The Smart Kitchen Project – An Application of Fieldbus Technology to Domotics

Stefan Soucek, Gerhard Russ, Clara Tamarit
Institute of Computer Technology
Gusshausstr. 27-29/384
A-1040 Wien, Austria
{soucek,russ,tamarit}@ict.tuwien.ac.at

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Abstract

The market for networked home appliances and for residential gateways is gradually expanding and attracts interest from both research and industry. The Smart Kitchen project evaluates different fieldbus systems with respect to upcoming domotic applications. A number of small, inexpensive devices are networked to implement functions for increasing comfort, security, safety and better energy management in the home. Fieldbus to Internet gateways are used to access data from the home. An example uses a web-server, which publishes energy measurement on kitchen devices.

1 Introduction

The market for networked appliances in buildings and especially in the homes is gradually expanding and attracts attention from both research and industry. A number of research projects [1,2] have brought forward intelligent devices, which implement a number of smart functions in relatively complex devices such as coffee-machines, microwaves, or refrigerators.

The *Smart Kitchen* project outlined in this paper focuses more on the usage of many small and inexpensive devices. These interact in a distributed fashion while communicating with more complex devices and the outside of the home using gateways to a public network. A large number of devices suggests different criteria for the single device than for a small number of sophisticated devices. Cost, hardware complexity, power consumption and functionality of the individual device become more important the more devices are in the system.

Communication between the devices must be possible over a cheap and easy-to-deploy media. The chosen communication media and protocols also have a substantial impact on device and system cost. Even more important for existing homes, cabling should re-use existing installations such as twisted pair phone lines or power lines. Network systems that have been especially developed for a certain area of field devices that need to communicate are commonly known as *fieldbusses* [3]. The main advantage of fieldbus systems over other popular networking platforms such as Ethernet is the greater optimization to the specific environment of operation. Due to real-time requirements, cabling, device complexity, and communication protocols a large variety of fieldbus systems successfully coexist on the market.

The Institute of Computer Technology has acquired expertise in the research of different fieldbus systems over many years and investigates the interplay of different protocols, cabling schemes, applications and device manufacturers in a *Center of Competence* [4]. For an installation hosting nodes from many different manufacturers (multi-vendor system), interoperability between the devices is most important. This holds especially true in the area of home automation, where the user should be able to easily deploy and operate devices.

After all, the main goal of home automation is to increase the level of comfort, security and quality in life in the home. The usage of home networks including fieldbusses and their interface to external service providers eventually results in a complete *domotic* application. The interface between the home network and the outside is accomplished by a *residential gateway*, which represents the home and subscribes to services and provides telemetry data. Since the services typically are of pure electronic nature they are referred to as *telemetry e-services*. One of the first examples of telemetry e-services is remote meter reading or demand side management [5]. Typically, communication between the residential gateway and the service provider is accomplished over public networks such as POTS, ISDN or more recently the Internet. The last solution might seem to be the most appealing but it also introduces a number of security issues [6].

The goal of this article is to show how fieldbus systems can be integrated in a domotic application, using the Smart Kitchen as an example. The paper also reports on the current activities and results in that project. Section 2 introduces the cornerstones of fieldbus technology and discusses its usage in home automation.

In Section 3 we break down the functionality of the individual nodes of the fieldbus network. Finally, section 4 presents the concepts of fieldbus-to-Internet connectivity and discusses the residential gateway and telemetry e-services.

2 The Fieldbus in Domotic Applications

2.1 Domotic Applications

Domotics amplifies the meaning of home automation. When talking about home automation, discussion leads to ideas such as switching on and off lights by timers or scenery management. This automation type, however, is quite simple. More sophisticated applications consist of numerous “smart” devices connected by a modern communications infrastructure called the home network. Domotics essentially combines the concepts of home automation, telematics and communication. A domotic application works by creating an environment in which all systems of the home that offer comfort, security, safety, energy management, entertainment and communication to the residents, are well developed and thus can be adapted and even can learn from change of the living situation and can react to them. The focus in a domotic application is without question the integration of several classes of devices in order to reach the above qualities.

2.2 Fieldbus Technology in the Home Network

In order to have the devices in the home communicating with each other a communications infrastructure is required in the house. This is the responsibility of the home network. Field devices are generally sensors or actuators that participate in a distributed application to control some part in the house. Highly specialized communications systems for this class of devices are fieldbus systems. System design in home automation is cost-driven, which urges the engineer to tailor the communications system and the system components to the basic requirements of the application. As a result there are a number of different fieldbus systems, which are suitable for different areas of operation. Systems adhering to the event-driven paradigm rather than a time-slotted scheme generally allow greater levels of complexity and flexibility. Nodes can easily be added and networks can expand. These systems are well suited for soft real-time requirements making them feasible for applications in building or home automation.

On the physical layer, fieldbusses typically use cheap, easy-to-use transmission media, such as any pair of twisted copper (i.e. using an RS-485 transceiver) or power-line communication, facilitating an already laid-out cabling infrastructure. Any media has its signal propagation limits, thus limiting the spatial spread of the network.

Each fieldbus node has-low cost computing power installed in it, making each node a “smart” device. Each device is able to execute simple functions on its own such as diagnostics, control, and maintenance functions as well as providing bi-directional communication capabilities. These devices can communicate amongst themselves as well as a human controller. In essence the fieldbus replaces centralized control networks with distributed-control networks.

Fieldbus technology is gaining more and more acceptance in the home automation market due to the continuing price reductions in micro electronics, thus enabling low-price home networks. The integration of this technology to architectural spaces contributes to a higher quality of life and security.

2.3 LonWorks and EIB

LonWorks has been designed by Echelon Corp. as a flexible and generic fieldbus. It is an open technology standardized in the U.S. (ANSI/EIA 709.1) and Europe (ENV 13154-2), that any company can use to create products [7]. Interoperabily guidelines work not only as sales incentive, but also allows the creation of better products which easily work together with nodes from different manufacturers.

LonWorks can use a variety of different communication media including twister pair, power line, link power, coaxial, optic fiber, and radio frequency. Thus, an installation can be easily configured for any situation. This characteristic plays an important role in home automation, since some times the network has to be adapted to a house that was built some years before without thinking about the possibility of future automation. Moreover allowing different communication media in the same network makes the system much more flexible.

Another important aspect is that LonWorks supports simple and reliable communication between nodes. It provides an authentication service preventing unwanted communication relationships of nodes inside the network. The IO-points of the network are represented by the concept of network variables. Network variables simplify the tasks of designing application programs for interoperability with multi-vendor products and facilitating the design of information-based, rather than command-based, control systems. A network variable is any data item that a particular device application program expects to get from other devices on the network (an input network variable) or expects to make available to other devices on the network (an output network variable).

Each LonWorks device attached to the network contains a micro-controller (Neuron-Chip) and a transceiver in an appropriate mechanical package. Depending on the function of the device, there may also be embedded sensors and actuators, input-output interfaces to external legacy sensors and actuators, interfaces to host processors, or to another Neuron Chip and transceiver in a router.

The Neuron-Chip is specially designed for providing intelligence and networking capabilities to low-cost control devices. It boasts built-in processors for the media access and communication protocol and removes the need for any development or programming in these areas. The Neuron-Chip also features an application processor that needs to be programmed with the node application. The application program implements the functionality of the device; it may be permanently resident in ROM or may be downloaded over the network into non-volatile memory.

Transceivers provide a physical communication interface between a LonWorks device and a LonWorks network. Transceivers simplify the development of interoperable LonWorks devices and are available for a variety of communication media and topology.

The European Installation Bus (EIB) is another fieldbus system designed for building automation and is mainly used in Europe [8]. EIB as compared to earlier conventional power networks simplifies the structure of the network for supply of electrical power. The installation bus is laid in parallel to the power supply network. The bus line connects the bus users (actuators and sensors) to all operational functions in an installation. The power supply is fed directly to the devices consuming energy and therefore makes no diversions via switching systems. The bus cabling can be laid under surface, in conduits, trucking, etc. whereby the cabling lies directly in parallel to the power supply lines at 230V/400V. The line serves not only for open information exchange between the actuators and sensors but also as a protected low-voltage supply for these users. According to function and purpose of application there are bus components for flush/surface mounting, din rail mounting, and for fitting into or on users own devices.

Each bus line has its own power supply. In this way the entire system continues to operate in the event of the drop out of a bus line, thus ensuring a high level of availability.

On each line up to 64 bus devices can be operated. Up to 12 such bus lines can be joined together with a line coupler to one bus area. Up to 15 such bus areas can in their turn be connected together by means of an area coupler. Beyond this the EIB can be connected with other systems via appropriate interfaces.

The design criteria, application area and acceptance level of LonWorks and EIB make these technologies a first choice for networking many small devices in a domotic application.

3 Functions in the Smart Kitchen

In order to select the fieldbus and corresponding nodes, the functions of the domotic application need to be defined. We have divided our system into four functional groups:

- Personal Safety
- Safety
- Comfort
- Energy management

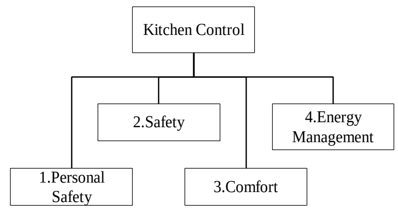

Figure 1: Functional Groups.

For each of these functions (see Figure 1), we have developed some applications. The chosen examples in the Smart Kitchen demonstrate the different ways existing technology can be integrated in the home and the wide range of possible applications.

3.1 Personal Safety

In order to improve personal safety for the family we install smoke detectors. Depending on if there is fire or

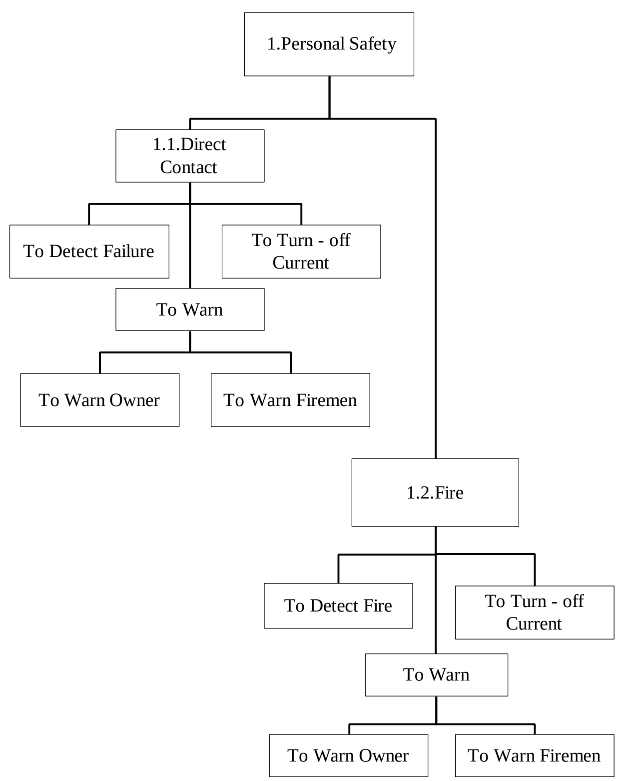

Figure 2: Personal Safety Functions.

just smoke they can warn the owner and the fireman and they switch off electrical devices automatically.

To avoid direct contact with the cooker the system can react by switching off the cooker and by an acoustical signal. The personal safety functions are depicted in Figure 2.

3.2 Safety

As well as personal safety for the family the safety for the house and the installations itself is one of our goals.

To prevent damages in electrical units the measuring of the energy that each device consumes allows to warn the user, when the value is higher than an average value.

Safety measures in the Smart Kitchen include the automated power turn-off and warnings when an electrical failure in a device is detected, in case of fire, or when water comes close to an opened power outlet.

Water-detectors will warn the owner if there is a leak and can close the water pipe. Because the detectors are placed near each water pipe, they can estimate, where the leak occurred.

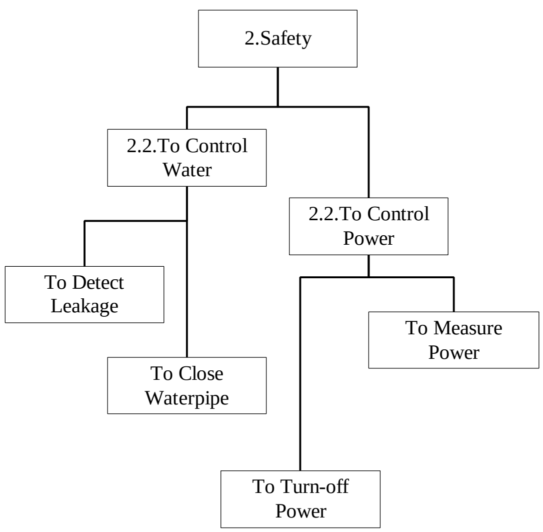

Figure 3: Safety Functions.

3.3 Comfort

After a hard working day it is important that you can enjoy the time at home. The Smart Kitchen should be able to support the owner in everyday activities.

The light control is being automated by an intelligent interaction of light intensity sensors, presence sensors, lamps, curtains and user requirements.

If there is someone at the door or the phone is ringing, but the owner cannot recognize it because the radio or the television is switched on, the system switches off the radio or the television.

You don’t have to switch on the light if it is dark and you enter a room any more – the occupancy sensor and the brightness sensor will do that for you. The comfort functions are summarized in Figure 4.

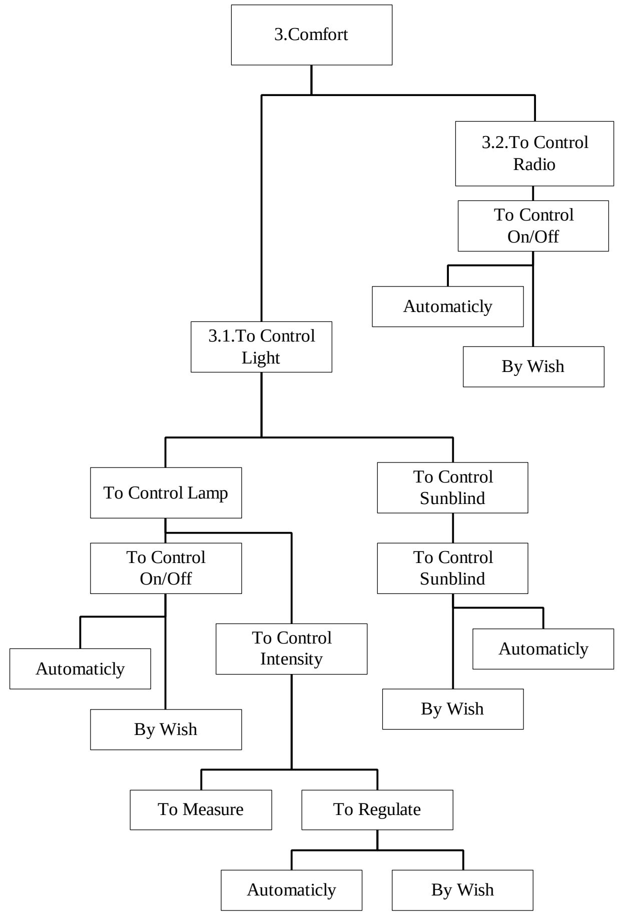

Figure 4: Comfort Functions.

3.4 Energy Management

One of the main aspects of the Smart Kitchen is to use energy more efficiently and more economically. The installation is optimized for saving energy.

When you try to switch on the light, the system estimates if it would make sense to open the curtain instead of switching on the light by measuring the brightness outside. Electrical devices such as lamps, TV, etc. will turn off automatically when the room is empty.

As above mentioned, there is a measuring of the energy that each device consumes. For example if there is a change in the average value of a refrigerator, that could mean, that it has to be defrosted. The energy management functions are depicted in Figure 5.

3.5 Components

For developing our Smart Kitchen we have looked for existing systems and components at first. But on the one hand there are no components for each requirement. We have used sensors without Neuron-Chips (i.e. humidity sensor) and had to make these sensors LonWorks compatible first.

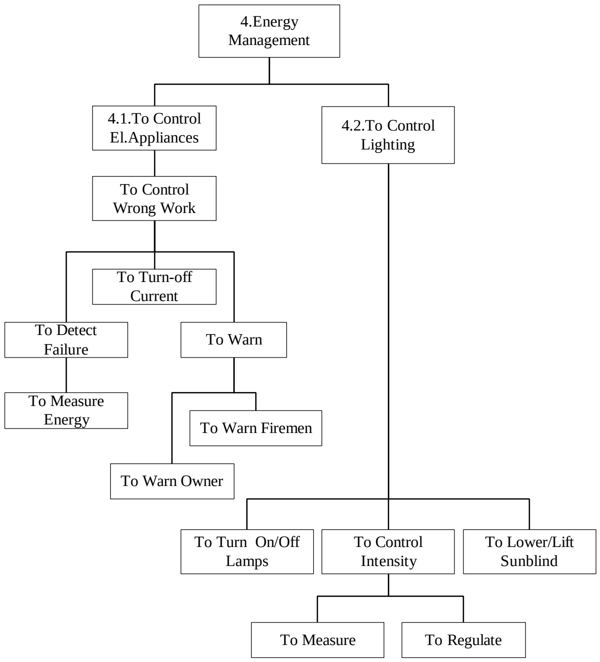

Figure 5: Energy Management Functions.

On the other hand we have reached the limits of the existing components soon. Standard components already have a Neuron-Chip and an application program built in. But these programs were insufficient for our needs. There were no descriptions of the programs, the way they compute an input or the way they create the output. When the manufactures write these programs, they don't know how exactly these nodes will be used. So they just make sure to a certain input follows the right output. They don't know, if, for the user, one output is more important than another one and that that output should be generated first. They don't know if the output should depend on one or more than one input.

In our project we have developed the function, that electrical devices will turn off automatically when the room is empty. But it wouldn't make sense, if all devices turn off if you leave the room just for a few moments, i.e. to get something out of the pantry.

Our automatic turn off depends on the time the room is empty and on the electrical device itself, because that time spread is not the same for each device.

Due to the restrictions of standard components we had to develop non-existing units. We had to get details about the units from the manufactures to write our own application programs and to download the program images to the components. For that reconfiguration of standard components we have used products (I/O, relays) made by SysMik.

Another problem was the power supply of the units. Some manufacturers use link-power technology where the unit gets the power via the data bus. Units by other manufacturers have an additional connection for the power supply.

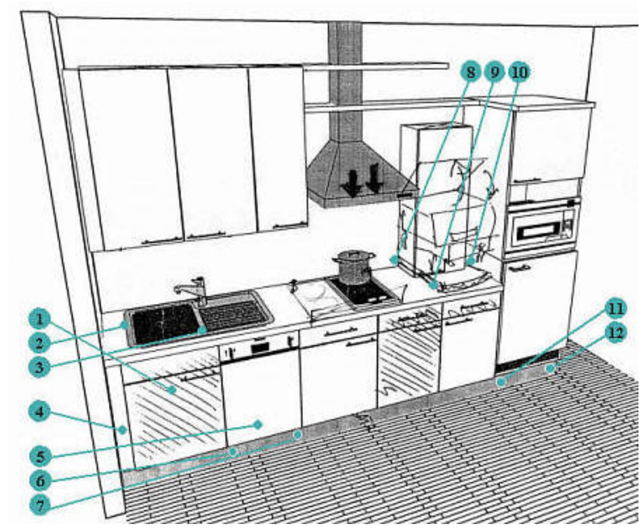

Figure 6: Node placements in the kitchen.

We had to be sure that these units have a decoupling of the direct-current voltage from the bus to avoid a damage by the higher current on the bus. Figure 6 shows the Smart Kitchen cooking corner and the placement of node groups. Each numbered arrow denotes a particular group of networked sensors and actuators.

4 Internet Connectivity

4.1 The Residential Gateway

The home network is one important part of the domotic application. A certain number of devices communicate to each other and implement some services within the home. The boundaries of the application, however, should not be limited to the home itself. The connection of the home network to external entities over public networks allows for other new services.

In the context of interfacing home networks to the outside world, the residential gateway plays a central role. It connects to the various home networks (ranging from fieldbusses to multimedia networks) and represents the home to external entities as a single point of access.

The data exchanged over the residential gateway is some kind of telemetry data. This includes a portion of control data and a portion of actual application data. Examples for control data are commands to turn on or off lighting, check a burglar-alarm system or control a coffee machine. Examples for application data could include the usage pattern of the coffee machine, the energy consumption curve of a household, or the peak times of milk consumption measured by a smart fridge. Providing application data to and processing control data from outside the home enables a new set of services: telemetry e-services.

A telemetry e-service represents the trade of telemetry data via some kind of contract between end-points in the home and a service provider over an electronic media. The end-point in the home is the residential gateway, which is configured to include some components that establish the e-service to the service provider. Service providers can be commercial companies such as utility companies or other individual homes or groups of homes. In a very essential way, the trade of telemetry data in an e-service can be bi-directional. Figure 7 shows the principle how telemetry e-services are established over a residential gateway infrastructure.

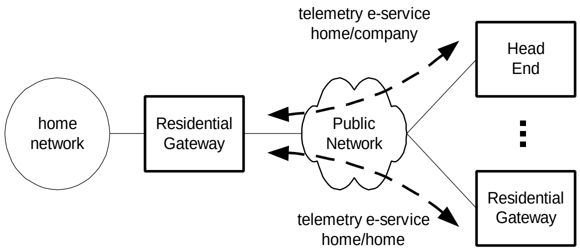

Figure 7: Residential Gateway and telemetry e-services.

The electronic media in most cases is a public network such as ISDN, POTS, or the Internet. The entities which participate in the telemetry e-service can be individual households, groups of households, or companies as service providers. Utility companies, for instance, can sell telemetry e-services for specific domotic applications. Companies that provide telemetry e-services use a so-called head-end to build the other end-point of the services. The head-end usually serves a large number of e-services to many customers and has connections to the corporate network.

Examples for telemetry e-service implementations in a Smart Kitchen are numerous. Assuming a certain financial model, a household, for instance, might choose to publish its food consumption data gathered by a smart fridge to a large food chain and in turn get discounts on certain products. The food chain could use the collected data to optimize its own supply and cut storage costs. Other possible applications might include the grouping of households to manage their energy consumption mutually. In any case, for a certain telemetry e-service, the service end-points, data supplier, data consumer and an underlying business model have to be clearly defined.

4.2 Gateway Architectures for Fieldbusses

The center part of the telemetry e-service architecture at the home is the residential gateway. If a fieldbus acts as the home network behind that gateway, it must implement fieldbus to Internet gateway functionality. The primary task of the gateway is to make objects in the fieldbus accessible using protocols commonly used on the Internet. Basically, the fieldbus application consists of a number of IO-points that control the various sensor and actuator nodes.

In principle, two classes of communication objects can be mapped: single IO-points or functional blocks of the nodes. For manipulating single IO-points over a gateway the use of the Simple Network Management Protocol (SNMP) proved to be a practical approach [9]. In this case, the IO-points are mapped to Management Information Base (MIB) variables that can be accessed over the Internet via SNMP. Single IO-points might also be controlled by a proprietary fieldbus API gateway [10].

Functional blocks on fieldbus nodes can be abstracted as objects, which are distributed over the network and communicate over their interfaces. Several standards for distributed objet-oriented systems are commonly used in the Internet: the Common Object Request Broker Architecture (CORBA), the Java Remote Method Invocation (RMI) interface and the Distributed Component Object Model (DCOM), which make them suitable for usage in application layer gateways [11]. Based on its DCOM architecture Microsoft has specified OLE for Process Control (OPC) [12], which also finds broad acceptance. Fieldbus-to-Internet gateways available on the market today include the Connector 2000 from Coactive Networks, Inc., Sausalito, Calif., the i.LON from Echelon Corp., Palo Alto, Calif., and the NECScom from NODUS GmbH, Hamburg, Germany.

Besides the actual access of the functional blocks, a residential gateway must include provisions to configure the functional blocks, the telemetry e-service definition, the communication peers, and if needed security mechanisms as well as payment methods. Today, a gateway operator is responsible for configuration and operation of the gateway.

4.3 Example Telemetry E-Service

An example implementation of a telemetry e-service in the domotic domain has been realized. The service lets the user watch the energy consumption of the kitchen. The telemetry e-service is run over a specific gateway between the EIB devices and the Internet, which is based on SNMP version 2 (Simple Network Management Protocol). The task of the gateway is to receive SNMP commands, process them, access the fieldbus if necessary and generate an SNMP response on behalf of the received data. The SNMP agent is specially designed for interaction with the fieldbus. The implementation includes a communication module for the EIB. Figure 8 depicts the SNMP gateway setup.

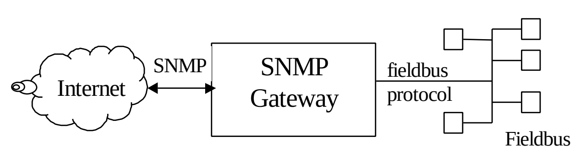

Figure 8: Example using a SNMP gateway.

For the sample implementation we use EIB energy counters to measure the energy consumption of a refrigerator and a microwave oven. The EIB is connected to a PC with an EIB server over an RS232 interface. The SNMP Agent receives the data from the server and makes that data available to a web server. The energy value can be viewed via the Smart Kitchen homepage at http://smartkitchen.ict.tuwien.ac.at.

5 Conclusion

This article has demonstrated how many small devices can be networked over a fieldbus in a domotic application. The advantage of fieldbus technology over other networking methods such as Ethernet is the high optimization level to the application. Fieldbusses network small sensors and actuators in the field using cheap node hardware and easy-to-deploy communications media. The goal of the Smart Kitchen project is to prove that the use of many small devices in a distributed fashion can bring higher comfort, security, safety, and better energy management to our homes.

The use of residential gateways allows to access the home network and thus the nodes from a remote location. The general term for new services, that can be conceived by exploiting this connectivity, is the telemetry e-service. Residential gateways hide the intricacies of fieldbus networks and represent a single point of access to the home. Implementations of gateways map single IO-points or complete functional blocks to Internet protocols. Approaches usually facilitate object-oriented technologies such as CORBA, Java/RMI or DCOM. Simple telemetry e-services can already be implemented using a web-server, which publishes certain telemetry data.

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