Mathematical model based software design for simulation of 4G wireless protocols

E. Kačerginskis, L. Narbutaitė

***Abstract*—** Implementation of new generation wireless networks is a challenging task that requires detail network planning and protocol level simulation in order to foresee possible problems and save investment and operation costs. Existing simulation platforms are very complex, expensive and vendor specific. It requires special knowledge for modifying and adopting protocols. This article presents Authors' designed mathematical model and model based software that allows universal packet level simulation of different wireless protocols. Software provides graphical user interface that allows to describe simulated protocol, control simulation, analyze time flow diagrams and graphical QoS results for different access and connectivity network nodes. In addition to article presents mobile WiMAX handover simulation example and provides QoS calculation results that prove the importance of network simulation prior to implementing real network in order to be able to foresee possible bottlenecks and plan required overheads.

***Keywords*—** 4G, handover, LTE, protocol simulation, WiMAX.

I. Introduction

New generation broadband wireless technologies are entering telecommunication market providing new opportunities for service providers that need to meet growing demand for mobility data throughput. Such technologies like WiMAX or LTE are able to accept these challenges, but require very accurate network planning and simulation in order to be able to provide mobile services with expected QoS and save implementation time and investment.

Simulations must be performed in as detail as possible manner, ensuring that all protocol level parameters are evaluated and that possible network growth is estimated, otherwise lack of planning may lead to continuous network reconstruction activities, loss of customers and revenue.

Simulation requires either very expensive or inflexible software either programmable environment which requires special knowledge and professional programming service. For example such software as OPNET [1] is very expensive for professional 4G simulation usage and despite it has many features, it requires special knowledge in order to be able to adopt required protocol. Other simulation software solutions either don't provide convenient user interface either don't allow to perform deep protocol level simulation [2]–[3].

E. Kačerginskis is with the Department of Telecommunications, Kaunas University of Technology, Studentų str. 50-452, Kaunas, LT-51368 Lithuania (e-mail: eugenijus@ntservice.eu)

L. Narbutaitė is with the Department of Telecommunications, Kaunas University of Technology, Studentų str. 50-452, Kaunas, LT-51368 Lithuania (e-mail: lina.narbutaite@ktu.lt

First part of the paper covers mathematical model, its structure and working algorithms. Cutouts from formalized mathematical specification are provided.

In addition to, article describes software graphical interface and functionality, which allow service providers seamlessly simulating QoS characteristics for different protocols in wireless channel and other network nodes and analyzing time flow diagrams for each data exchange between network elements. It allows evaluating such characteristics as latency, generated uplink and downlink data throughputs, message exchange and processing times, delays in network nodes.

Finally paper provides WiMAX handover protocol description example, QoS simulation results and analysis.

II. Imitative Mathematical Model

A. Model concept

Simulation software is implemented on imitative mathematical model basis. Imitative mathematical modeling allows simulating real time behavior of any environment consisting from separate elements. In mathematical models these elements are called aggregates [4]. From telecommunications point of view these aggregates are network nodes and communication channels.

Each aggregate in mathematical model performs specified tasks based on information of input and output signals. Aggregate principal specification is provided in Fig. 1.

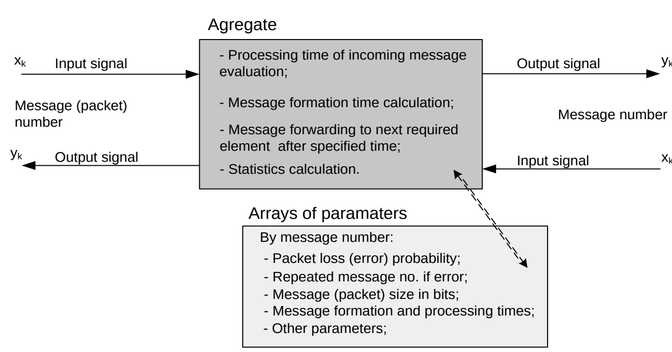


Fig. 1 aggregate specification

Model requires specifying internal and external signal flows and signal exchange between system aggregates. Such structure and mathematical formalization allows specifying each system node independently and requires common external signals to trigger each over.

Aggregate approach based simulation tracks simulation time independently from system clock and allows calculating time based parameters such as data throughput in bits per second.

B. Aggregative specification

For 4th generation wireless network simulation we use 5 aggregates that represent major network elements: Gen. – represent user generator, that initiates simulated procedure; MS – mobile station; Channel – wireless channel with loss probabilities; BS – base station, representing multiple base stations, participating in message exchange; ASN/CSN – connectivity network, representing Operator's core network elements.

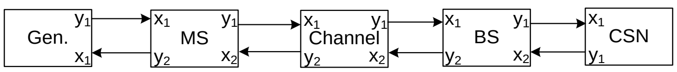


Fig. 2 model structure

Modeling time starts after initial trigger, usually from additional aggregate called generator. In wireless simulation, this element serves as user generator, simulating start of the packet exchange procedure. Time flow example of message exchange between wireless network elements is provided in Fig. 3.

Aggregate Generator sends signal to MS and starts procedure simulation. MS accepts message and keeps message arrival time. MS forms and transmits message to wireless channel with packet loss probability. Channel either transmits message to BS aggregate (probability 1-P1) either imitates packet loss in wireless channel (P1) and adds additional delay. In case of error, message is transferred back to mobile station for repeating. Number 0 is transferred as signal exchange parameter instead of next message number.

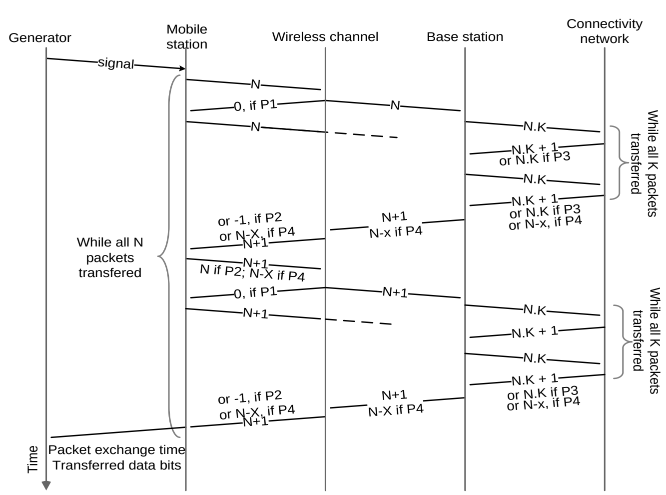


Fig. 3 message exchange cycle time flow diagram

If there are no errors in wireless channel message is transferred to base station aggregate. Respectively BS starts message exchange cycle with CSN that is required by messages parameters from MS. CSN after each message provides answer message that includes number of next message which must be sent from BS to CSN. There is probability that either message is lost in CSN either received negative answer (P3). In such case message is repeated from message number that is received in CSN answer message.

After successful cycle of message exchange between base station and connectivity network, CSN with last message sends message number that must be sent next from MS. With probability (1-P4) higher number is transferred to BS. It means that MS received positive answer from connectivity network and may send next message of simulated protocol. In case there is negative answer (P4) from CSN, it sends lower message number to BS. It means that MS must repeat previous message exchange. BS saves corresponding message number and after receiving next packet from MS, will compare saved and new message number parameters. BS sends next message request to wireless channel. In case of packet loss in channel (P2) it sends negative message number. After receiving next message number MS starts second iteration of message exchange cycle. In case negative or zero message number is received, MS repeats corresponding message.

When all message exchange cycles are completed successfully, MS sends signal to generator for calculating statistics such as cumulative message exchange cycle time and transferred data bits.

C. Formal mathematical specification

Formal mathematical specification is widely used for simulation of real time systems. Similar to algorithm, mathematical specification allows manually tracking simulation logic. Despite it is less visual, this type of specification provides ability to track system time and calculate system parameters for each time moment. It also is easily adoptable to programmable environment.

Specification requires mathematically formalize each aggregate describing input/output signal sets, internal and external event sets, discrete and continues state sets and transition operators sets [4]. This paper provides comments and simplified examples of formal mathematical specification for two aggregates – mobile station and wireless channel. Two specifications allow investigating signal exchange between aggregators in mathematical model.

Mobile station

1. *Input signal set.* Input signal sets describe signals that are received from other aggregators and initialize switching operators to perform calculations.

$$X = \{x_1, x_2\} \quad (1)$$

where:

x_1 – start signal is received from generator;

x_2 – number of next packet, that must be sent from MS.

2. *Output signal set.* Output signals sets describe signals that are sent to other generators in order to transfer information or initiate procedures.

$$Y = \{y_1, y_2\}$$
$$y_1 = (packet\_no)$$
$$y_2 = (service\_time, received\_data) \quad (2)$$

where:
packet_no – packet number that is sent between MS and BS;
service_time – packet aggregation time;
received_data – received data bits.

3. *External event set*. External events set describes events, that are initiated by input signals.

$$E' = \{e_1', e_2'\} \quad (3)$$

where:
e_1' – received message from generator;
e_2' – received message from wireless channel.

4. *Internal event set*. Internal events describe events, that are result of aggregator's internal operations and depends from management flows.

$$E'' = \{e_1''\} \quad (4)$$

where: e_1'' - message is formed and ready to be sent.

5. *Transition rates*. Transition rates between the system states specify parameters that control internal events.

$$e_1'' \rightarrow \{\xi_{2j}\} \quad (5)$$

where ξ_{2j} – message sending from MS to BS formation time;

6. *Discrete state components*. Discrete state components describe different parameters that are calculated for each time moment.

$$v(t_m) = \{packet\_no.packet\_lenght(t_m), \max(t_m), arrival\_time(t_m), last\_sent(t_m)\} \quad (6)$$

where:
packet_no.paket_lenght(t_m) – processed message (packet_no) lenght in bits;
max (t_m) – maximal number of messages for current procedure;
arraival_time (t_m) – moment, when MS iniates message sending;
last_sent (t_m) – last sent message number.

7. *Continuous state components*. Continuous state components describe time moments of internal events.

$$Z_v(t_m) = \{\omega(e_1'', t_m)\} \quad (7)$$

where:
$\omega(e_1'', t_m)$ – moment when message is ready to be sent to channel;

8. *Initiate state*. Initiate state describes initiate state parameters – not required for mobile station aggregate.

9. *Starting state*. Starting state parameters described at item 6 and 7. In this case, MS aggregate has no parameters at zero time moment.

$$z(t_0) = \{0,0,0,0;\ 0\} \quad (8)$$

10. *Transition operators*. Transition operators perform calculations, define next time moments for other operators and define output signals for other aggregators. Transition operators are active only if their event time is active.

$H(e_1')$ – received signal to start operation:

$$\max(t_{m+1}) = MAX\{packet\_no\} \quad (9)$$
$$\omega(e_1'', t_{m+1}) = t_m + \xi_{2\,packet\_no} \quad (10)$$
$$arrival\_time(t_{m+1}) = t_m \quad (11)$$

$H(e_1'')$ – messages are ready to be sent to channel:

$$\omega(e_1'', t_{m+1}) = \infty \quad (12)$$
$$last\_sent(t_{m+1}) = packet\_no(t_m) \quad (13)$$

$G(e_1'')$: (messages are ready to be sent to channel)

$$y_1 = packet\_no(t_m) \quad (14)$$

$H(e_2')$ – received message from channel:

If there are unsent messages (next_packet ≤ max)

$$\omega(e_2', t_{m+1}\} = \infty \quad (15)$$
$$packet\_no(t_{m+1}) = next\_packet \quad (16)$$
$$received\_data(t_{m+1}) = received\_data(t_m) + packet\_no.packet.lenght(t_m) \quad (17)$$
$$\omega(e_1'', t_{m+1}) = t_m + \xi_{2\,packet\_no} \quad (18)$$

Else (all messages are sent successfully)

$$process\_time(t_{m+1}) = t_m - arrival\_time(t_m) \quad (19)$$
$$packet\_no(t_{m+1}) = 1 \quad (20)$$
$$y2 = process\_time, received\_data) \quad (21)$$

Result that is given by transition operators' equations:

- (9) total number of messages that must be sent;
- (10) time, when message forming is finished, in this case it defines time moment for switching operator $H(e_1'')$;
- (11) saves messages arrival time;
- (12) time moment, when message will be sent to channel in other iteration, is not defined;
- (13) saves number of last sent packet;
- (14) signal with parameters are sent to channel;
- (15) time moment when next message will be received from channel is not defined;
- (16) next message number (this article present only simplified example, when there are no errors in wireless channels, otherwise it should be specified to repeat same message number as described in aggregative specification)
- (17) received data calculation for simulation results;
- (18) time moment when next message will be sent to channel

- (19) processing time calculation for simulation results;
- (20) resets packet number for next iteration (all current iteration packets are already sent)
- (21 returns signal to generator about finished message exchange)

Wireless channel

1. *Input signal set:*

$$X = \{x_1, x_2\}$$
$$x_1 = (packet\_no) \qquad (22)$$
$$x_2 = (next\_packet)$$

where:
packet_nr – number of packet that is received from MS;
next_packet – number of next packet, that must be sent from MS to BS, number is received from BS;

2. *Output signal set:*

$$Y = \{y_1, y_2\}$$
$$y_1 = (packet\_no) \qquad (23)$$
$$y_1 = (service\_time, received\_data)$$

where:
packet_no – packet number that is sent to BS;
next_packet – number of next packet, that must be sent from MS to BS, number is received from BS.

3. *External event set*:

$$E' = \{e_1', e_2'\} \qquad (24)$$

where:
e_1' – received message from MS;
e_2' – received message from BS.

4. *Internal event set*:

$$E'' = \{e_1'', e_2'', e_3'', e_4''\} \qquad (25)$$

where:
e_1□ - message is ready (formed) to be sent to BS;
e_2□ - message is ready (formaed) to MS;
e_3□ - error simulation is ended for message that was sent from MS;
e_4□ - error simulation is ended for message that was sent from MS.

5. *Transition rates.*

$$e_1'' \to \{\xi_{3j}\}$$
$$e_2'' \to \{\xi_{4j}\} \qquad (26)$$
$$e_3'' \to \{\xi_{5j}\}$$
$$e_4'' \to \{\xi_{6j}\}$$

where:
ξ_{3j} – message to BS formation time;
ξ_{3j} – message to MS formation time;
ξ_{3j} – error simulation time (MS side error);
ξ_{3j} – error simulation time (BS side error).

6. *Discrete state components*. Wireless channel doesn't include discrete state components, because wireless channel aggregate controls timing and doesn't perform calculations.

$$\nu(t_m) = \{\} \qquad (27)$$

7. *Continuous state components*.

$$Z_\nu(t_m) = \{\omega(e_1'', t_m), \omega(e_2'', t_m), \omega(e_3'', t_m), \omega(e_4'', t_m)\} \qquad (28)$$

where:
$\omega(e_1$□$,t_m)$ – time when message is ready to be sent to BS;
$\omega(e_1$□$,t_m)$ – time when message is ready to be sent to MS;
$\omega(e_1$□$,t_m)$ – end moment of error simulation from MS side;
$\omega(e_1$□$,t_m)$ – end moment of error simulation from BS side;

8. *Initiate state parameters*.
P_1 – error from MS side probability;
P_2 – error from BS side probability.

9. *Starting state*.

$$z(t_0) = \{0,0,0,0\} \qquad (29)$$

10. *Transition operators*.

$H(e_1')$ – received message from MS:
If not error from MS (not P_1)
$$\omega(e_1'', t_{m+1}) = t_m + \xi_{3\,packet\_no} \qquad (30)$$
Else (P_1)
$$\omega(e_3'', t_{m+1}) = t_m + \xi_{5\,packet\_no} \qquad (31)$$
$H(e_2')$ – received message from BS:
If not error from MS (not P_2)
$$\omega(e_2'', t_{m+1}) = t_m + \xi_{4\,next\_packet}$$
Else (P_2)
$$\omega(e_4'', t_{m+1}) = t_m + \xi_{6\,next\_packet}$$

$H(e_1$□$)$ – message are ready to be sent BS:
$$\omega(e_1'', t_{m+1}) = \infty \qquad (32)$$
$G(e_1$□$)$ – signal to BS aggregator:
$$y_1 = packet\_no(t_m) \qquad (34)$$
$H(e_2$□$)$ – message is ready to be sent to MS
$$\omega(e_1'', t_{m+1}) = \infty \qquad (35)$$
$G(e_2$□$)$ – signal to MS aggregator:
$$y_2 = next\_packet(t_m)$$
$H(e_3$□$)$ – error simulation from MS side is finished:
$$\omega(e_1'', t_{m+1}) = t_m + \xi_{3\,packet\_no} \qquad (36)$$
$H(e_4$□$)$ – error simulation from BS side is finished:
$$\omega(e_2'', t_{m+1}) = t_m + \xi_{4\,next\_packet} \qquad (37)$$

Similar specification is required for every aggregate in the mathematical model. For complex systems mathematical formalization can be quite difficult process that requires special knowledge, but such formalization provides flexibility and eases simulation automation process when implemented in programmable environment.

III. Simulation Software

Using described mathematical model, authors designed software for 4th generation wireless network simulation for Windows® platform. Delphi 7 platform was used as programming environment.

Initially software was intended to simulate registration and handover procedures of mobile WiMAX. Flexible mathematical model and designed graphical interface allowed utilizing software for simulation of almost any wireless protocol (WiFi, UMTS, LTE, etc) based on "hand-shaking" algorithms.

Software does not require any special mathematical knowledge. All input parameters of simulated protocol can be entered using graphical interface. Because of implemented mathematical model, the accuracy of the software depends only on the reliability of entered parameters.

A. *Designed software GUI description*

Graphical user interface (GUI) of designed software is provided in Fig. 4.

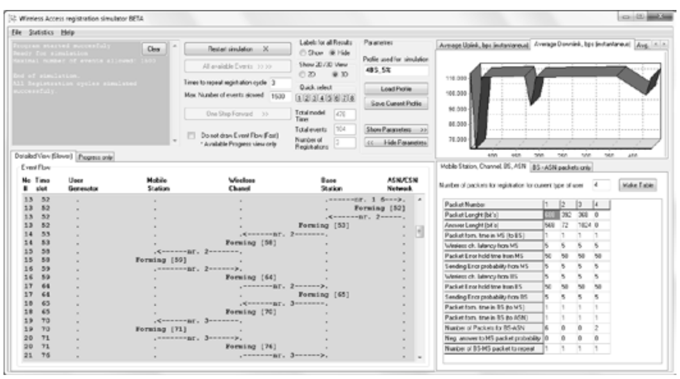


Fig. 4 software graphical interface

From functionality point of view interface can be divided into 4 major sections: simulation control section; parameter input section; simulation time flow section; section of graphical results.

B. *Simulation control section*

Simulation control section (Fig. 5) is designed for easy simulation management. It provides status window, where users can see simulation state and where can find additional explanations or required corrections for entered parameters. Window can be cleared any time in order to have actual information.

This section allows:

- start, restart or run simulation step by step;
- select how many times simulate protocol before final result;
- select maximal number of event allowed in simulation;
- monitor simulation cycles (modeling virtual time, number of simulated cycles, number of total events);
- Load or save configurations;
- Control viewing options of the results (enable labels, switch between 2D and 3D);
- Select simulation progress visualization type – time flow diagram for step by step simulation and analysis; progress bar for rapid simulation;
- Quick switch between displayed results.

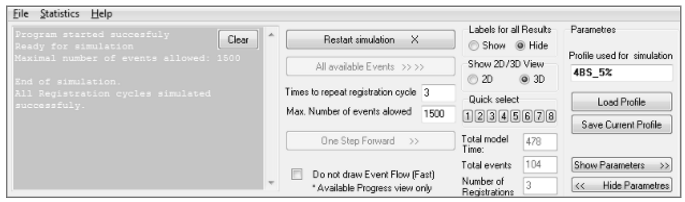


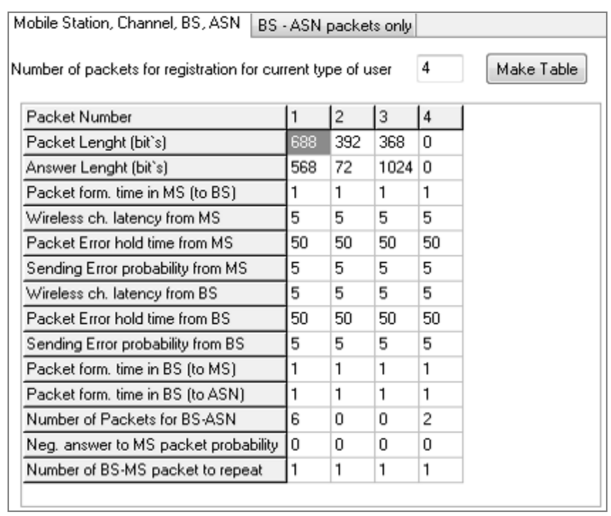
Fig. 5 simulation control section

C. *Parameter input section*

This section allows software users to describe protocol parameters if there is no available predefined profile or if it requires additional customization.

Parameter input section is designed as two configurable matrixes. User can enter the number of messages/packets that are used in for some protocol or part of it. Software forms table for each packet where users can enter parameters, such as packet length, latency of network nodes, error probabilities in wireless channel, packet processing or formation time, etc. For each MS-BS message system allows to select a number of BS-CSN messages, and to describe parameters for each.

This flexible and limitation free approach allows users easy customizing their investigation to achieve most detail results.



Packet Number	1	2	3	4
Packet Lenght (bit`s)	688	392	368	0
Answer Lenght (bit`s)	568	72	1024	0
Packet form. time in MS (to BS)	1	1	1	1
Wireless ch. latency from MS	5	5	5	5
Packet Error hold time from MS	50	50	50	50
Sending Error probability from MS	5	5	5	5
Wireless ch. latency from BS	5	5	5	5
Packet Error hold time from BS	50	50	50	50
Sending Error probability from BS	5	5	5	5
Packet form. time in BS (to MS)	1	1	1	1
Packet form. time in BS (to ASN)	1	1	1	1
Number of Packets for BS-ASN	6	0	0	2
Neg. answer to MS packet probability	0	0	0	0
Number of BS-MS packet to repeat	1	1	1	1

Fig. 6 parameter input section

D. *Simulation time flow section*

Simulation time flow diagram section provides graphical view of simulated protocol in time domain. This is one of the most important designed software's function, because allows users to monitor simulation in real time and analyze each message or packet. It allows verifying simulation accuracy.

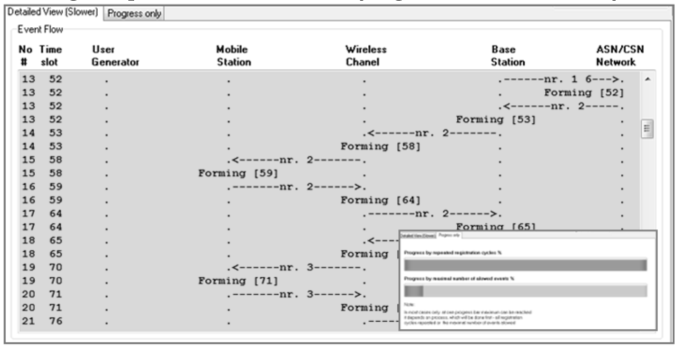


Fig. 7 simulation time flow diagram

In addition to, system allows disabling time flow diagrams for best performance when rapid calculations are necessary. In such case users can monitor simulation progress in progress bar view.

E. Section of graphical results

This section provides graphical results of simulation. There are many statistical results that can be analyzed in 2 and 3 dimensional views.

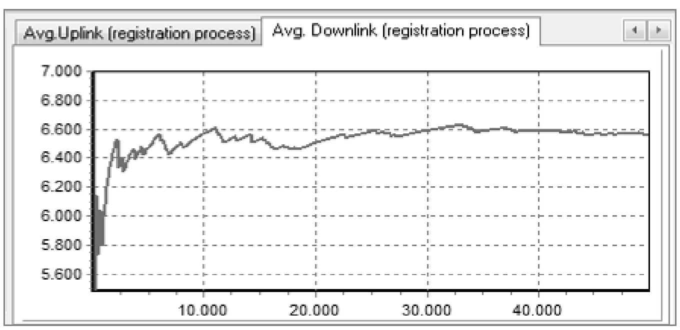


Fig. 8 view of graphical results

Software provides following statistics:

- complete message exchange time for each simulated cycle;
- average message exchange time;
- average uplink and downlink throughput (real time);
- average processing time in BS/MS;
- average delay in BS/CSN connection;
- average uplink and downlink throughput (full cycle).

IV. WiMAX handover QoS simulation

This paper section provides mobile WiMAX handover procedure description and simulation example. The objective of simulation is to evaluate what traffic is generated by mobile stations when performing handover procedure and what latency can be expected.

A. Handover procedure description

Handover procedures are performed when mobile station is in coverage of more than one base station sector and when neighbor sectors offer higher signal level than serving base station. This is implemented in order to achieve seamless connectivity for mobile network users as illustrated in Fig. 9.

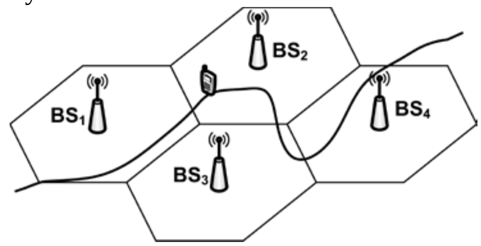


Fig. 9 handover between base stations [8]

Despite main purpose of the handover was to serve mobile users, handover also effects all users that are in overlapping areas of two adjacent base station sectors, where signal strength of few base stations has similar levels. Fig. 10 illustrates simplified example of overlapping coverage of two base stations.

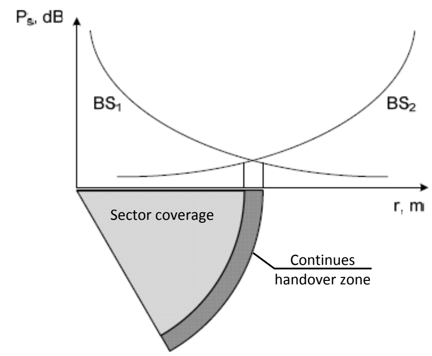


Fig. 10 overlapping coverage of two base stations

This mobility management logic leads to continues handover procedures generated my mobile stations that are in the area of sector edges. Overlapping sectors are common in wireless network implementation and continues handovers can be observed in earlier generation networks, such as GSM and UMTS. In opposition to GSM/UMTS, where signaling channels are used for mobility management, 4^{th} generation technologies share same channels for data and for signaling information. This can lead to decreased network capacity in multiple user environments.

Mobile WiMAX handover procedure consists of a number of messages that must be transferred between MS, BS and core network.

These messages are transferred in air interface as defined in air interface specification [5]:

- RNG-REQ (368 bits) – range request;
- RNG-RSP – range response (1024bits);
- MOB_MSHO-REQ (472 bits (1 neighbor BS), 584 bits (2 BS); 688 bits (3 BS)) – MS handover request;
- MOB_BSHO-RSP (464 bits (1 BS), 512 bits (2 BS), 568 (3 BS)) – BS handover response;
- MOB_HO-IND (392 bits) – handover indication;

- Fast_Ranging_IE (72 bits) – exchange of radio paramaters.

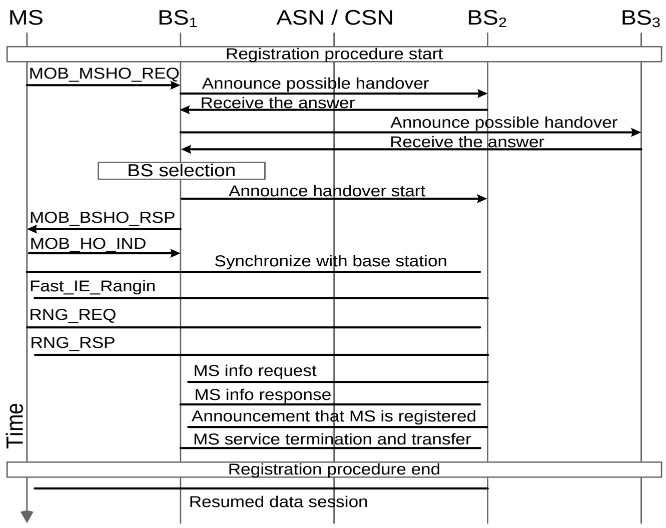


Fig. 11 handover time flow diagram [5]

B. *Handover QoS simulation*

WiMAX standard described parameters were used for simulation. It was assumed following timing parameters:

- message processing time in network nodes is 1 ms;
- wireless channel latency 5 ms;
- channel latency in packet loss case – 50 ms;
- packet loss probabilities – 0,2,5,10 perc. respectively for each simulation.

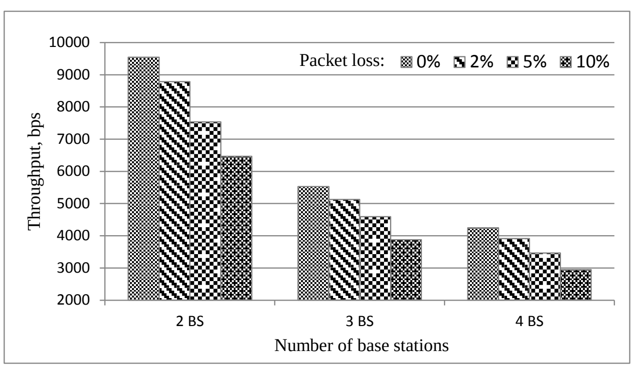


Fig. 12 Handover downlink throughput

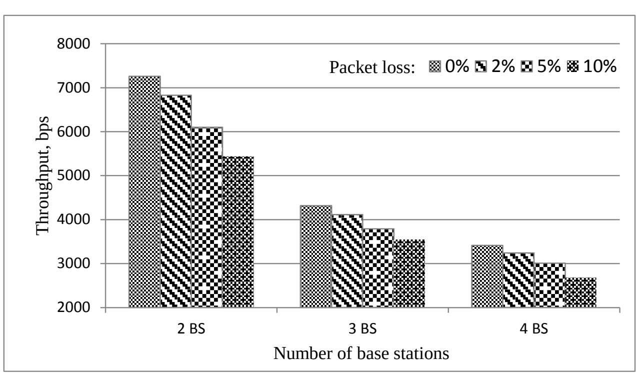


Fig. 13 Handover uplink throughput

Each simulation cycle (with different error probabilities) was performed 1000 times. Accumulated simulation results are provided in Fig. 12-13.

Handover procedure of one user can create from 3 to 9.5 kbps data throughput for downlink and from 2.5 to 7 kbps for uplink. [6] This is not significant load from perspective of one user, but it can cause sector capacity decrease in multiple user environments.

For evaluation of handover impact in multiple user networks it's required to perform basic network planning. First step is to estimate coverage (radius) of one base station and to calculate sector capacity. These tasks were automated using Authors' designed software package that includes standard radio propagation mathematical models and tools for calculating WiMAX data throughput dependencies from modulation schemes.

Following parameters were used for calculation:

Table I. Base station air interface parameters

Parameter	*Value*
Model	SUI-A (Urban environment)
Tx power	23 dBm
BS antenna gain	28 dBi
MS antenna gain	9 dBi
Frequency	3500 MHz
Channel size	10 MHz
Downlink/uplink ratio	80/20%

Fig. 14 illustrates signal strength dependence from distance from base station. In addition to it shows modulation rates that can be used and certain distances.

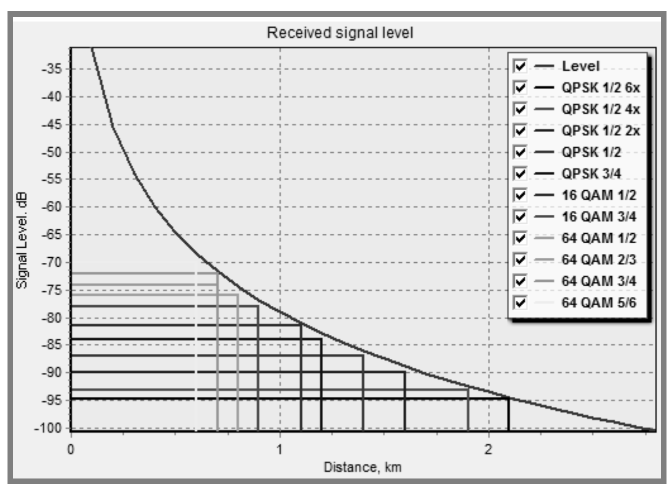
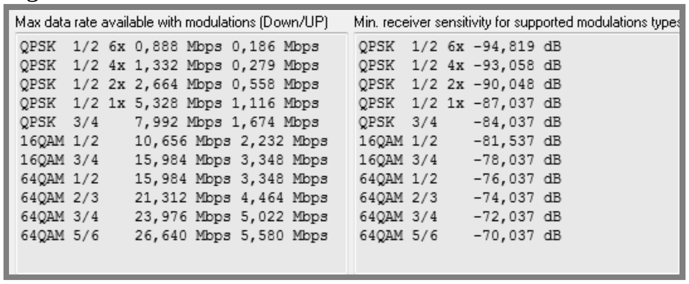


Fig. 14 signal level and modulations

The higher is the distance from base station the lower rate modulation can be utilized for communications – attenuation in wireless path decreases signal to noise ratio. Assuming Stanford University Interim (SUI) radio propagation mathematical model, in urban network environment highest rate modulation can be used only in radius of 600 to 800 meters. Lowest rate modulation (QPSK1/2) operational distance is about 1800 meters.

Data throughput dependencies from modulation and modulation dependencies from signal level are provided in Fig. 15.



Max data rate available with modulations (Down/UP)	Min. receiver sensitivity for supported modulations types
QPSK 1/2 6x 0,888 Mbps 0,186 Mbps	QPSK 1/2 6x -94,819 dB
QPSK 1/2 4x 1,332 Mbps 0,279 Mbps	QPSK 1/2 4x -93,058 dB
QPSK 1/2 2x 2,664 Mbps 0,558 Mbps	QPSK 1/2 2x -90,048 dB
QPSK 1/2 1x 5,328 Mbps 1,116 Mbps	QPSK 1/2 1x -87,037 dB
QPSK 3/4 7,992 Mbps 1,674 Mbps	QPSK 3/4 -84,037 dB
16QAM 1/2 10,656 Mbps 2,232 Mbps	16QAM 1/2 -81,537 dB
16QAM 3/4 15,984 Mbps 3,348 Mbps	16QAM 3/4 -78,037 dB
64QAM 1/2 15,984 Mbps 3,348 Mbps	64QAM 1/2 -76,037 dB
64QAM 2/3 21,312 Mbps 4,464 Mbps	64QAM 2/3 -74,037 dB
64QAM 3/4 23,976 Mbps 5,022 Mbps	64QAM 3/4 -72,037 dB
64QAM 5/6 26,640 Mbps 5,580 Mbps	64QAM 5/6 -70,037 dB

Fig. 15 signal level and modulations

Second step for handover impact evaluation in multiple user environments is estimation of area between overlapping sectors. These tasks can be performed using Authors' designed coverage calculator (out of scope of this article). It performs automatic geometry analysis, calculates number of users that share overlapping areas and allows automatic multiplication for estimating total generated data loads. Fig. 16 illustrates base station distribution when optimal network coverage is implemented (no gaps in coverage, standard frequency planning).

There are four wireless sector types in such base station distribution:

1) no overlapping areas;
2) overlapping with one base station;
3) overlapping with two base stations;
4) overlapping with three base stations.

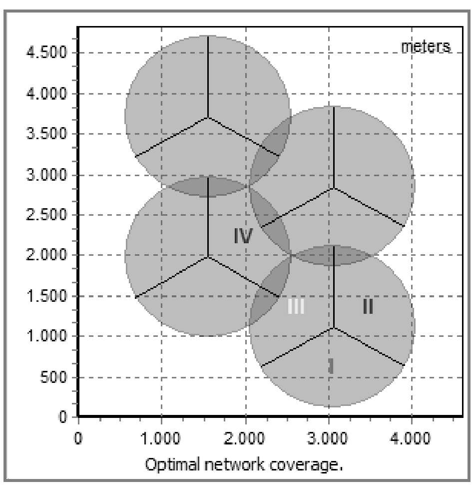


Fig. 16 base station distribution

1-3 sector types can be found at network edges. Sector type 4 is most probable in major area of network coverage. Fig. 17-18 provides handover generated data throughput results for different types of sectors (different number of overlapping sectors) and different number of users, assuming:

- 2 perc. packet loss probability;
- 50 perc. of mobile stations performs handover at sector edges;
- 25 to 75 mobile stations in sector;
- 15 perc. overlap of adjacent sectors.

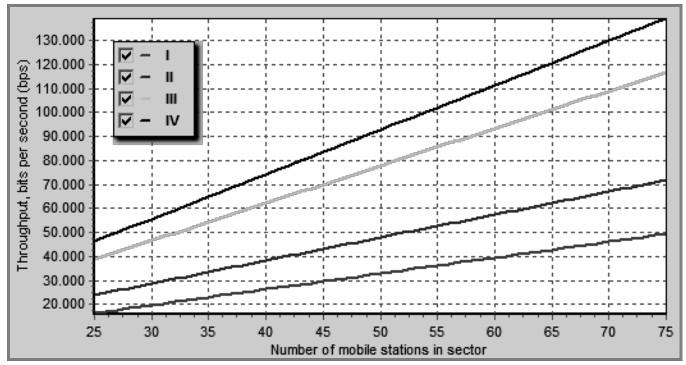


Fig. 17 Handover throughput for multiple MS (downlink)

In multiple user environment handover in type 4 sector can create data load from 50 to 130 kbps for downlink and from 40 to 120 kbps for uplink.

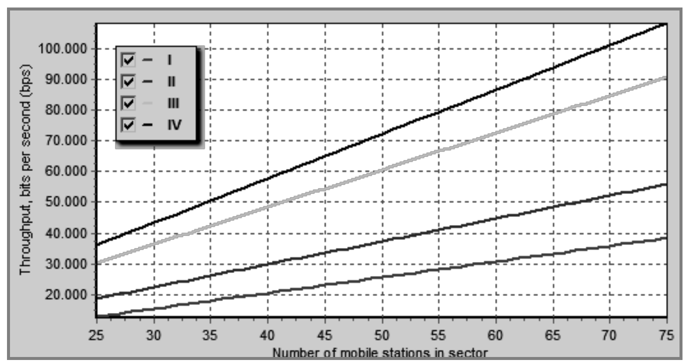


Fig. 18 Handover throughput for multiple MS (uplink)

These data loads are not significant talking about overal network capacity of 4 generation networks, but when lowest rate modulation QPSK1/2 is used, what is most probably at sector edges, handover can decrease sector capacity by 20% for downlink and 40% for uplink.

Calculation illustrates handover procedure impact when optimal network coverage is implemented. In real world environment optimal network planning is hardly achievable. Network providers can face situations where whole areas of few base stations overlap. This situation is possible in areas where additional base stations are implemented for higher network capacity. Such practice is widely used in many wireless networks, i.e. GSM/UMTS.

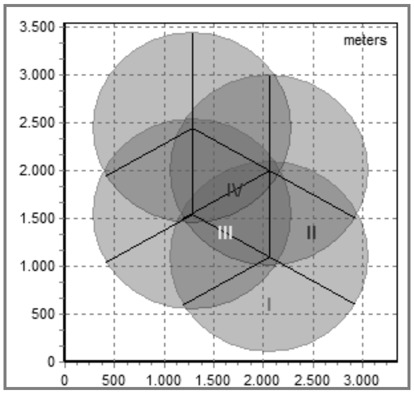


Fig. 19 base station distribution in high density networks

In such case, it's necessary to plan additional overhead when implementing mobile WiMAX network in order to compensate handover overhead impact and avoid inconsistences at sector edges.

Handover time (latency) simulation results are provided in Fig. 20. Handover time differs from 92 to 189 ms [6]. Such latency can cause instability or interruption in real time service such as VoIP. [7]

Accurate mobility management solution selection or additional signaling implementation can be utilized in order to implement successful services [9]-[10].

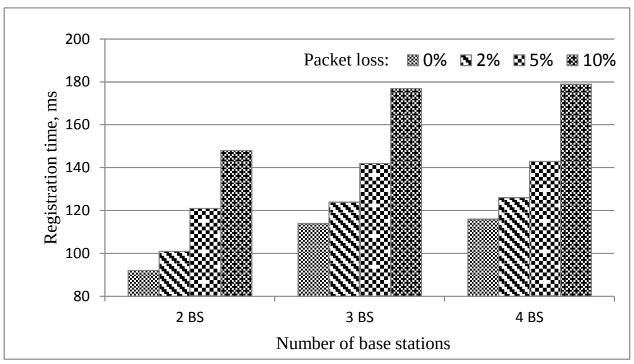


Fig. 19 Handover throughput for multiple MS

Conclusion

Implementation of new generation wireless networks is a complex task, which requires evaluation of many factors in order to be able to provide planned services. Network simulation allows implementation team to foresee possible issues and accordingly plan solutions. Mathematical imitative model based simulation allows to perform these tasks in most detail protocol level manner.

Authors designed software implements mathematical model and provides graphical user interface for easy and flexible operation that requires no special knowledge.

Mobile WiMAX simulation shows that even such regular procedure as handover can cause significant impact on sector capacity and real time service. Advanced simulation allows network providers to foresee possible bottlenecks and plan required overhead in order to avoid possible QoS disadvantages.

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