THE MOBY DICK PROJECT: A MOBILE HETEROGENEOUS ALL-IP ARCHITECTURE

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ABSTRACT

This paper presents the current stage of an IP-based architecture for heterogeneous environments, covering UMTS-like W-CDMA wireless access technology, wireless and wired LANs, that is being developed under the aegis of the IST Moby Dick project. This architecture treats all transmission capabilities as basic physical and data-link layers, and attempts to replace all higher-level tasks by IP-based strategies.

The proposed architecture incorporates aspects of mobile-IPv6, fast handover, AAA-control, and Quality of Service. The architecture allows for an optimised control on the radio link layer resources. The Moby dick architecture is currently under refinement for implementation on field trials. The services planned for trials are data transfer and voice-over-IP.

1. INTRODUCTION

Heterogeneous personal networks pose multiple problems, from the seamless interworking of diverse network technologies to the personalized service provision in each one of these networks. In fact, when, mobility is introduced in a network, a whole new set of problems has to be solved, such as user identifycation, communications rerouting, sharing and control of the communication channel, and interoperability in a multiple operator environment. The situation becomes more complex when traffic profiles are considered. While circuit-switched voice communications have dominated the telecommunications market in its beginning, packet-switched voice and data communications are currently the key drivers for the development of new communication systems and technologies.

The emphasis on packet-data communications brings an outstanding opportunity for heterogeneous environments. Recent developments in the TCP/IP protocol, carried under the auspices of Internet Engineering Task Force (IETF), may support the development of a multi-technology network mainly independent of the underlying physical layers, where all functions (either related with end-to-end communications or with internal network management and control) are performed at the IP level, with the exception of the most generic point to point transport functions. In the enterprise and in the local area environment, data communications are already the basis for most communications infrastructures, where voice and data is served in a uniform way. Cellular communications, however, are still dominated by the voice circuit-switching principle.

The importance of IP communications is already recognized in UMTS (as well as EDGE/IMT-2000), which provides an IP packet service by a tunnelling mechanism but still employs all mechanisms of 2nd Generation Networks. Even with these facilities, several operators question the approach of bringing the concept of packet switching into the existing telco environ-

ments, because it is considered as an intermediate step towards a pure IP-based solution [7]. For these operators, a more radical alternative would be to go for an IP-based technology right from the start (rather than introduce it evolutionary into an existing architecture), and develop any missing features required to provide the same services as in UMTS.

Currently several working groups, standardisation bodies and interest groups are working on technologies that could support such a network paradigm, merging the Plain Old Telephone System (POTS) network with the Internet, and the wired infrastructure with wireless networks. This trend can be exemplified with some work within the IETF that addresses the migration process on several levels. Mobile IPv6 [2, 8] and some related routing solutions [1] have been developed to support mobile nodes. These efforts are still not enough to support mobile networks, since the focus was more on terminal relocation rather than handover process. Recently, some work has also been published [8,9,10] to improve the performance of handover in mobile environments. The Mobile Wireless Internet Forum (MWIF) is also pushing for an open Internet architecture that enables seamless integration of mobile (wireless) telephony and IP-based services (voice, data, video, Web, etc.) for the wireless networks, independent of the air interface. The focus is on accelerating the deployment of open, Internet-based standards for mobile wireless networks, and its motivation is interoperability and open standards [7].

This paper reports on the architecture under development in the Moby Dick project, for the field trial implementation of a mobile, heterogeneous architecture based on IPv6 technology. The field trial will integrate wired Ethernet, WCDMA communications, and 802.11 wireless LANs, providing seamless voice communications between these technologies, and Quality of Service (QoS) support for data services. Section 2 of the paper will present the overall network architecture. The issues related to terminal mobility are discussed in section 3. Section 4 presents some of the problems of QoS provision and assurance. Section 5 presents our initial ideas related to network control and management. Section 6 concludes the paper.

2. NETWORK ARCHITECTURE

The Moby Dick architecture is being developed with two key design principles:
   a) The network should implement as many functions as possible using standard IP-based protocols and technologies, by reusing as many commonality in different access technologies as possible.
   b) The network should be able to provide voice services with quality comparable to traditional cellular networks. Furthermore, these services should be generally accessible regardless of the access network and uninterrupted services in case of a handoff should be provided.
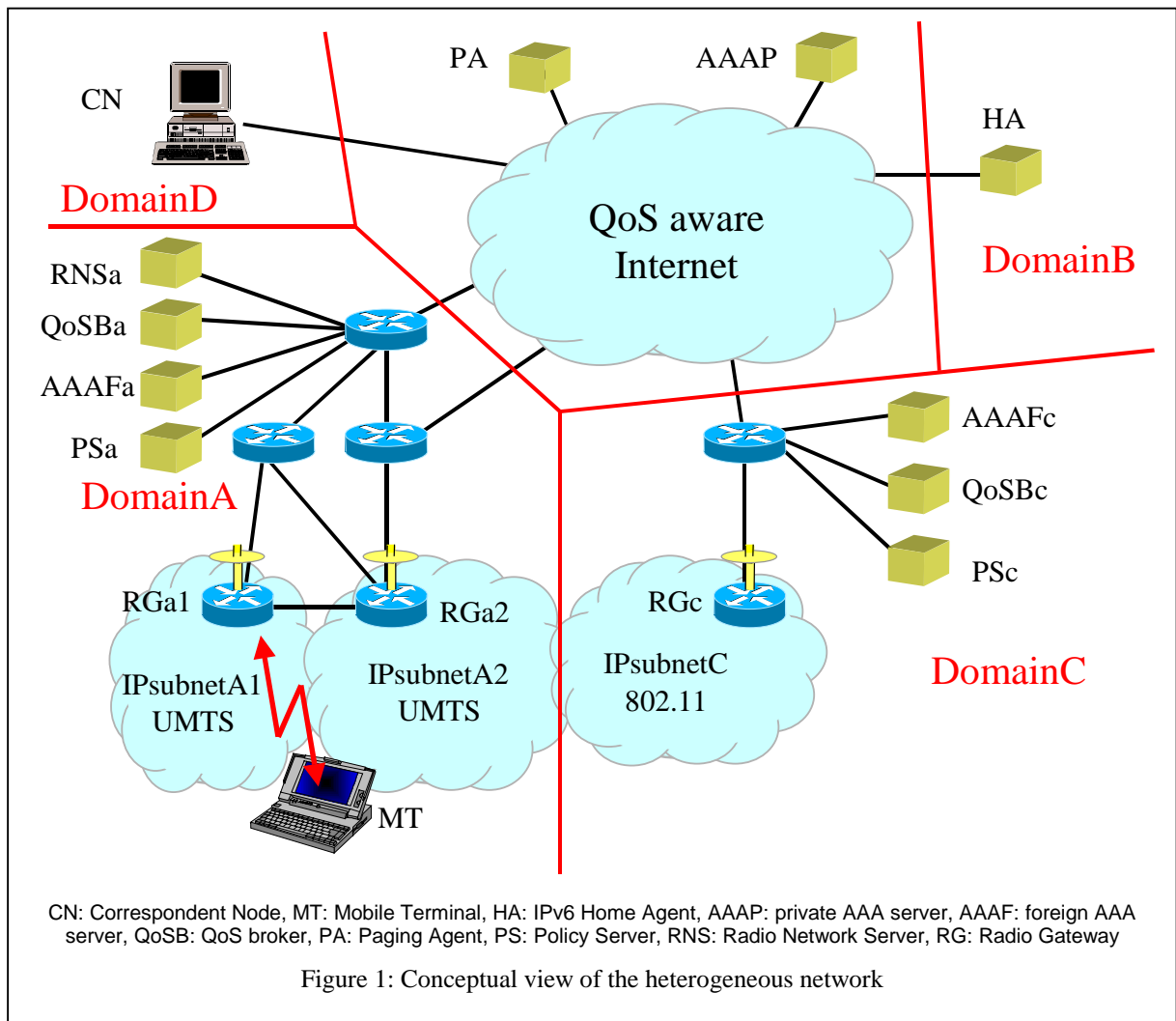
The overall network architecture of the Moby Dick approach includes several elements:
- Mobile terminals running user processes (applications). Each terminal can be equipped with interfaces of different technologies – one per technology. In particular, they may simultaneously have interfaces to W-CDMA (e.g. UMTS), wireless LANs (802.11), and fixed networks (Ethernet);
- Radio Gateways, providing an interface between a wireless and a wired network domain. It is assumed that these domains are different IP-subnets. These gateways are associated with the traditional concept of a Base Station, the actual access point of the wireless technology to a wired infrastructure.
- Routers in the fixed (wired) network;
- Servers and terminals in the fixed network.
- Network management servers in the fixed network.

All data communication is based on IPv6, and Differentiated Services Code Point (DSCP) will be used for QoS differentiation in the fixed network. Mobility in this environment will be handled as Mobile IPv6 mobility. Figure 1 depicts the network architecture. The diverse technologies depicted in the figure do not have to be necessarily UMTS or 802.11 LANs: the architecture should be able to evolve to support other physical media.

When confronted with traditional UMTS Terrestrial Radio Access Network (UTRAN) structures [13], this network is much simpler. The only radio-dependent elements are the W-CDMA interface and the radio link protocol. All other network elements (RNC, HLR, VLR, EIR, MSC, GMSC, SGSN, GGSN, …) and related interfaces and protocols are eliminated, and some are replaced by a functional IP-based equivalent. Data transmission is pure IPv6 end-to-end, without a permanent tunnelling protocol (like GTP), although temporary tunnelling may be required during a handover phase. For instance, the routing issues in UMTS (handled by the Home Location Registry) are replaced by the Mobile IP Home Agent (HA) concept.

The UMTS-specific Radio Network Controller (RNC) is the network element responsible for the control of the radio resources of UTRAN. It also terminates the RRC (Radio Resource Control) protocol that defines the messages and procedures between the mobile and the UTRAN. The RNC is responsible for load and congestion control in its own cells, and also executes the admission control and code allocation for new radio links to be established in those cells. In the Moby

CN: Correspondent Node, MT: Mobile Terminal, HA: IPv6 Home Agent, AAAP: private AAA server, AAAF: foreign AAA server, QoSB: QoS broker, PA: Paging Agent, PS: Policy Server, RNS: Radio Network Server, RG: Radio Gateway

Figure 1: Conceptual view of the heterogeneous network

Dick architecture, the functionality of the RNC is distributed to: AAA servers (AAAP - private AAA server and AAAF – foreign AAA server), a QoS broker (QoSB), Paging Agent (PA), Policy Server (PS), Radio Network Server (RNS), and to the base station, called the Radio Gateway (RG). These logical elements can be implemented either in distinct servers, or can be different processes in the same NMS station.
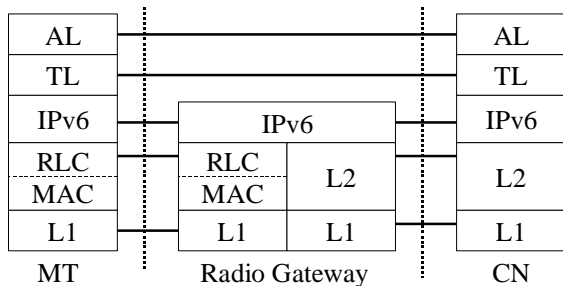
AL: Application Layer, TL: Transport Layer (e.g. TCP, UDP, etc.), L1: Physical Layer, L2: Link Layer, MAC: Media Access Control, RLC: Radio Link Layer

Figure 2: Protocol Stack for Data Transport for W-CDMA

This UMTS-IP replacement becomes clearer on Figure 2, where the protocol stack is shown. This protocol stack is used for any type of traffic since all traffic is IP in the cellular access network. The protocol stack is similar for all access technologies. Figure 2 shows that all communication is carried over IPv6, and only an extra layer, the radio link layer (RLC), which is part of the UMTS-releases, is required for the cellular network. Any other access technology could eventually be handled at the same level. The radio gateway mainly performs routing functions, changing the transport media from radio to wired infrastructures.

The architecture of Moby Dick is flexible as it addresses the needs of technology and market-driven behaviours, typical for an information-oriented society. From the administrative point of view, Moby Dick does not require any specific separation between ISPs and access technologies. A MT can change access technologies and still use the same network provider (e.g. a user leaving his office and moving to a meeting room, can maintain his connections within his company's wireless LAN), or can change service provider while in the same technology (e.g. changing cellular operators due

to pricing incentives). Moby Dick will support voice over IP (VoIP) services, with requirements similar to those for the 2G/3G networks. In particular a fast hand-over between radio base-stations of the same network are targeted [4, 5]. The adherence to standard IP mechanisms support Moby Dick aim to incorporate in its own trial novel network services developed for the Internet, as well as new management and inter-operation strategies between ISPs. Market forces, and legislature pressure, seem to present the ultimate limits to the envisaged Moby Dick architecture.

3. MOBILITY SUPPORT IN MOBY DICK

While Mobile IPv6 as a generic mobility management is intended to provide macro-mobility (inter-domain handoffs), the mobility support in Moby Dick has to be enhanced to handle micro-mobility (intra-domain hand-offs) for the requirements of real-time traffic. A large number of micro-mobility extensions to Mobile IP have already been proposed within the IETF frame-work. These Internet Drafts can be split into: hierarchi-cal architectures, e.g. HMIP (Hierarchical MIPv6) [9] or Regional Registration [10], non-hierarchical approaches, e.g. Fast Handoffs for Mobile IPv6 [8], and 'per host routes' base approaches, e.g., Cellular IP or HAWAII. These proposals will be evaluated against the needs of the Moby Dick framework. Both hierarchical and non-hierarchical approaches will further be evaluated against the requirements of the project. At the moment, the focus is on non-hierarchical approaches since these seem to provide fast handoff possibilities.
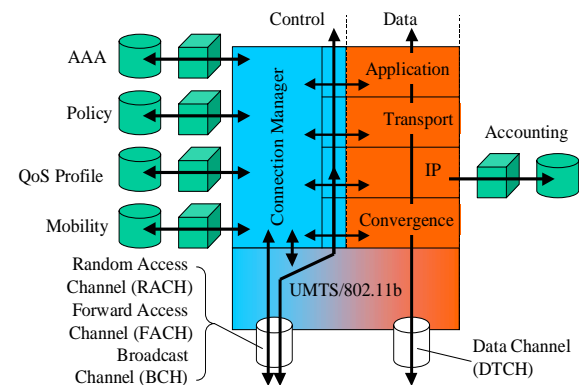
Figure 3: Protocol Stack for Data Control

All mobility will be handled at the IP-level or above, which impacts on the protocol stack. The RLC layer depicted earlier is just a part of a more powerful control stack. A MT protocol comprises two different entities concerned with mobility: a convergence layer (the RLC), and a connection manager (Figure 3). The convergence layer is responsible for the management of „current" information, requesting radio access (in the cellular) and/or requesting resources (in fixed networks).

The connection manager is responsible for taking hig-her-level decisions, such as selecting a particular cellular operator, or informing the convergence layer of specific QoS requirements for a given connection.

The cellular network will basically be handled as a set of links, and the MT will issue a mobile IP change-of-radio-gateway when a new RG is detected.

In the following, a modification to the 'Fast Handoff in Mobile IPv6' Draft is presented, which is currently evaluated the Moby Dick architecture.
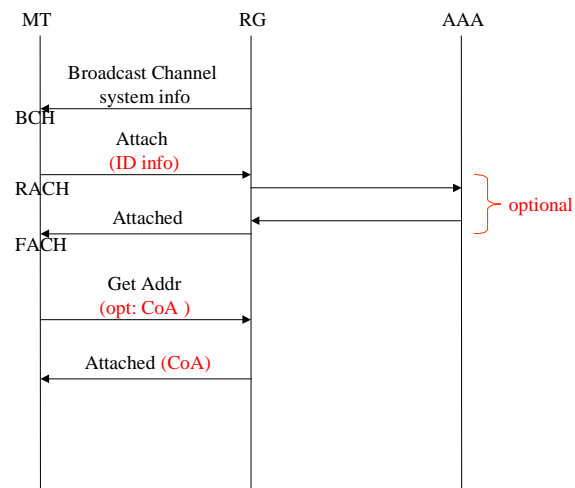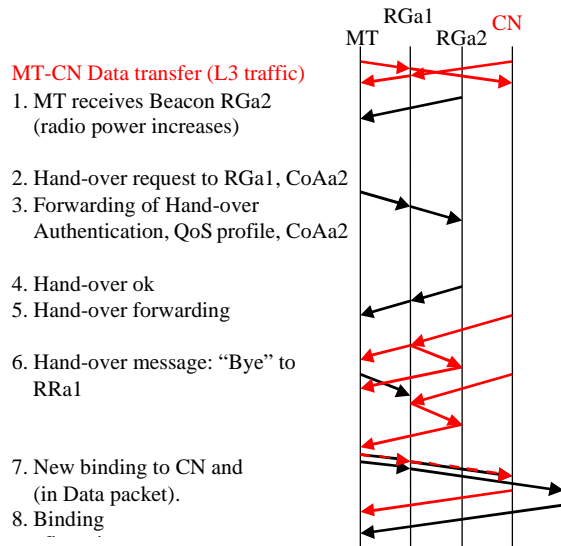
RG: Radio Gateway, MT: Mobile Terminal, HA: IPv6 Home Agent; RACH – Random Access Channel; FACH –Forward Access Channel;DTCH – Dedicate Traffic Channel; CoA – Care of Address

Figure 4: The Attach procedure

The starting point for the connection set-up scenario (the attach procedure) which is now being carefully studied is presented on Figure 4. The RG periodically broadcasts its identification on the cell. Upon connection establishment, the MT uses a link-layer address to contact the RG, and request an IP address, through the Random Access Channel. After receiving the address through the Forward Access Channel, the MT has a Care-of-Address, that can be used in any type of communi-cation. In particular, the MT is now able to perform emergency calls over IP. For other type of services, the MT has to be authenticated. IP messages are issued to complete this task. During micro-mobility transfers, this authentication may be waived. After successful authentication IPv6 bindings are issued.

Figure 5 takes this scenario one step further, showing a Mobile Terminal moving between two cells that are served by two separate Radio Gateways. The Mobile Terminal learns the information on Radio Gateway serving an adjacent cell from the broadcast channel. Depending on the hand-over decision mechanism, the MT can initiate a hand-over between RG, for which it will have to request new CoA addresses. Processing the cell information of the New Access Gateway (NAG, or RGa2 on Figure 5), the MT requests the Old Access

Gateway (OAG, or RGa1 on Figure 5), to initiate a hand-over. This is done by providing RGa1 with info on RGa2 and its previously acquired Care-of-Address (CoA) valid within the new cell served by RGa2. After the initiated hand-over phase is acknowledged, the OAG can duplicate incoming packets for the respective mobile node, forwarding one packet to the cell served by RGa1, and a copy to RGa2.

CN: Correspondent Node, MT: Mobile Terminal, HA: IPv6 Home Agent, RGa1: Radio Gateway Domain a-Subnetwork 1 = Old Access Gateway, RGa2: Radio Gateway Domain a-Subnetwork 2 = New Access Gateway, CoA: Care off Address

Figure 5: Intra-technology handover

The Mobile Terminal can now switch to the new cell area of RGa2 and is able to receive packets immediately. The resulting performance is a low delay, low loss (hopefully no loss) handover. No performance or service degradation should be experienced by the user, and no limit is introduced on the size of the network (scalability).

Note that in this strategy, micro-mobility is mostly handled inside the convergence layer, while macro-mobility is handled through the communication manager. Nevertheless, the approach taken is basically the same: differences may exist in the required times for AAA functions, and on the different levels of QoS able to be provided by each network.

A final issue concerning mobility support, is the concept of Paging, to be supported by the Moby Dick trial. In order to allow Mobile Terminals to enter an idle state, in which frequent location update messages to the network can be avoided, a mechanism has to be applied to notify the respective Mobile Terminal of the incoming traffic and to request its exact location. In idle mode, a Mobile Terminal's location is known to the network with the granularity of a Paging Area, which is a cluster of wireless access areas (cells). It is intended to keep Paging and the specific idle state

transparent to Correspondent Nodes and to the Mobile Terminal's Home Agent. The only nodes, which should be aware of the Mobile Terminal's current state, are a dedicated Paging Agent (PA) and the respective Mobile Terminal.

4. SUPPORT FOR QoS

Although there has been much research in the field of end-to-end Quality of Service, it is difficult to find a precise definition of the term 'end-to-end' anywhere in the papers [15]. This definition is provided in the ITU-T recommendations [11] and [12]. It refers to ISDN and telephone networks, but is general enough to be adopted in other networking technologies.

According to this recommendation QoS is: "*The collective effect of service performances which determine the degree of satisfaction of a user of a service*". This definition encompasses many issues that may affect the Quality of Service, including subjective customer satisfaction. In [12] the aspects of Quality of Service are restricted to the identification of parameters that can be directly observed and measured between the service access points (SAP). The SAP is the point at which the service is accessed by the user. Other types of QoS parameters, which are subjective in nature (i.e. depend upon user actions or subjective opinions) are not addressed in the ITU-T Series I.

The user-oriented QoS parameters provide a valuable framework for network design and are the ultimate subject of interest of service providers in service provisioning, but they are not necessarily usable in specifying *performance requirements* for particular connections. The *network performance parameters* indirectly determine the user observed QoS, but do not necessarily describe that quality in a way that is meaningful to users [11]. Both performance and QoS parameters are needed, and their values or value ranges must be quantitatively related. The definition of QoS and network performance parameters should make the mapping of values clear especially in cases where there is no simple one-to-one mapping.

As an IP-oriented architecture, Moby Dick aims to support QoS strategies developed within IETF. The Internet also presents a distinction between two main types of services, and classifies these in *quantitative* (where a given traffic parameter can be defined by a strict bound) or *qualitative* services (where the traffic parameters are defined by relative performance between multiple connections). End-user service performance can be similar with both types of services, depending on multiple network parameters (such as overprovisioning level, multiplexing effects, routing , etc ...)

The Moby Dick wired QoS infrastructure will be based on *DiffServ* concepts, providing aggregate service differentiation in the routers, without explicit per-microflow resource reservation. This leads to the concept of piece-wise quality of service, which relies on the conca-

tenation of services on the path from the sender to the receiver. The overall definition of a DiffServ-alike QoS network, for generic uncharacterised services, is a complex task, currently under research. However, the Moby Dick network aims to provide UMTS–alike behaviour with respect to QoS, which greatly simplifies the overall network design.

Four traffic classes have been identified in UMTS: conversational, streaming, interactive, and background classes. The main distinguishing factor between these classes is how delay-sensitive the traffic is: the conversational class is meant for very delay-sensitive traffic, while background class is the most delay-tolerant. This provides a basic conceptual framework for the development of QoS service models inside Moby Dick.

The architecture will be able to support different approaches to network QoS signalling. Although the core network supports per-aggregate differentiation based on DSCP marking, different control mechanisms can be implemented in the network. In an operational network, the contracted service will be enforced by the access point (the Radio Gateway), through some policy mechanism. In the Moby Dick trial, there is a larger range of options. The applications themselves can eventually request a given DSCP (note however that no mechanisms for exchanging DSCP codes into service level information is available). The Radio Gateway is also able to perform multi-field classification and marking, according to the user stored profile.

The ability of DSCP marking at the MT allows our architecture to implement efficient usage of the cellular networks. Radio resources are scarce and thus should not be granted to the mobile terminal continuously, i.e. throughout the duration of its presence in a visited domain. Instead, the resources should be requested - either by the terminal itself, or by the access node as a part of the session management – with a given associa-

ted QoS. This will be performed through the Connection Manager layer, and will apply only to radio hop-related QoS. The overall end-to-end QoS will still be built from these several per-hop-behaviours. Note however, that a simpler approach of radio link usage would request only the best possible QoS, and QoS differentiation would be performed at network level, and this can be a reasonable approach for some service scenarios. The requirement for QoS marking at the radio link level appears only for service scenarios where radio channel availability is the limiting factor, such as our VoIP target scenario, where many low-bandwidth users are assumed.

There are numerous parameters that must be controlled in the radio interface (Layer 2) to support QoS in the radio interface – see table 1 [14]. Moby Dick will define a mapping between these UMTS-alike services and proper DSCP codepoints.

Table 1. Value ranges for Radio Access Bearer Service Attributes, source: [23.107]

Traffic class	Conversational class	Streaming class	Interactive class	Background class
Maximum bitrate (kbps)	< 2 048	< 2 048	< 2 048 - overhead	< 2 048 - overhead
Delivery order	Yes/No	Yes/No	Yes/No	Yes/No
Maximum SDU size (octets)	<=1 500 or 1 502	<=1 500 or 1 502	<=1 500 or 1 502	<=1 500 or 1 502
Delivery of erroneous SDUs	Yes/No/-	Yes/No/-	Yes/No/-	Yes/No/-
Residual BER	$5*10^{-2}$, 10^{-2}, $5*10^{-3}$, 10^{-3}, 10^{-4}, 10^{-6}	$5*10^{-2}$, 10^{-2}, $5*10^{-3}$, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}	$4*10^{-3}$, 10^{-5}, $6*10^{-8}$ (6)	$4*10^{-3}$, 10^{-5}, $6*10^{-8}$ (6)
SDU error ratio	10^{-2}, $7*10^{-3}$, 10^{-3}, 10^{-4}, 10^{-5}	10^{-1}, 10^{-2}, $7*10^{-3}$, 10^{-3}, 10^{-4}, 10^{-5}	10^{-3}, 10^{-4}, 10^{-6}	10^{-3}, 10^{-4}, 10^{-6}
Guaranteed bit rate (kbps)	< 2 048	< 2 048		
Traffic handling priority			1,2,3	
Allocation/Retention priority	1,2,3	1,2,3	1,2,3	1,2,3
Source statistic descriptor	Speech/unknown	Speech/unknown		

Note that the IP-centric Moby Dick architecture does not preclude the usage of explicit QoS signalling between the MT and the network. In fact, per-flow reservation (e.g. through RSVP messages [17]) could be performed in this network. However, the core transport will support only DiffServ differentiation, and thus no per-flow identification will be performed in the core. This is in accordance to current Internet development ideas. If explicit signalling is performed, this will affect only the radio link usage, with essentially the same benefits as the proposed DSCP conversion management at the Connection Manager layer.

5. AAAC AND RESOURCE ACCESS

The overall management strategy for Moby Dick will be distributed across multiple entities, depending on the function and the time frame. At the higher level, traffic engineering would be performed for the overall

network. At the user level, a conceptual authenticcation, authorization, accounting and charging (AAAC) server will control the services available for user, while the QoS Broker (QoSB) for each domain will perform admission control for session, possibly through some Policy Server (PS). At the lower level, in the cellular networks, the Radio Gateway will enforce the radio link parameters, and the access to the wired network. The same task has to be handled by the access gateway (AG) controlling the network access by a wired or wireless terminal. Note that paging will require specific management across multiple cells.

In Moby Dick environment, users are mobile and will frequently access the network from dependencies other than their home domain. To become a model for future commercial networks, Moby Dick architecture must provide a way to authenticate these users, to authorize them to access services, to account the services that they use, and to charge them for these usage. This is the role of the AAAC infrastructure in Moby Dick.

The key problems for the AAAC are related to the creation of a unified method for handling authenticcation, authorization, accounting and charging. In particular, Moby Dick will have to be able to support fast inter-domain information exchange, potentially between domains with different business models (e.g. a wired ISP and a wireless UMTS operator). This brings timing pressures to an already complex process. Current Moby Dick approaches envisage local and remote AAAC authorities, in order to allow fast micro-mobility handovers. AAAC servers (both local and remote) will centralize this information, which will be distributed inside an administrative domain as needed – e.g. by a Policy Server and a QoS Broker.
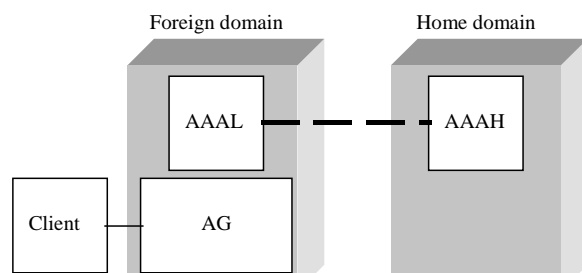

Figure 6: AAA server in local and home domains

Figure 6 illustrates the concept of the Moby Dick AAAC architecture supporting mobility. Upon receiving the client's request, the Access Gateway (AG) is likely to require that the client provide some credentials that can be authenticated before resources in the foreign domain can be consumed. In each home domain, the AAAC server will keep information about the users of the domain (for example, QoS agreements, roaming permissions, tariff information, etc.). The AAAC server in a visited domain will be in charge of authenticate, authorize, account, and keep charging information

for a user visiting this domain. To do this the AAAC server in the visited domain will contact the AAAC server in the home domain of the user visiting the domain. Different aspects as security, mechanisms to make impossible the repudiation of auditing information, description of different business models, are possible to be approached with this infrastructure.

The AG, receiving an authentication request from a MT consults a local authority (AAAL) attached to its administrative domain, which proofs the credentials of the requesting client. If required, the AAAL forwards these request to the entity of the home domain, and once the authorization has been obtained by the local authority (AAAL), and the AG is informed, resources are committed to the requesting client.

6. CONCLUSIONS

The Moby Dick project will implement an architecture able to provide UMTS voice services across several access infrastructures: wired LANs, wireless LANs, and UMTS cells. This architecture relies on the IPv6 protocol, and replaces most technology-dependent tasks by IP-oriented approaches.

This paper provides a snapshot of the architecture currently under development, showing how proposals already under development in the IETF can be re-used and mastered in order to achieve this goal. The architecture puts emphasis on use of Mobile-IP and its optimisations, fast handovers, a DiffServ-based QoS transport infrastructure, and a coherent AAA management structure. The architecture identifies similar elements across all access technologies, but maintains enough flexibility to support optimisations for the physical layers. This architecture is conceptually flexible and open, providing clear separation between the technology domain and the administrative domain.

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