3GPP Radio Resource Control in Practice
Antonio Barbuzzi, Pekka H. J. Perälä, Gennaro Boggia, and Kostas Pentikousis

Abstract—3GPP-standardized networks have been evolving at a very fast pace over the last decade. Cell capacities increased more than an order of magnitude, latencies have become considerably smaller, and worldwide deployment has changed the way people access services. In this evolution, efficient mechanisms for radio resource control (RRC) have played a key role. In this paper we will review the RRC state transition model and follow its development from its early stage backwards compatibility and integration with GPRS at the outset of UMTS Terrestrial Radio Access Network (UTRAN) deployments to state-of-the-art HSPA-enhanced networks. This paper also overviews recent work on empirical measurements from 3G networks that study the “theory and practice” of RRC state transitions. Finally, we present our 3G Transition Triggering Tool (3G3T), and use it to study empirically network configuration parameters that prompt RRC transitions. Our results come to the aid of fully understanding the behavior of RRC state transitions and lead us from “theory” to “practice” on RRC mechanisms.

Index Terms—Radio Resource Control, 3GPP, EDGE, UMTS, HSPA, LTE, Traffic Measurements.

I. INTRODUCTION

Effective radio resource management is a cornerstone in all wireless communication systems. In 3GPP networks, in particular, Radio Resource Control (RRC) evolution has been instrumental in delivering increased throughput and lower delays. In simple terms, RRC manages all things related with wireless resource allocation, effectively implementing the lower part of the protocol stack. Due to the scarcity of radio resources, wireless connections need to be managed with great care and accuracy. Wireless resource usage optimization is tightly coupled with end-user experience and the overall capacity of the system. For this reason, we will present the fundamentals of RRC in 3GPP networks shortly below, emphasizing the role of system evolution. We will focus on the role and importance of RRC state transitions and explain the inner workings both in theory (as specified in the standards) and in practice (as we measure state transitions in live, public networks). To obtain the latter, we developed a purpose-made tool which can accurately detect and measure state transitions.

RRC manages both active and idle connections. The former carry user traffic. Idle connections, in contrast, do not carry user traffic, but they provide global reachability for mobile devices, a pillar for the success of 3GPP networks. Besides being important for standard performance metrics such as throughput and delay, RRC is critical for energy efficiency, because many of its features were introduced to increase mobile phone battery life. This is an area of active research [1], but it is beyond the scope of this article.

This paper is an extended version of [2] and contributes towards a better understanding of 3GPP/UMTS networks in practice in three distinct ways. First, we present a comprehensive overview of the 3GPP standards with respect to RRC. We summarize succinctly the evolution path and key technical choices made along the way until we reach the latest system releases. Second, after introducing 3G3T (3G Transition Triggering Tool), which can be used to trigger RRC state transitions, to measure one-way delay, and to determine the delay due to paging procedures and/or channel setup, we present its extended capabilities. Third, we use 3G3T in a comparative study carried out in four live UMTS networks in three different European countries. Our study is, to the best of our knowledge, the most extensive in the published literature concentrating on studying RRC state transitions. It is also the most up-to-date as we empirically study all currently-deployed 3GPP releases (i.e., Rel. 99, 05, and 06). We show how the operator network settings may differ drastically from each other and that one cannot always infer network behavior based on the available literature. 3G3T is so far the only tool useful to bridge this gap, especially since operators are typically not willing to share this type of information.

The rest of this paper is organized as follows. Section II provides a comprehensive review of the evolution of RRC in 2G/3G, and beyond networks. Section III reviews previous work on simulation-based evaluation of RRC state transitions and presents our empirical evaluation of this transitions in live networks. Finally, Section IV concludes the paper summarizing the main points.

II. RADIO RESOURCE CONTROL EVOLUTION

In cellular networks, RRC refers to the functional block (including the associated signaling) that essentially controls the lower part of the protocol stack, that is, Radio Link Control, Medium Access Control and the physical layer. RRC is used to initialize connections, reserve resources, establish and maintain connectivity, and (at the end of connection lifetime) release all associated radio resources shared between users and network. RRC handles broadcast system information, manages radio bearers, controls paging and RRC connection mobility. Finally, RRC is responsible of ciphering control, outer loop power control, and User Equipment (UE) measurement and reporting [3]. Table I summarizes the relevant RRC technical specifications (TS) issued by 3GPP. In what follows, we will refer to this Table...
presenting the evolution of RRC.

**TABLE I**

RRC was first specified in the context of 3G/UMTS networks. However, similar mechanisms for allocating and managing radio resources were also defined for previous cellular systems, starting with the introduction of General Packet Radio Service (GPRS) for Global System for Mobile Communications (GSM) networks in GSM Rel. 97 (see Fig. 1). After all, the management of radio resources and their efficient allocation according to user needs is at the core of a wireless packet switched network.

**FIGURE 1**

The GPRS radio resource procedures and operating modes are specified in 3GPP TS 04.08 (see Table I). There are two radio resource operating modes: packet idle and packet transfer (Fig. 2). In packet idle mode, the UE listens to the Packet Broadcast Control channel and to the Paging channel without allocated Temporary Block Flows (TBFs), corresponding to unidirectional connections between the UE and the network (see TS 03.64, in Tab. I). If the UE is in idle mode and needs to transmit data, it switches to the packet transfer mode effectively asking for radio resource allocation through a TBF on one or more packet data physical channels.

The transition from transfer to idle mode (releasing any associated TBFs) is regulated by the TBF-Timer, restarted every time data is received on the TBF radio bearer. According to the specifications, the TBF-Timer is set to 5 s. The number of TBFs allocated is based on the capacity-on-demand principle.

GPRS was enhanced (Enhanced GPRS (EGPRS)) in GSM Rel."99 with the introduction of the Phase 1 of Enhanced Data rates for GSM Evolution (EDGE). EGPRS slightly impacts the radio resource and the mobility management (TS 04.60).

**3G/UMTS**

In 3G/UMTS networks, RRC is employed between the UE and the Radio Network Controller (RNC) in the access network. In all 3GPP releases (from Rel. 99 to Rel. 7), the RRC state transition model has remained largely unchanged (TS 25.331). Universal Mobile Telecommunication System (UMTS) terminals have basically two operational modes: idle and connected. Fig. 2.b illustrates RRC states and transitions as per see TS 36.331.

**FIGURE 2**

When the UE is powered on, it enters idle mode, i.e., it attaches to the network but does not actively engage in data transfers. When a RRC connection is established, the terminal switches to connected mode and the UE can be in any of the following four service states: Cell_DCH, Cell_FACH, Cell_PCH, and URA_PCH. In Cell_DCH state, according to Rel.'99, user data are transferred through a dedicated channel (DCH). If the network supports High Speed Packet Access (HSPA), the High Speed Downlink Shared CHannel (HS-DSCH) and the Enhanced DCH (E-DCH) may also be used for downlink and uplink transmissions, respectively. In Cell_FACH state, data are carried through common channels; typically, the Random Access Channel (RACH) for uplink, and the Forward Access Channel (FACH) for downlink. In Cell_PCH and URA_PCH states, UEs listen to the Paging Channel (PCH) and Broadcast Channel (BCH), but uplink data transfer is not possible [3], [4].

RRC state transition changed only marginally between Rel.'99 and Rel. 7. For example, in Rel. 6 a new method for a handover from GPRS packet transfer mode to RRC connected mode was introduced. Rel. 7 introduced Continuous Packet Connectivity (CPC), which is an improvement of the scheduling for HS-Rel.99 and Rel. 7. For example, in Rel. 6 a new method for a handover from GPRS packet transfer mode to RRC connected mode was introduced. Rel. 7 introduced Continuous Packet Connectivity (CPC), which is an improvement of the scheduling for HS-Rel.99 and Rel. 7. For example, in Rel. 6 a new method for a handover from GPRS packet transfer mode to RRC connected mode was introduced. Rel. 7 introduced Continuous Packet Connectivity (CPC), which is an improvement of the scheduling for HSPA-related channels, but does not affect the state transition model. CPC consists of three main building blocks: Discontinuous Transmission, Discontinuous Reception, and High Speed Shared Control CHannel (HSSCCH)-less operation [5]. Another important feature is the possibility to schedule HSPA related channels in Rel. 5 and Rel. 6, respectively.

RRC state transitions depend on Buffer Occupancy (BO) levels at the Radio Link Control (RLC) layer. Typically, a transition from Cell_DCH to Cell_FACH takes place when BO is zero and a threshold for Dedicated CHannel (DCH) release timer is exceeded. The transition back to Cell_DCH is carried out if the BO level exceeds a threshold value for a set time, that is, there are data waiting to be transmitted. Moreover, if the period of inactivity in Cell_FACH is long enough (ranging 2-10 s) the UE may change its state to Cell_PCH or URA_PCH. The transition back to Cell_FACH or Cell_DCH is usually carried out if user activity is detected. The RRC mode may be changed from connected to idle, if the inactivity timer triggers a transition, or the RNC is (over)loaded. In the latter case, the RRC connection is released [4].

Rel. 9 (released in 2009) and Rel. 10 (in 2011) do not introduce relevant changes in RRC.

**GPRS after Release 4**

3GPP specifications (Rel. 4 and later) describe the maintenance and evolution of GPRS/EDGE standards. We now discuss the relevant modifications introduced for radio resource allocation in light of the previous discussion on 3G/UMTS networks.

In Rel. 4, the GSM EDGE Radio Access Network (GERAN) (TS 43.051) was adopted to complete the evolution of GSM standards towards UMTS. GPRS may use the Iu interface (in addition to the classic A/Gb interface) and the QoS architecture of UMTS.

Concerning the radio resource management, the original long duration of TBF was shown in practice to deal poorly with bursty traffic, so that the Extended Uplink TBF (to maintain the uplink TBF during inactivity states) was added in Rel. 4 (TS 44.060). Its counterpart for the downlink was already introduced in Rel. 97.

The RRC protocol for GERAN Iu mode is the combination of the GSM and UMTS RRC radio resource operating modes.
The new protocol is a compromise between the adaptation of the GERAN Iu features to the UTRAN Iu mode and the need for backward compatibility [6]. New procedures, such as RRC connection and mobility management, were added to the GERAN Iu mode and others were modified, including handover and paging. Two operation modes were defined: RRC_IDLE and RRC_CONNECTED, equivalent to the ones for UTRAN Iu (see Fig. 2.a). After the connection establishment, when the mobile enters the RRC-connected mode, three states are defined: RRC-Cell_Shared, RRC-Cell_Dedicated, and RRC-GRA_PCH (TS 43.051).

Basically each state differs in the information on mobile position and in the type of allocated channel. In particular, the mobile position can be known on cell or on GERAN Registration Area (GRA) level (i.e, a specified set of cells analogous to UTRAN Registration Area (URA) within UTRAN). In RRC-Cell_Dedicated state, one or more dedicated physical subchannels in the uplink and downlink are allocated to UE, which can have also one or more shared physical subchannels. The UE position is known by GERAN at cell level. In RRC-Cell_Shared, the mobile location is known at cell level, but, unlike RRC-Cell_Dedicated state, it has no allocated physical channels. In RRC-GRA_PCH state, no physical subchannel is allocated to UE and its location is known at GRA level. In this state, the UE monitors the paging channel and initiates a GRA update procedure upon GRA change. Any activity leads to a transition either to the RRC-Cell_Shared or RRC-Cell_Dedicated state. There is a complex interaction between RRC and RLC/MAC layer for radio resource management, primarily due to legacy reasons. The MAC state machine has four states. In MAC-Idle state no shared or dedicated basic physical subchannel are allocated. RRC can be in RRC-Cell_Shared, RRC-GRA_PCH state, or RRC-Idle mode. In the MAC-Shared state, at least one TBF is allocated, but no dedicated physical subchannels are allocated. The corresponding RRC state is RRC-Cell_Shared. In MAC-DTM state, the Mobile Station (MS) has one or more dedicated physical subchannels allocated and one or more shared physical subchannels. The corresponding RRC state is RRC-Cell_Dedicated. In MAC-Dedicated state, the MS uses a dedicated physical subchannel, but no shared physical subchannels. RRC is in RRC-Cell_Dedicated state. As a simple rule, MAC layer deals with assigning, maintaining, and releasing of shared channels, while RRC deals with the dedicated channels.

In Rel. 6, the RRC is mostly unchanged; the major improvement in GERAN is introduced in the physical layer with the Flexible Layer One (FLO) (see TR 45.902), that allows physical layer configuration along call setup. This change was needed to support QoS in IP Multimedia Subsystem (IMS), for example, for future real time multimedia traffic: pre-existing GERAN radio bearers were dedicated for a given service and, thus, were not enough flexible to support new ones, differently from UTRAN. FLO is a further step towards the process of unifying GERAN to UTRAN, to enable seamless provision of services over the two radio access technologies.

**LTE**

In Long Term Evolution (LTE), introduced in Rel. 08, the RRC state model was simplified. As illustrated in Fig. 2.a, there are two main states: RRC_IDLE and RRC_CONNECTED. There is no need for additional states in LTE, since there is no concept of common or dedicated channels. In RRC_Idle the terminal monitors PCH to detect incoming calls. For Earthquake and Tsunami Warning System (ETWS) capable UEs, ETWS notifications are received, and system information changes are detected. Furthermore, the UE carries out neighboring cell measurements and possible cell re-selections. On the other hand, in RRC_CONNECTED state unicast data can be transferred in both downlink and uplink, while also Discontinuous Reception and Transmission (DTX/DRX) may be utilized. In this state, also network controlled handovers may be used with optional Network Assisted Cell Change (NACC) to GERAN. The UE monitors PCH and ETWS similarly to RRC_idle state, but additionally UE also monitors control channels associated with the shared data channel in order to determine if data is scheduled for it. The UE provides channel quality feedback to the network, performs needed neighboring cell measurements and reports the measurements. For more details see TS 33.331 and [5].

### III. RRC State Transition Evaluation

To the best of our knowledge, past literature mostly focused on analytical modeling and simulation studies of RRC. Previously published work aimed primarily on testing RRC management policies with regard to blocking and dropping rates as well as evaluating the overall system capacity and investigating the energy consumption of mobile device [7]-[9]. RRC state transitions can be modeled in an analytical way using a discrete time Markov chain; see for example [7]. The transition probabilities are calculated as the probabilities that the idle times are longer than the timers used. Of course, the use of any analytical model presents a number of obvious limitations and such model is used mainly for energy consumption studies.

The popular ns-2 network simulator (see www.isi.edu/nsnam/ns) has also been employed in simulation studies (see [8]). According to the authors, four generic states are common among the different packet switched cellular air interfaces (GPRS, EDGE, WCDMA, CDMA2000). Each technology is modeled by mapping its own RRC states to the generic ones. The states are differentiated according to the available bandwidth, defined transitions, latencies of the transitions and delays. Specific channels features are not modeled, and both uplink and the downlink channels are considered reliable.

CARMA (Comparative analysis of radio resource management strategies) [9] is another discrete event simulator used for studying the performances of different RRC management strategies. CARMA can simulate only Packet Switched (PS) services, the downlink channel and the various timeouts and setup latencies can be changed in a convenient way.
A. RRC State Transitions in Practice

While standards, in general, specify RRC operations, they are not sufficient to completely describe, in practice, the behavior of real networks: algorithms and the general methodology that regulate RRC state transitions are not explicitly defined by any standard, even if most networks use the same procedures and are customized through a range of - non disclosed - parameter settings according to specific design choices and characteristics.

The correct setting of these parameters becomes valuable for operators interested in their concurrent settings; researchers could use them for a realistic settings of analytical model or simulation tool. On the other hand, malicious users can also use these values to overload the paging channel or to initiate DCH starvation attacks.

Herein, we investigate on these, “non standard”, aspects of RRC: the mechanisms regulating state transitions, the parameters used by operators in real networks, the compliance to standards of commercially available networks, and the interaction between user traffic and RRC mechanisms. For this scope, we use the 3G3T, introduced in [10], [2], able to measure traffic over cellular networks and to discover RRC state transition parameters using active measurements techniques.

Through the description of 3G3T, we will guide the reader to the practical aspects involved in RRC operations, showing how lower layers’ networks procedure, usually hidden to upper layers, interact with user traffic. 3G3T can determine the values of idle timers, RRC procedures’ delays, and can infer the dynamics of transitions. The tool is based on the different delay characteristics in RRC states. For instance: high bandwidth/battery consumption states are characterized by lower delays whereas channels with higher delays typically are associated with lower bandwidth/power states. 3G3T exploits the fact that RRC state transitions are directly coupled with traffic generated by UE, without channel preemption (due to higher priority traffic, for example) or cell reselection (due to terminal mobility, for instance). Thus, we developed algorithms to generate traffic patterns able to trigger state transitions, based on the following principles. Typically, transitions from resource hungry to less resource hungry states are triggered by an idle timeout, measuring the time from the last transmitted or received packet. State transitions from Cell_DCH to Cell_FACH or from Cell_FACH to Cell.URA_PCH states are good examples. Thus, the usage of resource hungry states is correlated with user activity. Since our earlier work [2], 3G3T was evolved, based on what we learned from our experience. It was reprogrammed according to a new modular design, that allows us, for example, to exploit 3GPP TS 27.007 AT commands for automatically testing our inference on network status and then to identify if the network behavior differs from the one expected.

With respect to the measurements reported in the rest of this paper, three identical setups were used in three different countries: a laptop with two network interfaces, one connected to public Internet via wired connection (Ethernet) and another using a mobile packet data access card (HSPA), as in Fig. 3. Then, using 3G3T, sequences of packets were sent from one interface to other. Thus, our active measurement traffic patterns were injected into real operational cellular networks. It is important to note that in this case our focus was more on the hidden technical properties of 3GPP networks than user behavior. Combining a study of typical user behavior in 3GPP networks with the knowledge attained in this work would be a natural next step. The typical used test scenario is illustrated in Fig. 3.

FIGURE 3

We now briefly describe the 3G3T working behavior using an example.

Suppose we start with an UMTS connection in Cell_DCH state and we want to test the respective timer in the downlink. 3G3T injects a packet sequence with slowly increasing inter-departure times (IDT), from the wired interface, through the Internet, to the UMTS interface. Fig. 2.b reports the diagram for UMTS only state transition, to orient the reader across the various transitions. As soon as the IDT increases, the inactivity period exceeds the release timer threshold, $T_{DCH,off}$, configured by the operator, and a transition to Cell_FACH state is carried out. The state transition is observed as a change in packet delay, since the average downlink delay in Cell_DCH is significantly lower than in Cell_FACH. The IDT of the first packet experiencing a larger delay is, on first approximation, the value of the idle timeout that triggered the transition.

Delving a bit deeper in 3G3T operation, we note that connections in Cell_DCH state can use different Spreading Factor (SF) values (i.e., the ratio of the chips to the baseband information rate) according to user bandwidth requirements. Lower SFs correspond to higher available bandwidth and lower delays; higher SFs correspond to lower bandwidth and higher delays. Therefore, in the Cell_DCH state, packets experience different delays based on the used SF. The choice of SF can be regulated by inactivity timers.

We tested four commercial HSPA networks, in three different European countries; hereafter most remarkable results are reported, to clarify the RRC mechanisms understanding. Along the text, we do not distinguish results among the networks, since their behavior is similar and just the numeric values of the parameters change. We repeated the experiments with the new version of 3G3T tool, and, after six months, the network performances were substantially unchanged.

Fig. 4.a illustrates the one-way delay, $d$, for the downlink channel as a function of the packet IDT for a real operational network, as measured by 3G3T. The figure clearly shows the transition from Cell_DCH to Cell_FACH in the downlink direction, effectively visualizing state transition dynamic, values of the inactivity timer, and the procedure delays.

FIGURE 4

The value of the inactivity timer triggering the RRC transition (as can be estimated from Fig. 4.a) is 2.6 s. RRC transitions are not instantaneous, therefore a packet that arrives during the state transition has to be buffered until
the Cell_DCH related channels are torn down. Then, the buffered packets are retransmitted as soon as the transition is successfully completed and Cell_FACH channels are set up again. In short, during each measurement run, one packet that arrives during the transition is delayed more than the rest of the packets. This packet contributes, together with a packet from each repetition of the test, to form a “cloud” of packets (see the blue circle in Fig. 4.a). The average delay of these packets minus the average delay in Cell_FACH state can be used as a good estimate of the procedure completion time.

In the tested network, the measured release timer threshold, $T_{DCH,off}$, for uplink was very close to the one measured for downlink, so it is straightforward to conclude that the thresholds are the same for both uplink and downlink. We repeat measurements on a different network. Fig. 4.b shows a similar dynamic, but a series of additional steps are present: the first steps are related to a change of SF while the last one corresponds to the Cell_DCH to Cell_FACH RRC state transition. This behavior was verified using the proprietary NemoOutdoor air interface measurement tool (www.nemotechnologies.com). In particular, NemoOutdoor was used to extract the value of the SF values corresponding to each group of packets shown in the figure.

So far, we have focused on the transition from Cell_DCH to Cell_FACH, which is triggered by timers. On the other hand, the transition from Cell_FACH to Cell_DCH is triggered based on the Buffer Occupancy (BO) level. The threshold was measured by using a traffic generator to send 56 bytes long UDP packets. The transition back to Cell_DCH was reached with a transmission rate of 7 packets/s. In terms of Layer 3 throughput, the threshold was approximately 4 kbit/s.

3G3T can also be used to dynamically measure transitions from Cell_FACH to states with lower power consumption (i.e., Cell_PCH and URA_PCH, as well as transition to idle mode). Fig. 4.c illustrates an example, from a real network, based on our measurements. If we attempt to interpret the state transitions based solely on standards and theoretical descriptions, we may misinterpret results.

In particular, after the expiration of the inactivity timer, the connection would switch from Cell_FACH to either Cell_PCH or URA_PCH. However, when correlating 3G3T measurements with NemoOutdoor, we find that the network did not carry out such transitions, but rather RRC transitions directly to idle mode. Such a transition from connected to idle mode requires the release of all RRC connections; therefore, each subsequent sent packet requires a state transition to Cell_DCH. This is a time wasting procedure requiring three-way handshake signaling and the reestablishment of all related channels, which leads to long overall delays. As we saw before, we can take advantage of such delay differences to better understand cellular network inner workings. The difference between this delay and the mean Cell_DCH delay can be used as a good estimate for the procedure completion time. It is worth mentioning that such a big delay is observed by each initial packet starting a connection when the network is in idle state.

Fig. 4.c shows an IDT overlap in the range $63 \div 69s$ with packets experiencing alternating high and low delays. We found that packets with low delays are transmitted in Cell_FACH state. Such dynamics suggests that the idle timer is started after we enter the Cell_FACH state, and the nearly 6 seconds of overlapping account for the idle mode to Cell_DCH transition delay, Cell_DCH release timeout and Cell_DCH to Cell_FACH transition delay. This behavior was first explained in [10]. Subsequently, we measured and reported similar behavior in three different UMTS networks across three European countries (Italy, Austria, and Finland) [2]. Due to license issues with NemoOutdoor, the absence of transitions to URA_PCH states could not have been verified in all the networks, but their similar behavior suggests that this is not an isolated implementation case. In Fig. 5, we report threshold values and the procedure completion times with the bounds of the 90% confidence interval. It is evident that all the values are similar among the three networks, except for the threshold for the release of the Cell_FACH state, $t_{idle}$.

**FIGURE 5**

As a further consideration, we should note that RRC state transition mechanisms, designed to both optimize network resource usage and save mobile device battery power, become useful in presence of considerable background traffic, due to network scanning or worms. In fact, in such cases, inactivity timers are ineffective since they are reset by unwanted traffic. This phenomenon was experimentally verified in one of the tested network in both [10] and [2]. Some networks operators filter unwanted traffic and RRC mechanisms are more effective.

**IV. CONCLUSION**

We presented the evolution of RRC mechanisms in mobile cellular networks, from earlier GPRS systems to the latest 3GPP technology, mentioning the upcoming LTE. We detailed the evolution of standards, the step towards the process of unifying the radio layers GERAN to UTRAN and the implications in RRC. Furthermore, we practically showed how real networks behave and the differences with respect to the standards, analyzing RRC state transitions for real commercial networks. The work can be fruitfully exploited for understanding in depth RRC mechanisms, helping operators and researchers to improve the management and the evolution of present cellular networks and to propose new advanced services. Future work involves further developments of 3G3T as well as measurements in LTE networks.

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**REFERENCES**


Fig. 1. Temporal evolution of access capacities, radio resource control, and network topology in 3GPP standard releases.

### TABLE I

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All technical specifications (TS) are available from www.3gpp.org
Fig. 2. RRC state transition diagrams in 3GPP Rel. 8 (a) and UMTS (b).
Fig. 3. Schematic of the measurement methodology.

Fig. 4. Transitions from CELL_DCH to Cell_FACH for download in two different networks. In b) Transition from Cell_FACH to less power consumption states. In c) Spreading Factor variation can be observed.
Fig. 5. Extracted threshold and procedure delays for the three tested networks.