Service and interworking trials on the VIRTUOUS demonstrator: mobility, QoS adaptation and end-to-end connectivity in a multi-segment 2.5G-3G, terrestrial and satellite network

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ABSTRACT

This paper refers to the trial strategy that has been designed within VIRTUOUS project to evaluate the features of the VIRTUOUS demonstrator, which integrates three systems for mobile communication: GPRS, Terrestrial UMTS and Satellite UMTS. Three main functionalities have been implemented: QoS provision, roaming between radio access segments and IP end-to-end application-level connectivity. By exploiting these features, the trials in VIRTUOUS will produce significant results about concepts of mobile network evolution.

I. INTRODUCTION

The IST VIRTUOUS project (Virtual Home UMTS on Satellite) aims at demonstrating the feasibility of an integrated system for 3rd generation mobile communications, which constitutes itself a demonstration of a smooth migration path from GSM phase 2+ (GPRS) to UMTS. Such a system combines the use of a single core network with three radio access segments: GPRS radio access network, Terrestrial UMTS (T-UMTS) radio access network and Satellite UMTS (S-UMTS) radio access network. The UMTS access components are respectively based on the radio access standard for UMTS networks, W-CDMA, and its satellite counterpart, SW-CDMA, a candidate standard proposed by ETSI for wide-area coverage.

For this purpose, the VIRTUOUS project conceives the realisation of a laboratory demonstrator, which implements some major functionalities of the target system. This demonstrator respects the architecture of a classical mobile network, separating the elements into domains: user equipment, radio access network and core network, plus the external ISP domain. Thus, the VIRTUOUS demonstrator comprises a multi-mode mobile station testbed, an S/T-UMTS testbed, the GPRS and core network equipment and an external IP network. All these elements are obtained from commercial sources, or other research projects, or specifically developed for VIRTUOUS purposes. The architecture of the VIRTUOUS demonstrator is shown in the following figure:

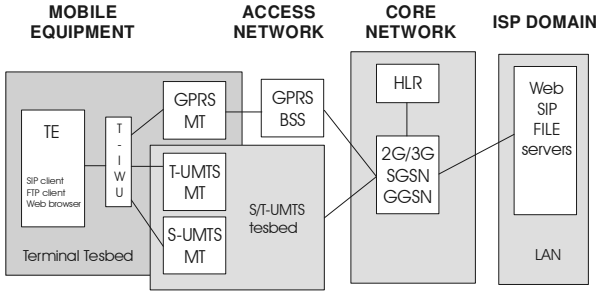

Figure 1. VIRTUOUS demonstrator

II. VIRTUOUS EXPERIMENTS

The goals of VIRTUOUS are materialised and grouped in three experiments: the Inter-segment Roaming experiment, the End-user Service experiment and the QoS experiment. Experimentation on the implemented demonstrator will consist on a set of trials, which are expected to produce valuable results in a variety of fields concerning fundamental UMTS concepts. Some of the most important aspects the VIRTUOUS trials plan to study and exploit are network integration, interoperability and interworking, since the target system envisages an heterogeneous mobile network that must offer seamless connectivity to subscribers irrespective of the radio segment in use or the desired end-user service. This internetworking focuses on two areas: mobility across different radio networks and end-to-end transport in a multi-segment environment. The former leads to the Inter-segment roaming experiment, while the latter addresses the End-user Service experiment.

Moreover, another key issue of 3rd generation systems that the End-user Service experiment is taking into account is the engineering of intelligent service applications, which could be deployed outside the operator realms. The conception of a media-independent

service plane implies that the network must provide an abstraction layer over the specific network protocols interconnecting the different domains of a mobile system (user domain, access network domain and core network domain). This global bearer, typically a TCP/IP-based layer, conveys the application traffic between the user-side and the network-side at the service level.

In addition to connectivity, the service plane requires that the network assures a level of quality for the user connections. It is a matter of the QoS experiment to probe the ability of the implemented network to perform a QoS adaptation between the features of the required user service and the capabilities offered by the available access segments. In order to survey both end-to-end connectivity and QoS provision in the VIRTUOUS demonstrator, different classes of applications are considered for the QoS and End-user Service trials: conversational class, interactive class, background class and streaming class.

Underlying the above-mentioned objectives, these three experiments will produce a significant contribution to the development of the S-UMTS standard in a practical way. The trial design includes the execution of the experiments under different scenarios at radio access level. This can be achieved by using the physical layer emulators of the VIRTUOUS T/S-UMTS testbed to simulate different propagation delays, multi-path fading, interference effects, etc. for the T-UMTS segment and the equivalent conditions for the satellite constellations in both LEO and GEO configurations for the S-UMTS segment. Thus, the trials can demonstrate the effectiveness of S-UMTS technology as an access alternative and the interworking of a satellite system with the terrestrial mobile network.

This paper focuses on the description of the design and strategy of the relevant VIRTUOUS trials on the one hand, and the expected results of each experiment on the other.

III. INTER-SEGMENT ROAMING EXPERIMENT

The Inter-segment Roaming is considered to be one of the key points of the whole project. Inter-segment roaming refers to the network ability to reach a called user regardless of the access network (either second or third generation, either terrestrial or satellite) which is presently serving the user, and to give this user opportunities to be served with segment-specific services. It is an essential functionality for mobility management in a system that integrates more than two access technologies since the serving network should distinguish the radio segment that subscribers are using to register their presence. Thus, the core control can optimise network capacity and performance. VIRTUOUS represents the way that this will be feasible by means of exploitation of the existing UMTS standards.

This experiment comprises several elements of the demonstrator. The user equipment hosts the Terminal Interworking Unit (T-IWU), which ultimately selects the access network to attach to, and three Mobile Terminations (MT) that handle with specific radio-segment aspects such as link quality measurement and value mapping. With regard to the network-side, the involved elements are the SGSN and HLR in the core network, which manage and contain user mobility data and user profiles respectively, and the UMTS radio access network entities. The latter acts as relay between the RRC (Radio Resource Control) protocol messages exchanged with the UMTS MTs and the RANAP protocol messages exchanged with the core network equipment. The link quality information is provided to the UMTS MTs by the physical layer emulators and by the GPRS testbed to the GPRS MT.

In order to start the Inter-segment Roaming there are two possibilities: manual initiation or automatic initiation. Both cases require that the signal quality of the chosen segment is checked whether it is sufficient or not. The signal quality of the segment is the decisive factor to trigger the Inter-segment Roaming procedure. The measurement is performed by receiving the Bit Error Rate (BER) delivered by the physical emulator. This value is mapped in the RRC subsystem of each MT according to the mapping function adapted to each radio access technology. The mapped values are transmitted over the mobility management subsystem to the T-IWU. In order to show the performance of this functionality by the above-mentioned two modes, the trials are split into two groups:

- Automatic mode: the sufficient factor for triggering automatic Inter-segment Roaming is the quality of the radio link. The functionality will be tested by means of the manual change of radio link quality (BER control) at the VIRTUOUS physical emulator and the configuration of a network preference list stored in the T-IWU. Initially, this element selects the suitable segment to attach to and later, according to radio link quality and user preferences, it roams to another segment.
- Manual mode: the sufficient factor for this mode can be the user wish based on the pricing factor, the current state of the radio segments, the quality of the offered service or any other requirements imposed by the end-to-end services with respect to the radio segments. These tests will check the Inter-segment Roaming capabilities when the T-IWU is in manual mode. Thus, the user initiates all procedures, and chooses when to proceed to change the radio segment. This can be accomplished by using the T-IWU GUI application. The radio link quality of each segment will be changed according to a predefined scenario.

Each mode has further three types of trial to cover the entire set of possibilities: roaming from GPRS to T-UMTS and vice versa, roaming from GPRS to S-UMTS and vice versa, and roaming from T-UMTS to S-UMTS and vice versa.

Each trial consists basically of four phases:

1. The initial phase consists of a pre-configuration of each demonstrator element and the establishment of the physical connections (TCP/IP or RS232) which link each one of the involved testbed components.
2. Measurement/segment selection phase. The periodically measured values in each segment are collected and mapped to the absolute values that the T-IWU can understand.
3. Mobility management phase. The attach/detach procedures and the Inter-segment Roaming procedure belong to this phase.

The final goal of this experiment test suite is to check the mobility management functionality implemented in both the terminal equipment and the network. These functional tests will check that the terminal chooses the appropriate segment according to the measures received from the different segments via the MTs. Both in manual and automatic mode, the following procedures must be checked:

- Attach procedure: the end-to-end (user equipment to SGSN) exchange of *attach* messages.
- Intersegment roaming procedure: the end-to-end (user equipment to SGSN) exchange of *routing area update* messages.

In both cases, the result of these procedures can be checked in the T-IWU and in the SGSN. The verdict criteria for the trials will require the terminal equipment to register correctly with the core network through the selected segment.

IV. QUALITY OF SERVICE EXPERIMENT

The QoS experiment is going to show the system performance over a particular combination of data sources. These performances depend, considering the same kind of traffic, upon the quality of the scheduling algorithm. The following picture represents the kernel of the system architecture, showing all the logical blocks involved in the scheduling module:

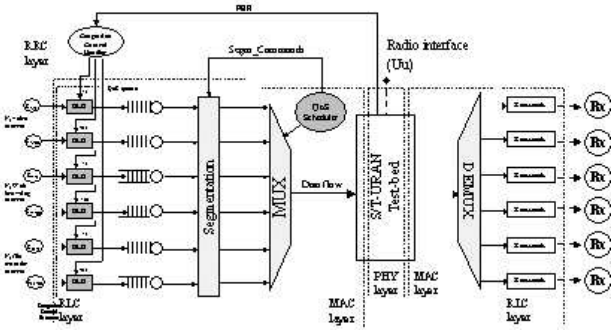

Figure 2. QoS experiment scenario

The DLBs parameters are considered to be fixed in the target system architecture, i.e. decided during the set-up phase by devices such as RSVP [see 2], so the attention of the experiment is focused on the MAC layer (furthermore, in VIRTUOUS the RSVP is not implemented). The QoS scheduler is responsible for the task of multiplexing between the available queued channels. In this way it is possible to implement the required QoS using the prefixed scheduling parameter for each channel. The multiplexed data flow will then cross the physical layer simulator and then will be demultiplexed on the other side, returning the separated channels to the receivers.

The implementation of the demonstrator has been projected taking in mind both portability and versatility of the system. The transmission traffic is generated from real applications. In this way it is possible to test the system under a lot of load situations. In particular the demonstrator is made up of four main modules running on Linux Systems:

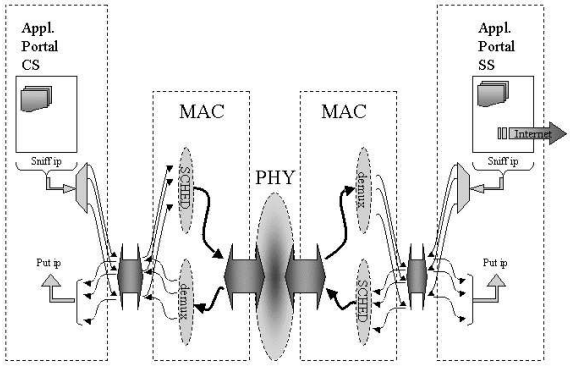

Figure 3. QoS implementation architecture

The leftmost and rightmost blocks represent the two Application Portals: from these machines all the IP traffic will be generated and received. In particular the client-side Application Portal will contain all client software (such as ftp clients, web browsers, Real Player etc.) while the server-side one will contain all the server modules (web server, ftp server, Real server etc.). The testing phase is actually a simple Internet navigation, using all the available software that runs on the web: Netscape for web browsing, WSFTP for file transfer, Real Player for video and audio streaming, and so on. All the traffic generated from these applications is captured from the "sniff ip" module and separated into different connections, which will be treated with the prefixed QoS parameters from the MAC module.

The MAC module is responsible for the packet scheduling selecting data from the parallel channels received by the Application Portal. In this phase all the captured data are transformed into a single stream to be sent through the physical emulator. The demultiplexing task runs on the other side, and it is in charge of "decoding" the single stream, reconstructing the

different channels and sending everything to the Application Portal, where the IP packets are put again back on the net. The backward path is almost the same.

The scheduling algorithm contained in the MAC module is easily configurable. In particular it is also possible to change the scheduling algorithm in order to compare the performance of different QoS implementations. For example, we have implemented three algorithm modules: the 3GPP proposed one, the "fixed length" and the innovative VIRTUOUS algorithm. See [1] for a description of these algorithms, together with a brief comparison of the relevant performance. Comparative logs of the tests can be easily obtained from the fifth (optional) module: the Graphical Visualizer. This is an external module that can be connected to the MAC block in order to view the transmission performance in real time and to log every piece of information sent from the MAC during the scheduling task. In this way it is possible to elaborate the demonstration results later.

The test cases can be projected just trying out particular sets of "parallel" Internet connections. Each connection will be transmitted through a particular channel (i.e., it will be scheduled with a particular QoS). The results of the simulation can be viewed directly while navigating in the virtual Internet or later elaborating the transmission logs.

The objective of the above-described tests will be the comparison among the performance of the various algorithms under different load conditions. In particular, the tests should stress the great advantage of the new algorithm proposed in VIRTUOUS [1], especially for the FTP-Web sources in all the operative conditions. This result should not have impact on the performance of the real time connections, since the operative method of the algorithm aims at maximising the overall number of data bits transmitted, also granting a fair and efficient treatment for the low-priority traffic.

V. END-USER SERVICE EXPERIMENT

The main focus of the End-user Service experiment is to demonstrate typical end-user services like SIP-based telephony, web browsing and file transfer in an integrated GPRS/T-UMTS/S-UMTS service area. From the user point of view, the VIRTUOUS end-to-end service may be regarded as applications on top of a full multi-service IP connectivity system. Several IP bearers with different QoS have to be used between the Terminal Equipment (user equipment domain) and hosts in the ISP environment of the VIRTUOUS demonstrator. Thus, the elements of the demonstrator involved in this trial suite include components from all the domains, due to the end-to-end nature of the experiment.

The Terminal Equipment (TE) part of the mobile station houses the client applications, while the three Mobile Terminations (MT) implement the non-access stratum functions, which are required to establish a packet bearer from the user equipment to the core network. The access network considered by this experiment uses a GPRS base station subsystem for the GPRS segment and the UMTS radio access network testbed to realise both the terrestrial and satellite 3G segments. This testbed comprises the technology-dependent access-stratum entities and the protocol translator units to forward messages on top of the different protocol suites used in the radio-specific part and in the core network-specific part. The network-side non-access stratum functions are handled by the core network, where the co-located 2G/3G SGSN/GGSN plays a crucial role in this experiment.

For the End-user Service experiment, a non-access stratum signalling connection is required to transfer the signalling messages between the multi-mode mobile and the SGSN/GGSN in the core network. This connection is formed by a RRC connection between the user equipment and the Radio Network Controller (RNC) as well as a RANAP connection between the RNC and the core network. In addition, the experiment requires an end-to-end IP connectivity for user data. This IP connectivity across the three segments (from the user equipment to the GGSN) is achieved by using the PDP context activation procedure, which establishes a packet bearer across the network.

The trials differentiate the control plane and the user plane. The control plane deals with the signalling exchange and is used to build up the user plane, which in turn is responsible for the transport of user data. The following figure shows the data bearers across the user plane:

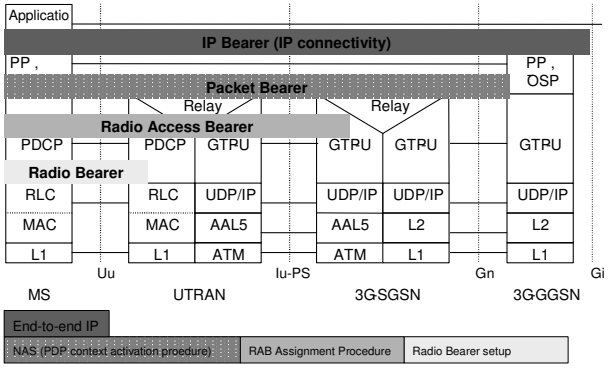

Figure 4. Data bearers and user plane

When an application requiring IP connectivity is started in the TE, the TE commands the correspondent MT to trigger the PDP context activation procedure. This implies an exchange of PDP context activation messages across the control plane using the RRC and RANAP connections to reach the SGSN. The PDP context activation procedure forces the initiation of the

Radio Access Bearer establishment and release. This Radio Access Bearer is composed of a Radio Bearer and an Iu Bearer. The PDP activation messages include several parameters that define the QoS profile of the global IP bearer and the underlying bearers to satisfy the application requirements.

The objective of the End-user Service trials is a dual one. First, the trials must demonstrate that the bearer establishment is successfully accomplished by checking the correct use of the control plane of the VIRTUOUS demonstrator. The second goal of the trials is to measure the efficiency of the user plane established over the three segments (GPRS, T-UMTS, S-UMTS) when transferring different classes of application traffic: SIP-controlled Voice over IP, web browsing and file transfer. Thus, the End-user Service trials follow a hierarchical structure, where all the considered applications may run over the three access segments, which in turn may be configured under different conditions.

The execution of this suite of trials is driven by the VIRTUOUS Application Launcher. This is a particular tool running in the TE that allows the VIRTUOUS user to select the access segment, the end-user application to be started and also a possible QoS profile for each individual application. When the application is launched, the TE checks if there is already an appropriate and active PDP context or it is necessary to activate one and request the SGSN to allocate an IP address for this mobile node and the given PDP context. To evaluate the end-to-end performance of the VIRTUOUS demonstrator, the End-user Service trials will collect some parameters from each trial case: transfer speed, delay and size of the received packets, and for the case of SIP service, speech quality and voice delay.

To approach a realistic environment and to fully exploit the capabilities of the VIRTUOUS demonstrator, the End-user Service trials consider a variety of radio configurations for the UMTS physical layer emulators and the GPRS testbed. The GPRS segment provides two different channel speeds by using only a timeslot for the slow channel and three timeslots for the fast channel. The UMTS segments and their physical layer emulators allow a greater level of complexity for the definition of scenarios. For the case of S-UMTS, both geostationary and low earth orbits are considered. In all cases, the simulation sets other variables such as bit rate (128 Kbps or 8 Kbps), urban/rural environment, terminal speed, satellite delay, fading, interference level, etc. For the terrestrial case, the determining variables are bit rate (384 Kbps or 128 Kbps), urban/rural environment, cell configuration, multiple access interference, multi-path fading, vehicular speed, etc. The combination of different values of all these variables and parameters will produce well-defined situations in the access network.

It is expected that the most critical trials are those related to the Voice over IP service, especially when running over the S-UMTS segment. The lower speed and higher delays are inherent to satellite links and may introduce severe distortions in the conversational circuit and decrease voice quality. The trials will reveal the optimum configuration for the satellite segment that minimises the negative effects on this service.

VI. CONCLUSIONS

VIRTUOUS main objective is to develop a laboratory testbed that represents a miniature multi-access 2G/3G terrestrial and satellite mobile network. The VIRTUOUS consortium has designed a trial strategy to exploit the relevant features that have been designed, studied and implemented in the VIRTUOUS demonstrator. This strategy has been presented in this paper, along with the experiments that groups the target functionalities of the demonstrator: the QoS experiment, the Inter-segment Roaming experiment and the End-user Service experiment. The trial suites planned for these experiments will produce valuable results and conclusions about interworking between 2G and 3G systems, Satellite W-CDMA radio access and many other essential aspects of the UMTS standards.

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