A Simulation Framework for the Evaluation of Scenarios and Algorithms for Common Radio Resource Management

Andreas Pillekeit
University of Duisburg-Essen
ICB, Research Group Systems Modelling
+49201183-4558
Andreas.Pillekeit@icb.uni-due.de

Bruno Müller-Clostermann
University of Duisburg-Essen
ICB, Research Group Systems Modelling
+49201183-3915
bmc@icb.uni-due.de

ABSTRACT

We present a simulation framework based on a systematic view on Common Radio Resource Management (CRRM). It enables a cost-benefit investigation of different CRRM algorithms and architectures. Different scenarios, centralized as well as decentralized ones, can be clearly defined based on five standard components, namely the radio access system, the environment, the user equipment, the CRRM information manager, and the CRRM decider. The costs and time consumption of CRRM operations are taken into account via chargeable messages. The clarity of the model enables an efficient investigation of CRRM algorithms based on optimization theory, game theory, physical models and other methods. The resulting framework has been implemented as a hybrid simulation model using OMNeT++. A convenient and straightforward integration of different wireless network technologies and user service demands is also supported; models for UMTS and GSM/EGPRS are already integrated. The scope of the proposed framework is demonstrated by the evaluation of realistic scenarios.

Categories and Subject Descriptors

C.4 PERFORMANCE OF SYSTEMS
C.2.1 Network Architecture and Design

General Terms

Algorithms, Management, Performance

Keywords

CRRM, JRRM, MxRRM, heterogeneous networks, always best connected networks.

1. INTRODUCTION

Due to the rapid development in the field of wireless network technologies today it is very common that different radio access technologies (RAT) coexist at the same time and the same location. Mobile devices are often able to make use of these different RATs. Since one RAT alone is not able to meet the diverse QoS requirements of mobile users seamless intersystem roaming will be an important feature of future wireless networks. Besides, mobile providers need time to deploy their next generation mobile networks. Recent results of several working groups show that a capacity gain of the combined wireless systems compared to disjunct systems can be exploited [1-9] and different approaches are suggested for this purpose. In [4] Fuzzy Neural algorithms, in [7] force based algorithms and in [9] algorithms based on cooperative games are investigated. A mixture of capacity surfaces together with a fuzzy approach is used in [3]. In [5] and [6] Markov Chains are used to evaluate CRRM scenarios. These papers mostly focus on the possible algorithms and capacity gains and neglect the expenses needed to achieve this gain. The question whether the algorithms work best in a centralized or decentralized CRRM environment and their sensitivity with respect to aged information (e.g. measurement times, old data in the database) is also not investigated. Our proposed framework enables a cost-benefit analysis of different CRRM algorithms and architectures. Not only steady state results but also the transient behavior can be evaluated. Different system architectures can be readily defined based on standard components. We derived these standard components based on a systematic view of CRRM therefore our model covers many different possible applications of CRRM algorithms.

The outline of the paper is as follows. In section two we review properties of CRRM scenarios and derive a model framework for the definition of scenarios for the evaluation of CRRM algorithms. Section three describes the translation of this model framework into a hybrid simulation model and section four shows possible applications of the developed simulator based on this model. Section five concludes the paper.

2. MODEL FRAMEWORK

2.1 Common properties of CRRM Scenarios

Here we give a brief summary of the systematic view on the logical structure of CRRM scenarios given in [10]. The logical structure of all different radio access technologies (RAT) can be described as follows: A user equipment (UE) is in wireless contact with a radio access system (RAS) which on its side is in contact with the core network (CN). A radio access network (RAN) can consist of several RAS. Each RAS has an autonomous local radio resource management (RRM) entity residing either close to the wireless transceiver or partly in the CN. The RAS can be a satellite in case of a WGAN, a cell layer in case of a cellular WWAN system like UMTS, or even a single cell in case of a WLAN system or other UE in case of ad-hoc networks. The Quality of Service (QoS) capabilities of the RAS have a major impact on the offered QoS of the whole network. This is due to

SIMUTools 2009, Rome, Italy
Copyright 2009 ICST, ISBN 978-963-9799-45-5…$5.00.

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2009.5594
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5594

the generally unreliable wireless connection, which is improved by diverse backward and forward error correction techniques. Each RAS uses different layer 1 and 2 protocols (ISO/OSI model) with unique QoS-features depending on the used RAT. The core network's main tasks are authentication, authorization, accounting (AAA), gateway support to other networks and QoS-brokerage. It can be assumed that the core network is capable to support the QoS-features of the connected RAS by design.

CRRM is accomplished by specialized entities which are in contact with local RRMs. The set of resources which shall be commonly managed define three different CRRM levels. Level A is the common management of the resources of different RAS of one RAT of one provider. Level B is the common management of the resources of different RAT of one provider. Level C is the common management of the resources belonging to several providers. The CRRM entities may reside on the side of the network or within the UE.

The CRRM can be seen as a control mechanism with a closed-loop control. It contains four phases. The first phase of the control loop is to measure the state of the network, the state of the UE and the QoS offered for existing services. There exist different measuring points on the network side (e.g. base station, radio network controller, mobile switching center) and on the side of the UE according to the measured parameters. The second phase distributes collected information to the CRRM entities. In the third phase the CRRM decision entities try to find the optimal solution under the given constraints. The solution has to account for the dynamics of the system (e.g. low blocking, low dropping, and only few ping pong handovers in the face of service and mobility changes) and for offering sufficient QoS to all active services and for minimizing costs as well. Many different factors can play a role in this decision [10, 12]. After evaluation of the available information several actions are possible to meet the defined goals of the CRRM. The execution of these actions defines the fourth phase. One of the most important options is to handover the UE to another RAS (intersystem handover, vertical handover). Other options are to adapt the offered QoS according to each service's QoS profile or to change the RRM-properties of the RAS (e.g. allocate additional frequency bands). The CRRM decision entities need suitable protocols and communication connections to initiate the execution of their commands. In our model framework we generally assume such protocols and connections are already available.

2.2 Scenario Model Framework

The proposed model framework covers a wide variety of different CRRM scenarios. The aim of the model is to represent the fundamental structure of wireless systems of different RATs. Additionally the model is also able to associate costs with CRRM operations. This enables us to assess CRRM algorithms in different scenarios not only by their ability to achieve good QoS for services but also by their expenses. The model components are environment (ENV), user equipment (UE), radio access system (RAS), CRRM information manager (CRRM-IM) and CRRM decider (CRRM-D). These components exchange messages over free and chargeable connections. The layout of these connections is based on real world communication paths depending on the scenario. A message from a network side CRRM-IM needs to use a RAS connection to reach the UE component. Each transport of a message over chargeable connections causes costs and time delays. All CRRM relevant information and commands are sent by this kind of connections. On the other side free connections are used to transport system inherent information not related to CRRM activities. CRRM components are only able to use chargeable connections. The layout of these connections is different for distributed, hierarchical or centralized scenarios. Figure 1 shows a scheme of all possible component connections.

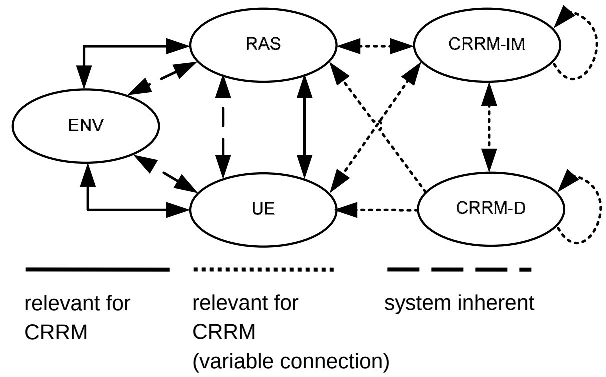

Figure 1. Model entities and their connectivity

Input and output parameters are defined for each component. The component environment (ENV) models the dynamic behavior of the system regarding the mobility of the UE. It provides the following output parameters:

- current state of mobility for UE
- available cells and received signal quality

and it needs the following input parameters:

- Parameters of UE (mobility parameter, connection state, possible RAT)
- Start/Stop UE measurements
- Parameters of RAS (cell properties)

The component radio access system (RAS) processes the service demands of the UE. Necessary functions of the CN like AAA control or RRM control are also included in the RAS component. Input parameters are:

- Connection attempts
- Begin/End of ON/OFF-phases
- QoS demands
- Position/speed, technical capabilities and administrative conditions of user equipments
- Measurement results of UE
- CRRM Commands

The RAS component's output is the following:

- Connection state
- Offered QoS
- Measurements

These component measurements include status information of cells in a RAS (load in cell, exhausted resources, cell properties) or of user equipments and its services connected to the RAS. In the case of a user equipment first and second order measurements are possible. First order measurements comprise all measurements which can be directly measured at the RAS for instance

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2009.5594
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5594

connection state, offered QoS, fraction of load in cell. Second order measurements comprise all information which has to be measured elsewhere and are then transferred to the RAS component, for example measurements collected by the UE or ENV component.

The component user equipment (UE) models the technological capabilities (e.g. supported RAT) and the dynamics of service demands of different UE classes. This component sets up the mobility parameter of the UE as well. Connections to RASs are restricted to RASs with supported RAT. Input parameters are

- Received QoS
  (e.g. delay, data rate, connection status)
- Cell measurement results of available RAS
- CRRM commands

The UE provides the following output parameters

- Connection required begin/end (which implies Mobility parameters, QoS demands, technical capabilities/ administrative conditions)
- ON/OFF-phases begin/end
- start/stop Measurements
- Measurements

In this component first order measurements are demanded/ received QoS, user satisfaction, technical capabilities and administrative conditions of UE. Second order measurements are status information of available cells, e.g. signal quality.

The CRRM components are defined according to the separation of information management (CRRM-IM) and decision management (CRRM-D). The CRRM algorithms are implemented via these components in a distributed, hierarchical or centralized way. The CRRM-IM component starts and stops measurements of system parameters (periodic or event triggered), it also collects and stores the results. The following input and output parameters are provided:

Input parameters:

- Data requests of CRRM-D/IM
- CRRM parameters/model (e.g. thresholds)
- Data request response of UE or RAS or CRRM-IM

Output parameters:

- Data requests to UE or RAS or CRRM-IM
- Start/Stop measurements commands
- Data request response to CRRM-D/IM

The CRRM-D component processes these collected information and initiates the adaptation of the system to meet the service demand requirements (e.g. intersystem handover, QoS adaption, RAS adaption). The following input and output parameters are provided:

Input parameters:

- Data request response of CRRM-IM
- CRRM parameters/model (e.g. thresholds)
- CRRM commands of CRRM-D

Output parameters:

- Data requests to CRRM-IM
- CRRM commands to RAS or UE or CRRM-D

Figure 2 shows how different CRRM levels may be realized with the proposed model framework. The indices i, j, k indicate that several instances of these components are possible. The components RAT, Provider and Roaming are only used for structuring the resulting architecture. Each RAT can contain several RAS. Additionally each provider can support several RATs and there are several providers possible.

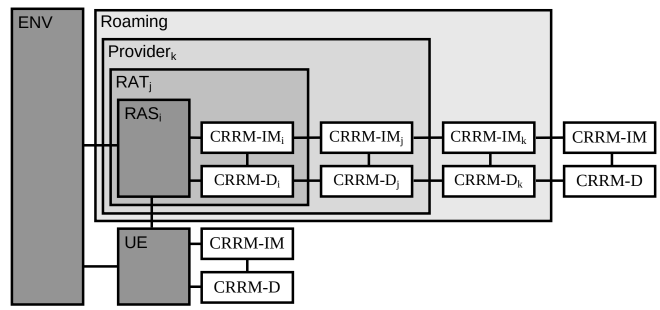

Figure 2. Modeling of different CRRM levels

Omitting different CRRM components creates distributed, hierarchical or centralized CRRM architectures. For example level B CRRM (see section 2) with a distributed decision and centralized information management can be realized as shown in figure 3. The figure shows a CRRM of GSM and UMTS micro/macro cell layer. The CRRM-IM component collects information of all RASs (micro/macro-layer) and UEs (via RAS) and provides them to the CRRM decision components. The CRRM-D components are able to relay their commands to other CRRM-D components.

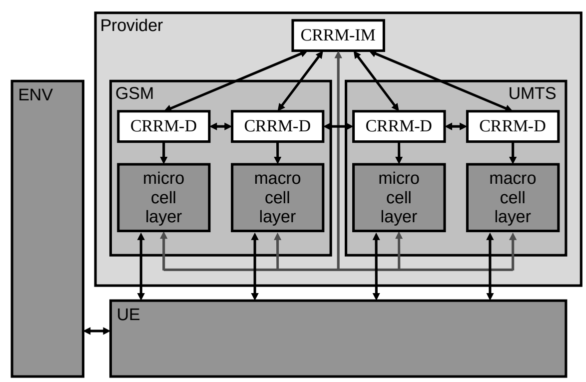

Figure 3. Example for level B CRRM

3. SIMULATION MODEL

3.1 General Concept

The simulator is designed for the fast creation and evaluation of different CRRM scenarios and algorithms. This is to create a tool for the quick assessment of new ideas for CRRM and possible interdependencies. The proposed model framework (section 2.2) itself allows for a readily definition of different scenarios. Since the modeling concept is based on a hybrid approach [11] analytical models (for radio access technologies and service demands) and simulation models (for mobility / service and information transfer dynamics) operate concurrently over time and do interact with each other. Analytical models allow for an easy implementation of several different RAT and

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2009.5594
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5594

service demand models, whereas the simulation model part enables the evaluation of time dependent behavior. This hybrid modeling approach also allows for short simulation runtimes even for complex CRRM scenarios.

3.2 Implementation of Model Components

The model framework introduced in section 2.2 is implemented by using the discrete event simulation system OMNeT++. Each model component ENV, RAS, UE, CRRM-IM and CRRM-D (Figure 1) is represented by a simple module. The components RAT, Provider and Roaming (Figure 2) are represented via compound modules. CRRM scenarios are specified by defining layouts for the modules as well as module connections in NED (Network Description) files and by setting up the modules parameters via XML files. Additionally pre-analyzing of analytical models is an important issue, where parameters supplied from XML files to a Java-tool are evaluated. This Java-tool shows the results of the used analytical models under the given scenario input parameters and allows for a variation of these parameters. Thus it is possible to check the scenario input parameters and to analyze aspects of the general system behavior e.g. the maximum cell data rate or the IP-delay for different load situations. This allows a fast creation of different CRRM scenarios.

3.2.1 Message Exchange

Information between model components is transferred via OMNeT++ message exchange functions using an error corrected version of the cTopology class for routing purposes. Each component registers itself at other components for receiving messages of defined message types. The messages are sent to the components either continuously or only if certain thresholds with respect to load or time have been reached. The message sending can be delayed according to a classification of tasks in low, medium and high complexity depending on the type of the message and the model component. Costs are also added according to this classification. System inherent information transfer (see figure 1) is done via pointers or messages without costs.

3.2.2 Component ENV

For each network type (WPAN, WLAN, WWAN, WGAN) layers with different spatial grid resolutions are defined. The WPAN layer has a very fine resolution whereas the WGAN layer has a very coarse one. Due to this versatile partitioning the simulation efficiency is considerably improved. The mobility of the UE is implemented at the grid element level. The UE travels from grid element to grid element and the camping time is calculated from its mobility parameters and the element's dimensions. The grid resolution is chosen related to the RAT of the UE's connection. Each grid element carries information on its position, neighboring elements, related higher and lower layer elements, the receivable RAS and its distance to the respective RAS base station as well as the quality level of the RAS. If a UE connected to a receivable RAS enters or leaves a grid element a cost free message is sent to this RAS. The RAS model is updated with each message. Figure 4 shows a model of overlaid network type layers. The UE travels from/to start/target points and during this travel some position update messages are generated. Each layer is a modeled as a borderless torus world, allowing for different mobility models, like random waypoint mobility as is used in the following experiments.

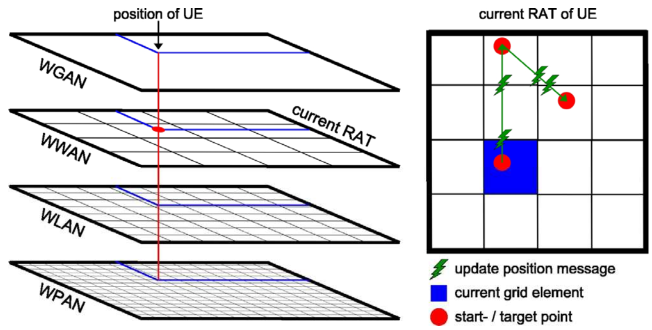

Figure 4. Model of grid layer environment for different RAT

UEs choose their targets and initial speeds according to a uniform distribution. To avoid speed decays and long initial transient phases, successive speeds within a UEs lifetime differ only slightly. Since the lifetimes of UEs are relatively short and long term behavior is not relevant the results obtained from the Palm calculus [13] are not applicable. Simulation studies (carried out for validation purposes) showed uniformly distributed UEs' positions and speeds.

3.2.3 Component UE

This component implements the algorithms for a set of different UE-classes. Each UE component can support several UEs. For each UE-class service, mobility and device characteristics can be defined by parameters which are imported via XML-files. Each UE can support one PS or CS service. Different uplink and downlink behaviors may be specified. New services are started according to a Poisson arrival process and stopped after their service demands are fulfilled or an error occurred (e.g. no coverage). A new UE is created with each new service demand arrival and it is removed after the service was stopped. It is also possible to set up a certain amount of services demands (UEs) which shall be in the system at all times. This feature is mostly used for validation purposes. Each type of service has its specific ON/OFF-model at the flow level. Resources of RAS components are only assigned to the service during the ON-phase. The ON-phase of a circuit switched real time speech service equals the duration of the connection. The ON/OFF-phase distribution of a packet switched WWW-browsing service is implemented according to the behavioral model of Choi and Limb in [14]. According to this model the ON-phase represents the time needed for fetching all objects belonging to one web request. Therefore the length of the ON phase depends on the data rate and the transferred amount of data. The OFF-phase represents the reading time of the user. The packet arrival process is considered via the mean *E[A]* and the coefficient of variation c_A of the packet interarrival time.

The QoS demands (data rate, delay, bit error rate) for each service are defined via a utility profile:

$$P_i = \begin{cases} 0 & \text{if } V_i < V_{i,\min} \\ 1 - \dfrac{V_{i,\max} - V_i}{V_{i,\max} - V_{i,\min}} & \text{if } V_{i,\min} \le V_i < V_{i\max} \\ 1 & \text{if } V_i \ge V_{i,\max} \end{cases} \quad (1)$$

where P_i is a QoS parameter profile, V_i is its currently offered value and $V_{i,min}$,$V_{i,max}$ are its corresponding minimal and

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2009.5594
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5594

maximal needed value. If $\prod P_i = 0$ the connection is not feasible for the service of the UE.

Each UE-class can support several RATs and several providers. Preferred RATs and providers are defined via a descending order in the parameter file. It is assumed that UEs use a separate receiver for each RAT, thus measurements do not influence each other.

3.2.4 Component RAS

This component implements the analytical models for different RAT. Each RAS can consist of several cells which represent one micro or macro cell layer. The grid elements defined in the ENV component are assigned to each cell distinguishing the three cases good, moderate and no signal reception. A perfect power control is assumed. The ON-phase of the service is composed of an accessing phase I and a data transfer phase TR. The RAS state is only updated in case of one of the following events:

- Begin/End connection
- Begin/End accessing and ON-phase
- Position update
- CRRM command

Each analytical RAT model implemented in a RAS component has to support the following input/output interface.

Input data:

- Server characteristics
- Service characteristics
- UE characteristics
- Number of UEs of a certain UE-class in one cell

Output data:

- Resource consumption per UE
- Offered QoS for UE
- Duration of accessing phase
- Duration of data transfer phase

According to the hybrid modeling approach the input data is provided by the simulation model and the output of the analytical models is vice versa the input to the simulation model parts.

As examples for CDMA and TDMA based systems analytical RAT models for UMTS and GSM/EGPRS have been implemented. Both RATs can handle circuit switched (CS) and packet switched (PS) connections. However EGPRS offers shared PS channels whereas UMTS offers shared and dedicated PS channels. Both analytical models are similar regarding the calculation of offered QoS and phase durations. Only the calculation of resource consumption is handled differently for UMTS and GSM/EGPRS. Therefore these RATs are well suited for creating various CRRM scenarios.

For CS connections it is assumed the offered QoS equals the demanded QoS until the connection is lost or ended. Access phase and data transfer phase are combined to a single service demand phase which duration equals the duration of the service's ON-phase. For PS connections the offered QoS is calculated as follows. Since both UMTS and EGPRS use a contention based uplink access control the model described in [15] was used to determine the mean uplink access time T_{Iu}. The parameter T_{Iu} is the mean time for contention T_C together with the mean time for establishing a packet flow T_{BF}

$$E[T_{Iu}] = E[T_C] + E[T_{BF}] \tag{2}$$

The parameter $E[T_{BF}]$ is taken from the parameter file and $E[T_C]$ is calculated as follows:

$$E[T_C] = \left(1 + \frac{1 - P[C]}{P[C]}\right) \cdot T_P \tag{3}$$

with T_P is the time between contention phases and $P[C]$ is the overall probability of successful contention.

$$P[C] = \frac{E[S|i]}{i} \tag{4}$$

where i is the number of accessing UEs and $E[S|i]$ is the mean number of successful UEs.

$$E[S|i] = H \cdot P[S|i] \tag{5}$$

with H is the number of Slotted Aloha Contention slots and $P[S|i]$ is the success probability for a UE in one slot.

$$P[S|i] = \sum_{n=0}^{i} P[S|n] \cdot P[n|i] \tag{6}$$

with $P[S|n]$ is the success probability if n competitors compete in one slot and $P[n|i]$ is the probability for n UEs competing in one Slotted Aloha Contention slot when i UEs are in their accessing phase and H slots are available.

$$P[n|i] = \binom{i}{n} \left(\frac{1}{H}\right)^n \left(1 - \frac{1}{H}\right)^{i-n} \tag{7}$$

T_P, $P[S|n]$ and the downlink T_{Id} are scenario parameters.

The model for the offered QoS on the wireless connection includes the received data rate $E[R]$ and the experienced IP packet delay $E[D]$ and RLC block error rate $E[Err]$ of an active service i. The IP-packet delay is based on the determination of the service time of an IP-packet $E[B_i]$ and the scheduling slowdown caused by other active services $E[S_i]$. In case of a dedicated channel there are no other services which have to be taken into account except for the service itself.

$$\mathrm{E}[\mathrm{D_i}] = \mathrm{E}[\mathrm{B_i}] + \mathrm{E}[\mathrm{S_i}] \tag{8}$$

The channel is here modeled as a GI/G/1/PS queuing station. Long range dependencies and self-similar properties of IP traffic are neglected. In case of EGPRS all traffic channels used for packet transmission are considered as a single server. Moreover it is assumed that all UEs are capable of using all EGPRS channels in parallel (max. eight channels). The approximation of $E[S_i]$ is based on the connection of PS scheduling times and FCFS waiting times described in [16].

$$E[S_i]_{PS} \approx \frac{2}{c_{B_i}^2 + 1} \cdot E[W_i]_{FCFS} \tag{9}$$

where the FCFS waiting time is solved approximately via the Krämer/Langenbach-Belz formula for the GI/G/1/FCFS model described in [17]

$$E[W_i]_{FCFS} = \frac{\overline{W_0}}{(1 - \sigma_i)(1 - \sigma_{i+1})} \tag{10}$$

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2009.5594
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5594

$$\overline{W_0} \approx \sum_{k=1}^{C} \rho_k \cdot \frac{c_{A_k}^2 + c_{B_k}^2}{2\mu_k} \cdot G_{KLB}$$
$$G_{KLB} = f(\rho_k, c_{A_k}^2, c_{B_k}^2) \qquad (11)$$
$$\sigma_i = \sum_{k=1}^{C} 1_{\{P_k \geq P_i\}} \rho_k \qquad \rho_k = \frac{E[B_k]}{E[A_k]}$$

This allows for the approximation of slowdowns caused by other services with a low computational complexity together with the consideration of different service and interarrival times (E[B], E[A]) and their respective coefficients of variations (c_A, c_B) as well as different service priority classes P_i.

The mean service time $E[B_i]$ of an IP packet for service i is modeled at the RLC level of the wireless link. It is assumed an SR-ARQ error control regime is in action. Thus the model described in [18] is used to determine the service time under different channel conditions.

$$E[B_i] \approx \begin{cases} \left[1 - \frac{\ln(K+1)}{\ln(P_e)}\right] \cdot T & , \quad K \leq BT \\ \frac{K}{B(1-P_e)} - \frac{T}{1-P_e} + \left[1 - \frac{\ln(BT+1)}{\ln(P_e)}\right] \cdot T & , \quad K > BT \end{cases} \qquad (12)$$

$$c_B{}^2 = \frac{V[B_i]}{E[B_i]^2} \qquad V[B_i] \approx f(K, P_e, BT) \qquad (13)$$

with P_e is the RLC block error probability, T is the number of transmission time intervals (TTI) that fit in one round trip time (RTT), B is the number of transferred RLC blocks in one TTI and K is the number of RLC blocks which sum up to the IP-packet backlog. These parameter values are different for the RAS signal reception quality classes good and moderate and the used coding schemes. All available coding schemes are evaluated to achieve the shortest service time for the service i. The values for P_e, RTT, TTI, B, RLC block size are scenario dependent parameters. The IP-packet backlog B_i is estimated using M/M/1-results to avoid iteration loops.

$$B_i = \frac{\rho_i}{1-\rho_i} \cdot IP_i \qquad (14)$$

The IP-packet size IP_i and the interarrival time $E[A_i]$ define the mean data rate $E[R_i]$ for a certain service i.

$$E[R_i] = \frac{1}{E[A_i]} \cdot IP_i \qquad (15)$$

Maximal values for $E[R_i]$ are bounded with respect to a maximum channel utilization, i.e. $\rho_{ch} < 1$.

$$\rho_{ch} = \sum_{\forall i} \frac{E[B_i]}{E[A_i]} < 1 \qquad (16)$$

In case of a shared channel all active services have to be taken into account. In case of a dedicated channel only the service itself is considered. The data rate and the amount of data which has to be transferred in the ON-phase define the length T_{TR} of the data transfer phase.

The used resources in a cell of a RAS are quantified by the load index η_c with ($0 \leq \eta_c \leq 1$) which is calculated according to the proposed model in [7]. Each connected service i causes a load quantified by α_i which together sum up to the overall cell load.

$$\eta_c = \sum_{\forall i} \alpha_i \qquad (17)$$

The load caused by each service is based on the amount of used traffic channel time slots for GSM/EGPRS.

$$\alpha_i = \frac{U_i}{C} \qquad (18)$$

C is the number of traffic channels in the cell and U_i is the number of used traffic channels of service i. In case of CS services U_i is always one for service i. In case of PS services U_i is a fraction of the traffic channels assigned to EGPRS.

$$U_i = \frac{\rho_i}{\sigma_0} D \qquad (19)$$

with σ_0 is the utilization of the packet data channel and ρ_i is the utilization caused by service i and D is the number of packet data channels in the cell. Since EGPRS is a shared medium there is no direct assignment of traffic channels to services, thus U_i is a virtual number for PS services.

In case of UMTS the noise rise determines α_i in the uplink and downlink, respectively. See [19].

Downlink:

$$\alpha_i = v_i \cdot \frac{\left(\frac{E_b}{N_0}\right)_i}{\frac{W}{R_i}} \cdot [(1-\varphi_i) + \delta_i] \qquad (20)$$

Uplink:

$$\alpha_i = (1+\delta) \cdot \frac{1}{1 + \frac{W}{\left(\frac{E_b}{N_0}\right)_i \cdot R_i \cdot v_i}} \qquad (21)$$

with v_i is the activity factor, W is the WCDMA chip rate, R_i the service bit rate, δ the interference at the base station receiver, the interference seen by the UE δ_i and φ_i is the code orthogonality factor. E_b/N_0 is the energy per bit to noise ratio. The parameters are estimated with respect to the load in the cell, service class, distance to base station as well as speed of UE and the RAS quality levels (good, moderate). The availability of spreading codes for data rates is checked within the tree for orthogonal spreading codes.

3.2.5 Component CRRM-IM

The CRRM-IM components implement different CRRM information collecting and lookup algorithms. The component can start, stop and collect measurements in the UE, RAS and other CRRM components. It may register at the components for certain types of measurements. The implemented algorithms can choose between two types of measurements: recurrent and non recurrent. Non recurrent measurements stop after the first measurement value is transferred whereas recurrent measurements have to be explicitly stopped by a stopping message to the respective component. At the measurement registration the following parameters can be set:

- start load threshold
- min load difference
- min time difference

Messages containing measurement values are only sent to the IM component if the start load threshold is reached and a minimal

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2009.5594
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5594

time interval passed by and a minimal difference in load occurred. If all parameters are set to zero new measurement values are sent to the IM component as soon as they are measured. Measurements can contain information about UEs e.g. received and demanded QoS, used resources, supported RAT, signal quality of received cells. They can also contain information about cells e.g. number of active/connected/accessing UEs, used resources or PS channel utilization. Parameter values for the IM algorithms are scenario parameters.

3.2.6 Component CRRM-D

The CRRM-D component processes the collected information and generates commands to influence the behavior of RAS or UE components. Intersystem handovers (ISHO) and service demand adaptations can be triggered via this component. Parameter values for the decision algorithms are scenario parameters.

4. SIMULATION SCENARIOS

To show possible applications of the simulator some example simulations are presented in this section. The scenarios are based on the following setting. A single provider offers UMTS and GSM/EGPRS services to its customers. Thus CRRM level B algorithms can be applied. The coverage area is a square (torus) with an edge length of 4.5 km. The grid elements' x/y - dimensions are 250 m. There are nine co-located cells in each RAS for GSM and UMTS. The area of good signal reception lies within 500 m around the base station. The area with moderate signal reception lies within 500 m to 1060 m around the base station. There is no area without coverage for both RAT.

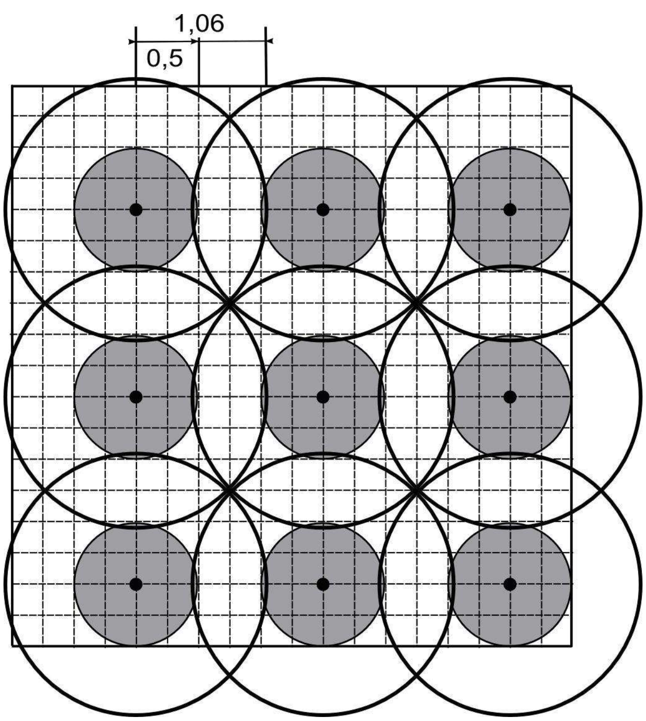

Figure 5. Nine cells scenario with good (r = 0.5 km) and moderate (r = 1.06 km) signal quality classes

See figure 5 for a visual representation of the scenario. The UMTS cells use a 5 Mhz frequency band with a chip rate of 3.84 Mcps in each link direction. The GSM cells use three 200 kHz frequency bands and offer 22 traffic channels each for up- and downlink connections. In each cell 13.6 % of the resources are reserved for handovers within the RAS and are not accessible for new UEs. All UEs move at a speed ranging from 1 to 5 km per hour. The first hour of simulated time of each simulation is seen as a transient phase and thus the data collection for statistics starts after one hour of simulated time. All values given in graphs and tables are (aggregated) mean values over 100 simulation runs with a 95% confidence interval. If the confidence interval is larger then it is given together with the respective values. Consumed processing time per simulation run is typically less than one hour for 24 h of simulated time.

In order to validate the model, simulations with CS services for UEs have been performed to test the accuracy of the simulator; criteria to be fulfilled are given by Little's law and the Erlang-B-formula. The used parameter values are listed in table 1.

Table 1. Scenario CS-A

	GSM	UMTS
call duration	90 s	90 s
UE inter arrival time	0.811 s	0.4382 s
offered traffic per cell	12.33 Erl	22.82 Erl
CS channels	19	31 (estimated) E_b/N_0 = 5.1 dB
Intersystem handover	No	No

In scenario CS-A a blocking probability of 2% was expected (as given by the Erlang-B-formula) and blocking probabilities of 2.08% for UMTS and 2.06% for GSM were seen as simulatin results. Little's law predicted a mean value of 12.076 active UEs for GSM and 22.345 for UMTS. The simulation results show mean values of 12.068 active GSM UEs and 21.845 active UMTS UEs. Scenario CS-B is similar to scenario CS-A except for the additional feature of intersystem handovers. The Erlang-B-formula predicts a blocking probability of 0.4 % for the joint system and the observed (simulated) blocking probability was 0.46 %. In scenario CS-B the blocking of new connections and the dropping of ongoing connections for each RAS increased but the number of complete blocks (no RAS available) of a new connection decreased. See table 2. The used CRRM algorithm is suited directly at the UEs and it tries to connect to a different RAT if the preferred RAT has blocked the new connection (connection retrial) or has dropped an ongoing connection (intersystem handover).

Table 2. Effects of CRRM algorithm

	Scenario CS-A		Scenario CS-B	
	GSM	UMTS	GSM	UMTS
blocking events	2189.42 ± 17.81	4096.68 ± 25.38	3560.37 ±21.41	5754.78 ±34.40
Dropping events	1.95 ± 0.28	1.25 ± 0.27	2.57 ±0.39	1.67 ±0.29
complete blocking events	2191.37 ± 17.81	4097.89 ± 25.40	506.54 ±5.54	935.62 ±8.43
Connection retrials	0	0	3053.82 ±17.87	4819.14 ±28.48
Intersystem handover	0	0	2.57 ±0.39	1.67 ±0.29

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2009.5594
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5594

The next scenario CS-C is a test scenario and shows how the CRRM algorithm from scenario CS-B increases the chances of a successful connection establishment for arriving UEs. Figure 6 shows the ratio of UEs with successful connections to the total amount of created UEs. To reduce the influence of randomness in CS-C and in the following scenarios all UE classes have a fixed number of UEs in the system (a closed system is considered). Thus if a UE ended its service demand or it is blocked or dropped then it is instantly created elsewhere in the environment according to a uniform distribution. The CS service call duration is again 90 s. The maximum capacity of active UEs with CS connections in the GSM system is 171 UEs. For RAS internal handover purposes reserved are 27 channels. The UMTS system can carry approximately 279 active UEs with CS connections and approximately 45 channels are reserved for handovers within the RAS. Two UE classes were defined with the same number of fixed UEs each for GSM and UMTS.

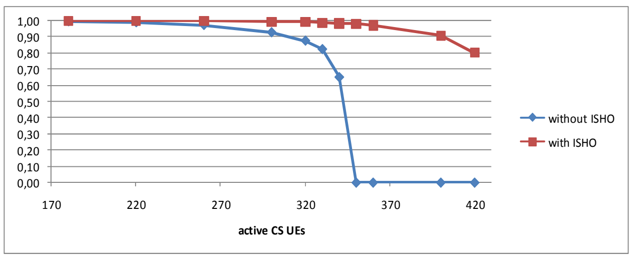

Figure 6. Ratio of normally ended to overall created calls

In figure 6 the x-axis show the combined number of UEs in the joint system. The sharply decreasing blue line shows the situation in the joint system without the possibility of an intersystem handover. As the number of active CS services reaches the maximum capacity of the GSM system the number of created UEs rises sharply. This is because most of the GSM cells have no capacity left. As a consequence the ratio of UEs which services' ended normally to the overall created UEs becomes very low. The situation changes, if an intersystem handover (ISHO) is possible. Now the free capacity of the UMTS system can be used and the ratio of normally ended UEs to the overall created UEs is higher. Figure 7 shows that this improvement is only possible due to a high number of connection retrials whereas the number of inter-system handovers remains relatively low (68.46 ±2.51 for 420 UEs).

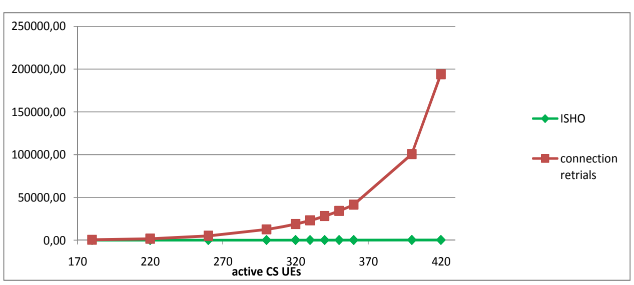

Figure 7. Number of ISHO and connection retrials

In the next scenario PS-A the behavior of the shared EGPRS PS channel is shown with respect to the influence of CS services in one GSM frequency band. To reduce the influence of randomness only one coding scheme is defined (MCS-4). The shared PS channel has the following parameters for good and moderate signal reception: transmission time interval 20 ms, round trip time 80 ms, RLC block size 352 bit, Block error probability 5 %. These parameters yield a maximum channel data rate of 16.72 kbit/s. In a cell a single frequency band with seven packet data channels (PDCH) is defined which leads to a maximum cell data rate of 117.04 kbit/s. The PS services have the following parameters: IP packet size 1460 byte, interarrival time 1.217 s with a coefficient of variation c_A=1 yield a service data rate of 9.6 kbit/s. Three PS services and one to six CS services are using one frequency band at maximum. Each active CS service reduces the number of packet data channels by one. The other parameters are not listed here for simplicity reasons. Figure 8 shows how the utilization of the PDCH and the delay of the IP packets increase as the number of active CS services rise. If six CS services are active the PDCH can carry only one PS service at a time. The other PS services are blocked or dropped. To reduce blocking and dropping CRRM would have to reduce the data rate of the PS services or alternatively handover the PS or CS services to another RAS.

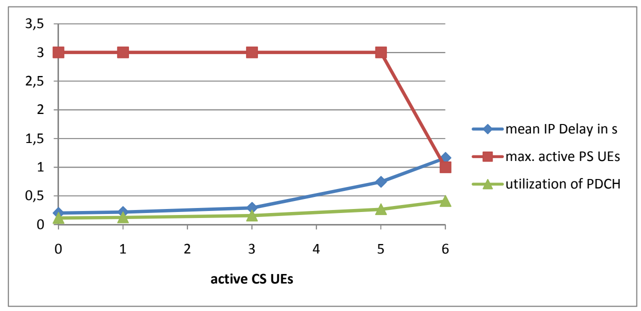

Figure 8. CS services vs. PS services in one GSM frequency band

In the last shown scenario PS-B the influence of CRRM on the system behavior over time is displayed. The PDCH and PS services use the same parameters as defined in scenario PS-A. GSM with EGPRS is the preferred RAT and all UEs are also capable of connecting to UMTS. In UMTS dedicated channels are used. At simulation start 60 UEs with PS services are in the system and at time t=13600 s another 160 UEs are added. Figure 9 shows the delay situation without ISHO.

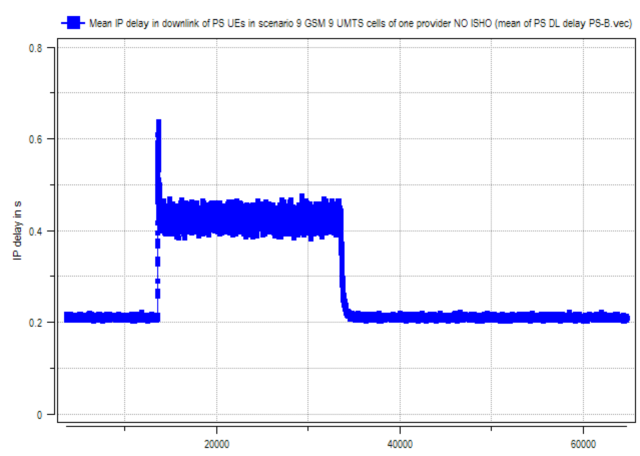

Figure 9. IP delay over time in scenario PS-B without ISHO

At time t=13600s the new UEs try to access the RAS and more and more UEs start their ON-phases, since only seven UEs can

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2009.5594
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5594

access a cell at a time. This leads to a spike for IP packet delays. Over time the different ON and OFF-phase durations of the PS services lead to a lower channel utilization and thus to lower IP delays. At time t=33600 s the number of UEs in the system is reduced to 60 again and thus the IP delay is declining too. In figure 10 CRRM is active and UEs which have been dropped or blocked are transferred via ISHO to UMTS. This leads to a lower mean GSM utilization and thus to lower IP delays. The UE service demand spike at time t=13600 s is transferred completely to UMTS. However the load in the UMTS cells is still low (see figure 11).

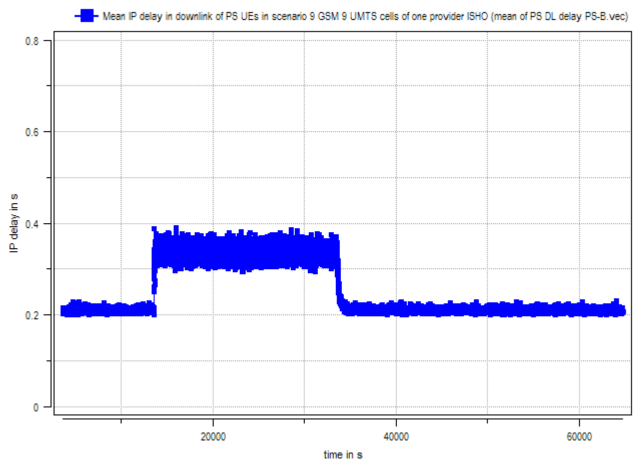

Figure 10. IP delay over time in scenario PS-B with ISHO

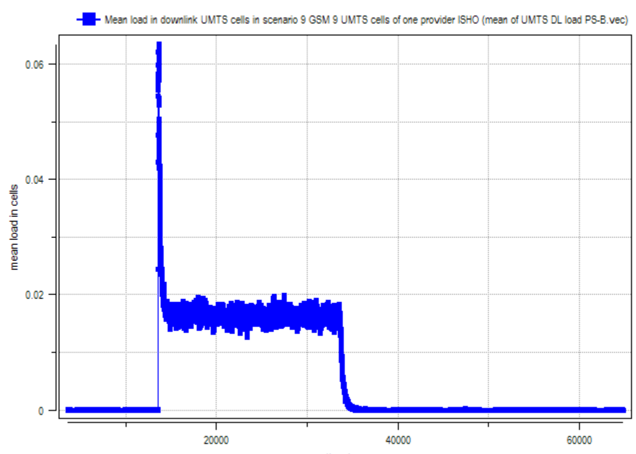

Figure 11. Mean load in UMTS cells over time.

5. CONCLUSION

In section two we presented a model framework for CRRM scenarios. Based on this model in section tree we derived a hybrid simulation model which allows for an efficient cost benefit analysis of different CRRM scenarios and algorithms. We showed how analytical models for UMTS and GSM/EGPRS can be integrated in the presented simulator based on our framework. The models cover the calculation of channel access times, service times, queuing delays, data rates and service ON/OFF-durations together with their resource consumptions. We presented simulation results to show the scope of the framework and applications of the simulator. Future work will focus on the suitability assessment of different CRRM algorithms for diverse CRRM scenarios together with the integration of analytical models for UMTS/HSDPA-UPA and IEEE 802.11 networks.

6. REFERENCES

[1] A. Tölli, P. Hakalin, H. Holma. 2002. “Performance Evaluation of Common Radio Resource management (CRRM).” In Proc. IEEE International Conference on Communications (ICC). NY, USA.

[2] Insoo Koo, Anders Furuskar, Jens Zander, Kiseon Kim. 2004. “Erlang Capacity Analysis of Multi-access Systems Supporting Voice and Data Services” In Proc. PWC’04. Delft, The Netherlands.

[3] K. Murray, D. Pesch. 2007. “Call Admission and Handover in Heterogeneous Wireless Networks” In IEEE Internet Computing, Vol. 11, No. 2, March 2007. pp. 44-52.

[4] L. Giupponi, R. Agustí, J. Pérez-Romero, O. Sallent. 2006. “A Framework for JRRM with Resource Reservation and Multiservice Provisioning in Heterogeneous Networks”. In Mobile Networks and Applications (MONET), Special issue on “Reconfigurable Radio Technologies in Support of Ubiquitous Seamless Computing”, Vol. 11, No. 6, Dec. 2006, pp. 825-846.

[5] S.J. Lincke. 2007. “Validation of a Load Shared Integrated Network with Heterogeneous Services” In Proc. 40th Annual Simulation Symposium (ANSS-40 2007), March 26-28, Norfolk (VA), USA.

[6] O. E. Falowo and H. A. Chan. 2007. “Adaptive Bandwidth Management and Joint Call Admission Control to Enhance System Utilization and QoS in Heterogeneous Wireless Networks” In EURASIP Journal on Wireless Communications and Networking, Vol. 2007, Article ID 34378.

[7] A. Pillekeit, F. Derakhshan, E. Jugl, A. Mitschele-Thiel. 2004. “Force-based Load Balancing in Co-located UMTS/GSM Networks.” In Proc. 60th IEEE Vehicular Technology Conference (VTC), Wireless Technologies for Global Security, September 26-29, Los Angeles, USA.

[8] Aurelian Bria. 2006. “Hybrid cellular-broadcasting infrastructure systems: radio resource management issues.” Thesis at Kungliga Tekniska högskolan, ID: kth:diva-3922

[9] I.M. Suliman, C. Pomalaza-Ráez, I. Oppermann, J. Lehtomäki. 2004. “Radio resource allocation in heterogeneous wireless networks using cooperative games.” In Proc. Nordic Radio Symposium 2004 / Finnish Wireless Communications Workshop 2004 (NRS/FWCW 2004), Oulu, Finland.

[10] A. Pillekeit, F. Derakhshan, B. Müller-Clostermann. 2007. “Modeling of Common Radio Resource Management Scenarios.” In Proc. 10th Communications and Networking Simulation Symposium (CNS'07) part of the 2007 Spring Simulation Multiconference (SpringSim'07), March 25 - 29, Norfolk (VA), USA.

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2009.5594
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5594

[11] R. G. Sargent. 1994. “A Historical View of Hybrid Simulation/Analytic Models” in Proceedings of the 1994 Winter Simulation Conference. ed. J. D. Tew, S. Manivannan, D. A. Sadowski, and A. F. Seila, pp. 383-386

[12] 3GPP TR 25.891 V0.3.0, 3rd Generation Partnership Project Technical Specification Group Radio Access Network; „Improvement of RRM across RNS and RNS/BSS (Post Rel-5); (Release 6)

[13] J.-Y. Le Boudec. 2004. “Understanding the Simulation of Mobility Models with Palm Calculus“ Technical Report IC/2004/53, EPF Lausanne, Swiss.

[14] H. Choi and J. Limb. 1999. “A Behavioral Model of Web Traffic ” International Conference of Networking Protocol 99' (ICNP 99'), IEEE Computer Society. Washington, DC, USA.

[15] V. A. Chitre, J. N. Daigle. 2003. “Performance of IP-Based Services over GPRS” In IEEE Transactions on Computers, Vol. 52, Issue 6, June 2003. pp. 727-741.

[16] A. Brandt, M. Brandt. 2006. “A sample path relation for the sojourn times in G/G/1-PS systems and its applications” In Queueing Systems Theory and Applications, Vol. 52, Issue 4, April 2004. pp. 281-286.

[17] G. Bolch, S. Greiner, H. de Meer, and K. S. Trivedi. 1998. “Queuing Networks and Markov Chains”. John Wiley and Sons, New York (NY), USA. pp. 239-241.

[18] Wei Luo, K. Balachandran, S. Nanda, K.K. Chang. 2005. “Delay analysis of selective-repeat ARQ with application to link adaption in wireless packet data systems”. IEEE transactions on wireless communications, Vol 4, Issue 3: pp. 1017-1029.

[19] H. Holma, A. Toskala. 2001. “WCDMA for UMTS - Radio Access for Third Generation Mobile Communications”. Revised Edition. John Wiley and Sons. New York (NY), USA.

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2009.5594
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5594