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Modeling Multistandard Wireless Networks in OPNET

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Abstract

Future wireless communication is emerging towards one heterogeneous platform. In this new environment wireless access will be provided by multiple radio technologies that are cooperating and complementing one another. The paper investigates the possibilities of developing such a multistandard system using OPNET Modeler. A network model consisting of LTE interworking with WLAN and WiMAX is considered from the radio resource management perspective. In particular, implementing a joint packet scheduler across multiple systems is discussed more in detail.

Introduction

The development of wireless broadband networks is mostly driven by the high demand for capacity. The new systems like Worldwide Interoperability for Microwave Access (WiMAX) or proposed by 3GPP Long Term Evolution (LTE) fulfill this requirement. However, they need to adapt and interwork with the already existing technologies, like IEEE 802.11 Wireless LAN (WLAN). Such coexistence is already enabled and described by the standards. It is expected that the systems will cooperate with each other and eventually merge into one heterogeneous platform.

Recently, there has been a lot of interest in cooperative communications not only among the nodes of one network but also between the different networks themselves. The idea of collaborating standards is also realized by the concept of the 4th generation (4G) networking, where transmission is possible over a number of different kinds of networks. The network resources are shared between the standards and therefore used more effectively which has a number of advantages. First, it increases the networks capacity. Secondly, it helps to balance the traffic load, as the users with multimode terminals capable to operate in different Radio Access Technologies (RATs) could be moved between various networks. However, this will also require a seamless handover across the standards that will not interrupt or affect an ongoing service. Moreover, due to shared functions it reduces the cost of maintenance which is important for the operators. Finally, all these features lead to a significant increase of the overall network performance as a whole when compared to a set of homogeneous systems [1].

Developing a multistandard network means sharing not only the radio spectrum but also a set of common functionalities. This includes mechanisms responsible for discovering the available systems, selecting a network to connect and controlling the admission process. Once the connection is set up, additional schemes to manage the network load by the effective packet scheduling and congestion control are needed. Therefore, a dedicated Radio Resource Management (RRM) system implementing those functions for a heterogeneous platform is desired [2].

There has been a lot of research effort in designing joint packet scheduling methods, as it needs to meet a number of criteria. First of all, it should utilize the information from the lower layers of the network, like those concerning the channel state. Second, it should exchange these details across the standards, so that the optimal cross-layer and cross-standard scheduling decision can be made. Furthermore, it should consider also the Quality of Service (QoS) requirements while taking the scheduling decision. Finally, user preferences like those regarding the service cost should also be taken into account. To make it even more efficient, there have been some proposals to integrate the scheduler with the resource allocation, for details see [3].

In this paper, we present the modeling approach to a new problem of evaluating the performance of multistandard networks. An initial model to investigate the packet scheduling algorithms is presented. Our goal was to develop a simulation environment that would enable such evaluation. As this is an introductory project, here we use one of the widely adopted packet scheduling algorithms based on channel state feedback. For further and more detailed processing, this model will be enhanced and improved.

The paper is organized as follows. The next section gives an overview of the developed model and presents its key components and functionalities. After that, simulation setup is introduced and the results obtained with the OPNET Modeler are discussed. Finally, the paper is concluded with some remarks on future work.

OPNET Wireless Scheduling Model

OPNET Modeler [4] as an advanced research tool enables modeling various kinds of networks and currently provides models supporting WLAN, WiMAX and LTE standards. These are of a great help when used individually, or when the integration is done at a higher network level. In the case of our project, very specific and limited functionality is needed and most of the processing will be done in the physical and MAC layer. Therefore, integrating those built-in models is a challenging task and a custom model needs to be designed and implemented.

The functionalities of a RRM system include radio access network discovery and selection, spectrum allocation and power control in the physical layer. On the medium access layer it is responsible for call admission, packet scheduling, load balancing and congestion control, as presented in Table 1. In this work we focus on packet scheduling. We developed an OPNET model to evaluate the performance of packet scheduling algorithms in a heterogeneous network scenario. The other functionalities are omitted at this stage and will be implemented with the model development.

MAC	Admission Control
	Packet Scheduling
	Load Balancing
	Congestion Control
PHY	Access Discovery
	Access Selection
	Spectrum Allocation
	Power Control

Table 1: RRM Funcionalities

The model consists of 3 node models, namely traffic generator, scheduler and wireless user terminals. Packet generator models various types of traffic and delivers the packets to the scheduler. There, packets are queued for further transmission. Based on the Channel Quality Indication (CQI) which includes Signal-to-Noise Ratio (SNR) reported by the user terminals, scheduler calculates the users' priorities according to the scheduling algorithm. Then, it passes the first packet from a queue to the user with the highest priority. The details of the particular node and process models are presented in the following subsections.

Traffic Generator

Providing an easy manageable model is the reason to separate the traffic generator from the scheduler itself. Bursty traffic representing three flows is generated according to the parameters presented in Table 2, based on [5].

Type	Characteristics	Distribution Parameters
Video	Packet size	Log-normal (mean 4.9 bytes, st.dev 0.75 bytes)
	Interarrival time	Normal (mean 0.033 s., st.dev 0.01 s.)
VoIP	Packet size	Constant (66 bytes)
	Interarrival time	Constant (0.02 s.)
	ON time	Exponential (mean 1.34 s.)
	OFF time	Exponential (mean 1.67 s.)
WWW	Packet size	Pareto (mean 81.5 bytes, shape 1.1)
	Interarrival time	Normal (mean 0.0277 s. st.dev 0.01 s.)
	Session size	Normal (mean 25 packets, st. dev. 5 packets)
	Reading duration	Exponential (5 s.)

Table 2: Traffic Parameters

The model is built in a flexible way that enables further enhancements, as the traffic parameters can be set easily.

Scheduler

Scheduler is made of a scheduler processor and accompanying set of transmitter and receiver modules, one pair to connect with the traffic generator and the rest for the user terminals representing each of the standards. The node diagram is presented in Figure 1.

The scheduler is designated to evaluate algorithms providing channel quality feedback, like Maximum SNR or Proportional Fair (PF). Every Time Transmission Interval (TTI), which is a node attribute, it schedules the packets received from the traffic generator to appropriate users. The scheduling decision is based on CQI reported by the users. The scheduler is designed in a modular way; the specific algorithms can be loaded as child processes and interchanged whenever needed, thus providing overall model flexibility.

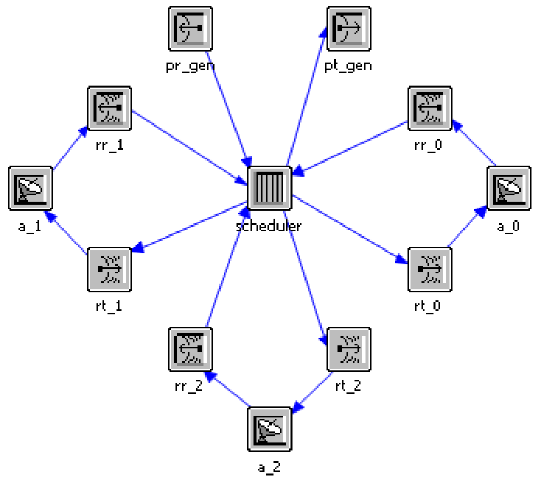

Figure 1: Scheduler Node Model

The scheduler handles the general packet processing and collects CQI reports, while child process deals with the specific node priority calculation. The process model of the scheduler is shown in Figure 2. After the initialization phase, the machine enters the IDLE state and waits for an interrupt. This can be caused either by an incoming packet- data from the traffic generator or CQI report from a user terminal, or by the expiration of the TTI timer. In the first case, a data packet is queued in a subqueue according to its destination. In the second case, the SNR value is extracted from the CQI packet and stored in a vector where position determines the CQI origin. Finally, when a TTI is triggered, it invokes the appropriate child process. When the control is returned to the master process, the scheduler forwards the packet to the user indicated by the scheduling scheme implemented in the child process.

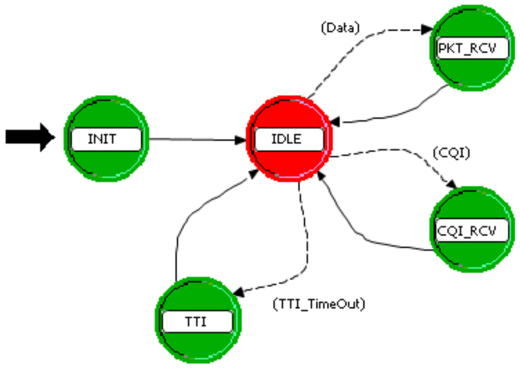

Figure 2: Scheduler Process Model

An example child process model is depicted in Figure 3 below.

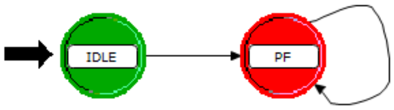

Figure 3: PF Child Process Model

In this example, we implemented the widely adopted Proportional Fair (PF) scheduling algorithm. The PF algorithm was proposed to be used in wireless networks by Qualcomm [6]. According to the algorithm, a user with the highest *k* parameter defined in (1) is chosen for transmission.

$$k = \frac{r_i(t)}{R_i(t)} \tag{1}$$

Where $r_i(t)$ represents the achievable data rate of user *i* at time *t* and $R_i(t)$ is the average data rate of user *i* over a time window t_c expressed by equation (2).

$$R_i(t) = (1 - \frac{1}{t_c}) \cdot R_i(t-1) + \frac{1}{t_c} \cdot r_i(t-1) \tag{2}$$

The achievable rate $r_i(t)$ can be determined by the scheduler based on the reported SNR value.

In the current implementation, Adaptive Modulation and Coding (AMC) is assumed to be set up at the LTE and WiMAX user terminal side. Based on the reported SNR value, maximum achievable throughput is determined according to the criteria presented in Table 3 and 4 based on [7-9].

Modulation	Coding Rate	SNR [dB]	Throughput [Mbps]
QPSK	1/2	5.0	2.88
	3/4	8.0	4.32
16 QAM	1/2	10.5	5.76
	3/4	14.0	8.64
64 QAM	2/3	18.0	11.52
	3/4	21.0	12.96

Table 3: SNR to Throughput Mapping: WiMAX (channel 10 MHz)

Modulation	Coding Rate	SNR [dB]	Throughput [Mbps]
QPSK	1/2	1.0	6.20
	3/5	3.0	7.99
16 QAM	1/2	10.0	11.45
	3/5	11.4	15.26
64 QAM	3/5	13.8	22.92
	3/4	15.6	27.38

Table 4: SNR to Throughput Mapping: LTE (channel 10 MHz)

For IEEE 802.11b WiFi we consider Adaptive Rate Selection (ARS) based on the signal strength, as in Table 5 [10].

SNR [dB]	Throughput [Mbps]
10.0	1.0
15.0	2.0
25.0	5.5
40.0	11.0

Table 5: SNR to Throughput Mapping: WiFi

User Terminal

The role of the user terminals is to constantly update the scheduler with the current SNR value and to receive the data packets; the node consists of a processor module, a radio transmitter, a receiver and an antenna. The node model is shown in Figure 4.

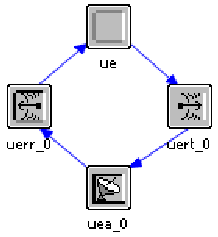

Figure 4: User Terminal Node Model

The process model of the user terminal is presented in Figure 5. After performing initialization, the machine proceeds to the ADDRESS state. This is to determine whether the node will be active during the simulation. It is particularly useful for scenarios with high number of nodes. In this case only one network topology setup can be prepared and specific nodes can be activated by setting the global simulation parameters. If a node is inactive, it remains switched off throughout the simulation. Else, it the machine reaches the IDLE state and waits for an interrupt. It may receive a data packet sent by the scheduler or be prompted to send a CQI update.

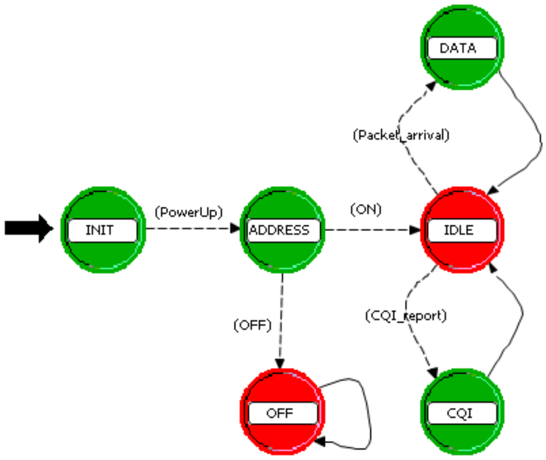

Figure 5: User Terminal Process Model

The user terminals are implemented as mobile nodes in order to take advantage of the wireless environment. However, at this stage of the project they are static and no trajectories are applied. In order to model mobility, the nodes generate SNR values according to their own patterns which are determined as follows. Each standard has predefined limits concerning SNR, as stated in Table 6.

	WimaX	LTE	WiFi
SNR Range[dB]	0.0-25.0	0.0-25.0	0.0-45.0
SNR Change Range [dB]	0.0-2.0	0.0-2.0	0.0-1.0

Table 6: Mobility Profiling

Maximum SNR Change (snrc) describes the mobility level of a node. Higher value implies higher mobility. This value is set randomly within boundaries specified in Table 6 once for each terminal and is valid throughout the entire simulation. Current change of the node SNR is chosen uniformly from the set <-snrc, snrc> and updated SNR is sent to the scheduler as a CQI report. The CQI packet has two fields, as depicted in Figure 6 below.

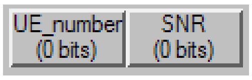

Figure 6: CQI Packet Model

It is presumed that CQI reports are error free and always available. Another important assumption is that, user terminal model enables AMC based on the measured SNR value. This allows estimating the maximum achievable throughput in the case of PF algorithm and was discussed in the description of the PF child process. However, the link between the scheduler and a user terminal is not affected by measured SNR and stays constant throughout the simulation. The channel model and transmission parameters are presented in the next section.

Channel Model

Three stages of the radio transceiver pipeline namely receiver group, closure and channel match are crucial at this phase of the project. For the two latter ones, we used the default models *dra_closure_all* and *dra_chanmatch* provided in OPNET. The default *dra_rxgroup* stage was modified, so that it prevents a terminal from overhearing its own transmissions. We do not consider any interference or noise affecting the transmission. The channels are defined as specified in Table 7.

	WimaX	LTE	WiFi
Min frequency [MHz]	3500	2110	2401
Bandwidth [kHz]	10000	10000	22000
Channel Throughput [kbps]	13000	30000	11000

Table 7: Wireless Channel Characteristics

As for the antennas used in the project, we included *wimax_omni_14dB* model provided by OPNET.

Simulation Results

In this section the results from a simulation experiment conducted in OPNET Modeler are presented.

We define a basic simulation scenario with a traffic generator, scheduler and three nodes, where each of the nodes represents one considered standard. Figure 7 shows the network topology. The goal of this setup is to investigate the influence of the network heterogeneity on fairness. As fairness measure the Jain's index [11], stated in (3) is used.

$$f(x_1, x_2, \ldots x_n) = \frac{(\sum_{i=1}^{n} x_i)^2}{n \cdot \sum_{i=1}^{n} x_i^2} \qquad (3)$$

Where x_i denotes the throughput of user i with n users in the system.

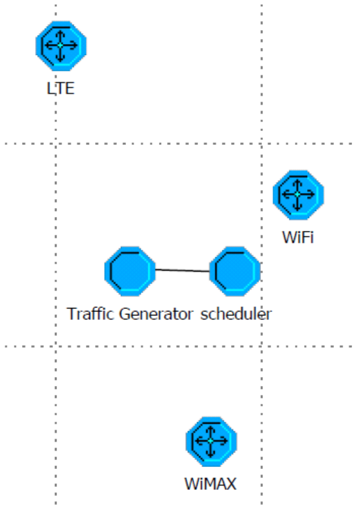

Figure 7: Network Topology

The simulation was run with the following parameters:
CQI frequency: 0.01 s.
TTI frequency: 0.001 s.
Window size t_c: 10
Simulation duration: 10 minutes.

The same setup is used for homogeneous network, where all the three nodes are set to use WiFi. The simulations were run with 5 different seeds and the averaged results are depicted in Figure 8.

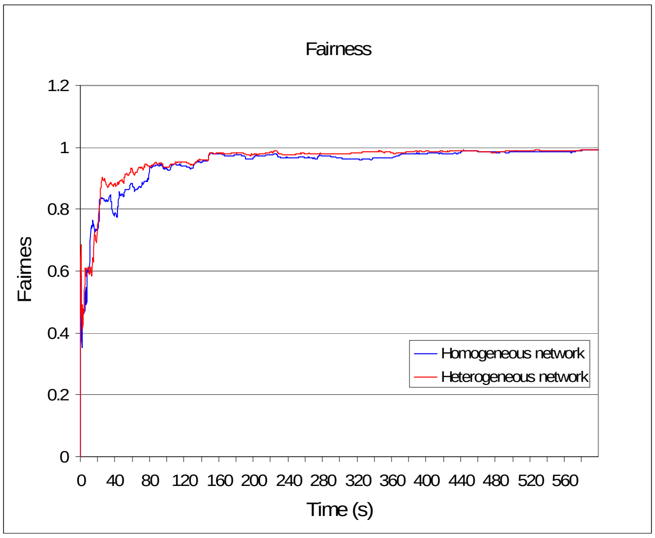

Figure 8: Fairness for Heterogeneous and Homogeneous Network

From the figure above, it can be observed that in both scenarios achieved fairness is very high but the stabilization time is quite long. Before the fairness reaches its maximum value, the heterogeneous scenario slightly outperforms the homogeneous one. In case of the heterogeneous network, PF algorithm not only achieves higher fairness but also reaches its maximum value faster than for the homogeneous network. This is due to the variety of user terminals. It may be very advantageous in the environments characterized by high mobility.

Additional information may be provided by the maximum throughput difference analysis, which is defined as the difference between the lowest and highest node throughput. The results for the two considered scenarios are presented below in Figure 9.

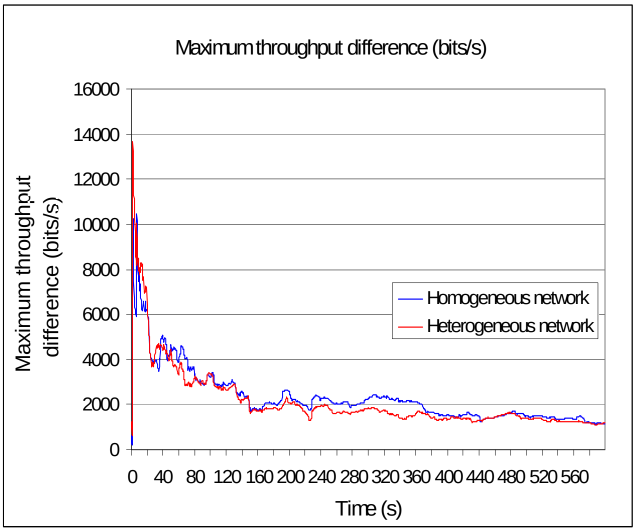

Figure 9: Maximum Throughput Difference

The difference between the throughput achieved by the nodes is nearly the same in both setups. Moreover, it is not so high, as it would be expected for the heterogeneous network, where the terminals have different throughput capabilities. Additional evaluation can be performed with higher traffic load. The scheme is very fair in terms of equal traffic distribution. However, this may lead to a situation, in which all the nodes achieve similar throughput regardless of the operating standard and those offering higher capacity will not be fully utilized. Therefore, obtained results indicate that the fairness definition for a joint scheduling scheme should be more accurate and take into account the capacity of the considered standards.

Conclusion and Further Work

In this paper, the problem and motivation for modeling heterogeneous networks was discussed and an OPNET model for evaluating channel feedback based packet scheduling algorithms was presented. Further improvements include modeling a dedicated joint packet scheduling scheme along with a multistandard reconfigurable base station (scheduler) and a multimode terminal which is capable to sense the radio environment or receive the information about the network availability.

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