TEACHING WIRELESS TELECOMMUNICATIONS: EXPERIENCING THE NETWORK TO STIMULATE THE LEARNING PROCESS

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Abstract

Teaching on wireless telecommunication networks faces a number of challenges, such as the fact that contents are dynamic in nature, the resulting framework is complex and heterogeneous, design principles can largely vary from one system to another, etc. In order to cope with these challenges, novel and advanced methodologies have to be implemented so that the expectations placed by students and industry are met. In this context, this paper will stress the relevance of the integration of theoretical contents and practical experience as key enablers for the learning process. The possibility of experiencing and interacting with real wireless communication networks largely facilitates the learning process and enforces the theoretical aspects by verifying some of them in real life.

Keywords
Teaching Wireless Communications, GSM, simulation tools, monitoring tools.

1. INTRODUCTION

Wireless telecommunication networks have faced an impressive grow, progress and evolution over the last two decades. By the end of 2007, it is expected to reach three billion people world-wide with mobile subscriptions. The rapid pace of global adoption and diffusion of mobile communications has revolutionized economic and social life.

Wireless telecommunication networks have become wide-spread around the world. Currently, there are over 700 GSM (Global System for Mobile communications) mobile phone operators across 218 countries. GSM is the most popular standard for 2G (second generation) mobile phones in the world. Besides, the so-called 3G (third generation) technologies, such as UMTS (Universal Mobile Telecommunications System), which enable network operators to offer users a wider range of more advanced services, have already been deployed. Furthermore, other wireless network technologies such as Wi-Fi, enabling devices (laptop, game console, cell phone, etc.) to connect to the Internet, have become common-use.

Focusing on the technological dimension, wireless telecommunication networks have become extremely sophisticated and complex. This is further enforced by the fact that wireless networks are heterogeneous in nature and, usually, different systems have been conceived, designed and implemented following different principles and targeting different objectives.

In this context, teaching on wireless telecommunication networks faces a number of challenges, such as the fact that contents are dynamic in nature, the resulting framework is complex and heterogeneous, design principles can largely vary from one system to another, etc. Furthermore, the teaching of mobile networks is inherently multi-disciplinary, covering multiple aspects of telecommunications (e.g. from services down to signalling protocols and radio transmission technologies). On the one hand this turns out to be in general more attractive for students, who perceive a holistic view of concepts already studied in other subjects, but, on the other hand, it introduces additional challenges in the teaching process, because all concepts should be put together in a coherent way to provide a comprehensive approach to the problem. In order to cope with these challenges, novel and advanced methodologies have to be implemented so that the expectations placed by students (who show high interest in these subjects) and industry (who demands skilled engineers in this field) are met.

Under this framework, this paper will stress the relevance of the integration of theoretical contents and practical experience as key enablers for the learning process. The possibility of experiencing and interacting with real wireless communication networks largely facilitates the learning process and enforces the theoretical aspects by verifying some of them in real life. The methodological approach has been built upon the following points, which are covered in the different sections of this paper: (1) theoretical sessions on wireless network design principles and specific wireless network systems (e.g. GSM), (2) practical sessions (on a two-people group basis) with the help of commercial software tools in the laboratory for the application of the general wireless network design principles and (3) practical sessions (on a two-people group basis) with the help of real equipment (mobile terminal enhanced with some engineering toolkits) to be tested in the field and interacting with the real wireless network for the verification of deployment, configuration and engineering aspects related to specific wireless network systems.

2. THEORETICAL SESSIONS ON WIRELESS NETWORK DESIGN PRINCIPLES

Given the rapid evolution in the mobile communication arena, where the life-cycle of a novel technology lasts for a decade before its replacement in the best case, it is prime important to provide general concepts and design principles, these being as technology-independent as possible, before the student is introduced into specific systems. This principle will ensure that the knowledge gained in wireless communications courses is a solid background facilitating the students to be able to evolve in its professional career.

The design of a complete communication system involves a number of engineering techniques to be incorporated into the different elements of the system. The resulting system design is highly influenced by the media between the transmitter and the receiver, which is known as communication channel. In wireless communication, the communication channel is given by the propagation of electromagnetic waves over the air. The behavior of electromagnetic waves is established by Maxwell’s law, which would provide the exact form of the magnitudes (level of electromagnetic field, received power, etc.) for certain contour conditions. At this stage, and given the complexity of a pure theoretical and mathematical approach, students are introduced into a series of propagation models, this constituting a good example of engineering, where simplified though sound characterizations are usually considered to represent the real world.

As a constant methodology across the theoretical sessions, students are motivated to anticipate what are the most relevant parameters and environment’s aspects influencing the propagation conditions, thus constituting the basic parameters to be included into propagation models. Afterwards, different propagation models are presented in a formal way, justifying the statistics used to characterize the different phenomena. Following with propagation aspects, and claiming for general procedures applied in engineering fields where the wide range of practical situations use to be simplified with a reduced number of representative scenarios, a number of propagation environments are presented (e.g. urban area, rural area, etc.).

At this stage, it is possible to introduce one of the key concepts in wireless communication networks: coverage. It is discussed that coverage in practical deployments has to be measured in statistical terms, this being consistent with the fact that the propagation models introduced before are statistical. Using these models, coverage is defined in a formal way with a reduced number of mathematical equations. These concepts are illustrated with several numerical examples, in order to familiarize the student with the typical orders of magnitude for the different parameters considered. Furthermore, some references to practical tools, used by network operators in order to predict the coverage provided by its deployed network, are done.

With solid foundations on the characterization of the communication channel and a suitable perspective on the disturbance that the different propagation phenomena tend to introduce into the wireless communication, different engineering techniques can be envisaged in order to minimize the channel’s effects (e.g. noise, distortion).

The need to introduce a certain multiple access technique arises when considering several mobile terminals who wish to connect to a given base station. Multiple access techniques allow several users to share the communications means with a given base station, then allowing the support of different connections simultaneously. Besides, the key aspects to be solved for the practical implementation of the different solutions are identified and the historical evolution of their corresponding use is highlighted. Arguments from the technical, economical and regulatory perspectives are described, then providing a broader perspective to students, who get familiarized with the eco-systems where systems are developed, deployed and exploited and get some insight on the complexity of the wireless communication business environment.

Moving towards a framework closer to real networks, several base stations and several mobile terminals operating at the same time are considered. In this view, inter-cell interference is defined as the major limiting factor in wireless communication networks. Emphasis is placed in the concept that wireless systems become interference-limited and, therefore, all efforts towards an efficient exploitation of radio resources have to be made in order to deal with interference in the best possible way. This is formalized with the definition of frequency-reuse and cell cluster concepts. Some formulas are derived for the case where cells are assumed to be hexagonal, which is a classical way to characterize cellular systems from a theoretical point of view.

The last step in the presentation of the general wireless design to introduce the key distinguishing factor in wireless compared to fixed networks: mobility. Certainly, the fact that at least one of the communication end moves around the scenario introduces relevant design challenges and makes wireless networks particularly complex. The need to support seamless handover (i.e. the capability to transfer a given connection from one cell to a neighboring one when the user moves far from the current cell and approaches the neighbor cell) is firstly discussed. Before entering into modeling and mathematical characterization of the mobility factor, students are requested to anticipate what the major system aspects are causing a higher number of handover procedures to be performed in a wireless network. Afterwards, a simple mobility model, introducing some randomness into the trajectories that users describe across the network, is developed. This provides some supporting formulation that result useful to gain insight into the problem. In particular, a mathematical expression is derived for the handover probability (i.e. how likely it is that a handover is performed), which depends on the above identified aspects (mobile speed, cell radius and connection's duration).

After all the above foundational aspects have been developed, students are ready to face the design methodology for a wireless communication network. First of all, the design criteria fixed by the operator deploying the network are identified and discussed. Several examples are given to illustrate that the operator's targets use to be contradictory among them. Conclusion reached is that the network design has to be understood as a whole. Then, a detailed methodology is introduced, with a clear identification of the inputs needed to apply the methodology and the outputs obtained as a result.

With all the above aspects, students are in the position to get a solid understanding and background of the difficulties faced in wireless communication networks, the engineering solutions to be incorporated to enable the establishment of wireless connections, and the methodology to be followed for a proper network design. It is worth remarking that the concepts presented along these theoretical sessions are rather general, this enabling an ulterior intensification towards particular systems and technologies.

In order to fix the above concepts, which are of general applicability, several theoretical sessions on a specific system realization are carried out. In this case, the presented system is GSM (Global System for Mobile), which can be considered a de-facto 2G standard worldwide. When presenting GSM architecture, multiple-access technique, air-interface design, etc., students observe how the general functionalities have been implemented in this technology.

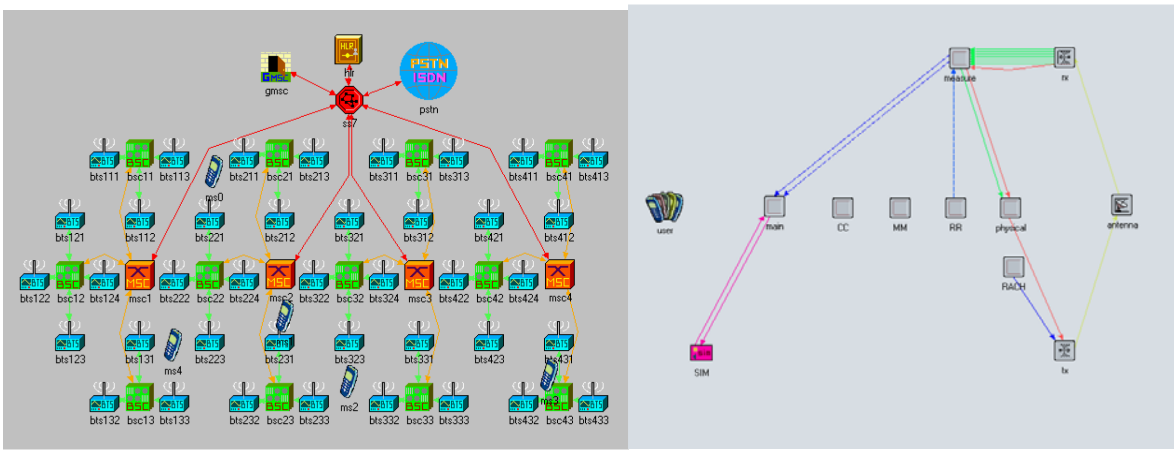
3. PRACTICAL SESSIONS ON GSM NETWORK SIGNALLING USING SIMULATION TOOLS

Protocols and signaling are a relevant aspect for any mobile network. Thanks to them, the mobile terminal can communicate with the different network elements so that eventually the end-to-end service can be finally provided to the user. Furthermore, different collateral but important procedures supporting the mobile service are implemented with the defined protocols and signaling messages in any wireless networks. This includes e.g. the paging mechanism to inform a terminal about a terminating call, the access mechanism used by the terminal to indicate its willingness to transmit, etc. Nevertheless, in spite of the importance of these procedures, introducing them in the teaching room has been traditionally something difficult, because in general students tend to find them a bit boring, so that keeping their attention and motivation in this area turns out to be an important challenge. Of course, the use of references to the daily procedures the students themselves use to carry out with their wireless devices, trying to go one step beyond the simple description of the message flows on some slides, can help in making the theoretical sessions more attractive. However, in order to consolidate the transmitted knowledge and to even reinforce the motivation of the students, the use of practical sessions turns out to be a good solution.

In that respect, the ideal practical session would be to make use of real devices, i.e. a mobile phone similar to the one that any student may find in a shop, so that the signaling procedures can be illustrated with the real experience. This is the case of e.g. the TEMS software, explained in section 4. However, when introducing the network dimension, i.e. the fact that the end to end service requires in general the communication and interworking between different nodes, an additional difficulty arises, because these network nodes (e.g. base station, controllers, switching centers, etc.) from the real network are in general not easily accessible to the final user (i.e. the student in this case) from the mobile terminal. Furthermore, building on the lab a testbed of the real network using real nodes just for academic purposes turns out to be a very expensive solution. Consequently, in this case the use of simulation models that include the detailed behavior and signaling messages between the different nodes in a wireless network turns out to be an efficient solution because students are able to graphically visualize the network and better understand the involved procedures.

Under the above considerations, the use of the OPNET simulation platform [1] has become a very useful tool to help in the teaching of wireless communications protocols, particularly the GSM network. OPNET is a generic event-driven software to simulate the behavior of different types of networks, and includes a wide range of models for different wireless and wired systems, in addition to a flexible platform to build new models. Furthermore, it contains a number of graphical interfaces to represent different types of statistics reflecting events from the simulation and even the ability to visualize animations of how the different network elements interact, which makes it an excellent tool to teach signaling procedures. In particular, in the framework considered here, a model built for simulating the GSM network has been adapted to illustrate the different signaling procedures.

Figure 1(a) plots the OPNET GSM network model. OPNET models are built using a hierarchical structure in which the network model is in the upper level and contains a set of nodes, which constitute the second level and have in general a direct correspondence with node elements in a real network, such as the MS (Mobile Station), BTS (Base Transceiver Station), BSC (Base Station Controller), MSC (Mobile Switching Centre), GMSC (Gateway MSC) and HLR (Home Location Register) [2][3]. Each node is constituted by different processes simulating the node behavior. Figure 1(b) plots an example of the node corresponding to the mobile terminal, where the different processes are identified. Each process is formed by a set of state transitions activated by the different events of the simulation (e.g. arrivals/departures of messages from one process to another one, activations from other processes requesting specific actions, etc.).



(a) (b)

Figure 1.- (a) GSM network model built in OPNET (b) Example of node model of the MS terminal

Based on this GSM model, the practical sessions to illustrate the different signaling procedures are organized around the following topics, and are carried out at the lab in groups of two students, which facilitates discussion and synergies:

a) GSM Network Model

The objective of this first session consists in achieving an initial familiarization of the student with the GSM model, looking at the topology of how the different nodes are interconnected. In addition to this, the concepts related with the cellular structure are also consolidated through simple exercises on how the frequencies are allocated to each BTS. Then, the session addresses the detailed study of the measurements carried out by the mobile terminal and its behavior in the so-called idle mode, in which the terminal is connected to the network but it neither generates nor receives calls, in terms of the quality measuring of the received signals and ordering of the different detected cells. This can be analyzed by observing the mobile terminal received power using different mobile trajectories, which involve coverage of different BTSs.

b) The mobile terminal in idle mode

The objective of this session is to deepen in the study of the procedures carried out by the terminal when it is in idle mode. This includes the detailed analysis of the messages transmitted by the network in the Broadcast Control Channel (BCCH), which contain the required information by the terminal in order to eventually access the network, such as operator identity, location areas, frequencies of the different cells, etc. This analysis is carried out also with the help of the GSM specifications [4], in order to familiarize the student with how real documentation from the standardization bodies is organized.

After having analyzed the messages of the BCCH, the students trace the mobile registration procedure, denoted in GSM terminology as IMSI Attach, and used by the terminals just after the switch on, in order to notify the network that they are ready for operation (e.g. for receiving calls). This can be easily analyzed making use of the animation utility available with the OPNET platform, which enables the visualization of the different messages. Particular attention is paid also to the random access procedure used to initiate the transmission from the mobile side. In this case, the effect of different configuration parameters of this access is analyzed. Finally, the parameters governing the cell reselection procedure used by the terminal to decide the best cell to be connected in idle mode are analyzed, with particular focus on the Cell_Reselect_Hysteresis, required in case those cells belong to different location areas in order to reduce signaling overhead.

c) Call procedures

This session allows the students deepening in the signaling message and protocols required for the mobile originating and mobile terminating calls. Specifically, using the animation utility, students can track the different messages and analyze their contents, so that they discover e.g. in which message the called phone number is transmitted to the network, how is the channel assignment carried out with different strategies, and how the call is routed to the PSTN through the BSC/MSC/GMSC nodes. As for the mobile terminating calls, particular emphasis is placed in the paging procedure, which allows locating the terminal in the network, through the cooperation of the location registers HLR/VLR in the interrogation procedure. In general, all the complete procedures are composed by simpler sub-procedures (e.g. in the mobile terminating call the paging procedure, followed by the random access, the call establishment and finally the call release). By splitting the different messages in each sub-procedure, better understanding of the whole procedure can be achieved.

Finally, this session concludes with the analysis of some specific case studies reflecting abnormal behaviors in the network, such as the case in which a mobile terminal initiates a call at the same time it is being receiving another call.

d) Handover procedures

Finally, this session addresses the handover procedure, which is used to change the BTS a mobile is connected to during a call. For that purpose, the session starts with the analysis of the handover algorithm and its configuration parameters, which decide the appropriate instant to trigger the handover in accordance with the received power and distance measurements to the serving cell and the corresponding neighboring cells. The impact in terms of performance from different configurations of these parameters is analyzed.

Then, the session continues with the detailed analysis of the signaling messages in the handover procedure, depending on the type of handover addressed, i.e. intra-BSC handover, inter-BSC handover, inter-MSC handover and subsequent handover. In all the cases, the animation facilities provided by OPNET are used, as illustrated in Figure 2.

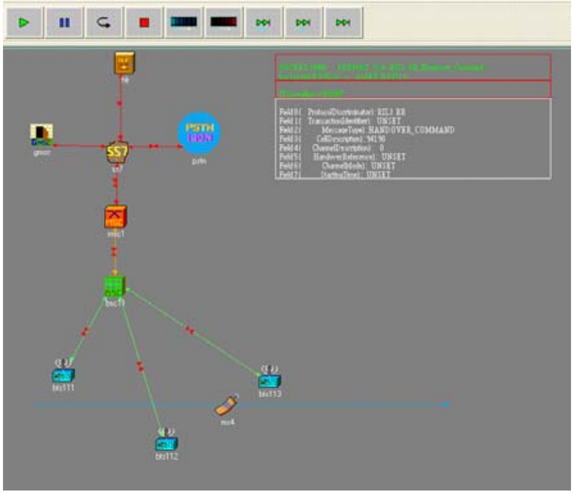


Figure 2.- Animation to illustrate the handover signaling

4. PRACTICAL SESSIONS ON GSM NETWORK SIGNALLING USING THE REAL NETWORK

As mentioned before, to illustrate the signaling procedures using real devices over a real network causes a strong motivation for the students. Thus several practical sessions have been designed to analyze GSM network signaling using the real network. To do these practical sessions a commercial handset together with a laptop and a software tool called TEMS Investigation, developed by Ericsson, have been used (see Figure 3).

Figure 3.- Equipment to analyze the real network

TEMS Investigation is the industry-leading tool for troubleshooting, verification, optimization, and maintenance of wireless networks. Offering data collection, real-time analysis, and post-processing all in one, TEMS Investigation is a complete solution for all of a network operator's daily network optimization tasks.

TEMS Investigation supports all major technologies, making it the ideal solution both for rolling out new networks and for ensuring seamless integration with existing networks. Using this tool, operators can achieve improved voice quality, increased accessibility, more successful call attempts, and better service performance. A wide range of powerful, easy-to-use features makes this tool essential throughout the network's life cycle. TEMS Investigation supports handsets from all major vendors across multiple technologies.

TEMS Investigation can be used to:

- Tune and optimize networks
- Perform fault-tracing and troubleshooting
- Verify true terminal behavior with phone based measurements
- Verify cell coverage, capacity, accessibility, etc.
- Troubleshoot the network
- Perform indoor, pedestrian, and outdoor measurements
- Post-process multiple log files

The practical sessions to illustrate the different signaling procedures are carried out at the Campus of the Universitat Politecnica de Catalunya (UPC) in groups of two students, and are organized around the following topics:

a) Real-Time measurements

This first session provides the student with an initial familiarization to the software tool and the equipment to be used.

TEMS Investigation allows obtaining measures about radio parameters, like the received power from the different GSM channels, C/I measurements in idle or dedicated mode, information on hopping channels, etc.

In this practical session the students get in touch with the parameters that manage the real network. They must find some parameters values, like the Location Area Code (LAC), the BCCH Absolute Radio Frequency Channel Number (ARFCN), and the Base Station Identity Code (BSIC) for example (see Figure 4 and Figure 5). This research forces the students to remember what these parameters mean, and helps to consolidate their knowledge.

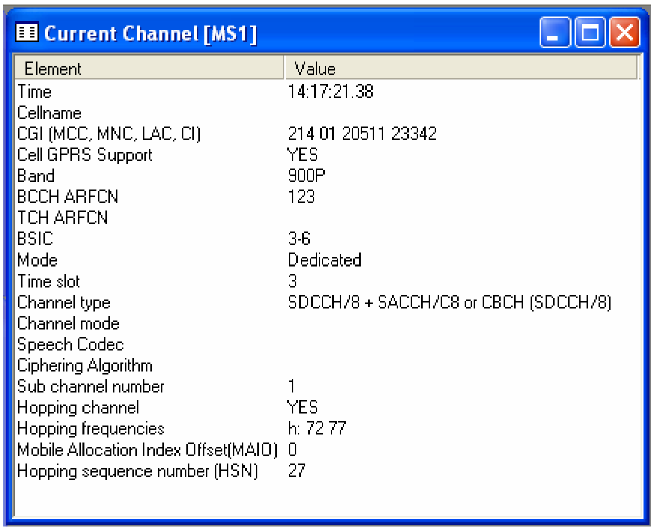


Figure 4.- TEMS Current Channel Information

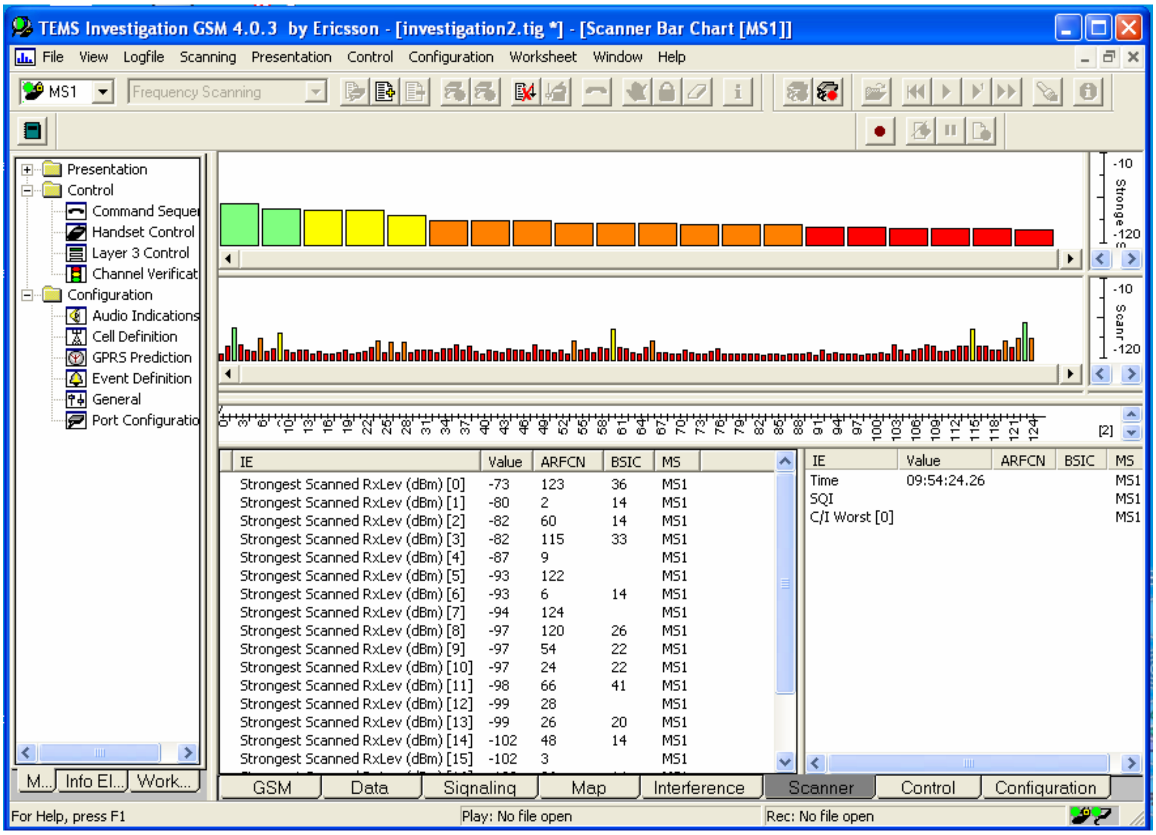
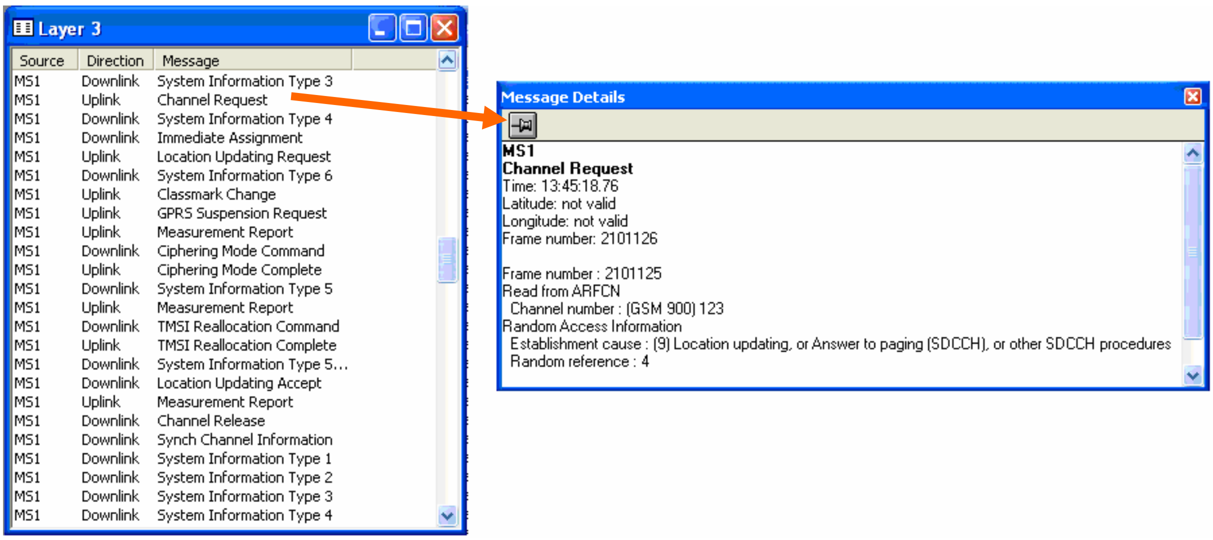


Figure 5.- TEMS Frequency Scanner

After having identified the former parameters the students must study the traffic processed by a cell through the analysis of the transmitted paging and immediate assignment messages.

b) GSM basic procedures

The aim of this session is to show the basic procedures carried out by the terminal through the real experience. First of all the attach procedure is analyzed (see Figure 6-a), then a call originated by the mobile (MOC) and a call terminating to the mobile (MTC) are studied. And finally a short message (SMS) sent and received by the terminal are analyzed.



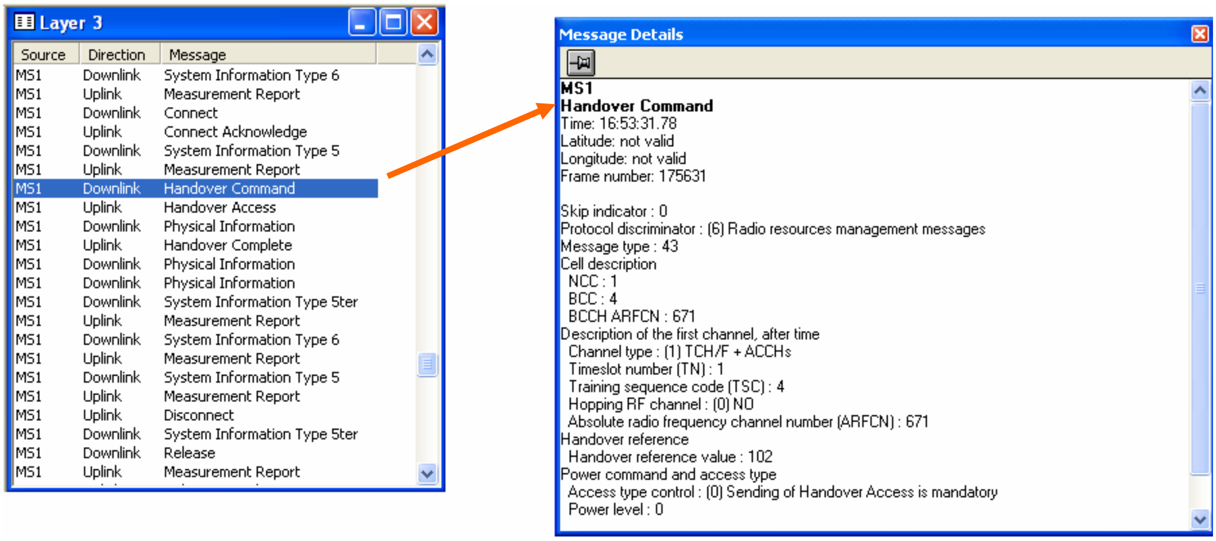
(a) (b)

Figure 6.- (a) TEMS Attach procedure signaling (b) Details of Channel Request message

To perform the analysis of these five procedures students save the log files while making the procedures under real network coverage. Later they analyze the log files which contain the messages sent between the terminal and the network through the air interface. Layer 2 and Layer 3 messages can be observed with detail, and this detailed research allows to student the deepening into the parameters exchanged between the terminal and the network. For example Figure 6-b shows the details of the Channel Request message sent by the terminal in the Attach procedure analyzed previously.

After write down the signaling of each procedure the students can check with the GSM Specifications [4] if the real implementation adjusts to them or not.

As well as these Basic procedures, the handover procedure and the related signalling can be analyzed with this equipment. For example the signalling belonging to a handover between GSM 900 and GSM 1800 is included in Figure 7.



(a) (b)

Figure 7.- (a) TEMS Handover procedure signaling (b) Details of Handover Command message

c) GPRS performance

This equipment allows also analyzing the General Packet Radio System (GPRS), the GSM evolution for packet services. The objective of this session is to go through all the activities developed around a GPRS session, including signaling and the GPRS information elements like: RLC/LLC Throughput Downlink and Uplink (kbit/s), RLC/LLC Retransmissions Downlink and Uplink (%), number of used time slots, PDP context, IP address, Coding Scheme, etc.

In order to test the GPRS performance and the related signaling a data session must be started. Typical services that can be used for data testing are HTTP, FTP, and Ping. In particular students are required to connect to an ftp server and download a file. Then they must answer the code used, the average rate transfer, some information sent in the context activation message, the assigned time slots, etc.

The session finalize with the analysis of a voice call originated by the terminal while it is connected in GPRS. Since this practical is realized with a terminal class B, which can be attached to GSM and GPRS simultaneously, but not connected to both, the students can observe a GPRS suspension and all the signaling related to this procedure.

5. CONCLUSIONS

Within the telecommunications field, the rapid evolution in the mobile and wireless communications systems together with the world-wide penetration of wireless systems such as GSM, UMTS, Wi-FI, etc., has motivated the importance of the learning in this area for telecommunications students. However this learning process is hard due to the dynamical nature of the contents, the complexity of the heterogeneous systems and the multi-disciplinary nature of wireless systems, covering multiple aspects of the telecommunications (e.g. from services down to signalling protocols and radio transmission technologies). Under this framework, this paper has stressed the relevance of the integration of theoretical contents and practical experience as key enablers for the learning process in the context of wireless telecommunication networks in order to, on the one hand, make it even more attractive to students and, on the other hand, to enforce the acquisition of the studied concepts.

In order to cope with this integration, novel and advanced methodologies have to be implemented so that the expectations placed by students (who show high interest in these subjects) and industry (who demands skilled engineers in this field) are met. In particular, the possibility of experiencing and interacting with real wireless communication networks largely facilitates the learning process and enforces the theoretical aspects by verifying some of them in real life. The methodological approach has been built first on the basis of theoretical sessions on wireless network design principles and specific wireless network systems (e.g. GSM), and then on practical sessions on a two-people group basis. Such practical sessions are carried out with the help of commercial software tools (i.e. OPNET simulator) in the laboratory for the application of the general wireless network design principles, particularly focused on signalling aspects, and with the use of real equipment, specifically mobile terminals enhanced with the TEMS engineering toolkit, to be tested in the field and interacting with the real wireless network for the verification of deployment, configuration and engineering aspects related to GSM. Conclusion reached after this experience is that students exhibit a high level of satisfaction with the applied methodology and the learning process is significantly improved.

Acknowledgements

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