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Ubiquitous Computing

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A Comparative Study of Communication Infrastructures for the Implementation of Ubiquitous Computing

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Translation: Steve Turpin

This article focuses on communication networks that could be used in a ubiquitous computing environment. These networks are heterogeneous due to the variety of device types that can be connected and the different kinds of traffic that can be transmitted. Communications networks can be split into two major types: control networks and multimedia networks. A separate study has been made of wireless networks, since their being so different from wired networks makes them of special significance to ubiquitous computing.

Keywords: Ubiquitous Computing, Ubiquitous Environment, Home Automation, Wireless Networks, Control Networks, Multimedia Networks.

1 Introduction

Ubiquitous computing is based on the need to give a great many day to day physical objects computational and communicational capability, thereby creating a large network of interconnected devices. This usually involves the deployment of heterogeneous communication networks, due to the great variety of devices which can be connected and the different types of information they can exchange.

An initial classification has been made of the type of network needed to be deployed depending on the type of traffic to be transmitted. Firstly we will be looking at control networks suitable for controlling any sort of electronic or electrical device.

These control networks can be further split into general purpose networks and home automation oriented networks. The former have a data oriented communication model, in which communication between two devices is achieved by establishing relations between transmitter and receiver variables. In the case of home automation, communication between devices is established by defining a set of specific functions which determine what operations can be performed.

Then we will be looking at multimedia networks. The term multimedia networks has been used to refer to networks capable of transmitting voice and video in real time. There are two basic requirements for this type of traffic which dictate some minimum features for multimedia networks:

- The first restriction arises from the need for a minimum bandwidth to be able to transmit multimedia traffic. This minimum is quite high, especially in the case of video, and the more quality you want the greater the bandwidth you will need. Control protocols do not have enough bandwidth to handle multimedia traffic. Also the infrastructure of this type of networks is too expensive for them to be used as control networks as well. This is why, for the moment at least, you will find two networks existing in parallel wherever there are ubiquitous devices.
- The second restriction is imposed by the isochronous nature of multimedia traffic. When a digitalized video/audio signal

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is transmitted samples of the each packet are sent. As the packets arrive the receiver extracts the samples and is able to reconstruct the analogue signal. For the reconstruction to take place in real time there is a limit to the latency between two consecutive packets. This means that the network must be provided with mechanisms to ensure an acceptable latency for the whole transmission.

Control networks and multimedia networks are very likely to exist side by side for some time to come, given the need for transmitting different types of information, and the excessive cost of using multimedia networks for control purposes.

Regarding physical transmission media these fall into two clear categories: wired infrastructures and wireless infrastructures. As a general rule wired networks currently favour power lines and twisted pairs:

- The power line has the advantage that existing wiring can be used and only the devices need modifying, which reduces costs and makes it easy to reach homes. However it is highly sensitive to noise and interference. There is the additional problem that electrical network parameters (voltage and frequency) vary from country to country which means devices either have to be duplicated or adapters need to be added.
- Twisted pairs mean having to deploy a new network, but give better performance.

Control networks for home automation purposes favour the power line solution, which is only to be expected since it enables them to capture a greater market share.

Wireless networks offer a solution which is a hybrid of the previous two, with the added advantage of eliminating the need for wiring. This type of networks, which can send both control and information data as well as multimedia information, is becoming the only option for a mobile ubiquitous system, and the most practical option to avoid wiring in a ubiquitous environment.

2 Control networks

These are networks used to control the sensors and activators of a ubiquitous environment. Two factors condition the design of these networks:

a) The information that is sent by the sensors or is received by the activators does not suffer rapid variations.
b) A large number of these devices can exist in the same environment.

The first condition allows the creation of simple protocols, which is linked directly to the second condition, since the additional cost of each device will be less.

2.1. General purpose networks

Among these networks EIB and LONWork are perhaps of most interest. Both are based on a decentralised system in which each of the devices connected has its own control. The network is like a logical bus to which the devices are added. As a shared medium is used, arbitration mechanisms are implemented to resolve collisions.

As they use a data oriented communication model, for an association between two variables to be possible they must be of the same type. This has meant that both protocols have tried to define data semantics which are flexible and as complete as possible. This data type definition is the key to achieving interoperability between different manufacturers, and one of its most immediate advantages is that the devices can carry out a great many different functions depending on how they are interconnected.

EIB

The EIB bus [Goossens 98] is set to become one of the standards which could dominate the European market in coming years. It is very well positioned, since it is backed by a large consortium of major European companies, Siemens being one of them. This position has recently been strengthened by the creation of Konnex.

Konnex is an initiative aimed at establishing convergence criteria among three of Europe's most important control networks: EIB, EHS and Batibus. EIB is the cornerstone of this initiative.

The EIB protocol can support 14,400 devices per network, transmitting at a speed of 9,600 bps over a twisted pair network and at 2,400 bps over a power line network.

In the field of research, progress is being made in the development of TCP/IP gateways, integration with Jini and intelligent agents. In Spain, EIB has been used both in private and public buildings, although there are still few related research projects [Fernández-Valdivielso et al. 00].

LONWork

LONWork [LONWork 99] is a proprietary standard belonging to the company Echelon, and is the most widely used in the USA. LONWork uses the protocol LonTalk for both control and state data exchange. All information about this protocol is available to any manufacturer on payment of a licensing fee to Echelon for each device manufactured. The companies Cypress, Toshiba and Motorola market an integrated circuit called Neuron which executes the protocol.

Each Neuron integrated circuit has a 48 bit unique identifier, which means that the number of devices is not an issue. Transmission speed is 4,000 bps over a power line and can be up to 1.25 Mbps over twisted pairs, but under highly restrictive conditions.

LONWork has a greater presence in Europe than EIB has in the USA. Projects carried out using this protocol may be found in both research and commercial fields. The Centre of Excellence for Fieldbus Systems of the Technological University of Vienna merits a special mention with regard to the latter field.

2.2. Home automation oriented networks

This type of networks is mainly used in residential environments. Among these networks X10, CeBus and SCP are of particular interest.

X10

X10 [X10] is a communication protocol which allows the control of electrical devices over the electric power network. The standard first emerged 20 years ago as part of a series of

experiments carried out by the company Picosystem and has been used in the commercial world for over 15 years.

The protocol's performance is rather limited due to its simplicity. Only 16 commands are defined, and the network can only support a maximum of 256 devices connected via the electrical network.

Even so, due to the fact that the devices are cheap and easy to install it is a very popular protocol in the United States and it has been used in a vast number of projects. Most home automation installations in the USA use this protocol. It can currently be found as a control bus in research projects related to ubiquitous environments [Coen 98].

CEBus

CEBus [Douligeris 93] bears some similarities to X10 as regards its design philosophy but its performance is far superior. CEBus allows different types of physical media and a larger number of devices. CEBus's most important contribution is the language CAL. This is a command oriented language which supports the control of devices connected to CEBus and assign resources. The language defines a set of functions for each device. CAL uses the object oriented programming paradigm. However, CAL objects are not organized in hierarchies (the concept of inheritance does not exist as it is understood in object orientation), but their behaviour depends on the context. For example, an analogue control object can be used to represent either a volume control, a thermostat or a regulator. The precise function is defined by the context in which the object is instanced. CEBus supports speeds of up to 8,000 bps.

SCP (Simple Control Protocol)

SCP [SCP] is an open protocol developed by Microsoft. It combines both network specific and general purpose features. It is a message oriented protocol for sending messages between devices. Each device is modelled as a set of properties which give status information, a set of actions providing functionality to the device, and a collection of services, where each service is a set of properties and actions. It also provides mechanisms whereby relations between variables can be established, so that when a variable changes the change is automatically passed on to the variables which are related to it. Another novel feature is that each device added to the network has to be registered. It is therefore quite easy to find out which devices are available at any given moment.

SCP is Microsoft's latest bid to get into the home automation market. At this moment in time SCP is in its development phase and the only possible transmission media is by power line.

3 Multimedia networks

An aspect which is intimately linked to ubiquitous computing is what could be called ubiquitous presentation. By this is meant being able to access multimedia information from any audio-visual device within the environment. To achieve this an intelligent and user-centred distribution of audio and video is necessary. A classic example is when music follows the user around all the rooms of the house[1]. To do this the system needs to be able to represent and control all continuous information flows produced. With the digitalisation of video and audio new protocols have emerged with the aim of providing a solution to the problem of interconnection of new electronic devices both from one device to another and to PCs. The current practice of transmitting all signals digitally is instrumental in reducing interconnection costs and standardizing equipment.

Among current multimedia networks IEEE 1394, USB and Ethernet are the most important.

	IEEE 1394	USB
Communication:	Serial/Parallel	Serial
Transmission speed:	400 Mbps	1.5/12/240 Mbps
Hot connection:	YES	YES
Power:	YES	YES
No. devices/network:	64449	127
Intended for:	Fast devices	Slow peripherals
Support:	Sony, Apple, Compaq	Microsoft, Intel

Table 1: Performance comparison of IEEE 1394 and USB

IEEE 1394 vs. USB

IEEE 1394 [IEEE_1394 95] and USB [USB 98] are two solutions which allow the interconnection of digital audio-visual devices. USB first appeared in the PC world as a high speed serial bus, and aims to become the standard for communication between peripherals and PCs. IEEE 1394 provides enhanced performance and allows a wider scope of application.

Both networks guarantee quality of service, by obliging devices intending to transmit to have previously booked part of the bandwidth. The protocol then decides whether or not to allocate bandwidth (Table 1).

IEEE 1394 provides the physical layer on which HAVi (Home Audio Visual interoperability) is executed. HAVi [HAVi 98] gives enhanced functionality in audio and video management. HAVi is an initiative driven by a consortium made up of various companies in the audiovisual sector who are trying to promote digital audio-visual transmission.

Ethernet

Ethernet is a local area protocol developed by Xerox Corporation in collaboration with DEC and Intel in 1976. As it is based on an arbitration protocol it has no mechanisms by which to guarantee necessary bandwidth for the whole duration of the transmission. However the standard has had more than twenty years of development which has consolidated it as a highly reliable, high performance technology. It also has two important advantages:

- As Ethernet's interoperability with the IP protocol is well supported, the gateway between the ubiquitous devices'

1. By passing from one speaker to another as required.

internal networks and Internet connection does not pose any problems.
- It allows transmission speeds from 10 to 100 Mbps. Although its primary aim was to transmit data between computers, it has the enough performance to enable it to carry multimedia traffic.

One example of a ubiquitous application using an Ethernet network is HomePNA [HomePNA 98]. It consists of a protocol which uses the wired telephone network combined with Ethernet technology to distribute information around various rooms in the house. HomePNA can currently transmit up to 10 Mbps, and it is reckoned that the network may support up to 100 Mbps. At the moment up to 25 devices can be connected to the network, which makes it more suitable for use as a high speed backbone.

4 Wireless networks

Although short range wireless networks can be used both for controlling devices and for multimedia information flows, they merit a special mention given their relevance to ubiquitous environments. If true pervasiveness of computational devices is the aim then the only possible solution lies in the use of a wireless network. To give full freedom of movement to the devices they will have to incorporate some kind of wireless technology.

Wireless technology provides a series of advantages over wire which can be summarised under the following two headings:
- Mobility: mobile terminals require a series of applications which are beyond the scope of a wired network. The possibility of connecting any device regardless of its geographical location is one of the keys to achieving truly ubiquitous computing.
- Flexibility: unlike wired infrastructures which are very expensive to set up, wireless networks are basically very easy to create, modify and remove.

Two types of wireless technology can be used:
- Infrared: traditionally by far the most common application of this technology has been in remote control devices. Currently applications for data communication between peripherals and the computer (IrDA protocol) are also being develop, while infrared can even be used to deploy computer networks. They use an infrared band in the radio-electric spectrum and to be able to intercommunicate terminals have to be in line of sight of each other with no intervening obstacles.
- Radio frequency: In this case higher frequency bands are used, usually the 2.4 GHz band since it has not been allocated on a worldwide scale. Modulation techniques are also different. While pulse modulation is used in infrared, radio frequency makes use of two modulation techniques: spread spectrum and frequency hopping. RF communications can be split into two types: narrow band and broadband, depending on the bandwidth used. Narrow band communication needs a clear line of sight, just like infrared, while broadband is more flexible as it allows communication with terminals not in line of sight.

Wireless networks are not without drawbacks, however: they also suffer from some serious problems which limit their use in some situations:
- Interferences: The physical media used is the air, where the signal is far more prone to degradation than if it were confined to a wire. In infrared technology the main source of interference is sunlight, which contains infrared components which can overpower the original signal. In radio frequency, for example, microwave ovens cause a lot of interference on the 2.4 GHz band. Also as its frequency band is not regulated it is also vulnerable to the emergence of new devices which could produce interferences.
- Availability: one of the basic conditions to define an acceptable quality of service is that the end user can get a good, clear connection whenever they want. Infrastructures not using wire have some serious drawbacks in this respect, due once again to physical media used. In infrared communications this factor is, if anything, even more critical, since an obstacle in the line of sight can permanently interrupt the communication between two terminals. In radio frequency connections, air quality can produce attenuation of the signal, both in time and in frequency, which can cause the signal to randomly disappear. These breaks in connection significantly reduce the system's performance, to the point where the quality of service may fall to unacceptable levels.
- Security: One of the advantages that radio-electric space has over wire is that media sharing between terminals is much easier. This also makes it much easier for intruders to tap into the channel. This disadvantage is heightened in radio frequency networks since the compromised terminal is not necessarily visible to the other terminals.
- Batteries: If the aim is to have truly mobile devices, then batteries with a long duration are required. The longer a battery lasts the more space it will occupy, which means bulky terminals.
- Cost: Nodes and terminals for a wireless infrastructure cost more than those for a wired one. As we have already seen, a network's terminals and nodes all need a certain degree of sophistication in order to be able to deal with interference and availability issues, as well as needing security mechanisms and a low power consumption.

We will now be looking at three protocols which play a prominent role in wireless networks for the home. IEEE 802.11 is the most popular protocol used in local area wireless networks, while HomeRF is the protocol of choice for wireless networks in the home. And we will also be taking a look at the special features BlueTooth has to offer.

IEEE 802.11

IEEE 802.11 [IEEE 802.11 97] is an open specification which uses Ethernet technology in wireless networks. In its latest specification (1999) it can reach speeds of 11 Mbps. To provide conflict-free media access the protocol CSMA/CA is defined. This is a variant of the protocol used in Ethernet networks. The difference lies in the fact that in wireless networks, when two stations transmit at the same time it is impossible to detect if there has been a collision. It allows the

use of the three techniques described previously: modulation by infrared, spread spectrum, and frequency hopping.

IEEE 802.11 is one of the most complete and powerful wireless solutions on the market. An example of its use in a ubiquitous environment is [Ortega et al. 01].

HomeRF

The HomeRF [HomeRF 00] Working Group's mission was to achieve interoperability between the greatest number of different devices located anywhere in the home. To this end an open, licence-free standard was developed based on digital communication via radio frequency. This is known as SWAP (Shared Wireless Access Protocol).

SWAP defines a common interface that supports both wireless voice and data services. It has been designed to operate over the basic telephone network and over Internet. It operates in the 2.4 GHz band, using frequency hopping technology. The protocol supports up to 127 devices per network and up to 6 voice connections simultaneously.

HomeRF's current evolution is centred around the development of an industry specification for multimedia traffic, and the development of a range of low cost, low power products.

BlueTooth

Bluetooth [Bluetooth 01] technology is an open specification for wireless data and voice communications. The specification is based on short range, low cost radio links, which allow the creation of ad hoc connections between mobile and fixed terminals.

It uses the 2.4 GHz band. The gross data rate is up to 1 Mb/s, which precludes video transport. Bluetooth makes use of shorter packets to transmit and uses much faster frequency hopping than other protocols. This reduces the impact of interferences from other devices and improves transmission in noisy environments, thus making it more robust.

The major mobile telephone companies have chosen Bluetooth as a standard for short range wireless communications. However by the end of the year 2000 Bluetooth had still not achieved the expected penetration due to the fact that, on the one hand the unit price of the integrated circuits which execute the protocol were still somewhat expensive for mass use, and on the other hand, terminals manufactured by different companies suffered problems of interoperability.

5 Conclusions

This article has looked at the technologies needed to interconnect components making up a ubiquitous environment. On the one hand there are control networks, which are cheap and flexible but have a very limited bandwidth. On the other there are networks which support multimedia traffic but are, however, too expensive to be used as control networks. The likely result of this will be both types of networks existing side by side. Of the multimedia networks the solution provided by Ethernet technology should be borne in mind, since it has had a considerable impact on the local area networks sector and provides adequate performance. A physical media which requires special mention is radio-electric space, since it displays characteristics which are significantly different from wire. Wireless technologies afford two advantages, mobility and flexibility, which make them indispensable for ubiquitous environments.

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