A New Generation Of Multi-Service Access Networks: Results Of MUSE Phase I
(Invited)

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ABSTRACT
The paper gives a survey of the major results achieved by the European MUSE project during its first phase. The research covers multi service access architectures, first mile solutions, residential gateways and their integration in end-to-end lab trials.

Categories and Subject Descriptors
Telecommunications

General Terms
Design, Experimentation, Standardization, Verification Documentation.

Keywords
Access Networks, Broadband, Network Architecture, Lab trials.

1. INTRODUCTION
The objective of the European IST (Information Society and Technology) project MUSE (Multi Service Access Everywhere) is the research and development of a future, low cost, multi-service broadband access network [1]. The access network should provide secure connectivity between end-user terminals and edge nodes in an open, multi-provider environment suited for the ubiquitous delivery of broadband services to every European citizen.

The large integrated project covers a wide scope of activities ranging from end-to-end access architectures, access and edge nodes, first mile solutions and residential gateways (cf. Figure 1). The expected impact and results of the project are a consensus about the future access and edge network by major operators and vendors in Europe. Anticipated major results include pre-standardisation work aiming at a joint position in standards bodies, as well as proof of concept demonstrators and lab trials.

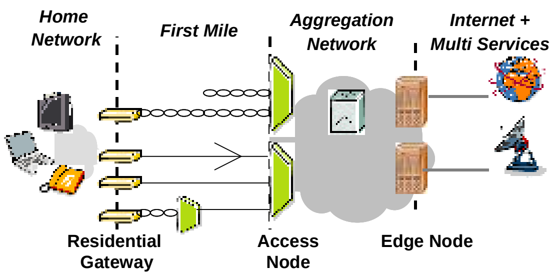

Figure 1: Scope of MUSE project ranging from residential gateway, via access and aggregation network, until edge node.

The MUSE consortium consists of major European players in the field of broadband access, among them vendors (Alcatel, Ericsson, Lucent Technologies, Siemens, Thomson, Infineon Technologies, ST Microelectronics), operators (BT, FT R&D, T-Systems, Telecom Italia, Telefonica, TNO (for KPN), TeliaSonera, Portugal Telecom, BSA), research institutes (IBBT, INRIA, NTUA, ACREO, BUTE, Lund TH, UC3 Madrid, TU Eindhoven, University of Essex, HHI), and a SME in engineering (Robotiker).

The project started in January 2004 and is planned for four years. A first phase was completed after two years and the consortium was granted a second phase of two years. The present paper gives a top level overview of the results achieved in the first phase.

2. ACCESS ARCHITECTURES
An important task for MUSE was the definition of an overall access network architecture from the customer premises to the edge. A trend observed at the start of MUSE was the emergence of Ethernet technnologies in the access and edge network. This was due to the general acceptance of Ethernet in private networks, the efficient multiplexing capabilities of Metro Ethernet, an attractive price setting of optical Ethernet interfaces, and the efficient reuse of know-how and components from the large LAN

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(Local Area Network) market. The challenge for MUSE was to provide secure and scalable multi-service and multi-provider capabilities in such an Ethernet based access network [2].

MUSE defined two forwarding models for the access network architecture: Model 1 is based on L2 (Layer 2) Ethernet forwarding and Model 2 on L3 IP (Internet Protocol) forwarding [3]. In the Ethernet forwarding model, the access node is an (enhanced) Ethernet switch. The Ethernet forwarding can be done based on an Ethernet MAC (Medium Access Control) address, also called "bridging" or on a VLAN (Virtual LAN) per subscriber line, also called "cross-connect". The "cross-connect" approach with VLANs is often proposed as solution for secure user segregation. VLAN stacking can be used to overcome to some extend the scalability limitation. As an alternative for L2 forwarding, MUSE has demonstrated that intelligent bridging with Ethernet MAC (Medium Access Control) addresses is possible in a secure and much more scalable fashion [4].

In the second model based on IP forwarding, the IP awareness and layer 3 functions are brought closer to the end-user by having access or aggregation nodes acting as layer 3 forwarders or routers in the aggregation network [5],[6]. These nodes completely terminate the layer 2 between the user side and the network side ports, while the IP traffic is forwarded between the ports. The IP forwarding model is an entirely new access architecture, which offers advantages with respect to the Ethernet model in terms of security, scalability, and QoS (Quality of Service) support. Research was also dedicated to opportunities for IPv6 (IP version 6) in an access network, its coexistence with IPv4, and impacts on autoconfiguration [7].

In order to realise multi-service capabilities in both network models, authentication, QoS provisioning, and multicasting were studied in a generic way [3]. In addition to the conventional PPP (Point-to-Point Protocol) approach, alternative auto-connectivity methods and per user authentication were elaborated, based on DHCP (Dynamic Host Configuration Protocol) and IEEE802.1x. The studies on QoS resulted in a novel architecture in which the resource admission control is distributed to solve the scalability of the current approach with a central resource admission control [8],[9],[10],[11]. MUSE studied the multicast architecture in access and provided a framework and reference nomenclature to standardisation. Another innovation in multicast was the impact on the access architecture when an end-user becomes the source of a multicast tree. As groundwork for the second phase, MUSE explored issues on nomadicity [12] and service enablers in access [13].

In order to address the multi-hosting capabilities, a thorough analysis was made of the business models. In addition to the roles of the network access provider, network service provider and application provider (which were already known from DSLF (Digital Subscriber Line Forum) documents [14]), an important improvement was to explicitly define the new business roles of a packager and connectivity provider. The former packages the services from different providers as a single entity to the end-user, whilst the latter is responsible for the connection and QoS across networks owned by different providers. MUSE described a reference architecture with the interfaces between the different possible players at data plane, control plane, and management plane. A dedicated activity described the network and service management model for a multi-provider environment.

Techno economic evaluations confirmed the architectural choice to migrate to the new MUSE access architectures. Previous research projects mostly concentrated on the up-front investment cost for different first mile solutions. MUSE made an evaluation of the total business case and compared several options, not only for the physical layer infrastructure, but also for functional choices in the higher layer network architecture [15].

The architecture work has also resulted in various contributions to standardisation, mainly in DSL Forum.

3. ACCESS PLATFORMS

Following the overall access architecture, MUSE developed different variants of access platforms in two of the subprojects.

One subproject on "migration scenarios" studied a multi-edge access platform that provides triple-play services in a Model 2 (IP forwarding) architecture [5]. The migration scenario was supported by legacy ADSL (Assymetric Digital Subscriber Line) solutions and access to the legacy Internet. The access platform contained edge nodes with innovative capabilities, such as a packet-to-packet gateway for multi-media conversational services and a TVoIP (Television over IP) Head-End with a novel Pro-MPEG (Motion Picture Expert Group) FEC (Forward Error Correction) capability. A TCP (Transport Control Protocol) accelerator and Time Shifted TV proxy were integrated in the access node to illustrate how higher layer service awareness can provide added value to the end users and the providers. A lab model of IPv6 in the Access was realised that proves the network architectural concepts. A methodology was elaborated that allows operators for assessing different variants of the MUSE platform against specific deployment requirements.

Another subproject focused on public Ethernet Carrier-grade multi-service access in accordance with the Model 1 (Ethernet forwarding) architecture [17]. It was based on service binding, a network access service connection bundled with an application service connection. The innovative implementation of the service connection concept provides a lightweight architecture to implement traffic separation. This ensures flexibility and scalability where a multitude of services can be delivered to several hundred thousand users attached to multiple edges in the network. A revolutionary and evolutionary approach to IPv6 in the access was compared. A node architecture based on the evolutionary concept that exploits the low cost paradigm of Ethernet was proposed. It concentrates IPv6 functions to the borders and uses standard Ethernet within a node.

4. FIRST MILE SOLUTIONS

Important research was required to get more bandwidth and quality out of the "copper resource" used by DSL. MUSE evaluated the spectral compatibility of ADSL and VDSL (Very high bitrate DSL) in the same binder and made important contributions to the European Spectral Management plan for DSL. The project compared the efficiency of dynamic spectral management and dynamic line code management. The results on modelling and mitigation of impulse noise in DSL lines were highly relevant for a good quality delivery of video streams. An other activity studied autonomous loop qualification and monitoring methods, which allow for the reduction of the operational expenses and maximising the bandwidth capacity of individual lines by measuring their characteristics. MUSE made a significant number of standards contributions in these areas to ETSI TM6, ITU-T and DSL Forum. The project also researched the promising concept of UWB (Ultra Wide Band) over copper paradigm aimed at transmitting up to several hundred Mbit/s over short distances of DSL [18].

While PON (Passive Optical Network) solutions have reached technical maturity in other IST projects, the research by MUSE Phase I on optical access focused on reducing the footprint of point-to-point fibre architectures and a review of more advanced FTTx (Fibre To The x) architectures [19]. A first approach was based on a compact dual bi-directional transceivers that allow for a PTP (Point To Point) optical access node with a density comparable to a DSLAM (DSL Access Multiplexer) [20]. A second approach reduced the size of the access node by an asymmetric PTP-PON approach [21]. MUSE also prototyped a new WIMAX over fibre solution [22]. The same principle of transmission of analogue radio signals over fibre was investigated for a new DSL over optics solution [23]. Lower cost CWDM (Coarse Wavelength Division Multiplexing) technology was evaluated in a ring architecture, which allows for feeding cabinets with different drop technologies, as well as fibre to the premises [24].

5. RESIDENTIAL GATEWAY

MUSE performed an extensive study into a residential gateway that would be suitable for use with the defined network architecture and triple play. Starting from the best effort, high speed Internet ADSL deployment and from the current standard specifications, the system research led to the specification of the functional requirements for a multi-service capable CPE (Customer Premises Equipment). This resulted in a rigorous residential network reference model showing the functional elements in the residential network, and a protocol reference model (also valid in the network), which is an excellent tool to map layered protocol functions at the data plane, control plane and management plane [25]. In addition, a model for QoS handling has been presented. MUSE forwarded its result on access architecture and residential gateway to the newly started HGI (Home Gateway Initiative) [26]. Contributions on auto-configuration and remote management capabilities were made to the DSL Forum [16].

A short term oriented prototype with an ADSL2+ interface was realised within the constraints of an industrial low cost HW (Hardware) and SW (Software) environment in line with the specified reference model and QoS architecture [27]. Another, long term oriented design of the residential gateway was based on a generic processor platform with fewer restrictions in processing power and more flexibility to try new functions. It also featured a fibre interface and paid special attention to the high throughput typical for a FTTx deployment [28]. A service gateway was realised that illustrates the capabilities of an OSGi (Open Service Gateway Initiative) based platform [29].

6. LAB TRIALS AND TEST SUITES

Three subprojects in MUSE successfully integrated the results from different workpackages into end-to-end lab trials, which proved the correct operation of the architectures and concepts.

A first lab trial demonstrated the operation of the novel IP forwarding architecture (Model 2). The set-up was on display at the BB Europe conference in Bordeaux in December 2005 [5] and is currently being evaluated in the labs of T-Systems and Telefonica I+D [30].

A second lab trial demonstrated the multi-service and multi-provider capable Ethernet Access platform (Model 1). The set-up was evaluated in the lab of TNO and another set-up at Acreo was connected to the Swedish National Testbed [17].

A third subproject successfully realised a lab trial of advanced optical access technologies at the HHI (Heinrich Herz Institute). Low cost CWDM technology was used to integrate analogue signals of DSL over optics and radio over optics, as well as high-speed digital baseband signals on a single fibre infrastructure [24].

The MUSE partners shared their efforts to jointly define a test suite of the evaluation of an end-to-end multi-service access network. This multi-disciplinary approach resulted in two reference documents on test objectives and methods for physical layer (DSL and Fibre), connectivity, and QoS.

7. FUTURE WORK

MUSE has successfully defined a low cost multi service access architecture and demonstrated it in different lab trials. During the extension, MUSE will continue to bring the results of the first phase to standardisation and evaluate them in integrated lab trials. The MUSE access network solutions will be further enhanced by

- embedding new service enablers in the access network elements to create more added value from multimedia applications,

- preparing the fixed access architecture to support fixed mobile convergence,

- comparing new concepts like distributed architectures and node consolidation.

The extensions will be validated by upgrades of the end-to-end lab trial set-ups.

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