# Field Evaluation of a 4G "True-IP" network

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## ABSTRACT

This article presents field evaluation results of an IP-based architecture for heterogeneous environments, covering UMTS-like TD-CDMA (Time Division-Code Division Multiple Access) wireless access technology, wireless and wired LANs, that has been developed under the aegis of the IST Moby Dick project. The 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 Moby Dick architecture incorporates mobile-IPv6, fast handover, AAA-control (Authentication, Authorization, Accounting), Charging and Quality of Service. The architecture allows for an optimized control on the radio link layer resources. The Moby Dick architecture has been implemented and was evaluated on field trials with multiple services.

## I. INTRODUCTION

This paper presents results obtained in an IP-based architecture for heterogeneous environments, covering UMTS-like TD-CDMA wireless access technology, wireless and wired LANs. This architecture was developed under the aegis of the IST Moby Dick project. It is briefly explained here; detailed description can be found in the references mentioned all along this paper. This architecture treats all transmission capabilities as basic physical and data-link layers and replaces all higher-level tasks by IP-based signalling strategies. The architecture developed incorporates aspects of mobile-IPv6, fast handover (FHO), Authentication, Authorization, Accounting (AAA)-control, and Quality of Service (QoS), while further supporting optimised control on the radio link layer resources.
The remainder of the paper is organized as follows. Section II summarises all the aspects tackled by the Moby Dick architecture focusing on the building blocks and is followed in Section III by the description on how they are integrated in the two Moby Dick tests beds. Section IV describes our evaluation on the Moby Dick's implemented solution. In Section V, we discuss some critical issues of 4th Generation (4G) networks, based on the experience achieved in our test beds. Section VI concludes the paper.

## II. THE MOBY DICK ARCHITECTURE

The migration from circuit–switched to IP-based technologies and the growing role of mobility pave the way to a next-generation integrated network. The importance of IP-based communication has already been recognized in UMTS (as well as in EDGE/IMT-2000), which provides an IP-packet service using tunnelling mechanisms, but still employing all the mechanisms of 2nd Generation Networks [1]. Even with these facilities, several operators question the approach of bringing the concept of packet switching into the existing connection-oriented network environments, since it is considered an intermediate step towards a pure IP-based solution, which will be available in the fourth Generation mobile communication (4G) networks. 4G networks will offer all kind of services in a single packet switched network using IPv6 as its network layer. Support for Mobility (including Paging), AAA and QoS must be provided in those networks, each fulfilling an essential functionality in the network. Integrating all the above functions in a single IPv6 4G network poses serious challenges:

1. Some aspects of the different functions overlap. E.g. both QoS and AAA must perform authorization
2. Some aspects of one function pose severe burdens to the performance of another. For example, authorization must be performed each time the user changes his point of attachment, posing serious constraints to FHO.

The Moby Dick architecture [2] meets these challenges (see Figure 1), clearly specialising each function in its tasks, defining the appropriate interfaces between them and performing trade offs to obtain maximum performance.

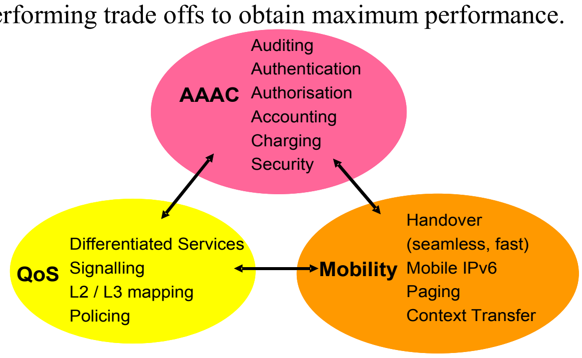


Figure 1 – The Moby Dick "True-IP" architecture

## III. MOBY DICK ARCHITECTURE TESTBEDS

Moby Dick architecture treats all transmission capabilities as basic physical and data-link layers, and replaces all higher-level tasks by IP-based strategies. The proposed architecture incorporates aspects of Mobile-IPv6 enhanced with fast handover (FHO), Authentication, Authorization, Accounting, Auditing and Charging (AAAAC)-control, and Quality of Service (QoS).
The Moby Dick "True-IP" Architecture is composed of different access networks, including Ethernet, Wireless LAN and WCDMA technologies, and a Core Network based on IPv6. The architecture provides user mobility (horizontal and vertical handover) based on Mobile IP procedures, QoS capabilities based on DiffServ, and Authentication, Authorization, Accounting and Charging based on IETF AAA procedures. We consider that this new architecture will be the future architecture for 4th Generation Networks in which users, while connected to the same terminal, will be transferred from one access network to another depending on the user preferences, cost, availability or better performance, in a transparent way. Over this framework any kind of services will be provided by using a common infrastructure.

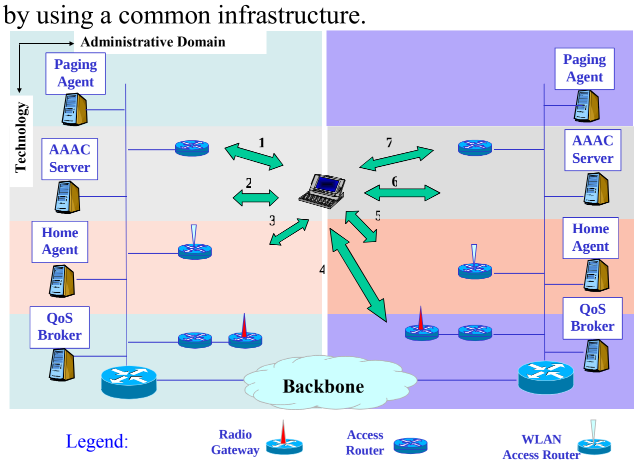


Figure 2 – The Moby Dick "True-IP" architecture

### *A. Mobility and paging in Moby Dick*

Mobility management and maintenance of sessions relies on the Mobile IPv6 approach in an application transparent manner. Mobile IPv6 defines a Home Agent (HA) and Mobile (MNs) and Correspondent Nodes (CNs). Enhancing mechanisms as fast handover have been integrated with the architecture. To support a mobile terminal's dormant state, a preliminary paging concept for heterogeneous access networks has been specified and integrated with the Moby Dick platform [3]. A central Paging Agent (PA) controls the various paging areas. First successful integration of heterogeneous access has been realized, including fast handover and paging performed using rather heterogeneous access technologies, such as Ethernet, IEEE 802.11 and TD-CDMA.

### *B. QoS in Moby Dick*

In 4G networks all the services will be supported by a single packet switched IPv6 network. Multimedia services (specially those providing replacements of existing communication practices, such as telephone talks) pose specific QoS requests to IP networks. There is no widely implemented IP-based QoS system at the moment. Nevertheless, differentiated services (DiffServ) approaches are very likely to be globally adopted, as they are being tested and seem able to solve the drawbacks of alternate solutions. QoS in Moby Dick [7] is based on DiffServ. The DiffServ architecture [2] defines two kinds of entities: edge (ingress and egress) routers and core routers. In a public network, the edge routers where the MNs attach to gain access to the network are called the access routers. All traffic entering or leaving a DiffServ domain must go through an edge router. Further a Bandwidth Broker is added to control these QoS enabled routers.

### *C. AAAAC in Moby Dick*

In order to transfer the still open Internet towards a commercialized system (which is a must, taking in consideration wireless license costs paid in Europe), operators have to charge for network resources. In this sense, an AAAAC (Authentication, Authorisation, Accounting, Auditing and Charging) infrastructure is required in order to both permit network usage only to certified users and to charge them accordingly to the contractual agreement between a user and the operator, which is generally described within the SLA (Service Level Agreement). The AAAAC architecture chosen in Moby Dick [5] is an enhancement of IETF's AAA architecture based on Diameter and its Mobile-IPv6 extension [6]. With such an extension the network operator can manage the users willing to gain IPv6 connectivity using his public network. Users can be local users or roaming users with contracts signed with foreign operators. The entities defined in the Diameter Mobile IPv6 extension are: MNs able to communicate with AAA attendants, located in the points of attachment to the public network, the Access Routers (ARs). The AAA attendants communicate with the local AAA server. The local AAA server communicates with other operators' AAA server.
Auditing infrastructure must also be provided to ensure that no violation of the SLA signed with the user occurs. Logger collectors run in Moby Dick in the ARs and they send their data to the Auditing module located in the local AAA server

### *D. Moby Dick heterogeneous network infrastructure*

All the functionalities described above have been provided and deployed in the Moby Dick field trial distributed between two test sites, Stuttgart and Madrid. The functional blocks have been implemented, validated and verified on three different access technologies which have been selected in order to demonstrate and prove that the Moby Dick approach has a certain level of flexibility and extensibility due to the use of the IPv6 layer as unique convergence layer for providing seamless mobility. Being more specific: Moby Dick used TD-CDMA, based on the UMTS-TDD band, WLAN 802.11 and Ethernet 802.3 for the following reasons: TD-CDMA is a wireless network technology which conceptually is evolving from circuit switched technologies and conceptually represents the 3G architecture, naturally with Moby Dick specific modifications. Ethernet is a wired network technology widely used and required in order to cover also wireless/wired network transitions. WLAN is the most promising wireless technology evolving from the Internet, common on hotspots. So, by adopting these three technologies we believe it can be proved the feasibility of the overall concept towards a 4G architecture where wireless and wired as well as the traditional data and voice networks are merging.

*E. Implementation*

Moby Dick field trials, located in Madrid (Spain) and in Stuttgart (Germany), have all the elements defined in our 4G architecture. Besides these sites, other test beds were also installed, in Aveiro (Portugal) and Sophia Antipolis (France). The trial sites have DiffServ Edge routers where the MNs and CNs attach to: i.e. Access Routers (ARs). The ARs have also AAA clients, Auditing and Paging modules.
Located inside the Core Network there were QoS Broker, Home Agent, AAAAC server and Paging Agent. Application servers, such as DNS, web servers, etc. acting as CNs could also be located inside the core network.
A Moby Dick trial site (as the one deployed in Stuttgart) is shown in Figure 3. Here, all relevant network components within the project have been installed. The whole network is based on a Linux environment with the Moby Dick specific modules. For TD-CDMA, the UMTS-TDD spectrum provided from T-Mobile (Deutsche Telekom subsidiary) is used. On this platform, seamless handover scenarios across all the three presented network technologies have been evaluated.

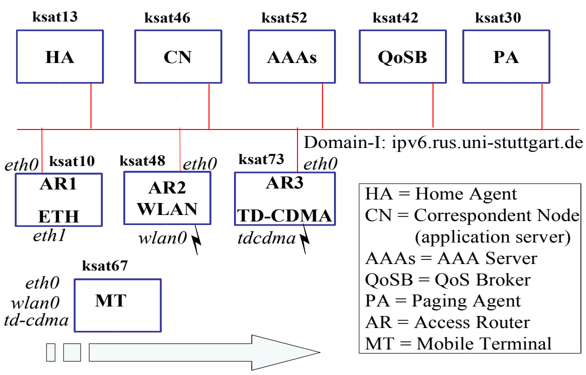


Figure 3: Moby Dick Stuttgart test bed description

The installed network nodes are: Access Routers for the different access technologies (Ethernet, Wireless LAN and TD-CDMA), AAAAC Server for controlling the administrative domain, QoS Broker for controlling the QoS domain, Home Agent and Paging Agent for the overall mobility management. Further key components are the mobile terminal and a Mobile IPv6 capable Correspondent Node (CN). The Mobile Terminal is a Linux-based laptop equipped with interfaces to all three network technologies. At the current status, multi-homing, that is the simultaneous access to different networks, is not supported, but foreseen in the successor project “IST-Daidalos” [3]. The Mobile Terminal is able to attach itself to one of the three networks technologies according both to availability and predefined rules.

## IV. RESULTS

The Moby Dick evaluation phase involved two kind of tests: those performed internally by partners (expert evaluation), and those made by external users -students- unaware of MD details (user evaluation). The former was made in order to provide valuable feedback to developers, as well as to perform a quantitative evaluation of network behaviour; the latter provided a qualitative view of the results achieved, via the usage of common applications in our 4G test bed [10]. Expert evaluation focused on critical variables, performing evaluation of those procedures that could slow down system performance, or those who are repeated often. All the measurements were averaged over several experiments and bounded by the precision of the measurement tools used.
The dimension of the integrated test beds was the major source of testing efforts. For instance, Madrid test bed had 14 machines, and each –depending on the entity type- an average of 7 software modules running.

*A. Users Tests*

Users could employ any available IPv6 application (web browsing, online gaming, VoIP, streaming, …) over Moby Dick test beds. Seamless FHO, paging, charging, and user profile dependent QoS under artificial network overload, could be experienced by users. Major complaints came from users with low priority QoS profiles or were related to the difficulty in configuring the applications.

*B. Mobility*

Basically, there were two key aspects to evaluate handover performance: packet loss and handover latency. These two parameters are related each other. By measuring packet loss with small packets sent at a fast rate (between a CN and a MN), we can estimate -within Moby Dick and also in a MIPv6-only architecture- handover latency HL (i.e. the time interval in which the MN is not able to send/receive packets to/from a CN).
On the other hand, it is also important to measure signalling time (ST) needed to prepare the handover procedure (make-before-break philosophy). This time (ST and QST in Table 1) is measured using protocol analysers like Ethereal.

| N | ORIG | DEST | MEASUREMENTS | | | | |
|---|---|---|---|---|---|---|---|
| | | | ST | QST | DL | PI | HL |
| 1 | Eth | WLAN | 24,3 | 22,6<br>4 | 0 | 50 | <50 |
| 2 | WLAN | ETH | 18,6 | 14,4<br>8 | 0 | 50 | <50 |
| 3 | WLAN | WLAN | 17,9 | 14,4<br>8 | 0 | 50 | <50 |
| 4 | WLAN | CDMA | 24,8 | 18,9<br>3 | 0 | 30<br>0 | <300 |
| 5 | CDMA | WLAN | 301,8 | 16 | 1 | 30<br>0 | 300-600 |
| 6 | ETH | CDMA | 25,9 | 22,5<br>2 | 0 | 30<br>0 | <300 |

Table 1: FHO results pinging from MN to CN

In this table the column "ST" (ms) represents the time needed to prepare the handover procedure. "QST" is a portion of this time and represents the delay required for the communication between QoS Broker and old and new ARs (ms). "PI" (ms) represents the interval of the ping packets sent out and "DL" represents the data loss (number of packets). HL (ms) is the handover latency (due to the L2 and L3 handovers). Because of the ping intervals used, we are not able to provide more accurate figures.
These figures remain constant even if delays between the MN and the CN are added. In the other hand, MIPv6 handover latencies are about 600 ms in local scenarios and over 1second in scenarios in which the MN and the CN are in different sites e.g. Madrid and Stuttgart.
Regarding to paging, it was important to measure the time needed to awake a dormant node. In the Moby Dick test bed, this time is over 500 ms. Major factor in this time is the delay needed to register the awakening node which is in the range of 200 ms, as described in Section D.

*C. QoS*

Two performance aspects were essential to evaluate in terms of the QoS architecture performance within Moby Dick: the installation time of the QoS context and the answer time of the QoS Broker communications. IETF's COPS [4] was the protocol used for this communication.
The QoS context (token buckets parameters) installation time in the new AR during a FHO took 0,15 ms for each token bucket. We also evaluated the time needed in the QoS Broker (QoSB) to calculate the new QoS context during a FHO and to transfer it to from the old AR to the new AR and found that this value was in the range of 17 ms (FHO in Table 2 and a term of QST in Table 1). These two parameters are important since they directly affect the total ST described in Section B. This can be further detailed in the results presented in Table 2.

| Message | Response Time (µs) |
|---|---|
| Client-Open | 81 |
| Configuration Request | 54320 |
| Denial of Access request | 733 |
| Acceptance of Access request | 3857 |
| Keep-Alive | 140 |
| FHO | 17746 |

Table 2: QoS Broker answer times to AR requests

Effectively, the "FHO time" is one of the slowest times for the interaction between the QoS Broker and the Access Router, only superseded by configuration actions – which are performed once when the AR starts up. This value is quite large because the QoS Broker is operating in debug mode and printing messages for each action. Without these debug messages, the total FHO processing time is reduced to around 10ms. Notice that service acceptance or denial is quite fast, and should not be perceptible by applications.

*D. AAAAC*

We describe now the key aspects to evaluate the performance of Moby Dick's AAAAC architecture.
Charging calculation has to deal with massive amounts of data and thus is a resource consuming process. Charging in Moby Dick is done based on Diameter mobile IPv6 sessions, each session being represented by 2 or more records in a database. Time to process all the records and all the corresponding sessions is in the range of 20 s for about 50 sessions and 7000 records.
Auditing process has also to deal with massive amounts of data. The Audit Time encompasses the time to retrieve the users or entities identity, the time to retrieve the logs from the Audit Trail, the time to store the processed logs in the Archive, and the time to delete the processed logs from the Audit Trail. With 20000 logs auditing speed was 50 logs processed per second.
During registration, time to process authorization requests in the AAA.h server is about 1ms. During this process, Diffie Hellman (DH) keys are generated by AAA clients in ARs: this process takes about 200 ms, and the total time to register a user is slightly superior to this time. The extra delay to register a roaming user is due to the round trip time between the A4C servers in Madrid and Stuttgart.
Another kind of test was to register users with 0 s session life time, thus forcing continuous and immediate reregistration. We simultaneously registered 3 users whose terminals were attached to the same Access Router (AR). Registration time increased with the number of users. We repeated the test but with each terminal attached to a different AR. In this occasion, the registration time had little variation with the number of users.

## V. EXPERT ASESSMENT AND CRITICAL ISSUES TOWARDS 4G NETWORKS

*A. Criticality for fast response*

The make before break and bicasting paradigms employed in Moby Dick allow having almost no data loss during FHO, provided that the MN has coverage of both the old and new cells during the total FHO time. The less time this FHO time lasts, the less the cells will need to overlap. As explained in Section IV.B, in Moby Dick this FHO time includes the time needed to prepare the HO (ST) and the time to do the HO (HL). With the results of Section IV.B, we can estimate that a time of about 40 ms is needed to perform a complete FHO procedure. To support users moving at a maximum speed of 180 km/h we can deduce that in 4G networks cells will have to overlap 2 m which is negligible. Note that the biggest factor in ST time is context transformation in QoSB. Several QoSBs can exist within a domain, each controlling an appropriate number of Access Routers (and thus of Mobile Nodes) and, as a result, presenting no scalability concerns.
Another aspect that requires fast response is the awaking of a MN. It was shown in Section IV.B that this time is about 0,5 s. To avoid any loss in the data sent to the MN being awaked, the PA must have a 1 kb buffer reserved for each dormant MN, provide the data is sent to the MNs being awaked at a rate of 2 kbps. As this will be the start of a communication session, it is not foreseeable that these

assumptions are problematic. In fact, the users have not provided any significant complain when using the system with common applications (such as ftp, web browsing and instant messaging).

### *B. Criticality for scalability*

AAAC.h server centralizes all the AAAC processing for the users of a 4G operator. AAAC aspects dealt by the AAAC.h must scale. In Moby Dick we decided the AAAC.h to be stateless thus doing very few processing for each user and thus likely posing few scalability concerns for AAA aspects (only one 1 ms to authorize a user, as written in section IV.D). During registration, most of the processing is dealt by the AAA client in the Access Router, including DH key calculation. But since AAA clients do not centralize all the users (they only handle the users attached to the corresponding AR) this does not represent a scalability problem. On the other side, charging is a resource consuming process. Charging should be accomplished in machines different from the AAA.h server. Users and charging databases will be shared among the charging and the AAA.h server machines. This same comment applies for the Auditing process.

### *C. Criticality for efficiency*

MD provides a common framework for the development of any kind of services to be provided, by using a common infrastructure. However, in order to guarantee efficiency (optimal spent of resources) we should take into consideration the upper layers. Two representative examples can be given:

- VoIP application produces an extremely high overhead, due to the low payload generated (33 bytes) and the headers involved; RTP, UDP, Mobility, IPv6, and Ethernet account for 102 bytes. We introduced additional delay in packetization, increasing 4 times the payload (while producing almost unnoticeable delay for the users).
- TCP transport protocol implementation uses by default a segment size tuned so as to the efficiency is maximized (i.e.: payload TCP + TCP + Mobility + IP = 1500 bytes = MTU Ethernet). Due to the Moby Dick fast handover implementation, this MTU value should be reduced to 1460, because of the fact of packet bicasting, which adds an extra IPv6 header in the Access Routers and thus having the risk to create packets bigger than the MTU. IPsec also adds significant overhead.

## *VI. CONCLUSIONS*

In this paper we present field evaluation results of an IP-based architecture for a 4G "True-IP" network developed under Moby Dick Project. Moby Dick demonstrated the seamless integration of three disciplines, QoS, AAA and IP Mobility, over a heterogeneous network infrastructure focussing on three access technologies. These are: WLAN, Ethernet and TD-CDMA. Moby Dick considers as well multi-provider scenarios and user mobility by decoupling a user from an end-system and thus allowing customization via a centrally managed profile.

With respect to the market, Moby Dick architecture supports a seamless integration of various access technologies next to each other and enables a user to maintain any session while seamlessly changing his location. So, Moby Dick supports roaming agreements between operators of different technologies; the field trials were connected through the public IPv6 network showing the possibility to extend the system to a world-wide scale.

The field tests done provide indications on critical trade-offs for future 4G networks. Inexperienced users enjoying the most popular applications over Moby Dick test bed, prove that 4G networks can be a commercial reality. As a follow up, IST-Daidalos project [3] will allow users to access services everywhere and every time with cooperation of different providers in a framework of rich business models.

## VII. ACKNOWLEDGEMENTS

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