MOBILE INTERNET ENABLED SENSORS USING MOBILE PHONES AS ACCESS NETWORK

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SUMMARY: *We envision ambient intelligent environments with an infrastructure based on heterogeneous sensor and actuator devices accessible over the Internet. Initial steps to realize this concept have been taken by developing an Embedded Internet System (EIS) architecture for Internet protocol enabled devices. In many cases these devices will be in close proximity to a person. Such applications are found in for example sport and wellness. The mobile connection of such devices to the global Internet in a simple and cheap way is of particular interest. It is here proposed that such connection will make use of the existing and wide spread mobile phone networks. Since a few years most new mobile phones are equipped with Bluetooth technology making a mobile phone capable of connecting to 7 other Bluetooth devices. Thus by giving EIS devices a Bluetooth communication channel it will become possible to tunnel the EIS sensor communication through a mobile phone nearby the sensor. The proposed architecture will be described with discussion on limitations due to existing infrastructures and business models in the telecom networks.*

KEYWORDS: *sensors, embedded, mobile, internet connected*

1. INTRODUCTION

Todays technology makes wide usage of sensors to get systems working. These sensors have the capability to communicate data by either a display or some electronic data communication means. Currently most sensor communication schemes deployed in are point to point like RS-232 or similar or buses like IEEE-488.2 standard (Goeble) or the Fieldbus standard efforts (Glanzer IEC). Other approaches are the ASI standard (ASi), and the IEEE 1451 standard (Chen and Kee, 1999). These approaches will make data available only to a few predetermined users. Extensions to these standards will give each technology a window to the Internet.

In the future we project that many if not all sensors will be given the capability to become a node of the Internet. Examples of such developments can be found in (Delsing et al. 2000, Östmark et al. 2003). Thus providing data to many users that probably will give rise to better overall performance and also to entirely new ways of doing business.

We envision ambient intelligent environments with an infrastructure based on heterogeneous IP-enabled devices. These devices may range from simple sensors and actuators to consumer electronics, all accessible over the Internet. Traditionally this have been done by connecting sensors, actuators or other devices to a central server or gateway on which an application have been running that enables such devices to be visible on the Internet. This architecture is illustrated in Fig. 1. Several approaches in this direction have been published, e.g. (Dunkler 2001, Lee and Schneman 1999).

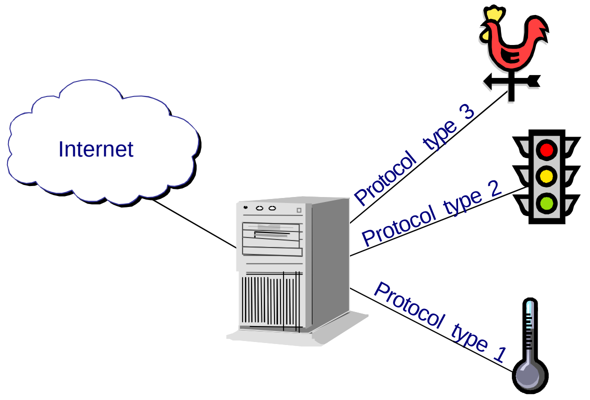

FIG. 1: Large server architecture for connecting small devices to the Internet.

However, this architecture suffers from the need to develop an application that is capable of communicating with the devices connected to the server. Dependent on the devices connected, the server has to be able to receive for example sensor data, communicate configuration data, alarms etc. Furthermore such a server is required to have the hardware communication capability that enables the device communication. To make sensors mobile in this architecture it is possible to use suitable radio or optical communication. However the access, radio or optical, infrastructure has to be built for the particular case.

A much more attractive solution would be to find an architecture where devices can connect to an existing access network in an ad-hoc manner. Such devices will have the full capability of talking the ``TCP/IP" suite of protocols and, when ``connected", the ``TCP/IP" communication is tunnelled through the existing access network.

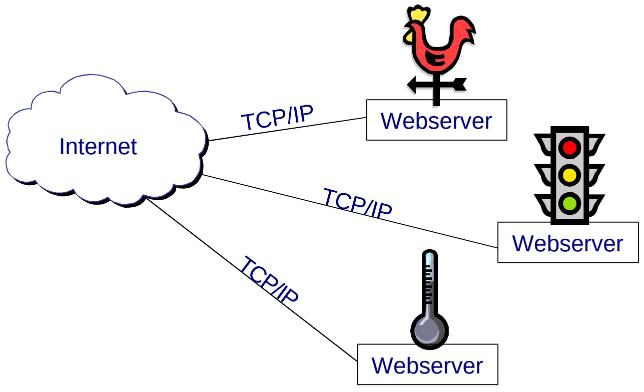

FIG. 2: Minimal Internet server architecture for ad-hoc connection of small devices like sensors connected to the Internet.

To accomplish this goal we have developed the EIS architecture for Internet enabled devices and sensors. This paper will describe an architecture where small devices like simple sensors will become mobile nodes on the Internet. The general architecture is shown in Fig. 2, where each EIS device has the general architecture shown in Fig. 3.

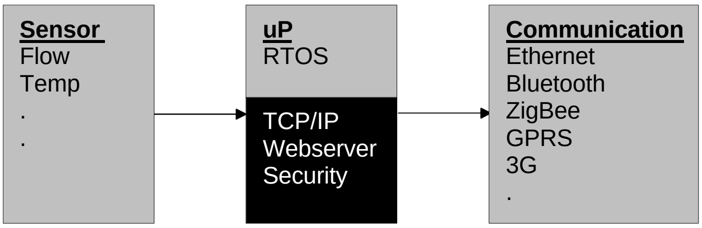

FIG. 3: General architecture of an EIS sensor. A sensor is connected to a microprocessor running a real time operating system (RTOS) with appropriate parts of the "TCP/IP" suite of protocols and drivers for the chosen hardware communication link.

2. NETWORK ACCESS MODEL

The general question is which of the existing access networks are most suitable for small device communication. The selection criteria are a mix of the following:

- Coverage
- Wireless link distance
- Low power at wireless node
- Data bandwidth

We will find a huge number of medical, wellness and sports applications with bandwidth needs of less than 1 kByte/s. Further the power availability is limited since these types of devices are restricted in size and volume from application point of view. Assuming a device volume of less than 8 cm^3 we find that about 2 Ah at an operation voltage of about 3.6 volt will be available based on today's battery technology. To obtain device life times in the range of year this calls for an average device power dissipation of less than 850 µW or a current of 236 µA.

In general the communication is the major power consumer in mobile devices. For radio based mobile devices we often find the communication to account for 50-90% of the power budget. The general way to reduce this is by reducing amount of data communicated and using a short range radio technology.

To make the usage of small EIS devices feasible in many applications we have to select an access network technology with large coverage. Thus we are left with three major existing radio access networks, mobile phone i.e. GSM/GPRS, GSM/GPRS + Bluetooth and WLAN.

TABLE 1: Comparison of radio access networks.

	GSM/GPRS	GSM/GPRS + Bluetooth	WLAN
Coverage	Good	Good	Fair
Link dist.	Excellent	Excellent	Fair
Low power	Good	Good	Fair
Bandwidth	50 kb/s	50 kb/s	11 Mb/s

Considering a small device like a sensor it is clear that the bandwidth requirement most often is low or very low. Furthermore, it is clear that for mobile wireless devices the power availability is scarce. This imposes that radio link distances will be fairly short to preserve power. Based on these considerations it is from Table 1 clear that WLAN is not a viable access network. Thus remains cell phone or cell phone + Bluetooth access as the possible solutions. For applications where the small devices like body sensors are close to a person who are likely to have and regularly use a cell phone the Bluetooth access to the cell phone will be the most suitable solution. This gives us the following small devices access architecture, cf. Fig. 4.

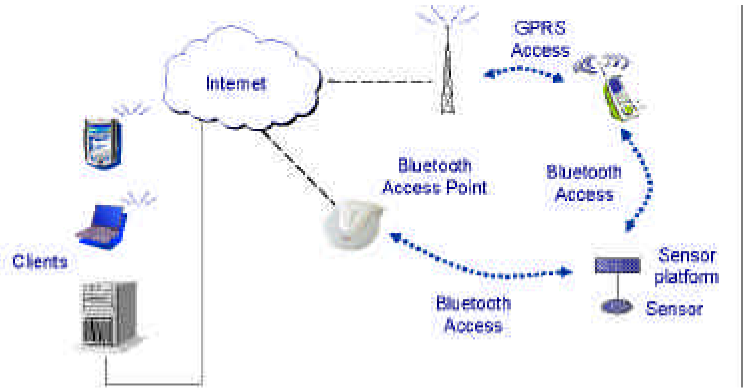

FIG. 4: An EIS device with Bluetooth communication connecting to the Internet via a standard mobile phone or possibly a Bluetooth LAN access point.

This architecture will enable up to 7 small EIS devices to be directly connected via Bluetooth to a mobile phone. The ``TCP/IP" protocol communication of the EIS devices will be tunnelled through the mobile phone to the Internet. In the following an implementation of this architecture will be presented.

As field of application for initial tests, a medical monitoring was chosen. Monitoring of medical parameters often limits the mobility of the patient, e.g., to the hospital. This, while the medical condition of the patient would allow or even benefit from mobility. From the patient's point of view, monitoring of medical parameters offers a degree of security, while at the same time restricted mobility degrades quality of life. A solution is sought where the patient is offered safety, while allowed the mobility to carry on with daily activities. As a first step towards this goal, we interfaced a Pulse oximeter to the aforementioned EIS platform. Our system allows pulse rate and blood oxygen saturation to be monitored on-line, while the patient is allowed mobility within the area of GSM/GPRS coverage. It is clear that the system architecture proposed will feasible for as well as the AEC industry as most other industrial, wellness and sports application. Examples from the AEC industry are monitoring of alone workers and machine maintenance systems which both will benefit from the EIS architecture.

2.1 EIS Architecture

The Internet Protocol (IP) provides standardized means of communication. Utilizing IP for communication has numerous advantages over developing proprietary protocols, e.g., compatibility, flexibility and ease of maintenance. However, traditional TCP/IP implementation requires extensive CPU and memory resources. For mobile applications we strive for small, light devices with low power consumption, thus long battery life. To meet this requirement a special TCP/IP stack lwIP (Dunkels 2002) has been used. It is a TCP/IP stack implementation optimized to reduce memory and CPU resources.

For the connection to the mobile phone, Bluetooth was used. The Bluetooth standard defines a set of profiles for communication. To support commercially available Bluetooth devices such as the Compaq iPAQ or cell phones like Ericsson P800, a minimized Bluetooth stack, lwBT (Öhult, 2003) has been implemented on our EIS device. The stack extends lwIP with Bluetooth LAN access capabilities such as the LAN Access Point (LAP) and Dial-Up Networking (DUN) profiles. The EIS device acts as a Bluetooth device providing a TCP/IP interface for data transport, configuration and maintenance. This concept allows user interaction through standardized WWW-browser technology from any device supporting the Bluetooth LAN Access Profile. The EIS provides platform independent client software for data presentation. The client software (e.g. applets) is distributed from the EIS device by HTTP. The applet is run under the client browser, enforcing security. Sensor data can then be transferred over IP and displayed on the client device for on-line monitoring.

3. ENABLING INTERNET ACCESS

One major problem is that we cannot assume that the application(s) on the EIS platform can receive unsolicited inbound connections. One fundamental reason for this is due to the scarcity of IPv4 addresses and the common way to conserve the IP addresses by deploying varieties of NAT (NAT). Depending on the telecom operator, we might be assigned a non-static mapped private IP address and hence, the service offered behind the NAT gateway will never be available to the public Internet. We present an experimental solution where sensor data, from the users' point of view, is accessible from virtually anywhere as long as the EIS platform is within range of a GSM/GPRS network. The aim of the architecture is similar to what a user experience when accessing resources on the Internet through a proxy server i.e. all returned responses appears to be directly from the addressed EIS platform. A user requesting a service from the EIS platform accesses a public known application server, acting as a host for all connected EIS platforms, instead of addressing the EIS directly. In turn, the application server relays the requests to appropriate EIS platform invisibly from the user s perspective.

It is obvious that this solution is inflexible. A preferable solution would be based on dynamic DNS together with a DHCP server to give EIS devices their own public IP number. Another solution will be based on IPv6. However, the draw back of increased header sizes is likely, thus increasing power usage for communication overhead.

As a front end to the users, a web interface is presented by the application server. The web pages are created and modified dynamically when EIS devices connect or disconnects to the application server.

To provide Internet connectivity for the EIS platform, we need to tunnel the EIS device data communication through the mobile phone onto the GPRS network. In our implementation, we use a standard Sony Ericsson T610 mobile phone. A Bluetooth communication using the DUN profile is between the mobile phone and the EIS device, thus using the mobile phone as a modem. By connecting over the GPRS services the service provider will provide the EIS device with an IP number thus enabling Internet access. When connected to the GPRS network, a user may experience to be on-line at all time. However, the users' perception may not coincide with NAT gateways view of active sessions. Since entries in NAT tables are finite, sessions considered terminated are removed. To prevent termination from the application server, the EIS devices send keep-alive messages periodically. To retain session activity, we assume a NAT entry to be valid for at least 4 minutes derived from 2 *MSL (Maximum Segment Lifetime). The MSL is arbitrarily defined to be 2 minutes, the time a TCP segment can exist in the internetwork system (Postel , 1981) and hence, the current implementation uses a timeout interval under this threshold. When started, the EIS device retrieves the own Bluetooth device address (BD_ADDR). The BD_ADDR will be used in announce messages sent to the application server. The BD_ADDR is mapped to a human readable name of choice before updating the web pages.

Upon access from users, the application server resolves the BD_ADDR and forwards the request to correct EIS device. The requests can be regular HTTP request to the on-board web server, or accesses to data sampled by the pulse oximetry sensor.

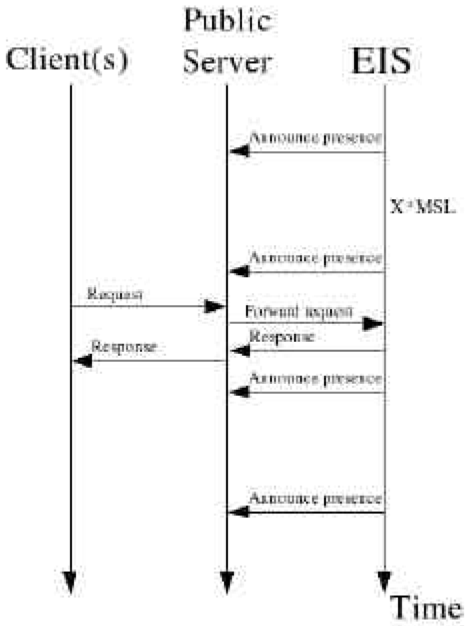

FIG. 5: Connection scheme for announcement and request response of an EIS device. Announcement of presence is made according to the number of Maximum Segment Lifetimes, MSL used by the telecom provider.

4. PLATFORM IMPLEMENTATION

The general architecture of an EIS device is given in Fig. 3. The current implementation of this architecture is shown in Fig. 6. This implementation is based on the usage of a sensor with a serial interface to a microprocessor in this case the M16C/62M from Mitsubishi. The communication to the Internet access network is Bluetooth where a Bluetooth module from Mitsumi WML-C10A is used.

The 16-bit Mitsubishi low-power one-chip microprocessor used is a 3 volt version equipped with 256 kB FLASH and 20 kB RAM as on-chip memories. It is operating with a clock frequency of 4.6 MHz. The Mitsumi Bluetooth module, WML-C10 AHR, is a power class 2 device with integrated antenna, which gives a nominal range of up to 10 m (at 0 dBm). The device is compliant with Bluetooth version 1.1 and is powered by 1.8/3.3 volt. The components are mounted on an in-house PCB board that also houses the RS232 serial interface.

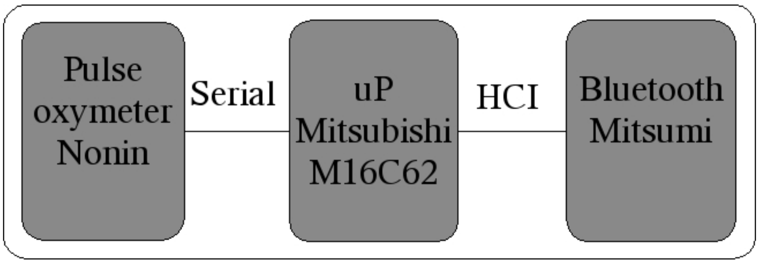

FIG. 6: The EIS test platform architecture. A sensor, in this case a pulse oxymeter, is serially connected to a microprocessor, Mitsubishi M16, running a real time operating system (RTOS) with appropriate parts of the "TCP/IP" suite of protocols and a host controller interface, HCI driver communicating with a Mitsumi Bluetooth 1.1 device.

The microprocessor is running a commercial real time operating system where two major processes are running. One is the sensor data retrieval process and the other is the TCP/IP communication process including web server etc. With this approach it is possible to connect any sensor with serial data output. The data acquisition from the sensor is simple to adapt to the sensor in question. Finally the user web interface have to be designed and implemented using e.g. HTML, Java applets and cgi scripts.

4.1 Pulse Oximetry Application

A finger clip sensor with an additional pulse oximetry module was interfaced. It provides a constant data rate (three bytes per second) of oxygen saturation and pulse rate values to a sensor application residing on the mobile EIS platform. A web-based interface is provided to give the user the possibilities of web-based configuration and management as well as reading data samples.

5. EXAMPLES

A few different trials and demonstrators have been developed with the described system:

- EIS heart rate sensor
- EIS breathing rate sensor
- EIS pulse oximeter

In a simple trial pulse data for a cross country ski-runner was collected. The ski-runner was wearing the EIS sensor and an iPAQ in a small bag on his back. Data was displayed in real time over the Internet. The collected pulse data is given in Fig. 7.

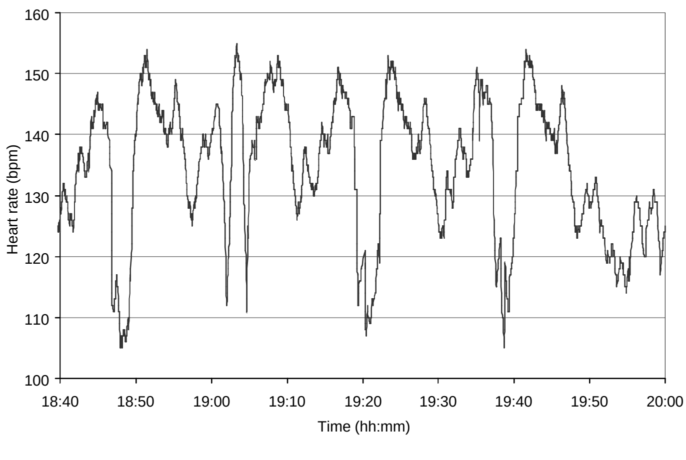

FIG. 7: Pulse data from a ski-runner using the EIS heart rate sensor.

The EIS devices have been tested in Sweden, Germany, Portugal, USA and Switzerland. The test in Switzerland was made possible by the courtesy of Sunrise, a Swiss telecom company. Sunrise did open their GPRS net for roaming from Telia Mobile customers for the test. This indicates one of the hurdles for widespread usage of EIS sensors. Another obstacle is that in many GSM/GPRS networks the operators have made voice the prioritized communication in the network. Thus GPRS communication can be discontinued when voice communication load is eating the available capacity of the GSM/GPRS network. For some tests made at Vasaloppet, the world longest and largest cross country ski-race, our operator Telia Mobile made a guaranteed GPRS capacity available. Thus the EIS sensor only has to compete with other GPRS customers. Data was obtained for the first 9 km of the ski-race before communication was lost due to insufficient GPRS coverage.

5.1 Power consumption

In our experiments, we used a worst-case scenario keeping the Bluetooth connection active all the time, thus not taking any advantage of power saving possibilities. Likewise, the microprocessor used offers numerous power saving modes of operation, something that was not explored. With this un-optimized approach, the power consumption of the EIS platform, including the pulse oximetry sensor, was measured to 270 mW. According to the pulse oximetry specifications (Nonin Medical Inc), its typical power consumption is 60 mW, leaving 210 mW for the EIS platform. The consumption remained stable throughout our experiment, regardless if meaningful data was transmitted. During the experiments, the device was supplied by two re-chargeable AAA 1.2 V Ni-MH batteries in series, providing a total capacity 600 mAh. With a power consumption of 270 mW, the expected lifetime was approximately 5 hours and 20 minutes. This was also confirmed in a series of tests. Depending on the specific requirements (battery lifetime and weight), other types of batteries can be used. Replacing the batteries with e.g. AA batteries could triple the operational period of the platform.

There are a number of ways to reduce the power usage of the EIS device. These include for example:

- Reduced frequency of sensor data transmission.
- Header compression (very effective for payload of a few bytes and less).
- Power management on microprocessor and Bluetooth module.

As an example of power management we find that during normal monitoring of pulse oximetry data, only three bytes of (pay-load) data is transmitted once each second, leaving the Bluetooth module idle most of the time. While being idle, the module could be put in sniff mode (Bluetooth SIG 2001) and consequently decrease the power consumption drastically. Utilizing the power saving features of the microprocessor could also make a very valuable contribution to any power saving efforts. Estimates based on reducing sensor transmission data frequency with a factor of 4 and applying some power management indicates improvements in the order of about 20 times. This gives a life time of the order of about two weeks. This can be further improved by applying header compression and more sophisticated power management strategies. Work in progress will give more solid data on the power reduction obtained by applying the different techniques.

6. APPLICABILITY TO AEC INDUSTRY

In the AEC industry we find several situations where mobile internet enabled wireless sensors are of interest. One is around the worker and worker security and health. Examples are, alone workers, workers in hazardous environments like rescue forces, health conditions of operators of “heavy machinery” such as cranes, tunnelling machines etc. It is clear that human health and security conditions can be improved using such technology and that this can lead to more efficient use of workers capabilities. The example above demonstrates that the technology already is applicable to worker health and security monitoring, even in rural and remote locations.

Another field is maintenances monitoring of machinery and equipment. Here vital parts can be equipped with internet enabled wireless sensors capable of accessing mobile access points such as mobile phones or fixed access points such as GPRS network access points. Such sensing communication technology enable maintenance schemes using an on demand approach instead of time based or disaster based schemes. Since this type of sensing communication technology is in its vicinity it is obvious that today non though of applications will emerge in the future.

7. CONCLUSIONS

We have here presented an architecture for Internet enabled small EIS devices. Our experiments confirm that within GPRS coverage, the EIS platform successfully provides data for on-line monitoring over the Internet. The use of TCP/IP connectivity over GPRS allows interaction with the mobile EIS platform through a standard WWW-browser, thus eliminating the need for deploying proprietary protocols and applications. To cope with limited GPRS bandwidth, the EIS platform provides computational resources able to refine data thus meet the enforced limitation. The architecture allows up to 7 small EIS devices to be visible on the Internet using a Bluetooth equipped mobile phone as network access point.

Currently, neither encryption of the data nor authentication of the user is performed; nevertheless, security issues are always a main factor while sending sensitive data over a network. This is especially true if the information to be sent consists of health related data and the network is wireless. Bluetooth provides a strong device authentication method, and together with the optional link encryption mechanism, the security offered by Bluetooth should be adequate for the communication between the mobile phone and the EIS platform. When it comes to the GPRS network security for both voice and data may be provided using ciphers. This is however an option that might not be available in all networks. Also, the technology is not allowed in all countries. This implies that security most likely has to be provided at a higher layer (e.g. SSL).

It is also clear that the current business models used by operators have to be redefined to solve the roaming problem and the priority problem between voice and data communication in GSM networks.

Finally, the battery life time of the experimental prototype is insufficient for many applications, such as long time monitoring. However, by applying power management techniques, we expect the time of operation for the prototype to be increased from a few hours to several weeks. Since low power design is a large field of research with rapid progress we expect the battery life time of EIS devices to reach the level of years within a not to distance future.

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