A methodology and test environment for QoS measurements in mobile networks

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***Abstract*—Voice services has been for a very long time the primary source of income for mobile network operators. Even with the increasing importance of the data traffic, voice services will keep playing a key role and will not disappear with the transition to a networking model based on the IP protocol. Moreover, the key industry players diagnosed years ago that mobile subscribers wouldn't accept a significant degradation in the quality of their voice services. Because of that, it becomes critical to ensure the Quality of Experience (QoE) in the transition to new generation networks based on packet switching communications. The work in the present thesis has aimed to analyze the behavior and the dependencies in the different voice services over IP (VoIP), as well as to identify optimal configurations, potential enhancements and methodologies to ensure acceptable quality levels while minimizing the costs.**

I. Introduction

Characterizing data traffic performance in mobile networks from the user perspective is a costly process that requires monitoring and analyzing an ample range of protocols and parameters with complex dependencies. To fully overcome this problem, it is required to analyze multiple measurements and correlate the behavior of the different layers. In this thesis, it is proposed a methodology to collect key information oriented to solve IP communication problems, linking it with radio propagation and mobility effects, such as cell changes or radio link failures, or with network load and resource constraints in specific geographic areas.

That methodology is based on the usage of native tools for information monitoring and storage in smartphones. A tool chain to enable extensive experimentation both in real networks and controlled test environments is also a central element in the proposed methodology. With the results provided by these tools, mobile network operators, service providers and mobile application developers will gain access to valuable information on the real user experience. This will allow improving service provisioning, as well as tailoring and adapting the behavior of applications and protocols based on IP mobile networks.

The main contributions of the tools and methods introduced in this thesis are the following:

- A tool for multi-layer monitoring in Android smartphones, named TestelDroid, that enables collecting key performance indicators from the user equipment itself. Furthermore, it provides features for active traffic generation and for connectivity test, which are very appropriate for field testing.
- A methodology to correlate the measurements collected at different layers. Additionally, users are also granted the option to directly access IP traffic information and radio measurements, to apply their own methodologies to derive additional metrics.
- It has been applied the methodology and tools in a real case study, to evaluate the performance of IP based communications on board of high speed trains.
- It has contributed to the creation of a realistic and highly configurable test environment for the design and execution of advanced experiments over 4G LTE technologies.
- It has detected potential synergies in the usage of advanced R&D instruments such as the UXM wireless test set, both for academic and research purposes in an University context.

The complete thesis is available in [1] and the related work have been published in multiple international conferences [2] [3] [4] [5] [6] [7] and journals [8] [9].

II. Study of Internet traffic in mobile networks

The global data traffic grew a seventy percent in 2012, exceeding in more than ten times all the Internet traffic by the year 2000. In addition, the mobile data traffic exceeded

Fig. 1. TestelDroid screenshots, from left to right: Preferences configuration, GPS measurement localization and Network information

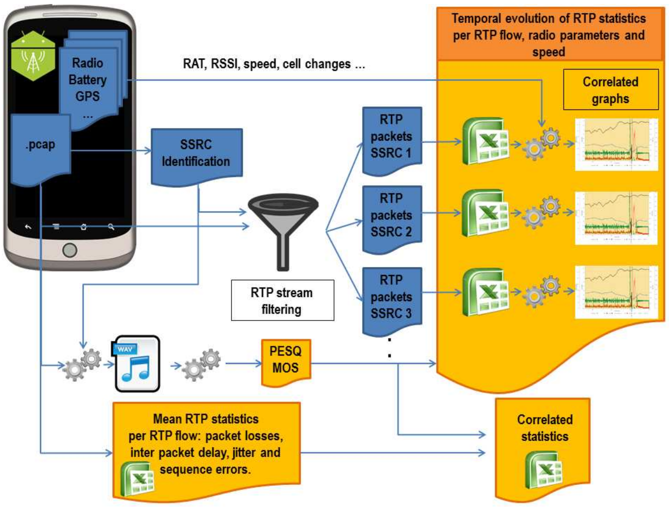

Fig. 2. The methodology developed as part of this thesis involves the inspections of radio access parameters, QoS parameters and QoE values

half the total traffic for first time, demonstrating the increasing relevance of mobile multimedia content. In 2014 the number of smartphone subscribers also exceeded 2600 million, expecting to double by 2020. In a certainly unexpected trend, mobile operators have seen in the recent years how third party players have capitalized on a big portion of the voice market share providing services over their networks at a very low or even no charge. Unfortunately, this has impacted also the quality of the provided services. In this context, users demand from mobile operators global high levels of quality everywhere.

To maintain adequate levels of quality the operators, the content providers and the developers need appropriate tools to monitor the performance of the services. Network operators usually have access to different levels of information, known as Key Performance Indicators (KPI), regarding the performance of their networks. These KPIs are mainly based on counter values collected at network elements. These performance counters are defined by 3GPP technical specifications (TS 32.405, TS 32.450, etc) and implemented at network elements such as RNC, MSC, SGSN or e-NodeB. However, these counters usually do not reflect the suscriber's experience because highly sophisticated filtering and correlations functions are not implemented in the static functions of network elements.

Content providers and application developers traditionally have to test their apps in a user environment without any knowledge of network information. Typically, communication monitoring tools for evaluating the user experience required dedicated hardware and were only available to network operators because of their prohibitive cost. However, it has recently become possible to use current smartphones themselves as monitoring devices with the help of software applications.

In order to collect IP performance parameters and MOS measurements two new developments have been undertaken as part of this thesis:

- A software tool for Android devices which provides advanced monitoring functionalities such as the logging of radio parameters and the capture of IP traffic (See Figure 1).
- A post-processing tools chain focuses on the processes of capture and analysis of key performance indicators (packet losses, jitter, inter-packet delay, PESQ, etc.) in real time services, such a VoIP, which lead to the achievement of a complete characterization of their behavior over cellular networks (See Figure 2).

III. Smartphones as Monitoring Tools

Smartphones have become a major platform for the execution of Internet services as more powerful and less expensive devices are becoming available. The verification of the performance of such services has also moved from the traditional PC plus modem setups to smartphone built-in scenarios. Testing configurations based on computer based tools are not enough anymore for the verification of Internet services on mobile phones. They are giving the way to measurement tools specifically tailored for smartphones, enabling performance analysis of services and applications designed for mobile devices. In this transition, it becomes critical to develop powerful tools providing native measuring capabilities for mobile based data services. Thus, a wide range of monitoring functionalities are needed to allow the fusion of information from many different sources and viewpoints, obtaining a complete profiling of mobile applications and services.

Following this approach the SymPA [16] tool was developed and successfully applied in the study of video streaming service in cellular networks [17]. With its successor TestelDroid we pretend to increase the monitoring functionalities with the features provided by Android and thus extend our research into Android services, applications and devices.

The first tools designed to operate in mobile devices, such as Qualipoc [13], were centered on the observation of service accessibility parameters such as availability, provided bandwidth, error rate, etc. To that end, they included active client features ranging from FTP (File Transport Protocol) to voice calls and message sending. These clients were used to test the services and verify general parameters. However, the rising complexity of mobile networks and applications requires test solutions to go a step further both in application and radio performance monitoring. By doing so, it will be possible to identify the actual sources of communication issues and to improve the user experience, as subscribers do not care whether communication problems are related to application, protocol or radio aspects, since they all result in experience degradation. Measuring solutions aiming to deal with many perspectives must therefore correlate information from all the communication layers.

Although active service probing is useful for some purposes, it is clearly unfeasible to include clients for every single application and service available, present or future. Passive monitoring represents a scalable alternative for general purpose analysis of mobile applications' performance. Different aspects may be studied jointly using the passive approach

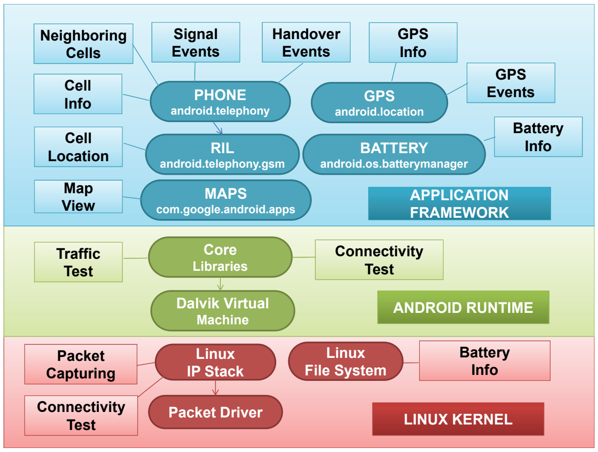

Fig. 3. TestelDroid diagram

including communication performance, memory usage and battery consumption among others.

Some very powerful tools, such as Anite Nemo Handy [14], are able to obtain very detailed information about RF performance, but are limited to specific devices for that purpose. Our intention has been to provide a generic solution that could be used in all the smartphones.

IV. TESTELDROID, ON-DEVICE MONITORING

TestelDroid [4] is a cross-layer monitoring tool which uses the engineering features provided by current commercial Android smartphones to profile the communication performance of mobile applications running on mobile devices. With TestelDroid smartphones become actual measurement probes that gather information closely related to final users. This proximity grants the methodology the potential to characterize the performance of the mobile applications from the point of view of subscribers. Moreover, user application level analysis, which includes KPI such as application specific download speed, upload speed, latency, jitter as defined in [15] and packet loss, requires access to performance counters which are only available at the user equipment.

Four different sets of parameters are obtained: IP traffic, GPS coordinates, battery consumption, and network related information. You can find a full description of the monitored parameters in [4]. The information retrieved by TestelDroid can be logged and exported for further analysis with our post-processing tools and other tools, such as Wireshark, or integrated with other applications such as Google Earth, as shown in Figure 5. Other features provided by TestelDroid are active traffic and connectivity tests. Active traffic test functionality is oriented to testing a mobile to mobile TCP connection. One mobile is configured as the server and the other side as the client. An auto generated file with the size specified by the user is sent while speed connection is monitored and the mean throughput is calculated. Connectivity test functionalities provide two diagnostic modes. The first one is based on the traditional ping functionality. The user can configure the number of pings, packet size and timeouts. The second mode enables checking the establishment of mobile originated TCP connections, given an IP address and a TCP port, which is useful for detecting reachability problems. TestelDroid retrieves information through the standard APIs (Application Programming Interfaces) provided by the Android OS, Android runtime and Linux kernel. The Android API provides access to network features such as cell identifier, available neighbors and signal strength, battery data and GPS location. The Android runtime is required to implement TCP connectivity and traffic tests. Finally, to implement packet capturing, ping and battery consumption, it is necessary to access the Linux kernel itself, which implies root access.

The information provided by TestelDroid in these three different levels is shown in more detail in the Figure 3.

We have profiled TestelDroid performance, monitoring VoIP calls on a Nexus One mobile device over an 8 hours period, in terms of CPU utilization, memory usage and energy consumption. Mean CPU utilization is less than 1%. Memory usage is 22 MB, which is a normal value for an Android process. Finally, the energy consumption is only the 0.2% of the total power during a measurement session. These results prove that TestelDroid presents a good performance for background monitoring during long periods.

V. PERFORMANCE STUDY OF INTERNET TRAFFIC ON HIGH SPEED RAILWAYS

Railway transportation uses specific technologies such as GSM-R for traffic signaling purposes, but commercial networks could also provide added value services to passengers and transport companies such as CCTV or telemetry. Furthermore mobile users increasingly want to be always connected even when they are traveling. Although current deployed technologies such as 3G provide wide coverage in general, when it comes to high mobility scenarios such as the railway, further analysis is required to ensure appropriate user experience. In this chapter we propose a methodology to collect and to organize traffic information related to the behavior of Internet services over commercial mobile networks (UMTS and HSDPA). We have applied our method to conduct an extensive study on a high speed train line in the south of Spain, as shown in Figure 4. The measurement campaigns comprised hundreds of VoIP sessions, comparing different network providers over more than 155 kilometers.

The measurement results reveal that bursts of packet losses and delay spikes are the main issues detected on high speed scenarios. They are caused by multiple factors, including frequent cell changes, poor radio conditions at cell edges particularly when RSSI decreases below -100dBm, allocation of low bandwidth bearers that are unable to sustain the required throughput and interference from neighbor cells, specially in transitions between rural urban areas, among others. After receiving feedback from key network players in Spain, we have concluded that the characterization method is useful to provide information for railway operators (for instance, to migrate from GSM-R to LTE), telecom operators (to fit their

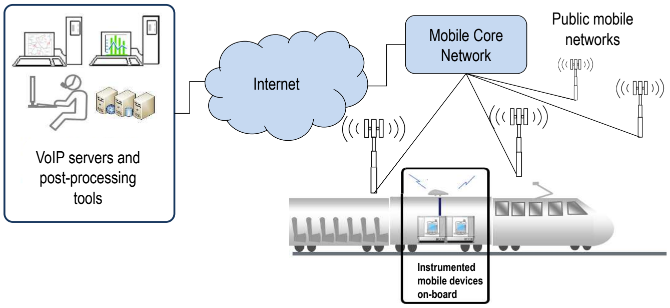

Fig. 4. On-board monitoring with instrumented mobile devices

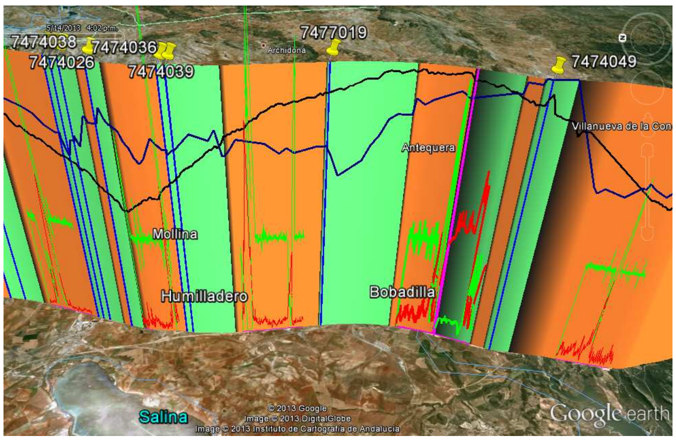

Fig. 5. Geographical representation of the measurements collected by TestelDroid

network deployments) and for mobile software developers (to adapt their applications to the high speed environment).

VI. The need of a realistic testbed for repeatable testing

The enhancement of QoS in a sustainable manner is a critical goal for network operators as management tasks are becoming increasingly complex. Although some initial efforts have been carried out by the standardization bodies there is still a significant gap to be covered in QoS and also in QoE optimization. Actually, current efforts towards improving QoS and QoE are typically based on estimations derived from costly drive test campaigns. Furthermore, involvement of human expertise is required to manually tune network configurations. On the other hand, most of the service and network configurations available in the literature are derived from simulations [18] [19] [20] [21] [22] [23]. As is widely known, in the process of modeling communication systems to simulate them, some details may be missed and thus misleading results may be derived. For example, it is very common to find that the consumption of control resources is ignored when evaluating different scheduling methods. However, control elements and data are both actually competing for time-frequency resources, and the allocation of control resources to multiplex users in PDCCH is not a trivial task. In this context, providing optimized network configurations based on measurements obtained directly from the subscribers' terminals and correlated with the information collected at the network will pave the way for a reduction of costs and more accurate tuning of network operation from the point of view of the QoS perceived by final users. Moreover, as stated by standards organizations (SDOs) or alliances with the participation of network operators such as NGMN [24], *the optimization of QoS still requires "real" developments to further study the direction in which to move forward*.

Test	Parameter	Operator 1	Operator 2
VoIP	max jitter $>$ 25 ms	87.37 %	71.46 %
	mean jitter $>$ 25 ms	2.52 %	7.47 %
	packet loss $>$ 1%	1.26 %	10.85 %
	max packet loss	63 %	65 %
	max interpacket delay	21 s	27 s
	2.5 $<$ PESQ MOS $<$ 3.5	4 .04 %	9.34 %
	PESQ MOS $\leq$ 2.5	6.56 %	9.09 %
FTP	SACK missing segments	0.03 %	3.25 %
	SACK duplicated packets	0.74 %	0.09 %
	Out of order	0.00 %	1.34 %
	mean transfer time	248.57 s	270.20 s

TABLE I
A comparative summary of the results

In this thesis we also propose the use of an experimental testbed [2] to carry out specific LTE (Long Term Evolution) experiences in a real context and to extract the correlation between LTE radio configurations and QoS parameters perceived at the application level. The configuration of the testbed is provided in Figure 6. The execution of exhaustive measurements campaigns using this testbed will enable the identification of specific performance counters, correlations between them and use cases for QoS and QoE optimization in LTE networks.

The focus of the thesis is on VoIP calls over LTE, which pose new challenges over previous technologies. In LTE voice calls are now delivered through an all-IP network (VoIP) instead of a circuit switched one, which means that voice has to compete for bandwidth with other services provided in the network. It is vital to at least guarantee the same QoE for VoIP calls that was available in pre-LTE technologies such as GSM (Global System for Mobile Communications) and UMTS (Universal Mobile Telecommunications System). This will be required to avoid significant impact on customers, who will demand a good service in all-IP mobile networks. Due to situations like this, the testbed has been conceived to validate the performance of the network configurations and problems presented in the research literature. Specifically for VoIP service we have correlated layer 1 and layer 2 LTE radio parameters with IP performance parameters and MOS (Mean Opinion Score) measurements based on the PESQ (Perceptual Evaluation of Speech Quality) algorithm as shown in Figure 7.

VII. Future work

We have included in this thesis an analysis of the potential application of a new generation of network emulators for

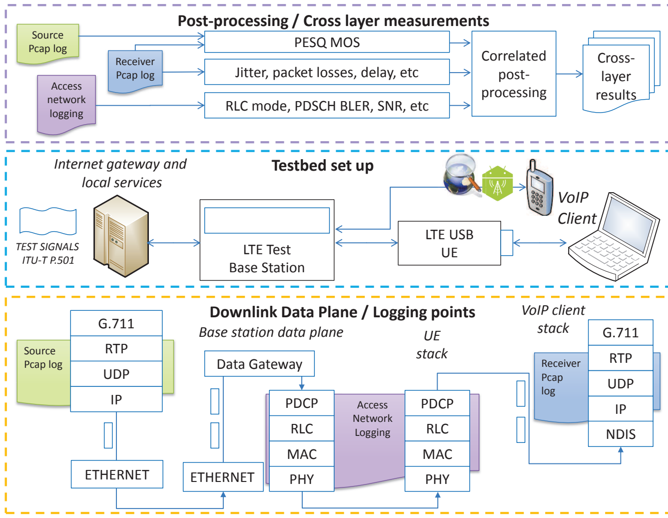

Fig. 6. Testbed configuration

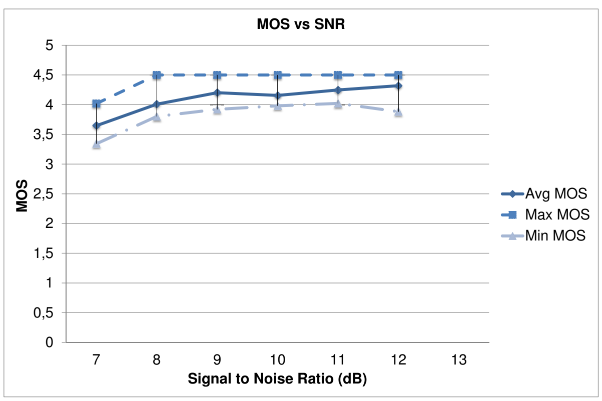

Fig. 7. MOS vs SNR

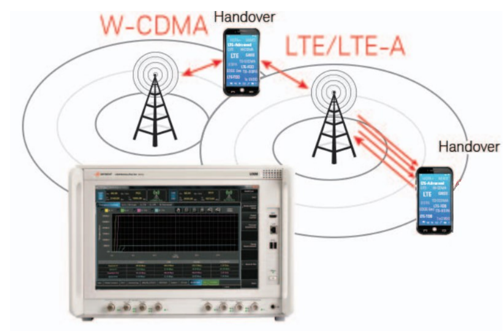

Fig. 8. UXM driven mobility procedures

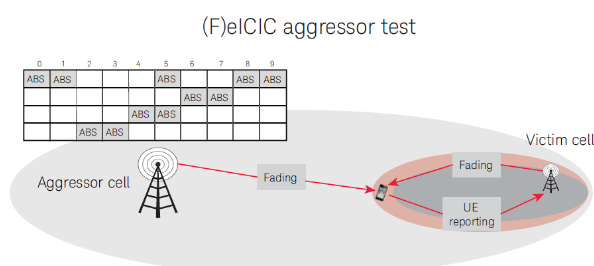

Fig. 9. Heterogeneous networking with eICIC

improved performance and extended functionality to cover a wider range of research scenarios. In particular, an initial assessment of capabilities of the UXM wireless test set from Keysight Technologies, that represents and evolution from the test equipment we currently use for the thesis, have been carried out. A wider range of research areas can be addressed with this new equipment, such as the performance study of mobility procedures, shown in Figure 8, or performance analysis in heterogeneous networking scenarios, shown in Figure 9. Moreover, taking advantage of the flexibility of our tools and methodologies, we will extend also the our evaluation scope to other applications and services that relay on IP based communications

VIII. Conclusion

Realizing the need to characterize QoS in mobile devices, we have contributed with tools (including the Testeldroid App) and methodologies, and applied them to scenarios of interest such as the evaluation of actual high speed railway communications. Additionally, we have also brought up a lab environment for real yet controlled experimentation with applications over LTE technologies. In the future, we will continue to further exploit the potential of the capabilities for network monitoring. Extending our network assessment campaigns to the comparative evaluation of 4G LTE and future technologies as they appear. The work in this thesis has been published in multiple international conferences and journals.

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