A LOW-COST INTERNET CONNECTION FOR INTELLIGENT APPLIANCES OF BUILDINGS

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SUMMARY: To date, the Internet has been a network connecting mostly desktop PCs, but soon all kinds of intelligent devices containing a small microprocessor will exchange data over the Internet. This will have a big impact on buildings and their technical systems, which now include a number of processor-based devices. Internet connectivity implies a totally new way to control and manage these devices. The potential benefits will be significant. Therefore, the need to design low-cost Internet appliances is worldwide today, and many commercial products are already available. This paper proposes a new technical approach to connect small processor devices to the Internet. The approach makes possible a connection both through the Public Switched Telephone Network (PSTN) and the Global Systems for Mobile Communications (GSM) network. The connection is based on networking software programmed in the processor device and a gateway server, which together transfer data between the PSTN and other communication networks. The data communication utilizes the Short Message Service (SMS) and the Extended Machine Interface (EMI) protocol. Besides the low cost, the proposed system has several benefits, such as uncomplicated structure and operation, standardized data transfer, and an ability to be embedded in an 8-bit processor device. Yet, the approach does not require high-speed data communication. Thus, it is especially suitable for applications controlling slow and non-critical building processes. The proposed system was demonstrated by designing a microprocessor device interfaced to an Air Handling Unit (AHU). Sensor data from the AHU was transferred to the Internet through the PSTN and the GSM networks. In addition, a Web-user interface was created for the remote control of the AHU. The results of the pilot project were encouraging and will be used as a basis for further development of the system.

KEYWORDS: Technical systems of buildings, HVAC, Internet appliance, Web appliance, remote control, monitoring.

1. INTRODUCTION

1.1 Internet extending to small, intelligent devices of buildings

The Internet, which is seen as a data highway that connects millions of computers into a single large network, is now extending to smaller computerized technical equipment. This trend is one part of increasing machine-to-machine (M2M) communication. An enormous number of microprocessors are at work in intelligent devices worldwide, which could be linked to the Internet, and many of them are located in buildings, and serve a part of the building systems. For instance, various control devices such as building and home automation systems, security and fire alarm equipment, water, energy and electric meters, and heating, ventilating and air-conditioning (HVAC) systems often operate as stand-alone systems, without any connection to the outside world. If these systems could be connected to the Internet, the controlling and monitoring of their operations would be radically changed. A prerequisite to the industry is that all this connection must be done at low cost.

Connecting intelligent devices of buildings to the Internet will have several benefits:
- Inadequate user interfaces can be replaced by versatile Web-browsers. The pages can contain not only plain text but also any kind of multimedia, such as hypertext, pictures, photographs, video and audio recordings, and even animations.
- The intelligent device can be even designed without a local user interface. As a result, production costs of the device can be lowered.
- The Internet provides the user with not just one but several ways of communication: wired, wireless, or mobile. This means that the intelligent device is accessible from multiple user agents, not just from a desktop PC but also from a laptop computer, mobile phone, or a Personal Digital Assistance (PDA).
- This worldwide networking or "Internetworking" will make it possible to create geographically large, even global automation systems consisting of small, decentralized microprocessor devices (Möttönen and Pakanen, 1997, Pakanen, 1998).

These opportunities provide the equipment service teams, building owners, and facility managers with a totally new way to supervise and maintain buildings and their technical systems.

1.2 Current Internet connectivity

Remote control via the Internet is not a new feature in building or home automation systems. It has already been utilized commercially for years. In hierarchical automation systems consisting of different buses for field, automation, and management, the natural access to the Internet is via the upper level bus, which is usually a Local Area Network (LAN). While in small systems the access takes place directly from the field bus (lowest level bus). Innovative communication technology in buildings, and especially in homes, involves a lot of new technology and has brought the Internet closer to the user and his/her everyday life. Commercial home network products, based on *de facto* standards, such as HomePlug, HomePNA, HomeRF, OSGi, UPnP, VESA, or HAVI, enable easy access to the outside world through a broadband gateway (Pakanen, 2001). In offices, the Wireless Local Area Network (WLAN) has become a competitive choice in networking and offers fast connection to the Internet. Most of these options provide at least one standard home or building automation bus for interfacing to new equipment. However, although technically feasible, these alternatives are currently too expensive for linking a single device to the Internet. Adding a new piece of equipment to an existing home network may be an economical decision, but setting up a totally new network or home bus for only one domestic appliance is currently prohibitively expensive. The costs must be taken into account because home networks, buses, and LANs in addition to automation systems are not yet commonplace in existing buildings.

The attempt to design a low-cost Internet connection for small intelligent devices is a worldwide effort. Such a system is usually referred to as an Internet appliance, Web appliance, or embedded Transmission Control Protocol/Internet Protocol (TCP/IP) (Webb, 2000). Many Internet appliance techniques rely on Point-to-Point Protocol (PPP) connection through PSTN, i.e. they use the subscriber's phone line in the building or home to dial up a local Internet Service Provider (ISP). This prominence is because PSTN is by far the most common communication line out of homes, offices, industrial buildings, etc. The following are examples of approaches that utilize PSTN as a data path. They all consist of the networking software, an interface for the host and a

modem. Most of them are commercial products. Advantages and disadvantages of the individual solutions are also presented:

- EMIT: An Internet-networking software that needs only a few kilobytes of program memory, embeddable in an 8-bit microprocessor. This microprocessor communicates with a desktop PC or 32-bit server computer connected to the Internet. EMIT represents an original idea to achieve Internet connectivity (EMIT, 2001).

- Internet Tuner: An embeddable design core for an integrated circuit that contains a hardware-based TCP/IP protocol stack, i.e. a collection of protocols needed in typical Internet connections. The core can be added to the customer's own integrated circuit. It contains an Application Program Interface (API) for a microprocessor and a serial port (Cravotta, 2001). The design core is a low cost solution, but applicable only for very high volume consumer products requiring Internet connectivity.

- S-7600A: An integrated circuit which consists of a TCP/IP stack, on-chip memory, and interfaces to both a microprocessor and a serial bus. S7600A is one of the first low cost solutions containing all necessary TCP/IP protocols on an integrated circuit. However, the circuit needs an additional modem, which increases costs (S7600A, 2000).

- IP2000: An 8-bit Internet processor, designed for communication applications. The processor circuit is equipped with an on-chip memory for a downloadable TCP/IP stack (Fowler, 2000). The processor represents promising new architecture and approach to create a link to the Internet.

- SmartStack: A Digital Signal Processor (DSP) software consisting of a TCP/IP stack and all modem operations. All software is programmed in a single DSP (Lipke and Carmagnol, 2000). The product is one of the few available solutions containing both TCP/IP stack and modem software on an integrated circuit.

- UDP server: A User Datagram Protocol (UDP) server, which is implemented using an 8-bit processor and a reduced version of the protocol software. The server needs special arrangements if a Web-user interface is required. A drawback of the UDP server is that the data transport mechanism is connectionless, and the delivery of data packets is therefore not guaranteed. (Loewen, 1998).

The above examples clearly indicate that an Internet connection can be accomplished using several techniques. There is no single solution currently available that has superior properties when compared to the others. Typically, communication between the host and a TCP/IP stack or an integrated circuit containing such software is not yet standardized, and the majority of interfaces and APIs are proprietary. Moreover, all available solutions cannot be considered low-cost due to the additional costs of a modem.

1.3 Objectives

The above-mentioned commercial products represent a few approaches to connect appliances to the Internet. In this paper, more emphasis will be put on solutions that are appropriate to the technical equipment and systems of buildings. Whenever possible, these technical solutions should be usable in every building – even those not connected to the PSTN or any wired data path. It is further assumed that the intelligent device can be controlled over the Internet using a Web-browser on a desktop PC, laptop computer or PDA. Moreover, a good solution is open to all practitioners, and is implemented according to standard protocols and APIs. Typical stand-alone microprocessor devices in buildings can be controlled relatively easily by a small amount of data. Hence, the applied data transfer speed is not critical, and would be suitable for low transfer speeds (i.e. PSTN).

Intelligent devices in buildings are normally controlled by 8-bit microprocessors. Therefore, a perfect solution would be an Internet software package combined with an electronic interface to the chosen communication link, all embedded in the processor device, with everything located in the building. Such networking software should contain both Internet connectivity and modem operations. However, the computing and memory capacity of 8-bit processors are restricted. This fact sets practical limits on the size and operation of the embedded software.

This paper presents a solution which is consistent with the general objectives described above. A technical system was implemented in order to demonstrate the proposed Internet connectivity. The results are based on cooperative work, done by VTT and several cooperating companies.

2. OUTLINE OF THE SOLUTION

The proposed Internet link is accomplished using the connectionless Short Message Service (SMS) between the intelligent device and an HTTP-server on the Web. This type of connection enables the implementor to design a simple Internet appliance with low or moderate requirements for memory and computing capacity. Due to the delay of end-to-end transmission, accessing the device from the Web takes slightly longer than in PPP communication but the transmission of data is guaranteed. The proposed system does not require an HTTP-server in the building, as do most of the connectivity solutions described in Section 1.2.

Fig. 1 outlines the proposed system. The central idea in the proposed solution is to create connections between the existing telecommunication networks for transferring Short Messages from one network to another.
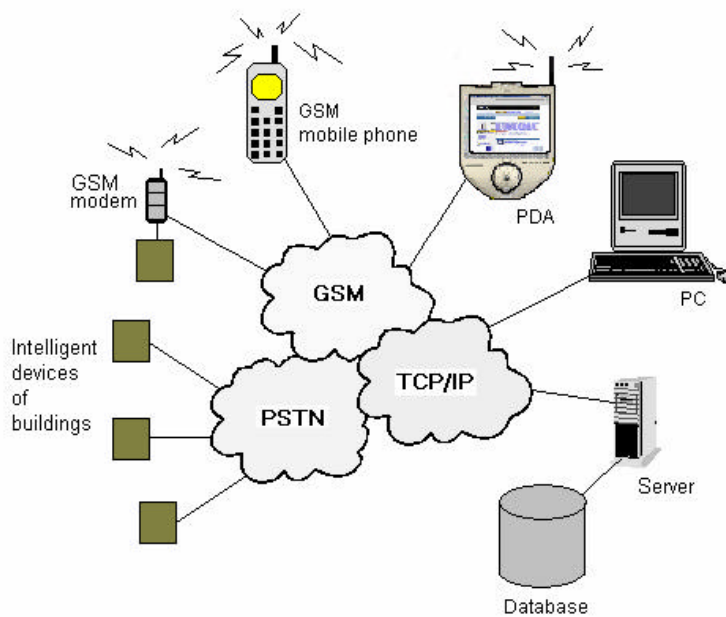

FIG. 1: System schemata of the SMS-based Internet appliance solution.

The left part of the figure presents intelligent devices in the buildings and their interfaces to the network. In each building, the Internet appliance is connected to the local subscriber line of the PSTN. Thus, each device serves as the "terminal equipment" of the subscriber line. The intelligent device is equipped with facilities that enable the user to send and receive Short Messages to and from the terminal equipment over the PSTN. In this way, data exchange between a remote device and a user in the Web becomes possible. Commercial systems are available which enable the user to send Short Messages from the PSTN to the mobile network, but not the other way. The authors believe that the proposed two-way SMS transmission between the terminal equipment on the PSTN and a server on the Web is a novel approach to Internet connectivity.

The right side of Figure 1 illustrates some user agents: a desktop PC, laptop computer or PDA. If these user agents are equipped with a standard Web-browser and linked to the Internet, the user can remotely control and view the intelligent device over the Internet. Some applications, such as recording water or energy measurements, may require a database for continuous saving of data. The database can be easily linked to the server computer, if necessary.

Note that a Short Message originating from an intelligent device can also be routed to a GSM mobile phone or to another intelligent device through a conventional GSM-modem. This is shown in the upper left hand in Figure 1. Thus, the proposed system enables the user to control intelligent devices connected to the GSM network, and

utilize a mobile phone as a simple user agent or a terminal equipment for alarm Short Messages. A GSM-modem is not an economical solution, but it can be easily justified in special cases where a PSTN connection is not feasible.

3. CONNECTIONS BETWEEN THE COMMUNICATION NETWORKS

Sending and receiving Short Messages is a conventional service in mobile communication networks. Thus, it is reasonable to take a closer look at how the GSM network can be connected to the PSTN and TCP/IP networks and how Short Message Services can be adopted in these networks as well.

When a mobile station, i.e. mobile phone sends a Short Message, it is first directed to a Short Message Service Centre (SMSC). The SMSC identifies the sender, and attaches a time-stamp to the message before submitting it to the recipient mobile station. Nowadays, with a new standard (ETSI TS 100 901), a Short Message may be received as an e-mail and a properly encoded e-mail message may end up at a mobile station as a Short Message. In this way, the SMSC has a gateway to IP networks. This opens up a new possibility to enlarge the range of the mobile network, to utilize services available in the Internet, and to establish new communication practices (Rao et al, 2001).

Besides mobile and IP-gateways, SMSCs are usually equipped with an interface for special Short Message Entities (SME), such as interactive voice mail systems, paging systems, or dedicated PC applications. Their main purpose is to send (and receive) Short Messages to mobile stations from a non-mobile system. Because the functionality of the SMSC is outside the scope of the GSM specifications, several proprietary interfaces have been developed. The European Telecommunications Standards Institute (ETSI) has standardized five of these *de facto* standards (ETSI TR 101 632) (Fig. 2). Although most of these protocols may utilize phone subscriber lines for data communication, only one of them, the SMSC External Machine Interface (EMI), is specified for transferring modulated low-speed asynchronous data. The proposed low-cost Internet connection in this paper utilizes this protocol. The following sections describe how EMI evolved and is used in the proposed system.
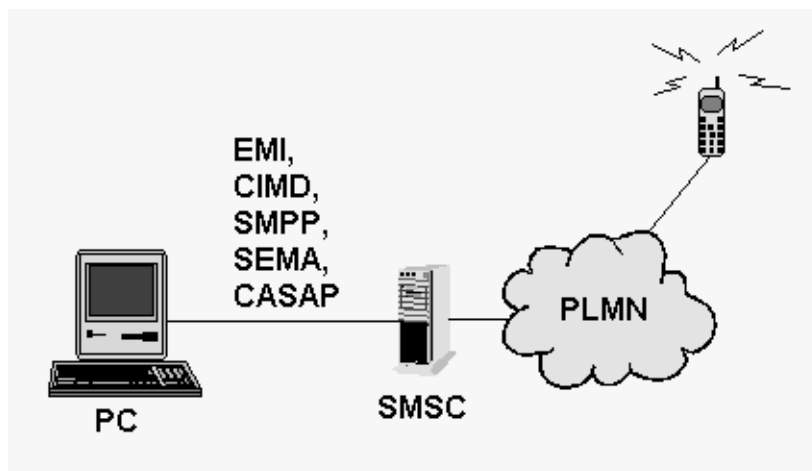

FIG. 2: Standardized protocols for data communication between the SMSC and a non-mobile SME. The protocols supported are Short Message Service Centre External Machine Interface (EMI), SMSC to SME Interface Specification (CIMD), Short Message Peer to Peer Interface Specification (SMPP), SMSC Open Interface Specification (SEMA) and SMSC Computer Access Service And Protocol (CASAP). PLMN refers to the Public Land Mobile Network.

If the SMSC is not capable of communicating with the EMI-protocol, telephone companies may still provide their customers with EMI-services using special arrangements. Some companies are offering gateway software, which when installed in customer's Internet server, enable direct connection to the SMSC over TCP/IP. These gateways are able to send and receive EMI-messages and transfer data to the SMSC, as shown in Fig. 3 (Content Gateway Overview, 2000). Such a gateway creates a link to the SMSC but also to the Internet. So, the gateway software can transform an EMI message originating from PSTN to a HTTP query, an e-mail message, or a Short Message to the GSM network. Besides of the commercial software, there are also open source SMS gateways

available. The pilot system was implemented using the open source Kannel WAP and a SMS gateway (Wirzelius and Marjola, 2000). The Kannel software has been designed to communicate using protocols specified by different SMSC vendors. The EMI-protocol is one of them. Such an arrangement makes the proposed system independent of the applied SMSC.
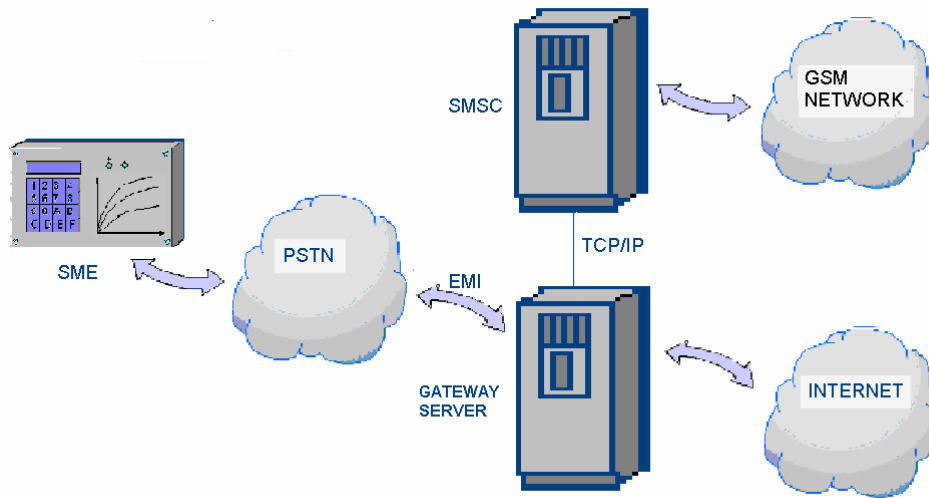

FIG. 3: A route to the Internet and mobile network through the PSTN, gateway server and SMSC.

4. EMI PROTOCOL

The SMSC External Machine Interface was originally defined for the European paging system ERMES (ETS 300 133-3) as its Universal Computer Protocol (UCP). The protocol was later modified by ETSI to a standard for SMSC interfacing (ETSI TR 101 632). The protocol is usually referred to as UCP/EMI or only EMI. The standard defines the command syntax, parameters and their data fields. The command set consists of both SME and SMSC originated messages, their acknowledgements and delivery notifications sent by the SMSC (Table 1). The UCP/EMI protocol defined by the standard has subsequently been amended. The most current version of the protocol at publication time is UCP/EMI 4.0.

Table 1. A command set of EMI messages (50-series) (ETSI TR 101 632).

EMI operation	Name	Initiated by
51	Submit_short_message	External Machine
52	Delivery_short _message	SMSC
53	Deliver_notification	SMSC
55	Inquiry_message	External Machine
56	Delete_message	External Machine
57	Response_enquiry_message	SMSC
58	Response_delete_message	SMSC

One alphanumeric Short Message in the EMI protocol may contain up to 160 characters of text. By combining several Short Messages, one can send up to 640 characters. Besides the start and stop characters, the header, and the checksum, which are included in all commands, the message frame may contain several parameters of different lengths. These parameters include the addresses of both the recipient and the originator, the need for notification, the notification address, the validity period, and the message type. Fig. 4 presents an ordinary sequence of messages between an SME and the SMSC.
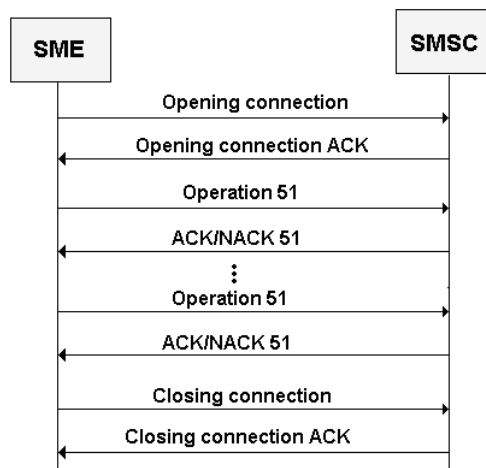
FIG. 4: Typical handshaking signaling between the SME and SMSC. After opening the connection a number of messages can be transmitted before the session ends.

5. DEMONSTRATING AN APPLIANCE INTERFACE

5.1 Electronic implementation

Interfacing the intelligent device to the PSTN and providing it with the necessary networking software is one of the main issues in the effort to develop a low-cost Internet appliance. There are several ways to implement the interface in practice. For a commercial product either of the following two alternatives are conceivable.

- An integrated solution, in which all software and electronics of the interface are embedded in the intelligent device.

- A fully separated interface consisting of an independent microprocessor circuit with serial links to both the intelligent device and the PSTN. In order to achieve a low-cost solution, all modem operations should be programmed in the microprocessor circuit.

Yet, the appliance interface was demonstrated using a third alternative: a processor-based intelligent device equipped with the networking software and an on-board modem. This is not a low-cost solution but allows for an easy and quick way to demonstrate the interface and functionally achieve similar operation as the above choices.

The prototype system consists of an Air Handling Unit (AHU) and a monitoring/controlling device, as shown in Fig. 5. The idea was to observe the recently installed AHU in order to see if it fulfils the requirements set by the customer. The processor device measures temperatures at a number of locations, such as the leaving water temperature of the heating coil, the supply air temperature and the outdoor temperature. These temperatures give a rough evaluation of the performance. Measurements are transferred to the Internet and stored in a database. The user can also control the device from the Web by changing the set point temperature for supply air.
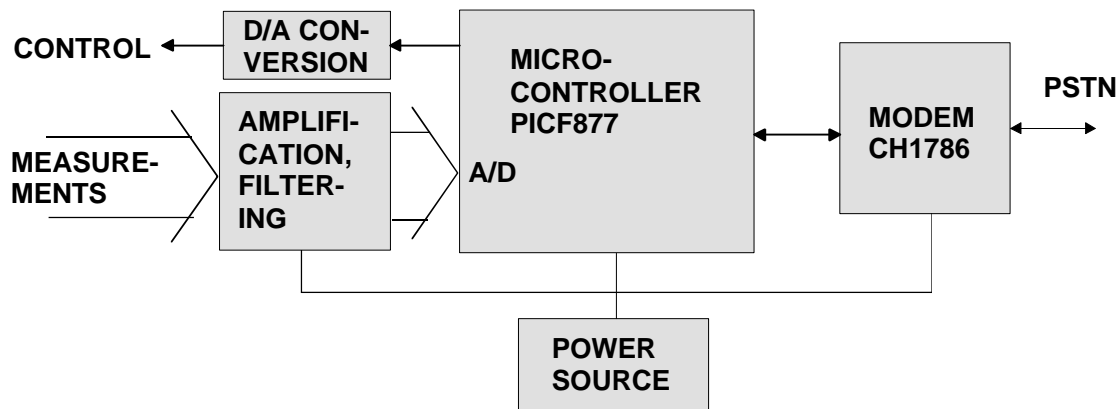
FIG. 5: System schema of the processor device applied in the demonstration.

The electronic implementation relies on two main components: a microcontroller PICF877 and an on-board modem CH1786. The former is an 8-bit microcontroller equipped with program and data memory in addition to input/output ports, a serial port, an 8-channel Analog-to-Digital (A/D) converter, timers, a watchdog, and other typical features of small microcontrollers. The analogic control signal is implemented by a Digital-to-Analog converter (D/A) (Fig. 5). The modem is an integrated add-on module, which is controlled through a serial port using ordinary AT-commands. The module also contains a telephone line interface, i.e. Data Access Arrangement (DAA), obligatory for all terminal equipment of the PSTN. If the SMS based system turns out to be successful the add-on modem can be later replaced by a software modem and a DAA.

The software was implemented using C-language, and then compiled and programmed in the processor circuit. All main operations concerning A/D-conversion, the processing of measured signals, modem control, calendaring, diagnosing, etc. are scheduled according to a real time clock. But the transmitting and receiving of characters from the serial port is synchronized by an interrupt, which branches the control to the right subprogram.

5.2 Operation

The microcontroller of Fig. 5 starts to send the measured data to the database of Fig 1 only after it has received a special command from the Web-browser. When it is ready to send a collection of data, it performs the following operations. First, the message is built up in its message buffer: the starting and stopping characters, the header, data and the checksum characters. According to the EMI standard, the data, and the checksum must be IA5-coded. The header contains the addresses of the recipient and sender, and the number of characters in the message among some other information. If the modem is ready to accept commands and the phone line is not busy, the processor gives an AT-command to the modem to take a phone call and to make a connection to the specified phone number. After establishing the connection the processor sends the Short Message to the PSTN and gets a short acknowledgment message in return. The whole operation takes only a few seconds, after the connection.

Note that the PSTN interface can be implemented without disturbing the regular phone line user. Usually, the intelligent device will not be equipped with a separate phone line but installed parallel to an existing telephone. Before entering the on-line mode, the DAA listens to the line and finds out if it is busy, and thus avoids disconnecting an ongoing phone call. When the device is receiving a message, the DAA together with the microprocessor can determine if the phone call is directed to the device or to the ordinary phone line user. Thus, the device can pick up the phone call before the ringing signal is activated. This causes no harm to the ordinary phone line user.

The ability to identify the number of the caller is also essential for security reasons, because it is difficult for an intruder to access the device directly through the PSTN. Moreover, the Short Message contains proprietary data, sensible only to the receiving device. Therefore, only a specialist can encode the data. If necessary, the data may also be encrypted by a simple code to increase the security of the data exchange.

6. DEMONSTRATING REMOTE CONTROL OVER THE INTERNET

An HTTP server and a database were set up in order to test data communication from the Internet appliance to the Internet. In addition, a few Web-pages (Fig. 6) were designed to allow remote control of the appliance from a desktop PC. The system was set up according to Figs. 1 and 3. Only one intelligent device was connected to the PSTN in this version of the implementation. The device controlled the AHU of the building. The user can remotely read recorded measurements and control the set point temperature of the AHU. If a temperature exceeds a prescribed limit an alarm message is automatically generated and sent both to the Web-server and a mobile phone.
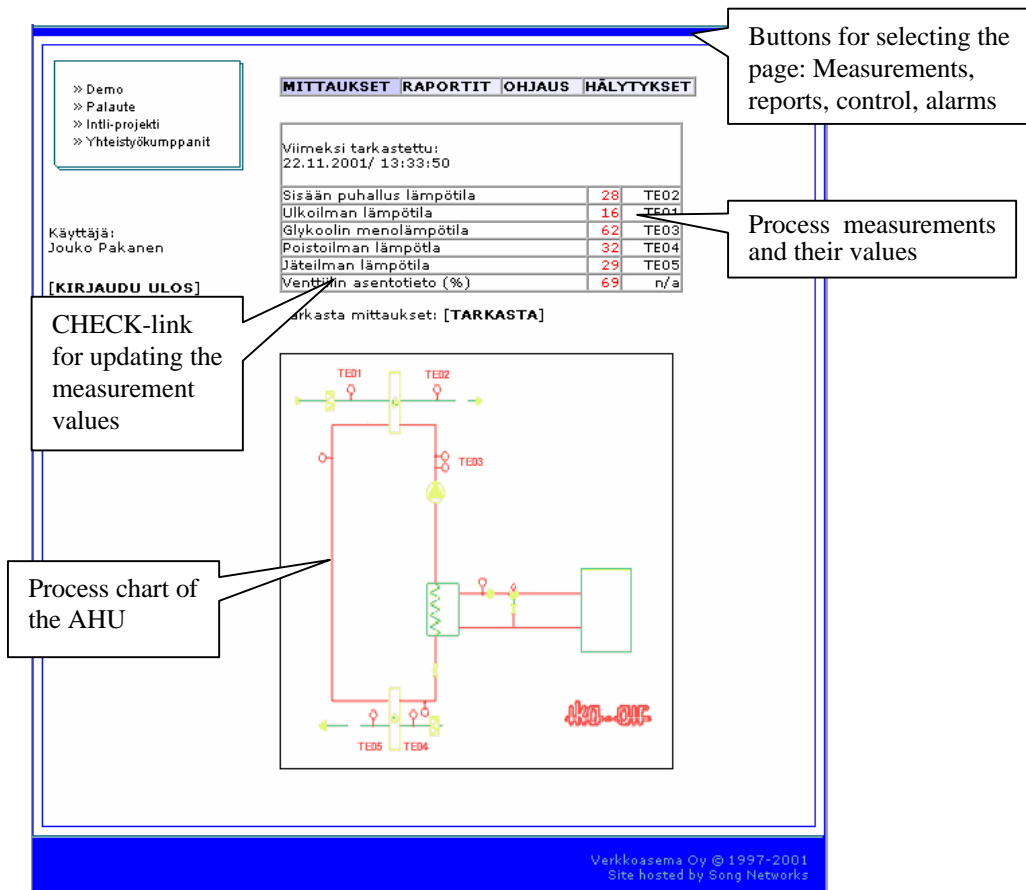

FIG. 6: One page of the user interface representing process measurements collected from the AHU.

The implementation was accomplished in two phases. The first Internet appliance was not the processor device described in Section 5 but a commercial controller equipped with a commercial add-on GSM modem. The controller was originally designed to communicate with a GSM network using Short Messages. This arrangement made it possible to concentrate on the server side procedures before testing the PSTN Internet appliance. In the second phase, the GSM modem installation was replaced by the PSTN Internet appliance system of Section 5.

When a session begins, the user loads a control platform, i.e. one or more Web-pages from a server to his/hers desktop PC. The Web-pages are application-specific, each containing scripts related to the sending or loading information over the network. The Web-page which is designed for remote control contains a form in which the user can start several control actions. For instance, a CHECK-link which transmits a Short Message to the Internet appliance when activated, as illustrated in Fig. 6. The return message carries all the relevant measurements stored in the database. The user may view the data either as a table or as a graphic curve. The SET-link sends a Short Message containing a set point value to the controller. Fig. 6 presents the Web-page related to the measurements.

7. DISCUSSION

The proposed Internet connection for intelligent devices of buildings relies predominantly on the device and its interface but also on the mobile data communication system built for SMS. Therefore, besides linking to the Internet, a connection is also established to a GSM network. Such a solution will be useful to building servicemen, because important messages can be directed to several communication networks and all buildings can be reached, even those not connected to the PSTN. Technically, the proposed solution is feasible and fulfils the baseline requirements of the client.

From a technical point of view, one of the drawbacks is the relatively long response time, which is an inherent feature of the SMS. The response time is even longer when the system is operated through the PSTN. However, delays generated by the PSTN will be inevitable in all solutions using the same network. This is due to the fact that data transfer takes a short time compared to the time needed for establishing and terminating the connection. Of course, the longer response time must be considered while choosing applications for the system. This is not a major deterrent, as building processes, such as heating, cooling, or air conditioning are rather slow and not as critical as many industrial processes. For this reason, SMS based access to the Internet is appropriate for building environment. The slow-speed data exchange is especially suitable for subscriber phone lines, since they have originally not even been designed for data transfer. Moreover, data communication relies on the existing ETSI standards. This is evidently a better alternative than the proprietary solutions represented by some of the commercial products.

The costs of the Internet connection per intelligent device can be estimated only roughly at this time, because they depend on several issues. But a comparison to the commercial products presented in Section 1 clearly shows that an SMS-based Internet appliance is relatively inexpensive. The memory and computing capacity needed to establish Internet connectivity for the processor device is low. Therefore, the networking software can be even included in the intelligent device. Unfortunately, some investments must be made in the communication systems. Nevertheless, the proposed system is able to serve thousands of intelligent devices, which will decrease the costs per device. The running costs depend on the rates for Short Messages and phone calls.

The pilot system was relatively easy to set up. No major problems were encountered in designing or testing the system. This is partly due to the fact that the pilot system was implemented only for illustrating and testing the proposed idea. Technical solutions for a commercial system will be different. Developing the intelligent device and its SMS-based data communication follows the conventional design rules of microprocessor based devices and the guidelines given in this paper, but the gateway transferring data between the networks must be designed carefully according to requirements of the user. Such a commercial system should be:

- scalable to meet growing remote access and data communication needs.

- resilient and fault-tolerant, enabling it to adapt to varying load conditions and recover from functional failures.

- technically reliable, usually achieved by increasing redundancy, i.e. the number of parallel, operational systems.

- secure, easy to maintain, operate and control.

Setting up and maintaining the proposed SMS based system as a commercial service, requires further development and productizing of the pilot system. Such a work needs expertise in several areas of technology and close cooperation with one or more telecommunication companies. Thus, the best way to organize the system commercially must involve the cooperation of companies, i.e. sharing expertise of several fields.

8. CONCLUSIONS

The proposed SMS data exchange between PSTN, GSM and IP networks ties together wired and mobile telecommunication systems and establishes a low-cost Internet connection for intelligent devices of buildings. The resulting network enables low-speed data transfer between the device and a Web-user and/or a GSM mobile terminal. The proposed system has several benefits compared to the available commercial solutions, including low cost, uncomplicated structure and operation, standardized data transfer, and the capacity of being embedded

in an 8-bit processor device. Building processes, such as heating, cooling, and air conditioning are rather slow and non-critical, therefore the proposed Internet connection is suitable for these types of applications.

Sending and receiving Short Messages from the PSTN to the GSM and Internet networks needs special arrangements. The proposed solution was based on a SMS gateway, i.e. an Internet server, which provided a link both to the SMSC and the Internet. The system was designed only for illustrating data transfer between the networks.

The Internet connection was demonstrated by designing and implementing an 8-bit intelligent processor device, capable of controlling and gathering data from an AHU. Also, a Web-user interface was created for remote control of the device. The results obtained with the pilot system were encouraging and will be used as a basis for further development and productizing of the system.

9. ACKNOWLEDGEMENTS

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