Performance Control in Wireless Sensor Networks

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Abstract—**Most of the currently deployed wireless sensor networks applications do not require performance control. The goal of the GINSENG project is sensor networks that meet application-specific performance targets, in particular with respect to latency and reliability. We present scenarios within the GALP oil refinery where the system will be deployed and some initial technical insights w.r.t. deterministic communication.**

I. Introduction

[1]Research on wireless sensor networks (WSNs) has mainly been focused on protocols and architectures for applications in which network performance assurances are not considered essential, such as agriculture and environmental monitoring. However, for many important areas, such as plant automation and health monitoring, performance assurances are crucial, especially for metrics such as delay and reliability.

Towards this end, the overall goal of the EU-funded GINSENG project [1] are wireless sensor networks that meet application-specific performance targets and that will integrate with industry resource management systems. Our results will be proven in a real industry setting, a refinery in Portugal, where performance is critical.

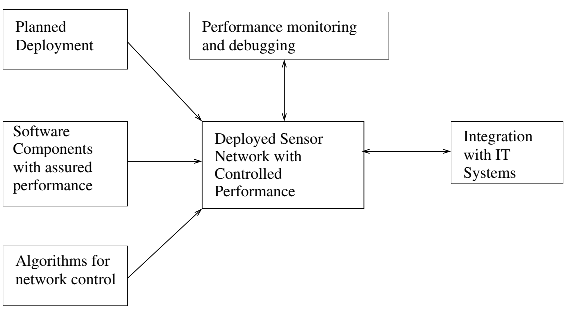

Fig. 1. The GINSENG approach.

[1]This is the author's version of the work, and it is not meant for redistribution. The definitive version was published in: Proceedings of the 6th International Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON). Rome, Italy. June 2009.

Fig. 2. GALP oil refinery.

Figure 1 depicts the GINSENG approach and its main components. In contrast to applications that are based on random deployment, GINSENG assumes a planned and careful deployment of the sensor nodes as a basis to achieve performance control. The second basis of GINSENG are software components with assured performance. This includes operating systems that execute tasks within a given time and predictable access to the radio medium by means of a MAC layer that enables access to the radio medium within a certain time bound. The third basis of GINSENG is a set of algorithms that ensure control with respect to the network topology and traffic. These three components enable the possibility to deploy sensor networks with assured performance. Due to the inherent uncertainties in e.g. node availability and the radio medium, it is possible to experience undesired changes in the operating environment, motivating the need to monitor and potentially debug the performance of the deployed system. GINSENG targets mechanisms and tools to perform performance debugging of deployed systems and reconfiguration when given performance metrics can no longer be achieved. Another objective of GINSENG is the integration with industry IT systems.

II. Application Context

The GINSENG target application is devoted to monitoring and control of industrial processes, safety and pollution supervision in the GALP oil refinery (Figure 2). Within this refinery, there are approximately 35,000 sensors and actuators.

Sensors are used to provide critical information to the refinery control centre to enable it to monitor and control all operations of the refinery. Currently, the vast majority of the devices used are linked to the control centre via copper cables which provide both power and communications. Although wired system is a tried and proven system, due to the prohibitive cost of laying cabling in an oil refinery environment, the use of wireless sensors is very compelling. Furthermore, wireless systems can also be deployed quickly, whereas wired systems usually require a lengthy deployment process. This makes wireless systems suitable for temporary deployments to monitor short term issues within the refinery.

There are currently three different monitoring and control systems in the GALP oil refinery: the indicatory system, the control system and emergency system. All three systems require performance assurances in terms of data delivery delay and reliability.

- The indicatory system is used purely to provide information to the control centre technicians to enable them to identify faults, monitor refinery status, increase refinery efficiency and schedule equipment maintenance. Within this system, information flows one way from the in-field sensors to the control centre.
- The control system is used to control different aspects of the refinery. Information flows in both directions from sensors in the field to the control centre and then from the control centre to actuators. There are two types of control system within the refinery, automatic and manual. In the automatic system, actuators are automatically controlled based on sensor data, i.e. if the pressure was recorded above a certain threshold, the pumps would be turned down. In the manual system, technicians can make manual adjustments to the actuators within the field.
- The emergency system is similar in function to the control system in automatic mode. However, the emergency system is used to monitor and control only mission critical systems. For example, pressure in pipes can be monitored and, in case of an overpressure situation, a shutoff valve is triggered to prevent an accident.

III. Network Elements for Performance Controlled WSNs

In order to provide a performance controlled communication service, the node operating system and the MAC layer need to be able to provide deterministic services. The sensor node operating system is crucial since it determines the event and message processing behaviour. This must be deterministic in order to forward messages and handle event in a timely manner. The medium access control protocol determines the message forwarding between two neighbouring nodes. A deterministic message forwarding behaviour between neighbouring nodes is required to build a performance controlled WSN.

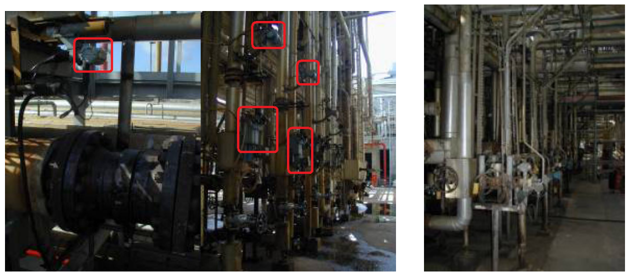

Fig. 3. Sensors installed in the GALP oil refinery.

Towards this end, we have proposed a TDMA-based MAC protocol for GINSENG-like WSN applications that demand predictable quality of service regarding message transfer delay and reliability [2]. Our collision-free protocol exploits topology knowledge. It is integrated with a routing mechanism and retransmission scheme to ensure that an upper bound for the node-to-node forwarding delay and a lower bound for the node-to-node forwarding reliability can be given. We performed our first implementation in TinyOS. During this effort, we realized that significant modifications to TinyOS are necessary to implement a deterministic MAC protocol efficiently. These modifications require changing the TinyOS programming model, for example, the split-phase operation.

We are currently reimplementing our protocol in the Contiki operating system [3]. Contiki was designed from the outset to support a future addition of a real-time layer on top of the kernel. Contiki's `rtimers` allow a task to be scheduled at a specified time in the future. The caller is notified immediately when a real-time task is unschedulable. We have successfully developed TDMA protocols with very short time slots of 10 ms based on this mechanism.

IV. Radio Communication in Outdoor Deployments

As other outdoor deployments, the GINSENG deployment in the GALP oil refinery in Portugal will be exposed to varying environmental conditions. In particular, rain, fog, and temperature might have an impact on the wireless communication between the deployed sensor nodes.

In order to evaluate the impact of the environmental conditions on radio communication, we performed multiple experiments with real hardware [4].

Our experiments show that the impact of temperature on the communication between sensors is high: Figure 4 shows this, and hints that the large difference in temperature between daytime and nighttime may affect the signal strength by several dBs. In particular, Figure 4 shows how the higher is the temperature, the weaker are the Received radio Signal Strength Indicator (RSSI) and the Link Quality Indicator (LQI). We experience this behaviour in different platforms operating at

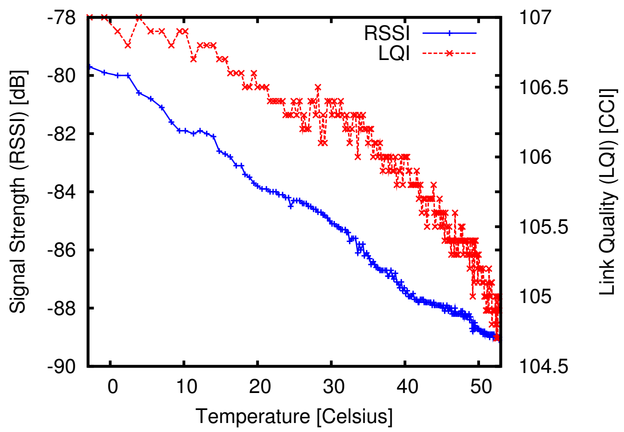

Fig. 4. Both the LQI and the RSSI indicators decrease as temperature increases. This applies not only to the Sentilla Tmote Sky, but also to the Scatterweb MSB430 platform that uses a radio chip operating in a different ISM frequency band.

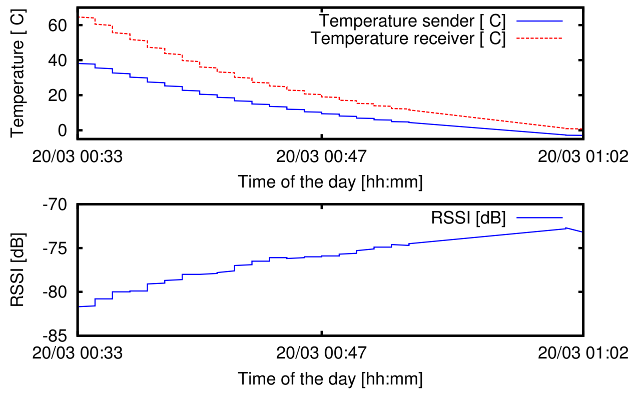

Fig. 6. Effects of the temperature on communication between sensor nodes inside ATEX enclosures, when the cases of both receiver and sender are cooled.

different radio frequencies: in particular we used the Sentilla Tmote Sky [5] and the Scatterweb MSB430 platforms [6].

We also show that the temperature has a larger effect on communication than fog and rain, when the latter is not heavier than 2-3 mm/hour.

Furthermore, in the potentially explosive refinery, it is necessary to enclose the sensor nodes in ATEX compliant enclosures [7]. The ATEX directives are regulations regarding the use of equipment in explosive atmospheres valid within the European Union, and thus, wireless sensor nodes deployed in such an industrial context must adhere to such standard.

Fig. 5. ATEX case with a sensor node.

We are not aware of any studies that have quantified the effect of such an enclosure on communication. In general, our measurements show that the impact of ATEX-compliant enclosures on wireless communication is small.

We also perform experiments where we warm the receiver and sender inside the ATEX enclosure. Figure 6 shows that the communication is stronger when both sending and receiving sensor nodes are at lower temperatures which confirms the results in Figure 4.

V. Conclusions

The main goal of the GINSENG project is wireless sensor networks that provide performance assurances for important metrics such as delay and reliability which are crucial for a broad class of emerging sensor network applications. The GINSENG results will be proven in an oil refinery in Portugal. In this paper, we have presented some promising results with respect to performance controlled low power wireless communication in outdoor sensor network deployments.

Acknowledgments

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