Simulation tool to evaluate Radio Resource Management algorithms for UMTS

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Abstract

This paper presents a system level simulator that has been developed with OPNET in order to evaluate the behavior of different Radio Resource Management (RRM) strategies in UMTS (Universal Mobile Telecommunications System) for 3rd Generation (3G) mobile communications under multiuser, multiservice and multicellular scenarios. The simulator includes models for the User Equipment, Base Station and Radio Network Control nodes. The functionalities that are implemented are those that deal with RRM functions (i.e., admission and congestion control, packet scheduling, handover control, power control and transport format management at MAC level) as well as those related with propagation, mobility and traffic generation models. Several performance statistics both in vector and scalar types are obtained.

Introduction

W-CDMA (Wideband – Code Division Multiple Access) networks, such as the considered in the FDD (Frequency Division Duplex) proposal for UMTS (Universal Mobile Telecommunications System) [1][2], provide an inherent flexibility to handle the provision of future 3G mobile multimedia services. 3G will offer an optimization of capacity in the air interface by means of efficient algorithms for Radio Resource and QoS Management. Within UMTS architecture, the RRM entity is responsible for the utilization of the air interface resources and it covers power control, handover, admission control, congestion control and packet scheduling [3]. These dynamic functionalities are very important in the framework of 3G systems because the system relies on them to guarantee a certain target QoS, to maintain the planned coverage area and to offer a high capacity. RRM functions are crucial because in W-CDMA based systems there is not a constant value for the maximum available capacity, since it is tightly coupled to the amount of interference in the air interface. Moreover, RRM functions can be implemented in many different ways, this having an impact on the overall system efficiency and on the operator infrastructure cost, so that definitively RRM strategies will play an important role in a mature UMTS scenario. Additionally, RRM strategies are not subject of standardization by 3GPP (3rd Generation Partnership Project), so that they can be a differentiation issue among manufacturers and operators.

The evaluation of the behaviour of such RRM strategies should be done under realistic scenarios that include suitable propagation and mobility models as well as traffic modeling and taking into account the interaction between the different involved procedures. As a result an analytical evaluation becomes a hard task and the best solution consists in the development of a system level simulator that allows the evaluation of different scenarios.

Within this framework, in this paper we present an OPNET system level simulation tool that has been devised to evaluate the performance of different Radio Resource Management strategies in a multiuser, multicell and multiservice scenario by making use of off-line results obtained from a link level simulator that characterizes the behavior of the physical layer transmissions. The input to the system level simulator will be essentially the scenario to be evaluated, characterized by the number and location of the base stations, the number of users per service as well as their QoS requirements and also the specific values for the parameters of the RRM algorithms to be evaluated. On the other hand, the simulator will provide several statistics that allow the comparison between the different algorithms.

This paper is organized as follows. In section II we give some general insights on UMTS architecture and specifically on RRM functions. In section III we describe our OPNET implementation of the simulation tool. In section IV, we present some simulation results and finally conclusions are drawn in section V.

Radio Resource Management in UMTS

Figure 1 presents the architecture of the UMTS system. Particularly, it is composed by the Core Network (CN) and the UMTS Terrestrial Radio Access Network (UTRAN). The UTRAN is composed by several Radio Network Subsystems (RNS) each one including a Radio Network Controller (RNC) and several base stations (node Bs). Finally, User Equipments (UE) can be connected to one or more node Bs. The RNC carries out, among others, all the functions that are related with the allocation of radio resources, RRM and QoS management while node Bs are responsible of physical layer procedures such as synchronization, channel estimation or power control.

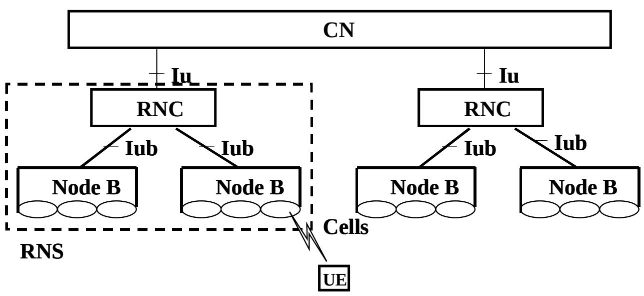

Figure 1: UMTS architecture

Whenever a certain service should be provided under certain guarantees QoS a bearer service with clearly defined characteristics and functionality must be set up from the source to the destination of the service, maybe including not only the UMTS network but also external networks. Within the UMTS bearer service, the role of the Radio Bearer Service is to cover all the aspects of the radio interface transport that are considered in the developed simulator.

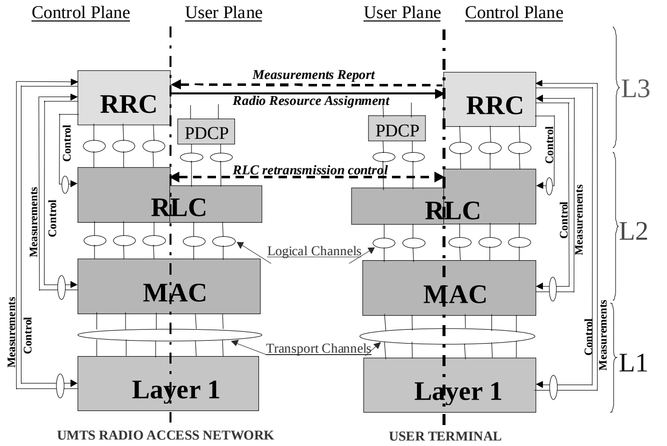

Figure 2: UTRAN radio interface protocol stack

The radio interface of the UTRA is layered into three protocol layers: the Physical Layer (L1), the Data link Layer (L2) and the Network Layer (L3). Additionally, the layer 2 is split into two sub-layers, the Radio Link Control (RLC) and the Medium Access Control (MAC). On the other hand, the RLC and layer 3 protocols are partitioned in two planes, namely the User plane and the Control plane. In the Control plane, Layer 3 is partitioned into sublayers where only the lowest sublayer, denoted as Radio Resource Control (RRC), terminates in the UTRAN, as Figure 2 shows.

Connections between RRC and MAC as well as RRC and L1 provide local inter-layer control services and allow the RRC to control the configuration of the lower layers. In the MAC layer, logical channels are mapped to transport channels. A transport channel defines the way how traffic from logical channels is processed and sent to the physical layer. The smallest entity of traffic that can be transmitted through a transport channel is a Transport Block (TB). Once in a certain period of time, called Transmission Time Interval (TTI), a given number of TB will be delivered to the physical layer in order to introduce some coding characteristics, interleaving and rate matching to the radio frame. The set of specific attributes are referred as the Transport Format (TF) of the considered transport channel. Note that the different number of TB transmitted in a TTI indicates that different bit rates are associated to different TF. As the UE may have more than one transport channel simultaneously, the Transport Format Combination (TFC) refers to the selected combination of TF. The network assigns a list of allowed TFC to be used by the UE in what is referred as Transport Format Combination Set (TFCS).

It is worth mentioning that for the optimization of the radio interface utilization, RRM functions should consider the differences among the different services, not only in terms of QoS requirements but also in terms of the nature of the offered traffic, bit rates, etc. The RRM functions include:

1. Admission control: it controls requests for setup and reconfiguration of radio bearers.
2. Congestion control: it faces situations in which the system has reached a congestion status and therefore the QoS guarantees are at risk due to the evolution of system dynamics (mobility aspects, increase in interference, etc.).
3. Mechanisms for the management of transmission parameters: are devoted to decide the suitable radio transmission parameters for each connection (i.e. TF, target quality, power, etc.).
4. Code management: for the downlink it is devoted to manage the OVSF code tree used to allocate physical channel orthogonality among different users.

Within the UMTS architecture, RRM algorithms will be carried out in the Radio Network Controller (RNC). Decisions taken by RRM algorithms are executed through Radio Bearer Control Procedures (a subset of Radio Resource Control Procedures) such as [4]:

1. Radio Bearer Set-up.
2. Physical Channel Reconfiguration.
3. Transport Channel Reconfiguration.

3GPP has provided a high degree of flexibility to carry out the RRM functions, so that the parameters that can be managed are mainly:

1. TFCS (Transport Format Combination Set), which is network controlled and used for Admission Control and Congestion Control.
2. TFC (Transport Format Combination), which in the case of the uplink is controlled by the UE-MAC
3. Power, as the fundamental physical parameter that must be set according to a certain quality target (defined in terms of a SIRtarget) and taking into consideration the spreading factor used and the impact of all other users in the system and their respective quality targets.
4. OVSF (Orthogonal Variable Spreading Factor) code

Description of the OPNET simulator

From a functional point of view, the procedures to be considered in the simulator are reflected in Figure 3. As an initial procedure, the network deployment module will be responsible for providing the simulator user with a mechanism to introduce the position of the different base stations and mobile stations as well as the other parameters characterizing the scenario to be evaluated. On the other hand, the RRM module is the core of the simulator responsible for carrying out the different RRM strategies, namely admission control, congestion control, management of transmission parameters and code management. The RRM module will act depending on the behavior of the mobile terminals in terms of traffic generation and mobility. Regarding the mobility issues, the simulator will contain modules to implement the trajectories of the terminals, to calculate the path loss to the base stations in the scenario and to decide the base stations in the active set depending on the handover algorithms. Similarly, traffic generation models will be simulated for each user depending on its corresponding service and the generated packets will be kept in buffers waiting for transmission. The RRM module will decide when and how the packets are transmitted through the radio interface. The power control mechanism will be responsible for determining the transmitted power of each transmission to reach a certain SIR target (Signal to Interference Ratio). Depending on this power and the position of the terminals the resulting Eb/No is evaluated for each transmission. Finally, the interaction with the off-line link level simulator results will decide the successful and erroneous transmissions. The buffers will be updated accordingly depending on the result for each transmission and on the availability of retransmissions.

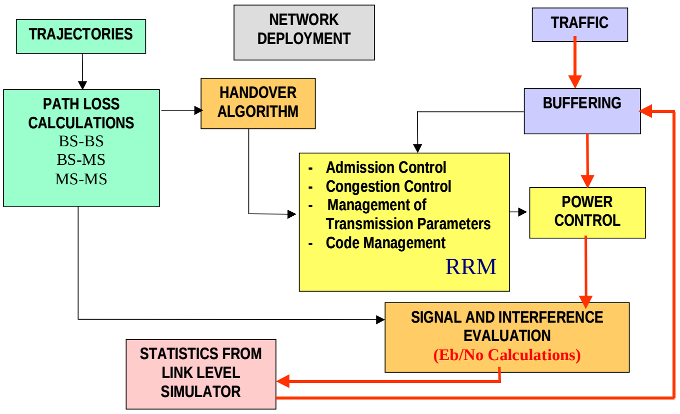

Figure 3: Functional Simulator Architecture

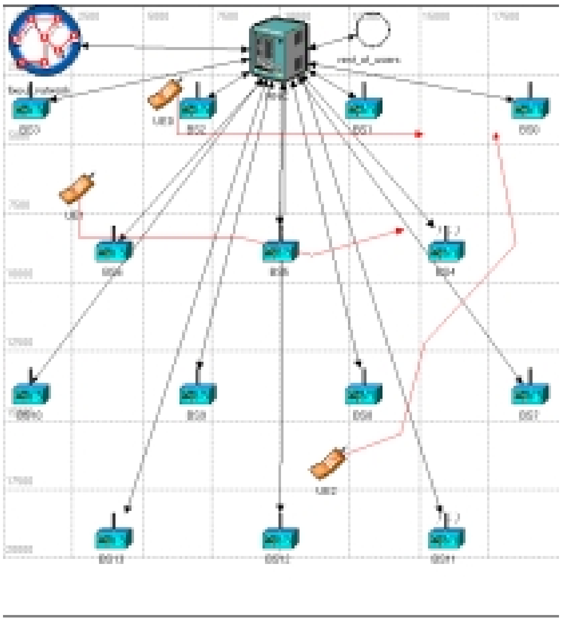

Figure 4: Network model

Figure 4 shows a network model representing a possible scenario under test for the system level simulator. All the nodes that have been designed are shown in this scenario. Particularly, the following nodes have been developed to implement the previously described functions:

- RNC node: It simulates the behavior of the Radio Network Controller (RNC) and particularly it deals with the RRM strategies.
- BS node: It represents a node B.
- UE node: It simulates the behavior of a User Equipment in terms of mobility, traffic generation and radio transmission functions.
- Rest of Users node: This node simulates the same behavior as the UE node but it does not represent a single user but a certain number of users. The idea behind the separation between the "UE nodes" and the "Rest of Users" nodes relies on being able to simulate a high number of UEs without having to locate all of them in the network model. This allows focusing on the particular behavior of a certain number of desired UEs (i.e., those defined as UE nodes) on a friendly graphical way but taking also into account the influence of all the other users in the system. The only functional difference between a UE node and a user in the Rest of Users node is that the first follows a user-defined trajectory while the second makes use of a mobility model.
- Fixed Network: It acts as the generation source for downlink traffic.

As it can be observed in Figure 4, there are three UE nodes, each one with a predefined trajectory (represented by red lines), and a total of 12 BS nodes. The network deployment will consist on defining which are the different BS and UE locations together with their corresponding attributes depending on the scenario under evaluation.

UE (User Equipment) node

The UE node simulates the behavior of a User Equipment entity. Its node model is shown in Figure 5. Particularly, the functions that are of interest to the system level simulator are the following:

- Uplink Traffic Generation: Packets are generated depending on the service to be provided to the simulated user according to a predefined traffic model. The services that are considered are representative of the four service classes defined in UMTS: videophone for conversational class, video streaming for streaming class, WWW browsing for interactive class and e-mail for background class [5].

- Radio transmission/reception: The different uplink packets are transmitted to the corresponding base station through the air interface. Similarly, the downlink packets are received. Depending on the measured Eb/No and the interaction with the link level simulator the received packets may be successful or erroneous. Then, the corresponding acknowledgement (positive or negative) is transmitted.

- MAC/RLC functions: The generated packets are kept in a buffer and transmitted with a certain Transport Format (TF) in each Transmission Time Interval (TTI). This functionality is responsible for selecting the appropriate TFs in each case and carrying out the required retransmissions (if the service allows them) for the erroneous packets.

- MAC configuration: Depending on the control messages received from the RNC the MAC is configured in terms of the maximum allowed TF. This configuration is carried out either at the beginning of a communication (i.e., after acceptance by admission control) or at the middle (for instance if congestion has occurred).

- Session management functions: They are responsible for initiating the admission procedure at the beginning of a communication and the release procedure at the end, depending on the behavior of the traffic generators.

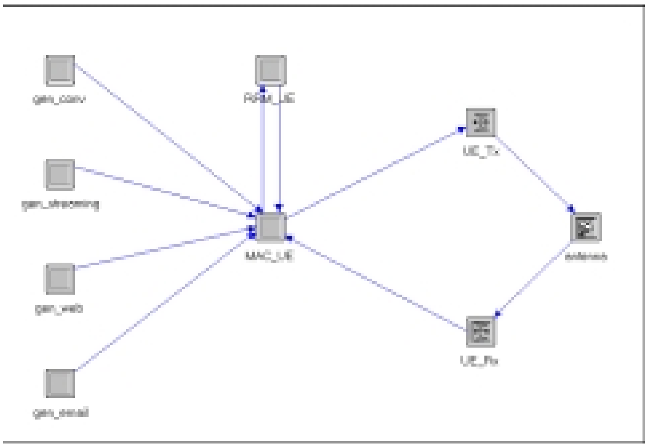

Figure 5: UE node model

These functionalities are achieved by means of 6 processes, as shown in Figure 5: four traffic generators (gen_conv, gen_streaming, gen_web and gen_email), the RRM_UE process that essentially controls and configures the MAC layer and finally the MAC_UE process, that implements the functions of buffering, and radio transmission/reception according to specific algorithms for the TF selection.

The state transitions for the MAC_UE process are depicted in Figure 6. As it can be observed, after the initialisation state (init) invoked at the beginning of the simulation, the process goes into the idle state waiting for different interruptions. There are 6 possible interruptions:

- UL_ARRIVAL: A packet coming from the uplink traffic generators is received. In this case, the process just keeps the packet in the buffer waiting for transmission.

- DL_ARRIVAL: A downlink packet is received. Depending on the measured Eb/No the process interacts with the link level simulation results to decide which transport blocks are successfully transmitted. The result is notified to the RNC node by means of an ACK packet.

- SEND_LAST_PACKET: This interruption comes from the traffic generator indicating that the last packet of a certain period has been sent. The generator will not generate any other packets until this packet is transmitted and the MAC_UE process sends the corresponding notification back to the generator. This restriction allows the implementation of traffic models like the WWW ones where no page is generated before the transmission of the previous one.

- CONTROL_PACKET: A packet is received from the RRM_UE process informing about the MAC configuration (i.e., indicating the maximum allowed TF that can be used for transmission).

- TTI_ARRIVAL: Each Transmission Time Interval (TTI) the process is interrupted and then it performs a radio transmission depending on the amount of information in the buffer and the algorithm that selects the Transport Format Combination that will be used.

- ACK_ARRIVAL: An acknowledgement packet containing the result of a previous uplink transmission is received. When this occurs, the process removes from the buffer the packets that have been successfully transmitted.

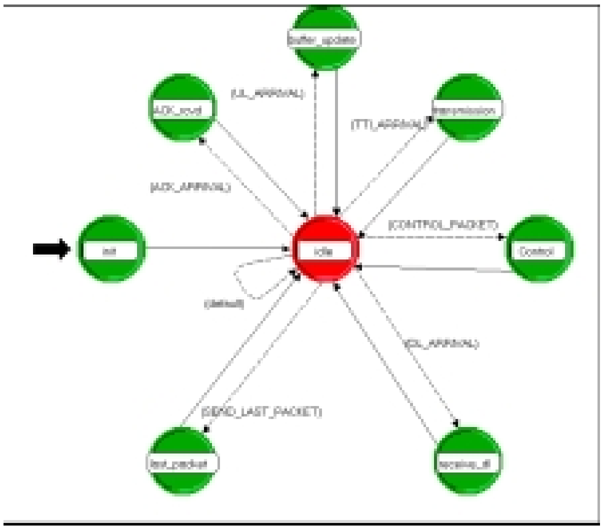

Figure 6: MAC_UE process

Rest of users node

The functionality of this node is identical to the UE_node and the only difference relays on the fact that it simulates the behaviour for a set of UEs that follow a mobility model instead of a user defined trajectory. Consequently, the process that are carried out are the same as for the UE_node.

RNC node

This node simulates a set of functions related with the radio resource management algorithms. Particularly these are:

- Admission Control: Algorithms to decide whether new sessions can be accepted or not.

- Congestion Control: This node carries out the detection of the congestion situation and triggers the corresponding algorithms to solve this situation.

- Handover algorithm: Depending on the measurements of the different transmissions the update of the active sets for the different UEs is carried out.

- Management of downlink transmissions: The different downlink packets are kept in buffers for the different users. The selection of the appropriate TF for carrying out this transmission is carried out in this node by executing suitable packet scheduling algorithms.

- Reception of uplink radio transmissions: This node computes the measured Eb/No for each transmission depending on the simultaneous transmissions in a certain frame. The decision about whether a transport block is correct or erroneous is carried out in this node depending on link level simulator results.

- Measurements: This node computes the required measurements to carry out the RRM algorithms. These measurements are Eb/No for each transmission, intercell interference, path loss and pilot Ec/Io. Although some of these measurements are carried out in the UE or in the BS of the real system, to reduce the simulator complexity and the amount of information exchanged between nodes, the simulator computes them in the RNC node, where they are processed and used by the RRM algorithms.

- Simulator synchronisation: This node establishes the simulation timing for the rest of nodes in the simulator. Particularly, it indicates the beginning of each 10 ms frame and invokes the rest of processes when required.

- Session management functions: This node handles the establishment / release of new sessions when requested by the uplink and downlink traffic generators.

The node model of the RNC node is depicted in Figure 7, and it is composed by 5 processes, namely admission, congestion, handover, InterfEvaluation and RNC_RRM.

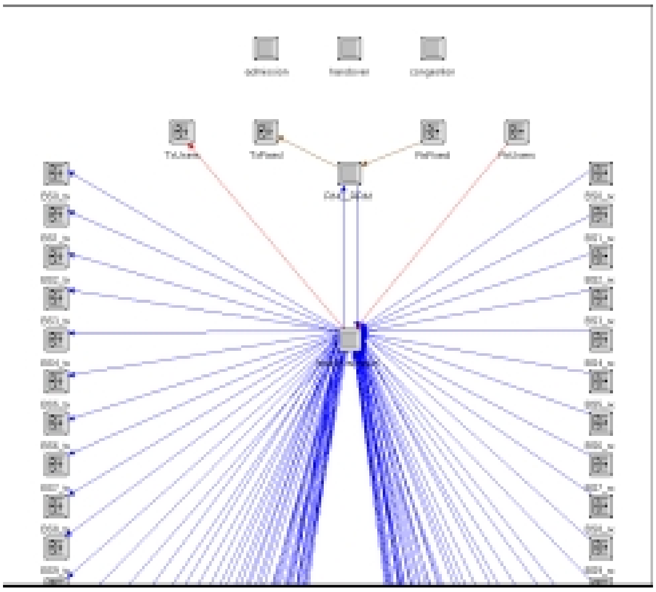

Figure 7: RNC node model

The RNC_RRM process is the main process of the simulator because it is responsible for tracking the simulation timing synchronisation of the different nodes involved in the radio transmission. Its state transition diagram is shown in Figure 8. After the initialisation state at the beginning of the simulation the process goes into the idle state. The interruptions that the process may receive are:

- FRAME_INTRPT: Each UTRA FDD frame time (i.e., 10 ms) the process receives this interruption and executes the instructions in the update_AS and DL_mgmt states. The first one carries out the different measurements (pilot Ec/Io, intercell interference, etc.) and decides whether or not it is time to verify if the Active/Reserved set requires to be modified for any user. If this is the case, it invokes the handover process. The DL_mgmt state decides the Transport Format to be used by each Radio Access Bearer in the downlink after executing the corresponding packet scheduling algorithm depending the required transmissions. This execution ends with the invocation of the InterfEvaluation process to perform the power control algorithm and decide the power devoted to each transmission. In turn, this process will invoke the MAC_UE process of the UEs that are active and whose TTI starts in the current frame.

- UL_PKT_ARVL: This interruption corresponds to the arrival of a control packet in the uplink direction. This packet may belong to an establishment / release procedure or may include acknowledgements of downlink transmissions. In the first case, the admission process will be invoked.

- DL_PKT_ARVL: This interruption corresponds to the arrival of a packet in the downlink direction, which can be either a control packet (establishment / release procedures) or a data packet (in this case the information is kept in the corresponding buffer of the user waiting for the appropriate frame to be transmitted).

- SEND_LAST: This interruption comes from the downlink traffic generators indicating that the last packet of a certain period has been sent. The generator will not generate any other packets until this packet is transmitted and the RNC_RRM process sends the corresponding notification back to the generator. This issue allows the implementation of traffic models like the WWW ones where no page is generated before the transmission of the previous one.

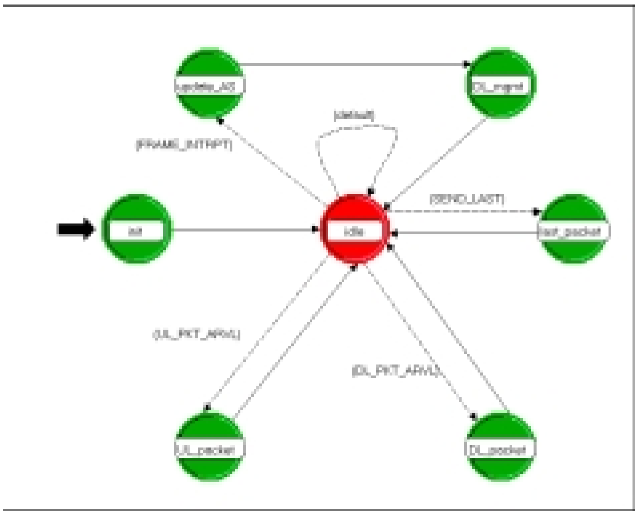

Figure 8: RNC_RRM process model

Figure 9 shows the state transitions diagram for the InterfEvaluation process. Essentially this process takes care of computing the path loss and the positions of the users in the “rest of users” node and it carries out the power control computations to derive the required transmitted power and measured interference by each transmission. After the initialisation state, it receives two types of interruptions:

- FRAME_INTRPT: Each frame time, the RNC_RRM process interrupts the InterfEvaluation process. When this occurs, it executes the following steps:

- Process_DL: The power control computations are executed for the downlink transmissions decided in the current frame by the RNC_RRM process. This allows the computation of the power required by each transmission. Each packet will then be sent to the corresponding UE through the corresponding BS.

- Process_UL: The power control computations are executed according to for the uplink transmissions that were received during the last frame. This allows the computation of the power that is transmitted by each user depending on the overall interference generated by the other users. Note that this process can only be carried out once all the uplink transmissions in a current frame have been received, because the RNC has not a previous knowledge of the TFC that is selected by the users that transmit in the uplink.

- send_ACKs: Once the measured Eb/No is decided for each uplink transmission, the link layer simulator results are used to decide the transport blocks that have been successfully transmitted. The corresponding positive or negative acknowledgments are sent back to the UEs.

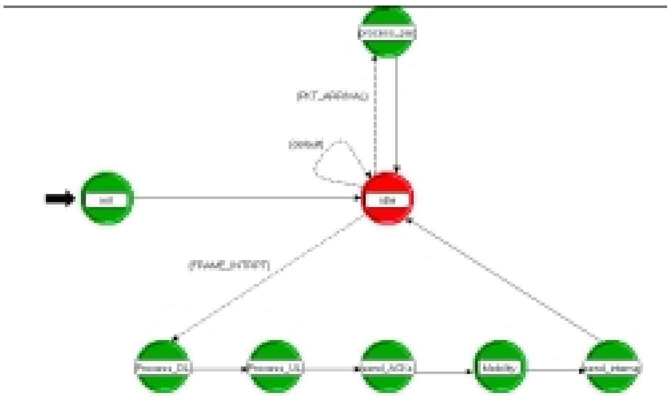

Figure 9: InterfEvaluation process model

- Mobility: The mobility model is applied to determine the geographical position of the users in the “rest of users” node. The path loss is computed accordingly. Although this information could have been computed in the rest of users node, since it is used by the RNC node rather than by the UE_node we preferred to compute it directly in the RNC node.

- send_interrupt: After having finished the previous steps an interruption is sent to the MAC process of all the mobiles that are admitted and whose TTI starts in the current frame. At the reception of this interruption, they will select the suitable TFC to continue with the uplink transmissions.

- PKT_ARRIVAL: This interruption invokes the process whenever a new uplink packet is received. If it is a control packet, it is sent to the RNC_RRM process. If it is a data packet it is kept until the reception of the FRAME_INTRPT interruption, when it will be processed.

Finally, the admission, handover and congestion processes have a common state transition diagram where, after the initialisation, they remain in the idle state, waiting to be invoked by other processes. In each invocation they execute the primitives included in the idle state to carry out the specific algorithm.

BS node

This node represents the node B behaviour. From the point of view of RRM, it simply transmits the different uplink packets to the RNC and the downlink packets to the UEs.

Fixed network node

From the point of view of Radio Resource Management, this node simply acts as a downlink traffic generation. Therefore, it simply contains traffic generators for the 4 service classes considered in the simulator (conversational, streaming, interactive and background).

Sample simulation results

In this section a set of sample results are shown in order to demonstrate how the developed OPNET simulator is able to evaluate the performance of different RRM algorithms. Each simulation scenario is set by means of more than 150 input parameters that define the traffic generation model, the mobility model, the physical parameters (i.e., power constraints, propagation models, ...), the number of users for each service and the parameters that define the behaviour of the specific RRM algorithms under test.

With respect to traffic, propagation and mobility models they are defined according to [6], and the characterisation of the used Radio Access Bearers for the different services is taken from [7]. Link level simulator results are obtained from [8].

Example 1: impact of different UE-MAC algorithms

One of the issues that can be analysed with this simulator is the effect of different algorithms for the selection of the transport format in the presence of interactive traffic. Particularly, the algorithms under test are the following:

a) Maximum Rate algorithm (MR): It simply selects the transport format that allows the transmission at the highest bit allowable bit rate depending on the TFCS and the amount of information in the buffer. Therefore, it will tend to use high bit rates which will turn into more interference to the other users.

b) Time oriented algorithm (TO): It selects the transport format that allows to send each packet in the buffer within a specified delay target.

c) Rate oriented algorithm (SCr): This algorithm tries to keep the average transmission bit rate by accounting the difference between the expected bit rate and the received bit rate for a user. This difference is called the Service Credit (SCr), and if SCr>0 the user has received less service than expected while if SCr<0 the user has received more service than expected. Therefore, the SCr is an indication of the number of transport blocks that should be sent in each TTI (or equivalently of the TF to be selected).

The differences in how these strategies operate are shown in Figure 10 and Figure 11, where the statistical distributions of the selected TF are shown for both the MR and the SCr strategy (with a guaranteed bit rate of 24 kb/s). It should be mentioned that TF1 corresponds with an instantaneous bit rate of 16 kb/s, TF2 with 32 kb/s, TF3 with 48 kb/s and TF4 with 64 kb/s. As it is observed, while SCr tends to use TF1 and TF2 (i.e., 24 kb/s lies in the middle of TF1 and TF2), MR tends to use TF4.

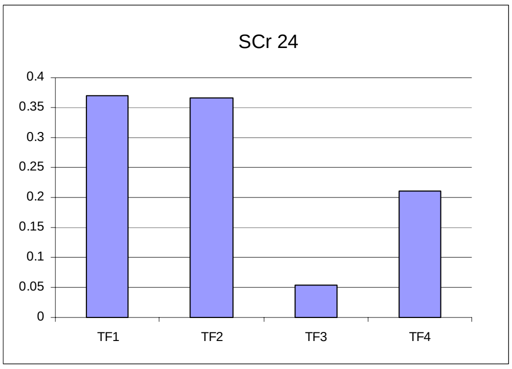

Figure 10: TF distribution for SCr strategy

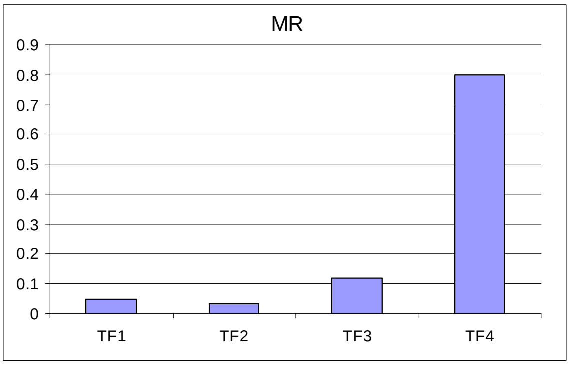

Figure 11: TF distribution for MR strategy

Similarly, Table 1 shows the performance of the different strategies in terms of dalay and rate. SCrX stands for service credit with X kb/s of guaranteed bit rate while TOX stands for time oriented strategy with a target delaly of X frames. As it can be observed, while the SCr strategy allows a differentiation in the rate (with the lowest jitter of the rate) the TO strategy keeps a low jitter for the delay of the different packets. On the other hand, MR provides the highest bit rate when compared to the other strategies but it is more likely to present congestion for high loads than the SCr or TO strategies. For further details, see [9].

Table 1 Delay and rate for different strategies

	Average packet delay (s)	Packet delay jitter (s)	Rate per page (Kb/s)	Rate per page jitter (Kb/s)
SCr16	1.8	2.28	14.2	2.1
TO18	0.18	0.16	21	12.1
SCr24	0.54	0.95	19	5.0
TO12	0.16	0.16	22.1	11.0
MR	0.12	0.18	23.6	11.3

Example 2: impact of downlink packet scheduling algorithm over a two-layered video streaming application
This example analyses how the downlink packet scheduling algorithm operates in the presence of video streaming users with two different qualities (i.e., a basic flow of 32 kb/s and an enhancement flow of 32 kb/s that is transmitted only if there are available resources. While the basic layer is transmitted through dedicated channels, the enhancement layer and the packet retransmissions for the basic layer are transmitted through shared channels.

Essentially the scheduling algorithm decides the transmissions for each frame prioritizing users depending on the bit rate that has been received from both flows, where the basic layer has a higher precedence than the enhancement layer. In order to evaluate the maximum number of allowable transmissions, the downlink load factor is measured and no transmissions are allowed when the expected load factor is higher than a certain threshold ϕ. Figure 12 presents the impact of this threshold over the bit rate achieved by the enhancement layer (for the basic layer the bit rate is always 32 kb/s). An optimum can be appreciated around 0.95. For further details see [10].

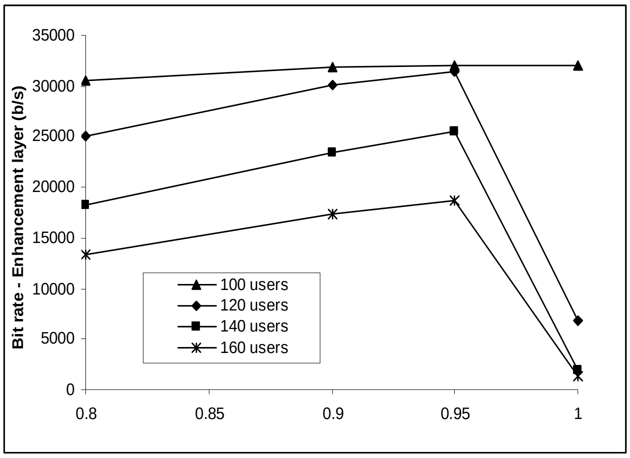

Figure 12: Bit rate for the enhancement layer

Example 3: impact of handover over admission control
In this example the influence of the handover procedure is presented. Specifically, in the admission control, a reservation is made for those users that are already in the system and are likely to start a handover procedure. Then, resources are reserved in the cell they are approaching. By means of this strategy, in an admission procedure, users in handover have precedence over new users.

The effect of this reservation strategy is shown in Figure 13, where it is observed that the reservation allows a reduction in the dropping probability (i.e., the probability of dropping a call because no resources could be allocated in the handover procedure) with respect to the case where no reservation is done.

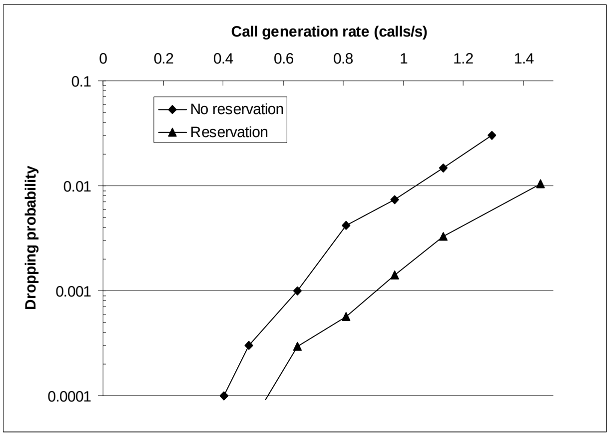

Figure 13: Impact of reservation strategy

Conclusion

This paper has presented a system level simulator that has been developed by means of OPNET in order to evaluate the performance of Radio Resource Management algorithms for UMTS. A description of the different nodes and processes of the simulator has been done and some sample results dealing with UE-MAC algorithms, packet scheduling and handover have been presented.

Acknowledgements

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References

[1] 3GPP TS 25.211, “Physical channels and mapping of transport channels onto physical channels (FDD)”

[2] H. Holma, A. Toskala (editors), *W-CDMA for UMTS*, John Wiley and Sons, 2000.

[3] 3GPP TR 25.922 v4.0.0, “Radio resource management strategies”

[4] 3GPP TS 25.331 v4.0.0, “RRC protocol specification”

[5] 3GPP TS 23.107 v4.0.0, “QoS concept and architecture”

[6] 3GPP TR 25.942 v.2.1.3, RF System Scenarios.

[7] 3GPP TS 34.108 v.3.2.0, Common Test Environment for User Equipment. Conformance Testing.

[8] J. Olmos, S. Ruiz, “UTRA-FDD Link Level Simulator for the ARROWS Project”, IST’01 Conference Proceedings, pp. 782-787.

[9] J. Pérez-Romero, O. Sallent, R. Agustí, “Admission Control for different UE-MAC Algorithms in UTRA-FDD”, 3rd International Conference on 3G Mobile Communication Technologies, London, May, 2002.

[10] J. Pérez-Romero, O. Sallent, R. Agustí, “Downlink Packet Scheduling for a Two-Layered Streaming Video Service in UMTS”, IST Mobile Communications Summit, Thessaloniki, Greece, June 2002.