Smart-Wire: Enhanced Communication Hardware

Christian Decker and Tobias Zimmer

Telecooperation Office (TecO), University of Karlsruhe, Germany

{cdecker@teco.edu, zimmer@teco.edu}

February 2002

Introduction

The progress in the design and development of small-scale computing devices to this date has established the possibility to integrate these computing devices into virtually all everyday objects. For the near future we expect the availability of even smaller and more densely integrated devices providing us with even more resources and computing power. Existing applications will benefit from this development as well as completely new applications will emerge. Nevertheless we have to be aware of the limited capabilities of devices in ubiquitous computing environments [Weiser, 1991]. The power of our approach presented in this paper resides in the interconnection of those devices.

We present the idea of a "Smart-Wire". Smart-Wire is a communication wire enhanced by integrating small computing devices into its connectors. Possible applications range from statistical use in network traffic accounting to active uses like altering the signal according to the physical characteristics and conditions of the medium.

In contrast to emerging RF based technologies like Bluetooth or WaveLAN, wires are still more reliable, offering a higher bandwidth and a higher degree of privacy. While RF based devices distribute their transmissions to an insecure medium, wired communication between the ends of one single wire can only be intercepted by manipulating the wire itself. This is an important privacy issue.

We think of Smart-Wire as a replacement for standard networking cable like, for example, TP Ethernet cable. On this account Smart-Wire has to provide, apart from its additional benefits, transparent communication for standard components. In the following section we describe the characteristics of the hardware and software needed to implement Smart-Wires and differentiate between the idea of Smart-Wire and related approaches to enhancing network communication. The section, "Benefits gained by the use of Smart-Wire", deals with the benefits that can be achieved by using Smart-Wire in existing network installations. In the section, "Smart-Wire Communication Infrastructure", we propose a communication environment for small devices, based on the special capabilities of Smart-Wire.

Smart-Wire: Enhanced Communication Hardware

The idea of Smart-Wire focuses on the seamless integration of computing hardware into a communication wire, enhancing the wire in this way. This additional hardware is to be integrated into the connectors of the Smart-Wire. These enhanced connectors are referred to as "Smart-Nodes". Therefore, a Smart-Wire is a device consisting of a communication wire and two Smart-Nodes.

The use of a Smart-Wire should be completely transparent to the attached devices. In this paper we assume the communication in the network, enhanced by the Smart-Wire, is packet driven. We will use Ethernet [IEEE, 2000] as an example for a network to be operated on Smart-Wire because of its wide use in LANs.

Smart-Wire Hardware

As described above the Smart-Wire consists of two Smart-Nodes at the ends of a communication wire. The Smart-Node, consisting of a processor, memory and I/O components, is connected to the communication wire and the Smart-Wire's external connector. It is integrated into the connector's chassis. The hardware of the

Smart-Node has to be small enough to fit in a chassis only slightly bigger than that of a standard Ethernet connector (Figure 1).

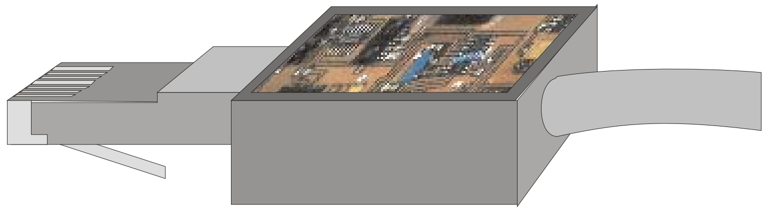

Figure 1 – Smart-Wire connector with integrated computing hardware.

A constant, non data-dependent power supply is necessary to save the state of the Smart-Nodes and perform computations even when no data is transmitted. The power supply for the Smart-Nodes consists of special inter-connection sockets injecting the operation power for the Smart-Wire network. Figure 2 shows a working prototype.

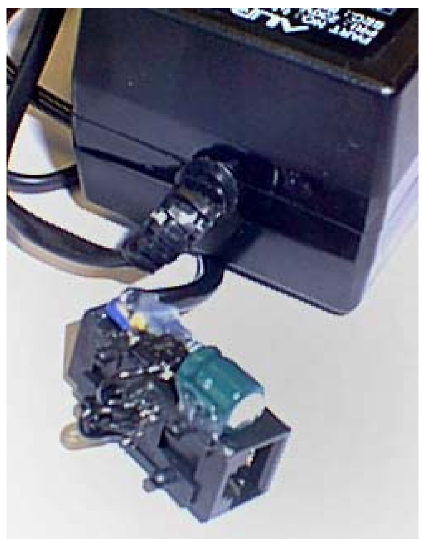

Figure 2 – Smart-Wire power supply

Smart-Wire Software

The software to operate the Smart-Wire resides in the Smart-Nodes. We propose Smart-Nodes to be programmable only by the manufacturer of the Smart-Wire, and most likely only once during the manufacturing process. This is because only the manufacturer himself is aware of all the electrical features of the wire he uses, and can therefore provide a guarantee of the software working smoothly with the particular wire. The Smart-Wire is not intended to be any kind of programmable platform or to host mobile agents. We also do not intend to establish any kind of active network [Tennenhouse et al., 1997]. Making Smart-Nodes programmable or reconfigurable leads to a very high complexity of the system and imposes high requirements on the hardware. In addition, re-programmable nodes would be more vulnerable to exploits.

The decision to make Smart-Wire an “out of the box” product, not configurable by the user, takes the probable limitations of the computing hardware into account by reducing the complexity of the needed Smart-Node hardware and the operating software. A disadvantage of this approach is the static nature of the Smart-Nodes during the lifetime of a Smart-Wire.

Re-programmable nodes may still become a highly desired feature for future applications, but are not part of our idea presented in this paper.

Benefits gained by the use of Smart-Wire

In the previous section we described our proposed design for Smart-Wire. This section will show how we might benefit from the Smart-Wire when integrated into existing communication systems. According to the definition of the Smart-Nodes, they are capable of altering the transmitted physical signal, as well as interpreting the payload data. Thus they are capable of understanding and even changing the data transmitted via the Smart-Wire.
A Smart-Node can be operated in passive or in active mode. In passive mode the node observes the connection on the Smart-Wire, while in active mode it is capable of additionally altering the transmitted signal and data. Table 1 gives an overview of the different modes and the tasks the node can perform.

Mode	**Role in the Smart-Wire network**	**Tasks**
Passive	Observer Smart-Node	Signal and data statistics
Active	Store-and-Forward Smart-Node	Data manipulation
	Signal Smart-Node	Signal manipulation

Table 1 – Operating modes of Smart-Nodes

We will now have a closer look at the possible applications of Smart-Wire and the benefits emerging from them according to the different roles the integrated Smart-Nodes can play.

Observer Smart-Nodes

An Observer Smart-Node operates in passive mode. It is capable of analysing the transmitted signal, for instance, counting the bytes transmitted. This provides the basis for accounting services that can track the amount of transmitted data down to the level of every device attached to the network. The operation of an Observer Smart-Node is completely transparent for all attached devices.

Store-and-Forward Smart-Node

Store-and-Forward Smart-Nodes operate in the active mode. In similar fashion to passive mode, nodes in active mode can analyse the signals and the transmitted data. Store-and-Forward Smart-Nodes appear to be the most potential because they are able to manipulate the data. Thus, for example, it is possible to encrypt an Ethernet frame travelling from one end of a Smart-Wire to the other, or to introduce some kind of FEC (Forward Error Correction), additionally securing the transmission.

Signal Smart-Node

Only the manufacturer of a communication wire knows the exact technical specification of his product. This includes signal dispersion or situation based attenuation of the signal caused, for instance, by the wire being operated under extreme conditions like deep or high temperatures. The idea behind the Signal Smart-Nodes is to provide the manufacturer of the communication equipment with the ability to alter the electrical signal transmitting the payload data to cope with different environmental influences. Furthermore, the manufacturer can choose different materials for reasons of cost efficiency or to achieve higher bandwidth. Nevertheless, the technique of Signal Smart-Node permits the fully transparent operation of such a Smart-Wire in existing communication systems.

The Smart-Wire Communication Infrastructure

The previous section investigated the transparent use of Smart-Wire in already existing communication hardware. This section goes further and presents a communication infrastructure for connecting many small Ethernet capable devices over a single Smart-Wire. A typical application for such an infrastructure is building an Ethernet backbone attached to small devices like the Beck IPC [Beck, 2001] integrated within a room. Such a backbone provides memory, computing power and an Ethernet network access in a distributed manner for general purposes. Laptops, hand-held devices and the sensor-equipped room itself can use the infrastructure to augment their abilities in an efficient, standardised and publicised manner. In this case, the use of Smart-Wire focuses on reducing the effort and complexity associated with the installation, operation and maintenance of such an infrastructure.

The conventional way for building up an Ethernet infrastructure is to use some hubs and various meters of twisted-pair cable. Hubs are needed to attach computer systems to the infrastructure. However, in comparison to the cable, the hubs are quite expensive and, even those considered small, are oversized for really hidden integration within the room. If one wants to connect many devices to achieve a very fine-grain equipped environment, one has to invest in more hubs and/or more meters of twisted-pair cable. Both possibilities result in higher costs and greater real-estate utilisation. The goal should be to reduce the hubs down to a size where they are not bigger than the cable itself.

Smart-Wire enables us to benefit from its cascading capability. By coupling one Smart-Wire segment to another we build up successively the entire infrastructure. Ethernet capable devices can be attached by using simple coupling pieces. To the device the entire infrastructure presents itself as an ordinary Ethernet such that the device is not aware of the Smart-Wire technology. Figure 3 shows the infrastructure.

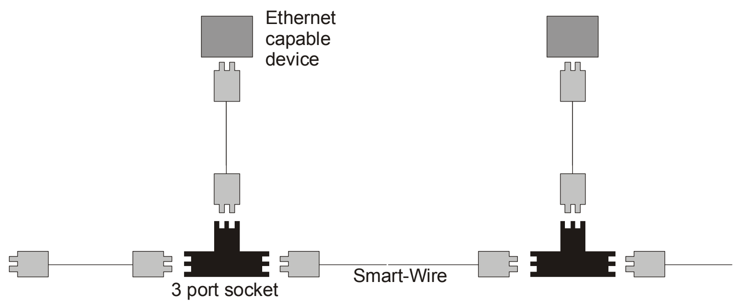

Figure 3 – The Smart-Wire Infrastructure

With this approach we achieve various advantages; the topology is much simpler. It is more like a long, single cable as opposed to the star-shaped structure of the conventional approach. However, because of the cascading capability, flexibility is maintained. Hence, the hubs are no longer necessary. Their functionality is replaced by the Smart-Nodes. These points are crucial for a seamless integration of the infrastructure into the application area.

Communication

When an attached Ethernet device sends Ethernet frames, they are distributed through the entire infrastructure, because there is no knowledge of where the destination device is situated. Therefore, every device can read every Ethernet frame. This straightforward approach impedes performance because every device participates in the communication at any time. Now, because Smart-Nodes can interpret the signals, they enable switching of Ethernet frames. Only the Smart-Wire segments for forwarding the frames to the destination are used and different communication processes do not interfere with each other. This results in increased throughput and reduced delay. With switching, any third device cannot read a transmission between two other attached devices.

By their signal measurement capability Smart-Nodes are able to detect points of failure and exclusively disable the Smart-Wire segment. Furthermore the node can report the failure to an administrative institution. This ensures a certain fault tolerance and helps in maintaining the infrastructure.

Coupling and Switching

The logic of how two Smart-Wire segments communicate with each other is pre-programmed within the Smart-Nodes. Coupling of Smart-Wires is therefore nothing more than connecting the pins of the connectors with each other. Three-port sockets offer the possibility to attach any Ethernet capable device to the infrastructure. The socket contains no intelligence. The Smart-Nodes themselves can detect whether there is a device attached on a port of the socket or not. According to that they can agree to change their communication behaviour to let the device participate in the infrastructure. However, this is done completely independent of the socket. Figure 4 shows a prototype design of such a socket.

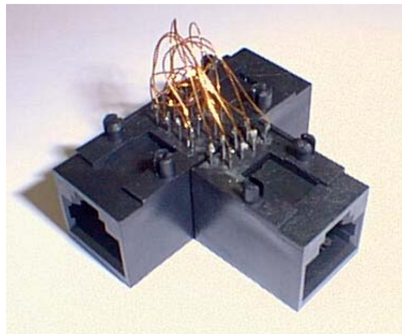

Figure 4 – 3-port socket

Instead of attaching an Ethernet capable device, it is also possible to couple in a power supply for the Smart-Wire. Special Smart-Wire enabled devices can use this power to operate themselves.
When switching is needed all participating Smart-Nodes start to build-up tables of MAC addresses associated with forwarding directions. This can be done by listening to the traffic (learning) or by an explicit exchange of information. Any incoming Ethernet frame causes a table lookup in a Smart-Node, which defines to which connected Smart-Wire the frame has to be forwarded. For unknown addresses a default forward direction can be given or the possibility of forwarding to all connected Smart-Wires. Furthermore, the complete switching behaviour is independent of the socket.

The Smart-Wire infrastructure provides a simple way to interconnect small devices. These devices can augment their abilities by distributing tasks. At the same time the Smart-Wire infrastructure itself is a distributed system for enabling communication between such devices.

Conclusion

We propose an idea of a computing technology enhanced wire, so called Smart-Wire. Costs for a segment of Smart-Wire might be higher than for a comparable wire without this technology but this will only be significant in the beginning. After Smart-Wires are accepted the quantities will lower the price down to a level comparable to that of an ordinary wire. In particular, we believe that upcoming requirements for accounting and security will push the Smart-Wire technology. The crucial advantage will be the seamless and transparent integration in already existing communication technology. By showing how Smart-Wire can be used in building up a communication infrastructure, we found various advantages for using it in distributed ubiquitous computing environments.

References

[Beck, 2001] Beck IPC GmbH 2001. *Single Chip Embedded WEB-Server*. Available from: http://www.bcl-online.de/ [Accessed 09/14/01]

[IEEE, 2000] IEEE Computer Society LAN MAN Standards Committee. *Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications*, IEEE Std. 802.3 2000

Edition, 2000. The Institute of Electrical and Electronics Engineers, New York

[Tennenhouse et al., 1997] Tennenhouse, D. L., Smith, J. M., Sincoskie, W. D., Wetherall, D. J., Minden, G. J, 1997. A Survey of Active Network Research, *IEEE Communications.* Vol.35(Jan), pp.80-86

[Weiser, 1991] Weiser M. *The Computer for the 21st Century*, Scientific American, September 1991 Vol. 265 No. 3, pp 94-104