Wireless Sensor Application for Dairy Cow Activity Monitoring

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Abstract

Within the Wirelessly Accessible Sensor Populations (WASP) project a research technology prototype has been build of an advanced Wireless Sensor Network (WSN) enabling Smart Dairy Farming. The current integrated WASP solution demonstrated in herd health control test bed can be well used as a research tool for animal and human behaviour scientists to enable data acquisition for periods up to several weeks to study behaviour and, in the end, come up with better models and treatments. Within the WASP test bed for Smart Dairy Farming, the focus has been on remote monitoring of activity-related problems like claw health and locomotion. Encouraged by the large-scale herd control deployment whose operation is limited to 10 to 12 days, we performed an exercise to assess whether it seems feasible to monitor a large number of cows over a period of a year without replacing the 8Ah batteries. Through this exercise, we wanted to get a feeling on application and deployment trade-offs like 1) acceptable time between packets generated at application level, 2) acceptable number of battery-powered mobile sensor nodes, 3) required number and positioning of battery- and/or mains-powered forwarder nodes and 4) required number and positioning of sink nodes, while considering application Quality of Service constraints in terms of size (and hence energy capacity) of batteries, packet delivery ratio and packet delivery latency.

Keywords: wireless sensor network, test bed, herd control, locomotion, application

Introduction

The infrastructure for ambient intelligence envisioned by researchers and industry in Europe, will consist of a myriad of wireless sensors working in collaboration. Much research in the academic world focuses on technology for Wireless Sensor Networks (WSN). However, industry is reluctant to use the results derived from academic research, principally because there is a mismatch between research at the application level and the sensor node and network level. The WASP project (EU FP6 project IST-034963 www.wasp-project.org) aims to rectify this imbalance by covering every link in the chain from hardware (for sensors, processors, communication, and packaging) to the information distribution and selection of applications. The main emphasis in the project lies in the self-organization and the services which connect the application to the sensor network. The nodes themselves also need research, because there is a strong link between the flexibility required and the hardware design. The applications need to be researched, because the properties of the used services will influence the configuration of both sensor network and application for optimum efficiency and functionality. Many of the design decisions inherent to the development cannot be handled in isolation as they depend on the hardware costs involved in making a sensor and the market size for sensors of a given type. The general goal of the project is the provision of a complete system view for building large populations of collaborating objects. The WASP results will be well suited for adoption by small and medium enterprises (SMEs). The consortium will define an active program to approach the appropriate SMEs and to familiarize them with the WASP results. A promising application field for WSN is livestock. To give individual animals in increasing herd sizes the required attention farmers are introducing individual animal monitoring systems based upon sensor technology.

Method: The WASP methodology

The WASP methodology connects Wireless Sensor Networks to Web based applications. To be able to build and support the chain from sensor hardware to the real world applications the WASP methodology is build up in different layers. The left side of Figure 1 shows from bottom to top the WSN layers: node, network, router, gateway and back-end with the enterprise integration component (EIC) and application platform. The application developer and the system integrator can choose in which layer to incorporate what data storage and intelligence. For example, accelerometer data can be used to monitor claw health of dairy cows. If step and movement of a cow is analysed on the farm management system, all data has to be transmitted. However, if the data is already analysed on the node then only average step and movement information has to be transmitted. This makes it possible to work with trade-offs (accuracy, energy) and to optimize the application for a specific situation. Figure 1 also shows that for each layer several components and/or services can be developed, allowing the application developer to choose between components. To support node-level application development, a dedicated programming model ECA (Event-Condition-Action) has been developed within the WASP project. However, the WASP system is flexible enough to make use of other programming models like uDSSP which has been demonstrated to work in parallel to ECA.

Results

In the WASP project, hardware and software components and programming models have developed by the project partners: Philips Research, CEFRIEL, IMEC-NL, CSEM, TU Eindhoven, European Microsoft Innovation Center, Health Telematic Network, Fraunhofer-Gesellschaft, Wageningen UR Livestock Research, Imperial College, ST Microelectronics, INRIA, EPFL, Centro Ricerche Fiat, TU Kaiserslautern, RWTH Aachen, SAP and University of Paderborn. In this section, a brief description of results obtained is provided. An extensive description has been made available on the WASP website (www.wasp-project.org).

Herd control application driver

The herd control applications within WASP are based on the anticipated increase in size of dairy farms around 2015 when the current milk quota system will be abandoned within the EU and today's small-scale (50 to 100 cow) farms may no longer be cost competitive. Besides the increase in farm sizes, also more effort is needed to monitor the welfare of cows and to early warn for upcoming diseases. For all these reasons, good observation of individual cow behaviour is needed. The so-called Smart Dairy Farming (SDF) concept aims to enable cost-efficient operation of large-scale (150 to 500 cow) dairy farms by automated monitoring of individual cows to identify cows that need attention in an early stage. Such cows are most expensive in food, labour, and

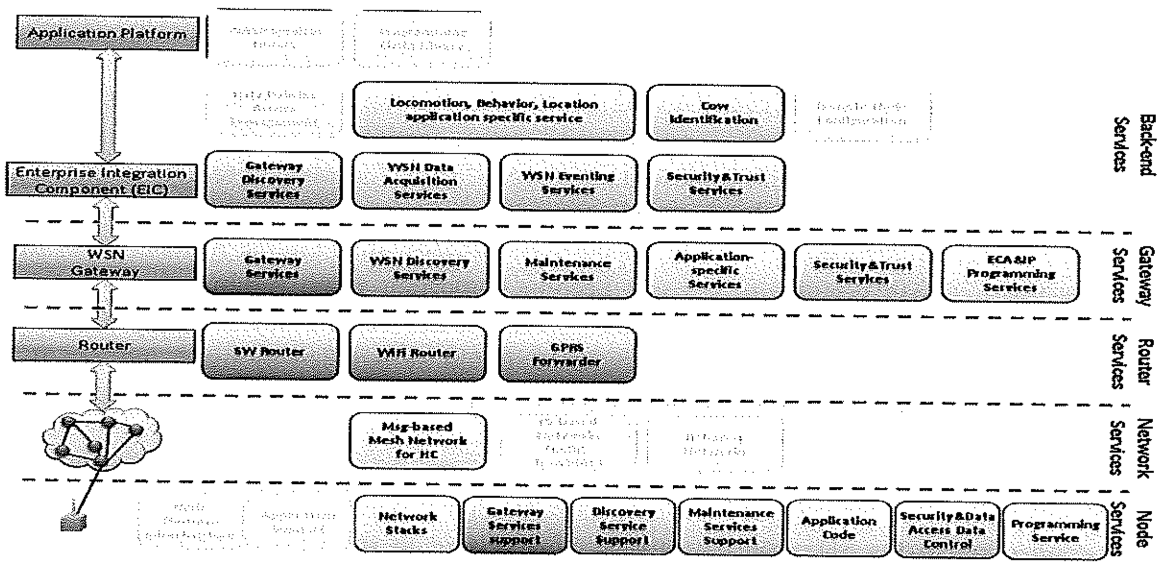

Figure 1. Schematic view of the different layers of the WSN and their components (services).

veterinary & medicine costs and usually suffer from a loss in milk production and increased risk for premature carry-off for slaughter.

The implications of the Smart Dairy Farming concept are several. If individual animals and the awareness of their variation are set as a basic element and the international and interesting development in Information and Communication Technology will be integrated in 'real time' management of livestock production chains, then a lot of topics can benefit. These topics have all their specific characteristics. Some of them are mentioned below.

Production efficiency and energy - In daily management it is important to use the expensive production factors such as labour, food, concentrates in an efficient and sustainable way. Production is closely related to energy and the carbon dioxide foot print. The focus on individual animals makes it possible to deal with their differences. There is a huge potential in this. Variation of 30 to 40% in production efficiency is still present. This becomes very important if production factors become scarce. A second part of production efficiency is to give individual animals the attention they need. This will also be a bridge to new or changed cooperation in the production chains. New services can be developed.

Animal welfare - Animal welfare becomes more and more objective. Measuring programmes are being developed and this will be the basis for intensive communication with society. It also can be a basis for new products. These objective animal welfare programmes are based on farm visits that take place at regular moments. The first sign can be seen that there will become a need for operational checks of animal welfare, since welfare is very sensitive for the context in which animals live. The SDF concept and the tools can be helpful in developing these realtime objective animal welfare characteristics.

Animal health - Discussions in the domain of animal health have different characteristics. From the perspective of individual animals and farmers there should be a strong emphasis on timely detection through early warning of farm related diseases. Reduction of these health problems probably will influence longevity of animals on the farm. Cooperation with service providers and veterinarian practitioners will be beneficial for both. A lot of discussions also focus on contagious diseases. National programmes and cooperation in the animal disease chain might benefit from real time animal data. However, for this, national or regional monitoring specific attention should be paid to regional modelling and location based animal data. This will lead to a more preventive and risk based monitoring task. Also, in times of crisis this information will help to react quicker and more precise. The herd control scenario selected in WASP falls within this topic and, more specifically, focussed on remote monitoring of activity and locomotion of individual cows as early indicator for claw health problems.

Product quality and food safety - Product quality is also individual animal related. So far this topic is not much in discussion, but can become important when product diversification becomes more prominent. Animal specific information can become the basis for new food chains. This will have logistic consequences that should be handled by using modern ICT based support systems. The SDF concept can feed the present used quality systems with new real time elements. Then also in livestock production chains the concept of quality based tracing and tracking becomes possible.

Environmental protection and regional development - This topic has also a high importance. The connection to the SDF concept is very close related to the whereabouts of individual animal activities. Individual activities of animals are in essence the source of environmental issues. Use of food, concentrates and manuring are context and animal related. This takes place in a specific region. New concepts of farming become possible. Interaction with protected areas such as Natura 2000 regions will provide operational management. For this topic also the location awareness and the real time integration in the regional system are important. Of course not all these aspect were used in the WASP prototype. But the relevance of observing cow activity behaviour and, more specific, the locomotion behaviour is made clear.

Herd control test bed

Within the WASP test bed for herd health control, the focus has been on remote monitoring of activity-related problems like claw health. Throughout various integration sessions in a dairy test farm in Lelystad (The Netherlands), of which an impression can be found in Figure 2, the components and tools have been gradually introduced and tested, thereby validating and refining the WASP system. The final achievement has been the successful deployment of a WASP prototype as indicated in Figure 3.

In the prototype illustrated in
Figure 3, a large-scale network of in total 79 nodes has been successfully deployed which involved 27 real cows (each wearing two nodes) 10 "virtual cows" (nodes attached on a test wheel to simulation motion and thereby to stress test the deployment), 14 stationary forwarder nodes and 1 base station node. In a separate large-scale laboratory trial a group of 127 nodes was used.

Various deployments tools have been used to remotely monitor the services installation on nodes (node monitor), the network topology (topology monitor), and network performance and node stability (statistics monitor) during run-time. Besides monitoring, also node settings can be remotely changed.

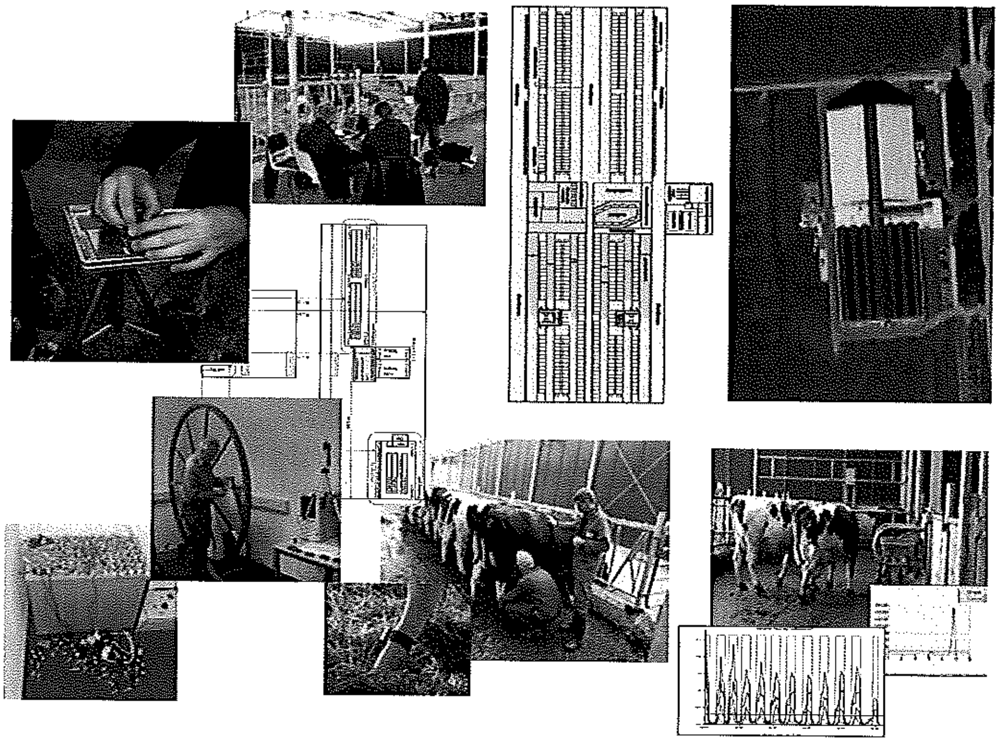

Figure 2. Impression of the herd control test bed development to validate and refine the WASP architecture and implementation during various integration sessions in the dairy test farm in Lelystad (The Netherlands)

For the interaction with the end user, the animal behaviour researchers of WUR developed and tested a prototypical Dairy Farm Information System. This Farm Information System is built upon a generic business mediation layer that was used to collect and store data from the experiments and to perform subsequent operations including establishing data trustworthiness.

From the various Smart Dairy Farm topics sketched in the previous section, our test scenario addressed animal health and, more specifically, focussed on remote monitoring of cow activity behaviour and locomotion to early detect claw health problems for individual cows. Measurements are performed with a 3D accelerator sensor that is integrated in the WASP sensor node. The measurement interval, duration and the frequency are adaptive to the behaviour of the animal. Cow activity behaviour is translated to different modes that are used during the testing phase:

- **MODE 0:** continuous stream of 3D values, 3x10 or 3x50 measuring values per second;
- **MODE I:** Data that the cow is laying (one value, e.g. '1');
- **MODE II:** Data that the cow is standing (one value, e.g. '2');
- **MODE III:** Data that the cow is walking (one value, e.g. '3');
- **MODE IV:** Step duration, length, swing (amplitude of the sideward movement) and amplitude (four values)

MODE 0 will not be activated during default operation, but has been implemented to check proper accelerometer operation by the WSN system integrator and for raw data collection by the animal behaviour scientist for off-line (activity classifier and locomotion) algorithm development.

MODES I, II, and III offer the option of switching to raw 3D-accelerometer data with a frequency of 10 Hz and an interval length of 1 s (10x3 measuring values) and in MODE IV there is an option of switching to raw 3D-accelerometer data with a frequency of 50 Hz and a interval length of 10 s (1500 measuring values).. The feasibility of using 3D accelerometers in a wireless sensor network (WSN) for determining the locomotion of the feet of a cow was explored; a procedure to distinguish steps and to derive step parameters (length and time) was developed. It is possible to detect steps and to derive step parameters. The algorithm seems to be effective and has been tested using a test wheel and on raw data collection from three cows.

Up-scaling from a first successful small-scale (15 nodes) deployment, showing the basic WASP system functionality, to the final large-scale (79 nodes) deployment proved rather cumbersome as we encountered (seemingly non-deterministic) node stability issues that, in the end, were caused by an accumulation of several sources on sensor node level. A big benefit of the integrated WASP system proved to be that, since debug facilities of sensor node deployed in an actual test bed are extremely limited, the ability to build and adapt remote monitoring tools to assess during run-time installed node services, node stability, network performance (packet delivery) and topology enabled to trace to origin of multiple sources. In its current state, we are confident that the integrated WASP system can serve as research tool for animal behaviour scientists at WUR to enable data acquisition for period up to several weeks to study behaviour and, in the end, come up with better models and treatments.

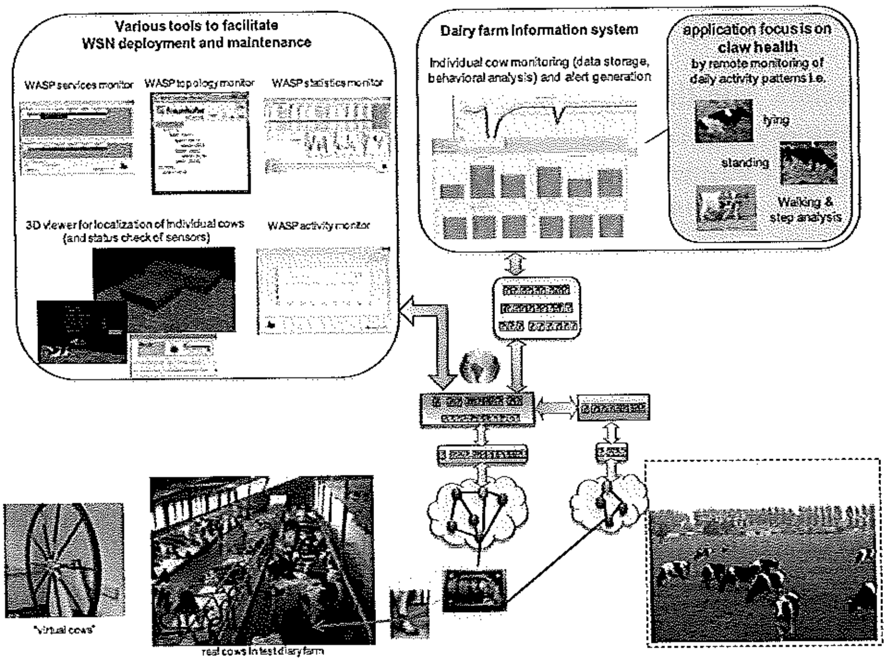

Figure 3. Herd control test bed setup for which the indoor case has been successfully demonstrated within WASP.

Throughout WASP run time, the herd control concept has been discussed with members of the Smart Dairy Farming (SDF) study group within the Netherlands, involving Friesland Campina, CRV, Agrifirm and the NOM. These discussions contributed to the further plans of the SDF study group and assisted in selection of priorities, like "real-time" cow observations, and follow-up projects. The final herd control test bed scenario and results have also been discussed with this SDF consortium. Among several application-oriented questions, the steps needed to go from a research tool to industrial farm management information tool were of interest. Here, our thorough analysis of encountered test bed problems and solutions proved very valuable insights to this community.

Application and deployment trade-offs

Encouraged by the large-scale herd control deployment whose operation is limited to 10 to 12 days, we performed an exercise to assess whether it seems feasible to monitor a large number of cows over a period of a year without replacing the 8Ah batteries. Through this exercise, we wanted to get a feeling on application and deployment trade-offs like

- acceptable time between packets generated at application level
- acceptable number of battery-powered mobile sensor nodes
- required number and positioning of battery- and/or mains-powered forwarder nodes
- required number and positioning of sink nodes while considering application QoS metrics constraints on
- size (and hence energy capacity) of batteries
- packet delivery ratio
- packet delivery latency

Figure illustrates two application categories and their associated time between (application) packets that are useful to monitor both healthy cows (sending health reports to the farm information system at low periodicity) and cows that need attention (and send frequent health reports and information about their location).

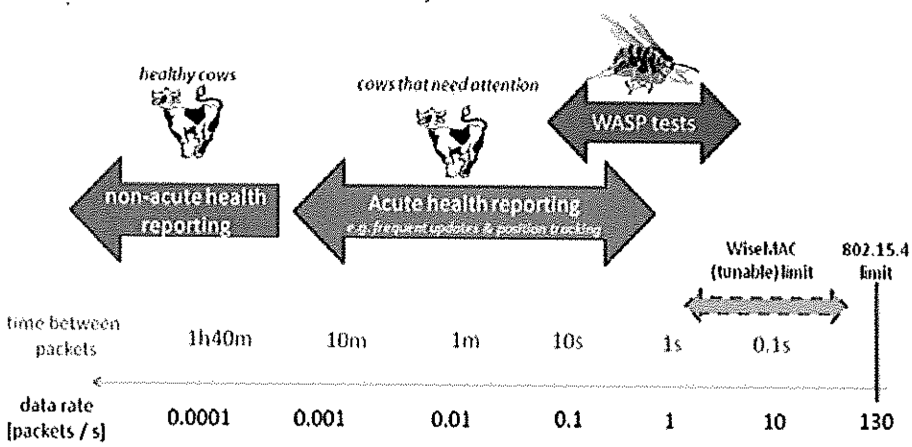

Figure 4. Application ranges for herd control

The figure also indicates the application traffic typically generated in the WASP tests that are deliberately in a regime to stress test the sensor network capacity and the amount of data that can be send to the WASP gateway and enterprise system.
The sink-to-router serial connection can handle up to around 9000 packets and, subsequent, router-to-gateway and gateway-to-backend links are not likely to form a capacity bottleneck as long as the right (IP-backbone) infrastructure is installed. The WASP gateway has shown to be capable of dealing with quite some traffic when using a modern PC and, hence, the major challenge is in deploying a wireless sensor network with manageable amount of sinks & forwarders.
Simulation results for a group of 10 cows and 50 cows are depicted in the Figure 6 below where the QoS metrics used before, i.e. average packet delivery ratio, average packet delivery latency, and average power consumption, are shown as a function of time between application packets. The results reflect that at relative long time intervals between packets, QoS performance is best which can be understood well since this corresponds to a low-traffic condition. At decreasing time intervals between packets, traffic density and, hence, competition for the radio channel increases which leads to degradation of QoS performance.
For 10 cows (i.e. 20 cow nodes), the QoS metrics are acceptable for the application requirements, but when sending packets at time intervals shorter than 30s, packet delivery starts to drop below 90%, latency goes up to minutes, and power consumption breaks the 3mW constraint of (battery-powered) operation of 1 year (= 8Ah / (364 days per year *24 h per day) * 3V). For 50 cows (i.e. 100 cow nodes), the time between packets needs to be significantly increased to far above 1000s (>17 minutes) to get acceptable QoS performance including a one year operation time.

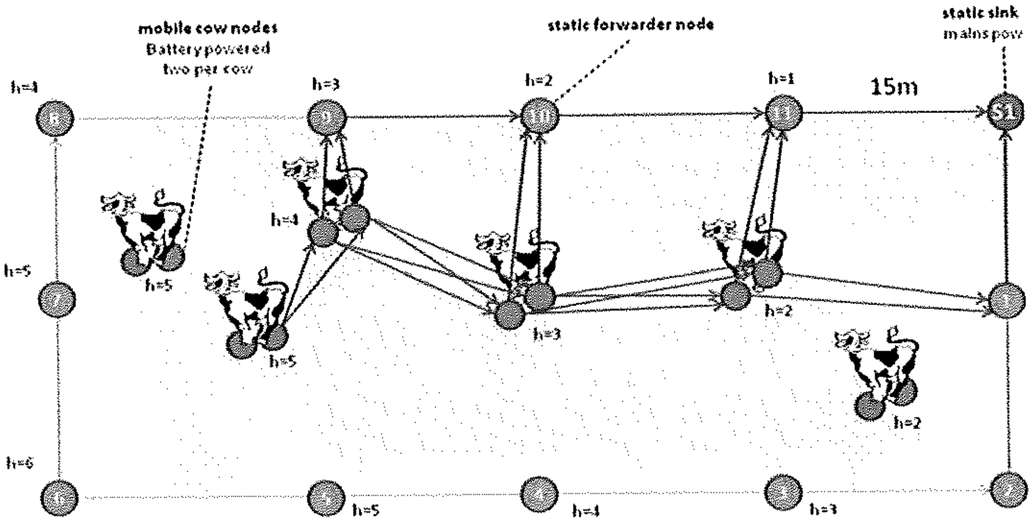

Figure 5. Simulation setup to assess application & deployment trade-offs for herd control

Note that this QoS performance is already fine for non-acute reporting (say once or twice a day) for the majority of cows while enabling acute monitoring for a few cows. Further QoS improvements can be obtained by (cross-layer) optimization of the (Gradient) routing and (WiseMAC) Medium Access Protocols which, due to the various technical issues encountered during integration, has hardly been pursued.

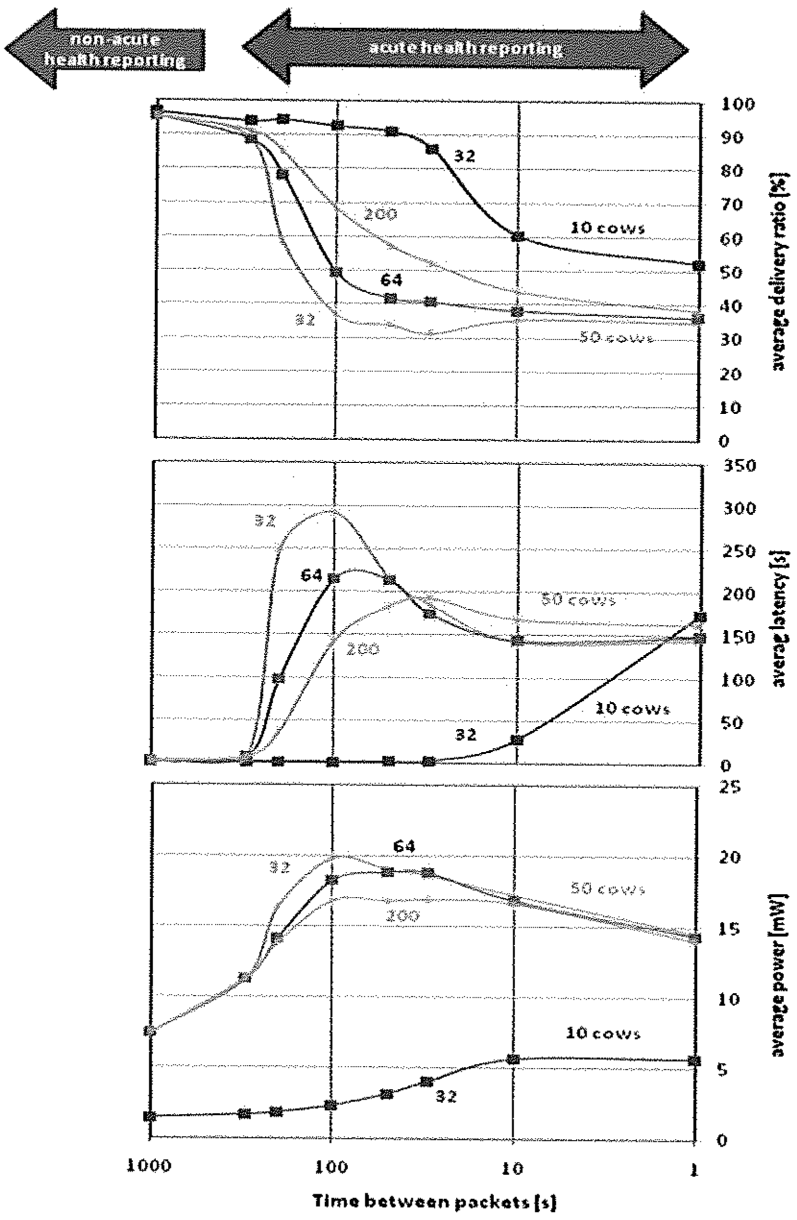

Figure 6. Simulation results for the Herd Control setting depicted in Figure 5. The numbers (32, 64, 200) next to the curves indicate the duplicate filter entries for Gradient.

For example, currently Gradient Routing only has a rather basic mechanism to filter duplicate packets that are so characteristic of broadcast-based routing protocols. This duplicate filter tracks whether a message from a given source with a given sequence number has already been forwarded and, if so, can be dropped. However, given memory constraints, only a limited number of message identifiers can be tracked. In large-scale deployments, the number of sources can outnumber the duplicate filter entries and thereby degrade filtering quality. This is illustrated for the 50 cow simulations in Figure 6 where simulations are shown for 32 (default used in the test bed), 64, and 200 duplicate filter entries.

Although stack optimization is always beneficial, QoS performance can readily be improved by adding multiple hardware routers to the deployment to provide an additional sink e.g. at forwarder #6 in Figure 5. The WASP IP infrastructure allows for the deployment of multiple (hardware and software) sinks and, thereby, to divert traffic going to a single sink although adding routers evidently comes at additional (hardware) costs. Another manner to significantly improve QoS performance would be to deploy mains-connected forwarders if allowed in the application environment.

Concluding remarks

Within WASP a Research technology prototype has been build of the advanced WSN system. WASP developments have been driven by three application domains. For the Herd Control applications, technology prototypes have been developed in an iterative way and tested for relevant application scenarios. The current integrated WASP solution demonstrated in the herd control test bed can be well used as a research tool for animal behaviour scientists at Wageningen UR Livestock Research to enable data acquisition for periods up to several weeks to study behaviour and, in the end, come up with better models and treatments. This understanding is essential to quantify benefits and costs and, thereby, to motivate any next steps from the current WASP research technology prototypes towards industrial application prototypes and, subsequent, commercial solutions.

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