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The *iDorm*: Gateway to Heterogeneous Networking Environments

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Abstract: This paper describes the structure and operation of the Intelligent Dormitory (*iDorm*), a student dormitory and intelligent inhabited environment test-bed developed at the University of Essex. In addition, it describes the different network technologies involved in the Essex *iDorm* and outlines a vision for combining gateways with embedded-agents to form omni-functional intelligent gateways. As a first step towards this goal we describe the prototype information gateway created to monitor and control our experimental *iDorm* environment.

1. Introduction

In recent years the market and opportunities for embedded computing, fuelled by advances such as: small processors, network connectability and compact artificial intelligence (AI) mechanisms, have seen an extraordinary expansion. These days, most of the electrical products that make up the everyday items in our life, such as mobile phones, home entertainment systems and domestic appliances contain embedded computers. The development of these embedded computer based devices has led to the focussing of research into how such technology could be deployed in people's everyday lives in a beneficial way without incurring prohibitive cognitive loading on the users. One way of providing increased functionality and decreased cognitive loading is to employ AI, which is the prime focus of the Essex group. In general terms, such research occurs under many headings e.g. Ubiquitous Computing, Smart and Future Environments, Intelligent Buildings, Virtual Home Environments, Intelligent Inhabited Environments, Invisible Computing, Disappearing Computing, Amorphous and Ambient Computing and Intelligence, etc.

The Intelligent Inhabited Environments Group at the University of Essex has the long term aim to carry out research into the essential mechanism and tools required to create a home environment that can learn non-intrusively from, and assist, residents in their everyday life. Our aim is to harness embedded AI techniques to enable lay-people to use the vast numbers of networked computer devices that will become available in the future without needing to become involved in complex technical operations. In the shorter term, we are focusing on the development of intelligent-building related systems supporting the independence, comfort and safety of people (i.e. elderly or disabled persons, or persons with need of special medical treatment). In this work, the Intelligent Dormitory (*iDorm*) forms a practical test-bed for this kind of research [1][2][3][4]. One of the *iDorm's* main purposes is to explore how we might enhance living conditions in personal spaces such as homes, cars, the place of work and, at one limit, on or in the body! Technology for networking building services is already widely deployed (e.g. Lonworks, BACnet, EIBUs, etc), as is technology for connecting domestic and mobile appliances (e.g. Cebus, Blue-Tooth). These are opening up the opportunities and technical difficulties afforded by highly connected and dynamic embedded-computing and networked gadgets. For users in a building setting the challenge is to produce some form of intelligent agent or process for the user of the building that is particular to that person and whose aim is to enable that person to get the most out of the technology without having to be specially trained.

In order to make the *iDorm* as sensitive as we can to the needs of the occupant we need to be able to comprehensively monitor activity in the room. For these reasons the *iDorm* is equipped with an array of embedded sensors such as temperature, occupancy, humidity and light level sensors, as well as a camera to be able to monitor what goes inside. It is possible to follow the activities inside the *iDorm*, via a live video link over the Internet though this is not directly involved in our attempt to develop embedded intelligent mechanisms. The *iDorm* makes provision for control of numerous systems such as entertainment, office-work and environmental control. In building the *iDorm*, the commercial reality is that the devices we have installed reside on several different types of network so that access needs to be managed and gateways *can therefore be regarded as critical components in such systems*, combining appropriate granularity with security.

1.1 Gateway & Intelligent Environments

One way intelligent embedded-agents are often deployed in the creation of intelligent environments [5] is to assign an agent to control a localized space (e.g. a room, a body). These spaces can map quite naturally onto to the domain managed by network gateways. We believe that a marriage of network topologies and agent architectures would hold many synergetic advantages such as:

1. The gateway domain could be readily made to match that of an intelligent building agent (i.e. both human activity and agent control equate to spaces such buildings, floors, rooms and bodies).
2. The gateway can bridge diverse sets of data and control networks (e.g. IP and LonTalk)
3. The gateway can provide a means of managing secure access.
4. The gateway can act as an area wide server providing managed access to the resources within its jurisdiction (e.g. remote home control via a web interface).
5. The gateway can "mine" information on activity under its control (for example, information on occupant's behaviour and use of equipment within the environment might be gathered and made available for the benefit of the occupant. In this case there would have to be agreement between individuals and manufacturers say on

equipment usage, and agreement between doctors and patients, in the case of medical care).

6. The gateway could provide a low cost way of providing computational resource for agent deployment (i.e. gateways will be there anyway).
7. The gateway concept is both scalable and extensible in a downward (micro-world), upward (macro-world) and horizontal (more of same) direction.

For instance, in a domestic environment there could be a gateway at the house level, further gateways to each room and gateways to complex devices within rooms (e.g. hi-fi systems) or body-wearable devices (e.g. with the mobile phone being the gateway). The use of gateways is therefore a scaleable solution to the problem of giving a degree of autonomy and security to different levels of any complex and hierarchical system. In our example - the *iDorm* - there are in fact a number of sub-networks that the common interface disguises and at the same time protects.

Currently there is much commercial and research interest in this area and there is a vast amount of related work underway around the world. This paper does not seek to review such work but rather, to give a small flavour of this, we describe a few relevant projects. The Cenelect [6] TC205 standard has concentrated on the residential and small business buildings and can be extended to other kinds of buildings. The European Residential Gateway (ERG) is a necessary component of the European Home and Building Electronic Systems. The ERG enables service providers to provide teleservices such as telecare, home appliance control and pre-emptive maintenance, remote metering and security monitoring; other service providers may provide energy management, entertainment services or information.

HomeGate [7] is the name the residential gateway standard being specified by WG 1 to define the connection between a wide area network and a local area network in a home or building. The primary controlling element of the Home Gateway model is the HESA (HES Agent).

Ericsson [8] has developed a system for delivering electronic services to the home using a residential gateway or a home server (the E-box). The e-box is positioned between an external IP-network and home-networks that connect a number of devices to the e-box. These devices may consist of practically any form of equipment with embedded processors, ranging from simple sensors to more complex terminal equipment. The E-box can be connected to a WEBPad, which allows a portable in-home screen for establishing an Internet connection.

Siemens Switzerland has launched “I-GATE” [9] which is a new wireless LAN at 2Mbit/s that is compliant with the norm IEEE 802.11. It has been designed for the smart office/home office (SOHO) market. Its main originality is based on the radio access point, which is also an ISDN router. This is especially economical: the end-user needs only one device to implement a complete radio gateway. The I-GATE gateway is connected to the ISDN S0 bus. The ISDN S0 interface is the single physical interface on the access network side.

2. *iDorm* Infrastructure

The *iDorm* is based on student accommodation currently available at the University. Superficially the room looks like any other student dormitory but above the ceiling and behind the walls lay a number of networks and networked devices. Currently the *iDorm* is based around three networks, Lonworks, 1-wire and IP although it would be possible to include others, providing a diverse infrastructure and for the development of network independent solutions.

2.1. Lonworks Network

Lonworks [10] is Echelon's proprietary network and encompasses a protocol for building automation. There are many commercially available sensors and actuators for this system. Each device has typed inputs and outputs. The Lonworks system allows association to be set up between inputs and outputs using a standard PC that is connected to the Lonworks network. The PC can then be disconnected and the

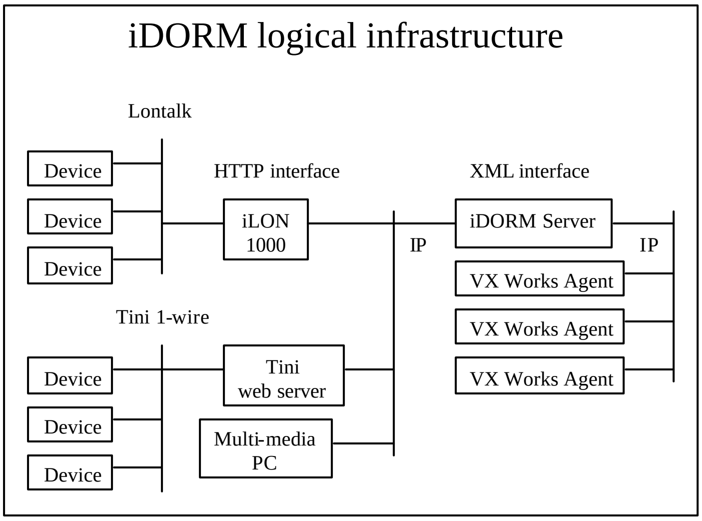

Fig. 1. Diagram to show the logical network infrastructure in the *iDorm*.

associations will continue to function. The system has no central coordination system, just a set of devices. The physical network installed in the *iDorm* is Lonworks TP/FP10 network. The gateway to the IP network is provided by Echelon's iLON 1000 web server. This allows the states and values of sensors and actuators to be read or altered via a standard web browser using HTML forms.

2.2. 1-Wire Network

Dallas semiconductor [11] developed the 1-wire network protocol. It was designed for simple devices to be connected over short distances. 1-wire offers a large range of commercial devices including small temperature sensors, weather stations, ID buttons and switches. Unlike Lonworks the 1-wire system has a central coordination system. The 1-wire network is connected to a Tiny Internet Interface board (Tini board) which runs an embedded Java Virtual Machine (JVM). In the *iDorm* the Tini connected to the 1-wire network runs an embedded web server that serves out the status of the networked devices using a Java servlet. The servlet collects data from the devices on the network and responds to HTTP requests; this forms a network interface server as shown in figure 1. This mirrors the Lonworks interface.

2.3. IP Network

The IP network forms a backbone to interconnect all networks and other devices like the Multi-media PC (MMPC). The MMPC will be the main focus for office-work and entertainment in the *iDorm*. Again the MMPC uses the HTTP protocol [12] to display its information as a web page.

2.4. *iDorm* Gateway Server

To create a standard interface to the *iDorm* we have an "*iDorm* gateway server". This receives XML [13] formatted queries from an agent, then connects to all the network interface servers in turn and sends an HTTP GET request to make any changes to the network devices requested by the XML request. It then receives an HTML formatted page describing the states of all the devices on each network. This

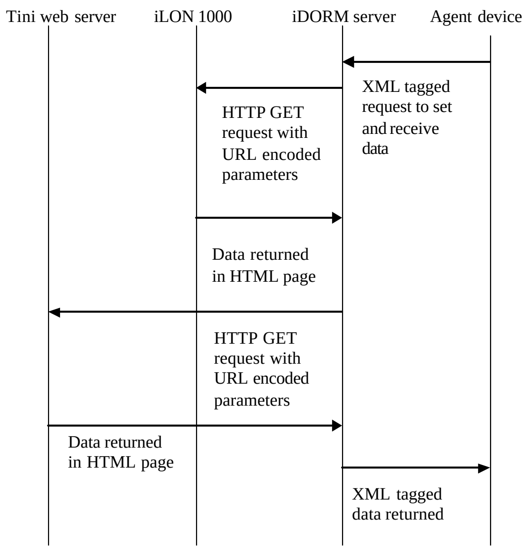

Fig. 2. Diagram shows the XML based communication between the devices.

document is then parsed to remove the correct information and formatted in XML to retain its context, before being returned to the requesting agent as shown in figure 2. XML is very portable and easy to parse which makes it ideal as cross platform communications syntax. Its other main advantage is that it's human readable and can be displayed easily in a number of ways depending on the applied style sheet.

The *iDorm's* gateway server is a practical implementation of an HTTP server acting as a gateway to each of the room's sub networks. This illustrates the concept that using a hierarchy of gateways it would be possible to create a scaleable architecture across such heterogeneous networks in domestic environments. The *iDorm* gateway server allows a standard interface to all of the room's sub networks. There could then be levels above this like a building server, or the granularity could be increased below this. This gateway system will allow the system to operate over any standard network such as EIBus, Bluetooth, Lonworks and could readily be developed to allow a 'Plug N Play' allowing devices to be automatically discovered and configured using intelligent mechanisms (surprisingly, Lonworks does not have such a facility). In addition, it is clear such a gateway is an ideal point to implement security and data mining associated with the sub network. Thus, although we have not yet developed such a device we see *the integration of the above into an omni-functional and intelligent gateway* as representing a viable commercial solution for the wide deployment of this technology. From the above, we would emphasis the critical role embedded-agent mechanisms in the gateway would play in making this possible.

3. Interacting with the *iDorm*

The *iDorm* being a Virtual Home Environment offers a variety of interactive interfaces. Most of our work concerns the use of embedded-agents to implicitly sense and control the environment in a non-intrusive manner based on the users behaviour including interacting with existing switches. Where more explicit control is needed we have developed a number of options. The first is that the room also features a web-based interface, which allows people to check or set the status of every device in the room. This has been extended to allow the same functionality from a WAP [14] browser.

Taken a stage further a VRML [15] model of the room was created, this allows a very intuitive interface to the room. This 'access from anywhere' interface brings problems of it's own, like security and priority in a potentially multi user environment. In addition to the above a voice recognition system based on Hidden Markov Models [16] has been implemented. This voice recognition system is natural and the technique used has proved good at recognizing commands spoken by different people, without the need for explicit training.

4. Scenarios

The specifications of the *iDorm* technology were developed by studying and seeking the advice of end-users, university students in this case. In support of this we have generated scenarios based around student life to highlight the *iDorm's* potential and functionality. The same principles could be used to design systems especially suited to applications involving care for the elderly or infirm since the agent can help monitor and control the environment. It is also the case that the gateway to a Virtual Home Environment, of the type described above, devoted to caring for elderly or infirm people could be used to support a data-mining function that would be able to identify deviations from expected patterns of behaviour and so give early warning to carers of deterioration in their behaviour. Table 1 illustrates levels of operation, varying from manual to intelligent, for some functions in the *iDorm*.

Table 1. Level of operation for some illustrative functions in the *iDorm*

	Manual / Remote	**Automatic (programmed by users)**	**Intelligent (learnt from users)**
Window Blind	Can be opened/ closed (to a certain degree)	Can be open/closed (to a certain degree) via an interface device	Can open/close i(to a certain degree) n response to other events (e.g. external light condition change)
Lights	Can be switched on/off in a normal manner	Can be switched on/off in response to detected movements within the home (e.g. lighting ceiling lamps when student enters the room, lighting bed lamp when student reads a book in the bed or lighting desk lamp during using the computer)	Can be set to switch on/off (to a certain degree) at dusk/dawn or during study or sleeping mode
Heater / Cooler	Can be switched off/on individually based on the room thermostat.	Can be linked to operate with other devices (e.g. Thermostat or humidity sensor)	Can be set to maintain different levels of temperature at day/night or when the iDorm is unoccupied

5. Conclusion

In this paper we have introduced the *iDorm* test bed, a standard student bedroom on the University of Essex campus. It uses sensors, actuators, gateways, networking and embedded agents to offer a rich set of control possibilities on behalf of and to the occupant. We have argued that the close physical and logical relationships between agents and gateways means that combining them can generate more cost-effective and functional possibilities than deploying either separately. We have described an environment - *the iDorm* - that has the potential to further explore this combined agent/gateway paradigm further. We are at an early stage of this work having built a rather crude information gateway that combines 3 networks and an agent but already the initial results are promising. Our immediate aim is to further develop the specification of the integrated communication and intelligent-environment gateway to include a broader set of functions and to conduct a set of experiments that would assess its effectiveness across various domain types

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