Technology Developments for Quality Multimedia Delivery for Residences: Coupling of the broadband and home network technologies

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Abstract

A new networking market, the *home networking*, is rapidly emerging as the focus of both PC and consumer electronic vendors. This market will drive higher demands for broadband last mile technologies and its development is a necessary ingredient for the widespread of broadband services. In this paper we provide a brief survey of state-of-the-art residential networks technologies, and applications. In order to deliver quality multimedia communication that includes voice, video, data and control, the network has to provide quality of service support. To provide such support QoS has to be integrated into the backbone, last mile and home networking technologies. We survey some of the existing support for QoS in the backbone and last mile technologies and point out recommendations for such support in home networking technology.

1 Introduction

A new networking market, the *home networking*, is rapidly emerging as the focus of both PC and consumer electronics vendors. For years vendors have been trying to develop home automation networks that tie together and control all home appliances (US middle class home has 30-50 devices that contain microprocessors). However, as we all know, the home automation market has not taken off as expected. This is due to the lack of a killer application that drives the market. Moreover, there are many technical challenges that face home networking, e.g. develops technology that works for each embedded system device regardless of its operating system while considering the fact that this solution has to be inexpensive, and easy to install and maintain. The main technological challenges have remained and even increased, i.e., the quest for high speed communication, but what has dramatically changed is the existence of the killer application: the desire to access data, voice and video from the Internet from each location in the home while sharing a single Internet connection to the home. This observation is supported by the following information provided by Lucent Technologies which predicts that by 2002: 80 Million (M) internet users, 70 M households with PCs, 27 M households with Digital Subscriber Line (DSL)/cable access, 79 M non-PC based web devices, and 139 M PCs. Given these facts, we believe that the home networking market will drive higher demands for broadband last mile technologies and its development is a necessary ingredient for the widespread of broadband services.

We will provide a survey of the following technologies: wireless LANs, powerline and phoneline networks followed by their common characteristics and comparison of these technologies.

In order to deliver quality multimedia communication that includes voice, video, data and control, the network has to provide quality of service (QoS) support. The ability to provide QoS for multiple users in to the customer premise gives service providers the ability to offer more than just Internet access. With QoS, service providers can expand their service offerings to include differentiated data services, voice and video. For example, a service provider can deploy integrated access devices that support both voice and data applications at the customer premise. To provide such support QoS has to be integrated into the backbone, last mile and home networking technologies. We survey some of the existing support for QoS in the backbone and last mile technologies and point out recommendations for such support in home networking technology.

The paper is organized in the following way. Section 2 provides a brief survey of the state-of-the-art no-new-wires residential networks technology that includes wireless LANs, phoneline and powerline networks. Section 3 introduces QoS terminology, residential applications and QoS requirements and current QoS network support. Residential gateways survey is presented in Section 4 and Section 5 provides analysis and recommendations.

2 Residential Networks Technology

In this section we will provide a survey of the following technologies: wireless LANs, powerline and phoneline networks followed by their common characteristics and comparison of these technologies. Wireless LANs exhibit the most mature technology supported by standard committees and working groups. We could find abundant material on these efforts. Since 10 Mbps powerline and phoneline based networks technology is new, we could not find any published standards or specifications. The information on these networks was mostly collected from the web sites of the companies that develop these products.

In this survey we will not cover the following potential technologies that may co-exist in the RAN:

1. Infrared technology which is a viable approach for line of sight point-to-point communication (e.g. connection between PC and printer) but because of its obstacle penetration inability it can not be used throughout the home.
2. Technologies that require new wires such as fiber optics and coaxial cable. These networks can provide very high speed communication but require the installation of new communication infrastructure which may be cost prohibitive.

2.1 Wireless Networks

For wireless LANs [5,6,7,8,19] we provide a brief survey of a number of standards and working groups such as IEEE 802.11 standard [9,10,11], two special interest groups Bluetooth [14,15,16,17,18] and HomeRF [13], and HYPERLAN Type 1 standard [12]. We provide a description of a number of wireless LAN features such as topologies, physical layer, media access control and security.

IEEE 802.11 Overview

IEEE 802.11 wireless LAN standard developed by Institute of Electrical and Electronic Engineering (IEEE) specifies both the physical layer and the media access control layer.

Topologies: Two network architectures are defined: the Ad Hoc Network and the Infrastructure Network (or Client/Server Networks). The Ad Hoc Network supports peer-to-peer communications for stations in the same coverage area. The Infrastructure Network supports wireless to wired communications through a device called Access Point (AP). The AP also allocates bandwidth within the coverage area.

Physical Layer: The physical layer standard specifies a diffused infrared and two RF transmission methods. The infrared uses 4 or 16-level pulse-positioning modulation method, which supports one and two Mbps. The two RF methods are Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS). They both operate in the 2.4 GHz, in the Industrial, Scientific and Medical (ISM) unlicensed band. DSSS uses the Differential BPSK (DBPSK) and DQPSK modulation techniques, while FHSS uses 2-4 level Gaussian FSK modulation methods. One and two Mbps are supported by the DSSS and one Mbps is supported by FHSS.

Media Access Control: IEEE 802.11 standard defines two access methods denoted as the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF) that coexist without interference. The seamless integration of the two access methods is obtained by the use of a superframe denoted as Contention Free Repetition Interval. Each Contention Free Repetition Interval includes the following two periods: 1) the contention free period in which PCF protocol is used and 2) the contention period that uses the DCF protocol.

The PCF protocol is based on a Polling Scheme controlled by the Point Coordinator (PC). A station with data for transmission in the contention free period has to register first with the PC in the contention period. The PC maintains the list of registered stations and polls each one according to the polling list. The standard does not define the polling order or for how long each station should transmit.

In the DCF period the media access control method for data transfer is similar to Ethernet IEEE 802.3 standard. While IEEE 802.3 uses the Carrier-sense, multiple access with collision detect (CSMA/CD), IEEE 802.11 uses the Carrier-sense, multiple access with collision avoidance (CSMA/CA). MAC operations are based on Physical layer information such as the clear channel assessment (CCA) algorithm that retrieves the strength of the received signal. It then identifies if the channel is idle or busy and passes this information to the MAC. To minimize collisions, the MAC implements an information exchange method by using the Request To Send (RTS), Clear To Send (CTS), Acknowledgement (ACK), and network allocation vector (NAV). The MAC also provides the following services: the association, re-association, and authentication.

Security: To protect privacy, IEEE 802.11 uses a technique called Wired Privacy Algorithm (WEP). WEP uses the 64-bit key and RC4 encryption algorithm to protect the transmitted data.

Bluetooth Overview

Bluetooth, which is a special interest group (core team members: Ericsson, Intel, IBM, Nokia, and Toshiba) developed a universal RF standard for portable electronic devices, such as cellular phones, notebook computers, personal digital assistants (PDA), keyboards, etc. The goal is to provide low cost and efficient ad hoc networks for both voice and data transmission.

Topologies: Bluetooth supports both point-to-point and point-to-multipoint connection up to 10 meters range. The devices, from 2 to eight, in the same range form an ad hoc connection called Piconet. One unit in a Piconet will become a master unit which will control the media access, while the rest become slaves.

Physical Layer: The standard that supports up to 1 Mbps specifies the RF transmission in the 2.45 GHz ISM band with the Gaussian-shaped frequency shift keying (FSK) modulation and fast FHSS (1600 hops/sec). Bluetooth also uses Forward Error Correction (FEC) to limit the random noise.

Media Access Control: Bluetooth MAC implements a frequency-hopping/time-division-duplex (FH/TDD) scheme. The scheme divides the channel into slots, 625 microseconds per slot, alternately used for transmission and reception. The standard supports two service types: Synchronous connection-oriented (SCO) and Asynchronous connectionless (ACL). SCO is used for symmetrical, point-to-point circuit switched connections, like voice, by reserving slots. The ACL supports symmetrical or asymmetrical, point-to-multipoint packet switched connections used for data transmission. For voice communications, Bluetooth implements a robust voice-encoding scheme based on continuous variable slope delta (CVSD) modulation.

Security: Bluetooth implements authentication and encryption algorithms for security. The main security features are a challenge-response routine (for authentication), stream cipher (for encryption), and session key generation.

HomeRF Overview

HomeRF is a working group (core members: Compaq Computer Corporation, Ericsson Enterprise Networks, HP, IBM, Microsoft, Motorola, Philips, Consumer Communications, Proxim and Symbionics) that has worked on a standard called Shared Wireless Access Protocol (SWAP). The goal is to enable interoperability between low cost consumer devices for both voice and data traffic in home and small office environment.

Topologies: SWAP supports two topology types: an Ad Hoc network and a Managed network. The Ad Hoc network supports only data traffic and the Managed network supports both data traffic and time critical communication, such as interactive voice.

Physical Layer: SWAP adopted the Digital Enhanced Cordless Telephone (DECT) and a relaxed physical specification of the IEEE 802.11. The standard specifies a 100 mW RF transmission in the 2.4 GHz ISM band. SWAP implements 50 hops per second FHSS with 2 FSK and 4 FSK modulation techniques that support 1 and 2 Mbps respectively. The standard supports up to 6 full duplex conversations for voice connections and up to 127 devices per network.

Media Access Control: The standard that is an adaptation of the IEEE 802.11 MAC standard, supports two service types: Isochronous and Asynchronous. Any node in the network can be an Isochronous node, Asynchronous node, or a mixture of both types. For Isochronous communication such as interactive voice, cordless tele-videophones, Time Division Multiple Access (TDMA) is used. Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA) is used for Asynchronous communication such as data transfer. The 20 ms channel access cycle frame structure is controlled by the Central Point (CP). The frame is divided into a CSMA/CA portion and a TDMA portion, with up and down link packets interleaved by the Beacon packet sent by the CP.

Security: SWAP implements the Blowfish encryption algorithm with over 1 trillion codes to protect the content of the transmission data.

HIPERLAN Type 1 Overview

HIPERLAN Type 1 was developed by the European Telecommunication Standard Institute (ETSI) along with other standards in this family: HIPERLAN Type 2, HIPERAccess, and HIPERLINK. HIPERLAN operates in the lower sub-layer, MAC, of the Data Link layer and Physical Layer in the OSI Model.

Topologies: HIPERLAN supports both the Infrastructure (cellular) model and the Ad-hoc (peer-to-peer) model. All traffic in the Infrastructure model will need to flow through a central controller. In the ad-hoc model two stations within range can communicate directly. HIPERLAN has also implemented an association mechanism called “neighborhood discovery” to allow a new station to join the network.

Physical Layer: HIPERLAN Type 1 is a wireless Ethernet standard that operates in the 5 GHz spectrum with the approximate data rate of 23.5 Mbps. It uses the GSM RF transmission scheme with the implementation of Gaussian Minimum Shift Keying (GMSK), a constant envelope modulation scheme.

Media Access Control: HIPERLAN MAC sub-layer includes two parts: the HIPERLAN MAC layer and the Channel Access and Control (CAC) layer. The HIPERLAN MAC layer defines the protocols for power conservation, security, multi-hop routing, and upper layer interface. The CAC layer defines the channel access rules that are based on the channel status, idle or busy. The CAC is designed to support time critical data as well as the fairness for data traffic. The priority for the CAC selected by the HIPERLAN MAC is based on the Residual Lifetime and User Priority. The packet residual lifetime is the time left until the packet should be discarded. The priority is constantly raised as the lifetime of the packet approaches expiration. HIPERLAN suggests two priority levels: normal and high. The channel access cycle is divided into three phases: the priority phase, the contention phase, and the transmission phase. A node will first listen to the channel in the priority phase and compare its own priority level to the selected priority. The node that has a higher priority than the selected priority will have the chance to transmit while the others will defer transmission until the next access cycle. When no higher priority packet exists, the node starts transmission which may lead to collisions with other packets of the same priority level.

Security: HIPERLAN uses the same Wire Equipment Privacy (WEP) used in IEEE 802.11. The stream cipher algorithm in the HIPERLAN is secret and held in custodianship by the ETSI organization.

2.2 Powerline Networks

Powerline [23,24,25,26,27,28,29,30,31] or "carrier-current" networks employ existing AC power lines to transfer information. There are four major powerline standards for very low data rate: 1) X-10 with 60 bps max. data rate, developed by X-10 corporation [24], 2) CEBus [25] (EIA IS-60) with 10 Kbps max. data rate, originally developed by Electronics Industry Association and further developed by CEBus Industry Council, 3) LONWorks [30] with 610 bps to 1.25 Mbps max data rate, developed by LONMark Interoperability Association and 4) Smart House with 50 Kbps max. data rate, developed by Smart House Limited Partnership for the National Association of Home Builders. Typical home automation applications that run on these low speed powerline networks include lighting control system, turn on/off the electrical devices and security systems. It is eminent that for a home LAN that transfers internet access as well as communication between home PCs and printers, a higher speed powerline communication should be developed.

Powerline communication channel characteristics:

1. **Attenuation**: There are many factors that cause attenuation, such as the phase coupling losses, the device impedance, and insertion losses due to the appliances that are plugged in the power line. Another major attenuation factor is the very large inductance at the main transformer that attenuates the high frequencies signal normally used for the data communication.
2. **Noise or interference**: The main sources of noise appliances that are plugged into the power line, cause the impulse that harm the data signal. For example, the dimming of the lighting system, the starting of an air compressor in the air conditioning system or a refrigerator, a vacuum cleaner or electrical drills cause harmonics similar to the switching power supplies (battery charger).
3. **Uncertain network topology**: There can be a lot of plugged in electrical devices that are turned on and off all the time. The computers or appliances that want to communicate with each other may stay in different phases (L1-N, L2-N, or three phase devices).

In today's market, there are a number of companies that currently develop powerline communication products and aim for 1-10 Mbps data rates: Intellon, Echelon, Adaptive Networks, Intelogis and Enikia.

2.3 Phoneline Networks

The phoneline networking [20,21,22] is the attempt to operate a network on existing phone wiring in a household while coexisting with existing standards dictated by FCC such as telephony and xDSL. HomePNA [20] (The Home Phoneline Networking Alliance) was formed to develop a standard for home phoneline networking. Its goals are to introduce inexpensive and easy to use technology. The founders are 3Com, AMD, AT&T, Compaq, Epigram, HP, IBM, Intel, Lucent, Rockwell, and Tut Systems. Now there are almost 100 companies that joined HomePNA.

Phoneline communication channel characteristics:

1. **Attenuation**: Due to the uncertain wiring topology, the signal that bounces back and forth in the phoneline will be attenuated. The impedance mismatch between phone jacks with and without plugged in devices also causes attenuation of the data signal.

2. **Noise and interference**: The uncertain transmission line characteristics occur due to the changing status (idle/in-operation) of the plug-in devices

like telephone, fax, and answering machine. Other appliances, like vacuum cleaner and air conditioning, may also cause noise in the phone lines.

3. **Uncertain wiring topology**: The telephone wiring structure deviates from time to time in a home. It also differs from home to home. Common devices, like a fax or answering machines, can be plugged in the telephone outlet at anyplace.

The phoneline network is designed to coexist with the other services. Regular voice uses the 20 Hz to 3.4 KHz frequency range, xDSL occupies the 25 KHz to 1.1 MHz, and the phoneline networking uses frequencies above 2 MHz. Tut System, a founder of HomePNA, released the 1Mbps specification for the Phoneline networking. The system operates at 5.5 MHz to 9.5 MHz. Tut implements passband filters that screen out and minimize the possible interference from DSL and regular telephone signal. For the Medium Access control (MAC), Tut adopts the IEEE 802.3 CSMA/CD which is used in regular Ethernet and for modulation Tut implements the Time Modulation Line Coding Method.

2.4 Common Characteristics of RAN Technologies

We observe that the wireless, powerline and phoneline technologies have the following common media characteristics:

1. shared broadcast media
2. harsh channel conditions: high attenuation, noise and interference
3. changing channel conditions
4. leakage of information between adjacent homes or apartments
5. dynamic network topology – network nodes join and leave the network constantly

In addition to the harsh media that these technologies have to cope with, we also request full support of quality of service for diverse multimedia applications. A comparison between the three technologies is provided in Table 1.

Technology	Accessibility	Standards / Working groups	Existing products' data rate	Media deterioration factors (should be solved by the physical layer)	QoS support in existing products
Wireless	Can be accessed from anywhere in coverage area	IEEE802.11 HiperLAN Bluetooth HomeRF OpenAir	1-11 Mbps	Obstacles (e.g. walls, partitions) Other RF equipment operating at the same frequency (e.g. microwave oven)	None
Powerline	Many power outlets in each room	NONE (standards exist only for very low speed home automation)	Less than 500 Kbps	Plugged in appliances (e.g. vacuum cleaner, drills)	None
Phoneline	Few jacks in the home	HomePNA 1.0 and 2.0	1 Mbps 10 Mbps	Devices such as fax machine, answering machine or indirect effect from power plugged appliances	None

Table 1: Comparison between wireless, powerline and phoneline technologies.

3 Quality of Service: QoS Terminology, Residential applications QoS requirements and Current QoS Network Support

The ability to provide QoS for multiple users in to the customer premise gives service providers the ability to offer more than just Internet access. With QoS, service providers can expand their service offerings to include differentiated data services, voice and video. For example, a service provider can deploy integrated access devices that support both voice and data applications at the customer premise.

In this subsection we first introduce QoS definitions. In subsection 3.2 we survey residential networks applications and their QoS requirements. In subsection 3.3 we introduce a number of solutions for QoS support on the backbone, last mile and residential networks.

3.1 Quality of Service (QoS) Terminology

The Qos is " The collective effect of service performances which determines the degree of satisfaction of the user " (ITU). In other words, QoS means the collective measure of the level of service delivered to users. It describes how good the service is. The level of service is determined from two perspectives:

- **User perspective:** users evaluate the quality of service based on the level of their satisfaction. Users use their feeling or perception to the service to judge how good the service is. Different applications have different QoS requirements. For example, users evaluate QoS of file transfer service by the speed of the file transfer, fast or slow or by the accuracy of files received. Users evaluate QoS of multimedia applications, such as video streaming, by the smoothness of the video motion or by the sharpness of the picture.

- **Network perspective:** This perspective focuses on the service provided by the network and how good the network performs the service. It is different from the user perspective which focuses on the quality of the application.

QoS parameters present the characteristic applications' QoS requirements. We focus on three QoS parameters, throughout, delay and delay jitter.

Throughput or Bandwidth

This parameter indicates the application bandwidth requirement. Applications can be classified on their bandwidth characteristics as follows:

- *Constant bit rate application (CBR):* These applications, such as IP telephony, uncompressed video and audio stream, generate fix data rate traffic. So the network has to provide this required rate for the application to properly deliver QoS. If the network provides less than this bandwidth, the application can not operate, and if the network provides more than this bandwidth, there is no improvement in the quality of the application. For example, IP telephony requires a constant bandwidth of 64 kbps. If IP telephony receives less than 64 kbps, the conversation is broken.
- *Variable bit rate application (VBR):* These applications, such as compressed video and audio stream, generate variable bit rate traffic and require some minimum bandwidth. QoS is improved as the amount of bandwidth it receives is increased until the bandwidth reaches a maximum point (peak bandwidth) beyond which there is no quality improvement.
- *Available bit rate application (ABR):* These applications, such as email and FTP, do not have any specific bandwidth requirements. These applications can provide services with as much bandwidth as the network can provide. The more bandwidth the network can provide the QoS will improve. For example, if FTP receives more bandwidth, the file transfer will finish faster.

Sample applications bandwidth requirements are provided in Table 2.

	Application	Uncompressed		Compressed	
		Standard	**Data rate**	**Standard**	**Data rate**
Audio	CD-Quality	--	1.4 Mbps	MPEG-Audio	192 kbps
	Telephone Quality	G.711	64 kbps	G.721	32 kbps
Video	HDTV 1920x1080/60fps	--	1500 Mbps	MPEG-2	25-34 Mbps
	Studio-quality digital TV	ITU-R 601	166 Mbps	MPEG-2	3-6 Mbps
	Broadcast-quality TV	--	132 Mbps	MPEG-2	2-4 Mbps
	VCR quality	--	40 Mbps	MPEG-1	1.2 Mbps
	Videoconferencing	--	18 Mbps	H.261	0.1 Mbps

Table 2: Applications' bandwidth requirement

Delay

This parameter indicates the maximum delay of a data packet transmitted across the network. A packet travels across the network through different devices and media and accumulates delay at each element. We can categorize the main sources of delay as:

1. Digitization and packetization delay at the source: The amount of delay depends mainly on the CPU power and load of the source host.

2. Network transit delay

   - Transmission delay: The transmission time of a packet which is a function of the packet size and transmission speed.
   - Propagation delay: The propagation delay between the source and the destination. This delay is a function of the distance between the source and the destination
   - Protocol delay in LAN segments: in case one of the hops in the packet journey from the source to the destination is a LAN, this delay is a function of the data link protocol (e.g. CSMA/CD for Ethernet) and the network congestion. This is a random delay.
   - Delay at intermediate routers: this delay is composed of routing, scheduling and output queueing delay. This delay is random and is a function of the congestion at the specific router and the router configuration (e.g. switching fabric, computation power).

3. Playout delay offset at the destination: Delay of the reconstruction of the packets. It depends on the CPU power and load of the destination host

This total delay must not exceed the applications' maximum delay requirements. For example maximum round trip delay requirement for telephone conversations is 400 ms and for virtual reality 100 ms.

Delay jitter

Delay jitter is the variation of the delay. In a packet switched network each packet travels through different path and experiences different congestion resulting in different delays. Delay jitter distorts time synchronization of the original traffic. The solution is to store the packets in the buffer and reconstruct the synchronization by playing back from the buffer. If the traffic has a large delay jitter, it requires large buffer size. Voice, streaming and interactive video are very sensitive to delay jitter.

3.2 Residential Network Applications and their QoS Requirements

The main applications of home networks [2] will fall into one of the following categories:

1. *Internet connection sharing* – this is the major driving force for the development of home networks. By sharing the Internet connection we do not need to have multiple Internet Service Provider (ISP) accounts or use multiple phone lines. The internet connection sharing will allow simultaneous use of applications such as distance learning, research, telemedicine, telecommunications (email, web phone, web pads, voice over IP, videophone conference), internet/remote games, electronics shopping/commerce, home banking, etc.
2. *Computer peripherals sharing* – today, for multiple computers we need to replicate their peripherals such as printers, scanners, CD-RW, hard disks, etc. We can obtain a much better performance and lower cost if we purchase one set of high-end peripherals and interconnect them through a home network than purchasing a number of low-end peripherals for each PC.
3. *File and application sharing*: multiple users can share applications, move files, and backup data.
4. *Voice and video over IP* – new digital voice and video services are rapidly introduced into mainstream networking. These services can be accessed through the home network from anywhere in the home by any device.
5. *Home automation* – provide a control network for:
   - 5.1 Electrical devices such as coffee machines, personal digital assistants (PDAs), intercoms, TVs, set-top-boxes, thermostat control, microwave oven, sprinkle control, washer/dryer machine.
   - 5.2 Energy control – lighting, heater/air conditioner, hot water.
   - 5.3 Security, safety and monitoring – burglar alarm, fire/smoke alarm, baby monitoring, door control.
6. *Entertainment* – home networks will enable popular multi-player network games either within the home or over the Internet. Digital video originating

from the home or from the Internet will be distributed through the network to all TVs, media players, etc.

We can categorize applications as real time and non real time applications based on their time sensitivity.

1. Non real time application – application that can wait for the information in the correct order, without loss and error such as email, and file transfer
2. Real time application – applications for which the delay is crucial. The information (packets) has to arrive to the users on time, otherwise that information may be useless and the users will experience interruption of service. Real time application can be categorized into :

   a. Interactive applications such as videoconferencing, IP Telephony, and remote presentation.

   b. Continuous applications such as audio and video stream.

Successful launching of real time applications necessitates end-to-end QoS guarantees in terms of bandwidth, bounded delays and delay jitter. Table 3 provides an example of QoS metrics requested by some typical applications. Table 4 includes the size of typical static WWW transfer such as text and picture.

In order to provide end-to-end QoS support, we need to provide QoS support in the wide area network (the Internet), in the last mile distribution system (wireless local loop, satellite, cable modem), and in the home network.

	Maximum Delay (msec)	**Maximum Jitter (msec)**	**Bandwidth**
Voice	250	10	4-64 Kbps (depends on compression)
Digital or Internet audio/radio	250	1	80 Kbps-1.3 Mbps (CD quality)
Compressed video (CD quality) *(MPEG1)*	250	1	1.5 – 3 Mbps
Compressed video (DVD, direct TV) *(MPEG2)*	250	10	6.5 Mbps

Table 3: Real time applications QoS requests

	Traffic type	Size
Text	ASCII	2 KB/page
	Fax	50 KB/page
Picture	600 dots/in, 256 colors, 8.5X11 in	33.5 MB
	70 dots/in, b/w, 8.5X11 in	0.5 MB

Table 4: Size of static WWW transfer

3.3 Existing QoS Network Approaches

3.3.1 Existing Approaches for QoS on the Backbone

Since inception, the Internet has been operating under one service model-the best-effort service model. All packets are treated the same, no matter what applications they belong to. Such a service model is no longer sufficient for today's Internet, where real-time applications such as audio and video are becoming important. Real-time applications are extremely sensitive to packet delays; thus they require a different kind of QoS from traditional Internet applications. The IETF has set up two working groups that are tasked to improve the Internet in the QoS area-the Integrated Service Model Working Group and the Differentiated Service Model Working Group.

Integrated Service Model

The Integrated Service Model defines three classes of services:

- Guaranteed service-packet delays have an upper bound
- Controlled load service-resembles best-effort service found in a network that is lightly loaded
- Best-effort service-the model in the Internet today

In providing guaranteed service, the Integrated Service Model Working Group has defined RSVP, which allows the receiver to request a certain amount of bandwidth allocated for its communication flows. Figure 1 shows the how RSVP works. The RSVP protocol places many demands on router resources. Each router along the path must maintain states for each flow. As the number of flows increases, the demands placed on routers increases proportionally.

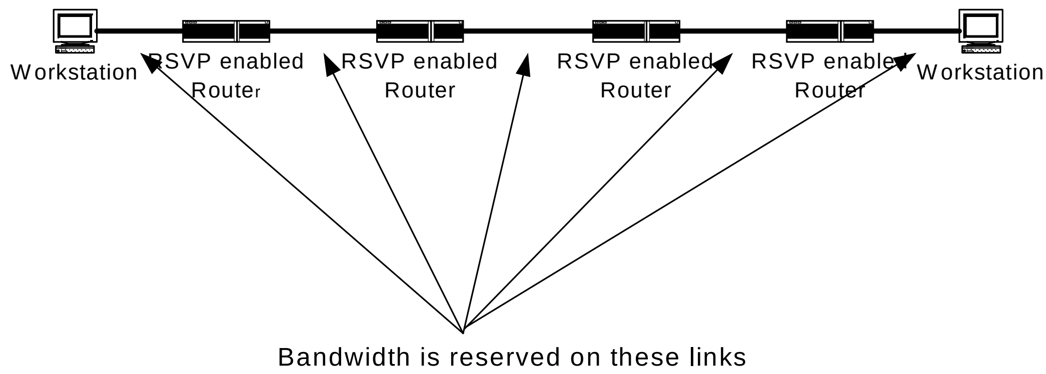


Figure 1: Bandwidth reservation for Integrated Services Service Model.

Differentiated Service Model

The IETF Differentiated Service Model provides a kind of QoS that requires less resources from routers, and at the same time can treat traffic flow differently according to application needs. With the Differentiated Service Model, routers do not need to keep state information for traffic flows. This architecture uses the type of service (ToS) field of the IP header and allows the sender to mark the field according to the need. Routers along the path look at the ToS bits and act accordingly.

3.3.2 **Existing Approaches for QoS on the Last Mile**

In cable modems, DSL and wireless broadband access, the channel is shared among several users. With this scheme, individual user traffic streams compete for available bandwidth resulting in degraded service for users. These limiting characteristics deny service providers the ability to effectively guarantee service level agreements.

Standard committees and companies have started to address the QoS issues for cable modems, e.g., DOCSIS 1.1 [39] developed by Cable Labs. Although the specification for DOCSIS 1.1 has not been finalized, certified products are expected in the third quarter of this year. The specification will support fragmentation in the upstream and downstream, allowing providers to offer tiered services and support QoS reliant applications. Much like the QoS found in ATM, this lets the service providers guarantee a given amount of bandwidth to its customers. Provisions for allowing telephone line quality voice over IP is another promising feature in DOCSIS 1.1. This will allow cable companies to compete with local telephone companies for dial-tone business. Many cable access providers are already gearing up for this new service.

Some broadband wireless and DSL equipment providers consider the use of ATM technology which can deliver multiple services. Exploiting ATM functionality the network enables the implementation of QoS, statistical gain and service flexibility.

3.3.3 Existing Approaches for QoS for Home Networks

Existing solutions in home networks use collision based MAC protocols (similar to Ethernet CSMA/CD MAC protocol) as channel access schemes. These protocols cannot guarantee quality of service in terms of bandwidth, bounded delay and delay jitter to multimedia applications such as voice, video, and control information. Some existing standards such as IEEE 802.11 and HomePNA 2.0 propose solutions for voice and video support, but we are not aware of any implementations or measurements that provide evidence that it provides Quality of Service support. In [31] the authors propose a software-based solution that works on any physical layer (wireless, phoneline and powerline) and provides quality of service support for multimedia applications. We report next a number of experimental results that we obtained in our laboratory.

Our testbed shown in Figure 2 emulates a home network wireless LAN that interconnects to the ISP through either a wireless local loop, cable modem or xDSL, and most of the information is retrieved from the Internet. We have 5 computers in the home that are interconnected through Webgear 2Mbps FHSS Wireless LAN cards. One of these computers acts as a gateway (similar to a residential gateway functionality) and has two network cards, one to the internal Wireless LAN card and one 10/100 3Com Ethernet card that interconnects the internal LAN to a server (the internet service provider) with bandwidth of 512 kbps. This is our way of creating a connection that emulates the home to ISP connection. The gateway PC includes Proxy software that allows the internal PCs to retrieve data from the Internet. All video and data files (ftp) are retrieved from the pipeline to the server acting as the Internet service provider. An extra computer is dedicated to be a network sniffer that collects the necessary data that we use to provide the network performance analysis.

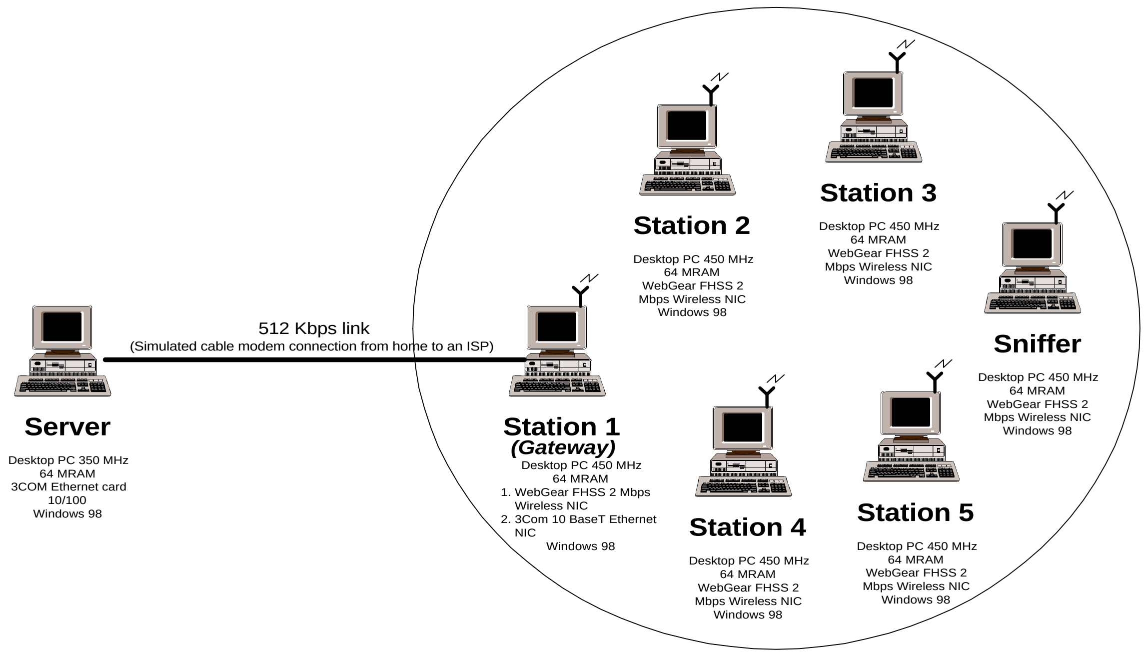


Figure 2: Home Wireless LAN Testbed

We retrieve from the server (i.e., the ISP) one video session and a number of FTP sessions. Figure 3 compares the bandwidth allocated to the video session as a function of the number of FTP sessions with and without our software framework presented in details in [31].

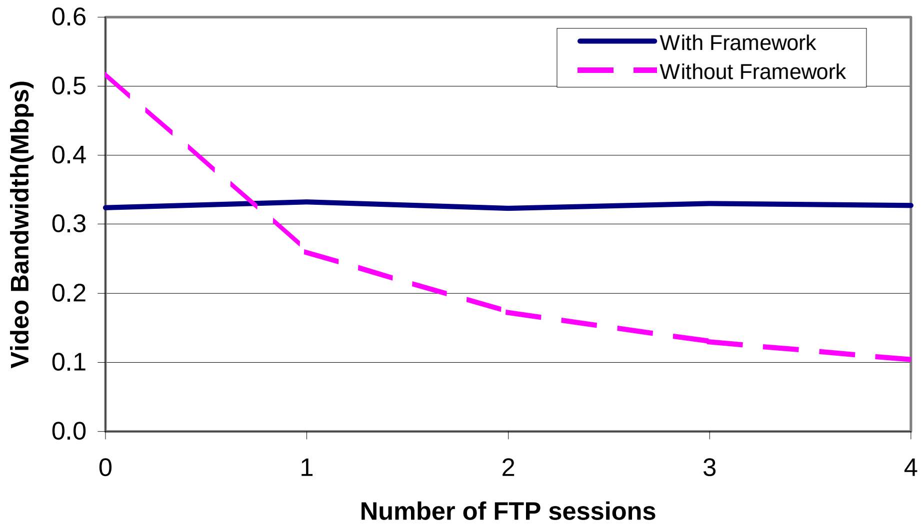


Figure 3: Bandwidth allocated to the video session as a function of the number of FTP sessions with and without the software framework

We observe that without our framework, the bandwidth allocated to the video stream decreases as the number of ftp sessions increases. Practically, after the first ftp session the video session does not get the required bandwidth. In contrast, we notice that with our software framework the amount of bandwidth allocated to the video stream is almost constant, i.e., it does not change as a function of the number of ftp sessions. In other words, the video quality is not affected by the ftp traffic.

4 Residential Gateway

Home users will be faced with the prospect of dealing with a very complicated multi-node switching problem that interconnects multiple home technologies (as stated in Section 2) with multiple last mile technologies. These same customers that have trouble programming a VCR (surveys indicate that up to 70% of the adults in fact can not program a VCR) can not be expected to deal with this problem. Therefore, there is only one option, i.e., devise a technology solution that will handle this function and hide the complexity from the consumer. This solution is a Residential Gateway.

The idea of the Residential Gateway, then, is to hide all of this complexity from the consumer and perform the needed functions in the background, similar in concept to the devices now available to automatically program VCRs. While the Residential Gateway concept is primarily aimed at filling needs for the consumer, it also meets the needs of network operators and device (consumer electronic) designers. The main concern for these latter two groups is in having a standardized interface point for their operations and for their design efforts.

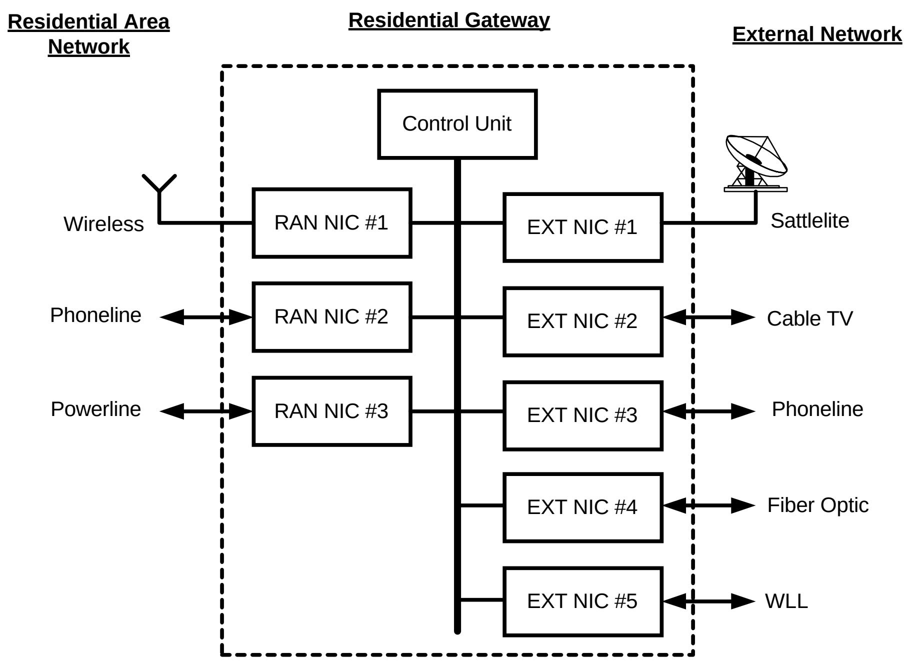
The residential gateway (RG) [2,3] that interconnects network devices inside the home to the last mile network (see Figure 4) should have the following functionality:

1. Seamless interface among different home network technologies (Phoneline, Powerline, Wireless, etc.)
2. Interface between home networks and external networks (POTS, Cable TV, ISDN, Wireless Local Loop, xDSL, etc.)

In addition to these two functions, RGs are expected to provide users the following intelligent services:

1. Security services (e.g. IPSec, firewall mechanisms such as packet filtering, encryption module)
2. Dynamic IP address management (e.g. DHCP server, local DNS functions) allowing the use of a single IP address for the home
3. Quality of Service modules
4. Billing software

5. Automatic network configuration module that allows Internet devices to boot up and begin functioning on the network without having to be configured with a network address. This scenario permits devices to begin functioning as soon as they are "out of the box." In addition, devices dynamically learn about their environment so that they can adapt appropriately when moved to a different network.
6. Remote management (e.g. SNMP compliant, TFTP services that allow download of new gateway configuration). This feature allows service providers to service the RG remotely.



EXT: External Network
RAN: Residential Network
NIC: Network Interface Card
WLL: Wireless Local Loop

Figure 4: An Example of a Residential Gateway

Many companies have developed their own RG products. However, more sophisticated and coordinated RG development requires the creation of standards. There are three major initiatives to create standards for residential gateways.

TIA's TR-41.5 committee — This committee has attempted to create specifications for a centralized gateway device that includes the following features:

- The physical interface to terminate all external access networks to the home, with multiple residential services being delivered over each type of access network
- The enabling platform for residential services to be delivered to the consumer, for example, telephone, television, and PC networking, or the termination point of internal home networks.

The proposed standard, originally referred to as a multimedia premises reference architecture, will be called TIA/EIA/TSB-110.

ISO/IEC's HomeGate — ISO (the International Organization for Standardization-Geneva) and the IEC (the International Electrotechnical Commission-Geneva) have proposed a residential-gateway model for HES (home electronic system). This model is called HomeGate, defined as the connection between a wide area network (WAN) and an in-home local area network. HomeGate's functions include WAN termination, protocol translation, resource arbitration, firewall security, and privacy assurance.

Working Group 1 of ISO/IEC JTC 1/SC 25 developed the first specification of HomeGate in October 1998. The working group has been seeking comments by developers of residential and commercial gateways. The HomeGate specification will eventually become part of a new standard under development, entitled "Interconnection of Information Technology Equipment."

Open Services Gateway Initiative (OSGi) — In March 1999, 15 leading technology companies announced an alliance, called the Open Service Gateway Initiative (OSGi), to establish a specification for an open service gateway. The goal of the alliance is to create an open interface for connecting consumer and small-business appliances with Internet services. OSGi will enable, consolidate, and manage voice, data, Internet, and multimedia communications to and from the home and small office. The service gateway will also function as an application server for a range of other high-value services such as energy measurement and control, safety and security services, health care monitoring services, device control and maintenance, and electronic commerce services. OSGi will also be designed to complement and enhance existing and emerging residential networking technologies like CEBus, LONWORKS, VESA, Bluetooth, HomePNA, HomeRF, and HAVi. The first draft of a specification from OSGi is expected to be ready in 2000.

5 Analysis and Recommendations

The rapid pace of change and the dynamic developments in broadband communications present great opportunities for both American consumers and the communications industry. Consumers stand to benefit from improvements in technology, which will lead to the provision of greater, faster, and more efficient services—all at affordable costs. Companies providing broadband services and

technology stand to benefit from an expanding market, which will lead to increased revenues and a greater number of products and services.
In order for these benefits and opportunities to be realized, however, there must be a competitive marketplace. Government can promote a competitive market by encouraging innovation, investment, and infrastructure buildout. In so doing, government insures that innovative and cost-efficient services will be provided to consumers by a diversity of entities—or multiple pipes to the home. There has o be choice and competition at every level of Internet access**: the backbone level, the last mile level and the home network level.** Each one of these networks has to have an open network architecture. The Commission's Office of Engineering & Technology should monitor this fact.

The Residential Gateway which is the entry point into the consumers' home, should also be designed with this flexibility in mind. The RG should allow the connection of multiple home networking technologies with multiple ISPs that potentially use different last mile network technologies. This design will allow the consumer to pick multiple ISPs and will allow ISPs to pick multiple last mile distribution technology. It will also allow consumers to shop for different services from different ISPs, the same way they shop for different products at different web sites.

Recommendations for QoS

The competition between ISPs is expected to have a positive effect on QoS offerings. First, QoS as perceived by the customer will be a key competitive factor between ISPs. Second, user demand will drive a more differentiated QoS offering, enabling customers to obtain the QoS level that they require and that they are willing to pay for. ISPs will therefore have to provide high QoS in order to attract and retain customers. The users have to be put in a position to make the best choice between different provisions at various QoS levels.

As explained in the previous chapters, the provision of QoS is a very complex issue due to the multidimensional QoS definitions, the multiple networks involved (backbone, last mile and home networks), and the possibility of divergence between QoS as perceived by customers (customer satisfaction) and QoS offered as measured by the level of QoS indicators (technical performance).

We propose the set up of a national committee that should be open to all interested parties: manufacturers, standardization bodies, service providers, equipment manufacturers, user associations. This committee that will have regulatory authorities and act as a catalyst will undertake the following issues:

1. Definitions of customer-oriented QoS indicators/service levels. These QoS levels must be reviewed regularly due to advances in network technology and applications, and users' expectations.

2. Derive ways to monitor QoS delivered to consumers, i.e., find measurement methods for the selected QoS indicators, define the reporting format and auditing procedures. If QoS performance targets are not met, consider penalty procedures.
3. Define who has the primary responsibility for QoS delivery to customers. Since the network is composed of multiple segments (the WAN, the last mile and the home network) a single entity (e.g., the ISP) should be responsible for the service contract.

Recommendations for Home Networking

One of the important issues in technology development for the home networking market and as a consequence the last mile technology are the following:

1. Standardization for powerline networks. Due to lack of standards in this area the technology innovation is slow and lagging behind the phoneline and wireless LAN alternatives.
2. Standardization for residential gateways. Encourage collaboration between existing working groups (e.g., TIA and ISO/IEC) that will result in a single international standard for residential gateways. This standards should include standard interfaces that will allow the use of multiple home networks and multiple last mile technologies. Also allow for future expansion as other standards appear such as powerline networks. Develop standard APIs within the residential gateways that allow the use of different software applications within the RG.

References

1. Residential Broadband Networks, by Uyless Black, Prentice Hall, 1998.
2. The third annual CONNECTIONS'99: Enabling the Networked Home, Vancouver, Canada, May 12-14, 1999.
3. The Residential Gateway: A Summary, Clif Holliday, http://www.apogeeintl.com/gateway.htm
4. Cable-Modem And Chip Suppliers Respond To Call For More IP Services, Loring Wirbel, http://www.techweb.com/news/story/TWB19980506S0011
5. The Wireless LAN Alliance, http://www.wlana.com
6. Home wireless networks, http://homewireless.com
7. Planning and Implementing Wireless LANs, Peter Rysavy, http://www.networkcomputing.com/netdesign/wlan2.html
8. WLI Forum, http://www.wlif.org/tech/spec_overview.htm, http://www.wlif.com/about/index.html
9. IEEE P802.11 Wireless LAN Standard.
10. White papers on the IEEE 802.11 Wireless standard, http://www.proxim.com/learn/whiteppr/80211wp.shtml, http://www.proxim.com/learn/whiteppr/80211wp.pdf http://www.wlana.com/standard/index.html
11. HiperLAN Type1 Technical Overview, http://www.hiperlan.com/hiper_white.pdf
12. HomeRF Working Group, http://www.homerf.org
13. BLUETOOTH -- The universal radio interface for ad hoc, wireless connectivity, by Jaap Haartsen, http://www.ericsson.se/review/pdf/1999031.pdf
14. GSM Data Knowledge – Bluetooth Technology, http://gsmdata.com/blutooth.html
15. Bluetooth Overview, http://www.bluetooth.net/tech_overview1.asp
16. Bluetooth, http://www.tdksys.com/bluetooth
17. IrDA versus Bluetooth, http://www.countersys.com/tech/bluetooth.html
18. Wireless Data Forum, http://wirelessdata.org
19. HomePNA http://www.homepna.org
20. Epigram Homepage http://www.epigram.com
21. Tut Systems Homepage http://www.tutsys.com
22. United Utilities, http://www.unitedutilities.com
23. X-10, http://www.x10.com
24. CEBus Industry Council Inc., http://www.cebus.org
25. Domosys Corporation, http://www.domosys.com
26. Intelogis, http://www.intelogis.com
27. Adaptive Networks, http://www.adaptivenetworks.com/
28. Intellon, http://intellon.com
29. Echelon, http://www.echelon.com

30. Home automation standards, http://hometoys.com/htinews/apr98/articles/wacks/wacks.htm
31. Converged Voice, Video, and Data Wired-Wireless LANs Testbed, A.Ganz, A.Phonphoem, N.Llopis, K.Wongthavarawat, University of Massachusetts, Amherst, and Z.Ganz, EnrichNet Inc., MILCOM 1999, Atlantic City, NJ, November 1999.
32. Connect Your Home to the Future, 3Com Technical paper, http://www.3com.com
33. RF directly converts on 802.11 line, Rishi Mohindra, EE Times, November 29, 1999, Issue 1089.
34. Standards Efforts from Europe, Japan and U.S. Coalesce around Gigahertz Networks, Loring Wirbel, EE Times, January 18, 1999, Issue 1044.
35. Clearing up some confusion about HiperLAN 2 standard, Larry Taylor, EE Times, October 11, 1999, Issue 1082.
36. The use of Existing Electrical Powerlines for High Speed Communications to the Home, Michael Propp, http://ksgwww.harvard.edu/iip/doeconf/propp.html
37. Which One Should I Use – Part III 120/240v Residential Coupling, Phil Kingery, HTINews Article, http://hometoys.com/htinews/jun97/articles/kingery/kingery3.htm
38. Low-Cost Multi-Service Home Gateway Creates New Bussiness Opportunities, Coactive Networks, White Paper, http://www.coactive.com
39. CableLabs, http://cablemodem.com