GENSEN Project

New Platforms and Applications in Wireless Automation

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***Abstract*— Seinäjoki University of Applied Sciences took part in the research and developing project *Generic Sensor Networks for Wireless Automation* (GENSEN). The project was done in cooperation with Vaasa University and Aalto University. The project was funded mainly by the Finnish Agency for Technology and Innovation (TEKES). Also seven companies from variable application areas participated in funding. The main objectives of the project were the development of generic sensor networking platform for wireless automation, protocol stack developing, system validation and testing through case studies and evaluation of the commercialization capabilities. The GENSEN research group in Seinäjoki developed a mesh topology wireless network, programming environment for ultra-low-power small-size sensor nodes and a new stackable hardware platform with several sensors. The research groups in Vaasa and Helsinki developed a high performance, versatile and modular sensor platform structure for demanding time-critical applications. They researched also the business potential of the wireless sensor systems. The Helsinki research group developed a universal A-stack communication protocol for wireless sensor devices. The existing and new platforms were tested in some application areas: crane control, greenhouse sensors, condition monitoring, cattle house automation, and energy production systems. Seinäjoki UAS tested the low-power sensors in a greenhouse, the mesh network topology in a cattle house and the data flow in a wind turbine. Vaasa University and Aalto University tested the existing commercial platform and the new platform in a greenhouse, in a cattle house, in trolley cranes and in the distributed energy production.**

Keywords: Wireless, Sensor network, Wireless automation

I. INTRODUCTION

The wireless technology is widely used in sensor networks in automation. However, there are not so wide set of wireless applications. The wireless network topology is mostly very limited star structure without multihopping and universal interface to other systems. The sensor nodes are quite simple without data processing and dynamic configuration.

While developing the wireless automation, the most expensive phase is to develop a platform up to such a level that makes it possible to product fast new applications. In the GENSEN project we focused to generate and develop generic sensor network architectures for wireless automation. We evaluated also new systems in five application cases: crane automation, greenhouse automation, agrotechnology, wind turbine and autonomous energy production.

GENSEN project funded by participating companies and by Finnish Funding Agency for Technology and Innovation (TEKES). The companies were in all preceding application areas: Konecranes, Martens, Mervento, Metso, Sensinode, The Switch and Vacon.

This paper is focused to describe wireless platforms and application cases done by Seinäjoki UAS and introduces also the work of the other GENSEN research groups.

II. DEVELOPED ARCHITECTURES

A. A-stack

At Aalto University, Helsinki, the GENSEN researchers developed the A-Stack protocol, which was developed for wireless data sensors for demanding applications. A.-Stack is a real-time protocol stack for time-synchronized, multi-channel and slotted communication in multi-hop wireless networks. The protocol is suitable in wireless automation and wireless structural health monitoring. Building blocks are the radio transceiver, MCU, FreeRTOS real-time kernel, interrupts, MAC –layer, pachet and service manager and applications tasks (Figure 1). The top-most layer is completely independent of target hardware and communication interface. [1] [2]

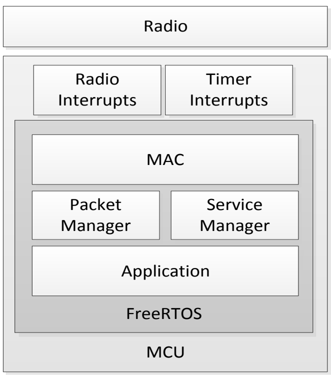

Figure 1: Building blocks of A-Stack [1]

B. UWASA platform

Vaasa University GENSEN researchers developed a new stackable, powerful, energy efficient WSN platform – the UWASA node - for wireless automation. The node consists of the versatile power supply (up to 10 regulators), the main ARM processor (LPC2378 from NXP), the wireless communication controller (CC2431 from TI), various interfaces and the extension module support. The size of the node is 45.6 x 45.6 mm (Figure 3). The accuracy synchronization is used for time stamping of the measured data. The slave extension modules can be for example sensor and actuator controller or application depending peripherals. The node is backward compatible with Sensinode Nanostack and runs FreeRTOS [3] (Figure 2).

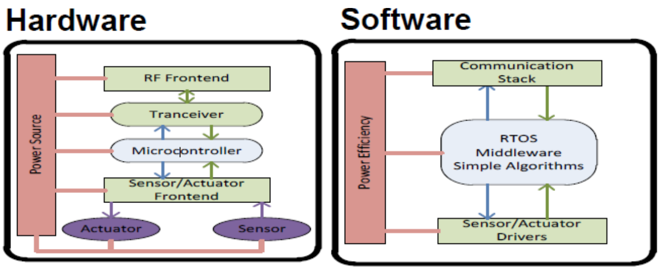

Figure 2: The UWASA node [3]

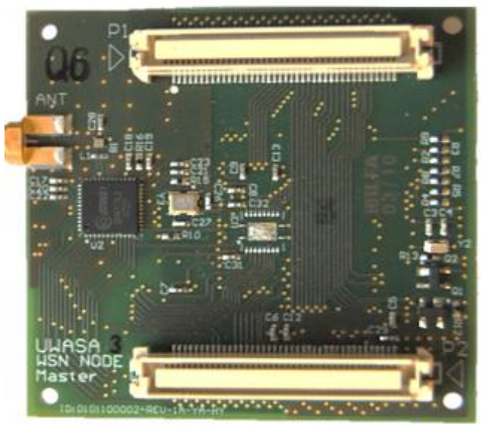

Figure 3: UWASA node hardware

C. SURFnet

Seinäjoki University of Applied Sciences research group developed two different hardware platforms for a low-power, low-size wireless sensor node (SURF = **S**einäjoki **U**AS **RF**), network protocol and a programming environment. The development continues the earlier research of wireless technology in Seinäjoki UAS [4].

1) SURFnet platform V 1.0

Following the earlier plans, we assembled a small-size wireless node for developing and testing purpose [1]. The node includes nRF24LE1 radio controller and MMA7360 3-D acceleration sensor. The size of the node is 23 x 14 x 5 mm. We developed also a USB-SPI bridge module for programming purpose and programming routines for radio controller using this USB-stick (Figure 4) [5].

Figure 4: USB-SPI bridge with wireless node [6]

2) SurfProgrammer

Based on the earlier routines, we developed a complete programming environment for wireless nodes: SurfProgrammer. This includes a source code editor with C-language, an open source SDCC C-compiler and transfer routines to and from the radio controller program memory (Figure 5). Also a bachelor thesis is going on to develop wireless programming feature including in SurfProgrammer. All source codes and documents are freed downloadable in Seinäjoki UAS Embedded Systems websites [7].

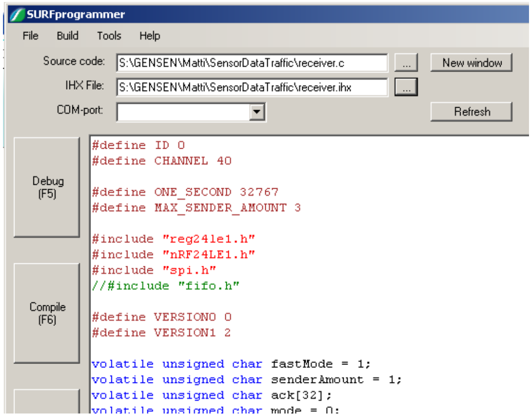

Figure 5: SurfProgrammer

3) SurfNet mesh network topology

Based on the earlier plans, we developed a mesh topology network protocol with multihopping gossip routing in which every low-power node can be a router. We reached the low power feature by minimum 0.035 mA power current, but in real application it is about 0.1 mA. The current curve in active 10 ms period inside 1.0 second synchronization period is shown in Figure 6, where time slots have the next meanings:

1: Controller starts by interrupt,
2: Crystal starts
3: Upload message
4: Receiving active
5: Process received messages
6: Sleep state
7: Possible message send pulse

Also a positioning method is added into topology, in which every node uses neighborhood connections and fixed-position anchor nodes to estimate its own X-Y position [6].

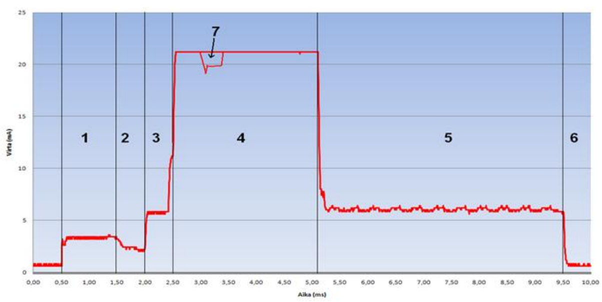

Figure 6: Active period current curve [6]

4) *SurfNet bridge module*

We made a bridge module to have a connection with higher level system. It functions as a sink node in the network and communicates via a SPI bus. A wireless bridge node collects all measured data in the network via gossip routing, as also all other nodes. In our test cases we have connected the bridge node with the platform developed at Vaasa University. The bridge module can download all collected data in network and send commands to SurfNet. In our research we use the same USB stick, which we use while programming the node (Figure 4). In addition to have programming features, it has a direct bridge or pipe via the virtual COM port in PC to the wireless bridge node in the USB stick. We added also the network commands, which are transferred via the bridge module using the flooding method. With commands it is possible to set up the features in the network: the ID numbers of nodes, the synchronization period, the RF channel, the RF power, the subnet address and positioning features. In addition to commands it is also possible to set and read the application depending variables of every individual node.

5) *Monitoring software*

The student members of the research group developed monitoring software using the network bridge module. The software collects both positioning data and the measured sensor values of the all nodes in the network. The positioning is shown in graphical mode and in a table. The measured values are shown as node position point colors or background/foreground colors in the table. The colors are depending on the minimum or maximum limits of the each sensor. The students added network command features to this monitoring software. This software was used in the cattle house case (Figure 7, Figure 8) [8].

The students developed also the monitoring software for the high-speed data flow. With this software it is possible to collect data in rate of 3000Hz, show the curves and save measured data in the database. This software was used in the wind turbine case (Figure 10, Figure 11) [8].

6) *SurfNet platform V 2.0*

Seinäjoki researchers developed the second wireless node platform to have a more flexibility with power source and sensor set. The new node platform is modular and stackable having several power supply sources and several sensors. The alternative power supplies are battery, solar panel, peltier element or magnetic generator. The alternative sensors measure temperature, humidity, acceleration, light and/or voice. The size of the node is 25 x 16 x 8.5 mm added with alternative modules (Figure 7) [9].

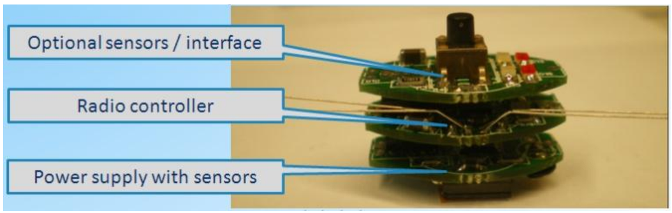

Figure 7: SurfNet stackable platform [9]

III. APPLICATION TEST CASES

A. *Trolley Cranes*

Aalto University researchers tested first the wireless communication using the channel emulator. The simulated environment was ta moving bridge including a moving crane. They studied the feature of the dual antenna structure. The results were: The packet delivery ratio can be increased to a max. of 50% and antenna switching gave 70% delivery ratio compared to 40% using single antenna [10] [2].

The next test was done in industrial hall. The transmitter had dual antenna (Figure 8) and data was collected by four nodes.

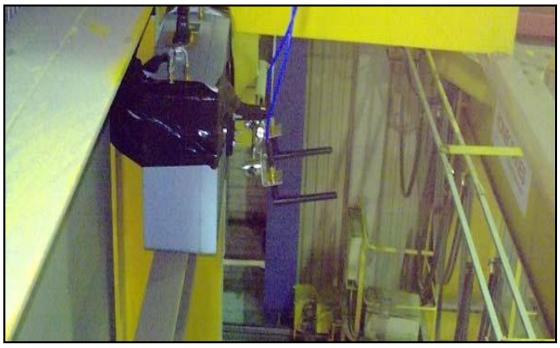

Figure 8: Dual antenna system in industrial hall

The measurements were done in three different environments: Open space (light), some machines standing on the floor (medium) and metal racks of tools in the line-of-sight (heavy). The measured packet drop probabilities in some cases are shown in Figure 9.

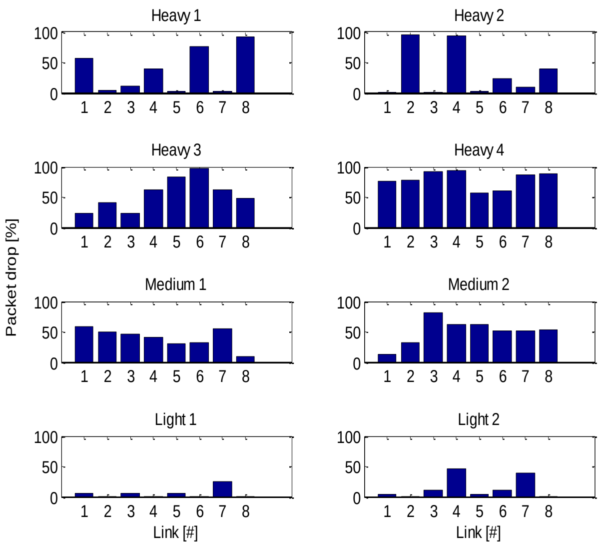

Figure 9: Measured packet drop probabilities

B. Wind Turbine

The communication between the Vacon frequency drive used in wind turbines and the wireless network were tested by Vaasa researchers. The used platform was UWASA node with an isolated RS485 slave module [11].

Wireless data flow and range in blade vibration monitoring were tested in wind turbine case. A wireless SurfNet node with 3D acceleration sensor was glued on the end of the blade of wind turbine. A laptop computer with USB-SPI bridge and bridge node collected real-time data into screen and into file. As result of the difficulty of test setup, the tests were done with only one 3D acceleration sensor position and only with 1.6 g maximum acceleration. While the blade is not moving, the measured data is flowing without problems with error rate 0 % (Figure 10). The distance between PC and sensor was about 20m.

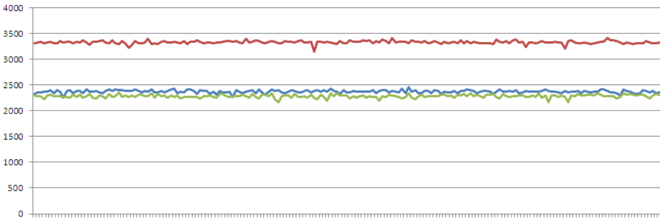

Figure 10: Measured data, while the blade is not rotating

As the blade starts to rotate, the 1.6 g acceleration limit is reached very soon in one direction. Every time, as the sensor was in shadow to PC, the data flow breaks. So the error rate was about 33 – 36% depending on distance between PC and lowest plate position. (Figure 11)

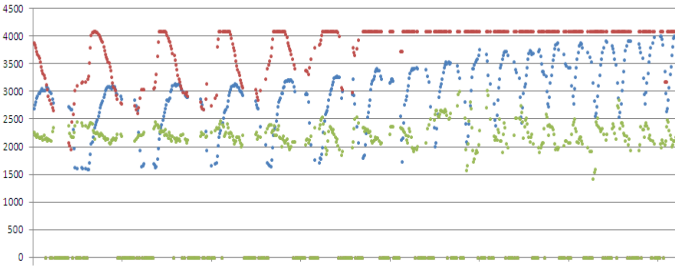

Figure 11: Measured data, while the blade starts to rotate

The error rate seemed to be depended on the positions of sensor and receiver. In this case, the sensor located inside the blade, so the blade covered regular the connection. If the sensor locates outside the blade as also receiver, the error rate can be radically lower. Also buffering the data in sensor makes it possible to measure data also in the shadow states.

C. Distributed Energy Production

The Meteoriihi museum and observatory is in middle of an old meteor crater near Vaasa (Figure 12). There are no external power supply lines, but a small wind turbine, solar panels and a diesel generator. All data connections are wireless.

Figure 12: Meteoriihi [12]

The Vaasa researchers group made a local wireless network using the UWASA nodes and the GPRS gateway to have a connection with university. Measured weather data and and energy battery charge level is transmitted to university and saved into the database. Also the remote control of the biodiesel generator is possible via the data link (Figure 13) [12].

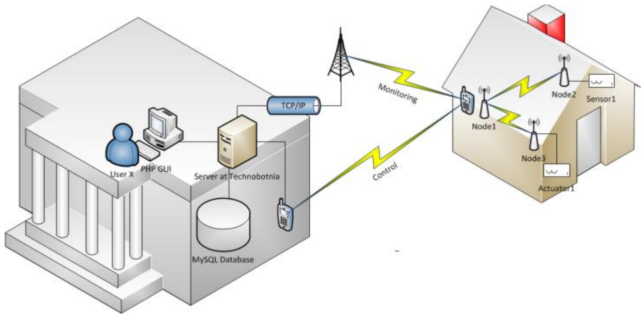

Figure 13: Meteoriihi data link [12]

D. Greenhouse automation

Aalto University researchers tested twenty wireless Sensinode Micro nodes with temperature and humidity sensors in a tomato greenhouse. The nodes formed a tree topology (Figure 14). The average processed data relay was 99.78% while sensor transmitted to the sin node three thousands data packets, one per second. [2].

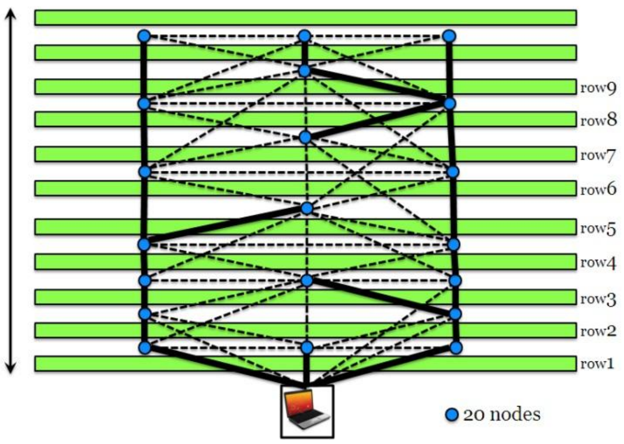

Figure 14: Greenhouse network topology [2]

In the greenhouse case made by the Seinäjoki researcher, the aim of wireless SurfNet node tests was to test very low-power sensor functions and wireless range in the real environment. SurfNet node had temperature and humidity sensors (Honeywell HIH-5030 and GE sensing MC65F103BA), which was turned on for about 5 ms in 1.0 second periods. The sensor values were uncalibrated. The values was very stable (Table 1), but humidity sensor must be calibrated; the real humidity in greenhouse was about 70%. The soil water content was measured indirect by air humidity using a closed pipe, which was open inside the soil. This sensor seems also to be usable after calibrating (Table 2).

Table 1: Measured air condition values

Node	Temperature	Humidity
3	18.9 °C	45.1 %
4	19.3 °C	45.1 %
6	19.6 °C	
7	19.3 °C	46.8 %
8	19.3 °C	41.7 %
10	19.3 °C	44.0 %

Table 2: Measured values in indirect soil humidity sensor

Node	Humidity
2	71.0 %
5	65.4 %
9	71.6 %

The development of the mesh topology was in early stage in time of the greenhouse case, so the result of range tests was not as relevant as possible. Although, the wireless range seems to be shorter as expected: only 1-5 m, while in the open area the range is about 10 m. The growth of the tomatoes absorbed significant the radio signal; specially, as the diameter of a tomato is near the same as the distance of the 2.4 GHz antenna.

E. Cattle House Automation

Aalto University researchers tested the wireless network in the cattle house same way as in the greenhouse. With sixteen nodes the average processed data relay was 99.92% while the nodes sended five thousand data packets, one per second.

In the cattle house case made by Seinäjoki researcher, the aim was to test in real conditions the SurfNet mesh network topology, the neighbor based positioning method and usable of the acceleration sensors while monitoring the behavior of the cows.

The cattle house was covered with 12 fixed-position anchor nodes in the ceiling, which functions as data routers and a fixed grid for positioning nodes (Figure 15). They measures also air temperatures.

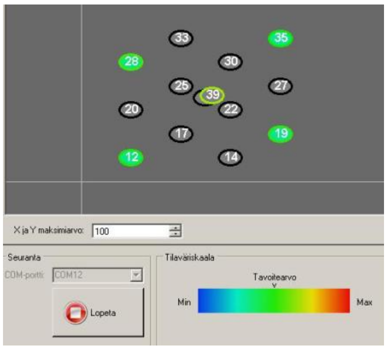

Figure 15: Fixed nodes and two positioning nodes

The sensing and positioning nodes was fastened in cows (Figure 16). They positioned it and measured 3D acceleration. The measured data was collected into PC via bridge node and USB interface. The measured mean acceleration was shown as colors both in the graphical display and in table format. Naturally, all measured data was visible also in numeric format. In table format in Figure 17 first node '1' is a bridge node, next 8 nodes are the fixed position nodes without sensors, next 9 nodes are the sensing nodes in cows and the last 4 nodes are fixed position nodes with temperature sensor [8].

Figure 16: SurfNet node fastened in a cow [8]

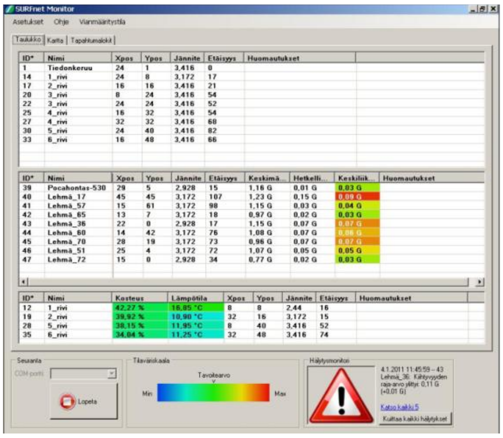

Figure 17: Table format display

The mesh topology and gossip routing works quite well. Because of multihopping routing and the slow, power saving synchronization, the measured data was visible in screen after

15 to 60 seconds. The iron structures and cement walls does not absorb the radio signal, but rather vice versa. The neighborhood based positioning was in troubles, because the walls functions as the plate antennas. This feature is shown in Figure 18. The object (a man in this case) is estimating the position quite well in middle of the cattle house, but near the wall the node reached better the farther neighbors and estimated itself more close with them.

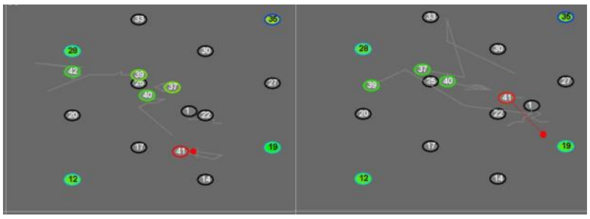

Figure 18: Neighborhood positioning

The monitoring of the activity of the cows via acceleration sensors was a little uncertain. The cows were moving very slowly. Although, as the cow rested, it chewed moving its neck, where the node located. Some results we get as shown in Figure 19.

This kind of monitoring system seems to be very useful, but needs a specialist other area to analyze the measured acceleration data to have the real benefit.

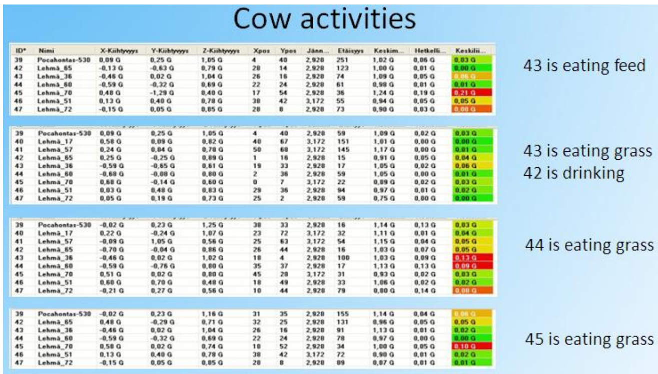

Figure 19: Measured cow activities

IV. Conclusion

The most important results in the GENSEN project was new wireless network platforms and topologies, which are easily to modify for the new applications. For much demanded applications the UWASA nodes are very powerful and versatile. The A-Stack protocol makes it possible to create the portable applications for the existing and future platforms. The wireless technology seems to be suited also in heavy industrial automation.

SurfNet nodes are very suitable for new ambient intelligent, price-critical applications using battery powered nodes. The energy harvesting feature and the small size makes the SurfNet platform to be very suitable to connect and monitor the objects, animals and humans wireless. The new possible application areas are the experience sports and games and security monitoring. Also, the GENSEN project gave our University the new know-how to be used in teaching and in new projects.

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