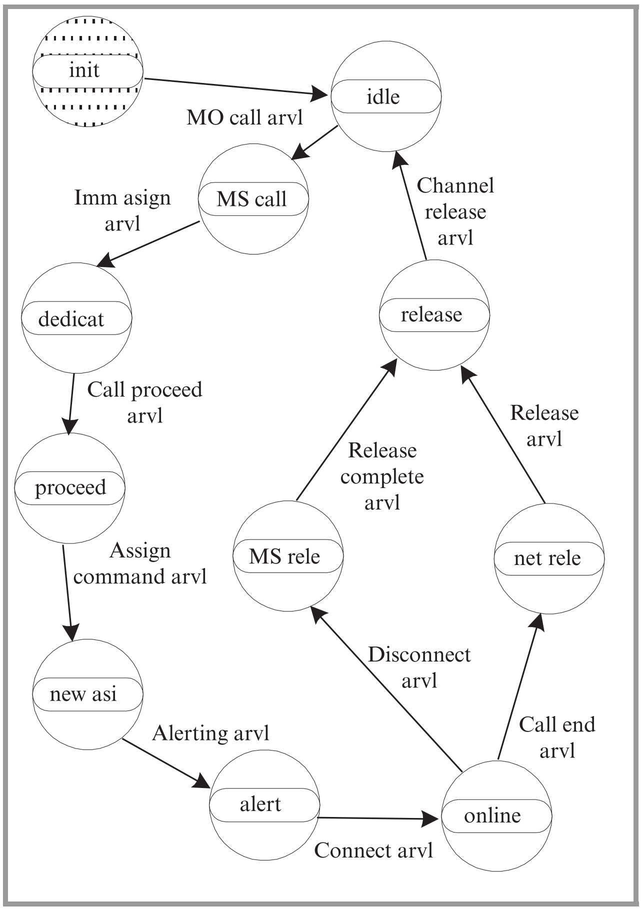

Fig. 9. Example signalling procedure process.

shows the signalling for the set-up of the call which is used in the model.
The abbreviations in Fig. 8 means logical channels: RACH – random access channel, PCH – paging channel, DCCH – dedicated control channel, DTCH – dedicated traffic channel and adequate protocols: RR – radio resource management, MM – mobility management, CC – connection control management.
Such signalling procedures are modelled by their implementation in processes form. The process states and conditional transitions are shown in Fig. 9.
After call beginning, each mobile station model starts its work from "idle" state. Its state is being changed when interrupt named "MO call arv" appears. In the MS call state, mobile is being waited for "Immediate assignment" procedure directed from the network (Fig. 9). After receiving this interrupt it is being moved to dedicated state and send "Request" and "Set-up" procedures to the network. Such situation last as long as the model achieve of "online" state. It means the MS has established the connection.
The MS model state is being came back to the "idle" state after receiving "Call end arvl" or "Disconnect arvl" interrupt. There are two ways of coming back, depending on disconnecting manner (disconnected by MS or by the network). It should be mentioned that this is only a part of whole signalling process model.

9. Example simulation results

The simulation results were presented in [2, 5, 12]. Figures 10 ÷ 12 show the example results of investigation of quality of service as a call and handover blocking probability versus mean traffic intensity in the cell for different method of channel allocation, for different values of handover region.
On the basis of presented results of simulation we can notice that:

- usage of the MDCA significantly decreases call blocking probability comparing to fixed channel allocation method,
- handover area decrease causes the call blocking probability increase,
- MS velocity decrease causes the call blocking probability increase.

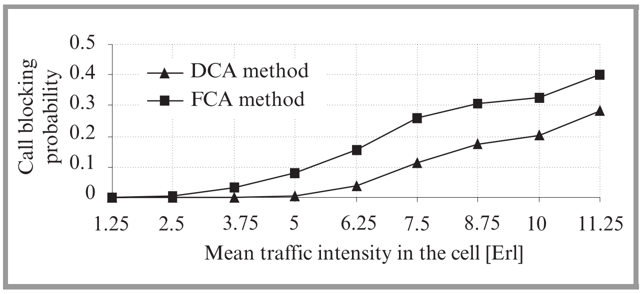

Fig. 10. Call blocking probability versus mean traffic intensity in the cell for two methods of channel allocation.

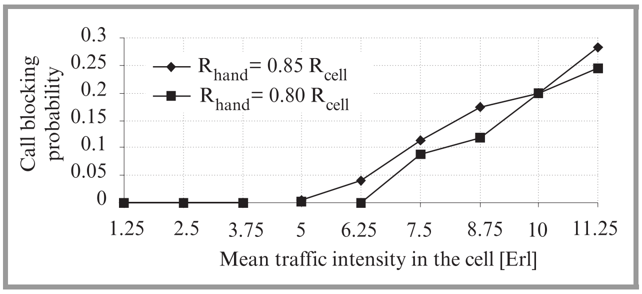

Fig. 11. Call blocking probability versus mean traffic intensity in the cell for two handover radiuses.

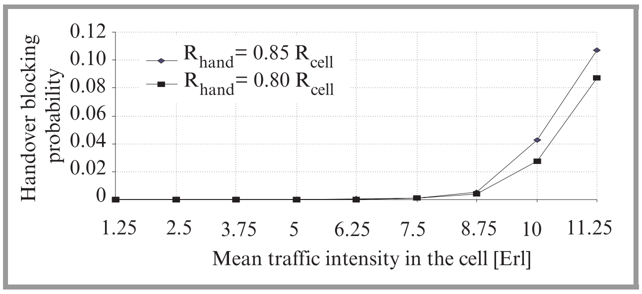

Fig. 12. Handover blocking probability versus mean traffic intensity in the cell for two handover regions.

10. Conclusions

The model of WCDMA system has been elaborated by authors for investigations and planning of universal mobile telecommunications system proposed as IMT-2000 standard. System behaviour was modelled as a set of procedures in OPNET C language. The system properties for modified DCA and soft handover as well as for various methods of channelisation and spreading was investigated. The obtained results confirmed that model is useful and flexible. Model is open and can be extended on the other procedures used in UMTS parts, for example on the information privacy methods.

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