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White Paper: "Inter-MAC concept for Gbps Home Network"

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Abstract

This paper describes the key challenges towards the Gbps home network and explains how OMEGA is felt as one of the most promising solutions for the future. It presents the technical topics investigated in the OMEGA project and its early assessments. Typical scenarios are described, followed by the technical options for building an ultra-broadband home network with quality of service guarantee are presented. Initial views on acceptance criteria, costs and benchmarks with other initiatives are also provided.

Keyword list

FP7, Home Network, Gbps, FTTH, Wi-Fi, UWB, PLC, FSO, Inter-MAC

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List of Acronyms

Acronym	Meaning	Acronym	Meaning
AV	Audio Video	**SIMO**	Single Input Multiple Output
CATV	CAble TeleVision	**SIP**	Simple IP
DLNA	Digital Living Network Alliance	**STB**	Set Top Box
DSL	Digital Subscriber Line	**UBB**	Ultra Broadband
FP6	Framework Programme 6	**UPnP**	Universal Plug and Play
FP7	Framework Programme 7	**UWB**	Ultra Wide Band
FSO	Free Space Optics	**VLC**	Visible Light Communications
FTTH	Fibre To The Home	**VoIP**	Voice over IP
GPON	Gigabit Passive Optical Network	**WAN**	Wide Area Network
HAN	Home Area Network	**WLAN**	Wireless Local Area Network
HDTV	High Definition TeleVision	**WPAN**	Wireless Personal Area Network
HGI	Home Gateway Initiative		
HWO	Hybrid Wireless Optics		
IMS	IP Multimedia Subsystem		
IGMP	Internet Group Management Protocol		
IRC	Infra-Red Communications		
ISP	Internet Service Provider		
LAN	Local Area Network		
LD	Legacy Device		
LED	Light-Emitting Diode		
LLC	Logical Link Control protocol		
MAC	Medium Access Control		
MIMO	Multiple Input Multiple Output		
MISO	Multiple Input Single Output		
OA&M	Operations, Administration and Maintenance		
OLDA	OMEGA Legacy Device Adapter		
OMEGA	Home Gigabit Access		
OSLD	OMEGA Serving Legacy Device		
PLC	Power Line Communications		
QoE	Quality of Experience		
QoS	Quality of Service		
RF	Radio Frequency		

Table of contents

1 Research challenges 6

1.1 The need for Gbps at Home 6

1.2 Research Scope 6

1.3 Key requirements 6

1.3.1 Typical use case: Evening in the family home 6
1.3.2 Improved Connectivity in the Gigabit Home Network 7
1.3.3 Compatibility with future access networks 9
1.3.4 Compatibility with future middleware 9

1.4 Driving postulates 10

1.5 World Wide Benchmark 12

2 Possible Options for the Gbps Convergence 13

3 OMEGA Vision for a Gbps convergent network 14

3.1 OMEGA Technology in a nutshell 14

3.1.1 Architecture Reference Model 14
3.1.1.1 The Inter-MAC basic block (I-MAC functionalities) 14
3.1.1.2 The basic functions of the OMEGA devices 14
3.1.1.3 The devices of the OMEGA Network 15
3.1.1.4 The OMEGA interfaces 16
3.1.1.5 OMEGA Network Architecture Reference Model 17
3.1.2 Race to Gbps 19
3.1.2.1 Radio (WLAN and WPAN) 19
3.1.2.1.1. WLAN specificities 19
3.1.2.1.2. WPAN UWB < 10 GHz specificities 20
3.1.2.1.3. WPAN 60 GHz specificities 20
3.1.2.2 Gbps PLC 20
3.1.2.3 Hybrid Wireless Optics 21
3.1.3 Inter-MAC Layer 21
3.1.3.1 Inter-MAC main rules for QoS Guarantee 23
3.1.3.2 Inter-MAC connectivity 24

3.2 Proof of concept by on-scale Prototyping 25

3.3 Acceptance criteria – Cost 25

4 Conclusion – Perspective 26

5 References 27

Executive Summary

The media richness of the services available to the end consumer has had a constant increase rate of about 8% per year over the last century. Therefore, a major bottleneck risk, that the home network jeopardizes the Quality of Experience of the future services, urges to have a clear Gbps answer for the home network. Indeed, the use case scenarios are going together with an overall capacity in the home area network of around 1 Gbps. However, the generalised wireless Gbps coverage that these use cases require is hard to achieve, given the basic law of physics preventing Gbps wireless links to travel across walls. The combination with power line communication provides a home backbone "without new wires." It thus appears evident to distribute the functions of connectivity inside the home with the help of interconnection points (the extenders) spread them throughout, and achieving the hybridization of technologies and the protocols implemented in the access/regional network can be profitably extended in that context. Several driving postulates give a more focused framework for the OMEGA technology.

From a quality of service point of view:

- The Gbps wireless is not QoS acceptable within more than one room. Considering that narrow band techniques reach Shannon's limit, new Gbps technology eldorados have to be found.
- From a network perspective, IP layer cannot manage PHY impairments to QoS acceptance while still being the de facto standard for the connected home.
- OMEGA devices have to be green.

And, from a simplicity point of view:

- Electrical sockets are the best medium term way to bring wire line connectivity in Europe.
- The final link of the in-house communication will preferably be wireless.
- The end user slogan will be: "The closer, the more bandwidth!" Gbps mobility at home is a second priority
- The end customer will have the final word!

Up to now, no impacting integration work has been done to converge all these physical technologies into one coherent framework. Nevertheless, there are signals sent by some of the industrial actors. OMEGA will choose an evolutionary solution based on the Inter-MAC concept to accommodate these challenges by elaborating a minimum upper interface (namely the middleware south interface).

The Inter-MAC concept applies to a set of OMEGA devices constituting the OMEGA network which is organized in the form of a mesh architecture bringing in the advantages of multi-path capabilities for traffic reconfiguration. Their association can be represented under the global name of "OMEGA device", keeping apart the OMEGA gateway in order to highlight the interface with the access network. This leads to the OMEGA architecture reference model presented below. In a real network, several end devices, extenders and legacy device adapters can be interconnected in a ramified and extensive way.

From a race to Gbps perspective, the multitude of radio systems operating in a single home network and using the overcrowded frequency bands will create coexistence and performance problems. Convergence at the radio layer will consequently be a key concept to be investigated. Furthermore, technological enhancements will be investigated in order to locally optimize the different radio technologies so that they provide the required performance in a converged network. Next, in order to meet the Gbps with PLC, the following advances are required: Higher channel efficiency in 2-30 MHz band, larger bandwidth (up to 100 MHz) and a new system approach by channelisation of this extended band. The IRC (Infra Red Communications) demonstrator will use a transmitter and receiver module that operates at Gbps rates and each module needs to be developed with the maximum field of view and range possible. For VLC (Visible Light Communication), due to the rather limited bandwidth of white-light LEDs (tens of MHz), it is a challenge to provide free-space data transmission rates in excess of 100 Mbps.

From an Inter-MAC perspective, OMEGA decided to extend the layer 2 based on Ethernet methods. Unlike routers, Ethernet switches are known to be cheap and auto-configuring. The driving key requirements for the Inter-MAC layer is that there is a fundamental difference among QoS flows and best effort flows. Each flow which belongs to one of the three QoS classes with QoS guarantees must undergo an admission control process and has the challenge of dealing with the changing conditions of the physical medium. Thanks to the Inter-MAC layer, the OMEGA network, from an IPv4/IPv6 point of view is a unique LAN. No L3 Routing is needed within an OMEGA network. The frames/packets are forwarded to the correct destination node thanks to a path selection algorithm.

Finally, one of the major objectives for OMEGA is to demonstrate the Inter-MAC concept but also new payloads contributing to the Gbps race at home. This prototype will be made available to early adopters for lab tests.

As far as industrial impact is concerned, OMEGA will develop OA&M methodologies for home network and equipment as well as production and price estimations for HAN equipment for both end users' and operators' perspectives.

1 Research challenges

1.1 The need for Gbps at Home

We should consider the following 2 major trends from over the last few decades:

- First of all, **it shall be observed that the media richness of the services available to the end consumer has had a constant increase rate of about 8% per year over the last century**. This leads to the need of Ultra Broadband (Gbps) at home to handle future services such as 3D [NOAM].
- Next, the bandwidth ratio between indoors and access, ranges from 5 to 10. The rolled out FTTH access is 100 Mbps symmetric thus implies Gbps indoors [BELL]. However, as there are no existing solutions to spread this access rate all over the house by the existing technologies, **there is a major bottleneck risk that the home network jeopardizes the Quality of Experience of the future services**.

1.2 Research Scope

The OMEGA network is centred around the needs of the user: gigabit RF and optical links, combined with more robust wide-area RF and visible-light communications will provide wireless connectivity within the home and its surroundings.

However, a generalised wireless Gbps coverage is difficult to achieve, given the basic laws of physics, almost preventing Gbps wireless links to travel across walls. Combined with power-line communications this provides a home backbone “without new wires.”

A technology-independent MAC layer will control this network and provide services as well as connectivity to any number of devices the user wishes to connect to the OMEGA network in any room in a house/apartment, and further, this MAC layer will allow the service to “follow the user” from device to device.

In order to make this vision come true, substantial progress is required in the fields of optical-wireless and RF physical layers, in protocol design, and in systems architectures. For OMEGA, an interdisciplinary team from leading institutes and companies in this broad range of technologies has been assembled.

1.3 Key requirements

In this section, the most representative scenarios for OMEGA are depicted as well as requirements for the compatibility with legacy devices and networks, with access networks (current and future) and with middleware and services (current and future).

1.3.1 Typical use case: Evening in the family home

The OMEGA use cases and scenarios are depicted in deliverable [OMD11]. The main purpose of that document is to outline a number of scenarios that form the starting point to derive more technical requirements for the Ultra Broadband Home Area Network. Section 2 of [OMD11] covers a wide range of home networking use cases and associated scenarios, comprising of the life of a family at home, of young single persons, or of elderly people. It also comprises of working from home and small offices. The focus of this document will be on two representative scenarios (as in section 4 of [OMD12]).

The first scenario tells the story of an "Evening in the family home", while the second considers the possibility of being connected to a neighbouring OMEGA network. The latter is referred to as "Multi-Home Scenario"**.** Figure 1 below presents the actors and the devices involved in the "Evening in the Family Home".

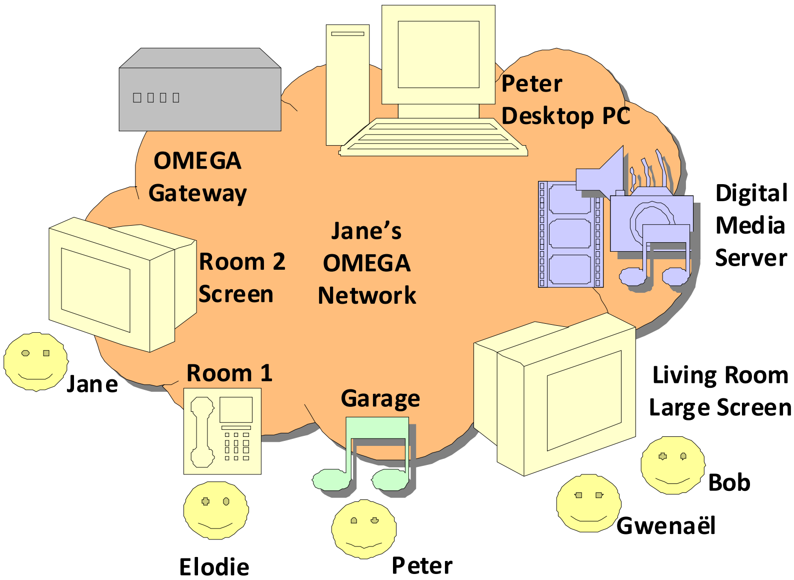

Figure 1: Evening in Family Home Scenario

The story associated to this scenario is as follows:

a) In the evening, Peter programs the recording of a HDTV documentary on the Formula One season, on the domestic digital media server.

b) Gwenaël invites his friend Bob round to show him the videos that he recorded with his father during their last holiday in Provence. Peter has just finished editing these videos, which are located on the hard disc of his desktop PC. The boys will view the holiday images on the large screen in the living room.

c) Jane, who had just started to watch a documentary streamed to the living room, will continue to watch it on the screen located in her room (room 2).

d) Peter spends the evening refurbishing his collector's car in the garage, whilst listening to his favourite music (available on the digital media server) on his HiFi.

e) Elodie is on the IP-telephone with a friend.

f) She wanders around between the living room, where she comes to glance at the screen from time to time, and her bedroom (room 1), where she goes to find more privacy when speaking to her friend.

1.3.2 Improved Connectivity in the Gigabit Home Network

The data rate considered for home networking in the project framework is related to the following traffic situations:

- The proliferation of simultaneous flows in the home area network linked to an increasing interactivity between terminals and services, to the need of rendering the different sources of contents on any terminal, and to the continuity of services between the home and the access.
- Availability of comfortable and easier use which allows the customer to access remote and bulky content with the same performance as if this content were local to the terminal of the customer.

These scenarios are going together with an overall capacity in the home area network of around 1 Gbps [OMD11], and it may be expected that they also pull up the data rates available on the access link of the customer.

The range vs. data rates performance of 'no new wires' technologies such as HD PLC or Wi-Fi 802.11n will likely remain limited even when using the most sophisticated improvements.

Other 'no new wires' techniques that belong to the domain of high bit rates such as radio UWB or 60 GHz or wireless optics are practically confined to the space of a single room due to propagation issues.

In the prospect of the Gbps data rate in home networking, **it appears thus evident to achieve the connectivity inside the home with the help of** multi-hop communication between the devices, on a meshed network topology. There might be OMEGA devices in the network that only do the forwarding in order to improve connectivity and to increase the range of the home network. This also achieves **the hybridization of technologies.** This scenario is illustrated in Figure 2:

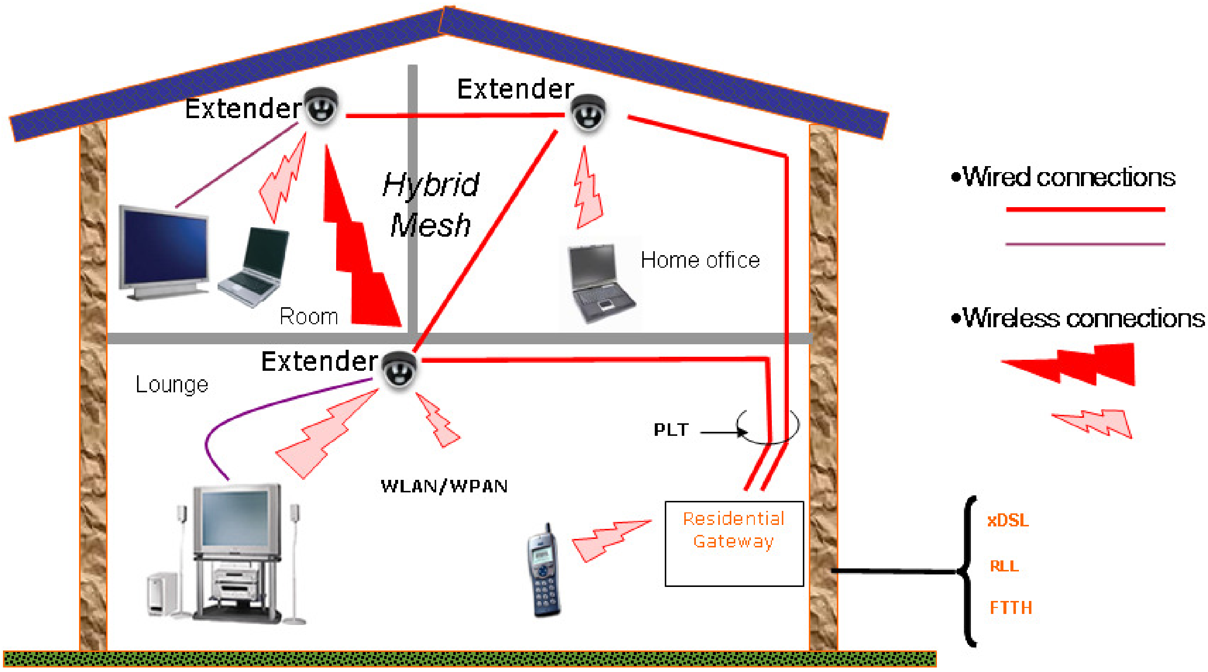

Figure 2: Illustration of hybridization of technologies inside the home network

Figure 2 highlights the interconnection of a wide range of devices with a mesh network ensuring the coverage of the whole home area, which cannot be completely disjointed, but classified in families or clusters:

- data communication devices (computers, PDA, notebook, …)
- gaming cluster
- AV communication devices (analog/digital phones, video phones, mobile phones, …)
- entertainment consumer electronics audio/video devices (STB, TV, MP3 player, HiFi equipment, …)
- domestic equipments (fridge, sensor networks, …)

Some of these devices may be OMEGA end devices (i.e. implement the mandatory functionalities of OMEGA devices, including the Inter-MAC framework), and belong therefore to the OMEGA network. The other devices are legacy devices and may use the same communication technologies that the OMEGA project puts forward (potentially Wi-Fi 802.11n, HD PLC, UWB, optical wireless, radio at 60 GHz) or any other communication technology.

The OMEGA network may also coexist with extensive legacy networks based on technologies, with which the OMEGA network should ensure backward compatibility (for instance Wi-Fi, PLC), or with legacy networks based on home networking technologies which are out of the scope of the project, for instance IEEE 1394 or Bluetooth.

In a general way, the OMEGA network should ensure upward compatibility with the legacy technologies it supports, by achieving the translation between legacy frames and Inter-MAC frames. If the legacy device is based on a technology which is not compatible with the OMEGA technologies put forward within the project, then the interfacing between the two domains can be achieved by a specific device (for instance a STB for a legacy TV set).The interfacing of the OMEGA network with legacy devices is achieved by a "serve legacy device capability" which provides a minimum set of functionalities to make the legacy device inter-work with the new OMEGA network with the same experience as when it was used before. It ensures in particular the translation from legacy data frames and networking into Inter-MAC data frames and networking, and the translation from legacy QoS requirements into Inter-MAC QoS (aiming at keeping the experience of the legacy network). This capability is basically supported by every OMEGA device. The legacy device can interconnect with an OMEGA device through a separate interface or through an interface that is also used for the communication within the OMEGA network, for instance, a WLAN interface.

1.3.3 Compatibility with future access networks

Another major concern for the architecture is the fact that the OMEGA network design should keep in mind continuity of the access network to a certain extent. The home gateway is commonly considered as the border network element between the home network and the access provider network. This does not imply that there may not exist some continuity between these two network segments. On the opposite, one of the purposes of the OMEGA architecture is also to highlight how the evolutions expected in the access network may impact the operation of the OMEGA home. Deep evolutions are expected in the operator access and regional network, even if their roadmap is slower than that of the area of home networking:

- the dramatic increase of the data rates in the access and, as a result of this fact, the emergence of optical fibre in the access, likely up to the client's premises, with the prospect of reusing the potential of that technology in the Gigabit home network,
- a packet oriented handling of the QoS,
- the emergence of an IPv4/IPv6 coexistence, with the prospect of some simplification of the configuration process of the client installation,
- the emergence of an integrated IMS as a new (SIP based) intelligent network based on an IP network,
- the consolidation of new powerful means of management of large scale networks.

Therefore, one clear ambition of the OMEGA architecture is to assess the impact of these evolutions on the organization of the Gbps home area network, and how the protocols implemented in the access/regional network can be profitably extended in that context. These aspects will be elaborated in a later stage of the OMEGA project.

1.3.4 Compatibility with future middleware

A common definition is that middleware is the "glue" between software components or between the software and the network. The goal of the middleware is therefore to make different devices inter-work for the delivery of the service to the end user and thus its main goal is to hide the complexity of the inter-working devises under the service layer and abstracting it from the physical evidence of the home network. Several middleware solutions already exist: UPnP/DLNA, DPWS, IGRS, BONJOUR, HAVI, but they are not interoperable. There is no standardised and widely accepted middleware standard so far, while the IP layer is addressing some of the middleware core functions as a pivot convergent technology.

In this context, the task for **OMEGA will be to elaborate a minimum upper interface (namely the middleware south interface)** in order to provide:

- the requesting/maintaining/releasing of service flows,
- guaranteed QoS requirements to these flows, and report limitations, instantaneously, to the middleware so that relevant means are taken by the application (reducing the flow data rate or even dropping the flow),
- easy local or remote management given a top level view to the end user or the ISP,

1.4 Driving postulates

This section deals with a number of beliefs or technical bolts of the state-of-the-art, driving the OMEGA technical approach. As they are not always explicitly explained but nevertheless shared among the OMEGA consortium, this section tries to give some more evidence to them.

The Gbps wireless is not QoS acceptable within more than one room.

The range limitation of acceptable QoS with wireless Gbps to a single room has to be overcome.

The most advanced wireless technologies deployed so far are Wi-Fi 802.11n/D2.0 and to a lesser extend UWB in the 3-10 GHz band. Classified as WLAN and WPAN technology, respectively, they both do not provide Gbps.

Their rather evident limits consist of:

- Very low transmit power (UWB): link budget lacks dynamics,
- Spectrum efficiency (Wi-Fi): Shannon's limit is almost reached, see below,
- Interference (Wi-Fi): a flat may be surrounded by more than 20 Wi-Fi access points in a building.

These limitations are addressed by upcoming Gbps wireless technologies, which are WPAN technologies beyond UWB, such as radio at 60 GHz and wireless optics, which accept "natively" these limitations to play 2 complementary cards:

- Gbps race: concentrating on Gbps short range connectivity,
- Networking: accepting limited direct range and integrating them into a mesh network.

Narrow Band techniques reach Shannon's limit – New Gbps technology eldorados to be found.

Given the recent developments of ultimate digital narrow band communications (channel coding, MIMO) in cheap products (due to computing power of silicon integration), marginal gains in getting closer to Shannon's limit will need tremendous additional complexity and funding. The only ways out are the following:

- enlarge the spectrum,
- boost the power.

This raises the matter of regulation (see UWB), so pushing consideration of new bands (60 GHz and optics). The power levels are limited to health and safety regulations.

IP-layer cannot manage PHY impairments to QoS acceptance while still being the de facto standard for the connected home.

The native construction of Internet Protocol 1.0 aimed at connecting 2 computers on an error prone cable. The simple construction made a rapid explosion of this network so that it has been a central communication protocol for several years (more than 2 decades ?), also with a strong impact on home network technologies such as UPnP.

However, as it is based on a packet technology, synchronous scheduling is still difficult to achieve for interactive services on Ethernet. It is anticipated that this limitation will be very severe in the context of Gbps home, because, even though it is very familiar to the end user, the communication channels are very aggressive, leading to several packets of errors, unperceived so far at medium speed. Pro- or re- active means to compensate these impairments will hardly be incorporated by the IP layer because they are in a competition with other "core" patches (security, IPv6…) that already put the IP layer evolution "out-of-breath" to accept patches other than the core ones.

Finally, given the fact that the IP layer is the de facto convergence "siphon" standard, there have not been many attempts so far to merge connectivities at lower layers.

Communications over power sockets is the best medium term way to bring wire line connectivity in Europe.

Considering firstly North America, the success of cable indoors is mainly due to the fact that houses and buildings are very recent and "by default coax enabled". The same situation applies also for the access networks. This partly explains the recent boost of coax technologies such as HPNA indoors to provide several hundreds of Mbps for in-house transport.

The situation is very different in Europe, especially in down town of major capital cities (Paris, London, Madrid, etc.) where the only existing wires are mains wiring to all rooms and telephone copper for some rooms.

Given the fact that only 1% of dwellings are renewed each year [OMD11] and hopefully with cable or indoor fibre, it will take 69 years to completely renew the dwellings and benefit from new cables. As a conclusion, there will be no other choice than to take mains wiring as a natural way of wire line transport at home for several years to come.

The final link of the in-house communication will preferably be wireless

Given the daily acceptance of wireless technologies, it seems that this type of connectivity will be a MUST for the end user in the coming years. The reasons are that the end user:

- should have the possibility to install the device (even wall mounted) wherever he/she desires,
- does not have to "de-interleave" the cable clutter,
- can enjoy small nomadism or moving from room to room without any connection problems ,
- can easily connect the devices via powerful and secure authentication protocols (not always fast enough in handover situation, see IEEE 802.11r).

The end user slogan will be: "The closer, the more bandwidth!"

Hybridization of wireless connectivities will be a credible answer towards "easy Gbps". The extensive and common use of mobile phones by the end user makes him understand and accept (rather naturally) that the wireless Quality of Service is subject to variations and globally obeys to the rule: "the closer I am to the access point, the better the quality I can enjoy". Then, considering meshing technologies and even hybrid solutions, either by wired or wireless means, it seems quite reasonable to imagine a Gbps hot spot in a room whose streams are subjectively less powerful when getting out of reach or sight.

Gbps mobility at home is a second priority

Except the trivial example of VoIP through the gateway by means of a 3G/Wi-Fi mobile phone, there are only a few examples of interactive Gbps services, especially videos requesting high QoS "on the move at home". The futuristic ambient scenarios even push towards the situation where the people will move but not the devices or network elements themselves which will remain rather static. The indoor "outage" is no more due to "trees" or "tunnels" but rather due to the shading by people or objects in the line of sight. Then, the only commonality between the cellular and the indoor mobility shall be understood as the medium being "error prone". Concerning other aspects like power dynamics and errors statistics these two systems are different.

The end customer will have the final word!

It shall be kept in mind that the OMEGA technology will be deployed in the private homes of the users. For several reasons, (technical, decoration, hypochondriac or actual beliefs of radio waves impact ..), the end user will have the last word as to whether and when to adopt the OMEGA technology, and to consider indifferently wire line and wireless convergence and let the customer choose himself which, the best way to deploy Gbps in his own premises.

OMEGA devices have to be green

Low energy consumption of OMEGA devices will be one of the keys to their success. The more mature OMEGA technologies like IEEE 802.11n, WiMedia and PLC already provide power management. This has to be supported by the other considered technologies, too. It is then the task of the Inter-MAC to coordinate the power modes of the different technologies and to make use of, for instance, intelligent wake-up procedures. Furthermore, energy-efficient hardware is the key!

1.5 World Wide Benchmark

As already mentioned, current solutions do not meet the expectations regarding QoS as well as the evolution of usages towards seamless integration of multiple technologies. **Until recently, no actual integration work has been done to** combine **all these physical technologies in one coherent framework.** There were some attempts to overcome this limitation but with limited impact only:

- **IEEE 802.21**: This group intends to offer seamless convergence across heterogeneous networks and provides a unified interface to upper-layer applications in order to support transparent service continuity. Even though 802.21 provides great support to handle heterogeneity between wireless and wired network, it does not meet the requirements of Ultra Broadband Home Area Networks (UBB-HANs), as the target is simply to improve handover mechanisms and does not address specifically any QoS issues.
- **IEEE P1901**: P1901 group is aiming to develop a standard for Broadband over Power Line Networks. But issues such as convergence and inter-working with other technologies are out of the scope of the group.
- **IEEE 802.1**: This working-group defines protocol layers above the MAC & LLC layers. IEEE 802.1D (MAC Bridges) suffers from several flaws and implementation issues. For example, the standard does not handle the traffic dynamics effectively, which can dramatically affect the QoS performance. Utilization of the network resources is not optimal, as some of the links are blocked. There is also ongoing effort within AVB and DCB task groups to define the specification of multimedia services for IEEE 802 networks. The IEEE 802.1 AVB task group provides advanced synchronous streams over Ethernet cables throughout the home, so that QoS is partly addressed while still beginning to address the more complex erroneous nature of wireless and PLC connectivities.
- **Wimedia LLC Protocol**: The design of this UWB sub-layer covers many functional needs of the Inter-MAC layer (topology, bridging, QoS) in a similar way as the IEEE 802.2 LLC.

Despite all these efforts to standardize protocols for the hybridization and convergence of different technologies, the impact has been limited up to now. **Nevertheless, there are signals sent by some of the industrial actors**, who are looking for solutions:

- **Wireless HD** [WHD]: Since first demonstrations at the Consumer Electronics Show (CES) 2008, this interface has proliferated in HD TVs.
- **Belgacom** [BELG]: They are also considering the option of multiple technology cohabitation within the Gbps Home Networks, with interoperation performed through the residential Home gateway. From their perspective, 2 technologies will be supported in addition to Ethernet: 1 wireless + 1 “no new wire”.
- **Orange Labs:** The Wi-Fi extender [WIEX], to be commercialized by Orange, combines PLC and Wi-Fi. Among the research solutions, baseband hybridization has been performed through a combined UWB/60 GHz prototype [VTC]. Radio over Fiber (RoF) is another example of a combination (fibre and UWB).

- **Thomson:** Within Prodim@ges [PROD] Thomson is developing an outdoor infrastructure for content production. They are working on an extender (connected to the production centre via optical links) that offers Ethernet and WiMAX via an IEEE 802.1D bridge to the camera person filming.

2 Possible Options for the Gbps Convergence

Questions

Several technologies are candidates in this approach: Ethernet, PLC, Wi-Fi, UWB, Free Space Optics and optical fibres. Their link layer characteristics do not allow meeting global coverage requirements individually. Figure 3 illustrates the complementarities of these connectivities in the case of radio technologies, and this aspect is also valid for the other HN technologies. An appropriate combination of several technologies should enable to react to the user requirements and expectations more effectively and to provide him with the best QoE (seamless usage of any type of terminal with very high throughput).

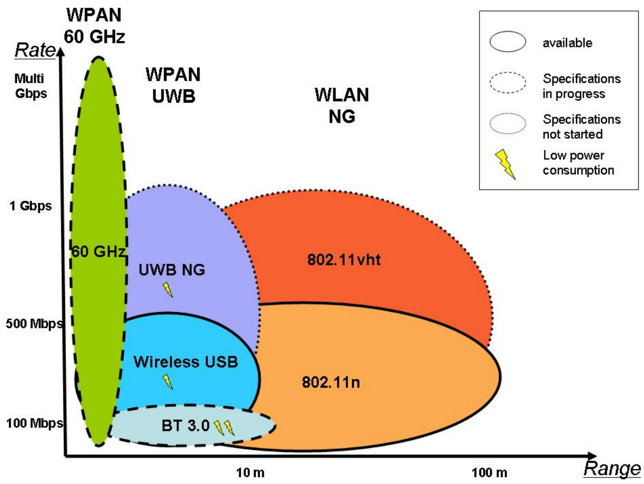

Figure 3: Complementarities of Home Network technologies: example of radio technologies

In order to make the UBB-HAN a reality, several questions need to be handled.

- Network topology and elements: single versus multiple home gateways, device capabilities in terms of routing and supported technologies, how to ensure interoperability with legacy devices … Those issues should be analysed carefully in order to select the best options for the home network architecture.
- How to handle heterogeneity: At the device level or at the gateway level.
- Evolution of the solution with new emerging wireless/wired standards: this element is of importance in order to facilitate system upgrades without major costs.

Solutions

Various options for the convergence can be foreseen, hereafter are listed three of them covering a large range of possibilities from highly conservative to more disruptive ones.

Option A: One more patch. A first idea would be not to modify any of the MAC layers, but to add convergence mechanisms at the IP layer. Such an approach would be easy to design and implement but would not bring more than IEEE 802.21 or equivalent initiatives: low latency and quality of service would be hard to guarantee if no deeper modifications are introduced in the protocol stack.

Option B: Adaptive hybrid. An initial survey of the existing technologies would give us a picture of the MAC layers. Case by case adaptation layers on top of the MAC layers of these technologies could then be proposed, to align mechanisms such as channel access methods or the frames structures. Then an Inter-MAC layer located between the MAC and the IP layer in the OSI protocol stack would unify the messages coming from the different technology specific MAC layers and give the possibility to take accurate decisions in the network.

Option C: Revolutionary solution. This very challenging option would consist of designing a common and generic MAC layer for all technologies potentially present in the Home Network. This means that this new MAC layer would need to be included in corresponding standards. It would likely provide the best performance, however getting this solution adopted worldwide would be almost impossible, especially if we expect the solution to be on the market in less than 4-5 years.

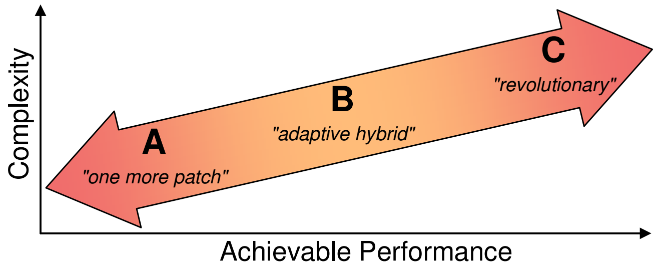

Figure 4: Three options for the convergence in Home Networks

Conclusion

Option B has been chosen for OMEGA.

3 OMEGA Vision for a Gbps convergent network

The OMEGA home network is heterogeneous at the physical layer and introduces an additional MAC sub-layer to provide convergence. A dedicated architecture for this type of network is defined.

3.1 OMEGA Technology in a nutshell

3.1.1 Architecture Reference Model

The OMEGA network can be considered as a set of OMEGA devices implementing the following functional components: Gateway capability, Extender capability, End Device capability and Serve Legacy Device capability. The rationale for the identification of these components is summarized hereafter. It is based on a functional analysis elaborated more extensively in [OMD61]. The functional components are identified by the set of functionalities that they implement.

3.1.1.1 The Inter-MAC basic block (I-MAC functionalities)

This basic block is common to all the different OMEGA devices. It includes data plane functionalities such as Inter-MAC forwarding and QoS marking, control plane functionalities such as path selection, load balancing and connection admission control, and management plane functionalities such as monitoring.

3.1.1.2 The basic functions of the OMEGA devices

The basic functions of an OMEGA device are represented in Figure 5 which is a projection of the elements of the data, control and management planes into one single plane.

In addition to the control and data functionalities of the Inter-MAC, new functions appear in the control plane (network attachment) and in the management plane (operation and maintenance, energy saving, device discovery, local device management, remote device management). In this figure, the security functions, which have components in the data, control and management planes, are represented in a parallel backplane. The solid lines represent the exchange of information inside the OMEGA device. The dashed lines represent the exchange of information with peer devices.

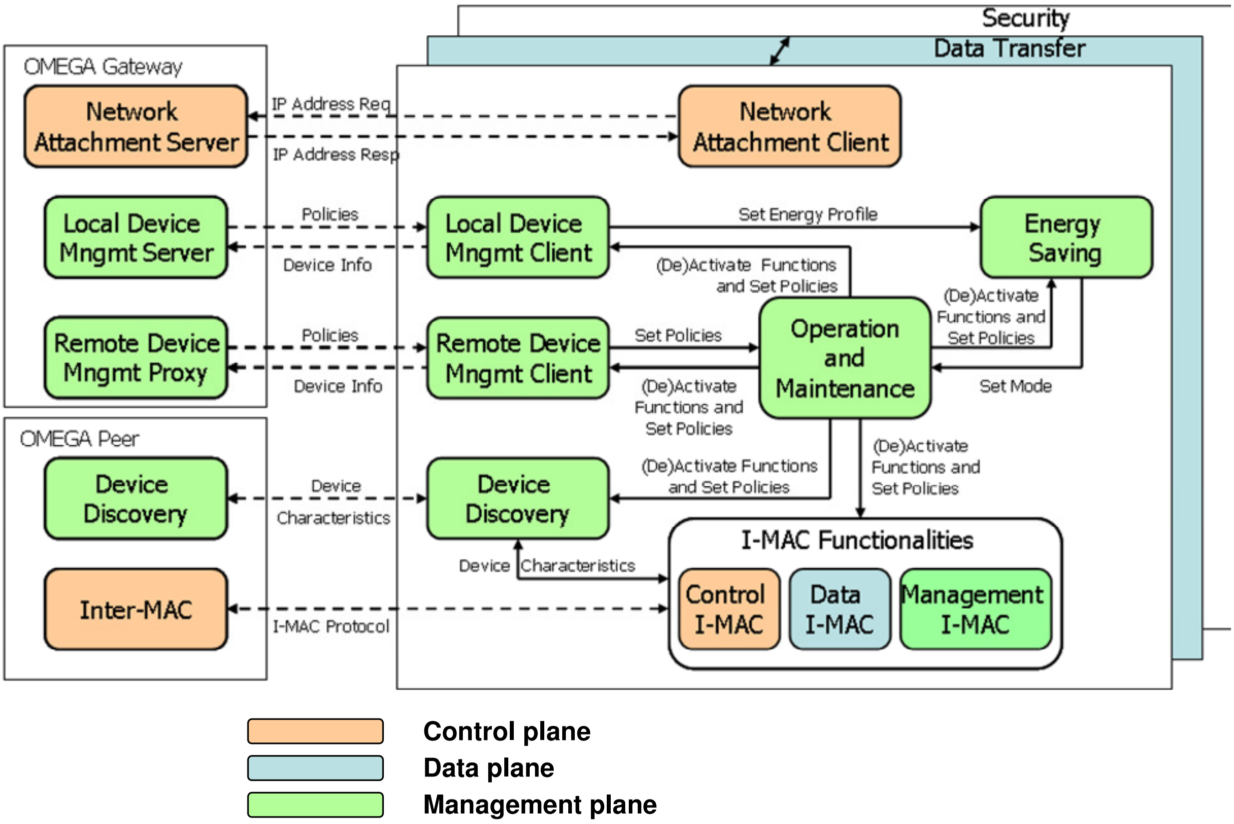

Figure 5 : The basic functions of an OMEGA device

3.1.1.3 The devices of the OMEGA Network

The following Figure 6 shows how the devices of the OMEGA network can be elaborated by adding specific functionalities to the basic functions presented in the former section.
An OMEGA Gateway is elaborated by adding a WAN connectivity, a signalling agent (performed at the session level and ensuring the establishment of communications with the access network), and the functionalities of a network attachment server (achieving the IP addressing), a local device management server and a remote device management proxy.
An OMEGA End Device is elaborated by adding the functionalities of user input support and signalling agent.
An OMEGA Serve Legacy Device is used to interface the OMEGA Network with legacy devices or networks. It is elaborated by adding the functionalities of specific legacy device signalling agent and of QoS and frame translation for PHY/MAC interfaces capable of communicating with legacy devices.
An OMEGA Extender does not need any further elaboration. The basic OMEGA functions are sufficient to provide mesh connectivity and QoS support in the OMEGA network.

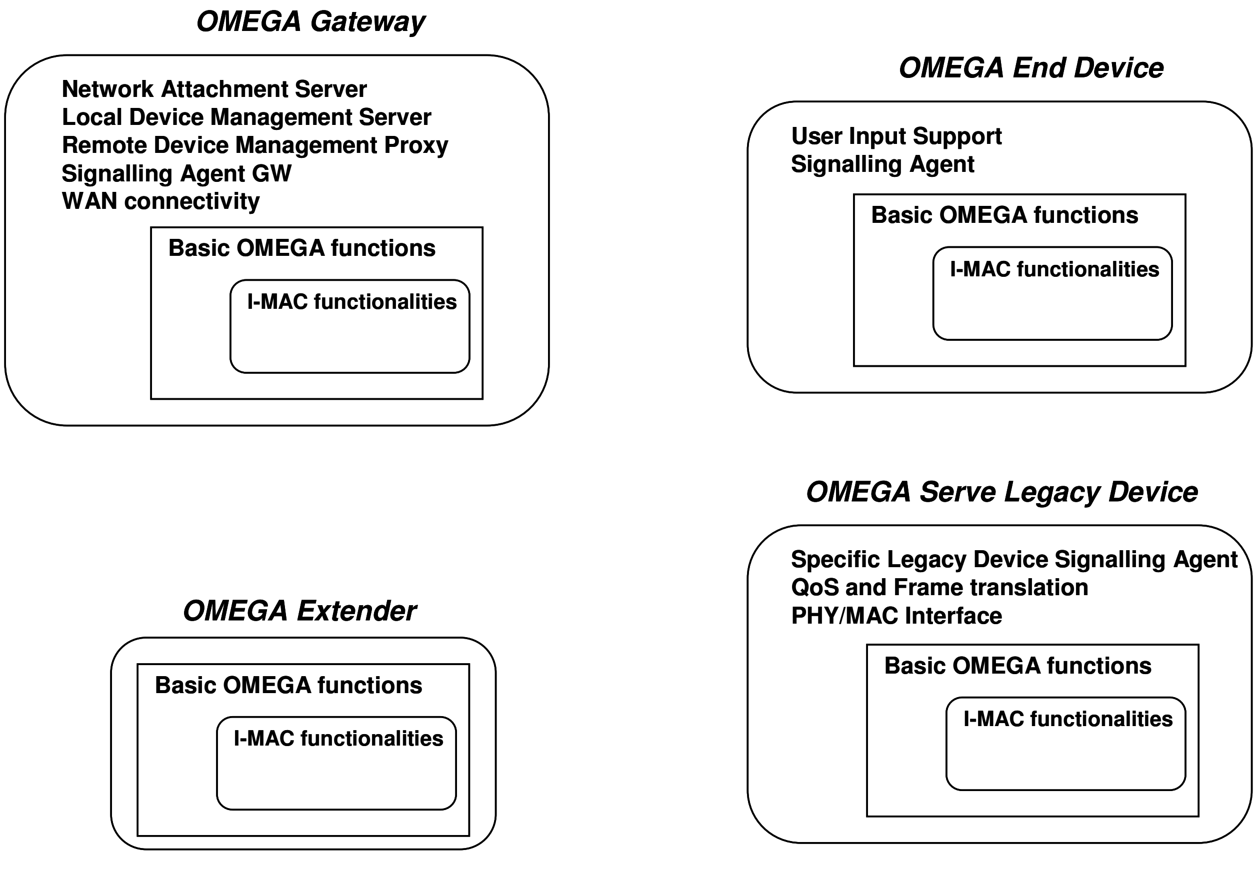

Figure 6: Functional structure of the devices of OMEGA Network

3.1.1.4 The OMEGA interfaces

The concern of the interfacing of the OMEGA devices presented in the former section is raised in this section.

First, the *Ω interface* is defined: it is used by OMEGA devices to connect each other through Ω links. The Ω interface is based on the Inter-MAC layer which is located below the IP layer (if it exists in the device) and above the IEEE 802.2 link layer (see Figure 7 illustrating the data plane OSI layer stack between two nodes A and B of the OMEGA Network through an Ω interface).

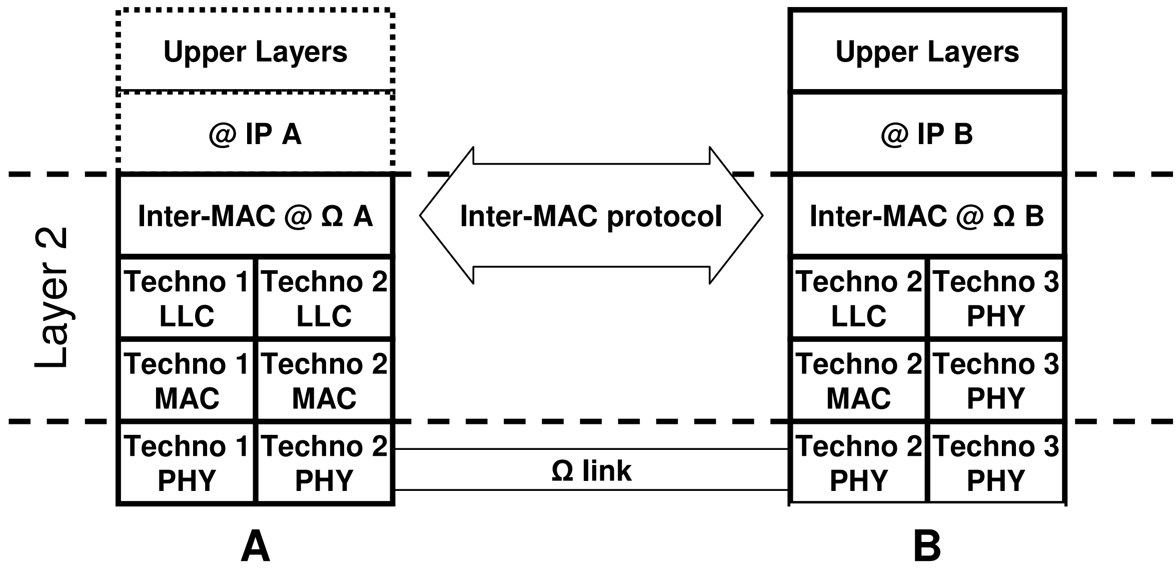

Figure 7: Illustration of the Ω interface and the OSI layer stack

Therefore, a given OMEGA device has at least one logical Ω interface and at least one Ω link per directly neighbouring device. The Ω interface operates on Inter-MAC addresses. IP and upper layers exist typically for the gateway and the end devices. At the physical and MAC layer, the Ω link relies typically on a broadband home networking technology, for instance IEEE 802.11n radio communications, Power Line Communications, UWB radio communications, 60 GHz radio communications, or Wireless Optics.

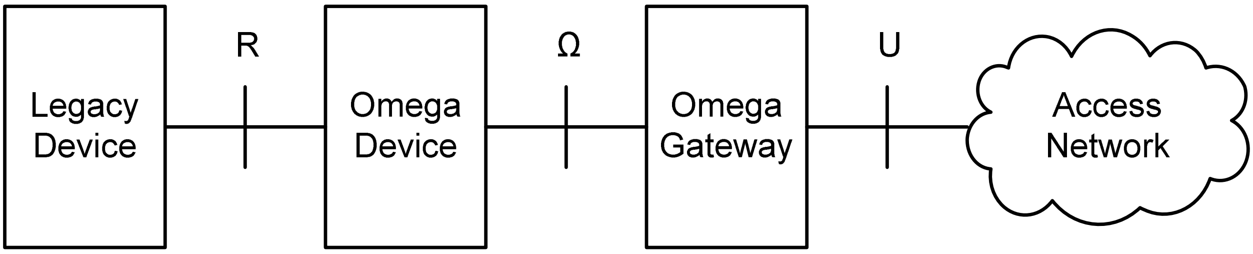

Figure 8: Interfaces of OMEGA Architecture Reference Model

Figure 8 shows all the interfaces of the OMEGA Architecture Reference Model. For simplicity, only one OMEGA Device is shown. It represents a multitude of OMEGA devices connected by Ω links with Ω interfaces in a mesh topology. By reference to the documents from the ITU-T [ITU] and from the Broad Band Forum [BBF], the *U interface* is defined as the interface providing connectivity between the OMEGA network and the Access Network. The U interface relies on a broadband access technology, for instance, ADSL2+, VDSL2, FTTH GPON, CATV, WiMAX.

In the same way, the *R interface* is defined as the interface ensuring the connection of legacy devices and networks (which do not support the Inter-MAC framework) to the OMEGA network. The R interface may rely on various home networking technologies such as USB, SCART, IEEE1394, WiFi, UWB, Bluetooth, etc.

3.1.1.5 OMEGA Network Architecture Reference Model

An OMEGA network can be considered as a set of OMEGA devices such as those described in section 3.1.1.3 (gateway, end device, serve legacy device, and extender). They are organized in the form of a mesh topology bringing in the advantages of multi-path capabilities for traffic reconfiguration. This leads to the following OMEGA Home Network architecture reference model, shown in Figure 9 and based on the interfaces defined in section 3.1.1.4:

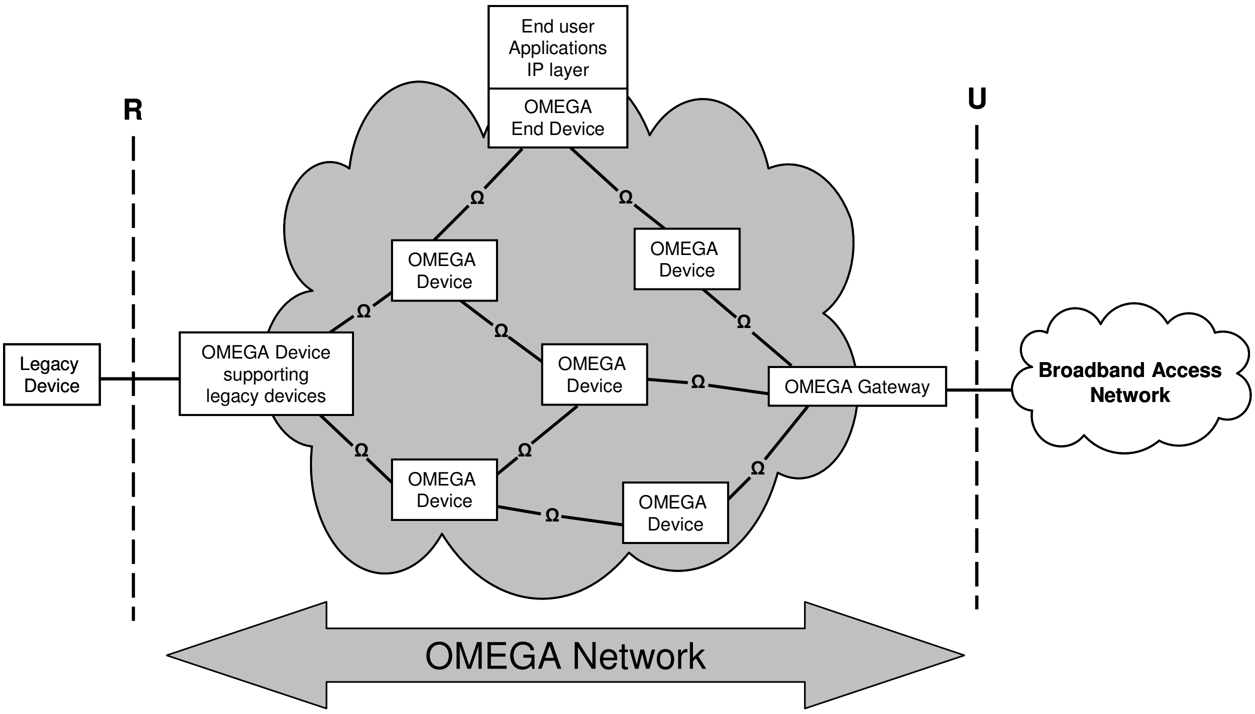

Figure 9: OMEGA Architecture Reference Model

In a real network the number of OMEGA devices is arbitrary. It is noticeable that from the point of view of the Inter-MAC framework none of the OMEGA devices occupies a privileged place. Actually the OMEGA network constitutes one single layer 2 domain managed in an overall way by the Inter-MAC framework. It is also noticeable that the OMEGA architecture does not require an explicit separation between domains attached to the different segments of technologies.

In a real network several end devices, extenders and legacy device adapters (specific nodes implementing the OSLD capability) can be interconnected in a ramified and extensive way. The multi homing scenario, where more than one interface to external networks exists, is also possible. The following figure shows a possible implementation of the OMEGA architecture in real devices.

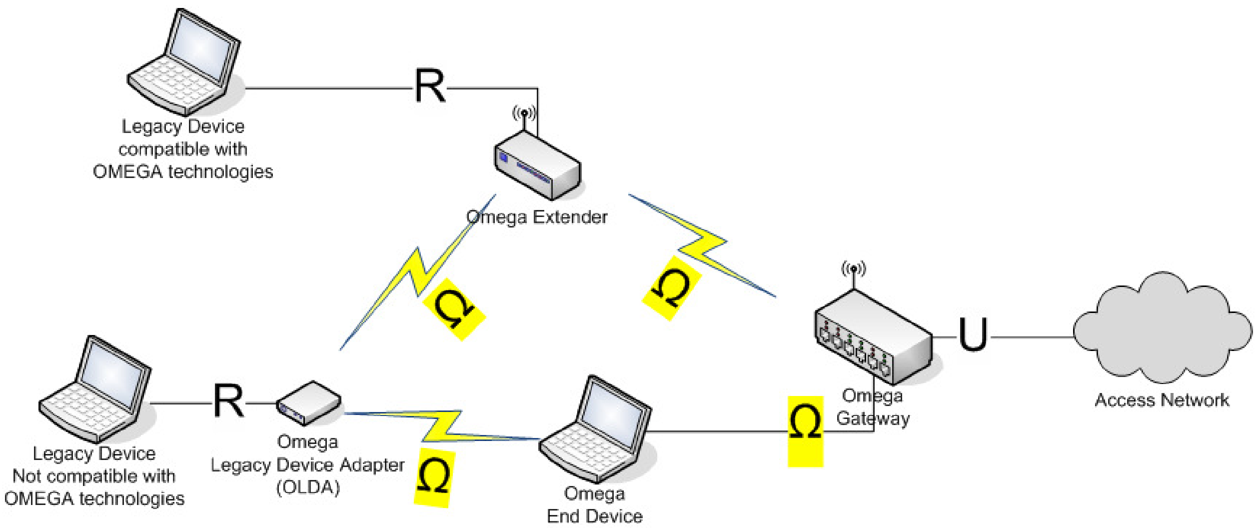

Figure 10: A typical OMEGA architecture configuration

This figure illustrates the mesh structure of the OMEGA network and the generic feature of the Ω interface. It also illustrates the fact that the interfacing of legacy devices can be achieved by different kinds of OMEGA devices: for instance, if the legacy device presents an interface based on a technology supporting the OMEGA functionality, at the PHY as well as at the MAC layer (potentially Wi-Fi, PLC, UWB, Optical Wireless, 60 GHz), then it can interconnect to the OMEGA network through an Extender. And if the legacy device presents an interface not compatible with the OMEGA technologies, then it can interconnect to the OMEGA network through an OMEGA Legacy Device Adapter (OLDA), that could be an OMEGA device supporting the OMEGA Serve Legacy Device capability.

This can be exemplified by means of a set-top box as an OMEGA device: it interconnects the OMEGA network to a TV set which might have a SCART interface. In addition to the necessary digital processing functions (decoding), the set-top box translates the Inter-MAC frames from the OMEGA network into non Inter-MAC frames, since it is an OMEGA device, therefore in that case the set top box is an OLDA.

The concept of OLDA could also be useful in the prospect of collecting information related to the OMEGA environment.

It is noticeable that, from the point of view of the Inter-MAC framework, none of the OMEGA devices occupies a privileged place. The OMEGA architecture is built on the interconnection by 'no new wires' transport technologies of network components belonging to the four categories of network capabilities identified above. Actually, the OMEGA network constitutes one single domain managed in an overall way by the Inter-MAC framework. It is also noticeable that the OMEGA architecture does not require an explicit separation between domains attached to the different segments of technologies.

3.1.2 Race to Gbps

3.1.2.1 Radio (WLAN and WPAN)

The multitude of systems operating in a single home network and using the overcrowded frequency bands will create coexistence and performance problems. Such difficulties will increase with the deployment of systems such as UWB in addition to WLAN systems. Therefore, improving the coexistence and cooperation between such systems is a necessity for reliable communication within the home network. **Convergence at the radio layer will consequently be a key concept to be investigated.**

In addition to the crucial aspect of convergence at the radio layer, advanced PHY, MAC and cross-layer mechanisms are to be developed. These mechanisms will be investigated in order to **locally optimize the different radio technologies so that they provide the required performance in a converged network**.

3.1.2.1.1. WLAN specificities

Standardisation: Beyond possible improvements of 802.11n, the IEEE 802.11 working group has shown great interest in the 60 GHz band since 2008 and will develop a new 802.11 standard (802.11ad) focusing on very high throughput. This future standard should consider specific mechanisms to guarantee coexistence with other existing standards and more precisely with the ongoing one, 802.15.3c.

Additionally, this future standard should permit dual band operations with the other upcoming very high throughput standard (802.11ac) operating on frequencies below 6 GHz. Moreover, even the PHY specified in 802.15.3c could be considered, so that IEEE 802.11ad could present the opportunity to combine some aspects of 802.15.3c and 802.11n, such as MIMO.

Technical challenges: To achieve high capacity WLAN for applications, the increase of the PHY data rate (e.g. by using large bandwidth, high coding scheme, high modulation) is not sufficient. PHY and MAC overhead intensely limit the MAC throughput. Therefore, the MAC efficiency defined as

$$MAC\_Efficiency = \frac{MAC\_Throughput}{PHY\_datarate}$$

decreases as the PHY data rate increases. For 802.11a standard with a PHY data rate of 54 Mbps, the MAC throughput is about 30 Mbps (MAC efficiency = 55%) and for 802.11n standard with a PHY data rate of 300 Mbps, the typical MAC throughput without MAC enhancements is about 60 Mbps (MAC efficiency = 20%). The main challenge for new high-performance WLAN design is the improvement of MAC protocol overhead: idle time to access to the medium, inter frame spacing, acknowledgement and collision management. By efficiently using the MAC enhancements defined in 802.11n, the MAC throughput and efficiency can be significantly increased (e.g. 500 Mbps and 83%, respectively, for the 600 Mbps mode). However, the improvement strongly depends on the configuration of the enhancements, which is beyond the scope of the standard. Furthermore, the specified toolbox options can not applied in every situation. Moreover, the benefit of the new standard will be limited if the frequency is shared with 802.11 legacy devices or other standards (co-existence, protection mechanism, backward compatibility …).

3.1.2.1.2. WPAN UWB < 10 GHz specificities

Technical challenges: WPAN UWB transmissions based on WiMedia/ECMA PHY/MAC layer [ECMA] are characterized by a high probability of being affected by interference from other devices operating in the same band. Advanced Detect and Avoid (DAA) techniques have been investigated to ensure scalability in the sub-channel allocation algorithm. These techniques use dedicated time slots to sound sub-channel occupancy and estimate the cumulative power density function to detect a narrow band interferer.

Interference occurs between ECMA devices operating in the same beacon group. To cope with these issues, advanced solutions such as *dynamic* sub-carrier mapping allocation may be used. The idea is to use different sub-carrier interleaving patterns upon successive multi-carrier symbols. Dynamic interleaving is also foreseen as a possible enhancement for multi-band OFDM processes to introduce propagation diversity.

3.1.2.1.3. WPAN 60 GHz specificities

Technical baseband and RF implementations: The 60 GHz signal generation is very sensitive to phase noise due to a high Doppler shift involved by the high RF frequency. Furthermore, multi-Gbps wireless systems involve a high sampling rate for DAC/ADC (Digital ↔ Analogue Converters) and digital baseband processing. Advanced baseband techniques are investigated to enhance performance in a low complexity manner.

60 GHz Propagation characteristics: The second important characteristic of the 60 GHz band is the high attenuation of the channel and the small wavelength set to 5 mm. The high attenuation involves an additional attenuation of 20 dB compared to 5 GHz bands and does not allow transmission through brick walls and obstacles. The transmission is limited to a single room with a limited number of obstacles. It can be also see as an advantage in the frequency reuse of allocated resource. MISO and SIMO techniques are investigated to cope with the radio line cut-off.

3.1.2.2 Gbps PLC

State of the art of power line communications (PLC) is extensively documented in [OMD31] under the following points of view.

Electrical network: The network topology and the equipment characteristics depend on the country.

Regulation and standardisation bodies: A very large panel of standardisation activities has been focused on PLC. The three main directions dominating the PLC standardisation for transmission aspects are ETSI PLT; IEEE P1901; ITU G.hn. Additionally, consortiums such as HomePlug Powerline Alliance play an important role in the definition and proposal of PLC systems.

The most recent advances were thanks to the approval of the proposals to form the baseline specification P.1901 in January 2009. "The baseline specification of more than 2000 pages includes FFT and Wavelet OFDM modulation schemes and an option for compatibility with the ITU-T Study Group 15/Q4 G.hn Recommendation under development." Thus, the convergence of different PHYs coming out of the different technologies by a common MAC is now a standardised reality for the PLC ecosystem. It should be noted however that the PHY payloads are limited to 200 Mbps. This also paves the way for a unified future Gbps PHY that OMEGA will contribute to.

In order to develop efficient PLC systems and propose improvements to the existing technology, it is necessary to accurately characterize the electrical infrastructure. In [OMD32] a channel characterization was proposed, based on measurements and mathematical models, that allows showing that in most cases, it is feasible to achieve 1 Gbps within PLC in-home networks.

In order to meet the Gbps, **the following advances must be derived:**

- **Larger bandwidth (up to 100 MHz)**, that OMEGA extensively measures and models. The goal is to guarantee that the derived solutions have a high potential of penetration or eligibility in European countries.
- **Higher spectral efficiency** using advanced modulation schemes based on OFDM
- **A new system approach by channelisation of this extended band** and local improvement of each channel
- **Backward compatibility** with Homeplug AV standard

From a use case point of view, PLC is well adapted to IPTV streaming through the home. Today, state of the art supports single IPTV but tomorrow, it is likely that PLC must support multiple IPTV. For this, PLC technology must support multicast at the PHY level (multi user tone map negotiation, etc.). PLC technology has developed extended feature for low level QoS management through PHY and MAC layers. HomePlug AV calls this CSPEC (connection specification). CSPEC gives the stream parameter that the PLC network shall support. This concept must be merged and potentially used as a reference with Inter-MAC.

3.1.2.3 Hybrid Wireless Optics

State of the art for the Wireless Optics technologies is captured in [OMD41]. The two main technologies investigated in the wireless optics domain are:

IRC (Infra Red Communication): Free space Gbps transmission is highly constrained by the availability of suitable optoelectronic components. To obtain coverage and high data rates arrays of sources and detectors are required, to allow user tracking. Arrays are difficult to obtain, and as component development is not appropriate for a demonstrator programme such as this, a modular approach will be taken. **The IRC demonstrator will use a transmitter and a receiver module that operate at Gbps rates and each module needs to be developed with the maximum field of view and range possible.**

VLC (Visible Light Communication): Due to the rather limited bandwidth of white-light LEDs (tens of MHz) it is a challenge to provide free-space data transmission rates in excess of 100 Mbps. This target will be achieved by a combination of approaches: (1) Line-of-sight links due to the fact that the room lighting will be provided by more than one lamp in order to achieve the appropriate illuminance in a room. (2) Very high signal-to-noise ratios due to the high illuminance dictate by legislative guidelines and the use of low-noise, large-are photo receivers. (3) Detection of the blue part of the emitted white light. This spectral region offers a modulation bandwidth at least ten times higher than compared to the use of the full spectrum. To implement the above strategies, one will need to develop new analogue driving circuits that are based on commercially available components, enable the modulation of several watts of electrical power. One will also need to develop highly efficient receiver optics and low-noise trans-impedance amplifiers. The multi-level modulation needed in order to achieve the target of 100 Mbps will be based on discrete multi-tones (DMT), which is a well-proven technique.

3.1.3 Inter-MAC Layer

A pragmatic solution to build a Gbps Home Network based on heterogeneous technologies is to benefit from this variety by using the best technology available for each specific case. Convergence of heterogeneous technologies should be possible at IP level, but at high cost and with complex, manual configuration of the required routers. Therefore, OMEGA decided to extend the layer 2 based on Ethernet methods. Unlike routers, Ethernet switches are known to be cheap and auto-configuring. The

novel concept consists of introducing a convergence layer, located between protocol layers and the technology-dependant MAC layers, the Inter-MAC layer. This new layer, technology-independent, would use the information received from the underlying technologies to select the most appropriate one fitting to the services requirements. The Inter-MAC is located in each OMEGA device between the network protocol layer and the medium access control layer. The Inter-MAC layer establishes and manages the OMEGA network, assuring QoS to the end-user applications acting as an intelligent bridge between PLC, Radio and HWO.
The Inter-MAC applies technology independent procedures to manage the network resources, interacts with the signalling, the management and the data plane to transparently setup a HAN giving a sensation to the applications that the HAN is a unique and homogeneous technology and not a cooperation of extremely different communication technologies. Thus, the Inter-MAC convergence layer integrates arbitrary heterogeneous communication technologies in a single home network by providing a path selection and QoS support over these technologies.

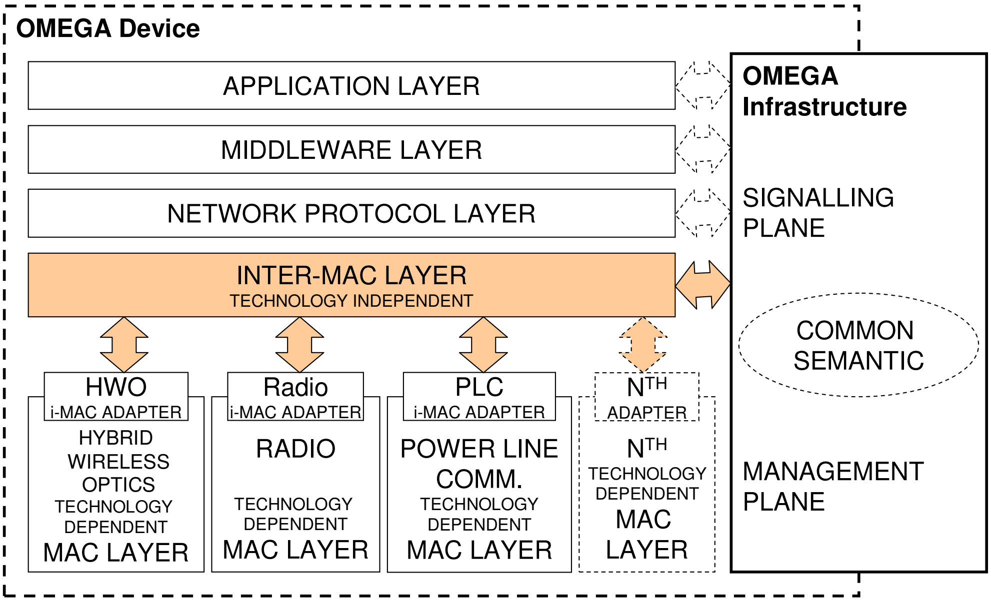

Figure 11: Inter-MAC layer stack.

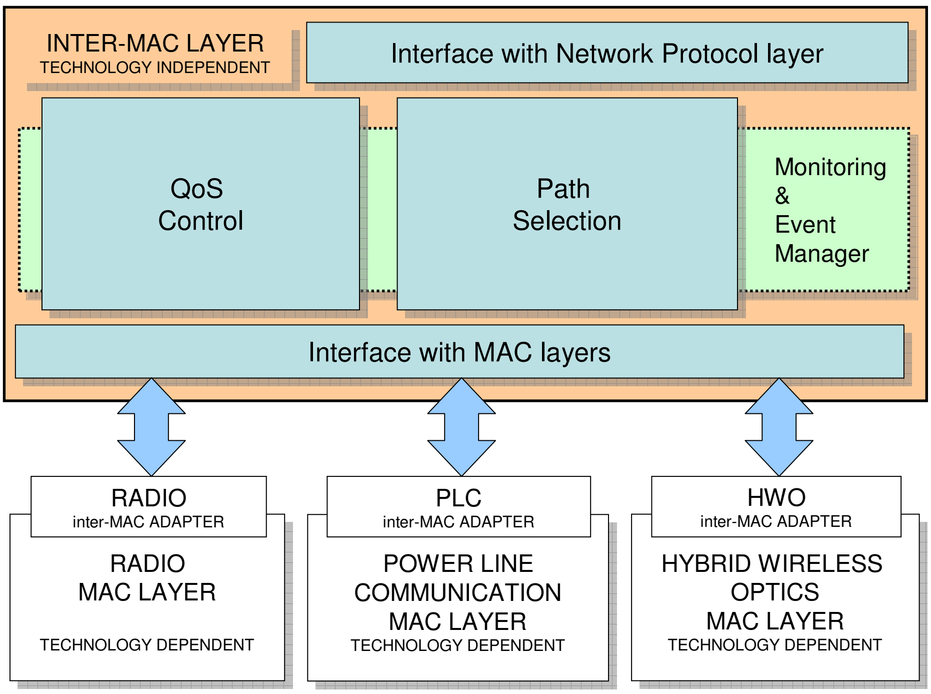

Figure 12: Inter-MAC overview, convergence below layer 3.

The Inter-MAC is in charge of responding to network changes, like link failures or decreases of QoS, guaranteeing session continuity and transparency. A monitoring system collects and sorts the information gathered from the technology dependent MAC layers and the Inter-MAC peers. As shown in the figure above, the gathered information is analyzed in an event manager located in the Inter-MAC. Each event triggers a counter-reaction that aims at stabilizing the system in order to guarantee the best working conditions. The Inter-MAC provides path selection functionalities in order to automatically develop a hybrid mesh network supporting multi-hop connectivity over dissimilar technologies such as radio, PLC and HWO.

QoS Control is provided by the Inter-MAC in order to cope with the different QoS requirements between the higher network layers and the MAC protocols (Net-to-MAC adaptation), as well as between the different MAC protocols themselves (MAC-to-MAC adaptation). The QoS control is also in charge of managing the network resources under the premise to guarantee the agreed levels of multi-hop Quality of Service. Furthermore, an intelligent access control is provided to define which physical links to use for each session, performing a session handover between different technologies whenever needed, adapting the different QoS parameters defined for each technology dependent MAC layer.

Adapters, labelled "extenders", will be introduced into the network to enable bridging the different technologies.

3.1.3.1 Inter-MAC main rules for QoS Guarantee

1. **Distinction between QoS flows**

One QoS flow consists of either a managed flow or a best effort flow. There is a fundamental difference among managed flows and best effort flows. Managed flows have a minimum set of QoS parameters, while best-effort flows do not require any QoS guarantee. In OMEGA networks managed flows are used for high quality services. QoS flows are configured using admission control mechanisms to avoid overload situations. The use of QoS classes as proposed in [OMD12] or in the HGI will enhance flow management possibilities.

2. **Admission Control for QoS flows and call rejects**

Each flow which belongs to one of the three QoS classes, with QoS guarantees, must undergo an admission control process. The process is done automatically and is not notified to the user as long as the bandwidth is available. The following mechanisms trigger admission control:

- SIP signalling for VoIP or multimedia calls
- IGMP messages for joining or leaving multicast flows
- UPnP messages for in-house audio/video streaming sessions
- Manual configuration of pipes.

For example if the user initiates a video phone call between a PC and a videophone, admission control is done for 2 voice flows, 2 video flows, 2 end-to-end control flows and 2 control flows between the terminals and the network. The flows will use different QoS classes and different bandwidth values. Control flows might use best effort quality and hence require no admission control at all. Flow admission control must be done on every link along the path of a flow, from end to end. This sounds complex, but in practice can be simplified. For example, over a link a number of voice flows could be pre-configured. Then the admission control reduces to check that the number of flows has not been exceeded. OMEGA must not deal with admission control in the public network. Only the links within the home network are considered. Algorithms for flow admission control are more complex the lower the bandwidth of a link is. Conversely over a high speed Gigabit link admission control could be entirely dropped. Within the FP6 MUSE project, admission control algorithms have been derived for DSL links. They are being adapted for shared medium OMEGA links, wireless and PLC.

The selective drop / disabling of flows in case of overload conditions will be treated seriously within OMEGA. Application priorities will have to be considered, such as for example emergency calls, but also user preferences and user acceptance. For example a user could tolerate temporary degradation of video image, but not picture flickering. This could imply the distribution of video streams to several flows, for example a basic picture flow and an enhancement flow. The latter could be suspended in overload periods. Temporarily suspending a flow could be done faster than release and re-start. The OMEGA network control plane will have to be intelligent, self-adaptive and flexible for future updates. Similar control plane mechanisms could apply for the setup of new flows. For example a user requesting a HDTV video could get a standard TV video instead if not enough capacity is available.

4. **Dealing with changing channel conditions**

The channels used by the OMEGA technologies can be subject to severe fluctuations. For example, closing a door within the house might degrade a WLAN link from 54 Mbps to 11 Mbps. For PLC, the activation of a hair dryer might degrade the shared bandwidth to a similar amount. Free space optics could be distorted by moving persons or objects within a room. In OMEGA, these effects are treated depending on the time scale.

The hair dryer example leads to repetitive throughput degradation with a 10 ms repeat interval. In this short time range, only data plane measures can be applied. These are priority queuing and selective packet discard according to the QoS classes. For control plane measures the reference time is the flow setup time which is less than one second. Distortions originated by human behaviour are typically longer than one second. For example, if a door has been closed it will not be re-opened within one second. Hence, these time ranges are long compared to the flow setup time. **Therefore, the control plane can react and readjust the flows.**

3.1.3.2 Inter-MAC connectivity

A connection has end-devices at its endpoint. It can be an OMEGA connection if both end-devices are OMEGA end-devices; otherwise it is not an OMEGA connection. The OMEGA connection exists from the first to the last device crossed by a given flow.

Thanks to the Inter-MAC layer, the OMEGA network, from an IPv4/IPv6 point of view, is a unique LAN. No layer 3 routing is needed within an OMEGA network. The frames/packets are forwarded to the correct destination node thanks to a path selection algorithm.

Figure 13 (see below), depicts a connection from an OMEGA end device to a web server on the Internet. Despite heterogeneous MAC layers crossed by the flow between the end user and the gateway, there is a single and common Inter-MAC layer along the path, within the home network. This architecture also allows IP connectivity to be guaranteed up to the WAN.

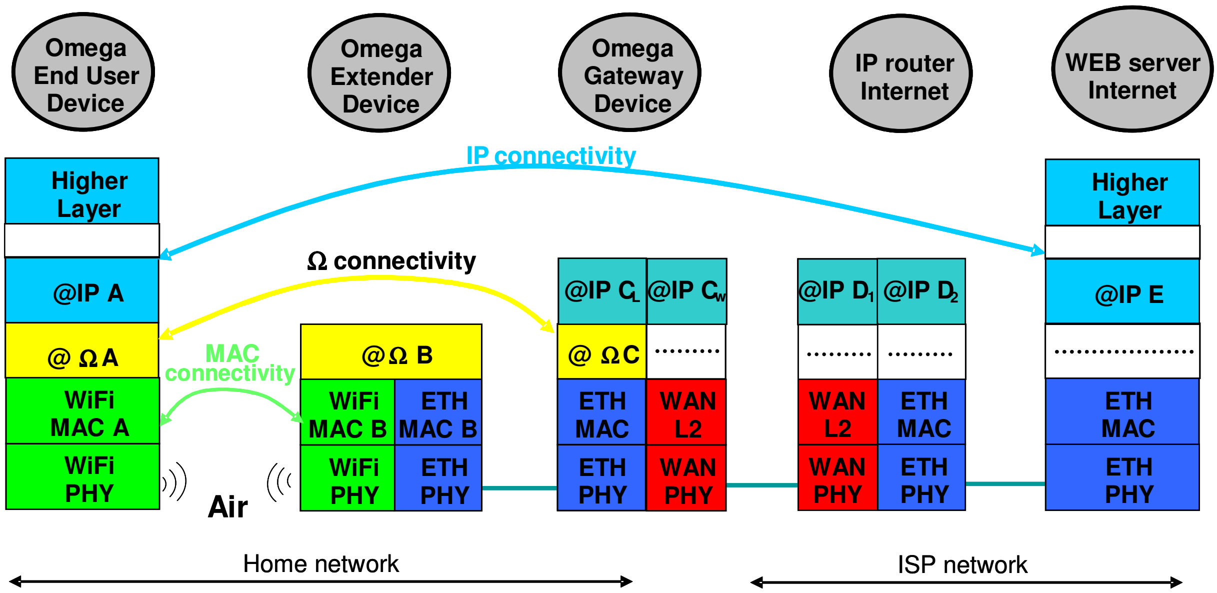

Figure 13: Connection from the OMEGA End User device to a Web Server (overview)

3.2 Proof of concept by on-scale Prototyping

One of the major objectives for OMEGA is to demonstrate the Inter-MAC concept but also new and enhanced technologies contributing to the Gbps race at home.

These labs experiments target firstly at a fine qualification of the respective technology payloads developed throughout OMEGA: Hybrid radio (Wi-Fi, UWB, 60 GHz), hybrid wireless optics (VLC, IR), Gbps PLC for the transmission backbone. Once complete, initial testing will measure QoS, latency and other performance parameters, in order to ensure correct operation. Then, a series of OMEGA scenario tests will be undertaken, to ensure the original project aims are met. The lab phase will be followed by a "to scale" show room in an apartment in order to give a lively demonstration of the OMEGA technology. The services will involve using the existing ones (present on the access network) being delivered using the novel heterogeneous transmission medium developed by the project. In addition, the capabilities of OMEGA will be used to show prototype services that require the performance of a UBB HAN.

This prototype will be made available to early adopters for labs tests.

3.3 Acceptance criteria – Cost

OMEGA will develop OA&M methodologies for Home Network and equipment as well as production and price estimations for HAN equipment. It will progress beyond state of the art by compiling and maintaining an update HAN cost components database, as well as providing general rules about housing evolution and its impact on HAN evolution

In the meantime, the rest of this section discusses a number of - somewhat subjective - key questions often asked by actors of the home network.

End user perspective:

- **How will the end user manage his home network? What about terminals (picture frames, PDAs) bought in the retail market?** The ultimate view of home management is as follows: the "non-geek" user buys a device or extender in a retail store, enters some trusted IDs, or simplified easy pairings, plugs it to his home network … which automatically recognizes it. For the service, some easy human interface may be imagined to handle contents and services and choose renderers to enjoy them.
- **Will it be possible to enjoy home services anywhere at home, but also anytime? On the move?** Enjoying a phone call at home, when commuting or even at the office, is already a reality. The generalisation of this service can be exemplified by the possibility of sharing (user-generated) multimedia contents when visiting friends or relatives by means of either their home networks or mobile phones.
- **What about costs?** The major cost battle is on the network infrastructure which will be needed to deploy UBB at home. The reasonable way to achieve this is to derive and make accepted international standards for a massive industry adoption and scale factor. The OMEGA technology will be deployed at home, in millions of pieces and the design effort shall target "cheap reference designs". Cheap means 20 to 40 € for an extender.
- **Is it that simple to install and operate OMEGA?** The topology of the OMEGA network will be made available locally with comprehensive human interface so that the user can assess the status and performance of the OMEGA network. Indeed, complexity shall be hidden from the customer or the IP network, by having correspondence of Inter-MAC to IP as well as topology discovery means.
- **Shall I purchase another laptop?** OMEGA shall be upward compatible with existing home network technologies; a legacy terminal shall inter-work with the OMEGA network, and an OMEGA terminal shall inter-work with a legacy terminal via the OMEGA network (see section 1.2.2 above). Legacy devices will be able to communicate with OMEGA extenders fitted with a legacy device adaptor.

Operator perspective:

- **What is the roll out scenario?** The operator uses its own transport, access, backhaul and core networks to provide these services to the customers. Furthermore, the operator is assumed to have an established position in the market, and a strong market share among the customers. The main reasons for an incumbent operator to migrate into OMEGA are to retain the existing customers, as well as keeping the current revenue levels or even increasing them by offering new and attractive service bundles. Furthermore, the OMEGA customer may choose from various bundles of services (OMEGA packets). In addition, the customer gets, for free, some new OMEGA exclusive services that are limited at the beginning but will increase over the years. The annual erosion of tariff is foreseen to be 5%.
- **What is the market?** OMEGA customers will generally come from customers converting from the operators own customer base, plus the addition of customers from competing operators that wish to take advantage of the value–added services that OMEGA offers. It is assumed that at the time when OMEGA is introduced, there will be no similar products from other operators for a short period of time (the first year of the study period). But if the operator does not invest in OMEGA, it will start losing customers to other operators that will provide products similar to that of OMEGA. It is estimated that the market share in this case, will go down due to competition and lower price bundles by competing operators.
- **What about standards?** The acceptance of the technology by the industrial ecosystem is a key factor. Uphill contacts shall be taken by relevant bodies down to co-signed contributions to ongoing standards. The OMEGA technology shall make possible the future existence of accepted procedures and testers to assess conformance of OMEGA devices.

4 Conclusion – Perspective

This paper describes the key challenges towards the Gbps Home network and explaines how OMEGA is felt as one of the most promising solutions for the future:

- research of Gbps wireless solutions,
- push the limits of powerline communications to reach Gbps,
- explore the bandwidth of optical transmissions in a wireless mode,
- imagine a new layer 2 , namely Inter-MAC, under IP layer, for high QoS
- prove this advances by prototyping them,
- envision roadmaps and business cases to make this technology a truly accepted and pervasive technology,

This paper has been written at the end of the 3-year project's first year and describes some of the key findings so far:

- a clear panorama of the state of the art and the preconisation of the key enablers to Gbps,
- a robust Inter-Mac architecture with simple but essential functionalities,
- captured in a number of public deliverables to disseminate these first findings.

OMEGA is now ready to come to hardware/software design to produce a V1 prototype by the end of 2009.

More advanced features will be simulated and evaluated so that a V2 prototype with advanced functionalities will become a reality before end of 2010.

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