Remote Agriculture Automation using Wireless Link and IoT Gateway Infrastructure

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***Abstract*— The publication presents a system architecture for remote agriculture process automation, involving sensors and actuators connected to IoT gateway running OPC UA server. Sensors and actuators are very general and do not need any intelligence related to the process under control. Acquired data processing and control algorithms that produce control stimulus are executed in the gateway. This approach features the advantage of convenient possibilities to change control rules from Cloud services (installing or configuring process controller) without updating firmware of remote sensors/actuators. Throughput of data collection channel (long range radio) and IoT gateway performance are limiting factors for real time control or observation of agriculture processes. Therefore, achievable channel "sensors-OPC UA server" throughput is investigated experimentally. Potential agriculture applications that may benefit from the proposed architecture are identified.**

Keywords—precision agriculture, automation, OPC UA, wireless link, IoT.

I. INTRODUCTION

Advances in embedded electronics, local wireless connectivity, and efforts in developing communication protocols and hardware for interconnecting heterogeneous networks to IP (Internet Protocol) based Internet has paved the way for the wide scale deployment of IoT (Internet-of-Things) network. Precision agriculture and animal farming are among many application fields that are expected to benefit from services enabled by the IoT [1]. Connection to the IoT of variety of distributed sensors and machinery used in agriculture and livestock can open new implementation alternatives for automation tasks. In the generic IoT architecture the device called IoT gateway is bridging the information exchange between field devices and Internet network [2]. In case of agriculture the IoT gateway being connected to local heterogeneous field networks (often wireless) from one side and to the Web via WAN (Wide Area Network) from the other side, potentially presents a convenient infrastructure for remote control applications. In our research we seek to investigate options, benefits and restrictions to integrate remote agriculture process or object automation functionality to the state of the art IoT gateway. Our research focus is on wireless local network suitability to server needs of remote automation tasks [3], [4]. Therefore, remote control applications in agriculture are overviewed first. Next, preliminary tests with the implemented IoT gateway prototype equipped with selected wireless link are carried out for data delivery throughput estimation.

II. RELATED WORKS

A. *Remote Automation and Monitoring Applications in Precision Agriculture*

Several designs describing agricultural automation and process control exist. In these designs connection between process control automation and remote sensors and actuators are often presented. Examples of such designs are presented for example in [5], [6]. These designs however do not specify a delivery method for data to and from sensors and actuators. The data flow is matriculated in several designs, but the time constraints are considered in general level [7].

The presented designs call for separation of data and applications. Meaning that the measurements from a sensor should not be tied to that sensor, but they are to be accessible by any data user [5], [6]. This requires for connecting the sensors to an integration platform, which usually is Internet based. Also, adaptivity to any kind of sensor actuator or control module is required. Agricultural primary production is very diverse and utilizes many different techniques; also the used equipment in terms of sensors and actuators (machinery) is diverse. To manage this diversity and to allow the needed adaptivity it can be beneficial to locate the control automation into the integration platform itself.

The proposed and implemented designs however are more focused on management on tactical and operational level of production process as presented in [5], [8]. These implementations are not capable of hard real-time control loop over cloud process control automation. The implemented systems were used in providing nowcasts and in selection of

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machine parameters, when arriving to execution location, but not for adjusting the machine during the execution [5]. To perform for example spraying parameters in during spraying operation to wind conditions in order to optimize the droplet size and to prevent windfall a data link capable of round trip of less than half of sprayer control frequency is needed. Based on experience this is around 4 Hz.

B. Advances in Wireless Automation and Connectivity

The wireless infrastructure enables inexpensive communication between gateways, sensors & actuators spread around farms and fields over long distance. Nowadays, two most popular wireless automation standards are WirelessHART and ISA100.11a. They both are based on IEEE 802.15.4-2006 2.4 GHz DSSS physical layer [9]. In general electromagnetic wave signal strength loss between two antennas is characterized by Free Space Path Loss (FSPL)

$$FSPL = (4\pi DF / c)^2 , \quad (1)$$

where D is distance, F is radio signal frequency and c is speed of light. Assuming relatively long distances in agriculture applications we are looking for a lower carrier frequency. Therefore, we consider the ETSI EN 300 220-1 V2.4.1 (2012-01) standard approved in 2012. For the purposes of meter reading applications the frequency band 169.400 to 169.475MHz is allocated according to this standard. A disadvantage of lower frequency communication systems is larger antenna sizes. For example, for 169 MHz frequency a quarter-wave monopole antenna is around 44 cm length.

In EN 300 220-1 standard the spectrum access and mitigation requirements are characterized by duty cycle ($d \leq 10\%$ per 1 hour), accumulated maximum transmitter on-time ($t_{On} \leq 100\,\text{sec.}$ per 1 hour) and minimum transmitter off-time ($t_{Off} \geq 100ms$). These parameters limit a throughput of link between two communicating nodes.

Further, we will explore the options and limitations of this communication channel for remote process automation. Several semiconductor manufacturers including Texas instruments (CC1120), STMicroelectronics (SPIRIT1), Semtech (SX1276), etc. supply off-the-shelve ultra-low power long range transceivers for the 169MHz band that can be integrated to the embedded systems connected to remote sensors/actuators. Most transceivers available on the market oscillate in 10mW-100mW output power, but external power amplifier till 500mW can be used for extending transmission range.

III. Suggested Automation Architecture

A. Requirements for Automation System Wireless Link

The following set of requirements is important when designing a simple remote automation system and data delivery channel:

1. Remote nodes' energy consumption minimization.
2. Channel throughput/data rate (sampling period, speed of reaction) in bit per second (bps).
3. Required channel capacity in terms of total number of bits per time unit in order to complete automation task. Dependent on the monitored and/or controlled process features (temperature variations are slow (hours), but actuators' control related processes are much faster (miliseconds) the corresponding rate of observation is required. The energy consumption is influenced not only by the channel throughput but significantly by the volume of information required to deliver over the channel to complete a control task.
4. Link reliability (bit error rate) and deterministic behavior.
5. Positioning (fixed, mobile, direct view) and distance between communicating nodes.
6. Parameterization (loading maps, changing parameters, changing control coefficients like PID controller coefficients, etc.), maintenance, security, conditional access, scalability options.
7. Independence from WAN telecommunication infrastructure. In some remote areas 3G/4G, WiFi networks coverage may be absent.

Many of these requirements are contradictory and the solution is only a tradeoff between them. For example, throughput, link reliability and coverage distance can be increased at a cost of increased power consumption.

B. Deployment Perspective: Mapping to IoT Infrastructure

A remote process or object classically can be automated by establishing a local controller that observes the process outputs and generates stimulus for actuators according to control algorithm (Fig. 1). By the remote process we denote a process or object that is located in some considerable distance from the electronic controller or human operator. Controller on the other side is often connected to the industrial network (wired or wireless) for remote configuration, visualization, process data logging, etc.

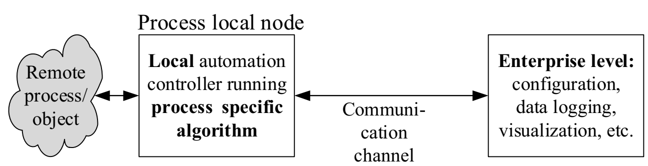

Fig. 1. Remote process classical automation system.

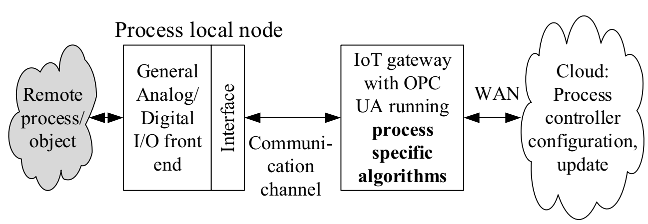

Fig. 2. Remote process automation system based on IoT infrastrcture.

The IoT architecture includes sensors and actuators connected to IoT gateway via various heterogeneous local networks (most often wireless). The other side of the gateway is connected to IP based WAN and can be accessed from Cloud systems. The classical automation system can be mapped to the modified IoT architecture as shown in Fig. 2. We suggest that the IoT gateway could be the entity running process specific algorithms instead of local node connected to the automated process directly. A control algorithm may be very simple like tracking a defined threshold or much more complex. A process local node does not need any knowledge about the process control algorithm and it basically supports only analog/digital inputs/outputs (and maybe some simple wired data communication interface). In case of a need to update control algorithm and settings this is the advantage as it cancels any demand of firmware update of remotely installed controllers. Control algorithm installation can be facilitated by the OPC UA (Object Linking and Embedding for Process Control Unified Automation) server [10]. IoT gateway is running OPC UA server and user can upload plug-in from Cloud services for the selected control algorithm.

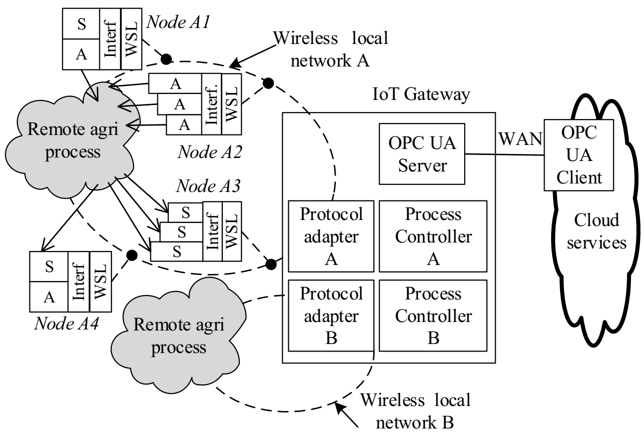

Fig. 3. IoT gateway based automation architecture. A – Actuator, S- Sensor, Interf. – interface, WSL – wireless link.

C. IoT Gateway Architecture

For the concept testing purposes the IoT gateway (Fig. 3 and Fig. 4) was designed. Texas instruments Cortex A8 processor running at 1 GHz clock frequency is selected. The operating system is Linux. At the application level OPC UA server developed using Softing Software Development Kit (SDK) is installed. The OPC UA protocol is used to expose data acquired by the gateway to remote clients operating in IP based WAN (Fig. 3). Software protocol adapter module is connected to OPC UA server using Linux socket inter-process communication. Protocol adapter (PA) is responsible for handling communication layer between wireless transceiver flow controller (FC) and OPC UA server. Many protocol adapters can be installed to implement various heterogeneous field networks to OPC UA server. A process controller (Fig. 4) is a software plug-in module which is responsible for executing remote agriculture process control algorithms. The process controller (PC) can interact with OPC UA address space nodes (Link1) or with PA directly (Link2). Both options are investigated in experimental system throughput estimation. In case of Link2 scenario PA and PC can be built as single software module offering faster communication between PA and PC. The advantage of Link1 scenario is separation of communication layer (PA) and control layer (PC) implementations. This opens an opportunity to utilize standard approach of using OPC UA server address space methods type nodes for control algorithm integration in the overall system.

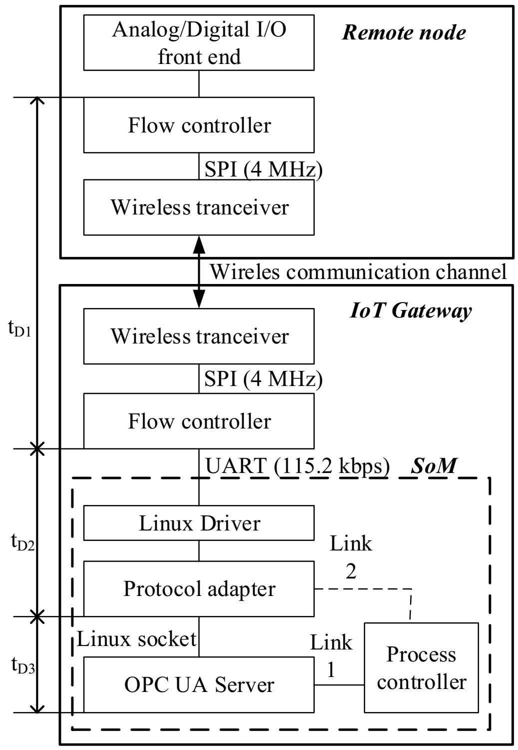

Fig. 4. IoT gateway and remote node architectures.

User payload is sent to FC using UART interface. The FC communicates with wireless transceiver (WT) using 4MHz serial peripheral interface (SPI). WT encapsulates user payload to radio media packet (Fig. 5). FC based on STM32L162 32MHz Cortex M3 microprocessor is responsible for the implementation of wireless data link layer.

D. Local Network Topology and Communication Protocol

Communication data packet structure (Fig. 5) is specified in the utilized transceiver's documentation [11]. Preamble, synchronization word and error check (CRC-16) fields are mandatory, while user payload is configurable by the user. User payload optionally contains payload length and node address fields (1 byte each). Therefore, a real payload carrying user application data is reduced by two bytes. It was chosen to carry out experimental testing using 4 and 16 byte user payload. The first length (2 bytes real application data) was selected to represent minimal information amount needed to deliver process parameter readings and control signal to process actuators. The second length (14 bytes real application data) was selected as representative for more complex setups when either several sensors/actuators are served by one wireless transceiver (Node A2, Node A3 in Fig. 3) or smart sensors readings are more extensive than one sample of physical process data (for example GPS (Global Positioning System) coordinates and time, wind speed and direction, etc.).

Preamble (3 bytes)	Sync word (3 bytes)	User payload (4 or 16 bytes)	CRC-16 (2 bytes)

Fig. 5. Packet structure

In case of 4 bytes payload the whole communication packet is 12 bytes or 96 bits. At the transmission rate of 19.2 kbps a packet transmission duration is $T_P = 5ms$ and at the rate of 4.8kbps it is $T_P = 20ms$. Assuming packets are evenly spaced over the time, the ETSI EN 300 220-1 V2.4.1 standard's requirement not to exceed maximum transmitter on-time t_{On} leads to the maximum achievable acquisition frequency

$$F_{Max1} = t_{On} / (3600 \cdot T_P); \quad (2)$$

which equals to 5.5 Hz for 19.2 kbps and 1.4 Hz for 4.8 kbps data rate.

The limited duty cycle and transmitter off-time restrictions limit maximum acquisition frequency

$$F_{Max2} = (d/100\%)/(T_P + t_{Off}); \quad (3)$$

which equals to 0.95 Hz for 19.2 kbps and 0.83 Hz for 4.8 kbps data rate. On the other hand, when LBT (Listen Before Talk) channel access technique is used in combination with AFA (Adaptive Frequency Agility) the duty cycle restrictions do not apply and only the restriction by expression (2) is valid.

E. Wireless link parameters to estimate

In this initial study we focus on radio link reliability investigations characterized by packet error rate (PER) measure.

Also, we are looking for estimation of remote process real time monitoring and control options, which are defined by achievable data acquisition period. The acquisition period (or frequency) limitations defined by the wireless channel throughput and IoT gateway implementation are studied. To estimate achievable acquisition period we have chosen to measure experimentally round trip delay defined as a time interval between sample request and sample arrival to the Process controller of IoT gateway software. Let us denote the round trip delay

$$t_{RTD1} = 2(t_{D1} + t_{D2} + t_{D3}), \quad (4)$$

when the PC receives data from OPC UA server's address space and the round trip delay

$$t_{RTD2} = 2(t_{D1} + t_{D2}), \quad (5)$$

when the PC receives data directly from PA. t_{D1}, t_{D2} and t_{D3} denote delays in data delivery channel as shown in Fig. 4. Multiplier 2 in (4) and (5) indicates that sample request message first must propagate to the remote node and then the response must propagate back to the PC.

Corresponding achievable acquisition frequencies are

$$F_i = 1/T_{RTDi}, \quad (6)$$

where i is the number of equation (1) or (2).

IV. Estimation of the Wireless Link

A. Wireless Link Reliability Estimation

One of the most important factors taken into consideration during radio system deployment is distance. How far radio nodes can go from each other keeping reliable link is characterized using Link Budget analysis. Landscapes might have some obstacles like trees, uphills, rivers, lakes, stones, buildings, etc. Environmental conditions might impact radio communication performance in major scale. Important factors considered in link budget analysis usually include available output transmitter power, receiver sensitivity, FSPL & fading, modulation technique, antenna gains, cables and connector losses.

We have conducted experimental measurements of PER using Texas instruments CC1120 transceivers. 1000 packets of 16 byte length were transmitted using 4.8 kbps (2-GFSK modulation, 0.5 modulation index) and 19.2 kbps (4-GFSK modulation, 0.5 modulation index) data rate at 15 dBm transmitter power. PER was measured in the following conditions between communicating nodes:

1. 300 m view-of-sight (despite link settings PER<1%),
2. 3190 m (PER<4%) and 4530 m (PER<1%) non-view of sight in city environment with a lake between transceivers,
3. 400 m (PER<3%) and 550 m (PER between 13% and 75% dependent on settings) in coniferous wood dominated forest,
4. 1450 m open field in typical agriculture landscape (PER< 3%).

Analyzing obtained results we see that link reliability is acceptable for distances up to 4.5 km in view-of-sight conditions. Much larger PER are observed in forest environment. However, it was not due to stronger path loss (attenuation in woods), because RSSI (Relative Signal Strength Indicator) was not reduced compared to open filed conditions (Test 4). After measuring radio spectrum in the forest we find a rather high level of electromagnetic radiance close to 169MHz frequency band. It could have been caused by the special services transceivers operated in nearby airport. The finding only confirms that wireless link conditions are subject to various unpredictable industrial interferences and the need for intelligent communication protocol dealing with data delivery assurance.

B. Acquisition Frequency Estimation

The round trip delay was measured using implemented IoT gateway prototype equipped with 169MHz Texas instruments CC1120 transceiver and a prototype of remote node equipped with the same type of transceiver. Two transmission speeds, namely 4.8 kbps (2GFSK modulation with 1.5 index, deviation 3.6kHz) and 19.2 kbps (4GFSK modulation with 1.0 index, deviation 14.4kHz), were selected for experimental testing. The measured power at the transceiver output was 15 dBm.

Linux operating system timestamps were recorded at the moment of data request and response reception event. In case of Link1 scenario (Fig. 4) both timestamps were taken from OPC UA nodes (timestamps are handled by SDK) and in case of Link2 scenario timestamps were recorded by PA module. The difference between two timestamps represent the estimate of round trip delay. Resolution of Linux timestamps is 1 ns. For each set of channel setup options 100 samples of round trip delay were measurements in laboratory conditions. Calculated acquisition frequencies are shown in Fig. 6.

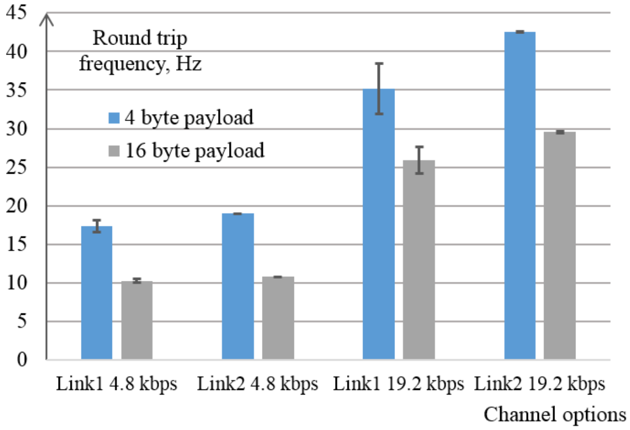

Fig. 6. Acquisition frequency vs data acquisition channel options

Together with the average acquisition frequency its standard deviation is shown in Fig. 6. Larger deviation in the case of Link1 is explained by the Linux inter-process communication non-deterministic behavior (Link1 is implemented using sockets technique as shown in Fig. 4).

Influence of the SoM processor load upon acquisition frequency due to the execution of parallel software modules in IoT gateway (Fig. 3) was analyzed by simulating system load using "stress" utility (http://people.seas.harvard.edu/~apw/stress/). The "stress" utility was configured to load system with equal number of CPU intensive and I/O intensive tasks. Each task is capable of loading CPU up to 100% (measured with Linux OS manager utility *top* which displays Linux tasks activities) on its own and was executed with the same scheduler priority as OPC UA server and PA. Noticeable increase of acquisition period was only observed when running 10 "stress" tasks in parallel to OPC UA server and PA. Running 4 tasks caused acquisition period variation increase but little influence upon its average value.

V. CONLCUSIONS

The system presented in this paper is one implementation of data delivery system between remote sensors and actuators that fulfills requirements of remote configurability, separation of sensing/actuation devices from application control devices utilizing OPC UA server based IoT gateway infrastructure.

Considering relatively long distances in remote agriculture processes, 169 MHz frequency band described ETSI EN 300 220-1 standard is suggested for wireless network deployment.

Assuming a minimal application specific communication packets payload of 2 bytes, it was found that channel throughput restrictions are mainly defined by the standard spectrum access and mitigation requirements (5Hz data acquisition frequency is possible) rather than limitations of technical transceivers and gateway implementation (35 to 43 Hz data acquisition frequency is achievable).

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