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Evaluation of technological and socio-economic issues affecting the deployment of home networks: evidence from the ICT-OMEGA project

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Abstract Home networks (HNs) are rapidly becoming the next battlefield for various telecom carriers and companies. The European project ICT-OMEGA seeks to enable the convergence of the diverse wireless and wireline technologies at the Medium Access Control (MAC) layer. In such a world of converging, heterogeneous HN technologies, system designers needs to take into account several technical, economic and social aspects that will effect the development and the rate of adoption of HNs by the general public. Careful roadmapping is required to ensure a smooth transition from existing to the

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next generation HN systems. The objective of this paper is to provide an evaluation of the key technological and socio-economic issues, which may affect the deployment of HNs. Within the OMEGA project, such issues are addressed using surveys conducted by the project experts, designed based on the Analytic Hierarchy Process (AHP). In this paper, the results of the surveys, conducted using pairwise comparison (which is an important ingredient of AHP) are presented. Several critical aspects are identified and their importance is weighted. The conclusions drawn are important for the overall roadmapping effort of future HN technologies.

Keywords Analytical hierarchy process · HDTV · Home networks · Pairwise comparison · Roadmap · VoIP · Extender device

1 Introduction

The future Internet will require an extremely high-bandwidth "core" and "access" network, along with the associated developments in transmission and switching. Home networks (HNs) will play a critical role in achieving broadband penetration, acting as the last network segment and thus enabling the provision of end-to-end services. Traditionally, in-building networks, such as those found in corporate or academic settings have a tenfold higher bandwidth than their access points to the telecommunication infrastructure. Given that fiber-to-the-home (FTTH) technology promises symmetric data rates of at least 100 Mbit/s per household, this implies HNs supporting high data transmission and a required latency time in the tens of milliseconds regime. Meeting such performance requirements will ensure that no bottlenecks will occur in end-to-end HN services. The HN must also have the necessary capacity for delivering local services such as instant access to mass media storage and maintain several services simultaneously, each with different set of requirements. Furthermore, the network components must be low-cost and simple to manufacture in large volumes.

The objective of ICT-OMEGA, an Integrated Research Project financed within the seventh EU R&D framework program [1], is to cope with these strict and sometimes conflicting requirements. The ICT-OMEGA project will develop a user-friendly home area network capable of delivering high-bandwidth services and content at a transmission speed of one Gigabit per second. The project aims to combine three different technologies, namely optical wireless, radio and Power Line Communications (PLC) into a single inter-MAC (Medium Access Control) layer. The OMEGA inter-MAC layer is located between the second and third of the Open System Interconnection (OSI) model. The inter-MAC is technology independent, providing common functionalities over heterogeneous communication technologies [2]. It is in charge to setup a resilient, reliable and easy-to-use gigabit home network to guarantee the quality and the continuity of services within the home environment. In the prospect of the gigabits per second data rate in home networking, it appears thus interesting to distribute the functions of connectivity inside the home with the help of interconnection points (the extenders) spread in the home, and achieving the hybridization of technologies [3].

The extender device, illustrated in Fig. 1 plays an important role in the overall OMEGA network as it is destined to extend the HN coverage and allow the communication between the various OMEGA devices, possibly having different Physical Layer (PHY) interfaces. As shown in Fig. 1, the extender functionality may be incorporated in wireless hotspots on the ceiling of the room or even in the terminal devices themselves. The term OMEGA device refers to any network element of the OMEGA network and potentially OMEGA devices will also serve as network extenders and "multi-hoppers", in the sense that they will be able receive and forward traffic for which they are not an end point. As far as the legacy (pre-OMEGA) devices are concerned, these are connected to the OMEGA network through a legacy device adapter (which is also considered an OMEGA device) able to convert non-OMEGA traffic to OMEGA traffic and vice versa. This hybrid network architecture is illustrated in Fig. 1, highlighting the interconnection of a wide range of terminals in a mesh network, ensuring the coverage of the entire home area. These terminals can be classified in families or clusters, not completely disjoint such as data communication terminals (computers, personal digital assistants—PDAs, notebooks, etc.), gaming cluster, voice/video communication terminals (analog/digital phones, videophones, mobile phones, etc.), entertainment consumer electronics audio/video terminals (e.g. set top box—STB, television, multimedia player, high fidelity—HiFi equipment) and domestic equipments (e.g. fridge, sensor networks).

Each transmission technology that can be used in the heterogeneous network has different characteristics. Fiber-based systems can provide high quality wire-line communication inside the house. Plastic optical fibers are

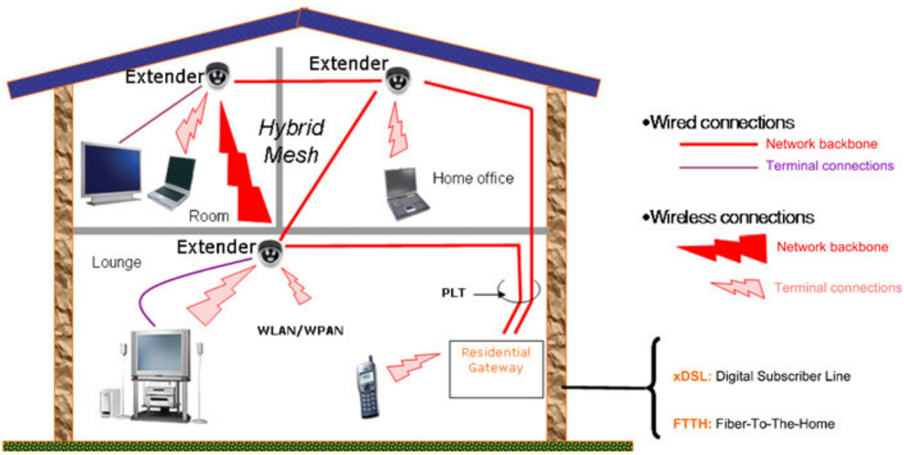

Fig. 1 Illustration of hybridization of technologies inside the HN (Source: ICT-OMEGA)

very well suited for indoor applications [4]. Installing fiber cables inside old buildings is not a particularly attractive option however. Wireless radio technologies, such as the IEEE802.11 standards are already commercially available and the IEEE802.11n standard promises wireless home connectivity at several hundred megabits per second using multiple-input multiple output (MIMO) features [5]. However, it is difficult to achieve gigabit per second connectivity because of the limited bandwidth available in the 2.4 and 5 GHz bands. Millimeter wave (MMW) operating at the 60 GHz band [6] and Ultra Wide Band (UWB) [7] radio solutions may further increase the achievable bit rates. MMW systems are particularly interesting since the bandwidth at this band is unlicensed and sufficient to transmit gigabit per second signals. However, such systems are still far from reaching market maturity. An additional feature of MMW signals is that they can not pass through walls, necessitating the use of many hot spots in order to cover multiple rooms of the house. This is not the case in IEEE 802.11 networks where a single hotspot can provide wireless connectivity over multiple rooms. On the other hand, state of the art PLC systems [8] provide hundreds of megabit per second wire-line connectivity, but extending them in the gigabit per second regime is also a challenge because of the particularities (low bandwidth) of the PLC channel. Optical wireless (OW) [9] take advantage of the high bandwidth optical transmitters and detectors used traditionally in optical wire-line systems. These systems can also provide gigabit-per-second data rates wireless indoor connectivity in the future either in the infrared or visible spectrum region [10]. Much like MMW systems, OW must overcome important technical limitations such as blocking in line of sight systems and poor signal to noise ratio in diffuse configurations. The above considerations seem to indicate that no single technology will be provide the Holy Grail in home networking, and future HNs will probably consist of hybrid solutions. The combination of the above technologies is quite challenging and requires the network designer to be aware of many technical, economic and social issues affecting the acceptance of HNs from the public. In this context, a “no new wires approach” is envisioned in the OMEGA project, according to which installation of new cables such as fibers should be avoided within existing households in order to enable a smoother integration of the HN infrastructure in the home environment. The wired connections appearing in Fig. 1 may concern the backbone HN and in order to be compatible with a no new wires approach, PLC systems can be used to provide such connections.

The objective of this paper is the evaluation of various crucial technological and socio-economic issues that affect the deployment of future HNs. This evaluation is carried out through a number of surveys conducted using elements of the Analytical Hierarchy Process (AHP) framework and specifically pairwise comparison, which is used to quantify the importance of each technological and socioeconomic aspect. A part of the surveys concern the general properties of the future HN while other focus on more OMEGA-related issues such as the extender device and the deployment of High Definition Television (HDTV) and Voice over Internet Protocol (VoIP) over this network. This paper is mainly addressed to a technical audience but it also aims to motivate the interest of a general audience to the OMEGA network and future HNs in general. The rest of the paper is organized as follows: In Section 2, the basic notions of the AHP method are presented, while in Section 3, the survey objectives as well as various criteria and factors are defined for the case of the OMEGA network, the extender device and the HDTV/VoIP services. The HDTV and VoIP are representative services of HNs and important from an operator point of view. Section 4 presents the results obtained by the surveys providing a discussion on their impact for HN deployment. Some concluding remarks are given in Section 5.

2 Methodology

The methodology used in this work is based on the pair wise comparison (PWC) method [11, 12] which is a fundamental ingredient of AHP often used for technology evaluation [13]. AHP has been used around the world on numerous occasions where a decision must be made between a set of alternatives, in sectors such as government, business, industry, healthcare and technology. AHP has been applied in the field of telecommunications networks as well. For example in [14], AHP is applied in vendor selection of a telecommunication system. In [15] the methodology is applied on network selection for integrated WLAN and cellular systems. The present paper focuses on prioritizing crucial issues of home networking technologies, which is a subject not previously addressed in the literature.

The AHP model adopts a hierarchical form using three conceptual levels, which are depicted in Fig. 2. On the first level, the objective for evaluating technologies is defined. In the present case, the overall objective is to provide a roadmap for the deployment of future home networking technologies and understand the relative importance of various critical issues related to next

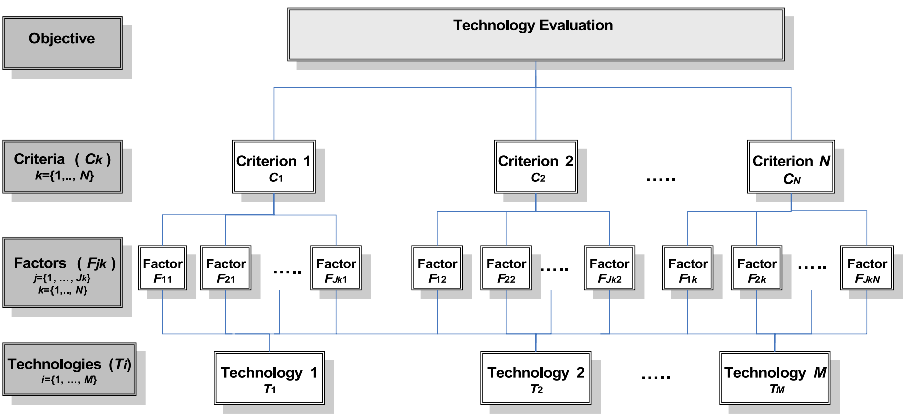

Fig. 2 The hierarchical model developed for evaluating technologies

generation HN adoption. In addition, we seek to identify and compare the issues involved in the deployment of broadband services over the future HN. The relative contributions of technologies to the objective are evaluated by determining the weight of importance of the criteria, the relative importance of factors of each criterion, as well as the relative impact of technologies on each factor.

2.1 Criteria and factors

Once the objective has been clearly established, one proceeds with the identification of the various criteria and factors affecting the decision. A criterion can be a general attribute of a technology. For example, service performance may be an important criterion in the adoption of VoIP and HDTV services. Criteria are often general in nature and incorporate several aspects of the technology. Service performance for example includes several performance-related issues such as the available bandwidth, coverage, etc. The set of criteria used in the decision making process form the second level of AHP as shown in Fig. 2. In the third level, the criteria are clarified further by recognizing a number of factors for each criterion. A factor is an indicative attribute that can be quantified and characterizes a criterion. For example, data rate could be a factor of service performance. Note that the factors can be either quantified in terms of numerical values (e.g., in the case of the achieved bit rate, in megabits per second) or using a qualitative scale [13]. The criteria and factors used in this paper are described in detail in Section 3.

2.2 Pair Wise Comparison (PWC)

The importance of each criterion is identified through a series of PWCs that the experts are requested to perform in the surveys. The advantage of PWC is that it can provide a relatively simple way to compare the importance of either several different criteria or different factors by carrying out comparisons in pairs instead of directly assigning a weight on each of them. Avoiding such direct assignments, PWC can provide a more impartial view on the priority of several issues affecting the decision making process.

Within the context of PWC, the experts fill out a table containing the upper triangular elements A_{ij} of a $N \times N$ matrix $\mathbf{A} = [A_{ij}]$ where N is the number of criteria. The experts may simply assign values between 0 and 100 to the elements A_{ij} with $i < j$, thereby signifying the relative importance of criterion C_i compared to criterion C_j. For example, if an expert assigns $A_{ij} = 60$ this implies that according to his/her point of view, the weight of criterion i is 60% compared to the total weight of both criteria while that of criterion j which is 40%. The same process is carried out for the factors of each criterion separately. Using the upper triangular elements of $\mathbf{A}$, a new $N \times N$ matrix $\mathbf{P} = [P_{ij}]$ is calculated where $P_{ij} = A_{ij}/(100 - A_{ij})$ for the upper diagonal elements ($i < j$), $P_{ij} = (100 - A_{ji})/A_{ji}$ for the lower diagonal elements ($i > j$) and the diagonal elements P_{ii} are all set equal to 1. The elements of $\mathbf{P}$ represent the relative importance of criterion C_i compared to criterion C_j. To evaluate the weights one must calculate the eigenvector $\mathbf{x} = [x_k]$ which is associated with the maximum eigenvalue $\lambda_{\max}$. The weights are then determined by [16]:

$$w_k = x_k \left[\sum_{l=1}^{N} x_l \right]^{-1} \tag{1}$$

The same procedure is followed for the estimation of the weights of the factor of each criterion according to the following equation:

$$f_{jk} = y_{jk} \left[\sum_{i=1}^{J_k} y_{ik} \right]^{-1} \tag{2}$$

where J_k is the number of factors for criterion C_k, y_{ik} are the elements of the eigenvector $\mathbf{y}_\mathrm{k} = [y_k]$ corresponding to the maximum eigenvalue of the matrix $\mathbf{P}_k = [\mathrm{P}_{ij}^k]$ obtained by the pairwise comparisons of the factors of criterion C_k. It should be noted that the elements of the matrices $\mathbf{P}$ and $\mathbf{P}_k$ must be consistent. More specifically in the case of matrix $\mathbf{P}$, the consistency index (CI) and the consistency ratio (CR) are determined as follows [12],

$$\text{C.I.} = \frac{\lambda_{\max} - \text{rank}(\mathbf{P})}{\text{rank}(\mathbf{P}) - 1} \tag{3}$$

where rank ($\mathbf{P}$) is the rank of matrix $\mathbf{P}$ and

$$\text{C.R.} = \frac{\text{C.I.}}{\text{R.I.}} \tag{4}$$

The consistency ratio for $\mathbf{P}_k$ is the same as for $\mathbf{P}$. In Eq. 3 rank ($\mathbf{P}^{(m)}$) is the rank of matrix $\mathbf{P}^{(m)}$ and in Eq. 4 RI is the random index, which can be determined by the rank of $\mathbf{P}$ as discussed in [17]. In general, a value of CR less than or equal to 0.1 is considered acceptable [18]. Larger values require the expert to reduce the inconsistencies by revising his comparisons.

The calculation of the weights of each factor and criterion provides important information by itself but is also a key part of the AHP methodology. Using w_k and f_{jk} one can estimate an index called technology value (TV) for each technological alternative under consideration [13], defined by

$$TV_n = \sum_{k=1}^{k} \sum_{j=1}^{J_k} w_k f_{jk} V_{jk} \left(t_{njk} \right) \tag{5}$$

In Eq. 5, TV_n is the Technology Value of technological alternative n, t_{njk} represents the value of factor F_{jk} in either actual units (say Mb/s for the achieved bit rate factor). The function V_{jk} is a function that determines the desirability values of each factor maps the values t_{njk} to a number between 0 and 100. The functions V_{jk} as well as the present and possibly future values of t_{njk} are determined by additional surveys. Within the present work, the

TV was not calculated for the various technological alternatives considered in the OMEGA project, since most experts felt that many home networking technologies, such as OW and MMW were still quite immature and it was not possible to predict future values for the underlying technological factors, rendering the calculation of the TV for these solutions somewhat uncertain.

3 Survey design

The pairwise comparisons were conducted by a web-based survey/road-mapping platform incorporating all elements of the AHP framework where experts log on to the platform and fill out the questionnaires. The web-platform has been developed and maintained by the University of Athens [19]. The data supplied by the users are saved in a database and the survey designer can perform the pair wise comparison in order to estimate the weights that signify the importance of criteria and factors according to Eqs. 1–5.

3.1 Survey objectives

In this section we describe the objectives of the four surveys carried out within the ICT-OMEGA project in an effort to determine the importance of the various issues associated with future HN deployment. These surveys were initially designed by the University of Athens with France Telecom and Telefonica and were further refined according to the feedback of the rest of the partners. Below we give some details on the scope and the objectives of each survey:

1. *OMEGA Network survey*. This survey concerned the importance of various issues determining the deployment of home network aspects (technical, socio-economic, etc.). There were a total of 27 participant and the on-line completion was conducted during a period of 1 month in February 2009. No specific service bundle was envisioned for the network and hence the experts filled in the comparison matrices without having any type of service in mind.
2. *Extender Device Survey*. The extender functionality was considered as one of the fundamental aspects of the OMEGA HN and it was therefore decided to have a dedicated survey for the extender device. Twenty-five experts have participated in this survey that was conducted during a period of 1 month in March 2009. Again no specific service bundle was specified for the network.
3. *HDTV Survey*. Telecom operators as well other partners within the consortium advocated that HDTV is an important service that would enable future HN penetration and it was therefore decided to carry out an analysis concerning this type of service. Twenty-six experts have participated in this survey that was conducted during a period of 1 month in April 2009.

4. *VoIP Survey*. VoIP was also deemed important for enabling future HN penetration. This survey is similar to the one described above but concerns the VoIP service. Again, 26 experts have participated in this survey that was conducted during a period of 1 month in April 2009.

The survey design including the definition of criteria and factors was extensively discussed among the several OMEGA partners. The feedback from the telecom operators was interesting enough and very useful for the final survey design as they emphasized on the definition of criteria and factors taking into account the user perspective in both the performance-related issues and the socio-economic aspects. The experts are employees of various organizations inside the OMEGA project consortium [20] which constitutes a well balanced blend between industry and academia from many parts of Europe (France, Italy, UK, Germany, Spain, Austria, Slovenia, UK and Greece). Their expertise lies primarily in the field of HN technologies. It should be noted that in all surveys there were more than 20 participants, thoroughly briefed on the survey objectives, and this constitutes a considerable group size for the purposes of AHP [13, 14, 21, 22].

3.2 Definition of criteria and factors

Tables 1, 2 and 3 summarize the factors and criteria identified in all four surveys described in Section 3.1. The tables also contain a description of the factors. The corresponding weights of the factors calculated by PWC are also quoted. The weights of the criteria will be presented in the next section in the form of figures. Regarding the first survey (Table 1), there was an attempt to make the factors of the system performance criterion as simple as possible while at the same time retaining useful information. There was a widespread consensus that system performance concerns primarily (1) the coverage provided by the network inside a domestic or business environment and (2) the available bandwidth. The bandwidth was more easily quantified in the PHY layer in terms of the maximum downstream data rate that can be supported. Upstream traffic throughput was considered secondary to downstream, particularly for home users. On the other hand, coverage was defined as the portion of possible positions inside the house or room where the maximum data rate can be achieved. Interestingly enough coverage concerns both wireless and wire-line technologies. The link reach is an issue in PLC as well in plastic fiber-based systems. The performance factors for the extender device (Table 2) are similar except that upstream throughput is also included since the extender must be able to forward data traffic to other OMEGA devices as well.

The economic issues are related to the influence of several cost components [23] in the deployment of the network and include not only the cost of the components themselves but the installation and maintenance costs. Technologies such as IEEE802.11 have very small maintenance and installation cost but OW and MMW may require the installation of multiple hot spots on the

Table 1 Criteria and factors for the Omega network

Factor		Description	Relative importance, %
C_1: System performance			
F_{11}	Coverage	The fraction of possible terminal positions inside the house or room, where the maximum bit rate is achieved	56.13
F_{12}	Maximum bit rate	The maximum downstream PHY-layer bit rate that a single user terminal can achieve	43.88
C_2: Economic			
F_{21}	Installation first cost	The cost to install the OMEGA system for the first time	54.36
F_{22}	Maintenance cost	The cost to maintain the OMEGA system per year	22.20
F_{23}	Cost of OMEGA devices	The cost of OMEGA devices such as multi-technology extenders, OMEGA Gateway, End Connectivity components	23.44
C_3: Flexibility			
F_{31}	Ease of installation/ maintenance	This quantifies the installation complexity	24.69
F_{32}	Interchangeability	Signifies whether components are interchangeable with same or similar components made by manufacturers commonly available in electronic stores	21.16
F_{33}	Upgradeability	Are hardware and software updates easy to perform?	23.90
F_{34}	Compatibility with legacy systems	Is the HN compatible with existing networks and home appliances?	30.25
C_4: Social acceptance			
F_{41}	Security/privacy	Are security and privacy issues important?	14.80
F_{42}	Health issues	Are health issues important? (meeting radiation exposure, eye-safety, skin-safety, etc standard)	33.08
F_{43}	Home integration with no new wires	Is it acceptable to install new wires in the house?	15.84
F_{44}	Usability	How difficult is to set up and manage the network from the average user point of view?	20.23
F_{45}	Design	How well do the OMEGA devices fit with the overall household decoration?	16.05

ceiling of the rooms. It is pointed out that the main components for all cases of technologies in the OMEGA HNS are OMEGA extender as well as OMEGA gateway and therefore for these components a cost/price forecast has been conducted within the consortium providing a techno-economic model regarding their future market prices [23]. The results of this model also include a detailed analysis of all the investments, such as installation, maintenance cost as well as the subscription costs and the cost components of the OMEGA operator, its operational expenditures, its revenues and the financial outcome as expressed by financial indices. The rest of the criteria also incorporate

Table 2 Criteria and factors, under each criterion, for the extender device

Criteria—factors		Description	Relative importance, %
C_1: System performance			
F_{11}	Coverage	Defined as the fraction of possible positions inside the house, where the maximum bit rate is achieved	41.37
F_{12}	Upstream bit rate	The maximum upstream PHY-layer bit rate that a single user terminal can achieve when connected to the extender	23.54
F_{13}	Downstream bit rate	The maximum downstream PHY-layer bit rate that a single user terminal can achieve when connected to the extender	35.09
C_2: Simplicity of use			
F_{21}	Plug and play	Once installed, is the extender plug and play?	54.52
F_{22}	Compatibility with legacy devices	Same as OMEGA network	45.48
C_3: Design			
F_{31}	Design-integration to home environment	Same as OMEGA network	37.41
F_{32}	Volume of extender	The volume of the extender device in cubic centimeter	33.66
F_{33}	Weight of extender	The weight of the extender device in kilogram	28.94
C_4: Economic			
F_{41}	Cost of extender	The cost of purchase of the extender device	39.48
F_{42}	Annual cost of repair	The annual cost in order to repair the extender in case of damage or failure	22.44
F_{43}	Annual cost of operation	The annual operation cost of the extender. It mostly includes the influence of power consumption on operation cost	38.08
C_5: System trustworthiness/confidence			
F_{51}	Security/privacy	Same as OMEGA network	17.64
F_{52}	Health issues	Same as OMEGA network	48.19
F_{53}	Mean time between failure of extender	Mean time that intervenes between two consequent failures of the extender device	34.17

several other user-related aspects. Flexibility refers to the overall usability of the network components inside the home environment while the Social Acceptance criterion incorporates many user-related concerns (health, privacy, etc.). Regarding the extender device, the integration of the device inside the home environment was classified as an important aspect and was considered as a separate criterion in light of the fact that average users will not very willing to install bulky hotspot in the ceiling of their living rooms even if these provide gigabit per second connectivity.

Table 3 Criteria and factors, under each criterion, for HDTV and VoIP technologies

HDTV factors		VoIP factors	Description	Relative importance, %	
				HDTV	VoIP
C_1: Usability					
F_{11}	Mobility	Mobility	*HDTV*: Session mobility the possibility of switching the session between one TV set and another one *VoIP*: Mobility inside the home or even inside the Wide Area Network	20.89	58.75
F_{12}	Availability of different classes of services	Availability of different classes of services	Different classes (qualities) of services will be available according to user's subscription	27.81	41.25
F_{13}	Content	–	Content Popularity concerning the content that the service offers ex. the number of different channels and the content that they offer	51.30	–
C_2: Performance					
F_{21}	Quality degradation of picture	Quality degradation of voice	*HDTV*: Image freeze/ pixellisation	41.89	44.05
F_{22}	Quality degradation of sound	Perceived Delay	*VoIP*: Clicks/cut of sound	14.99	18.22
F_{23}	Service interruption	Service interruption	The possibility of an unexpected interruption of the service	43.12	37.73
C_3: Economic					
F_{31}	Service subscription rate	Service subscription rate	The cost of subscription for the service per month	51.57	54.30
F_{32}	Cost of television set	Cost of telephone set	*HDTV*: The cost of the television set and equipment VoIP: The cost of telephone set and equipment	48.43	45.70

Table 3 summarizes the criteria and factors for the HDTV and VoIP surveys identified by the OMEGA consortium. In the context of these end-to-end services, usability was perceived mainly from the user point of view, in terms of mobility. In the context of HDTV, the content diversity and popularity was also considered an important aspect affecting the service penetration. Again, economic criterion was also identified as an important aspect of both HDTV and VoIP, primarily determined by the service subscription rate and the cost of the television or telephone set, respectively. Service performance is characterized with similar attributes for both services which were identified primarily from the user quality of experience: service interruption is regarded as an important factor for both HDTV and VoIP.

4 Survey results

This section presents the results for the prioritization of the criteria and factors presented in Section 3. It is interesting to note for all judgments carried out by the experts the consistency ratio C.R. defined in Eq. 4 was less than 0.1, implying that all experts supplied consistent comparisons.

4.1 OMEGA network and extender surveys

The results concerning the weights of the criteria that affect the HN network deployment (first survey) are presented in Fig. 3. It is interesting to note, that according to the opinion of the experts, all criteria have more or less the same weight (≅25%) illustrating that on the average the experts believe that all the corresponding issues have equal bearing. The credibility of the results is enhanced by the fact that experts do not all come from a single organization. Figure 3 suggests that HNs should be designed in order to fulfill a number of diverse and possibly conflicting criteria. The results for the extender device are somewhat different as shown in Fig. 4. Design issues are deemed of secondary importance by the experts, probably because there are still many important technological matters to be resolved in order to provide reliable and cost-effective network extension functionality. Considering the OW technology for example, it is somewhat difficult to envision such network extension on a terminal basis in line-of-sight configurations because of receiver field-of-view limitations. Both OW and MMW could provide some form of network extension inside the room, but can not extend the network across multiple rooms because of the properties of the electromagnetic radiation at the corresponding wavelengths. This restriction does not hold for PLC and IEEE802.11 devices though.

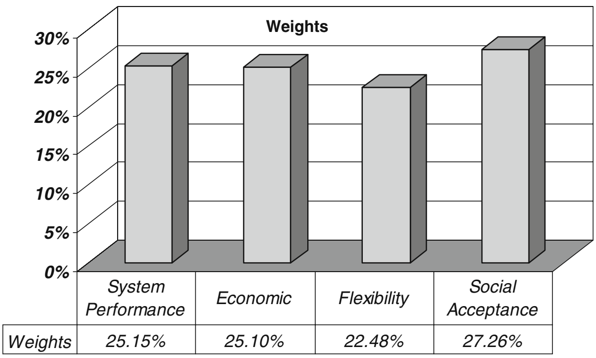

Fig. 3 Relative weights of OMEGA network criteria

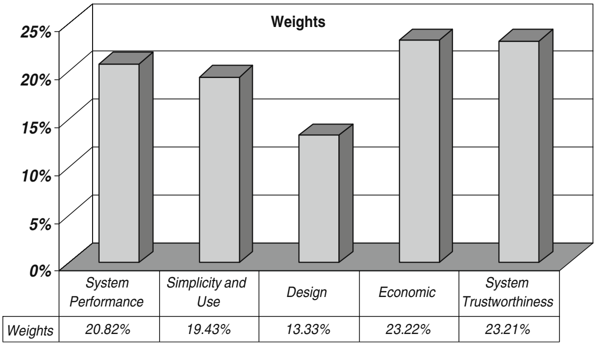

Fig. 4 Relative importance of extender device criteria

Although in both surveys, most criteria have similar weights (except the design criterion in the extender survey), the situation is quite different when one examines the weights of the factors under each criterion (Tables 1 and 2). Starting with the social acceptance criterion in the OMEGA network survey (Table 1), it is clear that health issues are the most important aspect to consider and this reflects the growing public concern on this subject [24–26]. The effects of the interaction of electromagnetic radiation with the human tissue are not yet very well understood especially in the microwave spectrum. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has established guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields that will provide protection against known adverse health effects [27]. Moreover, certain standards addressing the health concerns have been established such as the IEEE C95.1-2005 which provides recommendations to protect against harmful effects in human beings exposed to electromagnetic fields in the frequency range from 3 kHz to 300 GHz. On the other hand, visible light and infrared OW technologies are considered rather harmless as long as they comply with eye safety standards. Given the fact that the human body has been exposed to infrared and visible light radiation because of the sun, for thousand of years it is expected that both visible and infrared radiation will otherwise have limited negligible biological effects. In any case, the growing public concern warrants additional research in the effects of electromagnetic radiation and may hence provide leverage towards optical wireless solutions, especially in hospitals, nursing homes, etc. The importance of health issues is further corroborated by Table 2, where they receive the largest weight compared to system trustworthiness/user confidence issues. Surprisingly enough, security seems to be a minor concern compared to other issues for both the extender and the HN in general. This is probably a reflection of the fact that people believe that HNs would be inherently secure, incorporating some of the existing security protocols such as WPA2 [28], and security is somewhat less important than in corporate networks. It may also be that experts realize that privacy and security in internet transactions, which greatly interest the average home user, is implemented on an end-to-end basis. In the OMEGA network survey, usability seems to be the second most important social aspect and this is not surprising since the widespread adoption of future HNs will greatly depend on the layman's ability to setup and control the network infrastructure in the domestic environment. Considered separately, the factors integration with the home environment and the no new wires approach receive a modest ≅16% weight. However, once added together, one clearly understands that future HNs should intrude on the domestic environment as little as possible: unlike working environments, people are much less inclined to see wires extending or being installed in their homes. This raises an important concern since although the optical fiber (plastic, multimode and even single mode) would provide the ultimate solution in terms of bandwidth and coverage in new buildings, wireless and PLC solutions are more appropriate in older buildings where the residents are not willing to disturb their home environment and install additional cables.

Regarding the flexibility criterion of the OMEGA network, as shown in Table 1, compatibility with legacy systems seems to take precedence over other issues with a weight of 30%. This is an indication that experts tend to think that the adoption of future HN demands the compatibility with previous legacy systems and other home appliances, which have already been installed in their home environment. The results also indicate that future HNs should not interfere with any legacy network. Optical wireless and MMW technologies have an inherent advantage as such types of signals remain confined inside a room. In fact using transceivers on different wavelength it is easy to envision multiple OW local are network connections simultaneously supported inside the same room without any bandwidth reduction due to interference effects. These results emphasize the need for a device that adapts legacy equipment to next generation. Regarding the extender survey (Table 2), interesting results are obtained for the factors of the design criterion. Experts seem to believe that the design/integration to the home environment seems to be the most important aspect, emphasizing the need for "stylish" products. It is also deduced that both the volume and the weight of the extender are important issues: Network devices should be made as small and as light as possible for both practical and marketing reasons. Regarding the economic criterion, experts placed great importance on both the component and annual operation cost. Since the latter is mainly related to power consumption, this emphasizes the need for energy efficient devices. It is also interesting to note the values obtained for the weights of the factor obtained in the Simplicity of Use criterion. The plug and play feature is considered somewhat more important than the compatibility with legacy systems—probably because this feature is already present in Digital Subscriber Line (DSL) modems as well as IEEE802.11 wireless routers.

The results for the weights of the economic factors for the home network are also interesting. The most important factor is clearly the installation cost, with a weight of 54% as shown in Table 1. This is not surprising as home networking equipment should ideally be cheap to install. This also seems consistent with the high combined weight of the no new wire approach and design to home environment discussed in the context of the social acceptance criterion. Maintenance cost and equipment cost seem to be a secondary issue, probably because experts believe that the cost of network components should be small enough, or otherwise there is no hope to compete with existing solutions such as IEEE802.11. It should be noted however that in HN, the cost of components is far more critical than in metro or core networks and a low maintenance cost is clearly a motivation in order for a user to adopt future HN technologies. Table 2 discusses the importance of the economic factors for the extender. The cost of repair is rated as the least important economic factor (22%) compared to the rest. This low rating is probably due to the fact that the cost of purchasing the device should be low enough and when the device breaks down, the user will prefer to buy a new instead of repairing the old one. In the context of simplicity and use, depicts that both plug and play ability and compatibility with legacy devices are very important issues to take into account. It seems that experts gave a precedence of 9% to plug and play which is reasonable, if we consider that future adopters would prefer the extender to be easily mounted on their laptops and other appliances much like WiFi routers or USB sticks.

As far as performance is concerned, the experts seem more concerned about the coverage rather than the maximum achievable bit rate of the system. This indicates that HNs must guarantee sufficient coverage conditions or otherwise, any kind of service would be very easily interrupted or not supported at all. Coverage is not a severe issue for PLC since the reach of existing components can be 200 m at 200 Mb/s [8]. As discussed in the introduction, for wireless technologies, radiation on radio frequencies can pass through walls, while 60 GHz and optical wireless are confined inside a single room. In line of sight optical wireless better coverage is obtained using multiple resonant cavity light emitting diodes on a single chip [29]. Maximum bit rate also is also an important factor having a weight of 43%. This emphasizes the need for broadband HNs, extending to the gigabit per second regime. Distributing gigabit-per-second traffic inside an office or domestic building is not a trivial task however even for wired alternatives. For example, the 1 GbE physical layer specifications dictate that conventional twisted pair cable (1000BASE-T and 1000BASE-TX) range is limited to 100 m at best. As data rates are increased this range is further reduced and drops to 15 m for the 10GbE over copper (10GBASE-CX4). Optical fiber is a far more reliable medium for delivering gigabit-per-second. Because of its high capacity and reliability, multi-mode optical fiber generally is used for backbone applications in buildings, offering a range of about 300 m for 10GbE. Although OW and MMW promise bit rates extending 1 Gb/s, they are still immature technologies. On the other hand, PLC could provide a gigabit alternative if the technology is pushed to the limits using orthogonal frequency division multiplexing (OFDM) [30]. Wireless radio technologies are even harder to extend in the gigabit regime. The IEEE802.11n standard promises 600 Mb/s connectivity using advanced more efficient Forward Error Correction (FEC), shorter guard intervals, increased number of subcarrier frequencies and finally Multiple Input Multiple Output (MIMO) techniques. In the extender surveys, the experts have also placed great importance to downstream bit rate, possibly having in mind that in many types of popular services bandwidth requirements are asymmetric. The importance of upstream data rate is not trivial however (about 24%) probably because of several emerging symmetric service technologies, such as on-line gaming, distributed and peer-to-peer applications [31], etc.

4.2 HDTV and VoIP surveys

This section deals with the results of the HDTV and VoIP surveys. Figure 5a and b depict the weights of the criteria obtained by the pairwise comparisons conducted by the experts for both the HDTV and VoIP services. Experts seem to believe that performance is the most important issue in both cases, especially for HDTV where the corresponding weight is 49%. This is not surprising: the motive behind the adoption of HDTV is its high definition! The economic aspects follow, as potential buyers will care a lot about the cost of the services while usability issues seem to be secondary compared to the other criteria, especially in HDTV.

Table 3 shows the relative importance of factors for HDTV and VoIP. For the performance criterion, service interruption seems to dominate the rest factors followed by quality degradation of picture in the case of HDTV, whereas quality degradation of voice is most highly rated for VoIP followed by service interruption. This is not surprising since service interruption as well as degradation of picture (in HDTV) or voice (in VoIP) greatly determine the level

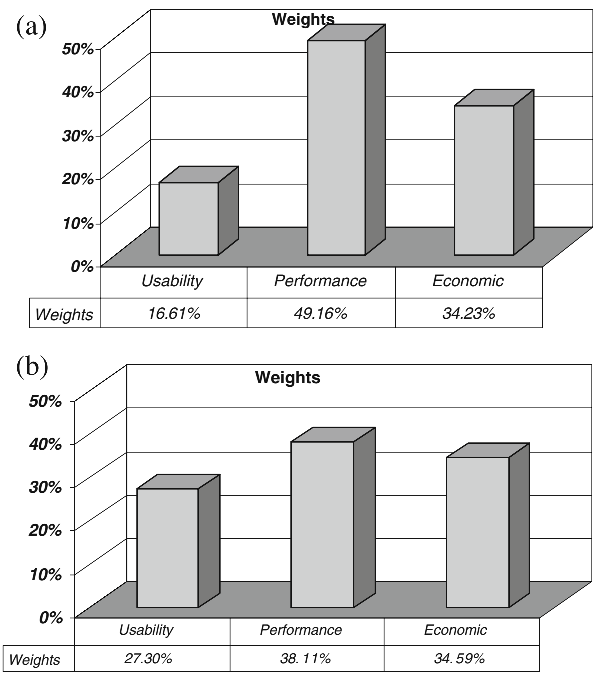

Fig. 5 Relative importance of criteria in the case (**a**) HDTV and (**b**) VoIP

of user satisfaction. Experts seem to believe that picture degradation is much more important than sound degradation for HDTV, probably because transmission of high definition video may require several megabits per second (see for example the H.264/MPEG-4 AVC video compression standard) while the bandwidth requirements for sound are usually in the order of a few hundred kilobits per second at best.

Interestingly enough, experts seem to believe that service subscription rate and cost of television set are almost of equal importance in HDTV. In the case of VoIP, as shown in Table 3, the service subscription rate has a precedence of 10% higher than the cost of the telephone set but also highly rated with a percentage of 45%. As a result there is not a single economic measure that stands alones as the dominant one, but they are both important costs from a potential adopter's perspective.

Regarding usability factors, the content of the HDTV service is weighted as the most important one with a great precedence of 51%, as presented in Table 3. Availability of lower class services and mobility follows with individual weights of 28% and 21%. Besides, content popularity (the number of different channels and the content that they offer) is an important motivation in order for somebody to adopt HDTV services. In the case of VoIP, according to Table 3, mobility turns out to be the dominant factor with a percentage of 59%, compared to the availability of lower class services. Mobility inside the home and even the wide area network is therefore an important aspect of VoIP service provision.

5 Conclusions

In this paper, the first steps towards a roadmap for the next generation home network have been undertaken. Based on pairwise comparison surveys conducted within the ICT-OMEGA project consortium, a number of technical, economic and social issues determining the penetration of future home networks have been evaluated and prioritized. It was shown that experts rate social acceptance of primary importance for successful product commercialization. Within this criterion, health issues have proven the main concern, possibly reflecting some public skepticism on biological effects of electromagnetic radiation. The authors think that as time goes by, health issues will crucially affect the deployment strategies for home networks. Regarding performance issues, coverage was deemed as the most important performance measured followed by downstream bit rate. If fiber installation is not an option, the existing technologies (radio, PLC, optical wireless or some hybrid alternative) may provide a broadband alternative each with its own merits and drawbacks however. Compatibility with existing solutions and home appliances was also highly weighted. From the economic point-of-view, the installation cost turned out to be the major factor. Wireless solutions and even PLC are compatible with the "no new wire" approach and could therefore a hybrid solution can lead to reduced installation costs. Various requirements for HDTV and VoIP, envisioned to be major service application scenarios for future home networks have been considered and weighted.

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References

1. OMEGA Project Consortium. Home Gigabit Access Project. http://www.ict-omega.eu/.
2. ICT-OMEGA White Paper. Inter-MAC concept for Gbps Home Network, April 2009. http://www.ict-omega.eu.
3. ICT-OMEGA Deliverable 6.1. OMEGA Architecture Model, December 2008. http://www.ict-omega.eu.
4. Randel, S., Lee, S. C. J., Spinnler, B., Breyer, F., Rohde, H., Walewski, J., et al. (2006). 1 Gbit/s transmission with 6.3 bit/s/Hz spectral efficiency in a 100 m standard 1 mm step-index plastic optical fiber link using adaptive multiple sub-carrier modulation. In *Proceedings of the European conference on optical communication*.
5. Ophir, L., Bitran, Y., & Sherman, I. (2004). Wi-Fi (IEEE 802.11) and bluetooth coexistence: Issues and solutions, personal, indoor and mobile radio communications, 2004. In *PIMRC 2004. 15th IEEE international symposium* (Vol. 2, issue 5–8, pp. 847–852).
6. ETSI TR 102 555. Technical characteristics of multiple gigabit wireless systems in the 60 GHz range system reference document.
7. ECC. Decision of 24 March 2006 on the harmonized conditions for devices using Ultra-Wideband (UWB) technology in bands below 10.6 GHz, ECC/DEC/(06)04. European Communication Committee.
8. Afkhamie, K. H., Katar, S., Yonge, L., & Newman, R. (2005). An overview of the upcoming HomePlug AV standard. In *2005 International symposium on power line communications and its applications, 6–8 April 2005*.
9. O'Brien, D. C. (2007). *Cooperation in optical wireless communications, cooperation in optical wireless communications*. New York: Springer.
10. O'Brien, D. C., Zeng, L., Le-Minh, H., Faulkner, G., Walewski, J. W., & Randel, S. (2008). Visible light communications: Challenges and possibilities. In *PIMRC 2008. Proceedings of the IEEE 19th international symposium on personal, indoor and mobile radio communications, 15–18 September 2008*.
11. Saaty, T. (1980). *The analytic hierarchy process: Planning, priority setting, resource allocation* (p. 287). New York: McGraw-Hill.
12. Kwiesielewicz, M., & van Uden, E. (2004). Inconsistent and contradictory judgments in pairwise comparison method in the AHP. *Computers & Operations Research, 31*, 713–719.
13. Gerdsri, N., & Kocaoglu, D. F. (2007). Applying the analytic hierarchy process (AHP) to build a strategic framework for technology roadmapping. *Mathematical and Computer Modelling, 46*(7–8), 1071–1080.
14. Tam, M. C. Y., & Rao Tummala, V. M. (2001). An application of the AHP in vendor selection of a telecommunications system, Elsevier. *The International Journal of Management Science, 29*, 171–182.
15. Song, Q., & Jamalipour, A. (2005). Network selection in an integrated wireless LAN and UMTS environment using mathematical modeling and computing techniques. *IEEE Wireless Communications, 12*, 42–48.
16. Saaty, T. L. (2003). Decision-making with the AHP: Why is the principal eigenvector necessary? *European Journal of Operational Research, 145*, 85–91.

17. Saaty, T. L., & Ozdemir, M. S. (2003). Why the magic number seven plus or minus two? Elsevier. *Mathematical and Computer Modelling, 38*, 233–244.
18. Bhushan, N., & Rai, K. (2004). *Strategic decision making: Applying the analytic hierarchy process*. New York: Springer.
19. National and Kapodistrian University of Athens. Online Survey Tool. http://195.134.67.63/roadmapping/PHome.aspx.
20. ICT-OMEGA Deliverable 1.4. Focus Group Sessions Report, April 2009. https://www.ict-omega.eu.
21. Byun, D.-H. (2001). The AHP approach for selecting an automobile purchase model. *Information & Management, 38*, 289–297.
22. Chang, C.-W., Wu, C.-R., Lin, C.-T., & Chen, H.-C. (2007). An application of AHP and sensitivity analysis for selecting the best slicing machine. *Computers & Industrial Engineering, 52*, 296–307.
23. ICT-OMEGA Deliverable 1.5. OMEGA Final Business Cases, October 2009. https://www.ict-omega.eu.
24. Institute of Electronics and Electrical Engineers (2005). Standard C95.1-2005: IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz.
25. Foster, K. R. (2007). Radiofrequency exposure from wireless LANs utilizing Wi-Fi technology. *Health Physics, 92*(3), 280–289.
26. Kuster, N., & Schönborn, F. (2000). Recommended minimal requirements and development guidelines for exposure setups of bio-experiments addressing the health risk concern of wireless communications. *Wiley InterScience, Bioelectromagnetics, 21*(7), 508–514.
27. International Commission on Non-Ionizing Radiation Protection (ICNIRP) (1998). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields. *Health Physics, 74*(4), 494–522. http://www.icnirp.de/documents/emfgdl.pdf.
28. IEEE-SA Standards Board (2007). Wireless LAN medium access control (MAC) and physical layer (PHY) specifications. Communications Magazine, IEEE.
29. O'Brien, D. C., Faulkner, G. E., Zyambo, E. B., Jim, K., Edwards, D. J., Stavrinou, P., et al. (2005). Integrated transceivers for optical wireless communications. *IEEE Journal of Selected Topics in Quantum Electronics, 11*, 173–183.
30. D'Alessandro, S., Tonello, A. M., & Lampe, L. (2009). Improving WLAN capacity via OFDMA and cyclic prefix adaptation. IFIP Wireless Days 2009, Paris, France.
31. Oram, A. (2001). *Peer-to-Peer: Harnessing the power of disruptive technologies*. California: O'Reilly & Associates, Inc., ISBN:059600110X.