An original adaptation of the UMTS protocols for a Direct Interconnection with IPv6

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ABSTRACT

This paper describes the adaptation of an experimental software radio system, based on UMTS-TDD and providing direct interconnection with an IPv6 Core Network, developed in the context of several research projects. It focuses on the convergence of a 3GPP-based system towards "pure-IP" architecture. The platform presented is designed using open architectures at both the hardware and software level and is primarily PC-based, running under Linux and RTLinux.

In the target architecture, IPv6 functionalities for Mobility, Quality of Service and Paging replace UMTS mobility management and Core Network functions. The traditional Base Station becomes a Radio Gateway with IP routing capabilities, and controlling its own IPv6 subnet. The adaptation of the platform is achieved by introducing a new component, the Generic Radio Access Adaptation Layer (GRAAL) and modifying the 3GPP standard-based Radio Resource Control (RRC). The GRAAL provides the middleware for interfacing IPv6-based mechanisms with 3GPP-specific mechanisms for the access network. It is developed as en extension of a standard IPv6 network device driver. The RRC is reduced to the procedures identified as necessary to comply with this new requirement, enhanced to support the IPv6 functions described above, while at the same time, maintaining the control of the other 3GPP-compliant lower layers of the Radio Interface Protocols.

I. INTRODUCTION

A primary research activity of the Mobile Communications Department of Institut Eurécom is the development of real-time reconfigurable radio platforms. Our platforms are designed using open-architectures at both the hardware and software levels and are primarily PC-based. The use of software-radio technology allows for reasonably low equipment costs and provides an ideal way to experiment with real-time radio resources. The hardware and software solutions are made available to the research community by Eurecom at www.wireless3g4free.com.

The Software Radio Platform is used to innovate and experiment in areas related to Beyond-3G (B3G) wireless networks such as

- IPv6-based radio resource management for heterogeneous multiple radio-access technology wireless networks
- smart-antenna technology
- resource allocation and scheduling
- Quality of Service management.

It implements the UMTS - Time Division Duplex (TDD) standard in its release 4 [1]. The hardware architecture is centred on a PC system that gives access to, and allows experimenting with, wide band radio resources. The platform is scalable and allows configurations from a powerful base station with smart antennas to simpler mobile terminals with a single antenna. It provides functionality at three levels: hardware, Digital Signal Processing (DSP) software, and link level software.

The software portion of the platform is an extension to the Linux Operating System and makes use of a hard real-time micro-kernel known as RTLinux [2] for performing the UMTS-TDD processing. Networking functionality is provided by the Linux kernel and open-source extensions.

Layer 3 deviates from 3GPP, in the sense that it provides a direct interconnection with an IPv6 network in the base station. Section 2 describes the target architecture, where the traditional base station becomes a Radio Gateway (RG) with IP Routing capabilities. In the subsequent sections, the two main components achieving this objective are described. The Generic Radio Access Adaptation Layer (GRAAL), a software entity doing the work of a standard IPv6 network device driver plus the adaptation between the IPv6 and the UMTS worlds is described in section 3. The modification of the layer 3 of the UMTS, the Radio Resource Control (RRC), required to comply with this new architecture is presented in sections 4 and 5, together with its interactions with the GRAAL.

II. A NEW "PURE-IP ARCHITECTURE" AND ITS BENEFITS

This new architecture is at the convergence of 3 technological trends:

- Collaborative radio standards 3GPP , IEEE 802.xx
- Next generation mobile internet technology - IPv6 , Mobile IP
- Open-source software and operating systems – Linux , RTLinux [2]

It can be qualified of «pure-IP» architecture to differentiate from the "all-IP" architectures which bring the IPv6 protocol statically on top of existing protocol stacks. It avoids in that way a non optimal "IP-on-IP" encapsulation.

In this architecture, the Radio Access Bearer service introduced in the UMTS architecture between the Mobile Terminal or User Equipment (UE) and the SGSN is no longer present. This implies to replace the PDP Context Activation procedure. In 3GPP, a UE uses this procedure in order to establish a virtual connection with its GGSN and to express its Quality-of-Service (QoS) requirements for the connection. It may also ask for a dynamic address allocation in case of IPv6 stateless auto-configuration. The replacement is part of the RRC/Middleware entities described below.

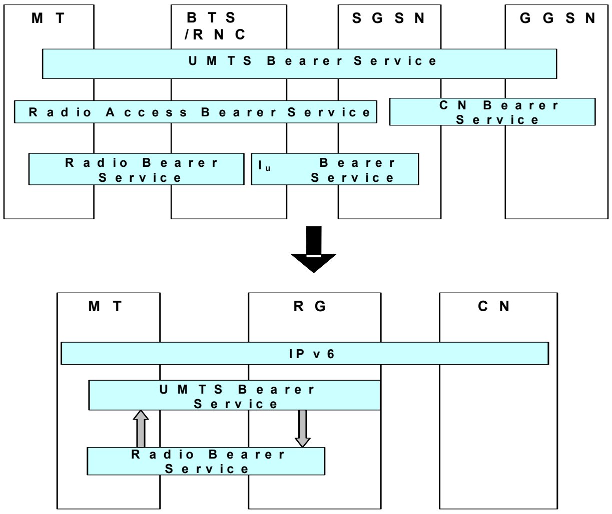

Figure 1 : Evolution of 3GPP Networking towards pure-IPv6

Figure 1 shows the evolution of 3GPP networking entities towards the architecture considered here based on an IPv6 core network (CN). We can see from the figure that running IP up to the RG has a strong impact on the overall network architecture of the system, since we bypass some basic 3GPP networking entities (i.e. RNC/SGSN/GGSN), which results in a reduction of the number of bearer services. A bearer service enables the provision of a contracted QoS using the lower layer services. An interface that remains completely unmodified is the Radio Bearer Service which defines the access stratum configuration for the service. UMTS bearer service is also required a priori. The need for the Radio Access Bearer Service, however, is questionable. The CN Bearer Service as well as the Iu Bearer Service are definitively not present in the proposed architecture since the corresponding interfaces do not exist. This has an important impact on the various interface levels that the RG must offer.

The IPv6 functionalities replace the UMTS mobility management and other functions. The 3GPP SGSN and GGSN are dropped and replaced by standard IP routers. An UMTS-TDD cell is considered as an IPv6 subnet, with its own prefix, and thus, in this sense, the RG is a router for the users of the subnet/cell. Each RG is able to control its own IPv6 subnet This allows the usage of the IPv6 stateless autoconfiguration and a seamless roaming between various access technologies, in particular between UMTS and WLAN.

High-level protocols are usually described in the Control Plane for signalling data and User Plane for user data. This new architecture impacts both Planes. In the Control Plane, we can benefit from Mobile IPv6 for roaming and seamless handover. The QoS attributes of DiffServ are mapped onto the UMTS QoS architecture. Security and accounting are performed using a AAA Diameter Server. Paging and Notification are executed at IP level, according to the IP Paging architecture described in [3]. The Radio Interface broadcast is adapted to forward IP-System information in the cell through the point-to-multipoint broadcast channel, avoiding the use of point-to-point channels and the waste of resources. The major advantage relies however in the User Plane, where packets are directly routed with the standard and cheap IPv6 routing.

Measurements performed during the tests show behaviour of the UMTS subsystem completely equivalent to that of a WLAN subsystem. The handover latency is slightly higher (around 200 ms increase), because the WLAN implementation has been optimized when the UMTS is not and is rather considered as a proof of concept.

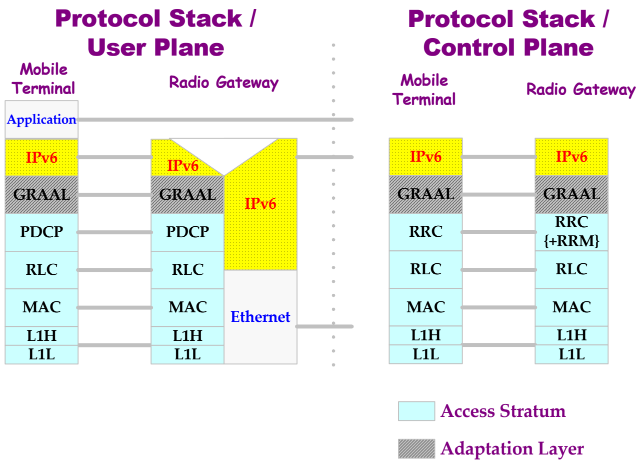

Figure 2 : Overall Protocol Stack

The direct inter-connection between UMTS-TDD and IPv6 is performed using the protocol stack shown in Figure 2 and adapted from [1].

The new Radio Gateway is acting as a Node-B plus a subset of the RNC (Radio Network Controller). The protocol stack complies as much as possible with the UMTS 3GPP standards, in the extent described below. From top to bottom, the layers involved are

- an inter-working function, called GRAAL, for Generic Radio Access Adaptation Layer, operating in both the Control Plane and the User Plane. It is introduced in section 3

- in the control plane, the Radio Resource Control (RRC) is a subset of the protocol described in the UMTS specification [4]. It is further described in sections 4 and 5.
- at Layer 2 , the MAC, RLC and PDCP layers are compliant with the standard.
- the PHYsical layer, made of the L1H and L1L sub-layers, follows also the UMTS-TDD standard

The PHY, MAC, RLC, PDCP and RRC protocols make up what is called the Access Stratum (AS) in the 3GPP, when upper protocols are part of the Non Access Stratum (NAS).

III. The GRAAL

The GRAAL provides the middleware for interfacing IPv6-based mechanisms for signalling and user traffic with 3GPP-specific mechanisms for the access network (e.g. for mobility, call admission, etc.). It is developed as an extension of a standard IPv6 network device driver.
When IP packets enter the GRAAL, they pass through a classifier which separates signalling packets marked for control plane and data packets marked for user plane. The signalling packets are either processed or transferred through the radio interface signalling path. The data packets transferred through the user plane are forwarded to their corresponding Radio Bearer.

The GRAAL's control plane communicates with the RCC using Service Access Points (SAP). The GC (General Control) SAP provides an information broadcast service. It is used to enable the IP Network entities to provide information and give commands that do not relate to specific users. This service broadcasts information to all UEs in the cell area. The Nt (Notification) SAP provides paging and notification broadcast services. The information is broadcast in the cell area but addressed to a specific UE. The DC (Dedicated Control) SAP provides services for establishment/release of a connection and transfer of messages using this connection. A connection is a relationship with a temporary context in the RG. It is initiated at the establishment of the connection, and erased when the connection is released.

A. Radio Broadcast for handover and autoconfiguration

In the RG, the GRAAL intercepts the IPv6 Router Advertisement. It builds a list of neighbouring RGs and provides both to the RRC for broadcasting in the cell
When it receives this broadcast information, the GRAAL in the Mobile Terminal (GRAAL-MT) is able to retrieve the network prefix of the cell and, by using IPv6 stateless autoconfiguration, determine its IPv6 link local and Care of Address (CoA). The GRAAL computes the EUI-64 Interface Identifier [5] using the 3GPP-defined IMEI [6] as equivalent of the LAN burned-in MAC address. The list of neighbouring RGs is used by the Mobile Terminal to choose the candidate for a potential handover decision.

B. Camping on an IPv6 cell

On request from a user space module in the MT ("Register" button on some User Interface), and when it has received at least once the Broadcast Indication from the Access Stratum, proving that the mobile is "camped on the cell", the GRAAL triggers an attachment request in the RRC. This request is followed by an initial signalling message which contains the Mobile Terminal CoA and possibly some AAA credentials for authentication and authorization in the network. From this time until the successful end of the connection procedure, the GRAAL delays or buffers any other IP message.
When it receives the Connection Establishment Indication, the GRAAL-RG checks if local resources (such as the maximum number of simultaneous connections) are available to handle this Mobile Terminal. It requests acceptance from the AAA/QoS entities based on the information contained in the initial message from the Mobile Terminal. When it gets the feedback from the network, the GRAAL answers through the Access Stratum, accepting or rejecting the connection. In case of success, signalling radio bearers are setup and able to carry IPv6 signalling traffic, without requiring any dedicated resource.
The GRAAL-MT is also responsible to trigger the release of a connection, in case of handover for example. This will be described later. In the case when it is informed by the Access Stratum that the connection has been lost, the GRAAL releases all the resources allocated to the corresponding MT. The GRAAL-MT may either inform upper layers or try by itself to re-establish the connection.

C. Classifying IPv6 flows

The GRAAL is responsible to relay IP traffic to the corresponding data Radio Bearer based on the IP DiffServ Code Point introduced in the IPv6 header. For that purpose, it maintains a table with the mapping between layer 2 and layer 3 QoS classes of service. It is also able to intercept some of the IP signalling messages (QoS, Mobile IP Binding Update …) marked with a dedicated code point and forward them on signalling Radio Bearers instead of data Radio Bearers.
On request from an incoming session, it asks the QoS provisioning entity in the network about available resources. If accepted, the GRAAL-RG starts the establishment of a new RB after mapping the DiffServ code point to a radio class of service. If resources are not available, either on the radio link or in the network, it rejects the Radio Bearer establishment.
When outgoing traffic is started, the GRAAL-MT sends a request to the GRAAL-RG via the signalling radio bearer to request the opening of a new data path with a given QoS profile. It later sorts IP packets between the data and signalling paths. When the Radio Bearer is no longer needed, the GRAAL-RG is able to request the release of the corresponding radio resources.

D. Handover

In the current implementation, the handover is initiated by the Mobile Terminal. The GRAAL-MT compiles the list of neighbouring cells received through the broadcast with quality measurements made in the PHY layer and reported by the RRC. These measurements help the local Mobility Entity take the IPv6 handover decision. When this decision is made, the Mobile IPv6 mechanism is activated, which results in the detachment (Connection Release) of the Access Stratum and its attachment to the new cell indicated by the Mobility entity.

IV. THE RADIO RESOURCE CONTROL – STATIC PROCEDURES

A. General description

This section describes how the Radio Resource Control (RRC) of the standard has been modified and implemented to replace the UMTS functions by IPv6 functions, for operations such as access control, handover, paging and QoS resource flexibility
The RRC layer handles the control plane signalling of Layer 3 between the MTs and the RG. RRC messages carry all parameters to set up, modify and release layer 2 and layer 1 protocol entities. They also carry in their payload the higher layers signalling.

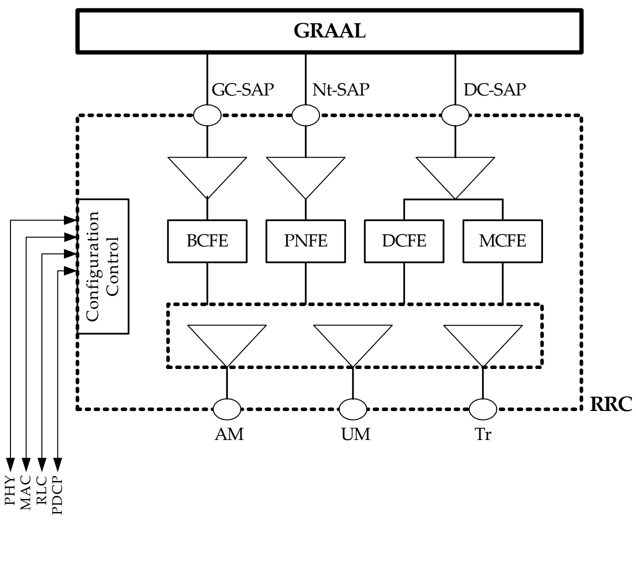

Figure 3 : Internal description of the Radio Resource Control

The subset of RRC identified to comply with the requirement of direct interconnection with IPv6 contains the following sub-entities, shown in figure 3:

- the GRAAL interface through GC, Nt and DC SAPs derived from [7],
- the BCFE : Broadcast Control Functional Entity,
- the PNFE : Paging and Notification Functional Entity,
- the DCFE : Dedicated Control Functional Entity,
- the MCFE : Measurement Control Functional Entity,
- the Configuration Control towards PHY, MAC, RLC and PDCP protocol entities.

The AM (Acknowledged Mode), UM (Unacknowledged Mode) and Tr (Transparent Mode) are Service Access Points towards RLC entities handling the signalling RBs.
The Radio Bearers (RB) available for transmission of RRC messages are defined as "signalling radio bearers" (sRB). The RRC entities select one from the 3 sRBs for their own messages, choosing between RLC-Tr, RLC-UM or RLC-AM. An additional sRB is reserved for the RRC messages carrying higher layer (NAS) signalling.

B. GRAAL interface: UMTS-to-IPv6 interworking function

This sub-entity builds, decodes and forwards messages exchanged with the GRAAL. The interface, adapted from the 3GPP standard [11] will be presented in the paragraphs below, together with the associated procedures.

C. BCFE : IPv6 signalling broadcast in the subnet

The purpose of this entity is to manage the broadcast of System Information from the RG to the MTs in the cell. The information is broadcasted in System Information Blocks (SIB), as defined in the 3GPP. The enhanced mechanism implemented in this architecture is able to broadcast in the cell the IP signalling data received from the GRAAL. Any type of data could be broadcasted. The following information has been identified:

- IPv6 Router Advertisement: this IP packet is included transparently in the SIB1. In 3GPP, the SIB1 is used to broadcast Non Access Stratum (e.g. upper layers) data.
- List of suitable neighbouring cells: this information is included in the SIB18. We have modified the format of this block to include the list of RGs identified by their Cell_Id and their IP addresses instead of the PLMN (Public Land Mobile Network) identities.

More radio-specific information shares the broadcast channel with the IPv6 signalling information.
The INFORMATION_BROADCAST_REQ primitive in the RG and INFORMATION_BROADCAST_IND primitive in the MT carry the NAS data packet via the GC-SAP.

D. PNFE : IPv6 Paging

The RRC layer can broadcast paging information from the network to selected MTs. In the current implementation, as paging is performed at IP level, the Paging Request packets are forwarded transparently on the air interface.
The PAGING_REQ primitive in the RG and NOTIFICATION_IND primitive in the MT carry the original IP Paging packet via the Nt-SAP.

V. THE RADIO RESOURCE CONTROL – SUPPORT OF ELEMENTARY PROCEDURES

A. DCFE : Handover and QoS configuration

Only a subset of the RRC procedures specified in [4] is implemented. They mostly comply with the 3GPP standard. The chosen subset of procedures and how they have been adapted to comply with the IPv6 requirements is described below. All the primitives transit through the DC-SAP.

B. IPv6 Registration and Handover support

The purpose is to establish and release the attachment of the Mobile to the IPv6 subnet. This attachment is very close to the 3GPP standard. From a macroscopic point of view, the UE can be either in idle or in connected mode.
The User Equipment (UE) is first switched on. Then it enters the "Idle" mode where it listens to the synchronization channel and then to the broadcast channel (BCH). After this first synchronization phase, the UE is "physically" attached to the RG. It is said to "camp on the cell". It monitors the messages broadcasted by the Radio Gateway (RG). When applicable, the UE RRC forwards the information received to the GRAAL.

The UE enters connected mode on GRAAL request during registration to the network or during a handover.
The GRAAL-MT triggers this transition by sending a CONN_ESTABLISH_REQ primitive containing the target Cell ID chosen in case of handover. The MT sends a RRC message to the RG, carrying the unique identification of the Mobile Terminal, its IMEI. This request is forwarded to the GRAAL in a CONN_ESTABLISH_IND primitive. If the answer returned in the CONN_ESTABLISH_CONF is "Accepted", the RRC contacts its associated Radio Resource Management (RRM) entity. This entity provides the RRM algorithms normally found in the RNC of a 3GPP network. It computes a new radio configuration for the cell, adding the new Mobile Terminal. The MT-part of this configuration is returned to the Mobile and corresponding resources are allocated in the lower layers. When everything is setup successfully, including the signalling radio bearers, the GRAAL-MT is informed with a CONN_ESTABLISH_RESP. The MT is attached to the IPv6 subnet and can start IPv6 signalling.

The Connection is released in case of handover or when the MT is stopped. The decision is taken in the Mobile Terminal and notified by the GRAAL to the RRC with a CONN_RELEASE_REQ message. This is a deviation from the 3GPP standards, accommodating the fact that we are performing a Mobile-initiated handover and with the aim to improve the overall handover performance by reducing the number of messages exchanged between the entities. In the RG, the RRC informs the GRAAL with a CONN_RELEASE_IND that this mobile is no longer present in the cell.

C. IPv6 Signalling Transfer

During the attachment to the network, several signalling radio bearers are established. As described before, the sRB3 is reserved for the GRAAL and upper layers signalling. Packets are transferred between the two entities, using DATA_TRANSFER_REQ and DATA_TRANSFER_IND primitives

D. Flexible QoS configuration

Prior to data transmission, a Radio Bearer must be established by the GRAAL. A number of Radio Bearers can be established to an UE at the same time. In standard UMTS, this implies two steps: PDP context Activation and then Radio Access Bearer establishment. In our platform, this has been streamlined to a single step: Radio Bearer establishment. We directly map Radio Access Bearers to Radio Bearers.
The network performs admission control and checks whether resources are available to set-up the service (congestion, QoS,…). If the answer is positive, the GRAAL-RG triggers the establishment procedure with the RB_ESTABLISH_REQ primitive, containing the requested QoS radio traffic class mapped from the IPv6 DSCP code. The RRC contacts its RRM entity which selects the optimal set of radio parameters describing the RB processing in layer 2 and layer 1, possibly using unbalanced radio resources (asymmetric uplink and downlink). This function includes coordination of the radio resource allocation between multiple radio bearers related to the same RRC connection.
The MT-part of this configuration is forwarded to the MT according to the RB control procedure described in [4]. When the data Radio Bearer is setup successfully, the GRAAL-MT is informed of its existence with a RB_ESTABLISH_IND, providing the QoS information and the DSCP code. A completion message is returned to the RG and forwarded to the GRAAL in the RB_ESTABLISH_CONF primitive. IPv6 data transfer can start.
The Radio Bearers are released in the same manner.

E. MCFE : Layer 2 trigger for IPv6 Mobility

The MCFE entity in RG sends control messages to its peer in the MT, which collects all measures and generates some reports used in the RG by the RRM. Measurements such as the UE transmission power, the received signal strength power (RSSI) or the transport channel block error rate (BLER), are reported periodically to the network.
In our implementation, this entity is also responsible to report these measures to the NAS inside the Mobile Terminal. This information makes up the Layer 2 trigger that helps the IP and Mobile IP control entity decide of a Layer 3 handover. The measures are reported in a MEASUREMENT_IND primitive and cover each monitored cell.

F. Configuration Control

This entity performs the control of the other Radio Interface Protocols described in section 2, based on information and algorithms located in the Radio Resource Management (RRM) component.

VI. CONCLUSION

We have described in this paper the two main components performing the adaptation of the UMTS-TDD Radio Interface towards a direct interconnection with IPv6. The implementation of the GRAAL has started and is currently continuing within French RNRT projects [8]. The RRC implementation started with the IST project Moby Dick [9] and is continuing within RNRT projects. The system has been the subject of several public demonstrations, at 3GSM World Congress, Eurecom-Hitachi Symposiums in Sophia Antipolis and Moby Dick Summits. During these demonstrations, we have been able to show traffic transfer through wide band channels and perform some smooth and direct handovers from/to WLAN and Ethernet IPv6 subnets, at the same time as a close integration with Diffserv QoS and an AAA Diameter system. Some measurement results are provided in Moby Dick Deliverable D0504, available at [9] .The hardware and software platform has been included in several additional RNRT projects proposals in 2003, as well as IST projects under the FP6 framework. New features such as multicast, reconfigurability, public safety support, end-to-end QoS support, enhanced algorithms for radio resource management, will be tested with the platform.

We have proved that existing technologies and architectures can be reused and adapted to converge and meet new requirements. The system described here prototypes the potential evolution of 3G systems towards the integration of multiple radio interfaces (coexisting with IEEE 802.11, 802.20…) and wireless networks, basis for the future 4G networks.

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