Wireless Infrastructure in a District Heating Substation

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Abstract—A new wireless sensor and actuator network architecture for a district heating substation is presented. The implementation allows for new control algorithms to save substantial amounts of energy and therefore reduce waste and indirectly CO₂ emissions. The wireless network uses TCP/IP all the way to the sensor level, which can enable a standardized Service Oriented Architecture and the possibility to upgrade software of each node remotely over the Internet. New diagnostic services are also available to improve service and maintenance.

I. INTRODUCTION

Pervasive technologies can be a blessing if they contribute to society without increasing stress or frustration to the population. An area where pervasive technology can make a substantial improvements is energy management and control within district heating. For the purpose, we here present a control and communication architecture based on wireless sensor/actuator network (WSN). The architecture is implemented through a wireless network of sensors and actuators to control the energy transfer from a district heating distribution network to a building while promoting the potential of Service Oriented Architecture (SOA) towards an easy integration and expansion of the pervasive technology.

The approach permits the development of new control strategies in the optimization of energy transfer operation because the system offers more information. Such strategies target an increased cooling of the distribution network, i.e. a higher ΔT over the substation. A higher ΔT is beneficial for a district heating system regarding increased co-generation of electricity, reduced energy losses, and more efficient utilization of infrastructure investments.

The implementation of new control strategies and services will be much simplified using a SOA based approach [1], [2], [3]. Thus it is important that the WSN:nodes have SOA properties like service discovery and a service description semantics which enables an orchestration of services such that new control strategies can be deployed on-line.

The general objective of the paper is to demonstrate a new control and communication architecture for district heating substation and to show that WSN with SOA is a feasible technology for this architecture.

To outline the paper, we first give a background to district heating and describe the wireless nodes used. We follow by presenting the wireless network and making the case of Service oriented architecture. The subsequent section discusses

the implementation of the wireless infrastructure and its functionality.

A. District heating

District heating is a technology that enables heating, i.e. both space heating and hot tap water, from one single source to many buildings. It is energy efficient when buildings are close together. An analogy is common transportation where a bus that is more efficient than several cars. Quite often the original heat is a byproduct from an industrial process. The industry can recover some of its cost while end users have a lower heat cost, not to mention the benefit to the environment. This is a winning concept when correctly implemented.

The heat is distributed through networks of pipes to commercial buildings, apartment buildings and houses. The distribution network is also known as the primary circuit. In Sweden, its energy is not used directly in the buildings but rather transferred through heat exchangers within a district heating substation located within the serviced building.

A district heating substation transfers the heat energy from the primary circuit to the building's radiator circuit and hot tap water circuit. These circuits are referred as the secondary circuits. Control systems, electronic and mechanical, regulate the flow of the primary circuit through each heat exchanger via respective valves depending on the energy demands of each of the secondary circuits. It is in the substation that the amount of energy transferred is measured for billing purposes.

B. Control and architecture

The current problem is that these control systems only aim towards comfort but do not pay attention to optimize the performance of the substation. This results in wasting heat energy in the primary circuit. To optimize the system, additional information is needed but which is nowadays not available. With a wireless connection between sensors and actuators, the new infrastructure allows for the optimization as well as new diagnostics and services.

The traditional control and communication architecture is shown in figure 1. The heat energy measurement is located on the primary side of the substation. The controls of space heating and hot tap water delivery to the house are made from the secondary side of the substation. These two functions are independent and unaware of each other.

Fig. 1. Traditional control and communication architecture in a district heating substation. Please note the heat measurement at the primary side has no communication to the control at the secondary side (red line).

Fig. 2. New control and communication architecture in a district heating substation. Here all sensors, actuators and control devices regardless of location can exchange information.

In the hereby introduced architecture, shown in figure 2, all sensors and actuators are enhanced with or replaced by WSN nodes from which a wireless sensor network based on TCP/IP is established.

This means that the barrier between the primary side with heat metering and the secondary side with heating and hot water control is taken away. This opens up for new measurement possibilities as discussed by Yliniemi [4] and new control strategies as discussed by Wollerstand *et al.* [5] and Gustafsson [6].

These new measurement and control strategies have substantial economical potentials. Very rough estimates shows savings of more than 1 million Euro per year when increasing the ΔT by 5°C in a 760 GWh district heating system.

Using a SOA architecture for the measurement, actuation and control will allow for online changes to measurement and control strategies. Thus providing an architecture that is adaptable to new needs and ideas in a way that is not possible with an architecture based on hard wired systems.

C. Wireless nodes

Within the new architecture, each sensor and actuator is associated to a wireless node. We here describe these nodes which we have named Mülle [7], [8].

The Mülle platform is a small embedded system capable of communicating wirelessly with other nodes using TCP/IP over Bluetooth and ZigBee. As all embedded systems, it is able to measure a sensor signal and/or request an action from an

actuator. In some cases, the sensor or actuator communication is done serially.

The Mülle features a Renesas M16C/62 micro-controller and in our system, a Bluetooth 2.0 module. It has an on-board 2 MB flash memory, allowing storage of large amounts of sensor data. Flexibility as well as time driven performance are provided by a real-time clock, a temperature sensor, a battery monitor, LEDs and a high density expansion port. The latter is a 60-pin connector that enables connection to analog and digital I/O pins, power supply, and serial communication lines. The compact design occupies a total of 24x26x5 mm.

Power consumption is an issue for the nodes that are not connected to the electric network or associated to actuator. An example in our system are the temperature sensors. They must provide information for a very long duration, which ideally should be years. The current approach is to turn off the Bluetooth module and put the micro-controller to sleep. The power consumption in its lowest sleep mode is only 12 μW . The micro-controller is woken up every 15 minutes to measure the temperature. If there is a significant change in temperature, the Bluetooth module is momentarily turned on to communicate the information of the wireless network.

The Mülle software is designed in a modular fashion to allow adaptability to the system and the role of the node within the system. The Mülle can communicate with two of the worlds most widely spread technologies: TCP/IP and Bluetooth. The Mülle uses the lwIP stack, and can communicate using the following protocols: IP, TCP, UDP, DHCP, NTP, and HTTP. The lwBT Bluetooth stack provides support for the following layers: HCI, L2CAP, SDP, BNEP, RFCOMM, and PPP. The Bluetooth Profiles supported are: LAP, DUN, PAN, and SPP.

The use of TCP/IP and Bluetooth enables the Mülle to even utilize Bluetooth-equipped mobile phones as access points to reach the Internet, although, there is no need for that in a district heating application. This allows a Mülle to transmit sensor data directly to users on the Internet without any specialized gateways. The advantage of using TCP/IP at the sensor or actuator level is the clear standardization of the Internet Protocol. This detail enables the infrastructure to be flexible to different sensor and actuator suppliers and opens the door to standardized service oriented architecture.

The nodes can talk to each other or to an access point creating a wireless network. The next subsection describes the implementation of the wireless network.

D. Wireless network

The network used in this setup is a IP-based network with DHCP capabilities. The DHCP server is implemented in the Internet access point (c.f. figure 2), which is a Blackfin based embedded computer [9] running $\mu Linux$. However, any Bluetooth compatible device with the right protocols supported will do.

To be able to run the IP-network on top of Bluetooth, the PANU (Personal Area Network User) Bluetooth profile is used on the Mülles, and the corresponding gateway profile NAP

(Network Access Point) is used in the Blackfin Internet access point, see figure 3. These profiles utilizes the L2CAP + BNEP Bluetooth protocols to enable an easy integration of TCP/IP network on top, see [10] and [11] for more details.

Fig. 3. The Blackfin access point

The control loop is today located in the Blackfin device, but could in the future be distributed between sensor nodes to improve control robustness.

The network setup makes it possible to access all devices (Mulle) in the network from the Internet. This enables the system administrator to reconfigure and update the software in the nodes remotely.

For SOA, the natural solution would be to bring in protocols like DPWS [12], [13] or OPC UA [14]. Due to the constrained resources on the Mulle platform, the current implementation features service discovery mechanisms using Bonjour [15]. A special protocol, OLP v2, which could become a future standard for transmitting sensor data using TCP/IP, has been developed. OLP v2 is used to send information and requests between all the nodes.

II. IMPLEMENTATION

A Mulle node is placed on each actuator, sensor and meter. The nodes are small enough to fit in the electronics of the

commercially available actuators. The circulation pump is a Grundfos UPE 25-40 unit, see figure 4. It has its own micro-controller, several sensors such as pressure, and communicates through an RS-485 link using a GENIbus protocol readying the unit for industrial use. The Mulle is the link between the pump and the wireless network. The Mulle can request a given flow and provide to the wireless network information about the radiator circuit.

Fig. 4. The pump with belonging wireless node.

The control valve limiting the primary flow that serves the radiator circuit's heat exchanger is a Siemens valve model SQS65, see figure 5. Its control and feedback signals are over the range of 0 to 10V. The Mulle can request a valve position or measure what the position of the valve informs the wireless network.

Fig. 5. The valve with its wireless node.

The temperature wireless sensor node uses an external digital temperature sensor from Dallas Semiconductor (DS18B20), see figure 6. It uses a 1-wire interface to serially communicate with the Mulle. The Mulle itself has an on-board temperature sensor but the external one offers the possibility of measuring the temperature of pipes for example. In the current setting, the unit is used to measure outdoors temperature. This unit is battery powered and therefore makes use of the low power features of the Mulle.

The primary circuit's incoming and outgoing temperatures (with their difference being ΔT) as well as its flow are

Fig. 6. The battery driven temperature sensor node.

measured by the heat meter, a Kamstrup MultiCal 601, figure 7. The Mülle implements the Kamstrup Meter Protocol (KMP) to serially communicate with the heat meter and is a drop in replacement to the optional communication module for the Kamstrup heat meter.

Fig. 7. The Kamstrup heat meter.

A. Benefits

When taking into account the incoming and outgoing temperatures of the primary circuit in the control of indoor comfort, we can achieve a higher ΔT and therefore obtain a better energy transfer. The old architecture did not allow this which results in at least two forms losses. The first one is similar to an electrical short circuit, it allows the energy to go through the house without doing any work although pumps are being used to generate the flow. This also causes inefficiency if the heat is from an electricity co-generating plant (Combined Heat and Power plant). The second form of waste when ΔT is not maximized is the distribution losses through the primary network. That is there is large thermal gradient between the transport fluid and the outdoors temperature resulting in higher heat transfer to the environment. By maximizing ΔT , not only the return temperature will be lowered but the supply temperature can be lowered.

It should therefore be obvious that an efficient system will reduce the amount of wasted energy while maintaining comfort. This will indirectly reduce CO₂ emissions for heating

purposes which accounts for 30% of the world's current CO₂ [16]. If the heat is an industrial byproduct, then one could argue that it does not matter. However that would be incorrect as any excess heat can be used to serve other building, which use other means of heating.

The new architecture additionally allows improved quality of service and maintenance. For example, if the flow meter, which is a part of the heat meter, detects a flow while the control valves are closed, we can diagnose a leaky valve. The connection to the Internet permits the information to be received immediately by the heat supplier. As an other illustration, the circulation pump is able to measure pressure in the radiator circuit, but this feature was never used. With its wireless communication, the system can now, for instance, send a text message to the home-owner's phone to tell that there is not enough water in the radiator circuit.

III. CONCLUSION AND FUTURE WORK

We have developed a new control and communication architecture based on WSN and SOA for district heating substations. The architecture has successfully been implemented in a working substation. The use of TCP/IP and SOA in combination with a simple integration of the WSN node to any sensor, actuator or control device enables simple retrofitting of existing substations and demonstrates a technology for next generation of substation measurement and control.

For the future some of the new control strategies will be implemented in a pilot installation. At a planing stage is a larger pilot study comprising a large number of installations in a complex district heating system. Next then will come work on control strategies which does incorporate the end user and end user interaction with the WSN and SOA based control architecture.

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