Wireless Sensor Network - course:  
Project to investigate requirements and applications using  
wireless sensor networks on a construction site

Abstract

In a current modern construction site there are growing number of work 
machines with some kinds of automated systems. This means that there are 
also growing number of sensors involved. Many applications from localization 
to automated tool control are used in various ways. At the moment though the 
work machines do not communicate or collaborate with each other very 
intelligently although construction work requires a lot of collaboration. Also 
the sensors are only used on a specific task and the system architecture 
normally does not give any easy ways for wider usage of the sensor.

In the future more intelligent and flexible ways to improve the 
communication and the work process has to be invented. The machines are 
normally mobile, which means that usage of wireless technology is very 
important. Other important aspect is that the construction site network will 
change as work machines come and go. This means that the communication 
architecture should be able to change dynamically and tolerate brake downs. 
Because there are lot of different companies working as subcontractors in the 
site the system should be open and flexible and should accept wide variety of 
hardware configurations. The energy conservation is not the biggest problem, 
but there would be also sensors that do not have the possibility to get energy 
for long periods.

This study concentrates on the requirements and possible 
applications of using wireless sensor network (WSN) on a construction site. The companies are interested especially on applications that could improve 
their competence (e.g. cheaper and quicker building time, better quality, etc). Some advances of the WSN are discussed using a road construction site as an example.
INTRODUCTION

This paper focuses on road construction, because there have been some previous studies at VTT Electronics that supports it. In those studies use of new technology has brought improvements to the whole process.

Wireless sensor networks (WSN). Recent advances in the MEMS-technology (micro-electro-mechanical-systems), wireless communication and digital electronics have provided us the possibility to develop more advanced sensor systems, which are low-power, low-cost and multifunctional. This has given new application possibilities to many areas.

The Wireless sensor network concept is fairly new as an independent research field, although wireless communication and electronics have been used for many decades. Previous applications have been formed using old architectures and techniques, which have basically meant just replacing wires with wireless communication. This has been adequate solution for many applications. In the recent years more intelligent wireless systems have been needed as the amount of sensors have grown. In the last decade the key words in application solutions have been "smart" or "intelligent", which has meant that all devices have had to have some kind of sensors in them. Controlling the growing number of sensors has become hard using the old methods. This has lead to the research of more adaptive and intelligent architectures of wireless sensor networks.

A sensor network is composed of a large number of sensor nodes, which are densely deployed either inside the phenomenon or very close to it. (Akyildiz et al.). The idea in the WSN is that it does not need to be pre-planned or engineered. It can self-organize and every node has intelligent enough to process the data and only send the needed and filtered parts forward.

Many applications are possible ranging from military to personal health monitoring. WSN can be everywhere and monitor everything from temperature to chemicals. Here are some basic examples of possible usage:

- Military applications
- Health monitoring
- Vehicle tracking and detection

In many cases the possibilities of WSN technology are not completely processed and understood, which means that not many applications still exist. Military applications are understandably very interesting and popular. The army has resources and money to create possibilities if they see a potential
application. Also health monitoring will be very interesting area as the western
countries will face in the future a growing number of aging people.

WSN offers limitless possibilities, but at the moment there are still
lot of even basic issues that need to be resolved first. Old ways of creating
networks have to be abandoned and completely new methods and ideas need to
be implemented. One area of problem is the communication between the nodes
and the sink (or the requester). A single node or nodes should be able to send
the requested information to the source as optimally as possible. This has been

The requirements of this kind of system are more dynamic than
the current network topologies allow. There are two ways for nodes to transmit
the message forward; single-hop or multi-hop. Multi-hop is in theory more
energy efficient, because transmit energy increases in power of two compared
to the distance, but on the other hand less sensors that need to be used the
better. In practice the optimal energy saving way is to use multi-hop to the
point where the waking of a node does not take more energy than the whole
transmission.

A sensor network design is influenced by many factors, which
include fault tolerance; scalability; production costs; operating environment;
sensor network topology; hardware constraints; transmission media; and power
consumption.

Road construction. A road construction seems to be very complex and hectic
environment, but is actually very carefully planned in advance (Känsälä et al.
2003). In Finland, and probably in everywhere else, different road construction
processes, such as billing and material flow, are still handled manually. This
means that the information a foreman has is old and in many cases unreliable
(Känsälä et al. 2003).

VTT Electronics has recently finished a project (LAT0), which
focussed on producing a system to control the information flow at the
construction site wirelessly. The challenge was to create tools for different
types of users. A network, using standard components, server software and
mobile phones, was created to support wireless information flow between users
and a database. Although the system could be build using any software
environments, LINUX and JAVA technology were important part of this
network. Test results indicated very promising usages of this kind of
technology and architecture. (Känsälä et al. 2003).

The technology that will be used in a road construction site needs
to be open, simple and cheap. Many subcontractors are small companies and
have only few employees. They do not have resources to adapt to very
complex systems that requires long learning period and money. The LATO-
project proved that simple and cheap terminals, such as mobile phones, could be the possible platform for WSN.

Construction work is very demanding. Schedules are tight and delays are not accepted. So any possibilities to reduce unnecessary work is welcome. Such processes as billing or material flow could be more automatic, which would give the worker more time for other things. Also quality control can delay the work. This could be avoided if every machine would control the quality in real time and relay the information to the database.

**USING WIRELESS SENSOR NETWORK ARCHITECTURE ON A ROAD CONSTRUCTION SITE**

A road construction site has normally several heavy work machines operating on different work phases at different times, but they all still have a common goal, to produce a road. Several companies work in the site, but there is always a main contractor who controls the whole process. The main contractor chooses the subcontractors to work with and plans the schedule and the budget. Normally there are tens of different subcontractors working on the site. Many processes are done manually (billing, material flow, quality controls), which could be done more efficiently, if the information needed would be available automatically.

At the moment the work machines are designed independently. This means that they have only the sensors and computer systems that the machine itself needs. Although the machine works independently on the site, normally the work phase requires at least another machine to be completed (e.g. a loader and a truck). For this reason some collaboration schemes should be included in the design and development process. Example the loader and the truck could communicate what material and how much is transferred to the truck. The truck would remember this information when it arrives to the dump site and would relay it forward. The sensors and the intelligence put to a work machine could be more communication and collaboration oriented. The sensors could be placed and designed so that they provide useful information also to other machines and especially to the machines that they normally work with. Example: the loader would find out what material it loads and relay the information to the truck (and more generally to the contractor).

A work machine could work as a sink inside the WSN. All the local sensors (mainly inside the machine) would be under the influence of the sink. The sink then decides and distributes the information to outside and takes requests. Although locally the sensors could change information without the sink, which would be a faster way, the sink could only give a permission to communicate outside. This would prevent unnecessary and unwanted
communication (e.g. between competitors). The work machine would then represent the sink described in the WSN.

![Diagram of sensor communication in a work machine](image)

**Figure 1. A simple schematic what a work machine sensor communication would look like.**

Figure 1 shows the sensor communication inside the work machine between another sensor or the sink and how the sink controls the path to outside. The sink has been programmed to understand requests from outside in a simple universal format (and might even know several "languages"). A request might come from a supervisor or a master database to check if the machine is working properly and/or need of maintenance. The sink would then decide what information is needed to fulfil the request. This means that the supervisor does not need to know which specific sensor is needed to give this information. Another example would be that the supervisor or a supervising database is requesting the information on how many hours the machine has worked. Again the sink knows the sensor or a subsystem to get this information and relays it back to the requesting source. There might be also other machines (i.e. sinks) or even an internet between the requester and the sink, but for the both the transmit path is transparent and the communication protocol will relay the message through the optimum path.
Figure 2 shows how the system could work with multiple work machines. If a loader would like to communicate with a road grader, it would only have to send the message to the system. The system would find a way to the grader through other machines or even through internet. There could be a visual map of every machine connected to the system, but the network paths would change constantly depending on the positions of the machines. The advantage would be that there would not need to be any static base stations. Basically every machine would be a moving base station that can relay messages and interpret them. Also workers could be connected to the system through machines. Some techniques to adapt to different configurations could be done using swarm intelligence and dynamic domain hierarchy.

Another good feature of the system would be if the sink is asked to collect some data and then relay it to some specific location on a certain time frame. This would be optimal in situations where the sink is not always in range to send the information continuously or immediately on request. Also the information might not be relevant until some event has happened. These kinds of requests could be example; daily working hours of the machine, daily gasoline consumption, weekly maintenance information, etc. This means that the sink should be prepared to collect and store data for long periods and relay the information when needed.
The difference between the sink and the sensor is distinct. The sink controls and manages all the sensors in its range. It might have a sensor its own, but it definitely should have more influence power than a single sensor. This would be crucial if any privacy and restrictive communications are important. In small machines with only few sensors a single pre-determined sensor could be also the sink, but larger machines would have a dedicated sink just to control the communications.

Also a secondary sink should be selected from the sensors to improve fault tolerance. Even every sensor could have inherently a capability to work as a sink, but in a smaller scale than the real one. This would improve fault tolerance.

As mentioned earlier the work site might have tens of different companies using wide variety of different work machines, which are produced by multiple manufacturers. In worst situation all the work machines might be from different manufacturers. Despite that the sinks should be able to understand each other, which compared to human communications means that although every system might have their own language they all should understand some universal language (e.g. English). With this language they could communicate reasonably, but for more precise communication the native language of the system would need to be used. Of course the optimal solution would be if the manufacturers could agree on an universal language, but it is not likely to happen.

One future requirement from the system could be real-time services. VTT Electronics is doing research on possible ways to implement real-time services to an adapting wireless network (Rannanjärvi 2002). Figure 3 shows the near future research and expected timeline for usage of this kind of technology. It has been strongly noted that in the near future seamless services between machines, devices and humans are needed and possible.
Figure 3. Expected timeline of wireless communication.

The ISO standardized OSI layers (figure 4) of network communications can be used as basis for the WSN architecture development, but there are some inherent problems that prevent from direct usage. First of all the OSI model is designed for more static topology, which is not a feature of a wireless communication. Also closer collaboration between layers is required in the WSN as there are many features (e.g. power saving) that are not implemented in the OSI model. in the WSN the MAC protocol will be especially important and should provide means to meet the requirements of the WSN.

Figure 4. The seven layers of OSI model.
One suggested MAC protocol is the Sensor-MAC, an energy aware protocol (Ye et al. 2002), which is designed to minimize the power consumption of the nodes. Another feature of S-MAC is self-configuring; a certain level of knowledge of their neighbourhood.

Routing is a problem in the WSN as there is no predicted pattern of deployment and the nodes are moving randomly. One problem the lower protocol layers should address is the routing of the information from a node to the sink through other nodes. The OSI model does not give any solutions to this problem. There are many suggestions of mechanisms to do this, such as directed diffusion (Intanagonwiwat et al. 2000) and SPIN (Kulik et al. 1999; sensor protocol for information via negotiation). The difference between them are the ratio between events and queries. Directed diffusion is more query oriented and the SPIN more event oriented.

A road construction application might be event or query oriented, so the protocol should not exclude either one. Also flooding, high data rate and different priority messages are most likely to be needed. The model should be inherently robust and secure. The MAC protocol should be able to change between different wireless communication methods (e.g. WLAN, GPRS, GSM, etc) depending of the coverage. These features could give a firm backbone to produce useful applications.

Like it is suggested with WSN that not all of the OSI layers are needed to compile an optimal stack. Most important layers will be the lowest layers that need to handle many complicated tasks. As many hardware configurations will be simple and cheap the highest layers (application, presentation and session) could be replaced by one layer. This would give also more manageable system. It might be better to design the layers without the OSI involved. In general designing the MAC protocol will be the most important task. Three or two lowest layers (at least physical and datalink) need to completely support the MAC protocol and wireless communication. This will give efficient and robust backbone to the applications. all the rest could be joined as one efficient layer to handle the interface between application and the data.

**HUNTING OF THE KILLER APPLICATION**

Some application in a road construction site have been already discussed. The question is; do we still have a killer application? We will need a work phase or a process to prove that the WSN works and improves the construction process. It has been shown that WSN can be used to build an affordable, adaptive and dynamic network that would not need any static base stations. This is a crucial
backbone if we want to improve communication in the work site. The next step is to provide some content using the network.

The construction industry as a whole is very conservative. It has changed slowly in the last 50 years. Because there are so many small companies the resources for development and unifying is very hard, if not impossible. In many countries the competition between companies is very fierce. Only laws and regulations have effect and give some chance for improvements. In the industry the cost of a process is crucial. The usage of the WSN lies on the fact that it needs to lower the cost of a road construction process enough to be attractive.

The first application should be a small and simple to prove that the WSN works. This kind of application could be example monitoring an actuator that is crucial to the work process or information gathering. Preventive maintenance will be very important part of future machines as no unexpected delays are wanted. This could be one chance to test the WSN in use.

There have been done research and development for systems that communicate wirelessly and relay information. The CIRC project (Peyret et al. 2000) is one example where are system to improve road pavement construction was research. In this study the road pavement process was improve implementing wireless communication and GPS localisation. A universal vector database was used to show movements of the machines in a map to optimize the pavement process. The system was based using TCP/IP with peer-to-peer communications. For wireless technology the WLAN was used as it was found to be most potential.

**DISCUSSION**

For this kind of technology to be useful and attractive to a contractor or a manufacturer, it has to offer some significant practical improvements. These could be improved quality, faster road building, less maintenance of the machines, better scheduling, etc. In practice it will culminate to either building a road faster and cheaper or with better quality. There is a commission for both, depending on the need.

It is very hard to imagine how the technology advances in the future, but the most important thing to remember is that the application, not the hardware, will determine the success of the system. Engineers and researches have to think from a different perspective to understand what are the killer applications in this field.

The road construction industry is very fragmented. It is hard to apply any completely new systems, because there are several small companies
involved. For this reason it is easier to do research and development with only one company, preferably with the main contractor and/or the customer.

The WSN to be fully implemented will take a long time. It will need the support from government, trade unions, companies and workers to be successful. The possibilities are limitless and the technology will soon be mature enough, but the challenge is to convince the companies.

REFERENCES

I.F. Akyildiz, W. Su*, Y. Sankarasubramaniam, E. Cayirci, "Wireless sensor networks: a survey", Broadband and Wireless Networking Laboratory, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA


