# PERFORMANCE EVALUATION OF THE SOFTWARE DOWNLOAD PROCEDURE DURATION

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## ABSTRACT

The last years saw the development and the deployment of a plethora of different air interface standards all over the world. In this scenario, a common desire to produce a user terminal with a high degree of flexibility and able to work with multi-radio interface standards was envisaged. The implementation of such a fully re-configurable terminal implies the need for downloading various software modules from the Network to the Terminal in order to update/upgrade software and hardware entities in the handset, thus enabling the terminal to work with a new air interface. The aim of this paper is to evaluate the software download procedure performance, in order to understand which are the main aspects influencing it and how to increase the efficiency of allocated resources and download duration.

## 1. INTRODUCTION

A lot of different air interface standards are currently in operation world-wide, and also other new air interfaces are being standardized. In this context there has been a common desire to produce a user terminal with a high degree of flexibility and able to work with multi-radio interface standards. This has led to the development of the re-configurable radio (or Software Defined Radio - SDR) concept. When a re-configurable Mobile Terminal moves to a new network with a different air interface, most or all its layers (from physical layer to application layer) could be re-configured in order to communicate in the new air interface and to provide all services to the user according to the new network's capabilities.

The implementation of a fully re-configurable terminal implies the need for downloading various software modules from the Base Station to the terminal. These downloaded software modules will be used to re-program software and hardware entities in the terminal, thus enabling the terminal to work in a new network mode. Software download for the mobile terminals is one of the most critical issues, because this task is performed frequently due to user mobility or to user needs (e.g. the user needs to change the air interface for roaming access or download a particular software patch). Moreover the software download in the mobile terminal must be as fast as possible, easy to perform, user-transparent, and possibly error free.

In the paper an efficiency assessment of legacy systems (e.g. GPRS and UMTS), regarding the Over-the-Air software download procedure, has been performed in a simulative manner and taking into account the procedure defined by SDR Forum. This analysis leads to the estimation of the duration of the overall procedure in both cases of patch download and RAT download. In the paper, the over-the-air download technique considered has been implemented using the traffic and control channels of the actual cellular networks (GSM/GPRS or UMTS). The terminal must be active on one of these systems and, using the channels provided by said standards, can download the operative software related to another system. For example, a reconfigurable terminal that is using a third-generation system (UMTS) can perform the software download of a second-generation operative software (GSM/GPRS) using the third generation system channels.

The overall software download procedure is divided into distinct phases and each phase is characterized by a duration time, thus in order to evaluate the efficiency of the overall radio software download procedure, it will be necessary to estimate the duration of the complete process. This has been evaluated using a simulator able to take into account the radio interface used to set-up the connection, download the software and release the connection at the end. Moreover, also the system congestion (radio resource occupancy and availability) and how the resources are allocated by the RRM algorithms has been taken into account.

## 2. DOWNLOAD OF THE SOFTWARE

In this section a remind to the OTA Download technique and protocol description is reported. This will help to focus the attention on the particular aspects that could guarantee an efficient spectrum download of the software.

### 2.1. Over-The-Air (OTA) Download

As reported in [1], the software download technique in which is possible to have the maximum versatility is the Over-the-Air (OTA) download. In this case, the software download operation occurs using a radio channel of a pre-existent cellular network or an additional infrastructure. Three different working modes are defined:

1. The traffic and control channels of the actual cellular networks (GSM/GPRS or UMTS) are used. The terminal must be active on one of these systems and, using the channels provided by the standard, can receive the operative software related to another system.
2. A signaling or bootstrapping "universal channel" used for the download procedure is introduced: in this case, when the terminal is switched on, it automatically tunes itself on this channel and performs the operative software download related to the system present in that place.
3. A combination of the two methods can be used: the negotiation phase of the download is performed, for example, using an active standard (first method) while the software download method occurs by a specific channel dedicated to this operation (second method).

An accurate description of the advantages and disadvantages of the OTA download method is reported in [1].

### 2.2. Download Procedure

The radio software download procedure is divided into three distinct phases [2]:

- Pre-download Phase. This phase ensures that the radio software modules can be securely transferred based on the current configuration, capabilities of the device, and user requirements. This includes service discovery, mutual authentication, capability exchange, and download acceptance exchange.
- During-download Phase. This phase includes the transfer of software, the verification of its integrity, and retransmission requests in the case of errors.
- Post-download Phase. This phase includes the installation of software, the in-situ testing, the device reconfiguration, the non-repudiation exchange, and the recovery efforts in case of reconfiguration failures.

All the aforesaid OTA download methodologies are referring to the client/download path/server architecture. Hereafter, the main steps of a generic procedure for download with any of the methods previously described are reported.

The generic protocol for software download is client-server oriented, with the terminal assuming the client role and a generic node (software repository) assuming the server role.

The main steps of the procedure are graphically reported in Figure 1 and described in the following [3]:

- Initiation: the terminal (or the server) triggers the download procedure start. In case the network or the terminal cannot operate the download (due to lack of resources or for other actions with higher priority) the procedure is interrupted.
- Authentication: in this phase, the terminal and the server authenticate each other
- Capability exchange: the server communicates the information related to the software to be downloaded; terminal verifies if software can be charged in the memory, installed and started, on the basis of its own characteristics and parameters
- Download acceptance: the server communicates to the terminal the characteristics of the download (e.g. dimension and number of segments/blocks), of the installation and of the billing; the terminal, eventually with the user interaction, states if the server indication can be accepted or not.
- Software download and integrity test: download of the operative software and of data checks takes place; as the software is downloaded, an integrity test is run: the terminal requires the retransmission of radio blocks not correctly received.
- Installation: during the installation billing and licensing data are provided by the server.
- In-situ testing: before running the new operative software, terminal runs a test.
- Non-repudiation: the terminal confirms to the server the correct installation; after the reception of the confirmation by the server, billing procedures are initiated.

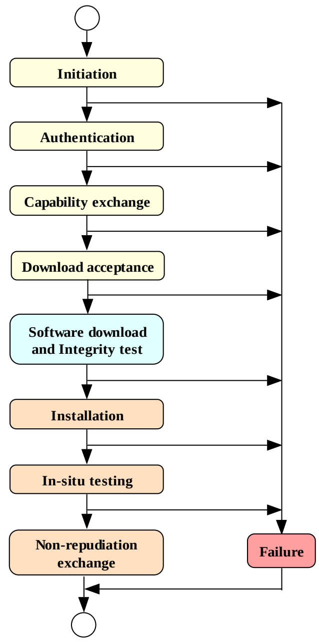


**Figure 1. Software download procedure**

### 2.3 Implementation Aspects

In this paragraph the implementation aspects of the OTA software download procedure are analyzed. In particular the architecture and the traffic generator used inside the simulator are described.

*5.1.1. Architecture*

The architecture is represented in Figure 2 where the nodes of a generic GSM or UMTS network are reported: the reconfigurable terminal is indicated by UE/MS; with GERAN and UTRAN are represented the radio access network of GSM and UMTS respectively. The architecture foresees that in the terminal is present a software (called OTA Client) able to manage the software download process from a specified node called OTA Server. Said node is directly connected to the GGSN of the Core Network.

The OTA Client and the OTA Server uses, as transport protocol, the TCP/IP protocols. The OTA server architecture foresees to have a context for each OTA Client for which a download session is active.

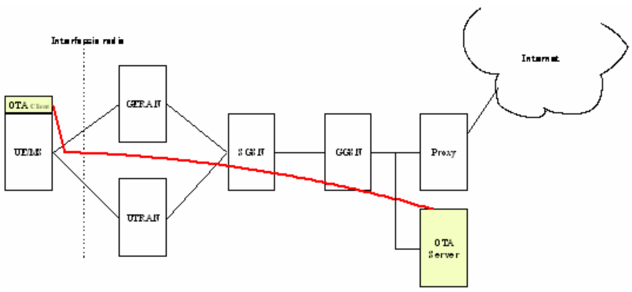


**Figure 2. The architecture used**

*5.1.1. Traffic Generator*

The OTAD Generator is a module used to simulate the generation of the traffic related to the download (started by the terminal or the network) of the software.

The main characteristics are the following:

- The interarrival time between one software download request and the next one, con be a fixed value of a random value with exponential distribution λ calculated taking into account the dimension of the software that has to be downloaded and the downlink traffic made by the user
- On the network side is possible to start the software download of a particular RAT (Radio Access Technology). Said software is characterized by a certain dimension and a certain decision probability. Dimension and probability are two parameters that has to be defined in the input file. In particular, if more than one RAT software can be downloaded on a terminal, in the input file the dimension of the RATs and the RAT decision probability must be defined according to some hypothesis of different technologies coexistence. The sum of the different RAT probability decision must be 1. The software to be downloaded is than chosen by extracting a random value with uniform distribution.
- On the terminal side it is possible to start the software download of a particular patch. Said software is characterized by a minimum dimension, a maximum one and the granularity that defines the possible dimensions that the software may have in the defined interval. These parameters are set in the input file. The patch dimension is than chosen by extracting a random value with uniform distribution.

## 3. CONSIDERED SCENARIOS

In this section, the main aspects of the considered scenario used for the evaluations are reported. In particular, the network topology and the main radio parameterizations are described. Moreover, the characteristic of the traffic generators used are reported.

### 3.1 GSM/GPRS Scenario

The considered GSM/GPRS scenario foresees the use of a macro-cellular layout with an ideal regular hexagonal coverage. This scenario is characterized by one BSC that manages 36 BTSs controlling 3 cells each. The cell radius is about 1150 m. The spatial disposition of the BTSs in the simulated area (where each site is tri-sectorial) and the irradiation diagrams of the three antennas are reported in Figure 3. The whole simulated area measures about 94.5 $km^2$ (9 km x 10.5 km).

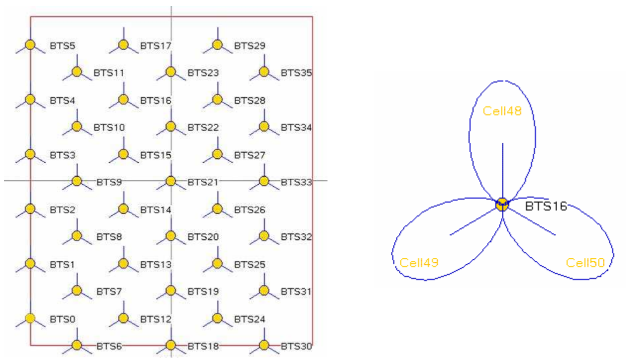


**Figure 3. Disposition (a) and irradiation diagram (b)**

Since an ideal scenario is considered, the Wrap-Around technique is used in order to avoid the border effect. The propagation attenuation is calculated according the following formula:

$$L = L_0 + 10 \cdot \alpha \cdot \log(R)$$

where $R$ represents the distance between the terminal and the BTS in km, while $L_0$ and $\alpha$ are simulation parameters set to 133.26 dB and 3.7 respectively. In the input file the Minimum Coupling Loss is set to 70 dB.

The propagation model used in the simulations takes into account the antennas irradiation diagram, the additional loss on the terminal and BTS side, and the shadowing. Each site includes three cells where the antennas are co-located (with an azimuth difference of 120 degrees).

Taking into account the path attenuation and the transmitted power of each antenna (set to 43 dBm), it is possible to calculate in each point of the simulated area the best-server, that is the cell which signal is better received. Figure 4 shows the best-server attenuations in the GSM/GPRS simulated area and the portion of the area ideally covered by each cell.

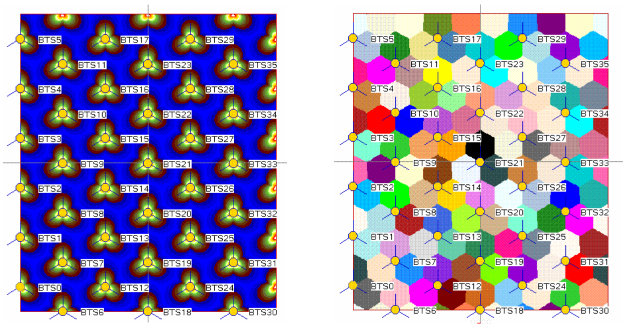

**Figure 4. Best-server attenuations (a) and portion of the area covered by the cells (b)**

About the radio configuration, homogeneous cells in term of carriers number and GSM/GPRS static channels allocation are considered. The frequency allocation foresees a set of 27 frequencies distributed among the various cells according to 9 cells cluster, with 3 carriers each. The channel allocation foresees two static channel for GPRS in each cell, which one of them is the master transporting the logical channel PBCCH.

### 3.2 UMTS Scenario

The considered UMTS scenario, as the GSM/GPRS one, foresees the use of a macro-cellular layout with an ideal regular hexagonal coverage. This scenario is characterized by one RNC that manages 12 NodeBs controlling 3 cells each. The cell radius is about 380 m leading to a whole simulated area of about 3.4 $km^2$ (1.98 km x 1.7 km).

Similarly to the GSM/GPRS scenario, the Wrap-Around technique is used and the same propagation attenuation model is adopted. The power transmitted by the physical channel CPICH of each antenna is set to 33 dBm.

The RAB (Radio Access Bearer) assigned to the terminals that effects the OTA download, have a nominal rate of 64 kbit/s at the RLC level, without errors and overhead due to the signaling. The RLC protocol is set to the Acknowledged Mode (AM).

### 3.3 Traffic Generation

In both GSM/GPRS and UMTS scenarios, in addition to the OTA download traffic it is also considered a certain amount of voice circuit traffic. The aim is to bring the system to work in a medium load condition, in order to analyze the OTA download protocol performances taking into account a certain interference level. The voice traffic is set to 10 Erlang for each cell.

Taking into account said voice traffic, different traffic conditions related to the OTA download are considered. In particular, both the possibility of download a patch and the software related to a new RAT are considered, loading the system in different ways. The nine traffic situations are used for both system GSM/GPRS and UMTS simulations.

Patch and RAT download is managed by the OTA software download protocol that segments the total amount of byte to be transmitted in block of 1024 bytes (set by input). The traffic generator foresees a certain interarrival time between one patch or RAT download and the next one. This interarrival time is set to 600 s for the patch download and 1800 s for the RAT one.

Regarding the RAT download, three different type of RAT software are considered: GSM/GPRS, UMTS and WLAN. According to the simulation scenario, the possibility to download the alternative RAT respect to the one defined for the scenario is given: in the GSM/GPRS scenario, the terminals can download a new RAT related to UMTS or WLAN; in the UMTS scenario, the terminals can download a new RAT related to GSM/GPRS or WLAN.

The parameters related to the OTA download traffic in the GSM/GPRS and UMTS scenarios are reported in Table 1 and Table 2 respectively.

| Parameters | Values |
|---|---|
| Patch dimension | 50-150 kbyte |
| Patch granularity | 25 kbyte |
| RAT1 dimension (UMTS) | 2 Mbyte |
| RAT2 dimension (WLAN) | 500 kbyte |
| RAT1 download probability (UMTS) | 0.8 |
| RAT2 download probability (WLAN) | 0.2 |

**Table 1. GSM/GPRS scenario OTA download parameters**

| Parameters | Values |
|---|---|
| Patch dimension | 50-300 kbyte |
| Patch granularity | 25 kbyte |
| RAT1 dimension (GSM/GPRS) | 1 Mbyte |
| RAT2 dimension (WLAN) | 500 kbyte |
| RAT1 download probability (GSM/GPRS) | 0.8 |
| RAT2 download probability (WLAN) | 0.2 |

**Table 2. UMTS scenario OTA download parameters**

 

## 4. DOWNLOAD EFFICIENCY ANALYSIS

In this section, the main results of the GSM/GPRS and UMTS system simulations are reported and analyzed.

### 4.1 GSM/GPRS System

The obtained results highlights the efficiency of the procedure described above. Said efficiency is quantifiable in the total duration used by the terminal to completely download the software. The total duration takes into account also the sub-procedures as, for example, authentication, capability exchange, software installation and related testing. Another important aspect valuated by the simulations are the causes of the procedure failure. These are essentially related to the situation of the network traffic congestion and can be essentially translated in the droop of the TCP link. Another fundamental aspect analyzed, is the one related to the RRM (Radio Resource Management) statistics that highlights the average number of allocated PSET, their average dimension, the average number multiplied on each PSET and the average dimension perceived by a terminal in downlink and uplink. Also the throughput in downlink and uplink at the MAC layer is reported.
The Table 3 reports the results related to the case of the RAT software download according to an increasing number of terminals that makes this kind of traffic. Results show that the efficiency of the RAT software download procedure decreases as the number of the terminal increases. This result is validated by the RRM statistics. In fact, the average number of terminals multiplied on the same PSET is increasing (from 1 to 6.8) leading to a decrease of the throughput at the MAC level from 38 kbit/s to 5 kbit/s.

| | 1 MS/cell | 5 MS/cell | 10 MS/cell |
|---|---|---|---|
| UMTS RAT Dimension [kB] | 2000 | 2000 | 2000 |
| WLAN RAT Dimension [kB] | 500 | 500 | 500 |
| UMTS RAT Interarrival Request [s] | 1710.1 | 1699.4 | 1706.5 |
| WLAN RAT Interarrival Request [s] | 1360.4 | 1689.5 | 1723.9 |
| UMTS RAT Download Probability [%] | 81.6 | 80.5 | 80.1 |
| WLAN RAT Download Probability [%] | 18.4 | 19.5 | 19.9 |
| UMTS RAT Download Duration [s] | 514.5 | 1792.5 | 3564.2 |
| WLAN RAT Download Duration [s] | 125.2 | 409.5 | 882.8 |
| MAC Throughput [kbit/s] | | | |
| Uplink | 10.8 | 10.7 | 10.6 |
| Downlink | 38.4 | 9.7 | 4.9 |
| RRM Statistics | | | |
| PSET Average Number | 1.2 | 1.0 | 1.0 |
| PSET Average Dimension | 3.6 | 2.8 | 2.8 |
| MS Average Number on DL | 1.1 | 3.4 | 6.8 |
| MS Average Number on UL | 0.6 | 0.6 | 0.7 |
| PSET Average Dimension per MS on DL | 3.6 | 2.6 | 2.4 |
| PSET Average Dimension per MS on UL | 1 | 1 | 1 |
| TCP connection failure [%] | 0 | 1.7 | 22.4 |

**Table 3. GSM/GPRS RAT software download results**

Analyzing the results reported in Table 4 related to the patch software download, it is possible to reach the same conclusion obtained by the RAT software download case: performances decreases as the number of the terminal increases (also if in a less heavy manner than the RAT download case). A phenomenon more evident in this case, is the decreasing of the average number of PSET as the number of the terminal increase. This is essentially due to an intrinsic problem of the RRM algorithm and to the number of GSLdevice that is not sufficient to satisfy the elevated number of requests. In this case in fact, due to the smallest interarrival time, the probability to have simultaneous requests is higher. Under these conditions, high simultaneous requests and number GSLdevice not proportionate, the RRM algorithm doesn't create new PSETs, leading to the consequences highlighted in the table.
Simulation with both patch and RAT software download traffic are also performed. In this case the performance are obviously worst than the single cases.

| | 1 MS/cell | 5 MS/cell | 10 MS/cell |
|---|---|---|---|
| Patch average dimension [kB] | 100 | 100 | 100 |
| Patch interarrival request [s] | 586.8 | 586.4 | 589.3 |
| Patch download duration [s] | 27.2 | 41.9 | 56.8 |
| MAC Throughput [kbit/s] | | | |
| Uplink | 10.9 | 10.8 | 10.8 |
| Downlink | 45.8 | 27.6 | 19.4 |
| RRM Statistics | | | |
| PSET Average Number | 2.8 | 1.2 | 1.1 |
| PSET Average Dimension | 3.2 | 2.9 | 2.8 |
| MS Average Number on DL | 0.4 | 1.1 | 1.5 |
| MS Average Number on UL | 0.3 | 0.5 | 0.5 |
| PSET Average Dimension per MS on DL | 3.8 | 2.8 | 2.6 |
| PSET Average Dimension per MS on UL | 1 | 1 | 1 |
| TCP connection failure [%] | 1.3 | 1.7 | 8.3 |

**Table 4. GSM/GPRS Patch software download results**

In conclusion, for the GSM/GPRS system, a strong dependence between the software download duration and the traffic load of the network is obtained. Performances may be improved using different RRM algorithms able to adapt the resources allocation according to the traffic type. However, it is necessary to highlight that while the results obtained for the patch download are acceptable, for the RAT download ones this is not true due to the high values obtained.

### 4.2 UMTS System

Starting from the same considerations made for the GSM/GPRS system, a similar analysis is made for the UMTS system. In particular, this is focused on the connection failures of the TCP link and on some other aspects related to UMTS only as the number of the rejected calls at RRC level or the average throughput at RLC level.
The Table 5 reports the results related to the case of the RAT software download according to an increasing number of terminals that makes this kind of traffic. Results show that the efficiency of the RAT software download procedure remains constant as the number of the terminal increases. This result is confirmed also by the average throughput at the RLC level that is about 26 kbit/s in all the considered

cases. This value is lower than the theoretical value of 64 kbit/s due to an elevated quantity of data retransmitted in downlink (about 52% of the total amount of the data transmitted). In fact, the interference condition perceived by the terminal, considering a conservative value of C/I target, leads to have an average BLER of 13%.

| | 1 UE/cell | 5 UE/cell | 10 UE/cell |
|---|---|---|---|
| **GSM/GPRS RAT dimension [kB]** | 1000 | 1000 | 1000 |
| **WLAN RAT dimension [kB]** | 500 | 500 | 500 |
| **GSM/GPRS RAT interarrival request [s]** | 1417.9 | 1556.45 | 1485.44 |
| **WLAN RAT interarrival request [s]** | 1655.6 | 1552.56 | 1503.58 |
| **GSM/GPRS RAT download probability** | 79.1% | 79.2% | 80.1% |
| **WLAN RAT download probability** | 20.9% | 20.8% | 19.9% |
| **GSM/GPRS RAT download duration [s]** | 295.5 | 303.2 | 299.1 |
| **WLAN RAT download duration [s]** | 149.6 | 148.9 | 147.7 |
| **RLC throughput [kbit/s]** | | | |
| Uplink | 18.7 | 18.0 | 18.2 |
| Downlink | 26.0 | 25.4 | 25.8 |
| Retransmission percentage | 51.5% | 52.5% | 52% |
| **RRM Statistics** | | | |
| RRC blocked connections on UL | 0% | 0% | 0% |
| RRC blocked connections on DL | 0% | 0% | 0% |
| Total RRC blocked connections | 0% | 0% | 0% |
| RAB blocked | 0% | 0% | 0% |
| RAB interrupted | 0% | 0% | 0% |
| **TCP connection failure** | 0% | 0% | 0% |

**Table 5. UMTS RAT software download results**

The same considerations can be obtained by the analysis of the Table 6 related to the case of patch download. The duration of the software download procedure is not affected by the traffic increase.

| | 1 UE/cell | 5 UE/cell | 10 UE/cell |
|---|---|---|---|
| **Patch average dimension [kB]** | 175 | 175 | 175 |
| **Patch interarrival request [s]** | 574.1 | 570.8 | 564.3 |
| **Patch download duration [s]** | 53.5 | 54.4 | 54.4 |
| **RLC throughput [kbit/s]** | | | |
| Uplink | 17.5 | 17.0 | 17.2 |
| Downlink | 25.6 | 25.1 | 25.3 |
| Retransmission percentage | 51.2% | 51.9% | 51.7% |
| **RRM Statistics** | | | |
| RRC blocked connections on UL | 0% | 0% | 0% |
| RRC blocked connections on DL | 0% | 0% | 0% |
| Total RRC blocked connections | 0% | 0% | 0% |
| RAB blocked | 0% | 0% | 0% |
| RAB interrupted | 0% | 0% | 0% |
| **TCP connection failure** | 0% | 0% | 0% |

**Table 6. Patch RAT software download results**

Simulation with both patch and RAT software download traffic are also performed. Also in this case the performances are acceptable for all the network traffic load considered.

In conclusion, for the UMTS system, the software download procedure has good performances in both case of patch and RAT download thanks to the power control algorithm that permits to maintain a constant C/I target at the receiver. It has also to be considered that the traffic load set in the UMTS system simulations, that is the same set for the GSM/GPRS one, it is lower than the theoretical maximum reachable: this is confirmed also by the absence of connection failure at the TCP level. Further studies may include than an higher traffic load and also the use of RAB with different values if nominal bit-rates (i.e. 144 kbit/s, 384 kbit/s).

## 5. CONCLUSIONS

In this paper, a software download procedure performance in case of legacy systems usage was analyzed by simulations. In particular, the GPRS and UMTS system were considered as bearers for software download procedure.

For GSM/GPRS it was noted that the software download procedure strongly depends on the RRM scheme adopted; in any case, the download of an entire RAT was considered too time consuming for the users. For UMTS system, it was considered also acceptable for the user perspective the entire RAT software download.

It has to be highlighted that in certain environments or situations, also the performances obtained by the UMTS system could be not acceptable. Alternative ways for downloading the software on a terminal may be studied and taken into account (e.g. MBMS).

## 9. ACKNOWLEDGMENT

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