A Review on Wireless Home Network Technologies

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Connecting residences to broadband access networks offers an unprecedented opportunity to extend the networking customer base beyond the satiated corporate environment. Yet despite this promising prospect, the market is evolving very tenuously: on one hand, there are numerous industrial consortia and standardization bodies that continue their work on independent and often non-interoperable specifications for residential networks; on the other hand, while there are multiple home PCs and multimedia network-enabled appliances, the majority of the houses can not support sophisticated interconnection, while most consumers are unwilling or cannot afford a large scale home rewiring. Among many competing technologies, wireless networks can resolve the rewiring issue capturing a major percentage of the Home Network market. In this paper, we review the available technologies in the home network area, and provide a comparison of the wireless broadband in-home technologies

I. Introduction

Connecting residential users to broadband access networks offers an unprecedented opportunity for offering added-value services and broadband Internet access, while multimedia products based on home networking systems technologies will exponentially increase the customer base beyond the satiated corporate environment. Until recently the major obstacle to "*digital networked house*" has been the inadequate access network infrastructure and the huge cost of new installations. Today, a number of competing emerging access techniques, ranging from copper enhancements (e.g. ADSL, HDSL, VDSL), wireless solutions (e.g. WLL, MMDS, LMDS) and satellite communications to Fiber To The Curb (FTTC) and to the Home (FTTH), have been evaluated and deployed [1][2]. A non-exhaustive comparison of access technologies is provided in Table I.

Despite of this promising prospect however, the home networking market is evolving very tenuously. One of the reasons is the numerous consortia and standardization bodies that have been working on independent and often non-interoperable specifications for residential networks [3]. Since the mid-1980s the lack of a widely accepted, ad-hoc standard, has given space to consortia, organizations and projects to design, build and promote technologies, protocols and products. Today, more than 50 candidate technologies, working groups and standard specifications for home networking already exist, providing guidelines for interoperation between access and in-home networks, while increasing the entropy in the home network industry.

On top of that, home data networks either do not exist at all or they are not able to support multimedia communications. A large amount of houses have PCs, modems or multimedia network-enabled appliances, however they are not designed to support their interconnection. Of course the most daunting cost of home networking is the cabling installation. Pulling wires in an existing home is difficult and it is not an amenable solution for the mass market. Moreover, most consumers are unwilling or cannot afford a large scale home rewiring. Thus, with a few exceptions here and there, great focus has been put on the so-called "no-new-wires" solutions that eliminate that need. These solutions are based on either existing in-home cables or wireless technologies.

In this review, we analyze and compare some of the most widely accepted current and future wireless home networking technologies able to support multimedia in home appliances. In Section 2, we present the wireless technologies and in section 3 we compare them based on various characteristics. Conclusions are recapitulated in Section 4

Access type	Physical Medium	Typical Applications	Comment
Plain Old Telephone Service (POTS)	Twisted pair	Telephony, Low rate data	Uses standard telephone lines, wide availability and low cost.
Integrated Services Digital Network (ISDN)	Twisted pair	Telephony, Medium bandwidth data	Widely available now. Telcos and ISPs are investing and building out the infrastructure to further develop it.
xDSL technologies (HDSL, HDSL2, SDSL, ADSL)	Twisted pair	Telephony, video on demand, broadband data	Use existing twisted pair, service coverage is spotty but improving, ADSL-lite and SDSL might get the highest market share short-term, full-rate ADSL and VDSL long-term.
HFC	Fiber, Coax	Telephony, broadcast video, broadband data	Good for new builds and rebuilds. It is based on the existence of Cable Network.
Fiber to the Home (FTTH) Fiber to the Curb (FTTC) + VDSL	Fiber	Telephony, broadcast video, video on demand, broadband applications, operations cost savings.	Long-term solution for broadband. Cost is the obstacle, deployment is still in the first phase, telcos have been unwilling to take the risk of upgrading their local loops to fiber solutions.
Fixed Wireless (MMDS/LMDS)	Air 2–3 GHz / 28–38 GHz	Broadcast video, Telephony, broadband data	Good for rapid deployment of video overlays. Combined with other technologies, such as ADSL, for point-to-point applications.
DBS	Satellite	Broadcast video	Provides broad geographic coverage; difficult to support local programming

Table I. Residential Access Alternatives

II. Wireless Network Technologies

The "no wires" RF technologies are considered the "Holy Grail" of the home networking and are expected to play a key role in pushing forward the digital house concept. Among the RF technologies, IEEE 802.11 an established, proved and mature technology, and Bluetooth, an emerging simple and cheap solution for short distances are considered the most promising ones. A detailed overview of the various wireless home network alternatives is given in the following subsections.

II.A HomeRF

HomeRF is an effort that aims to tackle the interoperability limitations of many wireless networking products. It is supported by the HomeRF Working Group (HRFWG), which was formed to establish the mass deployment of interoperable wireless networking access devices to both local content and the Internet for voice, data and streaming media in consumer environments [4][5]. HomeRF specification (Figure 1) defines a new common Home RF MAC and Physical layers, which support wireless voice and data networking in the residential side.

Meanwhile, many companies are working with the HRFWG to develop the Shared Wireless Access Protocol (SWAP) [6] for radio-based home networks. The SWAP specification aims to define a new, common air interface that supports both wireless voice and LAN data services in the home environment, provide higher data rates and ensure interoperability among various wireless products being developed by PC, communications and consumer electronics vendors for the home market.

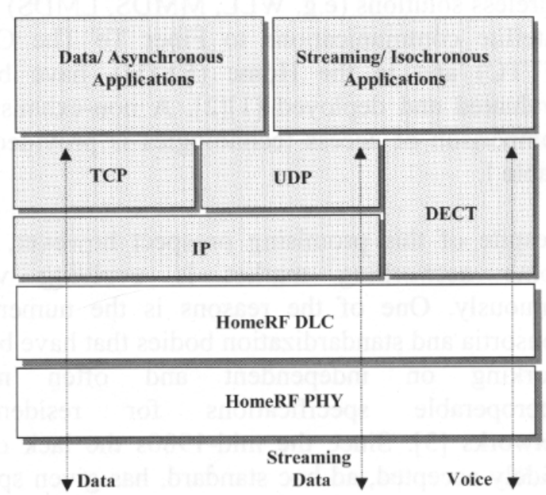

Figure 1. Home RF Protocol Stack

SWAP operates in the 2.4 GHz ISM band, which is available worldwide. It combines elements of the Digital Enhanced Cordless Telecommunications (DECT) and the IEEE 802.11 standards. It supports both a TDMA (Time Division Multiple Access) service to provide delivery of interactive voice and other time-critical services, and a CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) service for delivery of high speed packet data. The protocol architecture closely resembles the IEEE 802.11 wireless LAN standards in Physical layer and extends the Medium Access Control (MAC) layer with the addition of a subset of DECT standards to provide isochronous services such as voice. As a result, the SWAP MAC layer can support both data oriented services, such as TCP/IP, and the DECT/GAP protocols for voice.

The SWAP system can operate either as an ad-hoc network or as a managed network under the control of a Connection or Access Point. In an ad-hoc network, where only data communication is supported, all stations are equal and control of the network is distributed between the stations. For time-critical communications, such as interactive voice, a Connection Point is required to coordinate the system. The Connection Point, which provides the gateway to the PSTN, can be connected to a PC via a standard interface (e.g. USB) enabling enhanced voice and data services. The SWAP system also can use the Connection Point to support power management for prolonged battery life by scheduling device wakeup and polling.

The network can accommodate a maximum of 127 nodes of a mixture of four basic types:

- Connection Point that supports voice and data services.
- Voice Terminal that only uses the TDMA service to communicate with a base station.
- Data Node that uses the CSMA/CA service to communicate with a base station and other data nodes.
- Voice and Data Node which can use both types of services

II.B. Bluetooth

Bluetooth [7] is intended to serve as a universal low cost, user friendly, air interface that will replace the plethora of proprietary interconnect cables between a variety of personal devices. Bluetooth is a short-range[1] (10cm – 10m) frequency-hop wireless system, providing up to 1Mbps in the unlicensed 2.4 GHz band. It supports both point-to-point and point-to-multipoint connections. Currently up to 7 slave devices can communicate with a master radio in one device. It also allows for several piconets to be linked together in ad hoc networking mode, which enables extremely flexible configurations that would be suitable for meetings and conferences [9][10].

The Bluetooth protocol stack architecture is shown in Figure 2. It is a layered stack that supports physical separation between the Link Manager and the higher layers at the Host Control Interface (HCI), which is common in most Bluetooth implementations. The Baseband layer provides the functionality required for air interface packet framing, establishment and maintenance of piconets and link control. The Link Manager is responsible for link set-up and control including authentication, encryption control, physical parameters control etc. The HCI provides for a mechanism whereby the higher layers of the protocol stack can delegate the decision on whether to accept connections to the link manager and whether to switch on filters at the link manager [11][12]. The Logical Link Control Adaptation Layer Protocol (L2CAP) provides connection-oriented and connectionless data services to higher layer protocols. Finally Service Discovery Protocol (SDP) allows Bluetooth devices to discover what services are available on a device, RFCOMM provides an emulation of serial ports, and Telephony Control Specification (TCS) provides an adaptation layer that enables Q.931 call control

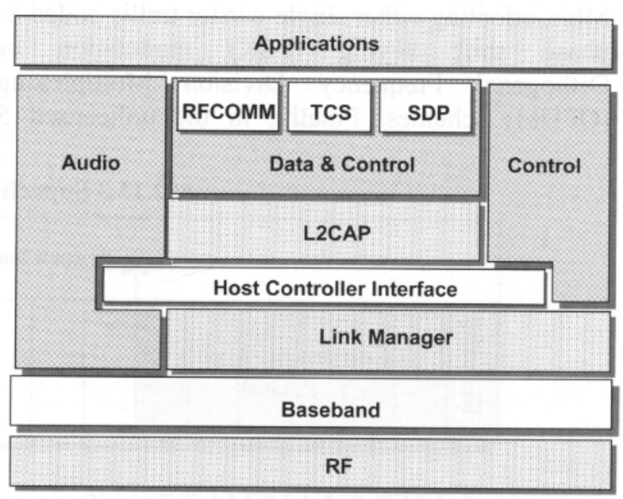

Figure 2. Bluetooth Protocol Stack

services.

Bluetooth is ideal for both mobile office workers and small office/home office (SOHO) environment [13][14][15]. For example, once VoIP is established, it can be used to automatically switch between a cellular and an in-door wireless phone, when one enters a house or an office. Of course the low bandwidth capability can support only limited and dedicated usage, and inhibits Bluetooth from in-door multimedia networking.

II.C. IEEE 802.11

IEEE 802.11 [16] is the most mature wireless protocol for wireless LAN communications, tested and deployed for years in corporate, enterprise, private and public environments (e.g. hot-spot areas), and is one of the favoured technologies for home networking. The IEEE 802.11 standard [17] supports several wireless LAN technologies in the unlicensed bands of 2.4 and 5 GHz, and share the same MAC over two PHY layer specifications: direct-sequence spread spectrum (DSSS) and frequency-hopping spread spectrum (FHSS) technologies. Infrared technology is also supported, but it is not really adopted by any manufacturer.

Initially IEEE 802.11 systems operating at the 2.4 GHz band, provided data rates up to 2 Mbps without any inherited QoS[18]. The wide acceptance however, initiated new versions and enhancements of the specification. The most important is the IEEE 802.11b PHY layer specification, which achieves data rates of 5.5 and 11 Mbps by using complementary code keying (CCK) modulation [19][20][21]. Recently, the IEEE 802.11g task group has formed a draft standard that achieves data rates higher than 22 Mb/s, adopting either single-carrier trellis-coded 8-phase shift keying (PSK) modulation or Orthogonal Frequency Division Multiplexing (OFDM) schemes. Finally, in the unlicensed 5 GHz band, the 802.11a technology supports data rates up to 54 Mb/s using OFDM schemes. In parallel, other 802.11 task groups aim to enhance specific areas of the protocol [22].

- **802.11d** task group works towards 802.11b versions at other frequencies, for countries where the 2.4GHz band is not available.
- **802.11e** task group works towards the specification of a new 802.11 MAC protocol in order to accommodate additional QoS provision and security requirements over legacy 802.11 PHY layers. It replaces the Ethernet-like MAC layer with a coordinated Time Division Multiple Access (TDMA) scheme, and adds extra error-correction to important traffic.
- **802.11f** task group aims to improve the handover mechanism in 802.11 so that users can maintain a connection while roaming between access points attached to different networks.
- **802.11h** aims to enhance the control over transmission power and radio channel selection to 802.11a, in order to be acceptable by the European regulators.
- **802.11i** aims to enhance 802.11 security. Instead of the Wired Equivalent Privacy (WEP), a new authentication/encryption algorithm based on the Advanced Encryption Standard (AES) will be proposed.
- **802.11j** specifies the 802.11a and HiperLAN/2 interworking issue.

In order to ensure interoperability and compatibility across all market segments [23], IEEE 802.11 product manufactures have agreed on a compliance procedure called Wi-Fi (Wireless Fidelity standard). Moreover a Wireless Ethernet Compatibility Alliance (WECA) has been formed

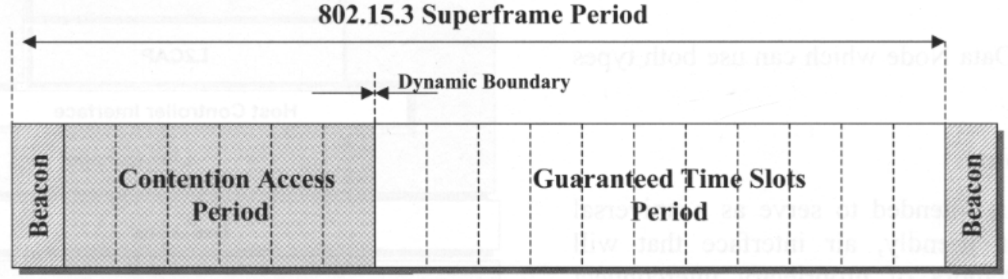

Figure 3. IEEE 802.15.3 MAC Superframe structure

in order to certify Wi-Fi interoperability of new products [24].

II.D. IEEE 802.15.3

The IEEE 802.15.3 is a new specification designed from scratch in order to support ad hoc networking and multimedia QoS guarantees. In ad hoc networking mode, based on existing network conditions, a device may join or leave a group or sub-network, and play the role of a master or a slave node [25].

The IEEE 802.15.13 PHY has some similarities with IEEE 802.11b. Both operate in the unlicensed frequency band of 2.4 GHz and employ the same symbol rate, 11 Mbaud. However, 802.15.3 is designed to achieve data rates from 11 to 55 Mb/s targeting distribution of high-definition video and high-fidelity audio. It uses 5 types of modulation formats: trellis coded QPSK at 11Mpbs, uncoded QPSK at 22 Mb/s, and 16/32/64-quadrature amplitude modulation (QAM) at 33, 44 and 55 Mb/s, respectively (TCM) [26]. The base modulation format is QPSK (differentially encoded). Depending on the capabilities of devices at both ends, the higher data rates of 33–55 Mb/s are achieved by using 16, 32, 64-QAM schemes with 8-state 2D trellis coding. Finally, the specification includes a more robust 11 Mb/s QPSK TCM transmission as a drop-back mode to alleviate the well-known "hidden node" problem. The 802.15.3 signals occupy a bandwidth of 15 MHz, which allows for up to four fixed channels in the unlicensed 2.4 GHz band.

The super frame defined in IEEE 802.15.3 is shown in Figure 3 [27][28][29]. Initially a network beacon is transmitted carrying network specific parameters (e.g. information for new devices to join the network, power management). Then a Contention Access Period (CAP) follows utilizing a CSMA/CD medium access control mechanism for transmission of frames that do not require QoS guarantee (e.g. short bursty data or channel access requests). Finally a Guaranteed Time Slot (GTS) period follows, allocated for image files, standard and high-definition video (MPEG-1, MPEG-2), and high quality audio.

IEEE 802.15.3 is optimized for short-range transmission limited to 10 m, enabling low-cost and integration into small consumer devices e.g. a flash card or a PC Card. The PHY layer also requires low current drain (less than 80 mA) while actively transmitting or receiving data and minimal current drain in the power save mode. Finally, the selection of the 2.4 GHz band is highly important, since the 5GHz band is prohibited for outdoor usage in many countries wouldwide, including Japan.

II.E. HIPERLAN/2

HIPERLAN/2 is the European proposition for a broadband wireless LAN operating with data rates up to 54 Mbps at PHY on the 5GHz frequency band. The HIPERLAN/2 is supported by the European Telecommunications Standards Institute (ETSI), and developed from the Broadband Radio Access Networks (BRAN) group [30][31][32].

HIPERLAN/2 is a flexible Radio LAN standard, designed to provide high-speed access to a variety of networks, including 3G mobile core networks, ATM networks and IP based networks, as well as for private use or wireless LAN system. HiperLAN/2 is a connection-oriented Time Division Multiplexed (TDM) protocol. Data is transmitted on connections that have been established prior to the transmission using signaling functions of the HiperLAN/2 control plane. This makes it straightforward to implement support for QoS. Each connection can be assigned a specific QoS, for instance in terms of bandwidth, delay, jitter, bit error rate, etc. It is also possible to use a more simplistic approach, where each connection can be assigned to a priority level compared to other connections. This QoS support, in combination with the high transmission rate, facilitates the simultaneous transmission of many different types of data streams, e.g. video, voice, and data [33][34].

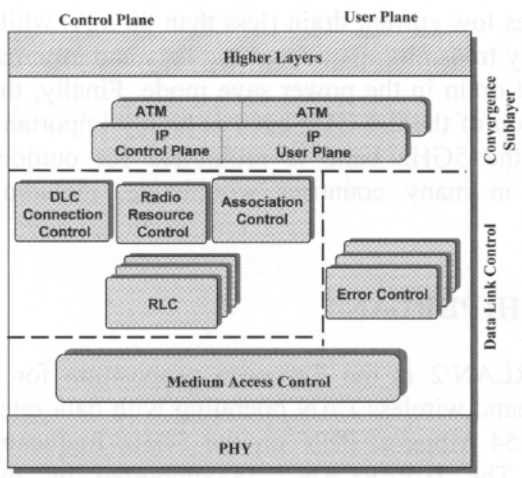

Figure 4. HiperLAN/2 protocol stack

The HiperLAN/2 protocol stack is shown in Figure 4 [35]. At the physical layer HiperLAN/2 uses OFDM to transmit the analogue signals. OFDM is very efficient in time-varying environments, where the transmitted radio signals are reflected from many points, leading to different propagation times before they eventually reach the receiver. Above the physical layer, the MAC protocol is built from scratch, implementing a type of dynamic TDMA/TDD scheme with centralized control. The MAC frame appears with a period of 2 ms. The Error Control is responsible for detection and recovery from transmission errors on the radio link. Moreover, it ensures in-sequence delivery of data packets. In the Control Plane, the Radio Link Control Sublayer (RLC) provides a transport service to the DLC User Connection Control, the Radio Resource Control and the Association Control Function. Finally a convergence sublayer is provided for each supported network.

II.F. 5GHz Unified Protocol (5-UP)

IEEE 802.11a is one of the most powerful in-door wireless technologies, however it does not provide any inherent QoS support; thus it is not accepted by the European regulators, who favor the ETSI HiperLAN/2. In order to overcome this issue, ETSI and IEEE have formed a joint venture called the 5GHz Partnership Project (5GPP), which aims to merge 802.11a and HiperLAN2 into a single standard, tentatively known as the 5GHz Unified Protocol (5-UP). By tying two or even three channels together, this standard would offer even higher data rates than the existing systems. Three channels will provide a real throughput of about 100Mbits/sec, more than most laptop PCs can handle, while secure approval within Europe for a future version of 802.11a [22].

The 5-UP [36][37] proposal extends the OFDM system in order to support multiple data rates and usage models. 5-UP is expected as an enhancement to the existing IEEE 802.11a standard that would permit cost-effective designs in which everything from cordless phones to high-definition televisions and personal computers could communicate in a single wireless multimedia network. 5-UP achieves this by allocating the carriers within the OFDM signal on an individual basis. As shown in Figure 5, multiple devices simultaneously transmit to an access point utilizing different OFDM carriers. By zeroing out some inputs to an inverse FFT transform, some carrier may be left to other devices.

III. Technologies Comparison

The Wireless technologies are expected to push forward the concept of the digital house. However, the selection among current and future technologies and standards is quite difficult. Among the most widely accepted, IEEE 802.11b as an established, proven and mature technology, and Bluetooth, as a simple and cheap cable replacement for short distances, are expected to

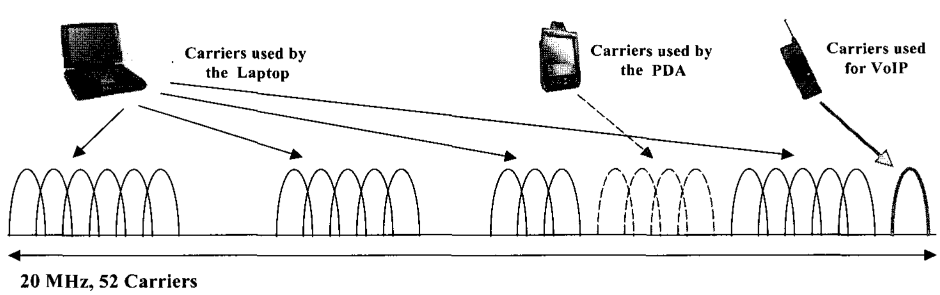

Figure 5. Example of 5-UP Scalable Carriers Allocation

	Bluetooth 2	HomeRF2	802.11b	802.11a	802.11g	802.15.3	HiperLAN2	5-UP
Frequency Band	2.4GHz	2.4GHz	2.4GHz	5GHz	2.4GHz	2.4GHz	5GHz	5GHz
Technology	FHSS	FHSS	DSSS	OFDM	DSSS/OFDM	OFDM	OFDM	OFDM
Max Range	10cm- 10m	50 m	150 m	50 m	150 m	10m	80 m	80 m
Power	Very Low	Medium	Medium	Medium-High	Medium-High	Medium	Medium	N/A
Complexity	1x	1.5x	1.2x	4x	~3.5x	1.5x	2.5x	2x
QoS	Yes	Yes	Inherited only in 802.11e. Backwards compatibility is questionable.			Yes	Yes	Yes
Thoughput								
Physical	≤10 Mbps	≤10 Mbps	11Mbps	54Mbps	22 Mbps	11-55Mbps	54Mbps	108Mbps
Effective	≤ 6 Mbps	≤ 6 Mbps	≤ 7Mbps	≤31Mbps	≤ 12Mbps	≤30Mbps	≤ 31Mbps	≤72Mbps
Regional Support	World	US/Asia	World	US/Asia	World	World	Europe/ Japan	World
Promoters	2000+	< 50	100+	~100	~100	~50	< 50	< 20
Target Application	Cable Replacement	Wireless Voice/Data	Wireless Data	Wireless Data	Wireless Data	Wireless Voice, Audio, Data	Wireless Data	Wireless Voice/Data

Table II. Comparison of Home Wireless Technologies

capture in short- to mid-term the maximum share of the market.

Until recently, IEEE 802.11b technology was too expensive for in-home use. HomeRF and Bluetooth on the other hand are simpler technologies than any of the popular IEEE802.11 variants [38]. "Simpler" means fewer and/or less demanding RF semiconductor chips and passive components, as well as less complex digital baseband chips, which results in a reduced Bill of Materials (BoM). However, as with most technologies, advances in VLSI, volume production and competition have significantly reduced the cost of the 802.11b implementation.

The major limitation of IEEE 802.11b is the lack of QoS and isochronous transmission slots. IEEE 802.11e will support QoS whenever available, however backwards compatibility is questionable. On the contrary, HomeRF 2 provides native support for 4-8 simultaneous high quality isochronous full-duplex voice connections, while it leverages the highly successful DECT protocol, and makes specific accommodations for inevitable interference and other channel impairments. Bluetooth was also designed to accommodate voice traffic; however, due to shorter coverage area, the following limitations can be identified:

i) It does not support the DECT standard,

ii) It does not provide a MAC layer interference mitigation against complete packet losses, thus it is sensitive to home appliances interference, and

iii) due to limited bandwidth, it is limited to just two active calls.

HomeRF2 also provides native support for prioritized streaming media sessions within the asynchronous data framework of the protocol. It supports a full range of options including multi-cast, two-way (i.e. videoconferencing) and receive-only destinations, where streaming sessions are not affected from other radio channel impairments or from asynchronous data traffic. IEEE 802.11a and 802.11b provide adequate bandwidth for wireless streaming multimedia distribution, however they do not inherently guarantee QoS in case of significant asynchronous data traffic on the network.

As per data throughput, technologies may be categorized in three groups: the Wireless LAN category, which consists of the Bluetooth 2, HomeRF 2 and IEEE 802.11b and provides approximately 10 Mbps, the Broadband category (IEEE 802.11a, 802.15.3 and HiperLAN2) offering circa 54Mbps, and the Ultra Broadband category of 5UP that promises aggregate data rates up to 108Mbps.

Comparing the coverage area, Bluetooth is rather limited to "room-distances", while the remaining technologies cover the normal home area network, achieving good performance in ranges of 50-80m. IEEE 802.11b and IEEE 802.11g support connectivity in even longer distances of 150-200m, given interference-free environment.

Another advantage of IEEE 802.11b is the wide acceptance in office environment. Corporate users are already familiar with 802.11b, while many laptops are already 802.11b-enabled eliminating the need for an extra PC card. Table II provides a comparison of RF Technologies, underlying the major differences and competitive advantages.

In Figure 6 a potential Digital Home Network architecture is shown. Wireless protocols like IEEE 802.11b, IEEE 802.15.3 and 5UP are utilised for different applications in different rooms. Moreover existing networks (e.g. power line, phone line, coaxial etc.) are reused for lower rate communication and control applications, while high speed emerging networks (e.g. IEEE 1394) may also be utilised for multimedia services. A new network device, the Resident Gateway (RG) is expected to be an omni-point of the home network. The RG will be the demarcation and interconnection device between the access and the in-home networks. It will provide Network Terminator (NT) and modem functionality, operate as base station of all the wireless protocols, interface and interoperate with all in-home networks. Additionally it can carry out the switching functions for telecommunication, computing and entertainment services, while

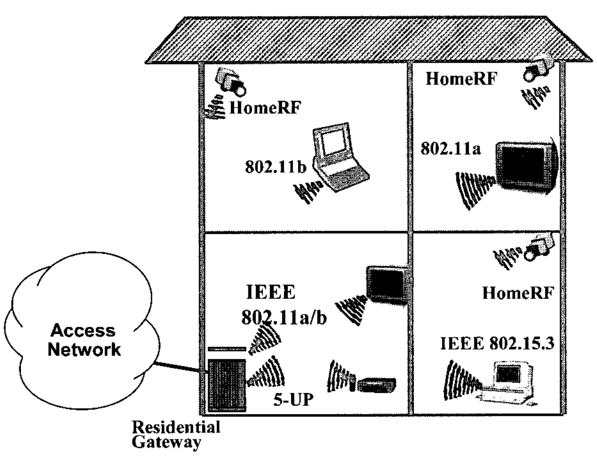

Figure 6. Digital Wireless House Network

providing at the same time overall control and management over a variety of electrical and electronic appliances. Its role within the end-to-end network architecture will be to offer transparent access to a diversity of services offered by network operators and service providers while at the same time allow for the introduction of new, added value services.

IV. Conclusions

In this paper, we have reviewed the major available technologies and standardization efforts in the wireless home network area, and provided a comparison of the competing broadband in-home technologies. It is the authors' opinion that multiple technologies will be finally used at the indoor side, however the "*no-wires*" technologies will dominate. Current deployed (e.g. IEEE 802.11a and b, HomeRF 2) and emerging (e.g. IEEE 802.15.3, HiperLAN/2, 5-UP) technologies may cover the main in-home networking requirements, while for sort distance and low cost communication Bluetooth is envisaged to be a major candidate.

What should be underlined however is that the Home Network infrastructure is only one of the aspects to be considered. Success will be based on the effectiveness, usefulness and cost of the end-to-end network system as a whole. Digital Home will be a reality, when added value services will be able to attract customers, providing the appropriate functionality and flexibility, fulfilling user requests and agreed quality, have sufficient content, and be favorably compared to standalone systems.

V. Acknowledgement

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