DATA TRANSMISSION AND MANAGEMENT FOR WIRELESS SENSOR NETWORKS IN GERMAN DAIRY FARMING ENVIRONMENTS

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ABSTRACT

The intensity of animal husbandry rises, as well as the regulation and documentation requirements every farmer must fulfil. Wireless Sensor Networks (WSN) are an option to improve efficiency and animal welfare on dairy farms. They provide information, that helps farmers to focus on the necessary chores and help automate documentation and control processes. However, a dairy farm is a difficult environment for wireless data transmission. This research shows the most common connectivity options in Germany and discusses the technologies regarding their usefulness for data transmission on a dairy farm. It is shown, that the digital transformation of a dairy farm requires different network technologies for different tasks. Data Management must integrate seamlessly and provide decision support as well as control over the farmer's data. A powerful middleware based on broker models can be a solution to bring together live sensor data and information from existing information systems. The digital twin model of the dairy research station of Technical University of Munich is shown, as example for the visualization of a custom user interface (UI). Intuitive UIs are needed for a successful adoption of the technology by farmers.

Keywords*:* Digital Transformation, Agriculture 4.0, Connectivity, IoT, Animal Husbandry

1. INTRODUCTION

In Germany, the intensity of crop farming and animal husbandry rises. However, German farms are still very small in international comparison. Many farmers produce high quality products tailored to several niche markets accompanied by documentation and traceability issues. Farm management information systems are on the rise to help farmers cope with the complexity of these very diverse production systems. In this context, an innovative approach for dairy farming is under development, the "Integrated Dairy Farming" project (Stumpenhausen et al., 2018), which is part of the precision dairy farming concept (KTBL, 2007). One part of the concept is to support the farmer by providing a digital real time model of his dairy and animal production system. The data needed for this information system is combined information out of existing documentation systems, paired with data from wireless sensor networks (WSN) on the farm. All the information available is pre-processed by a powerful middleware and displayed in a customized user interface (UI). Already in the early nineties, it has been recognized, that in order to run such a complex system, the failsafe and error-free transmission of sensor data must be guaranteed under adverse conditions found on farms (Schön, 1993). Today, there is the need to transmit, collect and process information out of different existing information systems and merge this data into one central system. Therefore, data transmission in this paper shall not only resemble the transmission technology used to transfer data from point A to point B but shall also reflect on the ability of smart systems to connect to each other automatically.

2. Methodology

The methods used are threefold. First, available transmission technologies, frequencies, standards and protocols are identified and compared, like for example WiFi and LoRa WAN etc. They are discussed regarding their benefits and shortcomings for agricultural use in a dairy stable environment. As a second step, qualitative expert interviews with four farmers from southern Germany, that already have gathered first-hand experience from using wireless sensor networks, are carried out. Their needs, wishes, and experiences are identified. In a third step, experiences from digitally transforming the dairy research station of the Technical University of Munich, where the concept of a digital real time model of a dairy farm has already begun to be implemented, are taken into consideration as well.

3. Results

3.1. Comparison of important connectivity options

Table 1 shows an excerpt of the analysed connectivity options and their technological differences.

Table 1. Comparison of the most commonly available Connectivity Options for Wireless Sensor Networks in Agriculture (own research)

Wireless technology	Frequency	Maximum Data rate	Maximum Range	Penetration	Energy consumption
Mobile communications (GSM – 5G)	700/8001800/ 2600 MHz	150 Mbit s^{-1} - 20 Gbit s^{-1} (5G)	35 km	low	high
WiFi	1,4/3,6/5,8 GHz	600 Mbit s^{-1}	30 m -100 m	low	high
Bluetooth	2,4 GHz	2,1 Mbit s^{-1}	100 m	low	medium
Bluetooth LE	2,4 GHz	125 kbit s^{-1}	40 m	low	medium-low
LoRa	868 MHz	0,3 – 50 kbit s^{-1}	5-10 km	high	low
Sigfox	868 MHz	0,1 kbit s^{-1}	5-10 km	high	low
Zigbee	868 MHz 2,4 GHz	20 kbit s^{-1} 250 kbit s^{-1}	1500 m 10-20 m	high low	low

There are two important categories. First, conventional connectivity technologies, such as for example mobile communications networks (Miki et al., 2005), WiFi and Bluetooth (LE). These technologies are easy to use and implement, because the hardware is already widely available on a plethora of mobile devices. Second, there are the so called "narrowband IoT" options (Mekki et al., 2018), such as for example LoRa, Sigfox or Zigbee. These options usually offer increased range, penetration and reduced power consumption (Raza et al., 2017). In return, they sacrifice data rate and convenience, and the network infrastructure usually has to be supplied by the end user for agricultural applications.

For the decision of which connectivity option to choose for a sensor network, additional criteria must be taken into consideration (Ried, 2018). For example, costs for hardware and running costs for service providers, the building structures on site (concrete walls, roofs, metal fencing, distance and orientation of buildings) and the energy supply concept for the sensor network (batteries, direct power supply or energy harvesting concepts, lightning protection).

Table 2 shows examples for use cases regarding the aforementioned connectivity options and their potential for transmission of sensor data in a dairy stable environment.

Table 2. Wireless data transmission technologies and examples of use cases in a dairy stable environment (own research)

Wireless technology	Suitable for	Distinct advantage	Example dairy-farm use-case
Mobile communications (GSM – 5G)	Long range – high data rate application	Service provider offers network	Tail mounted calving sensor (even on remote pastures)
WiFi	Short range – high data rate applications	Cheap infrastructure Minimal running costs	IP-camera for calving area
Bluetooth	Short range, high data rate peer to peer connection of end-devices	Technology widely available in existing end-devices	Remote control of slat cleaning robot
Bluetooth LE	Low energy medium data rate applications with multiple devices	Lower power consumption than conventional Bluetooth	Mesh configuration of regurgitating & movement sensors
LoRa	Long-range low energy low data rate applications	Easy to install own network structures, good penetration, long range	Cow tracking on mountain pasture
Sigfox	Indoor and long-range outdoor proprietary sensor systems	Wide array of out of the box sensor systems	Monitoring milk chamber temperature
Zigbee	Indoor automation tasks	Wide array of available actuators from the "smart home market"	Lighting & Energy management, smart locks

The research shows, that the diverse conditions on dairy farms make it necessary to use different connectivity solutions for different tasks. The tables above show the most important decision criteria, when deciding which connectivity option to use for a specific use case. In a dairy farming environment special attention must be paid to robustness of the hardware, penetration of building structures and data transmission to remote areas with minimal power consumption.

3.2. Needs, wishes and experiences of farmers

The farmers agreed, that the use of WSN offers potential for increasing animal welfare and productivity increase. However, they admonish, that the market is dominated by proprietary systems, what forces them to use multiple applications and programs on their end devices. This is a great hindrance for convenience and productivity. Data management and exchange between sensor-system-applications and already existing documentation systems does not work well. Sharing data between systems and along the value chain is a problem, causing a lot of time loss. This is backed by the research of Jungbluth et al. (2017). Some of the systems they have gathered experiences with, don't provide intuitive user interfaces, which is a problem for new or seasonal workers. Some of the farmers wish there was an across systems data management approach, which would facilitate their daily work with these information systems. To improve the situation of farmers and further unlock the potential of WSN in agriculture, the use of these systems must be made as convenient as possible for the farmer. As farmers face more and more documentation chores in their daily work, the automation of data generation, processing and sharing is important. Farmers need intuitive user interfaces and decision support, but also want the option to access raw data, manage data storage options and change or regulate automated decisions made by smart systems.

3.3. Experiences from WSN-use on the research farms

Experiences from using WSN on the dairy research farm of TUM show, that in practice, the range, data rate and penetration of the different connectivity options stay far behind the promises made in the technical specifications charts. This is mainly due to the adverse conditions found on a dairy farm. In international comparison, further problems arise due to the spatial availability of specific frequency bands, e.g. 433 MHz is implemented in the LoRa stack in the USA but not available to use for LoRa-based WSN in Germany. Another important factor are the dairy cows themselves. Their urge to play with sensor hardware and move erratically leads to the need for very robust sensors and network topologies. Especially in research, many use cases are close to breaking the duty cycles of certain protocols, an important factor to take into consideration, as regulation and control of this matter rises. The biggest problem after all, is the harmonization of different protocol stacks, bus systems and general data management, which is hard to integrate into one central system.

4. Discussion – Broker model

The introduction of digital broker models as a powerful middleware to preprocess and route data as well as offer a custom visualization of the data and historicization process, can be a solution to the problems mentioned above. It even offers the addition of a control layer, where actuators can be integrated to the system and linked to the WSN and other systems through a cyber-physical systems approach (Broy, 2010). Figure 1 shows the custom user interface of a broker model implemented at the chair of agricultural systems engineering of the TUM. It is based on open-source software for home- and industrial automation (ioBroker GmbH, 2019). The model aims to digitally transform the research farms of TUM. In Figure 1, the overview section of the WSN on the research dairy farm is shown. In this view, sensor nodes and systems are shown as colored circles. If all circles are green, no action is necessary, and all systems operate within their boundaries. If problems arise, the farmer is informed by a pop-up notification and can then access detailed information and graphs of the individual sensor systems. It is even possible to actuate simple actors like switches, doors, lights, valves and locks. The structure of the user interface is modular.

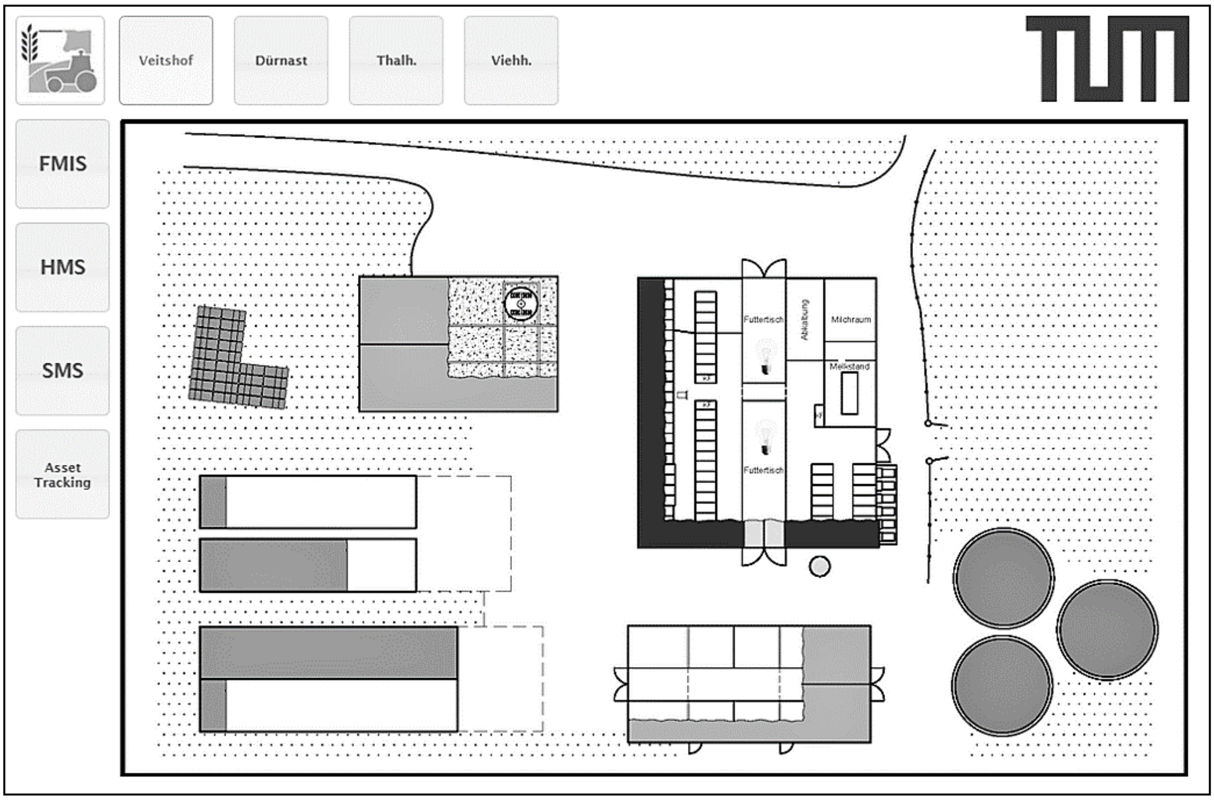

Figure 1. Custom User Interface combining live sensor data and information from documentation systems

The top buttons show the different research farm locations (Veitshof, Dürnast, Thalhausen and Viehhausen), while the logo in the top left represents a home-screen where information from external data providers like milk or diesel prices, as well as weather forecasts can be displayed. The buttons on the left offer access to further functionalities like asset tracking (e.g. tractor location), storage management system (SMS, e.g. grain silo temperatures and humidity), herd management system (HMS, cow-tracking, health and fertility monitoring) and the farm management information system (FMIS, digital documentation, crop farming etc.). The broker model can integrate live information from the installed sensor networks over a wide variety of connectivity options. Like this it is possible to link proprietary sensors and actors like zigbee hardware and integrate self-made systems based on open source technology like Arduino microcontrollers or raspberry pi single board computers with cheap sensor hardware. The broker model itself is running on a single board computer in server configuration and can also implement an access management for different user groups. The model is a work-in-progress project and will be enhanced and have further functionalities added to it for research and teaching purposes. Once completed, it will enhance the accessibility of data for researchers, and offer the opportunity to discover new dependencies in the processes of a dairy farm.

For the Model to be successful, APIs and adapters for different data protocols are essential. A further standardization regarding sensor data frameworks is desirable and should be noticed by the manufacturers of dairy farming equipment. A wide adoption of these models by farmers seems unlikely now, because of the complexity and time consumption to build these systems. A modular approach by external service providers, may help to make these systems available for farmers in the future.

5. Conclusions

Dairy Farms in Germany offer adverse conditions for the wireless transfer of sensor data, as there are long distances, concrete buildings, metal fencing, large rooftops and problems in energy supply that must be overcome. Therefore, different connectivity options are needed for different tasks.

Farmers recognize the benefits WSN offer for their daily work and animal welfare. However, they wish for more convenient solutions, easier documentation and more compatibility between systems. Digital Broker models offer the functionalities to overcome the limitations of connectivity today and should be investigated for agricultural use. Building a broker model for agricultural use is a complex and time-consuming process, hindering fast adoption. However, in the future, further development of sensor data standards (e.g. OGC) and APIs (e.g. for milking robots and automatic feeding systems) as well as a modular approach by software service providers, could make this technology accessible for farmers. This would offer them the custom, platform-independent information system for their individual farming business, that they desire.

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