POSITION PAPER: THE ROLE OF PLATFORMS AND OPERATING SYSTEMS IN SUPPORTING HOME NETWORKS

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ABSTRACT

As researchers look beyond the PC there is increasing interest in developing and deploying sophisticated home networks. Such networks might allow the seamless integration of information and services produced both within the home and externally, enabling applications such as the purchase of on-line AV content, tight coupling between kitchen sensors and "Web Van" order forms, and home remote control. From a manufacturers perspective, particularly those manufacturers traditionally associated with business computing, the home market is perceived as a major new opportunity to expand sales. As a consequence, home networks have been an area of intense activity in recent years with the emergence of a range of network solutions (e.g. HomeRF, HomePNA, IEEE 1394, Bluetooth) and middleware to support device interoperability (e.g. HAVi, Jini, UPnP). This focus on networking technologies and middleware platforms suggests that the area of operating systems for home networking devices has received relatively little attention. In this paper we discuss the reasons behind this apparent omission and consider the technological landscape within which operating systems for the home must be researched, developed and deployed.

1. Introduction

For many years researchers have investigated the deployment of distributed systems technologies within home environments. Indeed, solutions such as X.10, a power-line based device control architecture, have been commercially available for many years and most distributed systems platforms have been suggested as home networking architectures at some point in their lifecycle. The perceived benefits of deploying one or more home networks include support for:

(i) *Communication*

Enabling devices to exchange state information and content,

(ii) *Coordination/control*

Facilitating applications such as home automation and,

(iii) *Resource sharing*

Allowing, for example devices, without a display to utilise a nearby TV screen to present their user interface.

Two further factors that are influencing developments in the area of home networking are the rapid deployment of high-speed, always-on Internet links (such as cable and ADSL modems) and the wholesale transition to digital content in the AV domain. Combined with home networks, such trends enable the development of new applications and services including: sharing of single Internet access points; on-line purchase of AV content for presentation and storage in the home network; integration of on-line information and broadcast media for new services; home remote control; on-line multiplayer gaming; and, on-line customer-service for appliances. Consequently, the home is viewed as a major potential market by both service providers and the computer industry.

However, typical home environments are relatively difficult places to deploy traditional distributed systems technologies. Most significantly, the average home contains a wide range of heterogeneous devices with long life-spans: consumers simply do not upgrade their appliances with the same frequency as their PCs. Furthermore, home users are unlikely to install significant new cabling to support a home network, lack the skills and desire to carry out significant network configuration or maintenance and are extremely cost sensitive. In contrast, traditional computer environments are relatively homogeneous with one architecture and OS dominating, and users are tolerant of poor performance, frequent reboots, rapid upgrade cycles and the need to deploy new cabling and employ maintenance staff.

While developing technologies for these different domains, researchers investigating home networking have typically focused on two main problems; the physical connections between devices and the middleware to enable heterogeneous devices to interwork. In this short paper we begin by reviewing developments in both of these domains (section 2). Following a brief analysis of this work we consider the relative lack of activity in terms of operating systems work and attempt to explain this by considering the additional factors which constrain OS deployment in the home (section 4). Finally, section 5 contains our concluding remarks.

2. Developments in Home Networking

2.1. Networking Technologies

In recognition of the problems associated with deploying regular networking technologies such as Ethernet in home environments a number of alternative solutions have emerged.

Home PNA

The Home Phone Networking Alliance is a large consortium (over 100 members at present) that is promoting home networking using existing telephone cabling [HomePNA,98], hence alleviating consumers of the need to rewire their homes. The first version of the standard allows 1Mb/s communications while the emerging second version increases the bandwidth to 10 Mb/s. In both cases the standards are designed to operate simultaneously with phone calls, cable modem access, fax etc. and to be tolerant of the home phone line environment. In particular, the standards are designed to cope with the widely varying topologies found in most homes and the presence of many devices attached to the network including, for example, phones, fax machines and modems.

The first version of the standard has been the subject of a number of field trials reported in [HomePNA,99] which indicates that the equipment can be installed in 88% of homes with no difficulties. The remaining 12% required some additional filters on the line to help cope with problems from noisy consumer equipment and, in some cases, to stop the Home PNA equipment from interfering with existing equipment. There were approximately 2% of homes which caused problems due to their wiring topology. The standard seems to be being actively promoted and products are becoming available from suppliers such as Compaq.

HomeRF and 802.11

HomeRF is a proposed standard for wireless home networking. The standard has been developed by the Home RF consortium which is a collection of companies interested in home networking (see http://www.homerf.org for more details). The standard is at the physical layer and defines a Shared Wireless Access Protocol (SWAP) for use by wireless devices intended for home use. The SWAP essentially provides for a combination of DECT and 802.11 traffic to be sent over the same channel. In practice this means that the standard defines frames which include space for up to six simultaneous voice channels and an 802.11 style portion for data transmission. Total bandwidth is in the order of 1 Mbps. The motivation is that users will want to be able to use a range of wireless devices such as DECT phones, video phones, wireless web browsers etc. within a home environment. Since the voice channels are of a relatively low quality most multimedia applications would probably rely mainly on the data transmission capabilities. Note that the emergence of low cost 802.11 based solutions (e.g. the Apple Airport products) has significantly weakened the case for HomeRF solutions by opening up the possibility of widespread 11 Mbps IEEE 802.11 compliant wireless communications in the home.

BlueTooth

Bluetooth is the name given to the open specification of a new low-cost, short-range wireless system for voice and data communications [Bluetooth,99]. The aim is that the Bluetooth system can be implemented on a single piece of silicon, thus minimizing the cost. The proponents of Bluetooth envisage a world in which a wide range of devices can use Bluetooth to communicate in an ad-hoc fashion. At its simplest, this means that Bluetooth provides a replacement for cables currently used to connect devices enabling, for example, PDAs to be connected to mobile phones even when the phone is still in the pocket of the user. However, Bluetooth offers much more than mere cable replacement: up to eight devices can participate in ad-hoc multi-party communications and Bluetooth devices can, of course, be used as bridges to the Internet.

Bluetooth operates in the 2.4 GHz band and uses a combination of frequency hoping, fast acknowledgements, ARQ schemes and forward error correction to enable reliable transmission of data. The range of Bluetooth devices will typically be between 10cm and 10m but by increasing the transmit power devices capable of ranges of more than 100m can be produced. Bluetooth defines a gross data rate of 1 Mb/s and this can be used for voice and/or data communications. Voice communications are sent using a synchronous channel whereby each packet is sent in a reserved slot and packets are never retransmitted. Bluetooth can support up to three concurrent voice channels (each channel occupies 64 Kb/s). Data is sent using an asynchronous channel with retransmissions. This channel can be configured as either an asymmetric channel with 721 Kb/s in one direction and 57.6 Kb/s in the other or as a symmetric channel with 432.6 Kb/s in each direction.

IEEE 1394

Home AV networks are typically based on IEEE 1394 (marketed as iLink by Sony and Firewire by Apple). IEEE 1394 provides support for both asynchronous and isochronous data transfer at rates of around 400 Mbps with proposals to extend this to 1.2 Gigabits. When isochronous communications streams are established the infrastructure provides guarantees relating to both bandwidth and jitter for these streams. In addition, IEEE 1394 supports auto-configuration and self-management, hot plug-and-play, low cost cabling and interfaces. The 1394 standard allows for up to 16 devices to be connected in a single chain and working groups are investigating the issue of bridging between 1394 networks.

2.2. Middleware

HAVi

The HAVi architecture [HAVi,99] is a set of APIs and system services to support the development of multimedia applications for the home network. The architecture is targeted at Consumer Electronics (CE) manufacturers and independent software developers and is designed to be implemented on a range of devices interconnected using a 1394 based network. HAVi gains much of its power from the features of 1394 (e.g. “hot plug and play” and multimedia streaming) and HAVi implementations are expected to operate over 1394.

The HAVi standard defines four distinct classes of device which may form part of a HAVi network. These are Full AV devices (FAVs), Intermediate AV devices (IAVs), Basic AV devices (BAVs) and Legacy AV devices (LAVs). There are many differences between these classes of device but they may be summarized thus: FAVs are the most capable AV devices; they support the full range of HAVi system services and can act as controllers for other devices. IAV devices are simpler versions of FAV devices; they support a subset of HAVi components and can control a more limited set of devices. BAV devices are the most basic form of HAVi devices; they are controlled devices rather than controllers. Finally, LAV devices are 1394 compatible devices which do not support HAVi. They must be controlled using device-specific legacy protocols. Devices that do not use 1394 can be connected to the network via a host device.

HAVi FAVs support a Java VM that enables third-party developers to offer applications which can be installed on the home network and which can interact with devices through a set of HAVi/Java bindings.

UPnP

"Universal Plug and Play (UPnP) is an initiative to bring easy-to-use, flexible, standards-based connectivity to consumer networks, whether in the home, in a small business, or attached to the global Internet" [Microsoft,99]. From a technology perspective, UPnP is a suite of protocols and system services for device discovery and control in small to medium size IP networks. UPnP compatibility is defined in terms of the on-wire format used for messages and hence UPnP devices do not need to be windows based (c.f. Jini which is defined in terms of APIs). In addition, it should be noted that UPnP is a peer-to-peer protocol that does not require a PC to be present on the network in order to function. More specifically, a network consisting of two non-windows, non-PC devices could be created and the devices could use UPnP to discover each other's presence. However, while device discovery, the initial target domain of UPnP is not PC-centric, the emerging control architecture [Microsoft,99b] implies high levels of functionality in the clients including, for example, the ability to parse XML documents and user interface components based on browser technology. Such capabilities most often reside in a PC-type device.

Jini

Jini [Sun,99] is a distributed systems platform based on Java. It adds to Java and JavaRMI other services which are useful when implementing complex distributed applications, e.g. naming, lookup and discovery services, an eventing paradigm, distributed garbage collection and a transaction scheme. The selling point of Jini when compared to platforms which have gone before it (such as CORBA) is that it is language specific. As a result, it is possible to have a very tight integration between the programming paradigm and language (i.e. Java) and distributed systems services and components. This makes using distributed systems services more natural than is the case in systems such as CORBA where services are essentially add-ons to existing programming languages. In addition, Jini avoids the "mistake" of trying to add services which support network transparency. Instead, Jini pushes network concerns to the forefront and forces programmers to deal with those exceptions which might occur as a result of distribution.

Jini assumes an underlying platform of Java and JavaRMI which, in turn, rely on TCP/IP support. Where systems need to be deployed without this support, Jini services can act as proxies for non-Java devices. For example, a box might be installed into a house which acts as a Jini proxy for devices connected to, and controlled by, the box using X-10.

JetSend

"HP JetSend is an information exchange protocol for fixed-function and programmable devices. It supports any-to-any communication between an open-ended set of device types." [HP,99]. In JetSend all information is stored as electronic media (*e-media*) in areas called *surfaces*. A surface may contain instances of e-media or links to other surfaces. The basic communications paradigm is that devices exchange versions of these surfaces. More specifically, the device with the original copy of the surface (called the expression) creates impressions of the surface (i.e. not necessarily identical copies of the surface) on other devices. So, for example, a digital camera may have a surface which contains a photograph. It could then communicate with a printer to create an impression of this surface on the printer which would cause the printer to print the photograph. The key part of JetSend is that impressions of surfaces do not need to be identical copies of the original. In particular, the encodings used can be changed to ensure compatibility with the target device.

3. Analysis

The most obvious conclusion that can be drawn from section 2 is that there are numerous, potentially competing standards being proposed for home networking. Indeed, if we focus on one aspect of device interworking, i.e. device discovery, we find that the different middleware solutions each have their own technology to address this issue. For example, UPnP is based on the Simple Service Discovery Protocol (SSDP) [Goland,99] for device discovery while HAVi, Jini and JetSend all rely on their own proprietary forms of registry and associated protocols to support service discovery. None of the proposals make use of emerging work in this area from the IETF such as the Service Location Protocol (SLP) [Guttman,99]. However, while there is a significant degree of overlap between many of these standards there are also clear differences in substance between the major players. For example, while UPnP is postulated as a universal device discovery and control protocol that would be ideally suited to controlling home AV devices, the standard assumes an IP based infrastructure with no support for guaranteed QoS: a core feature of the HAVi/1394 pairing that is competing in this space. In contrast, HAVI does not offer the flexibility and extensibility of UPnP when applied in non AV domains.

Since each of the technologies brings strengths to its own target application domain, we believe that future home networks will consist of multiple networking and platform technologies, integrated through a series of gateways and shared devices. Indeed, the current level of activity in the area of home gateways goes some way to substantiating this viewpoint.

Based on sections 2 and 3 it might also be concluded that there has been relatively little published research on operating systems for devices in home networking environments. In essence this is because CE companies typically use commercial off the shelf real time operating systems to support their products. Such operating systems are based on well-understood technologies and provide a stable platform for product development.

Given the above, the challenge for researchers is not in developing new operating systems, but rather in realising services which support interworking between heterogeneous devices and, crucially, between heterogeneous middleware platforms, irrespective of the OS being used. More specifically, in the medium term home environments will feature devices and gateways that require access to common services such as data storage, security, version management etc. The key challenge is to design such services in a manner which enables them to be deployed in a wide range of home networking environments and which work in partnership with the different existing middleware platforms, real-time operating systems and networking technologies.

4. Concluding Remarks

Beyond the PC is a wide range of devices from mobile phones through portable media players to set top boxes, all of which will eventually become integral parts of home networks. However, despite the introduction of high-speed always-on Internet connections for service access, the home remains a hostile place in which to deploy distributed systems technologies. Nevertheless, the potential rewards are huge and much effort has been spent on developing networking and interworking technologies for the home. The majority of this effort has focused either above or below the traditional operating systems boundaries, creating an apparent gap in research activity. In this short paper we have attempted to explain why there has been relatively little activity in this area and why, in our opinion, this situation is likely to persist for the foreseeable future. In addition, we have suggested one area of potential research activity, i.e. the development of common services for use by devices connected using a range of networking and middleware technologies.

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