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UML Modeling of IEEE 802.16e Procedures

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Abstract. The communication standards tend to be extremely technical and tedious documents defining the very behaviour of a given system. The IEEE 802 set of wireless communications standards for the Personal/Local/ Metropolitan Area Network mainly specify the two lowest OSI layers (physical and link) of the system, yet they comprise hundreds of pages requiring time and trained personnel to be comprehended. With the increasing pace of technology evolution, the development and implementation of communication standards is calling for new approaches facilitating easier comprehension of standardised functionalities as well as development and testing of new procedures. In this paper we investigate the applicability of the Unified Modeling Language (UML) for modeling communication standards, in particular the IEEE 802.16e network entry process. As an example we provide a high-level overview of the process as well as a more detailed view on the message passing sequences and subscriber station actions, and we conclude with some remarks on the suitability of the proposed approach.

Keywords: UML modeling, communication standards, IEEE 802.16e, network entry and initialization

UML modeliranje procedur v IEEE 802.16e standardu

Povzetek. Komunikacijski standardi so praviloma zahtevni in težko berljivi tehnični dokumenti, ki specificirajo delovanje določenega sistema. IEEE 802 brezžični komunikacijski standardi za osebna, lokalna in mestna dostopovna omrežja, ki definirajo predvsem spodnja dva sloja OSI sistema (fizični in povezavni sloj), obsegajo več sto strani in zahtevajo precej napora in izkušenj za njihovo pravilno razumevanje. Z naraščajočim tempom razvoja novih tehnologij je treba za razvoj in implementacijo komunikacijskih standardov uporabljati nove pristope, ki podpirajo lažje razumevanje standardiziranih funkcionalnosti kakor tudi razvoj in testiranje novih postopkov. V tem prispevku analiziramo primernost uporabe jezika UML za objektno modeliranje komunikacijskih standardov. Kot primer smo izbrali modeliranje postopka vstopa v omrežje in inicializacije v IEEE 802.16e standardu, za katerega prikazujemo pregled celotnega procesa kot tudi vpogled v sekvence izmenjave sporočil med omrežnimi entitetami in v delovanje mobilne postaje. Prispevek končamo z ugotovitvami o primernosti uporabe predlaganega pristopa za standardizacijske postopke v komunikacijah.

Ključne besede: modeliranje UML, komunikacijski standardi, IEEE 802.16e, vstop v omrežje in inicializacija

1 Introduction

Wireless access systems that provide end-users with high bandwidth and mobility are seen as the key segment of the next generation networks. The market pressure for new technologies, supporting novel applications and higher bit rates, to become commercially available increases continuously, which translates in the increasing pressure on standardisation procedures and on system designers. This increasing pace of technology development is particularly visible in mobile communications and wireless access networks, two traditionally complementary technologies that are lately converging towards mobile broadband wireless networks. The success of the prevalent technology representatives, e.g. GSM with enhancements such as GPRS and EDGE and UMTS in mobile communications and WiFi in wireless access, can be to a great extent attributed to the timely standardisation process and its broad acceptance.

The main importance of standardisation in telecommunications is to arrive at compatible standards for user equipment and network solutions. This applies to radio and fixed networks as well as to mobile and satellite services. The broader the acceptance of a given standard the better interoperability between the equipment from different manufacturers, the lower the prices for the equipment due to the international competition and the economy of scale, and the higher the satisfaction of users. Nevertheless, the development of standards is a long and tedious process with thousands of experts working on different parts. A non-expert that takes a look at a typical set of communication standards is rapidly discouraged by the amount of information and technicality of the language.

Due to a short development time standards are typically specifying the main functionalities and interactions between layers and network entities. Thus they ensure the interoperability of systems and equipment from different vendors, while leaving the

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concrete implementation and the choice of most suitable algorithms to the equipment manufacturers. In order to ensure compliance with standard requirements and to be able to develop and test the newly implemented procedures under time pressure communication system designers need to make use of new approaches and tools. In the light of this, the Unified Modeling Language (UML) appears as an efficient tool for modeling communication systems and protocols. In particular, the UML model could help training novel personnel much faster by providing an overview of the system at different levels of abstraction; it could shorten the development time, ease integration and help maintain a system [1].

UML has emerged from the field of software engineering as a need to analyze and design object oriented applications. Its development started in 1994 [2] and the most up to date version is available from the developer, the Object Management Group (OMG) [3]. Nowadays UML is a standard language for specifying, visualizing, constructing, and documenting the artefacts of software systems, as well as for business modeling and other non-software systems. This way UML facilitates project teams to communicate, develop and validate system architectures. UML is being increasingly used also for the system on chip (SoC) design [4], real-time embedded system design [1, 5], quality of service (QoS) [6], etc.

The advances in UML as well as in communications systems (software defined radio, software implementation of the physical and link layers of OSI [7] as opposed to traditional hardware implementation) seem to open the road for modeling such systems using UML. Exporting UML-modeled communication systems directly to the source code capable to run on a device would significantly cut down costs and shorten time to market.

This paper investigates the applicability of UML for object-oriented modeling of communication procedures on an example of the network entry process according to the IEEE 802.16e standard. It is providing a high-level overview of the process as well as a more detailed view on the message passing sequences and subscriber station actions. The rest of the paper is structured as follows. In Section 2 a short overview of IEEE 802.16 standards is provided while Section 3 briefly presents UML. The IEEE 802.16e network entry and initialization modeling using UML diagrams is presented in Section 4. Section 5 concludes the paper.

2 IEEE 802.16 standard

IEEE 802.16 is a broader term for a set of standards that have evolved over time for a set of air interfaces based on a common Medium Access Control (MAC) protocol and different physical layer specifications dependent on the used spectrum and regulation requirements. The IEEE 802.16-2004 standard [8] for fixed broadband wireless access is a document of about 900 pages. It is integrating earlier editions of the standard for frequencies between 10 GHz and 66 GHz (IEEE 802.16 approved in December 2001) and its amendment IEEE 802.16a with some MAC modifications and a set of new physical layer specifications for frequencies between 2 GHz and 11 GHz (ratified in January 2003). The IEEE 802.16e-2005 standard [9] is an amendment to the IEEE 802.16-2004 standard with more than 800 pages. It is addressing mobility, better support for Quality of Service and the use of scalable OFDMA, and is written so that it deletes, updates or adds things to the IEEE 802.16-2004 standard. Thus, when searching for mobility-related issues, one has to switch between the two standards to get an updated and coherent picture of the system.

Two specific technology solutions based on the standards IEEE 802.16-2004 and IEEE 802.16e-2005 are WiMAX (Worldwide Interoperability for Microwave Access) and mobile WiMAX referring to systems built using the respective standard and the OFDM physical layer as the air interface technology. For the latter, the conformity tests are still under development, so modeling of such system could be of particular importance for system designers.

The IEEE 802.16-2004 and IEEE 802.16e-2005 standards are organized as follows: first an overview mentioning the scope of the IEEE 802.16 is given; then the three sub-layers: Convergence Sub-Layer (CS), Medium Access Control-Common Part Sub-layer (MAC-CPS) and Security Sub-layer (SS) of the OSI link layer are defined; next physical (PHY) layer aspects, configuration, parameters and constants, encodings and finally system profiles are defined [8, 9].

In order to investigate the utility of the UML-based approach in designing the IEEE 802.16 system, we chose the network entry and initialization procedure of an IEEE 802.16e compatible system. This procedure is defined in the Data/Control plane of the MAC Common Part Sub-layer and comprises 15 sections in the IEEE 802.16e-2005 standard, each section having several sub-sections or redirecting the reader to adequate paragraphs within the IEEE 802.16-2004 standard. Some sections use activity or state machine diagrams to ease understanding the message, but the use of these tools is not unitary and coherent. Getting a comprehensive picture of the system architecture and its operation is thus a tedious and time-consuming task.

3 UML

Complex system architecture and its behaviour as a whole are difficult to understand since they require a large amount of information to be blended in order to form a coherent picture. Training and time are needed for people to get to understand a system, and without a good modeling and documentation, the knowledge is hard to pass on or might be lost once the key people move on [10]. In a particular case of communication systems, which are hard to understand due to their abstract nature [10], good modeling and documentation are even more important. Well built UML models can help understand systems and keep trace of these rapid changes, thus easing the introduction of new protocol versions in the communication system model, and speeding up the development of software protocol stacks.

UML is a general purpose modeling language that uses a graphical notation to model a system. An abstract model of a system, called the UML model, helps define in a clear way the architecture of the system from macro to micro level, as well as interactions between different parts of the system. UML emerged from the software engineering field as a need to visualize, design, develop and document software systems. The language was also adopted by companies in non-software business that used it for modeling of business, mechanical systems, etc. One of the advantages of UML is its independence of methodology so that each organization can select the methodology and tool that best serve its needs [2].

UML can be used to model an application and UML tools allow automatic generation of source code based on the specified model. Code can be generated in an object-oriented language such as C++, Java and C#, or in non-object-oriented languages such as Fortran, Visual Basic and Cobol. There are also some tools that analyze existing source code and reverse engineer it into UML diagrams. Some tools exist for generating test and verification suites from UML models [3].

In this paper we investigate if UML modeling can be utilised for modeling communication system procedures, such as those specified in the IEEE 802.16e-2005 standard, and then used for personnel training, system development and maintenance purposes.

As with UML 2.0, 13 types of diagrams are defined that offer flexibility in modeling systems. Diagrams can be grouped into two main categories, the Structure Diagrams and the Behavior Diagrams; and one subcategory, the Interaction Diagrams (see Figure 1):

- Structure Diagrams are used for static modeling of a system/application by specifying what it should be comprised of. They model the structural composition. UML 2.0 Structure Diagrams include six types of diagrams: Class, Object, Component, Composite Structure, Package, and Deployment.
- Behavior Diagrams are used to describe the behaviour of a system. They model things a system should do and states it should go through. Behavior Diagrams include three types of diagrams: Use Case, Activity and State Machine.
- Interaction Diagrams are derived from the Behavior Diagrams and focus on interaction between system/application components. Interaction Diagrams include four types of diagrams: Sequence, Communication, Timing, and Interaction Overview [3].

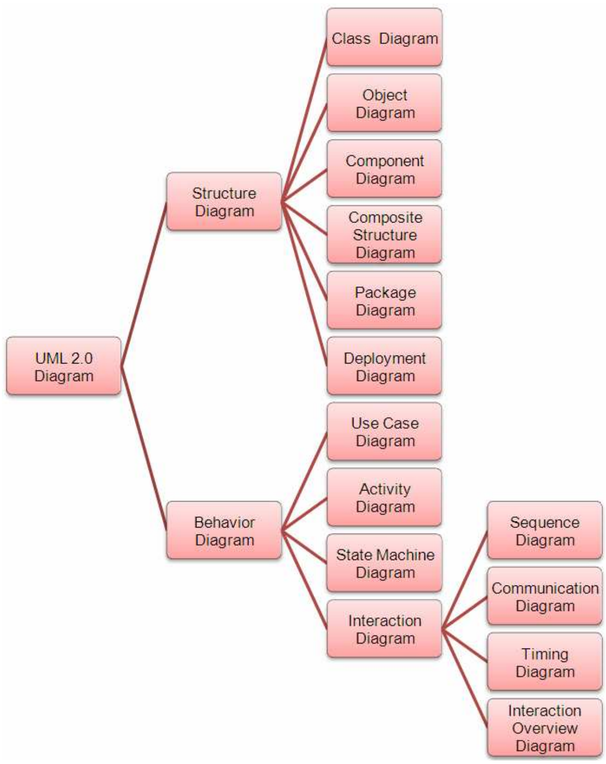

Figure 1. UML 2.0 diagram hierarchy [11].

The main criticism regarding UML is that it is too large and complex and contains too many redundant or infrequently used diagrams and constructs [11]. The bloat of the language is probably due to the fact that its aim is being general purpose. Another UML drawback seems to be the difficulty of learning and adopting the language [12]. The perspective of model-driven design in which the model can be exported to executable code is very appealing and UML 2.0 is aiming at it. Nevertheless, exporting UML models to code does not seem to be as straighforward as desired [13].

4 Network Entry and Initialization modeling

In the following, UML will be used to model the network entry and initialization according to the IEEE 802.16e-2005 standard. A high-level overview of the main stages in the network entry and initialization process is provided using a use-case diagram. For each stage a more detailed view of the messages that are passed between the base station (BS) and the subscriber station (SS) can be provided by sequence diagrams. After looking at the messages passed at each particular stage, a complete and unitary view of the message exchanges during the whole network entry and

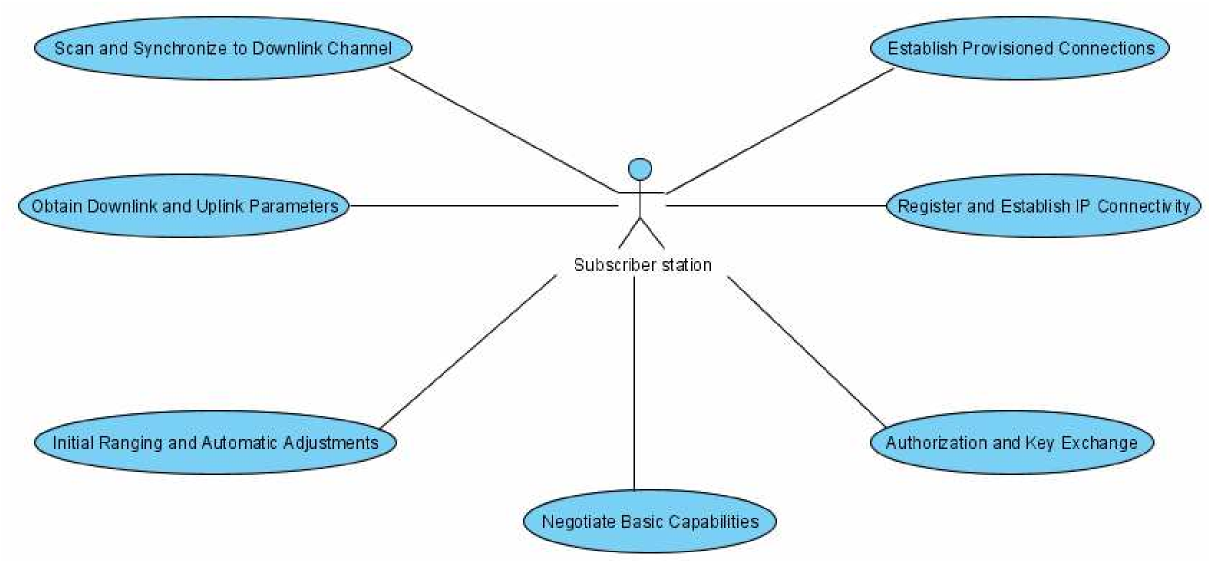

Figure 2. Network entry and initialization use case.

initialization process can be provided. Finally, the states of the SS during each stage of the network entry and initialization process can be detailed using activity diagrams. The aim of this approach is to help a non-expert to get a good insight into the network entry process in a short time. The documentation of the model can also be exported to an html document to facilitate fast browsing.

4.1 High-Level Overview

A high-level overview of the network entry and initialization in the IEEE 802.16e-2005 standard can be provided using behavior diagrams. By using behavior diagrams, the model describes the main things the system will perform. Use-case diagrams were chosen for giving this high-level overview due to their simplicity. Activity diagrams or state machine diagrams could have been also used, but these type of diagrams offer more details because of their nature. The activity diagrams offer information about the flow of the events in the system while the state machine diagrams show the logical transition between states. The use-case diagrams will concisely present the functionality of the system.

According to the IEEE 802.16e-2005 standard, the SS has to go through seven stages (see [8, 9]) in order to enter a network and use the services it provides (see Figure 2). The first stage consists in scanning and synchronizing to the downlink channel that is modeled by the Scan and Synchronize to Downlink Channel use case. The other six steps are modeled by use cases having suggestive names: Obtain Downlink and Uplink Parameters, Initial Ranging and Automatic Adjustments, Negotiate Basic Capabilities, Authorization and Key Exchange, Register and Establish IP Connectivity and Establish Provisioned Connections.

Without reading the entire documentation, a user knows from such an overview that the network entry and initialization in the IEEE 802.16e-2005 standard requires seven stages and knows their names. The sequence in time of the stages is not clear from the use case (aimed to keep the description simple), but it will become clear from the sequence diagrams.

Each use case has a short description that explains what it does. The Scan and Synchronize to Downlink Channel use case has the following description:

> *"During this phase, the SS listens to DL frame preambles, tries to synchronize with these preambles (PHY level synchronization), after which it listens for DL_MAP management message and tries to decode it (MAC synchronization)."*

According to this description, the device performs some kind of listening to the control messages sent by the BS on the channel. For more detailed information, the use-case documentation can be checked:

> *"The Scan and Synchronize to the Downlink Channel operation is the first step a SS performs to enter a network after signal loss or power on. The SS tries to connect to a BS using the last successful set of parameters. If it cannot achieve synchronization using that set of parameters, it scans the preferred frequencies provided by the operator."*

Further details can be viewed by checking the justification or sub-diagrams of the corresponding use case. Since UML has been initially developed and is

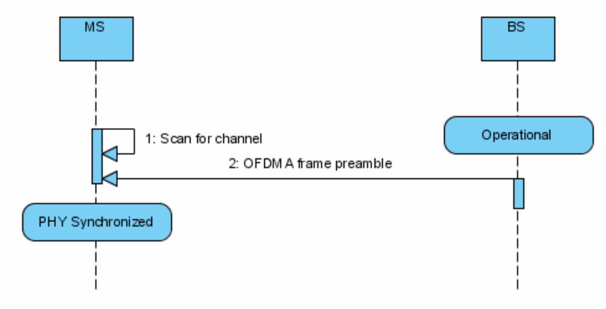

Figure 3. Achieve PHY Synchronization sequence diagram.

still mostly used for software engineering, many tools offer documentation template (leaf, rank, multiplicity, derived, etc.) specific to the industry which is not particularly well suited for modeling communication systems. Nevertheless, some of these templates can be configured to suit the needs of non-software applications, or, alternatively, tools for modeling non-software systems can be used (e.g. SysML [14]).

4.2 Detailed Interaction Overview

Each use-case diagram that models the network entry and initialization has one or more sub-diagrams modeling the message passing between the SS and BS during the corresponding phase of the procedure. As an example, the Scan and Synchronize to Downlink Channel use case has two sequence sub-diagrams: Achieve PHY Synchronization and Achieve MAC Synchronization. The first one shows the messages that are passed to achieve physical synchronization. It scans different frequencies on the downlink channel and synchronizes with an OFDMA frame preamble as depicted in Figure 3.

Each message that is passed is documented correspondingly, so the user can understand its role in the message flow. As en example, the Activation (vertical rectangle) on the SS's side is described as:

> *"The SS tries to acquire a downlink channel using the last operational parameters stored in a non-volatile memory. If unsuccessful, it scans for a channel using predefined, operator specific, parameters. SS can achieve PHY level synchronization using OFDMA frame preambles."*

This explains the actions of the SS while trying to achieve PHY synchronization.

Sequence diagrams were chosen to model the message passing between the communicating entities since they are able to show the time sequence in this communication. Interaction overview diagrams are also suited to model message passing, but these diagrams are more complex, as they show workflow through the sequences [15]. This kind of diagram combines sequence and activity modeling. Communications

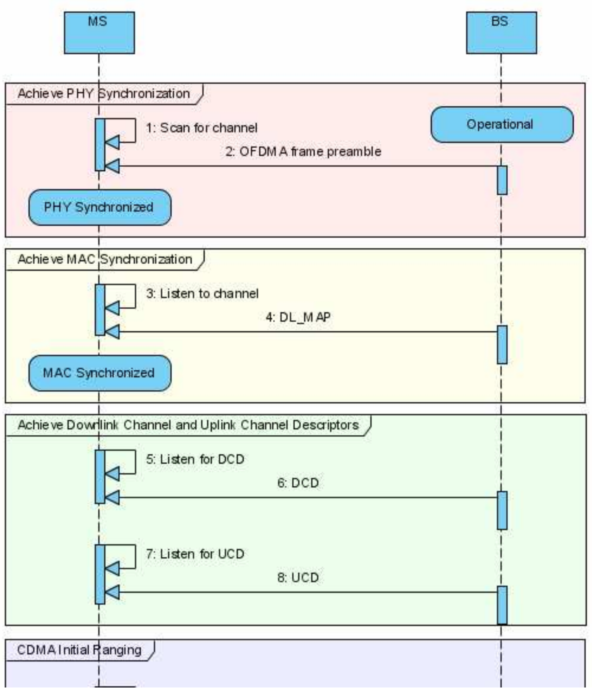

Figure 4. Network entry and initialization sequence diagram.

diagrams are similar to sequence diagrams but they are more suitable for use when showing the context of a communication is more important than showing the time sequence [15]. The timing diagrams were not suited for the purpose of this modeling since they offer clocking, i.e. synchronization information.

4.3 Holistic Interaction Overview

All the sequence use cases showing message passing during the stages of the network entry and initialization can be grouped in timely fashion to give an overview of the entire process. Figure 4 depicts part of the sequence diagram showing the interactions between the SS and BS during the network entry and initialization process. Each sequence diagram that was used as a sub-diagram of the use-case model defined in Section 4.1 is depicted with different shading.

By looking at the network entry and initialization sequence diagram one can see the order in which messages are passed in time to perform the network entry and initialization. First, the SS achieves physical synchronization, then it achieves MAC synchronization, it continues with achieving channel descriptors, proceeds with CDMA initial ranging, etc.

An alternative solution for the holistic interaction overview of the network entry and initialization model could be based on interaction overview diagrams. They would have offered a more detailed holistic overview of the process by incorporating activity information, thus providing an even better model.

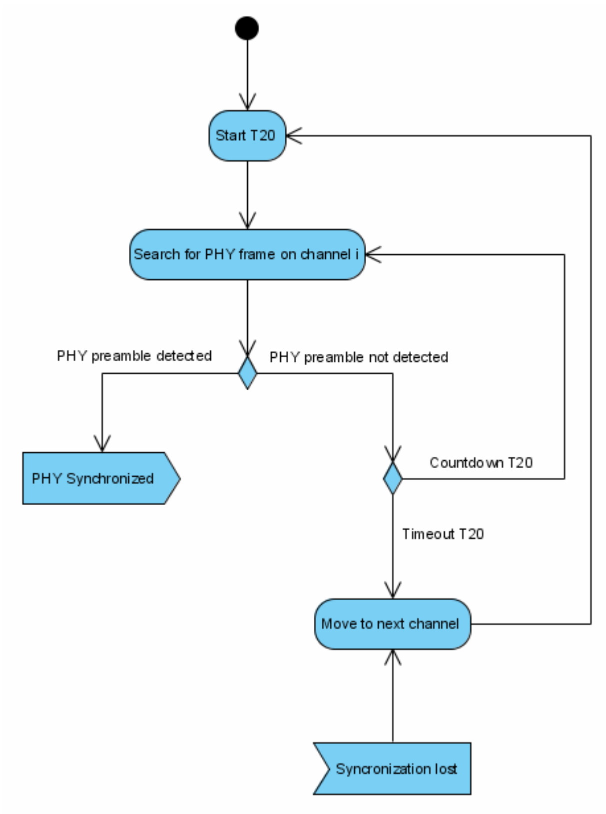

Figure 5. Achieve PHY Synchronization activity diagram.

4.4 Detailed Behaviour Overview

The detailed behaviour overview describes what is happening on the SS and BS side during the message passing interval within the network entry and initialization procedure. In this respect the states of the SS are modeled using activity diagrams, which were chosen due to their property of modeling behaviour, particularly sequence flows of activities.

Figure 5 shows the activity diagram corresponding to the activity happening on the SS side while achieving physical synchronization (see sequence diagram in Figure 3 or the corresponding diagram overview in Figure 4). After turning the power on or signal loss, the circuit blocks/software on the SS responsible for achieving physical synchronization start a timer (T20 in Figure 5), start searching for a valid downlink channel (a channel on which a BS advertises its services) and synchronize to it by detecting a preamble. If the SS manages to synchronize, it sends an appropriate signal and continues the network entry process, otherwise it moves to another channel. As with all other models, each state in the activity diagram is documented accordingly.

5 Conclusions

In this paper, an attempt is made of modeling the network entry and initialization according to the IEEE 802.16e-2005 standard using UML. A brief overview of the IEEE 802.16 standard and UML is provided and then the models are presented and discussed. High-level as well as more detailed overviews of the network entry and initialization ware given throughout the paper using suitable diagrams. Use-case diagrams are used to specify the high-level overview of what the SS should do to achieve network entry and initialization. For the interaction overview, the message passing is modeled in detail using sequence diagrams, while the behaviour of overview is presented by the activity diagrams. Advantages of some diagrams over others for modeling certain aspects are analyzed and alternatives for modelling suggested.

UML specifies a comprehensive set of diagrams suitable for modeling a variety of things: from classes in an object-oriented system to business models. For simple and small-scale tasks it seems redundant but it can prove to be a good tool for managing large projects with long life expectancy such as in avionics/aerospace, shipping and other similar industries where products lifecycle is of tens of years. For rapidly changing technologies, such as information systems, it can prove to be useful for managing, upgrading and, as pointed out in this paper, for representation of standards and their actual implementation. For the particular case of communications systems, however, UML has not been widely used although it is capable to perform a good modeling of such systems. The main reason lies in the fact that it is a general-purpose tool with several features that appear to be redundant or not optimised for modeling of communication systems and protocols. Nevertheless, the work in extending UML profiles for systems [14] and communication systems [16] is ongoing, so the future might focus more on modeling as a natural way of developing systems. In particular, a new modeling language, SysML (System Modeling Language) targeting modeling of systems has been standardized by the OMG recently. SysML uses some of the UML 2.0 diagrams, modifies others and adds extra diagrams to respond system modeling needs [14]. For instance, SysML defines requirement diagrams that can be used for a high-level overview as an alternative to the use-case diagrams in UML [5]. Another group is working on the definition of an extension for UML 2.0 that would support the modeling of communication systems. The extension will be inspired by the experience made with the Specification and Description Language (SDL) [16].

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