EXECUTABLE MODELS FOR PERFORMANCE ASSESSMENTS OF ADAPTIVE MOBILE SYSTEMS

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ABSTRACT

The design of radio communication systems delivering wide variety of applications with the best end-user experience through the overall wireless networks implies to develop innovative services to encompass adaptation capability requirements. Then the creation of efficient executable models becomes a mandatory step to enable system architecting of such systems under timing and power constraints. In this paper, we propose a method based on the creation of an executable model, defined at transaction level, of an adaptive multi-standard and multi-application radio communication system. A specific modeling technique is proposed to represent the behavior of the system environment for different use cases. A generic model of the system is also proposed to describe several dynamic services and the reconfiguration management functionality. Simulation results provided by the model enable to study impact of reconfiguration mechanisms.

1. INTRODUCTION

Current trend in the field of radio communication [1] consists in offering terminals able to easily roam among heterogeneous networks like cellular, wireless local and metropolitan area networks. The purpose is to increase data rate and to propose access to a wide variety of services anytime and anywhere with a single device. This implies to design multi-standard and multi-application radio communication systems able to adapt to their changing environments and to make decisions about their radio operating behavior to fully meet expected quality of service (QoS). In this context, it is required to provide means to encompass these new aspects that refer to concepts like Cognitive Radio (CR) and Software Defined Radio (SDR) introduced by Joseph Mitola [2] in 2000. Technologies such as UMA (Unlicensed Mobile Access) [3] or I-WLAN (Interworking-WLAN) [4] deliver solutions for convergence managed at the access network level. They respectively allow GPRS/WLAN and UTRAN/WLAN interworking. However, these solutions do not encompass the global problem of seamless handover between all networks. Standardization activity such as P1900.4 [5] are so ongoing to define system architectures and protocols to allow user terminals choosing the most appropriate radio access technologies (RAT) among the ones available. In the End-to-End Reconfigurability (E2R) project a reference model [6] is suggested to describe the different elements necessary in a user terminal to bring the full benefits of these concepts. As an example, innovative services are proposed to identify appropriate RAT and to obtain expected QoS for running applications. The Cognitive Pilot Channel (CPC) concept has been introduced in [7] to assist terminals in RAT selection. It consists in a dedicated channel carrying information about available RAT in radio environment. Moreover, specific mechanisms must also be supplied to dynamically adapt the radio interface to the best configuration. It consists in providing new services to manage, deploy and configure RAT on a set of processors GPP, DSP and FPGA commonly available on a SDR platform. As an example, Software Communication Architecture (SCA) has been proposed by Joint Tactical Radio System (JTRS) program as a common infrastructure for managing software and hardware elements available in a system [8].

In this context, a significant step aims at defining techniques to obtain executable specifications in order to evaluate reconfiguration mechanisms required in future radio communication systems at a high abstraction level. Model Driven Architecture (MDA) methodology and Unified Modeling Language (UML) profile for software radio are mostly used to specify systems exhibiting potential flexibility with supported communication standards and user applications. Researches described in [9] present a modeling approach based on the combined use of MDA and SystemC to simulate SDR systems build upon SCA. SystemC is then used to support a Transaction Level Modeling (TLM) approach. The TLM approach leads to only exhibit significant transactions required for the system under study. It offers a good tradeoff between modeling accuracy and simulation speed [10]. A similar approach has been proposed in [11] for the design of radio communication system platforms. It highlights the link needed between requirements captured in UML2.0 and models execution to achieve platform architecture analysis. In our case, we focus on modeling mechanisms defined at transaction level and required to express functional properties of adaptive multi-standard and multi-application systems.

In this paper, we propose to create a TLM executable model to capture new requirements identified in an adaptive multi-standard and multi-application radio communication system. The case study considered addresses a system that supports two RAT, UTRA and WiFi, used to access to cellular and local networks, and three typical user applications: voice calling, Internet browsing and video streaming. This system should offer means to take into account information related to the internal state of the terminal and the context environment to define the most appropriate RAT to use. In the following we focus on required modeling techniques to achieve an appropriate functional description. An approach based on scenario files is proposed to drive the behavior of the modeled environment in order to facilitate evaluation of different use cases. We also propose techniques to efficiently model various services supported and their related management. Proposed mechanisms make possible to model supported adaptation of services and associated management. Besides executable SystemC code generated by the considered tool from graphical model captured can be simulated to analyze timing properties and performances of radio communication system according to different use case scenarios.

The remainder of this paper is structured as follows: section 2 describes our reference radio communication system. Section 3 presents the TLM approach considered to capture system specification. Section 4 details the modeling techniques used to represent identified specific properties at transaction level. In this section we describe the obtained simulation results. Finally, section 5 summarizes problem solving and concludes this paper.

2. CONSIDERED CASE STUDY

As previously mentioned we consider a system that supports two RAT and three user applications. An appropriate management of radio interfaces should maintain required QoS to ensure end-user experience in various radio environments. This new property implies to integrate new services within radio communication systems. The system should support dynamic activation/deactivation of one or more RAT. This adaptation mechanism should be monitored by a decision making module based on delivered QoS for each application. We present in Figure 1 the considered environment and relations with the radio communication system under study in the middle. The internal structure of such a system is refined using the activity diagram representation [12]. System activities are depicted by a rounded corner rectangle. To distinguish between event and permanent data relationships, we use single arrow links to denote events and double arrows links for permanent data.

In the considered case study the user is supposed to request applications to the system through *Application request* and *Application response* links. The system delivers three kinds of information related to the three applications supported: *Voice frame*, *Web page* and *Video frame*. Expected QoS for these applications are 20 frames per second for video, one frame of 160 samples every 20 ms for speech decoding and Web browsing corresponds to reception of varying size of data at about 1s. The network environment includes the activities related to application servers and transmission of data according to UTRA [13] and 802.11 [14] specifications. These radio links are depicted with three links: *Downlink UTRA*, *Downlink WiFi*

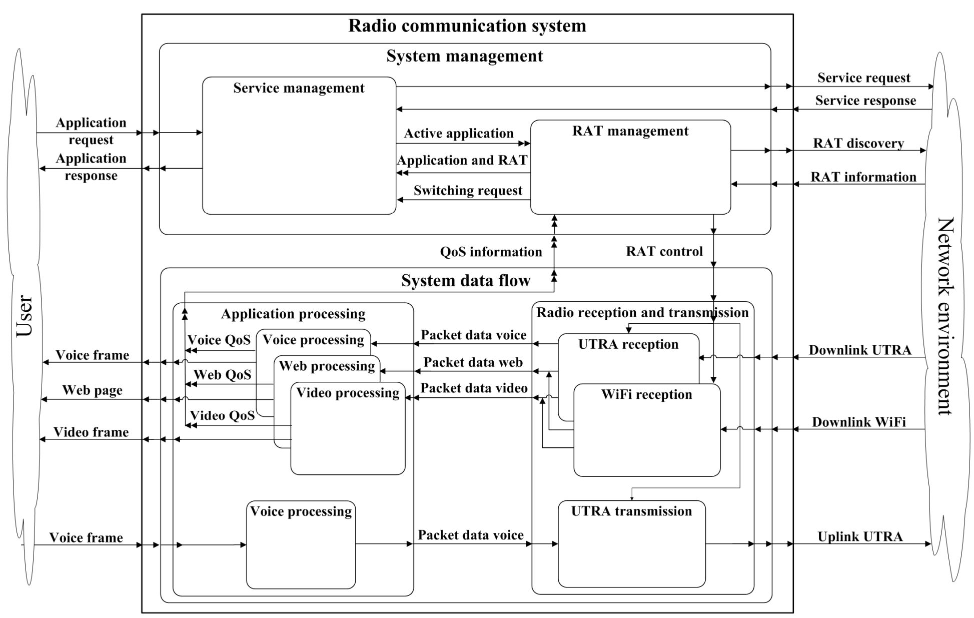

Figure 1: Activity diagram of an adaptive multi-standard and multi-application system and its environment.

and *Uplink UTRA*. The data size assigned per application in each radio frame depends on the channel quality of the link. For example, UTRAN is supposed to achieve at least 384 kbps in urban outdoor radio environment and at least 144 kbps in rural outdoor. WiFi has been defined to provide up to 54 Mbps data rate in indoor environment.

The internal structure of the system is composed of two subsets, *System management* and *System data flow* depicted in upper and lower part of Figure 1. The *System data flow* subset is made of activities concerned by data transmission in both uplink and downlink and application processing. UTRA and WiFi communication interfaces are depicted by *UTRA reception*, *WiFi reception* and *UTRA transmission* in *Radio reception and transmission* part, whereas applications are depicted with the *Voice processing*, *Web processing* and *Video processing* activities. The activities related to *System management* subset analyze QoS provided to user and perform request to the network environment. *RAT Management* activity receives information on data rate performance of the established radio link through the permanent relation *QoS Information*. In case of the QoS can not be maintained, *RAT Management* supports a discovery service to find a RAT offering better performance. It is also able to decide and carry out a reconfiguration process of radio interface based on information provided by the *RAT control* relation. This process consists in activating the required communication interface. Besides, the *Service management* activity communicates with the network environment according to the application request of the user. The RAT to be used depends on information provided by the *RAT management* through *Application and RAT* and *Switching request* links.

3. TRANSACTION LEVEL MODELING APPROACH

The benefits of a TLM approach are to offer an efficient evaluation of system performances through model execution with a limited simulation time. In our case, transactions identified in the data flow between the network environment and the radio communication system corresponds to the amount of data transmitted by each RAT. At this level, the associated payloads of transactions are defined according to expected throughput. For UTRA, transactions periodically occur every TTI (time transmission interval) set to 10 ms and the maximum payload is 480 bytes. For WiFi, the maximum payload is 2347 bytes and the transaction instants depend of the size of data to transmit. Considering this data granularity, activities can be described as finite state machines. For this description the formalism used is close to Statechart [15]. Figure 2 illustrates the technique used to obtain TLM description of the activities *UTRA reception* and *WiFi reception*. The FSM describe activities performed by layers involved in reception of data application (Medium Access Control layer, Radio Link Control layer for UTRA, Logical Link Control layer for WiFi). This type of description enables also to take into account the activation/deactivation of interfaces during system execution.

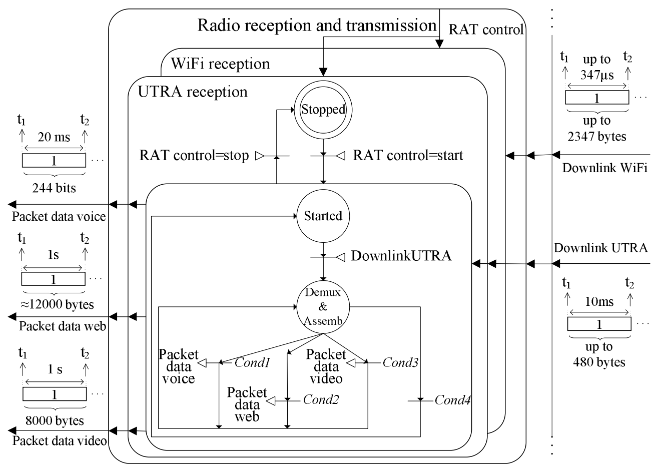

Figure 2: Activity diagram of adaptive radio interfaces.

When *UTRA reception* or *WiFi reception* activities are started, information are exchanged with other activities in the form of transactions. As previously mentioned *Downlink UTRA* and *Downlink WiFi* represent data transfer with the network environment. *Packet data voice, Packet data web* and *Packet data video* transactions represent the amount of data sent to related application processing activities. *Packet data voice* transaction must periodically occur every 20 ms with a payload of 244 bits. *Packet data web* transaction must be initiated 1s after the inquiring of the web page and contains quantity of data related to this web page. *Packet data video* must periodically occur with a payload of 8000 bytes every 1s so as to display video at a rate of 20 frames/s. When *Downlink UTRA* or *Downlink WiFi* transaction is initiated by the environment, *Demux & Assemb* state in reception activities carry out both demultiplexing of data (voice, web, and video) and reassembling of previously segmented application data packets. When an application data packet is fully merged a transaction is initiated and the activity related to the application processing can start to deliver a service to the user. The behaviors of *UTRA reception* and *WiFi reception* activities evolve according to the *RAT Management* activity. It decides to activate them through the *RAT control* link. These two activities can be in two states: stopped or started. This description represents the dynamic behavior of the RAT interface at transaction level.

4. TLM OF THE CASE STUDY

4.1. Modeling the system environment

The behavior of the radio communication system is closely related to external behaviors of its environment. Indeed the system is supposed to adapt its radio interface according to the expected QoS level. This level is defined as the minimum data rate required by the user for each application. Therefore, it is necessary to model the system environment to evaluate multiple use cases and to study the dynamic behavior of the system. A generic solution consists in capturing the evolution of the environment as a scenario file containing the main time information, application declaration and associated parameters. A similar technique has been used in [11] to express sequence of service requests provided by functional requirements. Figure 3 illustrates the solution used to model the evolution of the network environment.

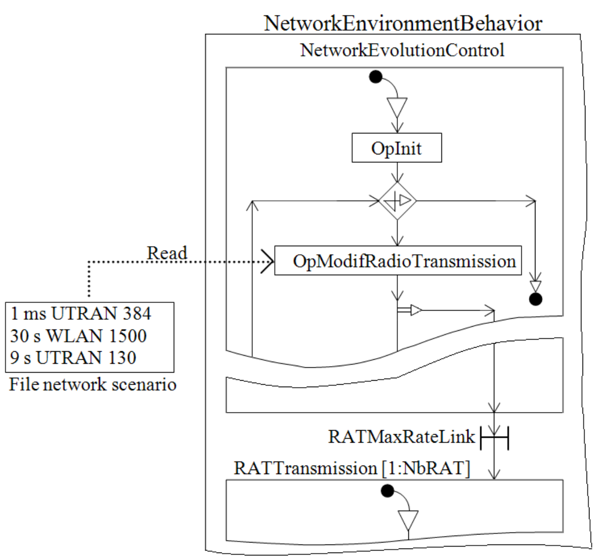

Figure 3: Management of the behavior of the system environment with network scenario file.

This figure presents a partial view of the network environment behavior captured with the graphical notation supported by the CoFluent Studio tool. This view focuses on one function used to describe the network environment activity. One role of the *NetworkEvolutionControl* function is to change the data rate offered by each RAT available in the network environment. Behaviors are described with basic elements: elementary operations (rectangle) and operators to obtain operation ordering description (initial instant, loop …). The content of the file directly impacts the function execution. Each line of the scenario file defines one change in the transmission conditions associated to the network environment. A line is composed of three fields. The first one gives the time information when the transmission condition changes. The two next fields define which access network is affected among UTRAN and WLAN and what is the new data rate delivered. The generic behavior of *NetworkEvolutionControl* function is described by operations that allow reading the network scenario file for model simulation. In the CoFluent Studio tool these operations are described in C++ language. At the beginning, the *OpInit* operation opens the network scenario file. Then the *OpModifRadioTransmission* operation repeatedly reads one line in the file. The time delay before sending the new data rate is associated to the duration of *OpModifRadioTransmission* operation. After this duration, the new data rate information is sent to the related *RATTransmission* function through the *RATMaxRateLink* channel.

We use a similar approach to describe applications requests for user. In the user scenario file, each line corresponds to an application request. The first field defines the time delay that must elapse before sending a request. The two other fields specify which application is inquired and if it must be started or stopped. This approach based on scenario files makes possible to rapidly create various use cases. We can then easily assess different system operating scenarios for several combinations of the user and the network environment behaviors.

4.2. Modeling an adaptive multi-service radio communication system

The system under study can be designated as an adaptive multi-service system. It is described as a set of functions that correspond to applications and communication interfaces. Moreover it offers services to adapt its radio interface to provide the best user solution in various changing radio environments. In this section we present a generic method to manage the resulting modeling complexity. We propose also techniques to model specific mechanisms related to the monitoring of QoS provided to users for running applications. Figure 4 presents the model created for the system. To facilitate the capture of each subset, functions of the *System data flow* have been modeled in a generic way. Each basic function is then an instance of an array of similar functions. The lower part of Figure 4 shows the resulting graphical model of the *System data flow* subset of the system obtained by using this technique. *UTRA reception* and *WiFi reception* activities are described with the same behavior named *RATReceptionBehavior*, whereas V*oice processing*, *Web processing* and *Video processing* activities are modeled through the *UserApp* function. The number of instances is defined with a parameter: NbRAT for communication RAT and NbApp for user applications. In the *RATReception* function, the *OpDataPacketAssembling* operation performs data demultiplexing contained in *DownlinkRATFrame* transaction. The time attribute associated to this operation corresponds to the frame duration of the RAT. Received data are then merged according to the related application. The *DataAppReceived* channel corresponds to the set of relations between the communication interface functions and the user application functions. The selector mechanism depicted as a triangle in the model is used to correctly select the appropriate instance according to the data manipulated. The *UserApp* function models the processes associated to each application. Each instance updates the *QoSInformation* shared variable with the data rate delivered by the RAT. The level of QoS is analyzed when applications are running. If need be, the application can use a new RAT. The discovery of RAT is then performed to detect if an appropriate RAT is available in the user environment.

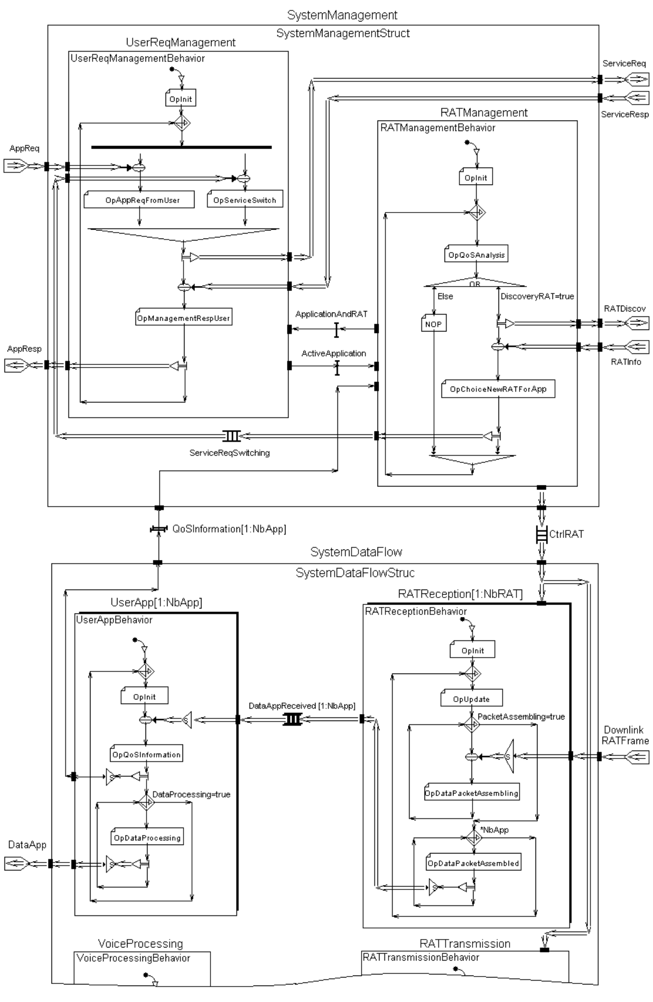

Figure 4: CoFluent model of an adaptive multi-service radio communication system.

The upper part of Figure 4 presents the model created for the *System management* subset. The *RATManagement* function periodically reads the *QoSInformation* shared variable indicating the different level of QoS delivered to user for each application. This information is analyzed in the *OpQoSAnalysis* operation to evaluate if each application is delivered to the user with its expected QoS. If one or more applications are not correctly delivered, RAT discovery is then activated. The *RATDiscov* channel is used to obtain information about available RAT in the environment and the data rate proposed. These information are received by the system through the *RATInfo* channel. The *OpChoiceNewRATForApp* operation decides if a new RAT should be used. The instances of the *RATReception* function can then be started or stopped during system execution. To model this functionality with the CoFluent Studio tool it is possible to define the *RATReception* function as a dynamic function controlled by the *RATManagement* function. The *CtrlRAT* channel is used to start, stop, suspend or resume the different instances of *RATReception*. This mechanism facilitates the representation of the adaptation capabilities of the considered system.

4.3. Simulation of the model

The CoFluent Studio tool supports the generation and simulation of an executable code. It is obtained by the translation of the graphical model in a SystemC description. The code size related to this model corresponds to 4476 lines of SystemC code and 62% are automatically generated by the tool. In our case, simulation consists in analyzing how the system reacts according to various use cases. Functional performance evaluation enables to verify if properties such as timing constraints and QoS can be maintained by the system. The selected use case considers a user who successively requests the three applications supported by the system. Moreover the user evolves in a changing radio environment. At the beginning of the system execution, only UTRAN is available with a basic data rate set to 384 kbps to ensure data transmission required by all running applications. Then the data rate of the UTRAN is decreased to 130 kbps to model a changing environment. Therefore the WLAN is detected to support the video streaming application with the QoS expected. Figure 5 shows a way to display simulation results to observe the detailed behavior of the TLM model of the system.

On the left side, functions and relations between functions described in the system and its environment are depicted. The arrows represent transactions performed between components of the model during the simulation of the use case. One can notice the successive start and stop requests of each application as expressed in the user scenario file. Initially the three applications are delivered by UTRAN. It is depicted by transactions between UTRAN reception (RATReception_1) or transmission (RATTransmission) and functions related to the user application. After 39 s, the user is in an area where the data rate delivered by UTRAN is not sufficient to ensure both the QoS for voice and video streaming applications. The system performs a discovery process and identifies a new RAT in its environment. Then it decides to activate the WLAN reception function and the video streaming application is switched on to this RAT. This type of display is useful to validate the functional and behavioral model of the system with timing information.

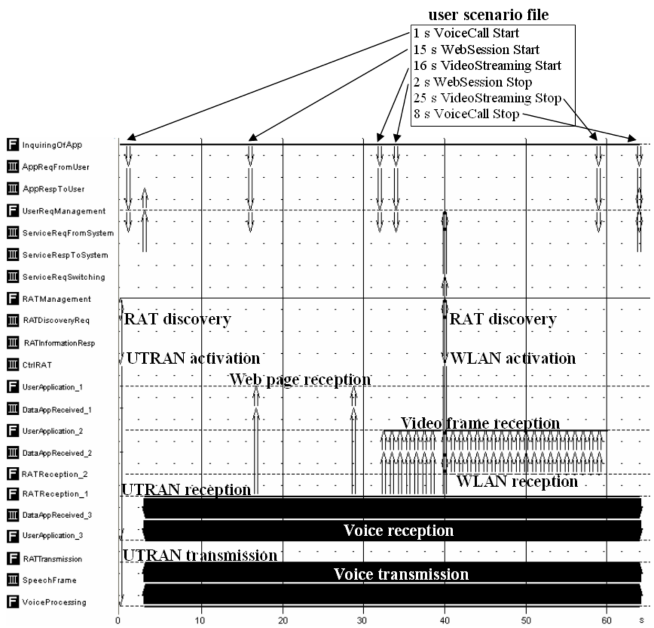

Figure 5: Transaction display of the radio communication system.

5. CONCLUSION

Radio communication systems are assumed to support new services to provide adaptation capabilities of radio functionalities according to internal and external changes. One important challenge is to provide performances evaluation of radio communication systems highlighting these new requirements. In this paper, we presented a solution based on transaction level model of an adaptive multi-application and multi-standard system. TLM leads to abstract representation to deliver reliable simulation results. An approach based on scenario files has been proposed to drive the behavior of the modeled environment in order to make easier evaluation of different use cases. We also proposed techniques to efficiently model various services supported and their related management. Executable SystemC code generated by the CoFluent Studio tool from a graphical model captured could be simulated to analyze timing properties and performances of the radio communication system. In the near future we plan to evaluate the related computation complexity required at transaction level to perform baseband signal processing for various RAT for platform sizing.

6. REFERENCES

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