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Posters

Poster Abstract: An End To End WSN Based System For Real-Time Traffic Monitoring

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***Abstract*—A novel Wireless Sensor Network based system is proposed for real time traffic monitoring and early queue detection. The system is composed of an array of acoustic sensors that allows for traffic surveillance in real time by the processing of the sound waves generated by the traffic flow.**

I. Introduction

Real-time traffic monitoring and early queue detection is of paramount importance in Intelligent Transportation Systems (ITS). Different approach have been proposed, spanning from loop detectors laser/radar system, passive acoustic arrays and video cameras, but they are affected by some straits in deployment. Distributed traffic monitoring at large scale based on non intrusive/obtrusive solutions are highly desirable.

Wireless Sensor Network (WSN) infrastructure offers flexible advantages and also a significant decrease of installation costs and allows a large scale deployment. Several solutions have been investigated, including wireless magnetic sensors [1] [2], and acoustic vehicle detection based on coherent cross-correlation [4].

In this paper a Traffic Monitoring Wireless Sensor Network system (TM-WSN), based on an array of acoustic sensors that detect and process the sound waves generated by the traffic flow using a low-cost microprocessor is proposed. It is composed by an hierarchical scheme of Master Nodes and Sensor Nodes linked with a multi-hop protocol.

The system allows for traffic monitoring and queue detection to be performed in real-time at unprecedented space scale, while demanding for extremely low investment/installation and maintenance cost. Due to the system structure, a multiple number of basic units, in fact, can be easily deployed along the carriageway without any particular setup while the use of acoustic sensors leads to a lower power consumption along with a reduced scheduling maintenance. Only the MN is intended to be power supplied, SNs are designed to be energy autonomous by means of a rechargeable lithium battery supported by a solar panel. A pilot site of the proposed system has been arranged on a motorway and extensive experimental demonstration is given for a long term operation test.

II. TM-WSN Description and Operation

The basic module of the system is composed of a Master Node (MN), connected to a remote database via TCP/IP over UMTS. The MN is wirelessly connected to a number of Sensor Nodes (SNs), regularly spaced, operating at low duty-cycle and waked-up on demand. In Fig. 1 a basic module infrastructure deployed along the motorway is represented. in this way 1 Km of motorway can be monitored, while the basic module can be spatially replicated on both side of the motorway to cover a wider area.

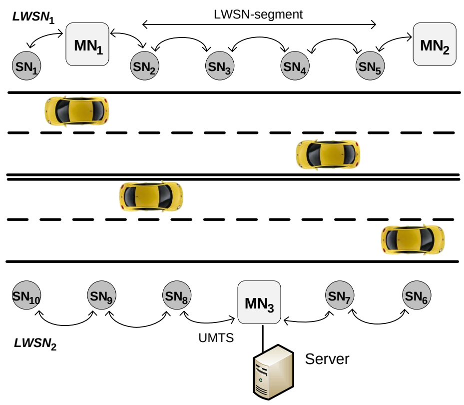

Fig. 1. Basic system infrastructure.

The MN performs traffic sensing by sound detection accordingly to what described in [3].

Sound waves generated by the traveling vehicles reach the two microphones, consisting in the MN's *sensor unit*, at slightly different times due to the difference in the air path; by using a *cross-correlation method*, the time delay between the two signal could be estimated. Mapping the position of the cross correlation peak, results in a digital *Sound Map*, shown in Fig. 2, representing the source motion along a predefined track according to the method described by [4].

To enable, automatically on-site, the *traffic parameters* extraction from the Sound Map, an effective and original post-processing algorithm has been developed. As a first step, we addressed the issue of removing unwanted traces generated by vehicles traveling in the opposite carriageway by applying a dynamic threshold estimated on the energy value of the correlation signal at the front-end of the process. The low frequency background noise like e.g. wind has been removed using a high pass filter. Now automatic traffic parameters extraction can be performed.

To detect a *vehicle transit*, two symmetrical points corresponding to the positive time delay τ_1 and the negative time delay $\tau_2 = -\tau_1$ are positioned on the y-axis of the sound map. A vehicle transit is detected if the sound trace intercepts in sequence the values τ_1 and τ_2 that occurs when a vehicle pass through the two virtual position X1 and X2 along the traveling path. Therefore as τ_1 and τ_2 are selected in the linear portion of the trace, the vehicle traveling speed, V_v, can be easily calculated.

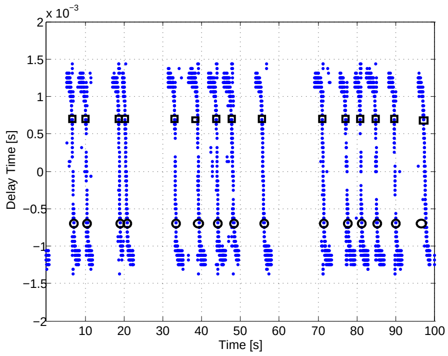

Fig. 2. Multiple detection transit.

In Fig. 2 a sound map is reported, showing the sequence of square and circle markers associated to multiple vehicle detection. As it can be observed all the passing vehicles are successfully detected in this case.

When a queue or a jam is detected at the MN location SNs of the basic module associated with the MN are switched, at the same time, in an *operative mode* to locate the position of the queue or jam. Thus providing a real-time picture of traffic flow sampled at the same space interval of the SN deployed on the motorway. The detection of traffic conditions (fluid flow or queue) is performed via analysis of features of the energy distribution associated with the traffic flow acoustic signal.

A fluid traffic condition, in fact, is associated to the presence of isolated energy peaks, while a queue or jam condition is associated to an energy floor, with a much lower associated average energy. The processing unit of the SN computes the energy distribution in the time domain and an algorithm based on a state machine makes the detection of the passing vehicle.

III. Protocol Design

Taking into account some important system requirements such as a low power consumption and the possibility of establishing a quick set-up and end-to-end communication, a MAC and a routing protocol were implemented. The MAC protocol is duty cycled and based on Asynchronous Reception and Synchronous transmission.

The routing protocol is a proactive algorithm belonging to the class of link-state protocols. It resorts to the signaling introduced by the MAC layer with the aim of minimize the overhead and make the system more adaptive in a cross layer fashion. The routing protocol includes also a recovery mode to provide a fault tolerant communication.

IV. Experimental Results

A prototype, composed of a basic unit of the system has been deployed near Florence, along the A11 highway operated by Autostrade per l'Italia SpA (ASPI) in order to get on-field testing and evaluation. The MN unit was first deployed on May 2009; since then it underwent extensive operation regularly collecting an transmitting traffic flow reports to the central server.

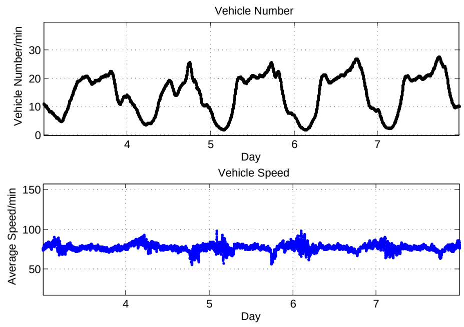

Fig. 3. Vehicle transit and average speed for a weekly observation slot.

In Fig. 3 a weekly data collection related to vehicles transit and average speed is shown, highlighting the periodicity of the traffic flow with different behavior depending by day and hours.

The system has been placed closely to a loop detector to test the MN functionality. The two systems have collected almost the same results in terms of shape and vehicles transit. As a consequence, the MN information is now fully integrated in the ASPI information system.

Thanks to the promising results obtained by the pilot site, ASPI has decided for an extensive system installation along A1 motorway.

V. Conclusion

In this paper a novel sensor network architecture and communication protocol for traffic surveillance has been proposed, exhibiting the unique feature of providing a complete and immediate state of the traffic flow at an unprecedented scale and in real-time. The main features are low installation and maintenance cost due to the sensing elements based on the use of passive acoustic transducers.

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Poster Abstract- Haar Digital Wavelet Transform Assessment on Wireless Sensors Nodes: Case Study

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***Abstract*—Digital wavelet transforms (DWT) implementation within wireless sensor nodes is constrained by the reduced energy budget and scanty computational capability. Nevertheless, the Haar DWT is a very simple wavelet transform whose implementation requires few subtractions and additions.**
Identification of transient signals *by thresholding* with Haar DWT could be very efficient from the energy consumption point of view. In this work we explore the event detection capability *by thresholding* of the Haar DWT on real wireless sensor nodes. Discussion about implementation issues and performance evaluation are presented. Simulations and measurements have revealed the presence of shortcomings and future research trends have been identified

I. Introduction

Traditionally, wireless sensor nodes are programmed for implementing continuous signal sampling and transmission, with overloaded memory, radio transceiver excessive usage and potential traffic congestion. The problem of implementing local signal processing is relatively new in the WSN arena and recently it has started to be studied [1]. The problem emerges for applications that process a huge quantity of data, for instance, WSN applications that involve 3-axis accelerometers per node for structural health monitoring [2] [3].
The DWT implementation is then motivated by the node's need of performing local signal processing in order to reduce battery energy consumption. Reduced energy consumption can be achieved because only signal features of interest (e.g. signal sharp spikes or transient edges) would be transmitted with reduced radio transceiver activity.
On the other hand, wireless sensor nodes are resource-constrained hardware and only a very simple DWT implementation could achieve reduced battery energy consumption. The Haar DWT [4] is characterized by the simple computation that results in reduced battery energy usage. Such DWT is then a potential candidate for WSN applications, nevertheless, examples as well as performance study for real WSN applications are scantily reported in literature.
In this work we have explored the Haar DWT detection capability *by thresholding* without overloaded processing of the wavelet coefficients, as it is usually done, for instance by means of differentiation.

II. Implementation

Among the large number of possible wavelets we selected the Haar DWT due to the following two reasons:
1) Easy implementation: the DWT implementation can be easily performed within wireless sensor nodes. It consists in running averages and differences. In contrast with most of the DWT, the reduced computational effort and low energy budget are in favor of the Haar DWT.
Coefficients for each sub-bands filter are reported in literature and clearly illustrates the algorithm simplicity. With reference to the Fig.1 we have that [4]:

$$a_{j-1}(k) = \frac{1}{\sqrt{2}}\left[a_j(2k-1) + a_j(2k)\right] \tag{1}$$

$$d_{j-1}(k) = \frac{1}{\sqrt{2}}\left[a_j(2k-1) - a_j(2k)\right] \tag{2}$$

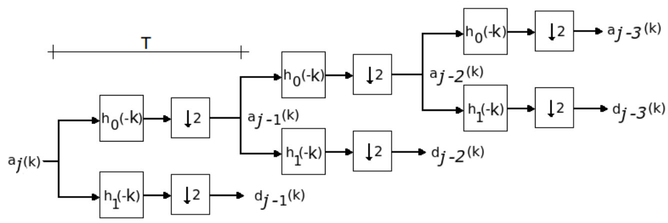

Figure 1. Filter bank in cascade to obtain the DWT coefficients [4].

2) Algorithm startup: the first coefficients ($a_j(k)$ in Fig. 1) are directly related with the sampled signal. For implementing a DWT it is necessary to calculate the startup coefficients $a_0(k)$ because they are used at the beginning of the filter banks. This statement is not evident but it constitutes the main pitfall in using DWT. Interested readers can find the mathematical treatment in [4]. However, for the Haar DWT, the signal samples $x(k)$ are in fact $a_0(k)$ ($a_0(k) = x(k)$) and it is not required extra computation beforehand.

A. Case study

The node under observation is the MICAz [5] that features the MTS300CB/MTS310CB sensor board with the low-cost 2-g dual-axis accelerometer ADXL202E. The accelerometer output signal is sampled while the node is being carried by a person who walks and takes pauses. The node is carried with aleatory orientation in a shirt's pocket and the goal is to detect changes in the walking pattern. The acceleration pattern is captured from the accelerometer's axis X but its relative position with respect to the movement is not known. It enables us to analyze the Haar DWT detection capability under spatial variances of the accelerometer. Sampled data are analyzed by the Haar DWT implemented into the node by using NesC language [6] on TinyOs [6]. The number of signal samples is $N = 1000$, the sampling frequency $f_s = 20\,Hz$ and only the coefficients $d_j(k)$ are sent from node's memory to the PC for analysis. Figure 2 shows an example of the accelerometer output signal captured by the node. The sections marked as (A), (C) and (E) correspond to the normal walking; the transient signals marked as (B) and (D) show that the the person suddenly arrested the walking and changed direction to take another path.

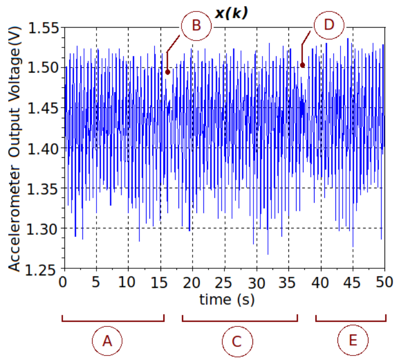

Figure 2. Recorded person acceleration while walking.

III. Results and discussion

In Figure 1 it is defined the execution time T for each Haar DWT stage. For the MicaZ node the measured value is $T = 15.8\mu s$ and the energy consumption is $E = 0.42\mu J$. If f_w is the signal bandwidth and Q the number of decomposition levels, then, the condition $2f_w < f_s < Q/T$ must be met in order to achieve the decomposition level Q for real-time applications. Numerical examples: for $f_w = 10kHz$ and Nyquist sampling frequency, it results $Q \simeq 3$ levels and for $f_w = 1kHz$ it results $Q \simeq 31$ levels.

Since signals from accelerometers rarely are higher than $1kHz$, the implementation is well suited for application where vibrating signals have to be analyzed because after level 6 or 7 Haar DWT coefficients can be considered as noise.

After analyzing data, on the contrary to what we expected, we concluded that it is not possible to detect the transients (B) and (D) *by thresholding*. For this, we used a digital lightweight low-pass filtering (FIR average filter) in order to enhance the Haar DWT detection capability. After performing the filtering, the resulting DWT coefficients $d_{j-2}(n)$ are shown in Fig. 3. Both transients event can be easily identified by means of a suitable threshold value. The events are marked with B and D. We had to evaluate by means of analyzing the DWT coefficients, the suitable threshold value and the decomposition level that detect can the events.

This innovative technique (case (B) in Fig. 3) appears to outperform other signal processing techniques such as FFT or EWMA (exponential weighted moving average). The Haar DWT detection capability by using thresholding is enhanced by means of a lightweight pre-filtering. This technique is in its infancy and more intensive research should be addressed to develop the theoretical aspects.

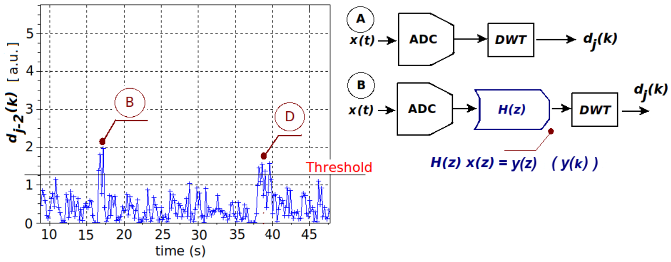

Figure 3. Left: coefficient $d_{j-2}(k)$ (decomposition level 2) after performing the lightweight digital low-pass filtering. The detection can be performed by thresholding. Right: (A) failed Haar DWT implementation, (B) successful low-pass filtering before Haar DWT implementation($x(t)$ is the input signal, $d_j(k)$ the coefficients after performing the DWT).

IV. Final Considerations and Conclusion

We summarize the observed drawbacks and detected open issues. The factors that deteriorate the detection capability in terms of effectiveness and reliability are:

1) Sampling frequency selection: we observed that the detection capability depends on the selected sampling frequency, because it affects the algorithm startup.

It has not been reported in literature a methodology ensuring the best sampling frequency selection to assure detection capability. This issue should be studied.

2) Threshold and decomposition level selection: At this moment, the state of the art does not provide the methodology to determine the decomposition level at which the detection could be performed, or to estimate the threshold value that assures the successful detection. Both parameters must be manually selected in accordance with the signal features.

The detection by thresholding works very well when it is correctly configured by using training signals. However this Haar DWT assessment revealed that reliability can not be guaranteed. The detection would fail if signal features and sampling frequency are appreciably modified.

These drawbacks are counterbalanced by other factors such as speed and a lot of potential applications where other signal processing technique can not be applied due to energy and constrained resources hardware. Rather than discouraging the Haar DWT, authors are continuing to study how to provide reliability to the detection by thresholding.

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Poster Abstract: Secure Cooperation of Mobile Sensors in an Underwater Acoustic Network

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Abstract— Methodologies and algorithms are presented for the secure cooperation of a team of mobile underwater sensors, connected through an acoustic communication network, within surveillance and patrolling applications. The work proposes a cooperative algorithm where the mobile underwater sensors (installed on Autonomous Underwater Vehicles – AUVs) respond to simple local rules based on the available information to perform the mission and maintain the communication link with the network. The algorithm is intrinsically robust, in the sense that with loss of communication among the vehicles the coverage performance (i.e., the mission goal) is degraded but not lost. The cooperative algorithm relies however on the fact that the available information from the other sensors, though not necessarily complete, is trustworthy. To ensure trustworthiness, a secure communication suite has been designed specifically oriented to the underwater scenario.

I. INTRODUCTION

INTEREST for Underwater Acoustic Networks (UANs) is increasing, due to their large application for exploring and monitoring the underwater environment and collecting information for scientific purposes. A UAN is composed of multiple nodes, which can effectively cooperate as a group to solve some common goals [1]. However, when multiple cooperating sensor nodes, fixed and mobile, are used in the underwater domain, communication issues become very relevant [2, 3], because of the strong variation in space and time of the communication medium. In fact, the physics of acoustic propagation, the main means of underwater communication, is strongly dependent on the specific environmental conditions, and during the evolution of the mission each vehicle can experience abrupt changes in the channel, with a consequent variation in communication performance. Moreover, acoustic communication is severely band-limited and range-limited. Sudden reduction of the channel capacity and bandwidth, or even a temporary loss of connectivity with the rest of the team, is a frequent condition for underwater communications, influencing the agents' ability to continue the mission in cooperation.

In this work the communication difficulties in node cooperation are tackled from the application level point of view, i.e., proposing a cooperation strategy that on one side attempts to minimize the information exchange among the nodes, and, on the other side, is robust with respect to connectivity loss or communication range degradation.

With this contribution we tackle the problem of secure cooperation of a team of mobile underwater sensors or AUVs within surveillance and patrolling applications. The main mission goal is that of protecting an asset (e.g. a critical infrastructure such as a power plant placed on the shore or directly in the water) using detection sonars mounted on each agent, while guaranteeing that, during the mission, the entire group remains acoustically connected even when environmental variations affect the performance of the vehicle acoustic modems. Within this context, we propose a novel cooperative *adaptive* and *reconfigurable* algorithm for the management of mobile nodes (or AUVs) of an underwater network and we design a set of network security solutions functional to the cooperative strategy and tailored to the communication limitations of the medium.

II. COOPERATION ALGORITHMS

The proposed algorithm defines each vehicle behavior through simple rules, obtaining the overall mission goal as the result of the emergent behavior of the team: 1) Move towards the critical asset, 2) Move away from the closest neighbor. The first rule assures the asset protection. The second rule modifies the behavior in order to let the AUVs cover the maximum area around the asset, with minimum overlaps of the on board sonar detection ranges, while guaranteeing the communication links. The vehicle interest for the i-th rule is defined by a "function of interest", $h_i(.)$ which determines in which way each agent enforces the specific rule, while a comparison among the functions of interest determines the priority of the rules followed at any time frame by each vehicle. Note that the algorithm makes each vehicle able to move back to the asset it needs to protect even when it loses the communication with the other team members, since each agent can always apply the first rule. In addition, during the mission each agent cooperates only with its closest vehicle, applying rule 2. In any case, the amount of information the vehicles need to exchange is limited, as they only require communicating to their closest neighbor two data: position and maximum detection sonar range. Finally, the agent control input is obtained as the vector sum of the gradient of each interest function: $u(t) = u_1(t) + u_2(t) = \nabla h_1 + \nabla h_2$.

III. SECURE COMMUNICATION

In order to practically deploy cooperation algorithms, vehicles must be able to securely communicate. Differently from conventional wired networks, an adversary equipped with an acoustic modem can easily eavesdrop, inject and modify packets. In order to address these threats, we implement the cooperation algorithm by means of two services, the ReKeying Service and the Message Security Service.

In a UAN communication bandwidth is limited, propagation time is very long, and vehicles have limited energy resources as they are battery operated. Therefore cryptographic protocols for UANs must be efficient in terms of number and size of messages. Applying traditional techniques such as ciphers, digests and digital signatures make messages to *expand* so introducing an overhead that is often comparable to, or even larger than, the payload itself. For these reasons, we propose a cryptographic suite that provides confidentiality, authenticity, and key management while avoiding message expansion.

A. The ReKeying Service

The ReKeying Service is responsible for revoking the current key and distributing a new one either periodically or upon a vehicle leaving. Vehicles are organized in order to form a *group*. Vehicles in the group share a *group key* they use to encrypt and authenticate broadcast messages. Whenever, a vehicle leaves the group, either because it has finished its mission or because it is (suspected to be) compromised, the current group-key is revoked and a new one distributed (*forward security*), according to the *group communication paradigm* described in [5]. The advantage of this rekeying scheme is twofold: i) it uses $O(\log n)$ rekeying messages, so it is scalable; ii) keys are *self-authenticated*, no authenticator or digital signature is necessary to prove the provenience of a key, and so no ciphertext expansion occurs.

B. The Message Security Service

The Message Security Service is responsible for protecting confidentiality and authenticity of messages by encrypting and decrypting them as well as generating and verifying proofs of their authenticity.

In order to avoid cipthertext expansion we use a cipher in the CipherText Stealing (CTS) encryption mode so that the size of the ciphertext is equal to that of the cleartext [4].

As to integrity, we use SHA-256 but we trunk the digest to 32 bit. Differently to a conventional network, in a UAN this size is sufficient to withstand an attack against the pre-image resistance property.

C. Denial of Service

Denial of Service (DoS) is one of the most severe threats against network availability in UANs. Actually, contrasting DoS in UANs is even more complicated than in traditional networks due to the specific, intrinsic limitations of the acoustic channel. The cooperative algorithm results reactive against DoS due to the emergent behavior approach. Whenever an enemy succeeds in disrupting communication among vehicles, the simple rules that drive vehicles' motion make them move closer to the asset in order to ensure the protection. It follows that a DoS attack results effective in degrading the performance of the cooperation, but cannot prevent a vehicle to continue its mission with a limited number of cooperating nodes, or at least individually.

IV. CONCLUSION

In this work we have described a methodology for secure cooperation within a network of mobile underwater sensors connected through an acoustic communication network. In particular, the work has described a cooperative algorithm based on the *emergent behavior* paradigm, in which each mobile sensor responds to simple local rules based on the available information to perform the mission and maintain the communication link with the network. Trustworthiness of the messages among the sensors is ensured through a security suite based on the *group communication* paradigm designed at the communication middleware level.

ACKNOWLEDGMENT

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Poster Abstract: MOTEL: Towards Flexible Mobile Wireless Sensor Network Testbeds

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***Abstract*—In this paper, we propose a novel architecture for wireless sensor network testbeds, called MOTEL. The main novelty compared to existing architectures is the possibility to include mobile sensor nodes. To support mobility, we deal with two main challenges: controlled mobility of sensor nodes, and the need to operate sensor nodes in the absence of a backchannel. We address these challenges together with traditional testbed requirements such as experiment repeatability, on-node logging, debugging and re-programming. MOTEL consists of two main components: MuRobA, a coordinated multi-robot architecture for enabling controlled mobility of the sensor nodes, and FLEXOR, a flexible sensor network architecture for enabling backchannel-free WSN experiments. MOTEL is work in progress and here we present the general architecture design of both MuRobA and FLEXOR, along with our first implementation and evaluation.**

I. Introduction and Motivation

Typical wireless sensor networks testbeds, such as the widely used TWIST [1], consist of several dozens to several hundreds of statically installed, backchannel assisted sensor nodes, and are remotely accessible for re-programming and result data gathering. Such backchannel based systems are convenient and easy to use, but they cannot incorporate node mobility. Moreover, they cannot completely substitute testing in a real world environment with its harsh properties such as battery unreliability, fluctuating radio transmission quality, specific topologies, limited access to the nodes and thus limited debugging and re-programming capabilities.

We propose a novel, flexible and extendable software architecture for mobility-enabled wireless sensor network testbeds, called MOTEL. Its main goal is to allow the rapid deployment of WSN testbeds in any environment, with current focus on indoor environments. Two main challenges need to be addressed: the eliminated backchannel and the controlled mobility of sensor nodes. We address the first one with FLEXOR, a flexible software architecture, which allows remote debugging, code exchange and data logging on sensor nodes without the need of a backchannel. The second challenge is addressed with MuRobA, a multi-robot architecture that allows planning and execution of well-defined mobility scenarios as opposed to the typically used random mobility.

II. Overview of MOTEL

Currently, MOTEL can be viewed as the combination of two independent components: MuRobA and FLEXOR. The sensor nodes run on FLEXOR (detailed in Section IV) and are piggybacked on robots, which run MuRobA. This can be seen in Figure 1, where sensor nodes are simply placed on top of robots. Both FLEXOR and MuRobA are highly modularized, platform-independent software architectures, which allows the usage of theoretically any sensor or robotic platform and any operating system or even simulator. We currently work with Memsic's TelosB as sensor network platform and with e-puck [2] as mobile robotic platform.

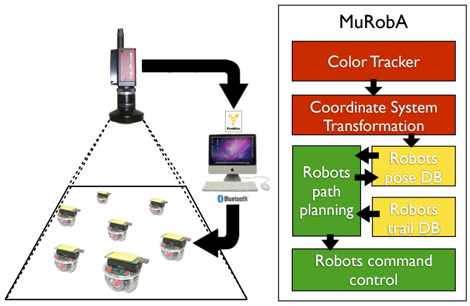

Fig. 1. Overview of MuRobA: the robot control system.

III. MuRobA: Multi-Robot Architecture for Coordinated Mobility

The overall MuRobA architecture is presented in Fig. 1. It consists of mobile robots, a camera attached to the ceiling, and a central computer. The computer analyzes the frames of the camera to estimate the current position and orientation of the robots and sends commands to the individual robots to follow predefined paths. In our current setup, we use a color camera equipped with a fish eye lens and working with a frame resolution of 2452x2056 pixels. With this setup, we are able to track all robots in a room of 9.80 m x 9.80 m. The camera is connected with the computer over a FireWire interface. The vision system tracks the position of colored paper patches placed on top of the robots. Figure 2 shows a sample camera image and the automatically detected robots in it. One particular issue is the mapping between robot IDs and detected color patches in the image. We chose not to use pre-assigned IDs or individually colored patches, but rather apply a system of trial and error: the control system gives a command to one of the robots to move and observes which one really moves. This approach allows for rapid and fully automatic deployment of MOTEL in any indoor environment.

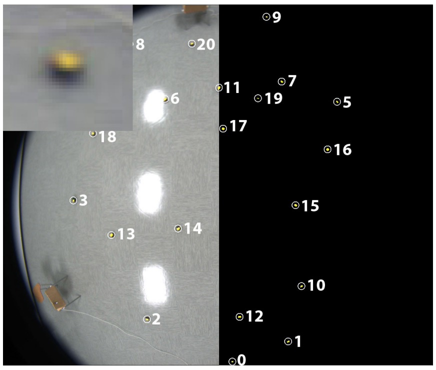

Fig. 2. Tracked robots from the ceiling camera.

The sensor nodes are placed on top of the robots and have no connection with them. The robots use a separate radio to communicate with the central control unit. They have their own micro-controller and power supply. This approach has the advantage that sensor network related experiment results – e. g. power consumption measurements or communication overhead – are not influenced by robot traits.

IV. FLEXOR: Flexible Runtime Management Software Architecture for WSN

The FLEXOR software architecture is designed to support the testing and management of WSN protocols and applications, mainly on MOTEL, but applicable to any WSN deployment. Its main goal is to provide run-time support to experiments on backchannel-free sensor networks in terms of on-node data logging, remote node control, and easy module exchange without explicit re-programming; tasks, which are usually enabled through the testbed backchannel. Our solution is to enable protocol/application exchange in a fast and low overhead manner and to allow for remote callback invocation in a multi-hop environment. FLEXOR relies on the fact that most real-world sensor network protocols and applications are the combination of a limited number of modules. Oftentimes, a testbed is used for comparing the performance of several protocols or algorithms, such as routing or link quality protocols. However, with native implementation, the hassle-free exchange of these modules is for all practical purposes impossible. FLEXOR, on the other hand, defines clear interfaces for the implementation of modules, so that they can be easily exchange during runtime. Furthermore, its core implements remote callbacks in multihop networks, which further allows us to control all nodes in the testbed without direct access to them.

The overall system architecture of FLEXOR is presented in Figure 3. We define clear interfaces for modules (components) and clear rules on how to inter-connect them (system specifications). All the required modules are pre-loaded on the system and reside inactive in its memory. A FLEXOR component called *ModuleManager* connects the modules on demand according to pre-loaded or run-time defined system

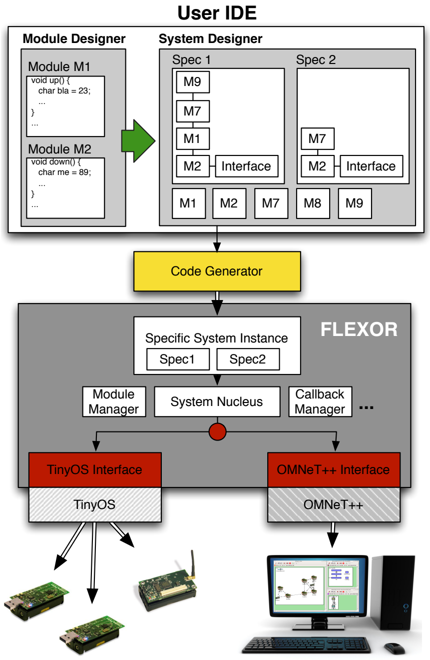

Fig. 3. FLEXOR system overview from the user to the hardware platform.

specifications. FLEXOR's core components enable local logging, remote parameter control, and callback invocation. These features make it possible to effectively assemble an ad hoc mobile infrastructure-free testbed that mimics the features of a real-world deployment.

FLEXOR is completely platform-independent and can be implemented over any embedded operating system, simulation system, middleware, etc.

V. Next Steps

Our immediate next steps include the full implementation of MuRobA and the evaluation and testing of the complete MOTEL. In future, we also plan to extend MOTEL by a physical connection between sensor nodes and robots, thus allowing steering the mobility from the sensor nodes and giving back some of the functionality of a backchannel. Furthermore, we plan automatic recharging stations for the robots, which will help us automating MOTEL and making it available as remotely shared testbed. Last, but not least, we work on the implementation of MOTEL for outdoor environments, which will require mainly a new localization system for MuRobA.

Acknowledgments

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Poster Abstract: Smart-HOP: A Reliable Handoff Procedure for Supporting Mobility in Wireless Sensor Networks

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***Abstract*— This poster abstract presents *smart-HOP*, a reliable handoff mechanism for mobility support in Wireless Sensor Networks (WSNs). This technique relies on a fuzzy logic approach applied at two levels: the link quality estimation level and the access point selection level. We present the conceptual design of smart-HOP and then we discuss implementation requirements and challenges.**

I. Introduction

While mobility support has been almost neglected in WSNs literature and applications, it promises to potentiate a new plethora of applications [1,2]. In some of these applications, the lack of network connectivity will not be admissible or should at least be time bounded, i.e. mobile nodes cannot be disconnected from the rest of the WSN for an undefined period of time. In this context, we aim at reliable and real-time mobility support in WSNs, for which appropriate handoff and re-routing decisions are mandatory.

This poster abstract drafts ongoing work on designing a mechanism for taking reliable handoff decisions in WSNs – **smart-HOP**. The main components of smart-HOP rely on Fuzzy logic, which is used to incorporate the inherent imprecision and uncertainty of the physical quantities at stake.

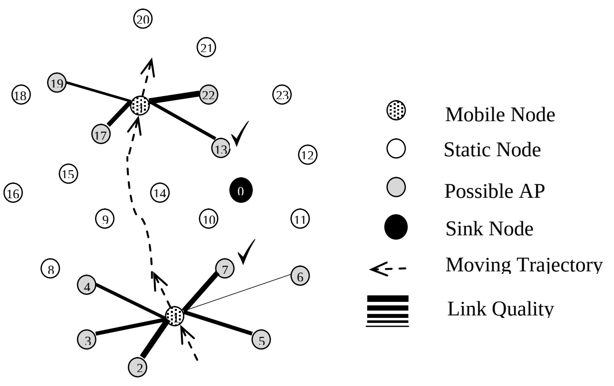

Figure 1 – Network scenario

Handoff refers to the process where a mobile node (MN, e.g. person, vehicle) disconnects from one access point (AP) and connects to another AP (see Fig. 1). Hence, the MN will need to (i) identify the best access point available and (ii) have the capability of switching to a different access point if the quality of communication decreases (handoff).

The remainder of this poster abstract outlines the basics of the smart-HOP mechanism and ongoing work towards its implementation and experimental validation.

II. Handoff Mechanism

The smart-HOP mechanism relies on a fuzzy logic approach applied in two hierarchical levels: at the link quality estimation level (lower) and at the AP selection level (higher). It consists of two distinct phases (Fig. 2): Phase I aims at taking a quick decision on whether a handoff is needed or not (i.e., it tries to avoid unnecessary handoffs). If a handoff is required, Phase II performs the actual handoff according to a fuzzy based rule.

During Phase I, MN performs an initial assessment of the link quality based on the received signal strength (RSS). We assume that APs periodically broadcast probe messages. Upon reception of multiple probe messages, the MN computes the average of the last “n” number of RSS values (RSS_{avg}). The parameter “n” should be set low enough to enable a quick assessment of the radio link (the higher the “n”, the longer it takes) and it should be also set high enough to attenuate (by averaging) sudden RSS fluctuations . If the RSS_{avg} value has not dropped below a certain threshold, the MN keeps associated to the current AP; otherwise it goes to Phase II of the algorithm, to perform a handoff.

In most wireless network protocols, the handoff is merely based on RSS values. We perform the handoff decision based on a more accurate estimation of the radio link quality (using F-LQE - Fuzzy Link Quality Estimator [3]) between an MN and the neighbouring AP, and also on AP-specific parameters such as its energy budget, traffic load and depth in the tree. F-LQE [3] has proved to be more accurate (particularly in the transitional region) than other LQEs as it merges four link quality metrics: (i) packet delivery, (ii) asymmetry, (iii) stability and (iv) channel quality.

In order to choose the best AP, an MN must also assess other criteria apart from link quality estimation: (i) energy level (EL), (ii) traffic load (TL), and (iii) depth level (DL). Each criterion is considered as a fuzzy variable and is assumed to be embedded in the payload of the probe messages. The best AP is chosen with a fuzzy rule comprising the F-LQE membership value together with the previously referred AP-specific parameters. Each of these membership values of the smart-HOP fuzzy decision rule must be weighted. This process is done by assigning a weight to each parameter indicative of its importance, and then, applying the fuzzy decision rule to obtain the final result. We then select the alternative that has the highest grade of membership. Finally, the last step of the algorithm disassociates the MN from the current AP and associates it to the newly selected AP.

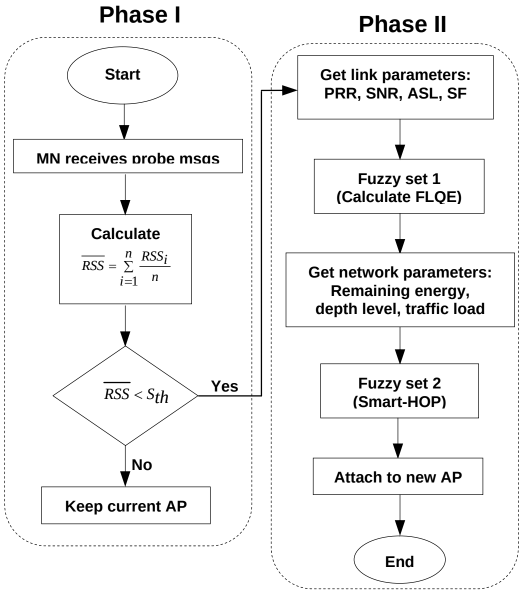

Figure 2– smart-HOP algorithm (simplified)

III. ONGOING WORK

We aim at testing, optimizing, tuning and validating smart-HOP through an experimental test-bed. The smart-HOP is implementing in nesC/TinyOS and integrating it in the IEEE 802.15.4 protocol, specifically in the official stack developed under the TinyOS 15.4 Working Group.

Although a previous implementation of the F-LQE existed [3], we had to re-implement it in a way to be more easily integrated with the IEEE 802.15.4 code and that the collection of radio metrics and computation are determined at run-time.

Link quality metrics must be collected both at the MN and the APs. We embed link quality information (Packet Reception Ratio) of the APs in the IEEE 802.15.4 beacon payload for the MN to perform all necessary F-LQE computations (i.e. stability factor and asymmetry level) at the mobile side.

We intend to use a fixed WSN deployment of TelosB and MICAz motes together with nodes attached to mobile robots. To verify the feasibility of the proposed algorithm under various conditions, the mobile node will be moved at different speeds and in different directions while APs are experiencing traffic load fluctuations.

We will then evaluate smart-HOP under different network topology settings, namely changing the number and location of MNs and APs. In order to facilitate the generation of different link qualities between MNs and the APs, we will generate precise and adjustable interference to affect specific APs.

IV. RELATED WORK

There are two major families of handoff decision for wireless networks. The most common models are the standard techniques, which are mainly used in cellular, wireless mesh, WLAN, and 6LoWPAN networks (e.g. [4]). These protocols build upon the mobile IPv6 mobility management mechanism. The handoff procedure in mobile IPv6 is initiated by predicting node mobility according to RSS information. The use of the mobile IPv6 technique (purely based on RSS and imposing high packet overhead) is not adequate for WSNs.

Besides the techniques described above, several heuristic models, considering various parameters, have also been reported to handle handoff in wireless protocols. They are widely classified into five groups of dynamic programming [5], pattern recognition [6], prediction-based approach [7], evolutionary algorithm [8], and artificial intelligence [9]. The use of artificial intelligence requires less computational time compared to the other, thus seems adequate for WSNs. In this heuristic group, the fuzzy logic approach describes a system intuitively using linguistic variables. By considering WSN constraints such as limited battery power and the imprecise characteristics of the radio link, the use of fuzzy logic rules seems to be the most efficient heuristic model, and hence, it is the one pursued in our study.

V. CONCLUSION

This poster abstract presents ongoing work on the implementation of smart-HOP, a reliable handoff procedure for supporting mobility in WSNs. We outlined a two-phase procedure to take handoff decisions according to several relevant metrics and combining them using fuzzy logic. The algorithm is implemented in TinyOS and is being tuned to get optimal results. We are planning to implement and integrate smart-HOP in standard WSN protocols such as ZigBee and 6LoWPAN, to demonstrate its feasibility and efficiency.

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Poster Abstract: An Open-Source IEEE 802.15.4 MAC Implementation for TinyOS 2.1

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***Abstract*—The IEEE 802.15.4 standard has been attracting strong interest, but in the academic community so far very little research related to the IEEE 802.15.4 MAC has been evaluated experimentally, with real hardware under realistic conditions. This is mainly due to the fact that a stable, open-source IEEE 802.15.4 MAC implementation has been unavailable for a long time. Vendor-specific implementations are often proprietary, cover the standard only partially or are customized to a specific platform. Our work aims at closing this gap: we present our open-source, platform-independent IEEE 802.15.4-2006 MAC implementation, which has been published as a part of the 2.1 release of the TinyOS operating system.**

I. Introduction

The IEEE 802.15.4 standard [1] covers the physical layer (PHY) and the medium access control sublayer (MAC) in the ISO-OSI layered network model. The goal is to enable wireless connectivity between "ultra-low complexity, ultra-low cost, ultra-low power consumption, and low data rate" devices in wireless personal area networks (WPAN). Since its first ratification in 2003 the standard has quickly been adopted by several other wireless communication standards, such as ZigBee, IETF 6LowPAN and WirelessHART. Yet, in contrast to the many analytical and simulation studies of the 802.15.4 MAC so far very little research related to the 802.15.4 MAC (and protocols on top/using it) has been evaluated experimentally, with real hardware under realistic conditions. While the first steps in wireless protocol design can often be made with the help of analytical and simulation models, the last steps, however, require the use of real hardware, in realistic environmental conditions and experimental setups.

The lack of empirical investigations is mostly due to the fact that available open-source 802.15.4 MAC implementations (e.g. [2]) have limitations and/or stability problems and most commercial implementations are proprietary, cover the standard only partially or are customized to the vendor-specific platforms. To close this gap, we have implemented an open-source platform-independent IEEE 802.15.4-2006 MAC implementation and published the core as part of the 2.1 release of the TinyOS operating system [6]. Our design is based on three goals:

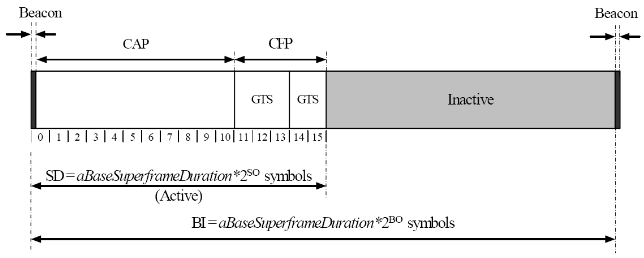

Fig. 1. IEEE 802.15.4 superframe structure (source: [1])

- **Platform Independence:** the MAC is decoupled from a particular mote platform and can be used on any platform that provides a compatible TinyOS 2 execution environment, namely, timers that satisfy the precision and accuracy requirements specified in the standard and a suitable radio chip (PHY) abstraction.
- **Modularity:** existing implementations of the 802.15.4 MAC/PHY can result in code sizes of up to 37.3 kB [3]. Given that a typical mote platform may have 48 kB of program memory and 10 kB of RAM, the implementation should follow a modular design that allows to select only the subset of the MAC functionality required by the particular application. We achieve modularity by mapping the MAC services to a set of software components and allow the user to select a suitable subset at compile time.
- **Extensibility:** To support the research community in evaluating MAC extensions and facilitate the transition to a future MAC revision our design is kept extensible: the component-based design in conjunction with an advanced radio arbitration mechanism allows flexible integration of new components and/or modification of the MAC superframe structure.

In the following we will provide a brief summary of the main 802.15.4 MAC functions and detail the status of our implementation, which consists of a core and the (optional) GTS and security services. For more details on the core implementation please refer also to [4].

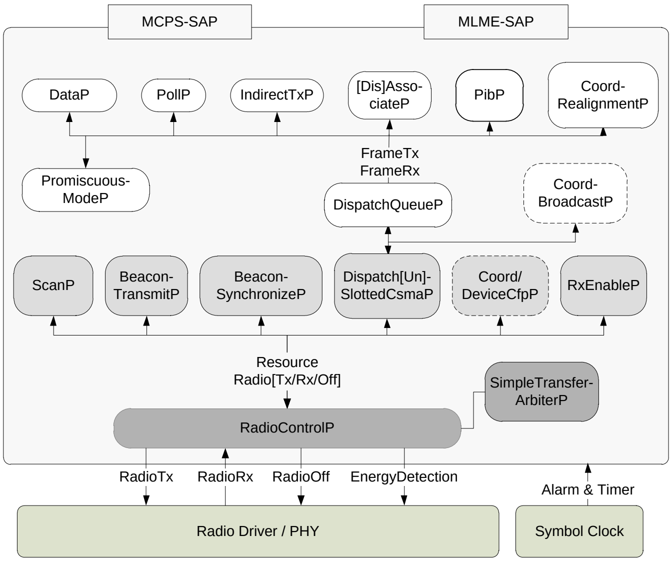

Fig. 2. Architecture Overview

II. The IEEE 802.15.4 MAC

The MAC sublayer supports different configurations and operating modes. One commonality is that every network has exactly one PAN coordinator, which is the primary controller responsible for PAN identifier and device address assignment and device synchronization. 802.15.4 PANs can either be nonbeacon-enabled or beacon-enabled. In a nonbeacon-enabled PAN frames are transmitted according to an unslotted CSMA-CA algorithm (nonpersistent CSMA): if the channel is detected idle the transmission can start immediately otherwise the device defers the transmission for a random time period uniformly drawn from an exponentially increasing backoff interval.

In beacon-enabled mode coordinators periodically transmit beacons which mark the beginning of a superframe as depicted in Figure 1. A beacon carries information about pending data and the current network configuration. Immediately after the beacon follows the contention access period (CAP). During the CAP devices use a slotted variant of the CSMA-CA algorithm: a device must sense an idle channel twice before it may transmit and both, channel sensing and transmission must be performed on backoff slot boundaries. The CAP is followed by an optional contention-free period (CFP), which is portioned in so-called guaranteed time slots (GTS). GTSs are allocated dynamically and the corresponding time interval can be used exclusively to transmit packets in a contention-free fashion. The CFP is followed by an optional inactive period in which all nodes can sleep to preserve energy and achieve low duty cycles.

III. Architecture & Code Status

Our architecture covers a platform independent 802.15.4 MAC implementation and defines the interfaces towards the layer below (PHY / radio driver) and above (to the network layer). Fig. 2 shows an overview of our implementation, its main components and the interfaces that are used to exchange MAC frames between them. For the purpose of explanation the architecture can be subdivided into three sublayers: the components on the top level (white boxes) implement several MAC data and management services, for example, PAN association or requesting (polling) data from a coordinator. These services typically utilize data and command frame transmission and reception and are connected to a component that prepares the channel access according to the (un)slotted CSMA-CA algorithm (`Dispatch[Un]SlottedCsmaP`). Most of the components on the second level (light gray boxes) are responsible for the other portions of a superframe in beacon-enabled mode, e.g. beacon transmission and tracking. The third level (dark gray boxes) manages the access to the radio driver: it controls which of the components is allowed to access the radio at what point in time based on an extended TinyOS 2 resource arbiter. The design and implementation of the radio driver (PHY) is platform/chip specific and thus not part of the architecture.

Our MAC implementation includes almost the entire functionality described in the 802.15.4-2006 specification including the optional GTS and security services. It consists of 26 core components with a total of approx. 8000 “Physical Source Lines Of Code” [5]. It is available online [6] as part of the TinyOS 2 core.

The implementation is currently available for the TelosB and micaZ platform. However, it can be ported to other platforms with little effort: a new platform must only (1) include a radio driver that provides the interfaces required by our MAC implementation; (2) provide TinyOS `Alarm` and `Timer` interfaces with a precision of a 802.15.4 symbol (62.5 kHz for the 2.4 GHz band) and an accuracy of ± 40 ppm; and (3) provide a TinyOS configuration component that connects (“wires”) our platform independent MAC implementation to the platform specific timer subsystem and radio driver.

Acknowledgment

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Poster Abstract: Smart Localization for Wireless Sensor Networks

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***Abstract*—In a system formed by hundreds of sensors deployed in a huge area, it is important to know their whereabouts. The position of a fixed sensor can be obtained the moment it is deployed. However, with mobile devices, it is necessary to implement a localization technique in these devices.**

This paper describes a novel range-free localization technique, focused on the reduction of energy consumption on mobile devices, called LIS (Localization Based on Intelligent System). This technique is based on fuzzy logic processing, with the objective of estimating the location of sensors according to the knowledge of the position of some reference nodes.

I. Introduction

WSN has been widely used in many areas [1]. In some applications the information gathered from the nodes is irrelevant without the knowledge of the associated position, for example in wildfire tracking [2]. In other applications the information required is the position itself [3].

The localization algorithms presented in the literature can be classified in two categories:

- **Range-Based:** These techniques estimate, point-to-point, the distance between all the nodes. With this information, using techniques such as triangulation, the absolute position of the non-anchor nodes can be estimated. Generally, these techniques require additional hardware. The most common ones are Received Signal Strength Indication (RSSI) [4], Time Of Arrival (TOA) [5] and Angle Of Arrival (AOA) [6].
- **Range-Free:** In this cases, the position of non-anchor nodes is obtaining according to implicit information provided by anchor nodes, usually based on messages exchanged, commonly called beacons. This information is usually made up of different aspects, such as radio coverage membership or number of hops between devices. The most common ones are Centroid (CL) [7] and DV-Hop [8].

II. LIS Algorithm

LIS is a range-free technique that determines the localization using a fuzzy system. The inputs of the fuzzy system are the RSSI measurements related to the non-anchor node. These RSSI values are measured once on anchor nodes that received a beacon sent from a non-anchor node. This fuzzy system offers a robust behaviour versus the noise. LIS estimates the position with the combination of two added algorithms, a distributed algorithm executed on every anchor node, and a centralized algorithm executed on the base station. LIS is composed of four steps, which are listed on table I.

Step	Description
Step 0:	Anchor nodes wait for non-anchor node beacons.
Step 1:	Non-anchor node sends a beacon.
Step 2:	Anchor nodes on the coverage area of the non-anchor node execute the distributed processing.
Step 3:	Anchor nodes send its partial solution to the Base station, where the estimated position based on the centralized processing is determined.

TABLE I
Steps of LIS algorithm.

RSSI node	RSSI Neighbours	Output
High.	All medium.	High
Low.	All low.	Low
Medium.	All medium.	High
Medium.	All low.	Low
High.	All high.	Medium
Medium.	Medium in current sector. Low in the rest.	High
Medium.	High in any sector except the current one. Low in the rest.	Low
High.	High in a neighbour of the current sector. Low in the rest.	Medium
High.	High in a neighbour, except on the current sector. Low in the rest.	Low
Medium.	Medium in a neighbour of the current sector. Low in the rest.	Medium
Medium.	Medium in a neighbour, except on the current sector. Low in the rest.	Low

TABLE II
Rules of the inference engine.

Localization starts when a non-anchor node sends a beacon (fig. 1.a). In order to save power energy, non-anchor nodes usually hibernate except on beacon transmissions.

A. Distributed Processing

According to the steps described on table I, once an anchor node receives a beacon, it estimates the position of the non-anchor node. These nodes using an algorithm which distribute the power consumption of the computation over the network. The area where the non-anchor node could be localized with a certain probability is called representative area.

This algorithm is based on a Mandani's fuzzy system distributed on every anchor node of the network. The base of rules are summed up on table II. These rules are a trade-off obtained by simulations between precision and noise immunity. This system uses a centroid concresor.

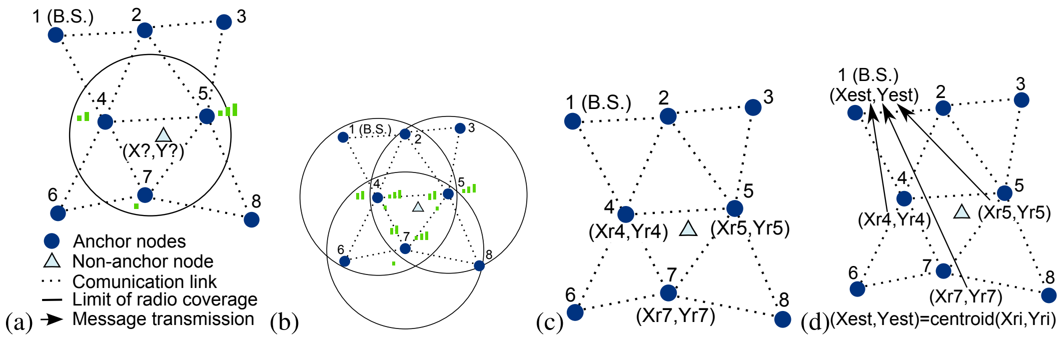

Fig. 1. Steps of LIS algorithm.

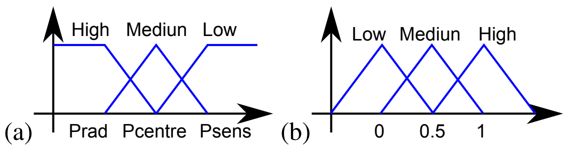

Fig. 2. Fuzzy sets. a) Imputs. b) Outputs.

What we call sector is the minimum area formed by three neighbours. An anchor node must execute the algorithm once per every sector.

Every node that receives a beacon measures the RSSI. Then these nodes send a broadcast message to their neighbours with its measurement (fig. 1.b), elaborating a table with this information. Every RSSI on the table is an input of the fuzzy system. These inputs have defined three fuzzy sets which represent High, Medium, and Low RSSI (Fig. 2.a).

The system offers an output for every sector. This output consists of a value on 0 to 1 range, where 0 represents the device that is not on the actual sector. It is represented on figure 2.b. According to this information, the anchor node evaluates the representative area with the union of one or various sectors that had a high output value of the fuzzy algorithm (fig. 1.c). This information is sent to the base station to calculate the estimated position (fig. 1.d). If all of the output of the fuzzy are low, the system send no message to the base station, and consequently saving power energy. This effect is specially important in extended networks, where the cost to redirect messages to a base station is generally high.

B. Centralized Processing

In the base station all the partial solutions are added. This process is called a centralized algorithm. It is made up by the next steps:

- Base station waits to receive a partial solution. When it is received, it is stored on a table and a timer is set.
- while the timer is running, all the partial solutions that receive the base station are stored on the table.
- When the timer is fired, the system combines all the partial results calculating the centroid of the solutions stored on the table.

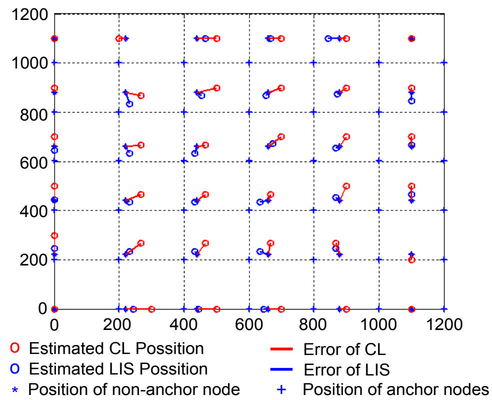

Fig. 3. Position error of CL algorithm and LIS algorithm.

III. Conclusions

LIS is presented in this poster. LIS has been compared to the CL algorithm, obtaining less localization errors in the simulations. As an example, figure 3 shows the absolute error versus the position.

LIS does not need a very high computation requisite or an extensive use of radio.

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Poster Abstract: Wireless Vibration Sensing Solution

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***Abstract*—We will present the design of a novel end-to-end wireless vibration sensing solution for continuously monitoring and analyzing seismic vibrations with low-cost sensor nodes and forwarding the computed information via relay nodes and a gateway to a monitoring application executed on a mobile handheld device. The sensed vibration signals are analyzed according to the DIN 4150-3 norm. All network nodes are battery-powered and equipped with a low-power radio transceiver. The nodes communicate with each other by executing a power-efficient protocol stack, which provides all functions to operate the wireless sensor network and uses a publish/subscribe messaging protocol for the communication between the sensor nodes and backend application. Results obtained in field tests show that the prototyped wireless sensor network offers an excellent performance in terms of power efficiency.**

I. Introduction

Seismic vibrations caused by earthquakes and ground drilling activities have to be continuously monitored and analyzed to detect potentially harmful vibrations for infrastructure buildings. To this end, we propose to deploy an advanced low-power wireless sensor network (WSN) in the area surrounding the building that comprises vibration sensor devices, relay nodes, and gateways to connect the WSN to a backbone network (see Fig. 1). The low-cost, battery-powered vibration sensor nodes are positioned at various geographic locations close to the foundation of the building. Each node measures the vibration acceleration and analyzes its measurement by computing the maximum amplitude and dominant frequency of the vibration velocity. If a computed value exceeds the threshold value given by DIN 4150-3, an alarm is triggered. To continuously trace the computed parameter values and to take the right action in case of an alarm, the retrieved vibration data and alarm signals can be forwarded from the sensors to a vibration monitoring application that resides in the demo on a handheld device attached to a mobile communication network. Efficient forwarding is achieved by using a novel protocol stack that executes all WSN functions and applies the advanced publish/subscribe messaging protocol MQTT-S [1] for communicating between sensors and application.

II. Wireless Sensor Node

Fig. 2 shows the main components of a wireless sensor node. It comprises the sensing and signal-processing module, the alarm detector, memory, and the radio networking module. The sensing functions and detector are always active for continuously monitoring vibrations, whereas the radio functions of the sensor and relay nodes are periodically put asleep to minimize energy consumption. The *sensing module* carries a MEMS-based 3-axis accelerometer, a multi-channel 16-bit ADC with a sampling rate of 2.048 kHz, 8 Mb of NVRAM, and a low-power FPGA to continuously analyze the vibration acceleration signals monitored in consecutive time windows of size 1 s. It computes the maximum absolute value $|v_i|_{\max}$ of the vibration velocity and its associated timestamp t_i, and the velocity spectrum with a 256-point FFT to obtain the dominant frequency f_i for each axis $i = x$, y, and z. The *alarm detector* compares the parameter values $|v_i|_{\max}$ with a threshold value $v_{th}(f_i)$ that depends on the building type and is given by the function $v_{th}(f)$ shown in Fig. 3. If $|v_i|_{\max} < v_{th}(f_i)$ for each i, no harmful vibration is detected; in this case, the parameter values $|v_i|_{\max}$, t_i, and f_i are locally stored and transmitted to the monitoring application as continuous data at the next time when the WSN becomes active. If $|v_i|_{\max} \geq v_{th}(f_i)$ for any i, a vibration alarm is triggered by additionally sending an alarm indicator to the application, which can issue a request to this sensing module for uploading all acceleration samples $\{a_i\}$ monitored in the corresponding time window as exception data. The *radio networking module* is implemented with an IRIS Mote radio and processor platform. The physical layer of the radio transceiver is compatible with the IEEE 802.15.4 standard and operates in the 2.4 GHz ISM frequency band with a data rate of 256 kbps. The controller is an 8-bit RISC processor, on which the operating system Mote Runner [2] is executed which constitutes the platform for executing the networking stack.

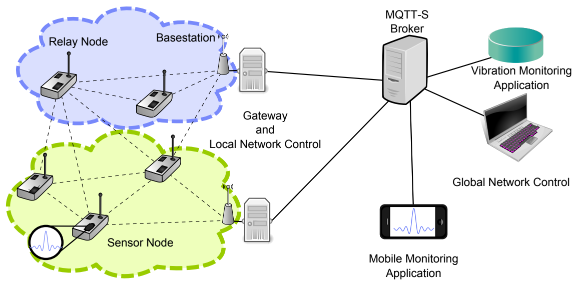

Fig. 1. Overall architecture of wireless vibration sensor solution.

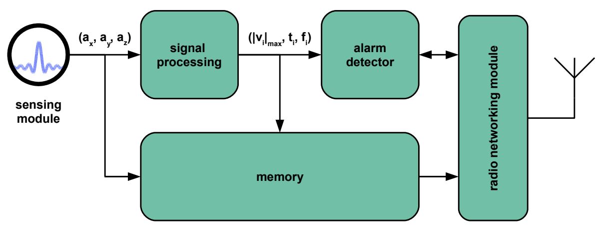

Fig. 2. Architecture of wireless sensor node with sensing capabilities.

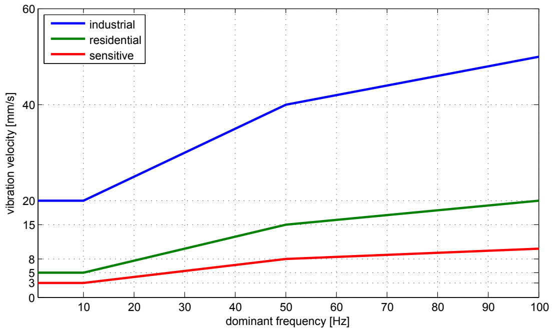

Fig. 3. Vibration velocity threshold function (DIN 4150-3).

III. Network Solution

Fig. 1 shows the architecture of the proposed wireless vibration sensing solution that encompasses various network protocols, middleware functions, and application software modules for communicating between the sensor nodes and the backend. On the sensor nodes, the vibration-sensing application is executed that uses the MQTT-S messaging middleware to transmit continuous and exception data packets via the *gateway* (GW) and MQTT-S *broker* to the vibration-monitoring application. This open, topic-based messaging protocol is very attractive for the envisioned application because it provides data-centric decoupling of the publishers and subscribers. To transmit packets hop-by-hop from the sensor nodes to the GW, a novel power-efficient WSN stack is run on all wireless nodes and the *basestation* (BS), which are controlled and managed by the *network cluster control (NCC)*. In case of a large number of nodes, the WSN can be further split into multiple clusters that are centrally controlled by the *global network control*.

To avoid wasting energy in the WSN nodes and to reduce the control overhead, a centralized hierarchical architecture with a time division multiple access (TDMA) protocol is used. This ensures that only one sender and one or several associated receivers are accessing the wireless medium at any point in time. As the NCC knows the overall topology of the network, it can centrally compute the required routing information and the corresponding TDMA schedule for all nodes. Each wireless node is operated in either management or synchronized mode. The management mode is used for network setup and configuration. In the synchronized mode, all wireless nodes follow the TDMA schedule provided by the NCC to switch their radio transceivers and controllers on for sending and receiving, and off for sleeping.

IV. Implementation Results

The wireless vibration sensing solution has been prototyped to demonstrate its reliable operation in lab and field tests.

Fig. 4 shows some components of the wireless vibration sensor solution. The wireless sensor node comprises the sensor board with a low-power FPGA and NVRAM, and the radio board with the IRIS mote and microcontroller. The vibration sensing processing algorithms have been programmed into an IGLOO AGL 1000 FPGA. As the NVRAM has a size of 8 Mb, it can temporarily store continuous data packets for 6.6 h and exception data packets for 64 s. The vibration-sensing application, the MQTT-S client, the WSN stack, and the operating system are executed on the controller and require 6 kB RAM and 45 kB flash memory.

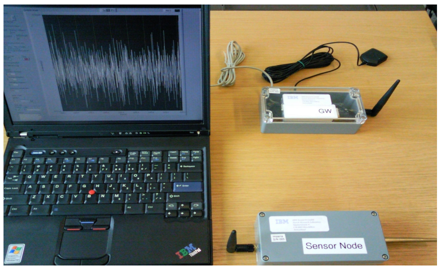

Fig. 4. Components of wireless vibration sensor solution.

The networking solution was implemented at an industrial plant to continuously monitor vibration events under realistic conditions. The network comprised 9 sensor nodes, 29 relay nodes, and one BS. The distances between neighbor nodes varied between 30 and 300 m. After installing all nodes and setting-up the WSN, the network was operated in synchronized mode for several days. During these tests, the sensor nodes successfully transmitted about 1 million continuous data packets via the WSN to the BS. Moreover, the nodes detected more than 1000 artificially generated exception events and reliably uploaded 400 of them to the BS for signal inspection.

To determine the lifetime of the network, the power consumption of the sensor and relay nodes was computed based on the TDMA schedule monitored in the field tests. According to this schedule, both types of nodes are alternatingly operated in the awake and sleep state with an average duty cycle of 1%. This leads to an expected lifetime of more than 6 months, if only relay nodes are considered with a battery capacity of 3 Ah, and a current draw of 0.2 mA in the sleep and 19.52 mA in the awake state. Similarly, it could be shown that a sensor node with a battery capacity of 19 Ah can reach a maximum lifetime of 76 days, if it draws a current of 10.3 mA in the sleep and 28.66 mA in the awake state.

V. Conclusions

We presented the implementation of a novel wireless sensor network solution for continuously monitoring seismic vibrations with accelerometers, pre-processing the sensed signals according to DIN 4150-3, and forwarding the retrieved information with low-cost relay nodes to a vibration monitoring application executed on a handheld device attached to a mobile communication network. As the data are pre-processed on the sensor nodes and a novel centrally configured TDMA-based network architecture with sleep-mode support is applied, a WSN lifetime of several month can be obtained.

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Poster Abstract: Wireless Network of Local Stimulators and Sensors for People with Neurological Disabilities

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Abstract—**Neurological lesions can result in weakness/loss of one or multiple limb movement. Functional Electrical Stimulation (FES) is used to improve/regain mobility in some conditions. However, FES users might experience difficulties using these devices due to wires. This work investigates the feasibility of a wireless FES system which consists of a network of sensors and stimulation units.**

I. Introduction

Each year, hundreds of thousands people are affected by a neurological related disease or lesion causing some of them partial or complete dysfunction of one or more limbs. Functional Electrical Stimulation (FES) techniques have shown a significant improvement in mobility and function to many of these neurological patients. FES is an artificial technique of stimulating motor nerves to cause contraction of muscles. Depending on the extent of the injury and complexity of the movement disorder, many sensors and channels of stimulation might be necessary to improve movement. However, this could result in a complex multi-channel stimulator which is often rejected by the user due to the size, complexity and cosmesis. These issues can be addressed to some extent by using distributed systems that split the complex function of the multi-channel stimulator into multiple local stimulators around the body. On the other hand, using conventional techniques will result in a complex network of wires making it difficult and inconvenient for the wearer.

The obvious solution is to replace wires with a wireless network where each node from the network communicates with one or multiple nodes, and is small enough to be placed where needed. As a consequence of the inherent safety implications in this application, any body area wireless network of this type should approach the reliability of the existing wired system and achieve acceptable latencies. This research involves choosing the wireless technology that can ensure reliability, short latency and low power consumption in all environments and conditions, and investigating the most efficient network topology that offers the best performance for this application. In addition, the research will investigate the use of intelligent sensors in order to minimise their number and hence improve the efficiency of the system.

II. Aims

The aim of this poster is to present the research work being done to investigate the feasibility of a wireless network of stimulators and sensors for FES applications. It explains the requirements for the wireless system in terms of reliability, latency, and power consumption. This research will lead to the design of a new generation of FES systems that are convenient for use and expandable so that new sensors or stimulators can be easily added.

This project is motivated by the findings of surveys conducted by Taylor et al. [1] [2] and feedback from clinicians in the National Clinical FES Centre (Salisbury District Hospital, Salisbury, UK). Taylor et al. discuss feedback obtained from patients using the FES system ODFS III (Odstock Medical Ltd, Salisbury, UK). In particular, it was noted that patients had difficulty dressing and undressing while wearing the device. Moreover they found the device occasionally unreliable, which was identified as due to breaking or inadvertent unplugging of wired connections. This suggested that a wireless network between the sensors and the stimulator units would improve overall FES system performance.

III. Methods

A key initial step in the project was to identify the wireless technology to be used as a wireless network. This system had to satisfy the following requirements necessary to be used for FES applications:

A. *Wireless requirements*

Reliability

Reliability is the most important requirement in this application since it affects directly the safety of the FES device. The reliability of this system should at least approach that of a wired system. Maximising reliability is essential to ensuring patient safety and confidence in any FES system.

Latency

FES devices rely on data from sensors to activate and inhibit stimulation. Therefore, any delay in receiving data from sensors will reflect on stimulation timing. This necessitates that the wireless system needs to have minimum latency.

Power consumption

All nodes in this system are battery powered, therefore low power consumption is essential to give the patient at least one day of battery life. Ideally it would give a battery life of six months which is usually the period between visits to the clinic.

B. *Prototype*

In order to verify these requirements a prototype wireless FES system was made. There are two types of nodes in this system; sensory node and stimulation node. Sensory nodes use accelerometers, gyroscopes, or pressure sensors to detect events in the gait and/or arm movement of the user. Sensors process data locally and transmit events to one or multiple stimulation nodes, depending on the required information for each stimulation channel. Stimulation nodes make decision on stimulation output depending on the received messages from sensors and/or other stimulation nodes.

A series of experiments were designed to investigate the performances of the wireless system.

This work also involved investigating the possible network topologies best suited to this application. This was done by comparing the advantages and disadvantages of each topology and concluding which is the best compromise in terms of reliability and power consumption.

Each node includes a microcontroller (PIC 18LF14K22, Microchip, USA) and a ZigBee module (ETRX3, Telegesis, UK), and is battery powered.

IV. Results

The available wireless technologies that can be used for this application are discussed by Hoa et al. [3]. ZigBee is designed to be a robust communication system that can handle interference. Moreover, it is designed to be low power and can run on batteries. In addition to this the cost of ZigBee modules is reasonably low. The disadvantage of ZigBee compared to other personal network area networks is the relatively low bit rate of 250kbps (in the 2.4GHz band).

ZigBee can work in different network topology configurations; star, tree, or mesh topologies. Although mesh topology ensures the highest reliability, it results in much higher power consumption than the other configurations. Moreover, if a message is routed through other nodes, it will increase the latency. Star topology on the other hand, favours power consumption since nodes communicate only with the coordinator and do not route any messages. Thus all nodes except the coordinator can be Reduced Function Devices (RFD) which do not require continuous operational power. However, enabling power conservation results in an increased latency compared to the situation where a message is sent directly from one node to another. Tree topology is a compromise between the two. Devices that require communication with multiple nodes can be made Full Function Devices (FFD) and nodes that need to communicate with only one node can be made RFD to save power.

The wireless prototype was tested both in the laboratory and under real world operational conditions to investigate the behaviour of the system. Experiment on the prototype showed high reliability, acceptable latency and power consumption. The findings from these experiments are being analysed.

V. Discussion and Conclusion

ZigBee was chosen to be used for this application as it is the most reliable Personal Area Network (PAN) commercially available and lower in cost. The relatively low bit rate is acceptable due to the nature of this application which does not require streaming data. A proprietary wireless PAN technology could be designed to perform even better for this application by reducing latency and power consumption. However, the aim of this research is not to design a new wireless protocol but adapt a commercially available technology to FES applications.

Although ZigBee uses the 2.4GHz band which is unable to penetrate the human body easily, research by Valdastri et al. [4] showed that using implants communicating via ZigBee modules was feasible.

By comparing the advantages and disadvantages of each network topology that ZigBee can handle, tree topology appears the best configuration for this application. This is due to the flexibility that it offers in terms of the type of device and direction of communication between nodes. For instance, a sensory node can be made RFD and made to communicate to a stimulator node (FFD) that relies on the data from this sensor to apply stimulation. This node can also forward messages received to other stimulator nodes as required.

Initial results of experiments on reliability, latency and power consumption of the wireless prototype are encouraging and show the feasibility of a wireless FES system.

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Poster Abstract: Network Coding with Limited Overhearing

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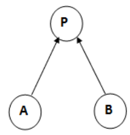
***Abstract*— The two key benefits of network coding are increased reliability and throughput. Most network coding approaches for wireless networks rely on overhearing neighboring transmissions. Overhearing in sensor networks, however, is not energy-efficient. In this paper, we extend GinMAC, a state-of-the-art MAC protocol, applying network coding with limited overhearing. Our approach reduces the delay allocating less retransmission slots. Our results show that network coding with limited overhearing reduces the power consumption of GinMAC while maintaining the desired level of reliability.**

I. Introduction

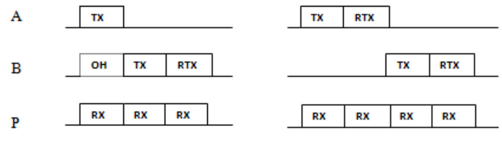
Network Coding was introduced by Ahlswede et al. [1], proving that it can increase the multicast capacity of network. Since then, it has been investigated in several different networked scenarios which demand different traffic characteristics. Especially for wireless networks network coding has become a favorable tool for throughput enhancements and reliability improvements. Many subsequent studies on wireless network coding were trying to exploit the broadcasting nature of wireless medium. Most of them, however, assume free overhearing of neighboring transmissions.

The assumption of free overhearing is unreasonable in some environments. Wireless Sensor Networks (WSN) is one such environment where nodes having stringent energy requirements. More specifically, due to the fact that idle listening consumes the largest portion of radio communication energy consumption, network coding with overhearing becomes unrealistic in WSNs. Most previous research has focused on theoretical aspects of applying network coding to sensor networks while recently researchers have also studied more practical approaches, employing network coding in state-of-the-art WSN protocols [2] and [3]. The latter considers the data dissemination protocol deluge [4] and proposes a network coded variant, while the former improves the reliability of collection tree protocol [5]. These approaches have not explicitly limited and evaluated the cost of overhearing and idle listening.

In this paper we apply network coding in GinMAC, a Time Division Multiple Access (TDMA) based Medium Access Control protocol [6]. A limited amount of overhearing is incorporated in to the TDMA schedule. We investigate the impact of this strategy in a data gathering protocol with controlled delay and reliability guarantees based on GinMAC. Furthermore we analyze trade off between energy consumption and performance gains.



(a) Sub Tree



(b) TDMA Schedule

Fig. 1: Left: Binary Tree Topology; Right: TDMA Schedules with(left) and without(right) Network Coding

II. Design and Implementation

GinMAC is a single channel state-of-the-art TDMA-based MAC layer for performance-controlled sensor networks [6]. GinMAC uses an offline process to dimension a network before deployment. The heart of the dimensioned network is a TDMA schedule with an epoch length consisting of E slots. There are three types of slots, namely $basic$ slots for transmission (TX) and reception (RX), $additional$ slots for retransmissions (RTX) to increase reliability and $unused$ slots to decrease the duty cycle. Furthermore, leaving $unused$ slots enables BurstProbes, a novel mechanism for estimating the number of required retransmission slots and a tool to debug time-critical data delivery. The schedule determines latency, power consumption and reliability. The latter is increased by adding more retransmission slots.

In GinMAC, network coding can reduce the length of an epoch E which helps to reduce delay and improve the maximum throughput for a fixed number of transmitting sensors. To achieve this, the TDMA schedule is reorganized incorporating a limited amount of overhearing (OH) followed by rearranged retransmission slots. A given node overhears its neighboring transmission once in an epoch, since it knows when a transmission is scheduled for its neighbor. Since GinMAC assumes a deployment where nodes' locations are carefully selected, we can assume overhearing is possible. According to the TDMA schedule, the system maintains a data collection tree topology, so that each node knows its parent node. A comparative illustration of TDMA schedules with and without network coding is depicted in Figure 1. For the sake of simplicity we consider a simple tree of three nodes.

Figure 1b illustrates the TDMA schedule for both approaches. In GINSENG it allocates one retransmission slot for each child node whereas in Network Coding it only allocates one retransmission slot for both nodes. Network coding is applied in the retransmission slot, where it sends a coded packet after performing binary XOR operation on its own packet and the overheard packet of the neighbor. This allows the receiver to recover one packet loss with a simple XOR operation. This saves one transmission slot from overall schedule compared to GinMAC with basic retransmissions, while paying an additional listening slot. Furthermore, our network coding approach does not rely on acknowledgements from the receiver when retransmitting as GinMAC.

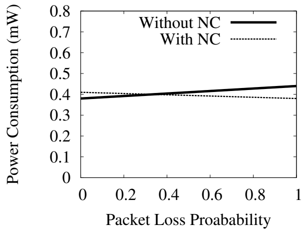
In addition to including overhearing in GinMAC schedule, we implement coding and decoding of packets in the MAC layer. We include an additional header field in the GinMAC frame to communicate the details of the coded packets to the receiver to recover the lost packet, which however adds a negligible overhead.

III. Evaluation

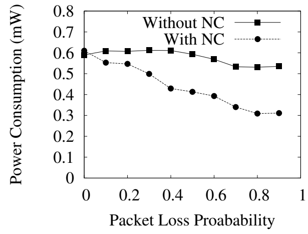
We analyze performance gains and trade-offs considering the binary tree with three nodes illustrated in Figure 1a, since both GinMAC and network coding approach recover errors in a hop by hop fashion. As the key contribution of our approach suggests limited amount of overhearing, power consumption becomes a primary performance metric. Furthermore, we measure the impact on reliability as the packet reception rate at the parent. We consider a simple analytical model with a constant packet loss probability of p in each link, with independent packet losses. The average power consumption for basic GinMAC with the TDMA schedule illustrated in Figure 1a is $2(1+p)E_{tx}+4E_{rx}$, whereas with network coding it becomes $(3-p)E_{tx}+4E_{rx}$ assuming constant power for transmission and listening. Accordingly the packet reception probability at the parent becomes $1-p^2$ for GinMAC while for network coding being $(1-p)(1+p(1-p)^2)$.

We use the COOJA simulator to simulate an environment monitoring application for a three node binary tree to experimentally verify the analytical results. We simulate GinMAC with and without network coding. We measure the power consumption using Contiki's software-based power profiler. Our results are shown in Figure 2. The experimental results show a decline in power consumption for both the approaches deviating from the analytical results. This is due to the difference of packet reception power consumptions between normal and erroneous packets which is assumed to be equal in the analytical model. Since network coding requires one less retransmission slot, it in turn reduces the average power consumption compared to the GinMAC, as our results show. Further, it shows a decline in power consumption when the packet loss probability is high, which is again due to having common retransmission slot for both child nodes. Even though an additional overhead incurs for overhearing, it balances out with the reduced cost of retransmission.

In Figure 3, the packet reception rate is plotted against the packet loss probability. This shows approximately similar error recovery capabilities in both GinMAC and network coded version of it. These results imply the introduction of overhearing

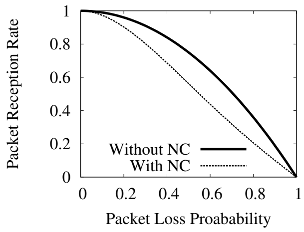


(a) Analytical Results

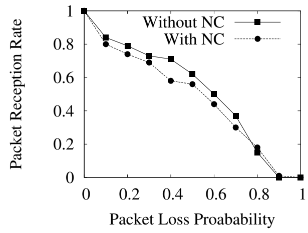


(b) Experimental Results

Fig. 2: Power Consumption Vs Packet Loss Probability



(a) Analytical Results



(b) Experimental Results

Fig. 3: Packet Reception Rate Vs Packet Loss Probability

followed by a simple network coding scheme can compress the TDMA schedule reducing the power consumption while trading off with reliability.

IV. Conclusions

We apply Network Coding with the limited amount of overhearing introduced in GinMAC, a state-of-the-art TDMA based MAC protocol. We apply Network Coding in GINMAC, a state of the art TDMA based MAC protocol introducing a limited amount of overhearing. Analytical and Simulation results verify that this approach reduces the delay and power consumption while maintaining a desired level of reliability.

Acknowledgments

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Poster Abstract: A Sensor Network for Ad-Hoc Person Localization and Area Monitoring

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***Abstract*—In this paper we outline a method for person localization and area monitoring in previously unknown environments via wireless sensor networks (WSN). In scenarios where information on the whereabouts of action forces can help the operation commander to logistically coordinate the operation, we propose to deploy an ad-hoc WSN. Stationary anchor nodes get an initial position estimation upon deployment from a pedestrian dead reckoning unit (PDR) or GPS (if available). It is then possible to localize mobile nodes carried by following action forces and to monitor the area of interest. The position and monitoring data are transported by the multi-hop WSN and visualized at a central data sink.**

I. Introduction

Mobile node localization in WSN has been a topic of interest for years and various concepts have been proposed for different application areas [1]. Applications can be found in mass-casualty events, in firefighter scenarios or also in the field of special forces. For example, if the liberation of victims in a hostage situation needs to be coordinated. If such an operation takes place in an outside area, person localization can be achieved by means of GPS, however, indoor scenarios or mixed in- and outdoor scenarios are more difficult to deal with. Especially if a seamless and real-time in- and outdoor localization is needed. One concept is to navigate by means of pedestrian dead reckoning (PDR), i.e. to estimate one's current position from a previously determined position and the current movement speed and direction. Inertial data can be obtained from an inertial navigation system (INS) and PDR can be employed whenever no GPS signal is available [2], [3]. Besides the principle problem with long-term stability of this approach due to sensor drift and inaccuracies, it is also not inherently possible to transport the determined position information to a central data sink for visualization. To solve these issues, we propose to implement a hybrid PDR/WSN ad-hoc localization system.

II. Intended Applications

The following scenario is considered: police forces arrive at a hostage situation. This situation goes on for some time (several hours or days) during which a constant surveillance of the area as well as a real-time localization of action forces would be desirable. To achieve this surveillance, an easy deployable WSN is brought out that allows the localization of persons equipped with on-body sensor nodes. These deployed anchor nodes get an initial position estimation upon deployment by means of a PDR unit or from GPS if a signal is available. Also, certain points of interest can be monitored by means of passive infrared (PIR) motion sensors or other sensors.

Fig. 1. Pedestrian dead reckoning unit with XSens MTI-g, LocNode sensor node, connection board and power supply.

III. State of the Art

Due to the integration of micro-electro-mechanical (MEMS) accelerometers and gyro sensors in most smart phones, the prices of these components have declined and the technology has been greatly improved recently. With this development, research interest in inertial measurement units (IMU) has increased strongly and there have been great improvements in the field of PDR and pedestrian INS. By far the most widespread concept in this context is the placement of an IMU on the shoe of a test person. Like this, the inevitable error in the distance estimation resulting from the double integration of the acceleration sensors can be coped with by re-calibrating the estimated velocity whenever the foot comes to rest on the ground (zero velocity update) [2]. Other approaches with different IMU positioning have also been proposed, e.g., on the hip [3]. However all INS can principally not provide long term stability without additional reference data.

On the other hand there has been a lot of research on various approaches to WSN localization [1]. Especially received signal strength (RSS) based schemes have been carefully evaluated under different conditions. In [4], the authors propose the MoteTrack system that aims at similar localization applications but requires a calibration procedure for a specific environment.

In this work we propose to integrate PDR with WSN localization for ad-hoc localization in previously unknown environments. A similar approach is presented in [5]. The authors demonstrate a hybrid localization scheme where an INS is aided by a WSN. However, this approach still requires map knowledge of the desired area before it can be put to use. The novelty of our work consists in use of PDR for position initialization of the anchor nodes upon deployment.

IV. Proposed System Design

In a set-up phase, anchor nodes are deployed in the area of interest by a person that is equipped with a combined sensor node / PDR unit. From this unit, the deployed nodes receive an initial position estimation upon deployment. If a GPS module is available and a fix can be obtained, this position is corrected during runtime. Once deployed, the anchor nodes broadcast their positions in regular intervals. Mobile on-body nodes receive these broadcasts and estimate their own position on-line. The PDR can use these broadcasts as reference data. The decentrally calculated positions are communicated through the network.

A. Hardware

For practicability reasons the concept to mount the IMU on the hip is preferred over the foot for the PDR node deployment (initial position estimation of anchor nodes). Fig. 1 shows the developed PDR unit sensor node. A sensor node (LocNode, in-house development) along with an XSens MTI-g IMU and a power supply is integrated into a robust plexiglass casing. This casing is designed to fit into a common belt pouch. In addition to 3-axis acceleration and gyro sensors, the MTI-g also provides a magnetometer, a barometer and a GPS receiver. The attitude calculation is done on an integrated DSP so that the sensor node's MCU can directly use this information for position estimation. A total of 70 sensor nodes, that can serve as anchor- or on-body nodes, are available to test the concept.

B. Software

For the ad-hoc network formation and multi-hop communication, the ZigBee network stack is used. A full mesh architecture is implemented to provide redundancy.

C. Position Estimation Approach

Fig. 2 shows the basic design of the implemented algorithm. All nodes basically run the same algorithm. The RSS to all nodes within communication range are measured, the corresponding distance is calculated from the log-distance path-loss model and the current position is calculated on-line by means of a Kalman filter. The system state $\vec{x}$ solely consists of the position $\vec{p}$ (upper part of Fig. 2).

One or more mobile nodes are used to deploy the network and additionally have an IMU available. The Kalman filter then gets an additional measurement input from the PDR calculation (lower part of Fig. 2). In this PDR calculation the pre-calculated attitude $\vec{\varphi}$ from the MTI-g internal DSP is directly used. The covered distance into this direction is calculated whenever a step is recognized from the 3D-acceleration dot product $\vec{a}^2$. The step length is estimated from the characteristic of the acceleration $\vec{a}$ with Weinberg's algorithm [6]. Additionally, a principal component analysis (PCA) is performed on the acceleration values to estimate the alignment of the IMU [3].

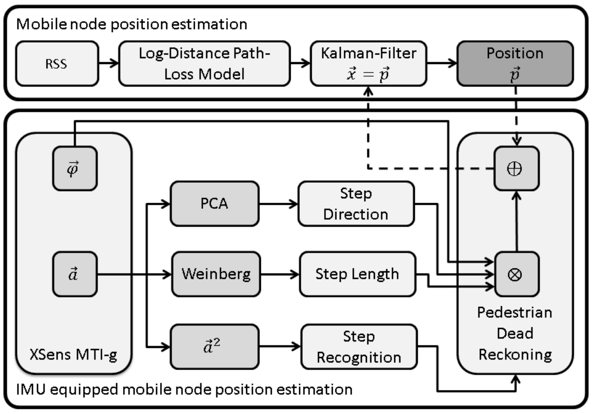

Fig. 2. Implemented algorithm: implemented on mobile nodes (upper part) and additional PDR calculation in IMU equipped nodes (lower part).

V. Conclusion and Future Work

At the current state of the development it can already be concluded that the proposed approach represents a good method to achieve person localization and monitoring in unknown environments. Experiments on PDR deployment and ranging based pedestrian tracking have been carried out and a framework has been designed and partially implemented. In the near future, we will further improve the different subsystems, solve implementation issues and investigate a decentral Kalman filter approach to improve the localization of the anchor node network once it has been deployed.

Acknowledgment

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Poster Abstract: Fuzzy Logic Based Framework for Adaptive Error Control to Ensure Reliable Communication for Indoor Sensor Network Applications

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***Abstract*— In most indoor environments, the channel statistics between low-power sensor nodes varies significantly with time due to operating equipments and motion of people in the surroundings. A framework incorporating fuzzy inference system is proposed to combat unreliability incurred in radio communication between sensor nodes due to temporal variation in link quality. The cascaded fuzzy logic is implemented which utilizes feedback information from the destination node to precisely characterize the indoor channel and then outputs an appropriate FEC (Forward Error Correction) for reliable packet transmission in dynamic environmental conditions. An extensive experimental analysis is carried out considering realistic indoor channel conditions and IEEE 802.15.4 compliant MicaZ node parameters. The performance results indicate the effectiveness of proposed framework.**

I. Introduction

Wireless sensor technology promises the ability to monitor an indoor environment, but the practical concerns of unreliable communication among resource-limited sensor nodes continue to lead to reluctance in their use [1]. In indoor environment, the signal components arriving from indirect and direct paths (if it exists) combine and produce a distorted version of the transmitted signal, resulting in a phenomenon known as multipath fading. Due to moving people and other obstacles, there are rapid and frequent transitions between Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS) conditions which cause uncertainty in reliable packet transmissions. Unfortunately, one can do little to eliminate multipath disturbances. However, if the multipath medium is well characterized, the transmitter and receiver can be designed to reduce the effect of these disturbances. Detailed characterization of radio propagation model is therefore a major requirement for successful design of the indoor communication system.

The application of Forward Error Correction (FEC) scheme ensures reliable communication at the cost of higher energy overheads due to transmission of redundant bits and increased decoding complexity. Employing same FEC scheme for all the nodes in a network could be a good choice, but not always especially when channel conditions are varying or the distances between the nodes are unequal which usually happens in an indoor environment. Therefore, for energy-efficient packet transmission under a wide range of error conditions, we propose a novel fuzzy logic based framework to precisely characterize the time-varying indoor environment and select appropriate FEC matching the underlying channel quality. The FEC scheme estimated by cascaded fuzzy inference system improves the transmission reliability with due respect to energy and complexity constraints of sensor hardware. Extensive numerical evaluations in realistic indoor channel model similar to [2] with MicaZ node parameters confirm the superior performance of the framework design over static FEC schemes.

II. Fuzzy Based Framework for Adaptive Error Control

The unstable link dynamics from indoor environments, together with energy constraints of nodes make reliable and efficient communication a challenging task. To address this issue, a hierarchical organization of two Fuzzy Logic Controllers (FLCs) that makes decision about appropriate FEC is shown in Fig. 1.

The primary (first) FLC is designed to estimate the strength of LOS/NLOS scenario by taking into account the LOS/NLOS indication and SNR, both approximated at the receiver. The membership functions (MFs) of input and output variables of first FLC are presented in Tables I-III. For Rician fading (LOS), the Bit Error Rate (BER) varies from 10^{-2} to 10^{-4} on increasing the SNR from -3dB to 9dB as compared to SNR range of 5dB to 25dB when Rayleigh fading (NLOS) is present. The MFs of SNR are chosen such that BER (Fig. 2(a)) obtained in a particular range could be distinguished. To determine the certainty of LOS/NLOS scenario, a method [3] has been developed in which the RSSI samples statistics at higher frequency collected from received packet data envelope is compared with that of Rician and Rayleigh/Lognormal distributions [4]. Here, for values less than 0.4, LOS component is dominant and the values greater than 0.6 confirm NLOS dominance. The range [0.4, 0.6] indicates the uncertainties in decision of LOS/NLOS estimation. Altogether seven rules define the relationship between inputs and output of this controller as shown in Table IV.

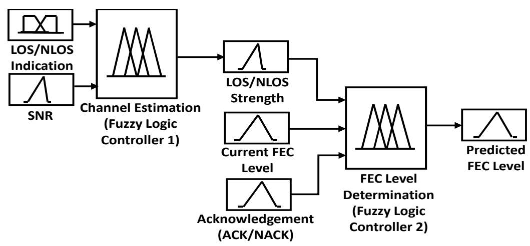


Figure 1. Cascaded Fuzzy Inference System for FEC Level Selection

TABLE I. MEMBERSHIP FUNCTION - SNR (INPUT)

Linguistic Value	Function	Values(dB)
Low	Trapezoidal	[-60 -60 -3 5]
Medium	Triangular	[-3 5 10]
High	Triangular	[5 17 30]
V. High	Trapezoidal	[20 30 50 50]

TABLE II. MEMBERSHIP FUNCTION - LOS/NLOS INDICATION (INPUT)

Linguistic Value	Function	Values
LOS	Trapezoidal	[0 0 0.4 0.6]
NLOS	Trapezoidal	[0.4 0.6 1 1]

TABLE III. MEMBERSHIP FUNCTION - LOS/NLOS STRENGTH (OUTPUT)

Linguistic Value	Function	Values
Max. LOS	Trapezoidal	[0 0 0.2 0.3]
LOS	Triangular	[0.2 0.3 0.5]
Min. LOS	Triangular	[0.3 0.5 0.7]
NLOS	Triangular	[0.5 0.7 0.8]
Max. NLOS	Trapezoidal	[0.7 0.8 1 1]

TABLE IV. FUZZY RULE BASE FOR LOS/NLOS STRENGTH DETERMINATION

Input - LOS/NLOS Indication	Input - SNR(dB)	Output – LOS/NLOS Strength
LOS	Low	Min. LOS
LOS	Medium	LOS
LOS	High	Max. LOS
LOS	V. High	Max. LOS
NLOS	Low	Max. NLOS
NLOS	Medium	Max. NLOS
NLOS	High	NLOS

The secondary (second) FLC determines the FEC code strength for the next packet transmission on the basis of three inputs: LOS/NLOS strength estimated by first FLC, acknowledgement information (ACK/NACK) of last few (three here) packets and present FEC level. The strength of LOS/NLOS scenario gives an idea about the channel error probability and the ACK/NACK status indicates the longevity of particular LOS/NLOS state. The MFs for ACK/NACK status is shown in Table V. Both present FEC and output FEC have same MFs (Table VI) and each FEC level is assigned a discrete FEC in the order of increasing redundancy from the codeset (Uncoded, BCH(127,120,1), BCH(127,113,2), BCH(127,106,3), BCH(127,92,5), BCH(127,78,7)). In total, 134 rules are defined to determine appropriate FEC after eliminating the redundant ones.

TABLE V. MEMBERSHIP FUNCTION - ACKNOWLEDGEMENT (INPUT)

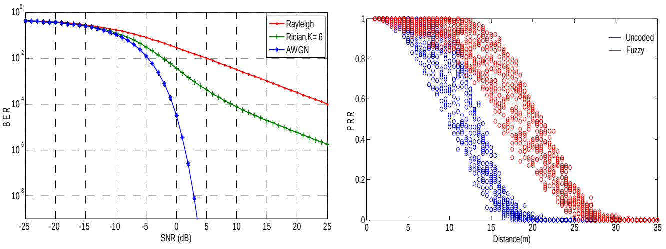
Linguistic Value	Function	Values
3-ACKs	Triangular	[0 1 2]
2-ACKs	Triangular	[1 2 3]
1-ACK	Triangular	[2 3 4]
1-NACK	Triangular	[3 4 5]
2-NACKs	Triangular	[4 5 6]

TABLE VI. MEMBERSHIP FUNCTION – PRESENT FEC(INPUT), OUTPUT FEC(OUTPUT)

Linguistic Value	Function	Values
NoFEC	Triangular	[0 1 2]
V. Low	Triangular	[1 2 3]
Low	Triangular	[2 3 4]
Med	Triangular	[3 4 5]
High	Triangular	[4 5 6]
V. High	Triangular	[5 6 7]

At different obstacle densities (0.005, 0.05, 0.15, 0.25), the application of fuzzy based FEC scheme significantly improves the Packet Reception Rate (PRR) especially over the distances which fall in transitional region. As shown in Fig. 2(b), the increased communication reliability over extended distances (from 15m in uncoded to 24m with fuzzy based transmission) eventually offers more flexibility in terms of node placement. Our experimental results in Fig. 3 show the benefits of fuzzy logic based adaptive FEC scheme over static FEC schemes in terms of Packet Error Rate (PER) and FEC Usage Efficieny at different communication distances.

We further explored memory usage for implementing this fuzzy based FEC scheme on WSN and the results confirm that it is very much suitable for low-power wireless sensor nodes with limited memory. The complete fuzzy based design when compiled to C code for 8-bit microcontroller takes 33 bytes of RAM and 802 bytes of ROM in contrast to 66 bytes of RAM and 876 bytes of ROM for 16-bit microcontrollers. Also, for microcontrollers having floating point support, it occupies 106 bytes of RAM and 1016 bytes of ROM.



(a) (b)

Figure 2. (a) Theoretical Bit Error Rate (BER) of IEEE 802.15.4 Physical layer over AWGN, Rician and Rayleigh Channel (b) Packet Reception Rate (PRR) Comparison between Uncoded and Fuzzy based approach

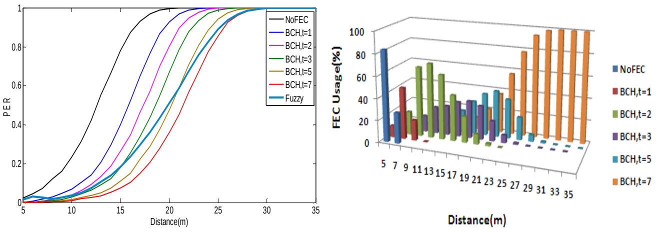


Figure 3. Packet Error Rate (PER) Performance and FEC Usage Comparison for Packet Size = 100 Bytes @ Pt = -10dBm, Obstacle Density = 0.05

III. CONCLUSION

Our proposed framework provides reliable and efficient wireless communication in an indoor environment. Due to resource-constrained nature of WSNs, the development of next generation algorithms with new attributes (such as self-organization, adaptation to dynamics) is highly desirable to fulfill the application-specific reliability requirements.

ACKNOWLEDGEMENTS

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Poster Abstract: Recognition of Personal Interest using Cooperation of Smartphone and Camera Sensors*

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***Abstract*—We present a system to detect individuals' potential interest in objects. Cooperating visual and smartphone sensors are employed to gain knowledge of both the items people are interested in and the ID of the mobile devices they are carrying. This can be used to trigger the timely delivery of content to a user's device which is relevant to the object they are interested in. In this paper, we evaluate the efficiency of the approach to matching devices to people. Results demonstrate the system performs with similarity to existing examples, while also being able to offer additional functionality.**

I. Introduction

Being able to provide a user with timely, relevant content about an object he shows interest in greatly enhances their experience and has a number of practical applications. Such a system could be highly valuable in a museum setting. Objects of interest are museum display items and upon observing objects one can receive relevant content on their personal devices. Some further useful applications include shopping or viewing a timetable at a train station.

We use combined data from a fixed camera and smartphones equipped with accelerometers to detect individual movement patterns. We recognize when a person shows interest in an object by detecting when one stops to observe it in a predefined area. With knowledge of who is showing interest and which device they are carrying, content relevant to the object of interest can then be delivered to them.

The primary contributions of this project include the provision of a working prototype demonstrating both algorithmic and communication functionality and an analysis of the system's performance with view for functionality in real-time.

Interest may be detected by sensing proximity to objects. Using mobile devices alone it is possible to estimate one's position [1], but including a camera will yield better accuracy.

An approach for matching moving people and devices such as in [2] uses a camera fixed to the ceiling, thus the field of view is dependent on room height. We do not require a precise localization and use a wall mounted camera to increase the viewing area. [3] has a ceiling-mounted approach and more energy requirements on the mobile device, while we wish to only use mobiles to transmit data upon request. While [4] has a non ceiling-mounted solution, it relies heavily on image processing in order to extract visual movement information. These examples focus primarily on the matching problem, whereas we take this further by incorporating interest detection with the aim to deliver relevant content.

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II. System Description

The system is a made up of a number of modules performing either a communication, processing or data delivery task. Figure 1 is a high level representation indicating the control and data flow of the system, highlighting the different tasks performed (numbered 1-5).

The motion tracking and sensor device modules deliver position and motion data to the system. The "Blob Tracking" component of the OpenCV library delivers position data relating to moving objects. Sensor devices are mobile units with smartphone sensors. We implemented software for the devices to enable recording of movement data and transmission of it upon request by the server.

We must be able to handle devices entering and leaving the system, communication errors and delay, and focus on achieving results with a minimum amount of data required. The discovery module (1) recognizes both new devices and new objects entering the area. Module (2) handles additional communication with sensor devices by requesting motion data when matching is performed.

In module (3), we need to match tracked objects to sensor nodes in the area by comparing the similarity of the data. Visual data and accelerometer data need to be transformed such that they have a common representation before being comparable. We estimate the velocity of each source based on an approach in [2] by taking the moving average of a distance measure from video data, and using the magnitude of accelerometer data to calculate its standard deviation. In this form, unique movement patterns are evident and the two data comparable. We use a correlation coefficient to obtain the closest matching accelerometer/object pairs. If no acceptable match is found, subsequent steps in the control flow are redundant and control returns to the top.

Interest detection (4) assesses whether a user is interested in an object. We maintain a set of predefined areas in the room that are centered around objects. Thus, an exact localization

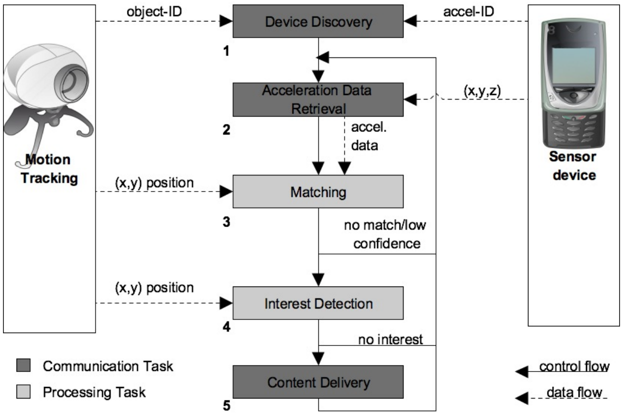

Fig. 1: Representation of system control and data flow

is not required and a single camera can be used to provide an estimation. It has been shown that the lowest point of a person being tracked object correlates to the location of feet on the floor. We use this as a basis to assess whether one is within an area of interest. If the person has a matched device, it follows that content be delivered to it (5).

III. Evaluation

Initial evaluation involved offline experiments to assess the algorithmic components without real-time constraints. Scenarios of 1-2 minutes each were recorded with up to 5 participants emulating movements typical for a museum visit. At various times, participants showed interest in any of three objects within indoor area of 15×7m, and the camera angled downwards from a height of 4m. The minimum distance between objects was 3m, with the intent to investigate the effects of more closely spaced objects in the future.

Video data was gathered using a digital video camera and recordings transferred to a workstation. Motion tracking was performed to produce sets of positions with timestamps for tracked objects. Accelerometer data was simultaneously recorded using an Irene sensor node transmitting data to a basestation. All devices are discovered by the system at the same time, but people enter the scene separately. For each scenario, object and accelerometer data were used as inputs to evaluate the system. Figure 2 shows an example of four from twelve scenarios with 2 and 3 participants. It demonstrates the calculated time consumed for tasks (1)-(3). In each block, P_x indicates the entrance of the x_{th} person in the area and the respective correlations that were calculated for each device. A successful match – defined here by a cumulative correlation larger than 0.5 – for the first person who enters can be achieved in around 3 seconds. Subsequent matches show longer total times as new data must be retrieved from unmatched devices. Data retrieval time is based on the transmission time of individual packets, which grows as matching time grows. Time required for discovery is smaller than 1 millisecond. Time savings can be achieved by combining multiple measurements in a single packet or for processing time by filtering out erroneous data. Nevertheless, the time span for each entrant is sufficient to proactively trigger content delivery and is similar

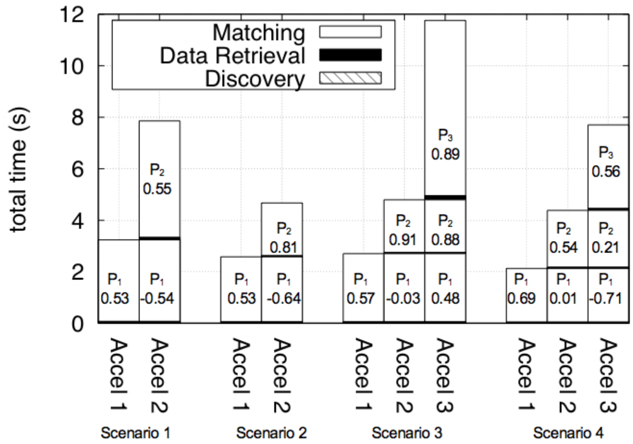

Fig. 2: Time consumption of tasks for scenarios with 2 or 3 persons

to other time and correlation measurements in previous studies [3], [5], while still offering additional functionality.

IV. Conclusion and Future Work

We present a system which can detect personal interest and deliver content to devices. Results using correlation comparisons alone yield a match within 3 seconds showing potential for a faster response.

We currently optimize the system for real-time constraints. As future extensions, the system can be evaluated with use of smartphones with integrated sensors rather than sensor nodes, or with of a wireless smart camera for motion tracking. Another area of focus may also be an investigation of timely content delivery based on the type of content.

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Demos

Demo Abstract: WiSpot - Detecting Wi-Fi Networks Using IEEE 802.15.4 Radios

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***Abstract*— Smart home and health care applications using the IEEE 802.15.4 compliant radios are getting more and more popular. A high penetration of these applications demands solutions that allow coexistence with almost 100 times more powerful Wi-Fi networks operating in the same 2.4 GHz ISM band. In order to avoid interference and ensure reliable communication, IEEE 802.15.4 networks are first required to identify potentially interfering channels. In this context, we have designed WiSpot, which uses a novel algorithm based on pair-wise synchronized channel sensing on a platform with two IEEE 802.15.4 compliant radios. It is able to detect IEEE 802.11b and IEEE 802.11g signal signatures with ca. 96 % accuracy indoors over a range of ca. 25 m with a maximum delay of 310 ms. Our algorithm is also able to detect multiple collocated Wi-Fi transmitters with overlapping and non-overlapping channels. The algorithm is robust against the IEEE 802.11b/g signal leakages on COTS NICs. Our algorithm is lightweight and is implemented on a COTS sensor node microcontroller. Our 'table-top' demonstration will show the various features of WiSpot and give audience the opportunity to interactively control the Wi-Fi transmission parameters and correspondingly observe the performance characteristics of our platform.**

I. Introduction

A surge of applications using IEEE 802.15.4 radios in home automation and health care domains has led to the problem of mutual interference with existing IEEE 802.11b/g based Wi-Fi networks. Since Wi-Fi transmitters use much higher transmit power levels, they tend to ignore IEEE 802.15.4 based networks which consequently suffer significant performance losses [1] [2]. In close proximities, IEEE 802.15.4 networks also cause significant performance degradation to Wi-Fi networks as reported in [3]. In recent years, Wireless Sensor Network (WSN) community has proposed interference mitigation solutions in medium access procedures to allow symbiotic coexistence with Wi-Fi networks [4] [5]. In order to avoid interference from Wi-Fi transmitters, reliable detection of the occupied Wi-Fi channels is a fundamental requirement.

Liang *et al.* [3] have analyzed interference patterns between IEEE 802.15.4 and Wi-Fi networks at a bit-level granularity. They have noticed that a significantly high packet loss ratio in IEEE 802.15.4 transmission is because of the corrupted header bytes while the rest of the packet remains uncorrupted. In order to mitigate Wi-Fi interference, the authors have devised a scheme of repeating back to back header in the frame and encoding the rest of the packet using Reed-Solomon based Forward-Error-Correction (FEC) scheme. While FEC based approaches can certainly reduce the packet losses in the case of wireless interference, selection of less interfering channels can lead to higher gains without imparting extra channel coding overhead [6] [7]. The faster a system is able to identify Wi-Fi interfering channels, the more energy efficient it is. Zhou *et al.* developed ZiFi [8], which utilizes an IEEE 802.15.4 radio to identify the existence of IEEE 802.11b/g access points generating periodic beacons. Compared to ZiFi, WiSpot is able to detect a Wi-Fi channel with approximately 2.5 times faster speed and gives a higher accuracy. Furthermore, WiSpot allows detection of multiple collocated Wi-Fi transmitters.

II. Design and Implementation

Our scheme is based on a dual-radio platform, where a microcontroller is interfaced to two IEEE 802.15.4 radios (Texas Instrument's CC2420) as shown in a simplified block diagram in Fig. 1. The SPI bus provides a means to read/write configuration registers and RX/TX FIFOs. The RSSI is also read over the SPI bus. The CCA and SFD lines interrupt the microcontroller with the status of the clear channel assessment and when an IEEE 802.15.4 frame is detected. In our prototype implementation (c.f. Fig. 2a), we have interfaced two TelosB nodes in a Master-Slave configuration as shown in Fig. 2b. The UART interface is used to read and write configuration commands to the slave radio and a GPIO interrupt line (INT) is used for coordinating the synchronized sensing operation. WiSpot achieves a speed of 70 μs to read an RSSI sample while 22 μs to check the status of CCA through an efficient implementation of the code. Furthermore, WiSpot requires a frequency switching duration of only 740 μs. Our algorithm uses software controlled CCA threshold and RSSI sample values for detecting the spectral masks of IEEE 802.11b and IEEE 802.11g signals. A timeout interval of 160 μs for an SFD interrupt at the master node after detecting simultaneous channel occupancy enables detecting IEEE 802.15.4 frames.

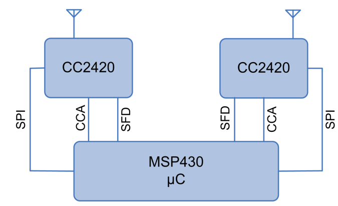
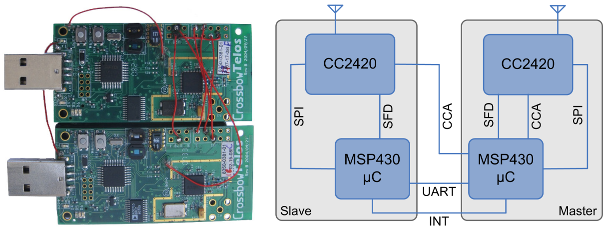


Fig. 1. A simplified block diagram of WiSpot consisting of an MSP430 series microcontroller interfaced to two CC2420 radios.



(a) Snapshot. (b) Simplified schematics.

Fig. 2. WiSpot prototype platform.

Our algorithm is computationally simple and relies on synchronized sensing of the adjacent IEEE 802.15.4 channels on the two radios. If the channel pair is found to be simultaneously unoccupied, the sensing operation is performed for a maximum duration of 100 ms, which corresponds to the typical Wi-Fi beaconing rate. In order to uniquely detect a particular Wi-Fi channel, a dual-radio platform requires three sensing cycles. However, using an elimination method, the sensing iterations on WiSpot are reduced to 15 for covering the complete 2.4 GHz spectrum. Once a channel pair is found to be simultaneously occupied, the mean RSSI values for channel pair is stored before switching to the next channel pair. The final analysis is carried out on the master node after scanning the complete spectrum. In order to identify Wi-Fi channels, the simultaneous channel occupation result of each sequence step is compared with the result of the subsequent step until all the 15 steps in the spectrum sensing sequence have been compared. The analysis includes finding the leaked signal, identification of multiple collocated transmitters and conflict resolution for overlapping Wi-Fi channels in the detection process. We will describe these algorithmic details during the demonstration.

III. Demonstration Description

We will describe the design rationale for different aspects of WiSpot. We will present the performance characteristics of WiSpot when using only the RSSI mode and when using the mode with combination of RSSI and CCA. The detection of IEEE 802.11b/g signals. WiSpot is able to detect IEEE 802.11n networks only when they are not using channel bonding, i.e. their bandwidth is confined to 22 MHz like IEEE 802.11b/g networks. In the case of channel bonding (bandwidth of 40 MHz), the algorithm requires minor modifications. The robustness of WiSpot against out-of-band signal leakages at short distances on commercially available Wi-Fi transmitters will also be shown. Furthermore, we would demonstrate the detection of multiple simultaneous Wi-Fi transmitters and the recognition of IEEE 802.15.4 frames. A WiSpy DBx signal analyzer will be used to observe the live signal characteristics as a comparison.

We have developed a GUI based visualization tool, which will allow the audience to interactively set the Wi-Fi channels and their transmit power levels using both IEEE 802.11b as well as IEEE 802.11g standards. Furthermore, the tool will also allow the users to start and stop IEEE 802.15.4 transmission. The detection characteristics on the WiSpot such as the IEEE 802.11b/g channel and detection duration will be indicated over the USB interface to a PC.

The demonstration and related visualizations will be accomplished in a ‘table-top’ fashion with a few WiSpot platforms, IEEE 802.11b/g access points, a WiSpy DBx signal analyzer, a TelosB sensor node platform and a laptop PC. The demonstration will be enhanced by a poster describing the schematics, algorithm details and selected performance evaluation results.

IV. Conclusions

WiSpot allows fast and accurate detection of Wi-Fi transmitters, which will enable the IEEE 802.15.4 based networks to avoid interference and improve reliability of data communication. WiSpot is robust to signal leakages on commercially available IEEE 802.11b/g NICs. The dual-radio WiSpot platform can be used as a usual single radio node in IEEE 802.15.4 networks while the secondary radio when required allows the possibility of detecting Wi-Fi networks. It can also be used as a dual radio platform such as in [9]–[11]. Since the algorithm is implemented on the host microcontroller, WiSpot can be integrated with low-power MACs such as [4], [5] for improving spectrum sensing and facilitating spectral coexistence.

Acknowledgment

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Demo Abstract: Using a Sensor Network to Enhance a Standardized Medical Test

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***Abstract*—We demonstrate how a sensor network can be used for enhanced medical testing. Our work makes use of a floor construction with acrylic floor tiles, resting on cheap and simple load sensors, which are in turn connected to sensor nodes. In combination with wireless networking capabilities and output LEDs in several colors, we present a test setup for a modified Timed Up & Go Test from medical diagnosis of elderly people.**

I. Introduction

In recent years, more and more wireless sensor network testbeds have become available. Very often these networks aim at the development and evaluation of new algorithms and communication protocols. Clearly, this is not an end by itself; instead, the final justification of the underlying research lies in new methods and tools for other sciences, and in enhancing the life of many individuals.

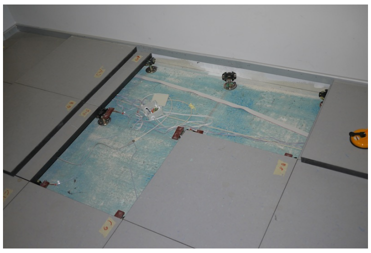
A particularly fascinating aspect of the design, development, and evaluation of sensor networks lies in the combination of local knowledge to obtain global goals, based on appropriate sensor data. To carry out such tests, we have developed a hallway monitoring system, consisting of 120 cheap and simple load sensors deployed beneath the hallway floor. The sensors are connected to a total of 30 nodes, which in turn can then exchange the measured values. Being highly correlated, these sensors serve as an ideal testbed for any algorithm performing data aggregation or in-network data analysis, such as distributed target tracking. See [2], [1] for further details.

In our demonstration, we show how this kind of technology opens up new avenues for other sciences. We illustrate this by an enhanced example of a standardized test from medicine.

II. The Timed Up & Go Test

The "Timed Up & Go Test" (TUG) is a simple and widely known physical test to assess the mobility of older persons [7], [6]. For the test procedure the subject is asked to stand up from a chair, to walk a short distance, to turn around, to walk back and to sit down. The result is the time needed to complete the test. There are approaches to enhance the informative value of the test, primarily using body-worn accelerometers to distinguish between patients with Parkinsons disease [8] or even to assess the risk of falling [5].

(a) The installation site.



(b) Floor tiles rest on columns.

Fig. 1. Hallway monitoring scenario.

III. Demonstration

We will demonstrate an application of wireless sensor networks in the field of medical computer science. As an example, our demonstration will show how the TUG can be standardized by using a controlled environment which is equipped with sensors. Our platform consists of 9 acrylic floor tiles that are deployed on a grid of 16 load sensors. Each 4 of these sensors are connected to one sensor node, which in turn is connected to one LED light and a speaker.

A. Sensors and Actuators

The load sensors are a simple and cheap construction. They consists of strain gauges, glued to small steel plates [2], [3]. Whenever the steel is strained or deformed, even by a few nanometers, the output value of the load sensor changes. Fig. 2 shows an example data sample of two load sensors, monitoring a single floor tile on which a chair is positioned. The top figure shows a front leg of the chair, when a person sits down, waits for some time, and then stands up. The bottom figure shows a rear leg of the chair during the same test.

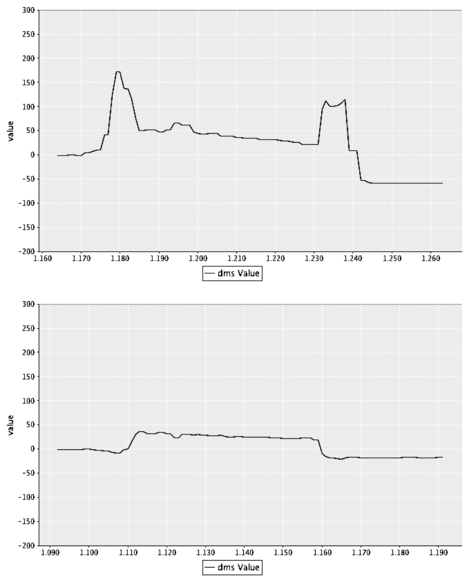


Fig. 2. Data samples of load sensors. Shown are the front and back pressure on the sensors below a chair; the first peak corresponds to a person sitting down, the right to standing up. Clearly, there is more pressure to the front of the chair than to its back.

The load sensors are connected to iSense sensor nodes [4]—each four load sensors to one node—to be used to process the data directly in the network. The floor is monitored in a distributed manner, so occupied tiles can be identified, even if a floor tile's load sensors are connected to several nodes.

Finally, each sensor node is connected to an actuator unit, consisting of a LED and a speaker to play back sound samples.

B. Construction

Our demo platform is a square-shaped wooden construction with a base area of 245cm x 245cm and a height of 25cm. It has a 4x4 grid of load sensors in the interior. Each of the 9 acrylic floor tiles has a side length of 60cm and is placed on the sensors, such that each of the tiles corners rests on one sensor. The tiles are held in place by a 22.5 cm wide wooden border. The LED lights are beneath the tiles in the corners of the 3x3 tile field while the speakers are built into the frame of the platform. Fig. 3 shows the whole construction.

C. Demo

Our demonstration will show how a sensory environment can be used for standardized medical testing, making results more comparable. More importantly, we show how such a standard can be enhanced by additional information. While the original TUG requires walking a straight distance of 3m, in our modified version of the test the test person has to stand up from one chair, walk along the perimeter of the platform to another chair and sit down. The test subjects will receive light and sound instructions from the platform during the test, while the platform surveys that the test person walks the right distance during the test and measures the time needed to complete the test. The test is controlled by our Corridor Control System (COCOS) [2] which displays the test results on the built in screen of the platform. As an additional feature, COCOS offers a client/server architecture, which allows full remote control of the demo platform and the test.

Fig. 3. The whole platform with illuminated floor tiles.

IV. Conclusion

We will show how a simple, standardized test that originally only yields a single number (the time for performing the test) can give rise to a multitude of differential data, for example step frequency and intensity. This allows a much finer and wider range of medical diagnosis, as well as tailor-made interactive testing and subject feedback.

Acknowledgment

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Demo Abstract: Realistic Simulation of Radio Interference in COOJA

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***Abstract*—Radio interference drastically affects the reliability and robustness of wireless communications. As wireless sensor network protocols are frequently designed and tested in simulation environments first, it is important to have simulation tools that provide means to study the impact of radio interference.**

Radio propagation models available in simulation environments are however often too simplistic, and can hardly capture the complexity of the real world. To increase the realism of simulations, we incorporate recorded interference traces into existing simulation models.

We extend the COOJA simulator with the generation of realistic interference sources in the simulation environment. We add new features, such as an interference-aware propagation model and loading of interference traces, which can be captured and recorded through a mote-based application.

In our interactive demo, we show the generation of interference patterns produced by devices operating in the 2.4 GHz band such as microwave ovens, Bluetooth, and Wi-Fi. We will monitor, capture, and record the ongoing interference at runtime, and load the recorded traces in our extended COOJA version. We then show how to use the captured patterns to simulate and study the impact of radio interference on sensornet communications and routing trees.

I. Introduction and Motivation

Radio interference considerably affects the reliability and robustness of wireless communications, hence representing a major problem in wireless sensor networks. The strong growth of the number of devices operating in the ISM bands increases the congestion in the radio spectrum, leading to poor performance, packet loss, and reduced energy-efficiency [1].

As wireless sensor networks also operate on these crowded ISM bands, it is necessary to design and develop protocols that are robust to radio interference. Sensornet protocols are frequently designed and tested in simulation environments first, and it is therefore important to provide simulation tools that offer accurate means to study the impact of radio interference.

Modeling radio propagation and interference is complex due to the large number of variables involved, ranging from the device(s) operating concurrently on the frequency of interest, their position, modulation, and transmission scheme, to the characteristics of the environment and the presence of moving objects or static obstacles. In certain scenarios with an excessive number of such unknown parameters, e.g. in a crowded shopping center or lively street, the creation of models that accurately reflect reality is therefore almost impossible.

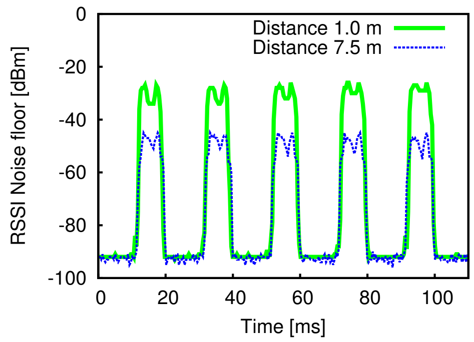

Fig. 1. Interference recorded from a sensor mote scanning channel 23 in presence of an active Lunik 200 Microwave Oven. Ovens typically emit frequencies with a periodic pattern, and for this particular model, the period is approximately 20 ms.

Instead of attempting to create more precise and realistic radio models, we augment existing simulation tools with the playback of realistic interference traces. We use off-the-shelf sensor motes to scan the radio channel and record the interference patterns, and we then play back the recorded traces directly in the simulation environment. Such traces can be added on top of any existing radio model, improving significantly the level of realism when simulating the impact of radio interference on sensornet protocols and communications.

II. COOJA Extensions for Realistic Interference Simulation

We enrich the COOJA simulator [2] with the generation of realistic interference sources in the simulation environment.

We upgrade the Multi-path Ray-tracer Medium (MRM) to correctly implement co-channel rejection according to the results of Dutta et al. [3]. Co-channel rejection is a measure of the capability of the receiver to demodulate a wanted modulated signal without exceeding a given degradation due to the presence of an unwanted modulated signal. Proper handling of co-channel rejection enables us to simulate the correct reception of a packet in presence of interference.

Unwanted signals are represented by (pre-)recorded interference traces in COOJA. Such traces are used to improve the realism of sensornet simulations. Using, for example,

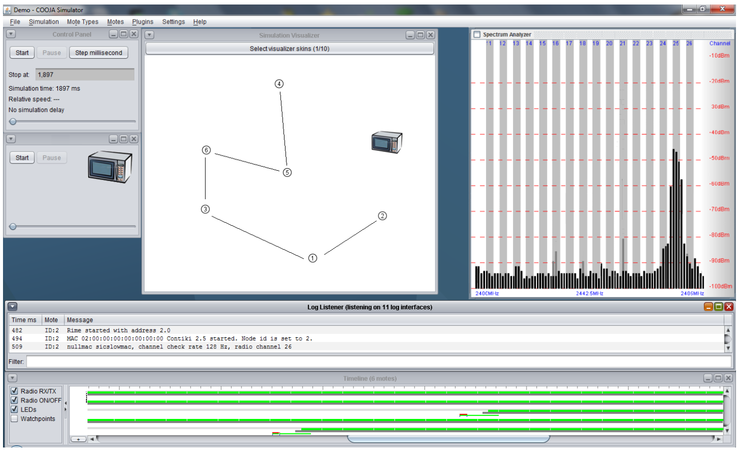

Fig. 2. Screenshot of COOJA with the proposed application.

pre-recorded interference traces that resemble the patterns generated by typical appliances operating in the crowded 2.4 GHz ISM band, the user can arbitrarily place a number of Wi-Fi and Bluetooth devices as well as microwave ovens inside the simulation environment. We assume the signal propagation can be modeled with the widely used log-normal model [4].

III. Demo Description

In this demo, we monitor, capture, record, and play back the ongoing interference at runtime.

We first show how to capture interference using a high sampling rate. We use off-the-shelf sensor nodes and measure the RSSI noise floor, i.e., the RSSI in absence of packet transmissions in both time and frequency.

As we are interested in detecting also short transmissions such as Wi-Fi beacons, we boost the CPU speed, optimize the SPI operations, and compress the RSSI noise floor readings. We achieve a sampling frequency of approximately 60 kHz (3.5 kHz) when scanning one (all) 802.15.4 channels. Figure 1 shows a sample interference trace recorded from a sensor mote scanning channel 23 in presence of an active microwave oven in the neighborhood.

To collect the RSSI noise floor readings, we attach two sensor motes to the laptop running COOJA. We use Maxfor MTM-CM5000MSP nodes, widely used sensor motes equipped with the CC2420 radio transceiver. The two nodes run Contiki [5]: the first node is used to scan the channel of interest and record the interference traces at runtime; the second node is used to give the user a snapshot of the ongoing interference in the whole 2.4 GHz spectrum as in [6].

We also pre-record several interference traces and build an object library of interfering devices available as new disturber mote types, including different models of microwave ovens as well as Bluetooth and Wi-Fi devices.

Finally, we create several simulation environments and show the impact of realistic radio interference on sensornet communications and routing trees. Figure 2 shows a screenshot of the COOJA simulation.

IV. Conclusions

In this demo we show how to monitor, capture, and record the ongoing interference in real time using COOJA. We then use the captured patterns to simulate and study the impact of realistic radio interference on sensornet communications and routing trees.

Acknowledgments

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Demo Abstract: Hazard Control in Forest Fire Fighting Operations

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Abstract— **The EIDOS system is a WSN-based support system proposed for reducing hazardous situations for people working in forest fire fighting operations. This paper describes a tool that demonstrates the functionality of the system. In particular, the behavior of the applications running at sensor nodes and handheld devices is shown by means of user-friendly graphical interfaces, which will be available for the attendants to the demonstration session.**

I. Introduction

Forest fire fighting operations frequently lead to hazardous situations in which firefighters are not aware of the evolution of the fire in the surroundings, risking their lives. To avoid (or reduce) these situations, the EIDOS (*EquIpment Destined for Orientation and Safety*) system [2] was proposed to directly provide the firefighters with real time information about the behavior of the fire fronts. A wireless sensor network (WSN) collects and processes environmental data that is displayed on the firefighters' handheld devices.

This paper describes a demonstration session of the overall functionality of the EIDOS system. Obviously, it is not feasible to spread a wildfire for demonstration purposes. For this reason, we have developed a forest area simulation environment, in which we can spread a wildfire and place firefighters and sensor nodes. Handheld devices (real or simulated) can connect to this tool to show the evolution of the fire fronts as perceived by the firefighters. Attendants will be able to interact with the system, checking its functionality by themselves.

Next, we describe the global architecture of the EIDOS system. Then, an outlook of the modules composing the demonstration tool is presented, including its graphical user interface.

II. The EIDOS System

Once a wildfire spreads through a forest area, the EIDOS system proposes the deployment of a large and dense WSN from the air by using aerial vehicles. This network is composed of thousands of small microelectronic devices, commonly called "motes". These motes are equipped with several sensors that are able to monitor environmental physical magnitudes, such as temperature, pressure, and humidity. Optionally, they are also equipped with GPS (*Global Positioning System*) receivers. In addition, motes have computing and wireless communication capabilities.

At the same time, the firefighters involved in the extinction activities carry handheld electronic devices, such as phones, PDAs, or UMPCs. These mobile devices are able to wirelessly interact with the network motes under coverage. Next, we describe the functionality of the two applications developed for the EIDOS motes and handheld devices, respectively.

A. Mote Application

The first task performed by the mote application is to determine its own spatial localization. It can be either obtained directly from an internal GPS receiver, or estimated running a distributed localization process [3]. After that, environmental data sensed is efficiently broadcasted, so that in each moment all motes know the set of points reached by the fire [7].

The mote application has been developed in NesC [5] over the TinyOS [8] operating system. A detailed description of this application can be found in [4], and it is out of the scope of the demonstration session.

B. Device Application

Handheld devices are able to access and process the information provided by the sensor network. The information gathered is displayed through an intuitive graphical interface, consisting of a compass showing four concentric rings (representing distances of 50, 100, 200, and 400 meters, respectively), which are divided into eight sectors (see Fig. 1). Green sectors represent secure areas, whereas red sectors represent burning areas. Moreover, an animated fire icon explicitly represents the last change listened. As will be shown

Figure 1. EIDOS handheld application.

This work was supported by the Spanish MEC and MICINN, as well as European Commission FEDER funds, under Grants CSD2006-00046 and TIN2009-14475-C04. It was also partly supported by the JCCM under Grants PREG-07-25, PII1C09-0101-9476, and PII2I09-0067-3628.

in the demonstration session, this information is updated in real time as the wildfire evolves. Of course, the application supports the device internal GPS and digital compass, in such a way that firefighter movements or rotations are instantly updated into the graph.

The EIDOS device application has been developed in Adobe Flash (with ActionScript 2.0), and published to Adobe Flash Player 7. This guarantees its compatibility with a wide range of handheld devices currently available in the market.

III. THE DEMOSTRATION TOOL

It is very dangerous to spread a wildfire only for demonstration purposes. At the same time, it is not economically feasible to deploy the required WSN with the commercial motes currently available. For this reason, we have developed a forest area simulation environment, in which we can deploy a WSN, spread a wildfire, place firefighters, and see the evolution of the fire fronts that they perceive.

As shown in the Fig. 2, the demonstration tool is composed of a forest area simulator and a handheld device simulator. Both simulators run at the top layer the software developed for the real EIDOS architecture, as described below.

A. Forest Area Simulator

The forest area simulator is composed of three independent and interconnected modules, which share information by means of a global MySQL database.

First, a wildfire is simulated over a particular area, by using real geographical, environmental and vegetation data. The tool employed for this purpose is FARSITE [1].

After that, a WSN simulator executes the EIDOS application for each network mote. It has been developed in Python/TOSSIM [6].

Finally, a browser (Fig. 3) allows us to graphically show the evolution of the simulation along time. We can observe the fire spreading in the area. We can also see how the WSN motes drop to the floor, estimate their position, detect close fires, and finally burn. At the same time, we can place and move a firefighter across the area. This tool has been developed in Adobe Flash 10 (with ActionScript 2.0), accessing to the simulation database through ColdFusion components.

B. Device Simulator

The EIDOS device application has been designed to

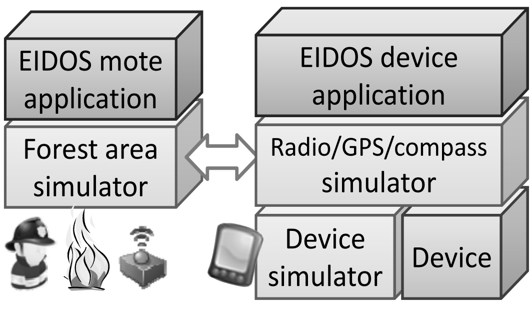

Figure 2. EIDOS demonstration tool.

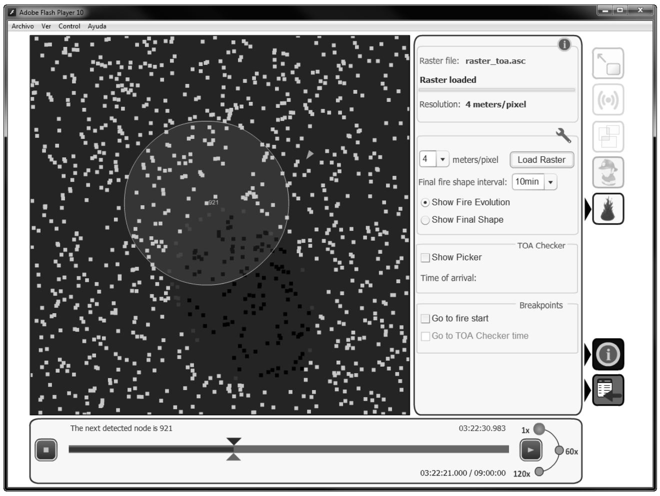

Figure 3. Forest area simulator interface.

wirelessly obtain information from the real WSN motes under coverage. Therefore, to interact with the simulated motes, we have introduced into the application an intermediate layer reproducing the radio communications by means of ColdFusion components.

Also, it is necessary to redirect the device internal GPS and compass to get the position and orientation of the virtual firefighter deployed in the area simulator. To do that, real time information is interchanged between both simulators by means of a Flash Media Server.

IV. DEMONSTRATION DETAILS

During the demonstration, we will describe the overall functionality of the EIDOS system. After that, attendants will be able to interact with the system. In more detail, they may spread a fire over the area, move the firefighter arbitrarily, and check the information perceived by the firefighter.

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Demo Abstract: Inverted Pendulum Control over an IEEE 802.15.4 Wireless Sensor and Actuator Network

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***Abstract*—Recent research efforts are considering the problem of performing control of dynamical systems over wireless sensor and actuator networks. However, existing results lack an experimental evaluation in real platforms. In this demonstration an inverted pendulum system is controlled over an IEEE 802.15.4 wireless sensor and actuator network. This platform can evaluate several sensor networks and control algorithms and is currently used as an educational tool at KTH Royal Institute of Technology, Sweden.**

I. Introduction

Recently, control systems are operated over large-scale, networked infrastructures. The use of wireless communication technology provides major advantages in terms of increased flexibility, and reduced installation and maintenance costs. By considering these advantages, several vendors are considering merging sensor devices with low-power wireless sensor networks (WSNs) for industrial automation and process control. While WSNs have been widely analyzed and deployed to extract information from the physical world [1], actuation over wireless networks is still taking its first steps and demonstrations of its use in real-time control systems have not yet been considered.

When wireless communications are used to perform sensing and actuation tasks in a control system several issues arise which may not allow the controlled process to maintain a required level of performance or even remain stable. These issues are mainly given by the limited bandwidth, information loss and delays. In a control theory perspective, many solutions have been proposed to deal with a probabilistic communication behavior with losses and delays, when performing control but this is still the scope of current research under the topic of Networked Control Systems (NCSs) [2]. From a sensor network point of view we notice increasing research on the protocol design of Medium Access Control (MAC) to deal with losses and delays for control systems [3]. Few protocols, TSMP [4] and WirelessHART [5] have been devised, which design the MAC and routing layers for industrial automation. Most of these protocols achieve high reliability based on scheduling the network resources, but no latency guarantees can be made. All these approaches consider the IEEE 802.15.4 [6] as the physical layer.

In this demonstration, we show how sensing and actuation of a real-time system can be performed over low-power a wireless sensor and actuator network (WSANs). The experimental setup consists of an inverted pendulum system closed over a IEEE 802.15.4 WSAN as depicted in Fig. 1. In

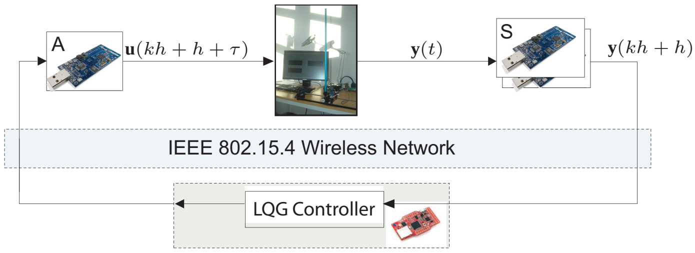
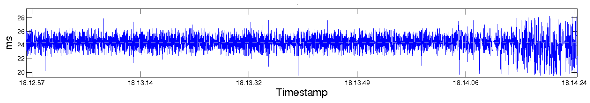


Fig. 1: Wireless Inverted Pendulum System

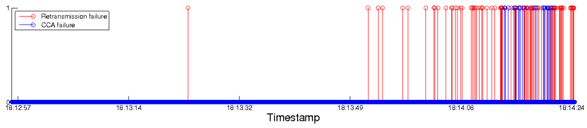
particular, a slotted mode of CSMA/CA algorithm of the IEEE 802.15.4 Standard is used and a Linear Quadratic Gaussian (LQG) is implemented at the microcontroller in order to perform a suitable sensor estimation and control of the inverted pendulum system. The Telosb platforms are used for sensing and actuation and a Zolertia mote is used for computation of the controller, both running the TinyOS operating system. The proposed demonstration system can be seen as a platform for validation of NCSs developments both from a pure control theory side but also from a sensor networks perspective. The inverted pendulum system is currently being applied in a large network where several other systems such as coupled water tanks and a 3 degree-of-freedom crane, are controlled over the same sensor and actuator network. In this network we investigate the performance of different MAC and routing protocols, but also how new control theory such as event-based control can be implemented in a WSAN context. This setup is also being used as an educational platform for two courses on Automatic Control and Hybrid and Embedded Control Systems, at KTH Royal Institute of Technology, Sweden.

II. System Design

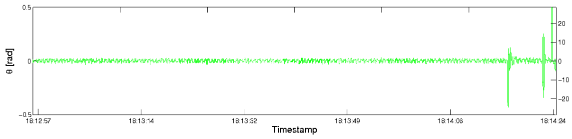
The inverted pendulum system is composed of a cart that can moved by a 6V DC motor in a track and carries a pendulum that freely rotates over the cart's axis of motion. The cart position and pendulum angle of rotation is measured by two incremental encoders which are interfaced with a Telosb mote through a digital counter using serial port interface (SPI) communication. The actuation of the cart is made by another Telosb mote connected to an amplification circuit which controls the DC motor and makes the cart move in the track in order to keep the pendulum in an upright position and not allow it to fall. A Zolertia Z1 mote is used to compute the control input to be sent to the actuation mote.



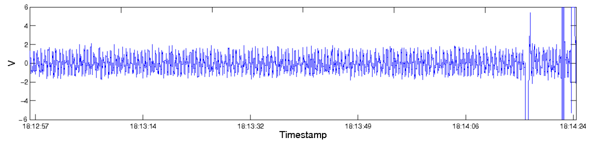
(a) Time between packets for pendulum angle



(b) Packet loss: Retransmission and CCA failures



(c) Angle θ of the pendulum



(d) Control voltage applied to the cart motor

Fig. 2: Network and Inverted Pendulum system analysis.

The MAC layer implementation of the IEEE 802.15.4 standard is made in TinyOS and follows the TKN15.4 [7] beacon-enabled design. The Zolertia Z1 motes are equipped with the new MSP430f2617 microcontroller (MCU) running at 16MHz which is twice as fast as the Telosb nodes. Since an LQG controller needs to be implemented at the controller node and several mathematical operations are required, a faster MCU is an advantage and so we chose to use the Zolertia Z1 for that purpose. For more details on the characteristics of the Telosb and Zolertia Z1 motes see [8], [9].

A separate circuit board is developed to interface the incremental encoders to the motes, where a digital counter LS7366R stores the number of encoder rotations and upon request, sends the data over SPI to the wireless node.

The rotation value for the cart position is translated into centimeters and the pendulum angle into degrees and sent over the wireless link to the controller mote where the control input $\mathbf{u}$ is calculated. The control input is then sent to another mote connected to the inverted pendulum. The sensed values $\mathbf{y}$ are transmitted periodically at every h ms. From the sampling instant until actuation in the actuator side there is a delay τ due to communication and computation time. The influence of the delay in the dynamical system can be compensated by suitably designing the LQG controller. Due to space limitations, the details on the controller can be found in [10].

Furthermore, we consider an interference node which induces stochastic packet losses and delays in the network transmissions. This node will periodically send messages in the same channel as the sensor nodes causing the channel to be busy and possibly generate packet collisions.

III. Evaluation

Fig. 2 presents the performance evaluation of the wireless network and the control system. In order to monitor all these parameters we deploy a special sensor node which is responsible for acquiring all the transmitted packets and log their data. Fig. 2b shows a snapshot of the packet loss on the wireless network. Furthermore, the inter-arrival time for each sensor packet is also measured which greatly influences the control of the inverted pendulum and is depicted in Fig. 2a, for the pendulum angle sensor. In the control side we evaluate the sensed pendulum angle, shown in Fig. 2c, and the cart position. Moreover, Fig. 2d shows the evolution of the control input as given by the LQG controller for the measured cart position and pendulum angle.

The sensors sampling period is selected as $h = 32$ms and the delay $\tau = 50$ms.

In Fig. 2, we consider three different scenarios of the network setup during 1min and 30sec of evaluation of the inverted pendulum system, which starts at 18:12:57. Up to 18:13:49 no interference is present in the network and a high control performance is achieved. After 18:13:49 an interference node is placed in the same network which transmits packets in the same channel as the sensor nodes with an inter-transmission period of 100ms which induces losses in the cart position sensor mote. However, the effect of these losses are negligible to the control performance of the inverted pendulum. At 18:13:55 the interference node is set to transmit a packet at every 10ms, which significantly increases the packet losses of the network. As a result of the losses in the pendulum angle sensor, the control performance degrades and at 18:14:22 the pendulum falls.

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Demo Abstract: uDPWS - The Devices Profile for Web Services for Resource-Constrained Devices

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***Abstract*—Web Service technologies are state of the art in distributed applications. To integrate highly resource-constrained devices, such as sensor nodes, into distributed applications via Web Services, gateways are commonly used. We present a novel solution, that enables the intermediate, homogeneous communication between enterprise applications and highly resource-constrained devices. Therefore, our demonstration presents uDPWS, a prototype implementation of an embedded enterprise compatible W3C Web Services profile. uDPWS is designed to work on sensor nodes. It requires only 8.5 KiB of ROM and 3 KiB of RAM.**

I. Introduction

A. Motivation

Recent investigations on IP-based communication for Wireless Sensor Networks (WSNs) promise to bring syntactic interoperability at the network layer of low-power wireless communication systems in the near future. In this area, the IETF 6LoWPAN (IPv6 over Low-Power Wireless Personal Area Networks) working group has defined, how efficient IPv6-based communication can be accomplished on top of IEEE 802.15.4 based wireless radio [1]. It is questionable, however, how syntactic interoperability can then be achieved at the higher application layers. From our point of view, Web Services are one of the most promising technologies to be used as application protocol in this domain. Therefore, we demonstrate that even complex W3C Web Services can run on sensor nodes. In conclusion, our demonstration shows, how a pulse oximetry sensor can be wirelessly connected to a IP-network and further be used on any kind of a network connected Host PC.

B. Devices Profile for Web Services

The Devices Profile for Web Services (DPWS) defines a subset of the WS-* specifications suitable for "resource-constrained endpoints" [2]. Even though there is no information about performance prerequisites given in the DPWS standard, it is obvious that devices with around 10 KiB of RAM are out of scope. DPWS proposes a Web Services based architecture for networked embedded devices and tries to foster interoperability between small embedded devices and fully Web Service-capable computers. The DPWS standard states that a DPWS-Device is represented through a Web Service which is called Hosting Service. The Hosting Service is found by DPWS-Clients in local networks using WS-Discovery. Furthermore, the Hosting Service provides the device description through WS-MetadataExchange. The device offers access to its functionality through Hosted Services. For publish-subscribe communication DPWS uses WS-Eventing.

C. Application Domain and Scenario

The presented demonstration is part of the German OSAMI project demonstrator [3]. The aim was to enable interoperability in distributed systems in the e-health and ambient intelligence domain. The demonstrator allows patients to perform an ergometer bicycle training at home under medical supervision, for example, in ambulant cardiac rehabilitation.

II. uDPWS Implementation

We implemented uDPWS[1], a very lightweight implementation of the DPWS standard, suitable for sensor nodes. uDPWS is designed to implement DPWS-Devices using the Contiki operating system [4]. As a result, uDPWS runs on all Contiki supported platforms, such as the Tmote Sky Board, Atmel RZ Raven, the Modular Sensor Board (MSB430) and the Embedded Sensor Board (ESB). For IP, as well as TCP and UDP communication, the uIPv6 TCP/IP stack and SICSlowpan for IETF 6LoWPAN [1] header compression is utilized. We demonstrate that enterprise Web Services can run directly on sensor node hardware. This enables internet- or network-connected computers to address sensor-nodes based on their IPv6 address and connect to their published Web Service interfaces.

The modular architecture of uDPWS is shown in Figure 1. The core (highlighted in grey) consists of the following four main modules:

1) The uDPWS-Process-module: handles the distribution of incoming connections and messages. It is the only module that interacts with the operating system (OS) Contiki. Thus, porting to other operating systems, such as TinyOS, can be accomplished by adopting the uDPWS-Process module.

[1] uDPWS is open source and available at http://www.ws4d.org/udpws/

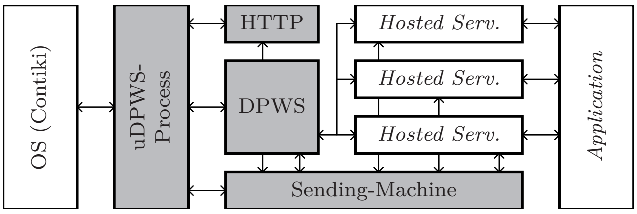

Figure 1. uDPWS Architecture

Contiki comes with an embedded TCP/IP stack and an implementation of 6LoWPAN which provides standardised IPv6 based communication over IEEE 802.15.4.

2) The HTTP-module: is responsible for receiving and buffering the request message. As soon as the complete message is buffered, it is forwarded to the DPWS-module.

3) The DPWS-module: forwards the message content to the corresponding service implementation, if the message is dedicated to one of the Hosted Services. Otherwise, if the message is a DPWS message (e.g., WS-MetadataExchange, WS-Discovery), the DPWS module itself handles the message. The DPWS module is the main module of the uDPWS-Core

4) The Sending-Machine-module: is finally used to create the response messages in a very resource-saving manner: As most parts of the XML messages are invariant (e.g., XML namespaces) and are already stored in ROM, this module avoids a separate response message buffer by concatenating memory references of XML message fragments to a list. Therefore, only dynamic message fragments (e.g., measurement values) need to be buffered in RAM.

For implementing a Device and it's Hosted Services, the DPWS-module provides a generic API. The application itself only uses the interfaces of the Hosted Services, which can be designed in any way.

III. Demonstration Setup

In Figure 2 the demonstration setup is shown. It consists of an Atmel RZ Raven sensor node which is connected to a Corscience ChipOx [5] pulse oximetry sensor. The RZ Raven runs a DPWS-Device that offers two hosted Web Services: (a) a SpO2 Service to retrieve the patient's blood oxygen saturation and (b) a Pulse Service to retrieve the patient's heart rate. As 6LoWPAN is used for IP communication over IEEE 802.15.4, a TelosB mote serves as IPv6-over-IEEE 802.15.4 interface for the Host PC. The IPv6 packets are transmitted from the TelosB to the Host PC via USB by using the Serial Line Internet Protocol (SLIP).

The DPWS-Client, used in this demonstration, is the DPWS-Explorer [6], a generic DPWS-Client to find DPWS-Devices in local networks. The DPWS-Explorer generates a graphical interface to the Hosted Services of a DPWS-Device. It is used to retrieve and show the real-time pulse oximetry values of the RZ Raven sensor node.

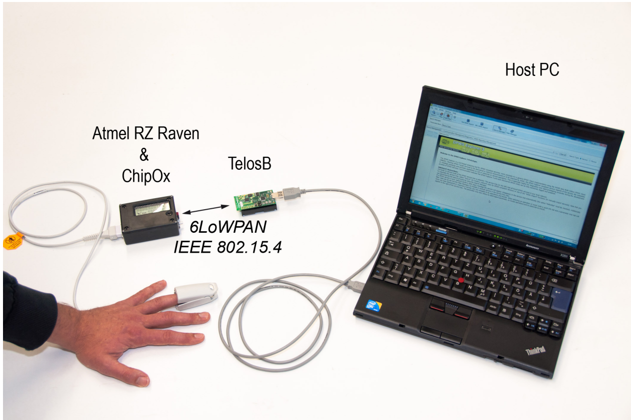

Figure 2. uDPWS Demonstration Setup

IV. Acknowledgement

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Demo Abstract: Self-powered Self-organized WSN for Condition Monitoring of Heavy Industrial Gears

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***Abstract*—We present a wireless sensor network (WSN) based condition monitoring (CM) system for heavy industrial gears. By continuously monitoring the oil temperature, an exact application profile of a gear over the time can be established. This allows to schedule maintenance tasks in advance and reduce costs. For ease of subsequent installation into existing plants and maintenance-free operation, this monitoring is achieved by a wireless sensor integrated in an oil drain plug and powered by a thermogenerator. The communication between the plug, a router network and a central data sink is Zigbee standard conform. We demonstrate a prototype of this plug and its functionality using a gear mimicking oil tub.**

I. Introduction

In times of increasing pricing pressure and austerity, industrial manufacturers more and more make use of CM systems to prevent expensive equipment failures through preventative maintenance [1]. In the field of heavy industrial gears, one possibility to monitoring the condition of a device is to exactly record the temperature of the gear oil. The established temperature profile then represents a measure of the operation intensity which again can be used to optimally schedule oil changes and thus reduce costs. Important requirements to realize such a monitoring system are robustness and feasibility of subsequent installation. To achieve this, we implemented an energy self-sufficient and self-organizing WSN and integrated a sensor and peltier element based energy harvesting device with a wireless communication module into an oil drain plug.

II. Related Work

CM by means of self-sufficient WSN has been an upcoming topic for a few years [1], [2], [3]. However, in spite of various prototypes, there is still no widespread use of wireless CM systems in industries. In [2] the authors present an implementation of a wireless CM system to monitor various data on a ship. The presented system is also energy self-sufficient; power is harvested from vibrations by means of a piezoelectric element. Another prototype is presented in [3], where similarly the monitoring of different kinds of data is motivated. This platform however does not provide an energy harvesting solution.

However, the research still seems to lack real world applications of the proposed system. To the knowledge of the authors, there are currently no products available to wirelessly monitor the oil temperature in heavy industrial gears.

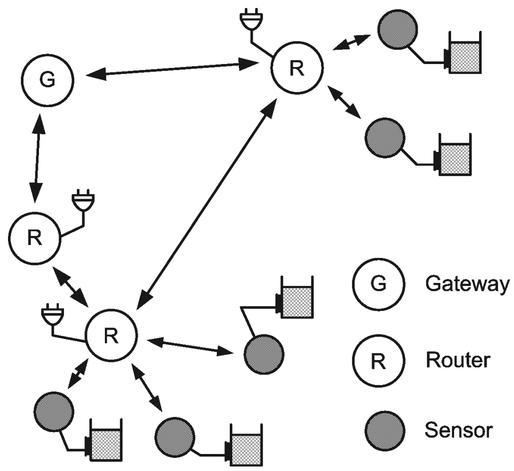

Fig. 1. Overview of network and power supply

III. System Description

The monitoring system can be divided into three major parts: data acquisition – sensors, communication – network and data processing – database. The network has a mains powered part consisting of routers deployed in the factory building across the walls and roof on one hand, and self-powered sensors on the other. The routers wait for data packets from the sensors and forward them to a central data sink, which corresponds to the Zigbee coordinator of the network (Fig. 1).

Noteworthy is that the sensors function only when the temperature difference is high enough, meaning that for cold oil no measurements are done. This is not a problem since the oil deterioration due to temperature do not overtake the natural deterioration until above 70°C oil temperature.

In following subsection we describe the main components of the oil plug sensor.

A. Wireless Communication Module

The sensor's hardware is based on Texas Instruments' MSP430F2618 (MCU) and CC2520 (RF chip). In the first revision a pcb antenna has been used what makes the integration into the oil plug easier, more robust and reduces cost of the sensor. Nevertheless, if in the field the channel link proofs to be unreliable, an external antenna can be mounted as the connector has been foreseen.

B. Thermogenerator

A peltier element in the thermogenerator converts the temperature difference between the oil in the gear (up to 120°C) and the surrounding air to electric energy to supplying the sensor. The voltage on its output is very small and a dedicated DC/DC booster raises it to approximately 3.3V. The energy is then stored in a capacitor with a very low loss tangent. The last block is the regulator which keeps the output voltage at 2.4V level suitable for MCU and RF chip. If the voltage on the capacitor's plates drops below 2.5V the thermogenerator is disconnected from the rest of the circuit until it raises back to 3.3V.

C. Oil Drain Plug

The oil drain plug has been designed as a replacement for standard plugs. It integrates all the components together in one housing. A lot of effort has been put into the construction of the housing, which must assure an excellent thermal flow to achieve the highest possible temperature difference between inside and outside parts and be mechanically stable and robust in industrial environment.

D. MCU Firmware

A major part of the firmware are the higher layers of the Zigbee stack. Besides, there are operating system mechanisms providing timers and tasks. In the application layer, a task is periodically reading out the temperature value of the oil and forwarding it to the database.

Due to low efficiency of the energy harvester and limited energy storage capabilities, the standard Zigbee stack parameters were modified to make network association and communication as energy efficient as possible. A dynamic energy management mechanism has been introduced. It controls the storage capacitor loading speed and does not bring the MCU and RF chip from the low power mode until enough energy for the scheduled task is available.

In the table below, the energy consumption of different phases is specified. The thermogenerator delivers up to approximately 8mJ energy per cycle.

Phase	Energy [μJ]
Sleep	7.2μW $\cdot$ 1s
Energy Scan	5800
Association	2000
Data transmission	1300

IV. Demonstration

To make a demonstration possible with the sensor working under real system conditions without the use of heavy industrial gear, a special oil tub has been manufactured. The oil inside is heated to any given temperature simulating the interior of a gear. Fig. 2 shows the set-up.

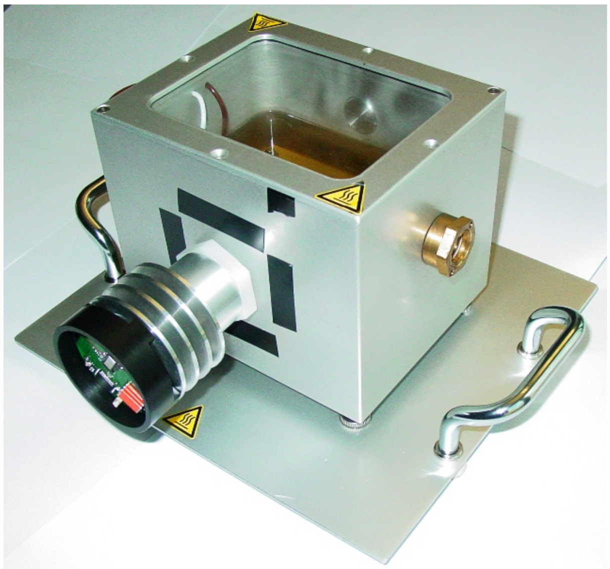

Fig. 2. Oil tub container mimicking a heavy industrial gear interior

A gateway with integrated network coordinator is collecting all incoming measurements from three sensors and forwarding it to a database. In our demonstration a PC collector application plays the role of the database and also visualizes the incoming data. All data packets currently sent over the air can be monitored with a packet sniffer.

V. Conclusion

In this paper, we presented an application of WSN for CM in heavy industrial gears. The demonstrated prototype allows to periodically transmitting information about the current oil temperature in the gear. Also, the energy self-sufficient integration into an oil drain plug allows easy subsequent installation. The system is developed to a prototype status and preliminary tests in real installations show that the concept works. For the near future, a large-scale long-term experiment in a real installation is planned.

Acknowledgment

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Demo Abstract: Enabling Remote Controlled Road Surface Networks for Enhanced ITS

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***Abstract*—Intelligent Transportation Systems (ITS) will in the future play a key role to improve transportation efficiency and safety. However, the cost-benefit of deploying traditional ITS is retarded by expensive equipment, infrastructure, installation and maintenance. The demo presents a replica of a real world experimental ITS application using recently proposed Road Surface Network architecture. The demonstrated "intelligent roundabout" application is intended to warn and inform drivers about an upcoming roundabout and to prevent driving straight into collision. We show a lab prototype of the system consisting of: an authentic sensor node platform enabled for car detection, secure multihop communications, the running light application and a base station with system control center.**

I. Road Surface Network Architecture

In [1] we proposed a Road Surface Network (RSN) architecture. The RSN architecture is illustrated in Fig. 1. It is built upon three principle entities: road marking units (RMU), road side units (RSU) and an open platform server (OPS) for enabling new RSN services in larger ITS systems. RMUs are autonomous on-road devices that may work independently or cooperatively to carry out sensing and actuating tasks. RMUs are capable of wireless communication with RSUs as well as communicating with each other by forming a wireless sensor and actuator network. RSUs are the gateway nodes for conveying data between RMUs and the ITS backend system. The open platform provides a set of open interfaces that connect RMUs to a backend ITS and front ends.

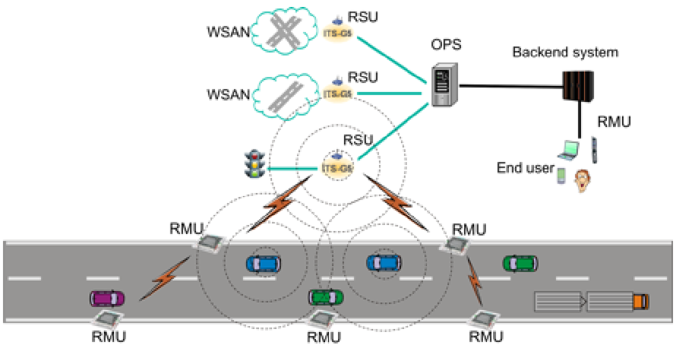

Fig. 1: The Road Surface Network Architecture.

II. Intelligent Roundabout Site in Luleå

To show the feasibility of the RSN-based ITS we deploy an "Intelligent Roundabout" site close to Luleå University of Technology. Fig. 2 shows the schematics of the system. The detecting RMUs are equipped with a magnetometer they are connected by a set of relay nodes to the base station, which triggers a warning scheme. All sensor and relay nodes are embedded into the asphalt and are placed 7.5 meters apart from each other. This distance is chosen in order to ensure the line of sight communications. In the figure, the red marked node is placed at the distance from the roundabout where a car should be detected. The blue marked node in the figure is placed at the least distance where the roundabout application should be turned on to allow comfortable deceleration ($-3m/s^2$). The preferred entrance speed into the roundabout is $10m/s$. The signal is propagated over the intermediate relay RMUs in multihop manner using an authentic Medium Access Control protocol [2] developed to meet the latency, reliability and security requirements. When the signal reaches the base station it activates the warning application in RMUs placed on the border of the roundabout, marked yellow. This application creates a visual effect of a running light in the driving direction of the roundabout.

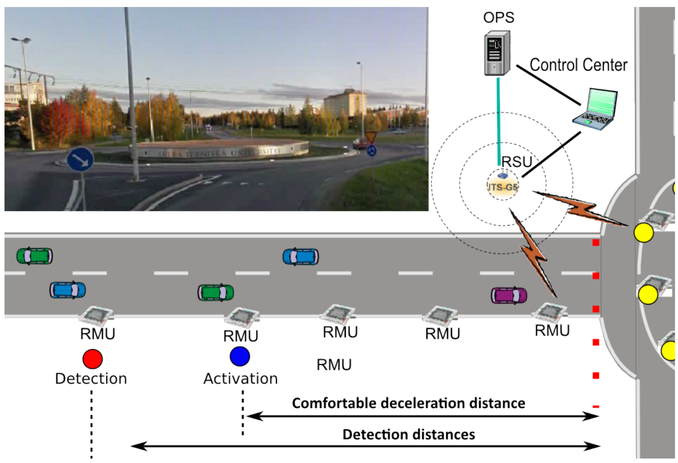

Fig. 2: The test site set up at LTU [3].

In spite of the seemingly simple application the design of the major hardware and software components of the system is far from being trivial. The system has to be responsive. For example if a car is approaching with a speed of $20m/s$ it will need $2s$ to comfortably decelerate to the entrance speed of $10m/s$. Therefore, the system has to detect the car, propagate the message and activate the running light application before the car will be at least 30m from the roundabout. This places strict timing and reliability requirements on the communication components of the system. These are not trivial to achieve in the real system due to rather orthogonal optimization problems (timing versus reliability versus energy efficiency) which needed to be considered during the design and the intrinsically unreliable wireless communication medium.

III. Demo Description

In our demonstration we will show the following:

1) Samples of LED-Guides, the enabling hardware technology for the proposed RSN architecture.
2) A lab version of the whole system prototype.
3) An online demonstration of the real installation's functionality in real time.

A. LED-Guides - the RMU

An RMU depicted in Fig. 3 is situated on the road surface endures the toughest of conditions: being overrun by cars, trucks, heavy vehicles, and harsh weather with rain and snow, not to mention snow plowing. The RMUs are composed of a number of subsystems including sensing and signal processing blocks, actuators and low power wireless communication components.

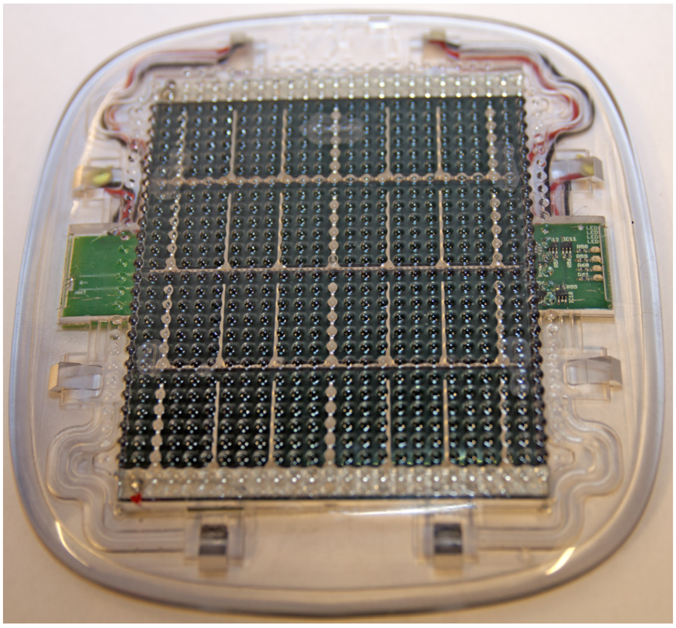

Fig. 3: Road Marking Unit - LED-Guide.

B. Car Detection Technique

Fig. 4 illustrates the detection algorithm used in sensor nodes. Vehicle detection is achieved by using a magnetometer that measures the change in the magnetic earth field induced by a magnetized metallic mass passing the sensor. Work flow of the detection algorithm: firstly, the static offset from the measured magnetic field strength is removed and the disturbance is derived. Secondly, the magnitude of the disturbance is calculated and thresholded. If the threshold is exceeded for a longer time period the disturbance is accounted to a vehicle and the detection flag is set to 1. In order to prevent double-detections of a single vehicle, a dead-time is added after each detection in which no detections are allowed.

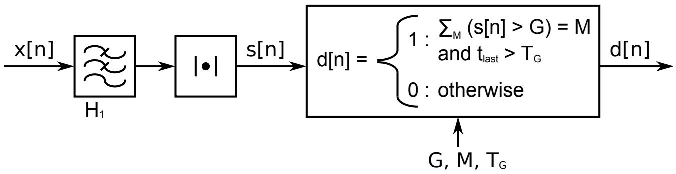

Fig. 4: Car detection.

C. A Lab Prototype of the System

The lab prototype of the system demonstrates car detection, secure multihop communications, and the running light application. During the demonstration the RSU, the backend server and the control center are shown as an entity on a single laptop. The car detection is done on a miniature race track with an RMU equipped with a magnetic sensor. We demonstrate the remote system configuration and management of the intelligent roundabout ITS.

D. Demo Execution

The car detection mechanism is shown on a miniature race track where the running light application is installed; the system parameters are set via control center and then deployed in the network.

IV. Conclusions

The emerging usage of Wireless Sensor Networks for Intelligent Transportation Systems is placing new demands on the architecture of WSN. In this demo we show an implementation of a remotely controlled Road Surface Network. We show the feasibility of the proposed architecture, possible pitfalls and the potential for improvement.

Acknowledgements

The research leading to these results has received funding from *Gunnar och Märtha Bergendahls Stiftelse*, GEVEKO AB and the Swedish Governmental Agency for Innovation Systems (VINNOVA). Students that have participated in different parts of the project are gratefully acknowledged.

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Invited Project Posters

Invited Poster:
WSNLab – A Security Testbed for WSNs

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***Abstract*—As the research of Wireless Sensor Networks (WSNs) focuses more and more on real-world scenarios (such as public safety), security issues become increasingly important. The goal of the project *WSNLab* is to set up a heterogeneous testbed for the evaluation of security measures in WSNs. For this purpose, a light-weight security architecture is specified. Furthermore, selected attacks and countermeasures are implemented and evaluated.**

I. Motivation & Objectives

Wireless Sensor Networks (WSNs) are deployed in a steadily growing plethora of application areas. Especially their deployment in the industrial, military, and medical domain renders security in these networks an issue of high relevance. The main goal of the German Federal Office for Information Security (BSI) funded WSNLab project is to build a WSN laboratory for the evaluation of security measures. A second goal is to develop, implement, and evaluate a security architecture for stationary and mobile WSNs. The work is supposed to consider different hardware and software platforms. Thus, all evaluations are performed within a testbed consisting of multiple operating systems and sensor platforms to ensure broad system support. As localization and (concerning security) dislocation are important aspects in WSNs, different localization algorithms are implemented and evaluated as well.

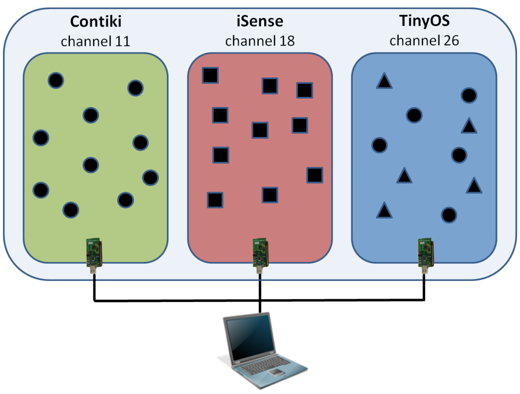

Fig. 1. WSNLab security testbed

II. Partners

The project is led by the communication systems group of the University of Bonn. This group brings in its experience on security and tactical wireless multi-hop networks. Within the project, they are responsible for the lab itself, which is located in Bonn, as well as the security architecture. The WSN experts of the Institute of Telematics (ITM) from the University of Lübeck and the Coalesenses GmbH provide their experience on iSense and WSNs in general. In this project, both take care of reliable and robust localization.

III. The Security Testbed

The heterogeneous testbed in its current setup consists of three operating systems (Contiki [3], iSense [2], and TinyOS [7]) running on three hardware platforms (TelosB [11], MicaZ [10], and iSense-CM10C [8]). Figure 1 visualizes the basic setup.

A simple collector application on the nodes collects and transmits the sensor data to the sink. As routing protocols, we run the Collection Tree Protocol (CTP) [6] and the IPv6 Routing Protocol for LLNs (RPL) [13]. Beside Over-the-Air-Programming, the testbed supports topology management for realizing complex topologies using virtual links (cf. [1]).

For evaluation purposes, we added a Jackdaw IEEE 802.15.4 Sniffer [12] (running Contiki) to the testbed. This device allows us to capture all packets of a wireless channel and analyze them using tools like Wireshark [14]. Moreover, we use a GNU Radio [5] USRP-Board [4] to run jamming attacks.

IV. The Security Architecture

An attacker can achieve his objective(s) through different kinds of attacks. These can be categorized based on the targeted layer. Figure 2 shows a threat analysis as well as countermeasures for WSNs. The threat analysis is first divided into the goals of the attacker. A goal is further connected to

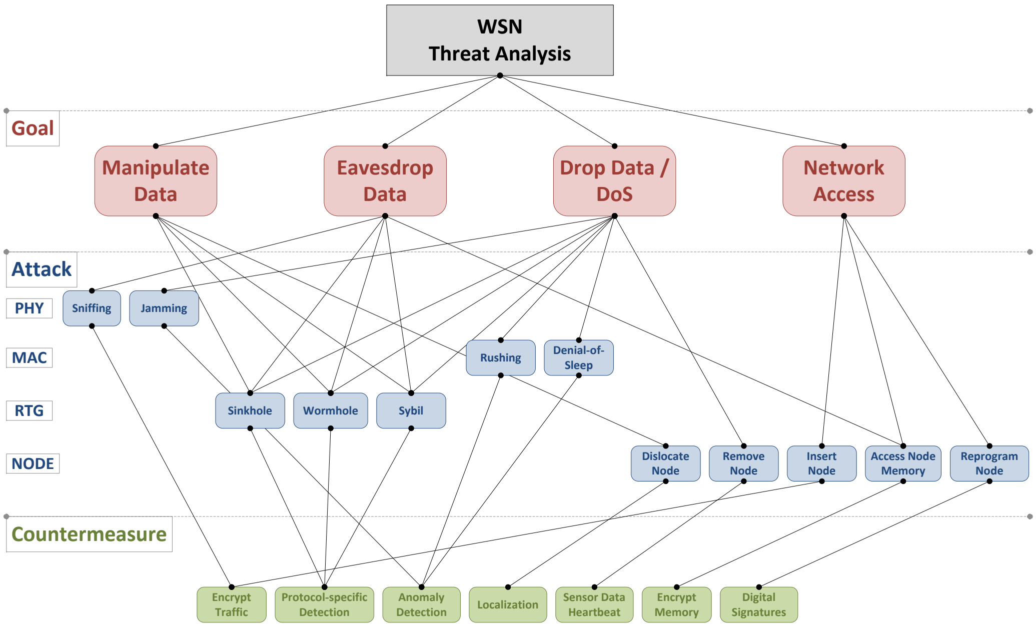

Fig. 2. Threat analysis and countermeasures for WSNs

the attacks that may be used to reach that specific goal. The attacks are grouped by the layer on which they are conducted.

The specific properties of WSNs lead to special attacks as well as new challenges for countermeasure development: The resource scarcity of the nodes in terms of computing power, memory, energy, and bandwidth requires countermeasures to be light-weight but also effective at the same time.

V. Localization

In addition to the security architecture, different ranging technologies and localization algorithms are simulated, implemented and experimentally evaluated. For single-hop ranging, distance estimation based on RSSI and time-of-flight are used and compared with regard to performance. Sum-Dist, DV-Hop and Euclidean schemes [9] are employed to convert distances from single-hop to multi-hop. Min-Max and Lateration algorithms [9] come into operation for position estimation.

VI. Conclusion and Future Work

We have introduced the project WSNLab. The security testbed architecture, threat analysis, and considered localization schemes were surveyed. In the future, we will implement and evaluate the security architecture in our WSNLab testbed.

Acknowledgments

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Invited poster: GINSENG: Performance Control in Wireless Sensor Networks

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***Abstract*—The goal of the GINSENG project is a performance-controlled sensor network suitable for time-critical applications like plant automation and control. Such sensor networks must monitor performance constantly and collect data in order to detect, diagnose and rectify problems. The GINSENG system contains a number of mechanisms used to collect, transport and analyse performance critical data. Performance data processing is carried out in a manner that ensures time-critical application data processing is not affected. In this paper we present the different performance debugging mechanisms included in the GINSENG system.**

I. Introduction

Most industrial process control and automation applications can be considered time-critical. In these scenarios, control loops are mapped onto wireless sensor networks. For such control loops to function, data needs to be delivered to a sink reliably and within a given time bound [1]. Furthermore, it might be necessary to react upon the received data and take a corrective action. Such a command needs to be sent from the sink to an actuator in the sensor network reliably and within a given time bound. As WSNs are considered to be relatively unreliable, they have seen little use for such tasks so far.

The EU-funded GINSENG project [2] aims to develop a WSN system that can be used to support the aforementioned time-critical applications. Unlike applications that are based on random deployment, GINSENG assumes a carefully planned and deployed network of sensor nodes as a basis to achieve performance control. GINSENG provides novel software components (for example, Operating System and TDMA Medium Access Control) and algorithms (for example, topology control and flow control) to ensure time-critical data delivery.

Due to the inherent uncertainties of the wireless communication medium, it is possible to experience changes in the operating environment that result in undesired deterioration in network performance, motivating the need to monitor and potentially debug the performance of a deployed GINSENG system. Therefore, GINSENG provides mechanisms and tools to carry out performance debugging of deployed systems and enable reconfiguration when given performance metrics can no longer be achieved. Within this paper the GINSENG performance debugging mechanisms are detailed.

Fig. 1. The GALP oil refinery in Sines, Portugal.

II. The GALP Refinery Application Scenario

The GALP oil refinery at Sines, Portugal, is used as a test application scenario for GINSENG. The refinery is a complex industrial facility that includes a wide range of processing, and such processing needs careful monitoring and control of operations. There are currently approximately 35000 sensors (some shown in Figure 1) and actuators in use in the refinery to perform real-time monitoring of industrial operations and systems allowing detection of leaks, measurement of pressure in pipes, fluid levels in tanks and providing data on environmental conditions. The monitoring of the environment in a refinery provides essential information to ensure the good health of both the refinery and its production processes.

The refinery provides a challenging environment as machinery and metal structures create interferences and obstacles that a deployed sensor network must handle. In such a testing domain performance debugging is essential.

III. The GINSENG System

Sensor nodes in a GINSENG system are deployed in groups (cells) of a few dozen nodes. Each cell uses a TDMA MAC protocol to ensure that data is delivered to a sink in a timely and reliable manner. The sink is connected to a wired backbone infrastructure. Multiple cells operating on different transmission frequencies might be used to accommodate a large number of nodes. Before network deployment a TDMA schedule for each cell is determined. This schedule must incorporate room for application and performance related data, corrective action messages and also allowing for potential message re-transmissions. Thus, the deployed network can compensate for link quality fluctuations to some degree by using retransmissions and topology re-structuring. However, these compensation mechanisms are limited and fail if link quality fluctuations exceed bounds anticipated at deployment time. Therefore, it is necessary to monitor the deployed network and to collect data that allows us to calculate a new schedule and adjust the deployment if needed.

IV. Performance Debugging in GINSENG

Each sensor node in a GINSENG system monitors network performance parameters. The majority of collected information is stored on nodes and is only transported to the sink when performance problems occur. After requesting performance debugging information from nodes, tools can be used to debug the network and isolate performance problems. The following describes the performance debugging system.

A. Data Collection

Active and passive methods are used to collect performance debugging data. Active data collection requires nodes to send dedicated probing packets in addition to application data packets. For example, GINSENG uses a probing mechanism to periodically measure burst error patterns of all links used in the deployment [3]. Passive data collection uses existing data transmissions to gather additional performance information. For example, the received signal strength of incoming data packets. The combination of active and passive methods ensures collection of rich performance debugging data.

B. Data Storage

A large amount of operations information is kept on each node within a Management Information Base (MIB). This MIB is available to all modules of the system and can be used for diagnosis of detected performance problems.

The limited bandwidth available in WSNs means only a fraction of the information available to nodes can be transported to the sink over the air. Rather than disregarding all of this unsent data we store some of it in the nodes onboard flash. Two flash storage systems are used, the Coffee file system provided by Contiki and a ring-storage system we designed. The ring-storage system targets scenarios with mainly sequential read and write operations, such as for error logging. Storing data in the flash provides a comprehensive archive that can be queried when required.

C. Data Transport

Along with the application data and the necessary fields required for message transport we include a timestamp, hopcount and sequence number in each message. This small amount of 'piggybacked' data provides delivery delay and packet losses which are key performance metrics in any WSN.

Excessive delivery delays or packet losses indicate performance anomalies in the network. However there are many possible causes of such problems, in order to diagnose them further information may be required. We provide a system to request this data from a specified node along with all the nodes along the path between the node and the sink.

D. Data Analysis

Data analysis can be performed both in the network and at the sink. Previously we presented a storage-centric approach for analysing performance anomalies in deployed sensor networks [4]. In this approach we have leveraged the local flash storage of sensor nodes to log performance data and combined this with on-node statistical analysis. For example, we have used data at the node to verify that there is a correlation between environmental conditions and the required transmission power for successful communication. Our results have shown that it is not only feasible to store and analyze large quantities of data on the nodes, but it is also more energy efficient than sending all data to the sink for analysis.

For analysis purposes at the sink resp. in the backbone infrastructure, we introduced a dispatcher component between the WSN and the wired backbone. This component reads, parses and augments incoming raw data (e.g., with packet delay). It formats the data and makes it available to other consumer components. Consumers can be backend data processing systems as well as monitor and debugging components. The monitor application is one such consumer that provides a GUI that network operators can use to get information on the overall network and individual nodes helping with the diagnosis of performance anomalies in the WSN.

V. Conclusions

The main goal of the GINSENG project is to provide a wireless sensor networks with performance assurances for important metrics such as delay and reliability which are crucial for a broad class of emerging sensor network applications. In this paper, we have presented the GINSENG approach to the performance debugging of the wireless sensor network.

Acknowledgments

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Invited Poster: makeSense: Easy Programming of Integrated Wireless Sensor Networks

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***Abstract*— WSNs are expected to play a critical role in the next computing revolution, as depicted in the visions of Cooperating Objects and the Internet of Things. However, designing and developing WSN software is currently very difficult. This may prevent WSNs from reaching large-scale adoption, especially in industry. The make*Sense* project aims at enabling an easier integration of WSNs in business processes, by allowing business process experts and WSN developers to express the high-level functionality required, while leaving low-level details to the compiler and run-time system. We envision the results of make*Sense* to be not only a landmark for WSN software development, but also a new way to look at WSN programming that increases productivity and business value, enabling a far-reaching adoption in key industrial domains.**

I. Introduction

Wireless Sensor Networks (WSNs) are a key component towards the integration of the physical and virtual worlds, as depicted in the visions of Cooperating Objects and Internet of Things. However, their widespread adoption in industry is still limited. Factors that hinder a more widespread adoption are the difficulty of WSN programming, as acknowledged in the CONET research roadmap [2], and the limited support for integration with existing IT infrastructures. In particular, although several programming abstractions are available in the literature [3], almost none of them explicitly supports the integration of WSNs with business processes.

The EU-funded make*Sense* project enables such integration by devising programming abstractions to express the high-level WSN functionality within existing business process modeling concepts. This allows for seamless specification of the behavior of the WSN and the surrounding business process. Low-level details are then left to a dedicated compiler and run-time system. The name, make*Sense*, reflects both purpose and ambitions of the project. The first part of the name, `make`, refers to the `make` tool, the software development utility that relieves developers of software development details.

Section II of this paper illustrates the make*Sense* approach and the overall architecture. Section III elaborates on the expected results of the project and concludes.

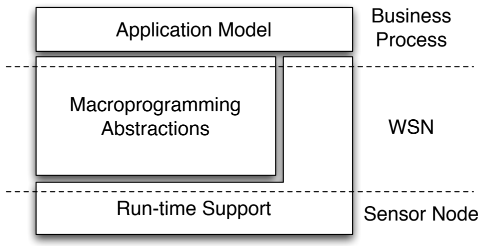

Fig. 1: make*Sense* architecture.

II. Approach

Consider an automatic building ventilation system that integrates with an on-line meeting room reservation application. The current approach is to manually ventilate the room either at fixed intervals irrespective of any meetings, or to trigger the ventilation manually, e.g., by the meeting participants. Smart control strategies for ventilation systems may allow to adjust the ventilation levels to the actual demand, based on a room's scheduled and monitored occupancy, while assuring adequate environmental quality. This can save up to 30% of the energy used for air conditioning in a building. The latter account for more than 40% of the energy consumption in Europe.

The smart control system uses WSNs to check the presence of people and the CO_2 levels in rooms. The CO_2 monitoring starts 15 minutes prior to a meeting. If CO_2 is above a specific threshold, the system automatically triggers the ventilation. This check continues periodically. Additionally, 15 minutes after the scheduled start of the meeting, the system starts monitoring the presence of persons. If presence is detected, the system updates the status of the room in the reservation application to "occupied"; otherwise, the room status is set to "available" and the periodic monitoring of CO_2 stops.

To ease the design and implementation of applications such as the one described above, make*Sense* follows an approach consisting of three layers, as depicted in Figure 1:

- The *application model* layer integrates sensor networks with business application systems by allowing WSN behavior to be expressed within a business process model.
- The *macro-programming* layer provides a network-centric

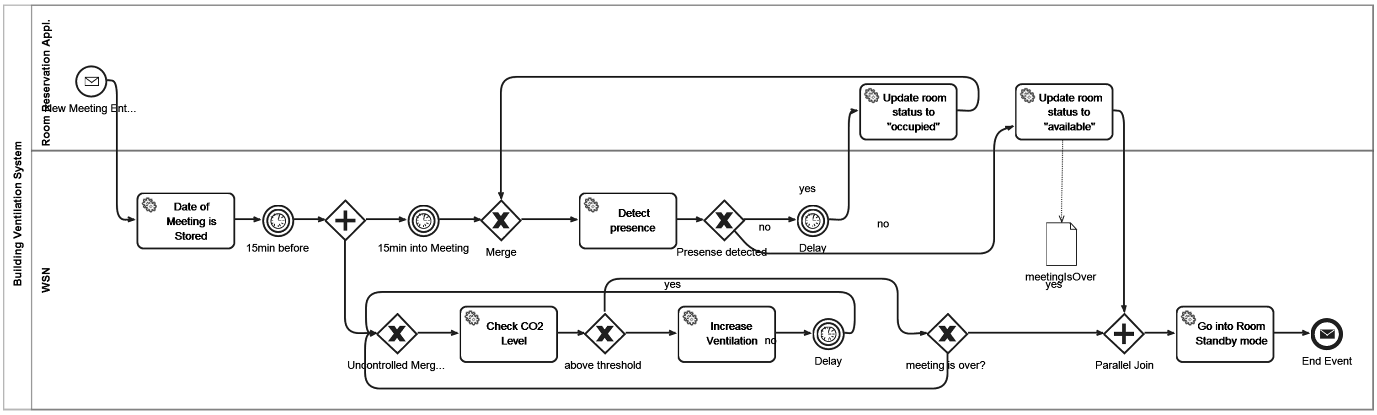

Fig. 2: Meeting room ventilation system: overall business process.

programming abstraction that relieves programmers from the low-level details, also allowing existing and future abstractions to blend smoothly.

- The *self-optimizing run-time system* layer adapts to the specific conditions in the deployed sensor network by optimizing communication and resource consumption based on inputs from the higher layers.

In make*Sense*, we use BPMN (Business Process Modelling Notation) at the application model layer, as this is the de-facto way in industry for specifying business processes. Moreover, BPMN is today integrated in the majority of tools used by business process developers, and compliance with such tools may foster a quicker adoption of make*Sense*.

Figure 2 depicts the BPMN specification of the meeting room ventilation system. Through a refinement step, developers specify the WSN processing to carry out the activity “Detect presence” and “Check CO_2 Level”. These WSN-specific functionality are expressed using custom BPMN constructs that may include constraints on sensed data, e.g., the conditions to detect the presence of persons.

The BPMN specification is used as input by the make*Sense* model compiler, along with the network model and high-level performance objectives. The former includes information on the application-level characteristics of the deployed nodes, e.g., their capabilities and logical location (e.g., “room ABC”). The latter express preferences on possibly conflicting performance goals; for example, to optimize energy consumption at the cost of increased latency.

Based on this information, the compiler outputs a macro-program that describes the WSN processing using high-level, network-wide programming constructs. For instance, the macro-code required for CO_2 monitoring looks like:

```
co2sensors ::= Type = ``sensor'' AND Function = ``CO2''
controller ::= {count (room) { role == controller } == 0}

when [co2sensors] report [suddenIncrease]
tell [controller] to [increaseVentilation]
```

The fragment of code above determines a subset of nodes responsible for sensing the CO_2 levels, and elects one controller per room in charge of triggering the actuation when necessary. The language leverages existing WSN abstractions, Logical Neighborhoods [3] and Generic Role Assignment [3] in this case, by integrating them seamlessly in the same programming framework. The macro-program is then input to a macro-compiler, along with the network model. The macro-compiler translates the network-wide program in executable node-level code, depending on the nodes capabilities and role.

The executable code runs atop a dedicated run-time layer, based on the Contiki [1] operating system. In addition to enabling dynamic reconfiguration of the deployed functionality, the run-time layer continuously runs a monitoring and self-optimization process. This provides feedback to the application model layer on the current system performance, and adapts the system operation based on the user-defined performance objectives and the current network conditions.

III. Expected Results and Conclusion

The core contribution of make*Sense* is a comprehensive programming system that enables the integration of WSNs and business processes. The programming platform is supported by a complete tool-chain starting from business processes down to the code running on the individual nodes, including tools to assist the developer in the programming activity and the compiler technology required to bridge the gap between the (business) application level and the WSN hardware.

We plan to evaluate the results in a real-world scenario. One possibility is precisely to deploy a prototype system developed with make*Sense* in the context of a building ventilation system. To this end, we will introduce wireless sensors performing real-time metering of relevant environmental parameters and the current energy consumption of the building. We will then qualitatively and quantitatively assess the developers’ productivity as well as individual component and overall system performance.

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Invited Poster - Middleware for Networked Embedded Devices

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Abstract— **The HYDRA project developed the LinkSmart middleware for networked embedded systems that allows developers to create ambient intelligence applications based on wireless devices and sensors. Through its unique combination of Service-oriented Architecture (SoA) and a semantic-based Model Driven Architecture, HYDRA enables the development of generic services based on open standards. A smart home application is built that facilitates intelligent communication of heterogeneous embedded devices through an overlay P2P network. We interconnect common devices available in private households and integrate wireless power metering plugs to gain access to energy consumption data. These data are used for monitoring and analyzing consumed energy on device level in near real-time. Apart from that the evolution of the LinkSmart in four new started FP7-projects is presented**

I. Introduction

Global warming — and its desastrous environmental and economic effects — is considered one of the major challenges that mankind will face during this century. The problem is mainly attributed to CO2 emissions that, for example, arise from the generation of electricity from fossil fuels. One way to reduce emissions of CO2 is therefore to reduce the overall consumption of electricity in industry and the private sector; especially the latter one is what several national and international initiatives aim at.

Home owners themselves have a high interest in reducing energy consumption because energy is an important private cost factor. Usage awareness alone has potential to reduce consumption by as much as 15% in private households [1]. However, electricity meters that are widely deployed in homes today, and the suppliers' analog billing systems based on yearly accounting periods, lack the feedback capabilities that are necessary to increase energy awareness and positively affect customers' behavior [2]. Smart metering shortens the feedback time from consumption of the energy to user billing considerably, and only by this enables energy awareness.

Yet current solutions of smart metering are proprietary and generally not generic or flexible. Even an agreement on a common standard for smart metering technology, protocols etc. does not seem to be in sight. Thus, to bring to the users the benefits of smart metering, it is worth researching generic solutions that are linked to the user and control at device level rather than to the energy providers. Intelligent smart home environments seem to be a promising basis for incorporating energy efficiency features in private households. Besides pure monitoring, such smart homes already provide the infrastructure to use e.g. energy pricing information to control devices.

Hydra as basis for interconnecting household appliances lays the ground for the presented energy aware smart home system. We realize not only monitoring but also control functionality with innovative approaches to user interaction [8]. We show that Hydra as a generic middleware framework serves well as for integrating energy awareness into the smart home and puts private households in control.

II. Hydra

The HYDRA project [3] developed the LinkSmart middleware for networked embedded systems that allows developers to create ambient intelligence applications utilizing device and sensor networks. Through its unique combination of Service-oriented Architecture (SoA) and Model Driven Architecture, the LinkSmart middleware will enable the development of generic services based on open standards. In particular, the LinkSmart middleware operates with limited resources in terms of e.g. energy and memory and allows interoperability of complex processes as well as heterogeneous infrastructures, services and devices. Hydra addressed three application domains: home automation, healthcare and agriculture.

The LinkSmart middleware can be incorporated in new and existing networks of distributed devices, which operate with limited resources in terms of computing power, energy and memory usage. It allows developers to incorporate heterogeneous physical devices into their applications and provides easy-to-use web service interfaces for controlling physical devices irrespective of their network interface technology. Based on a semantic Model Driven Architecture for easy programming it incorporates means for device and service discovery, peer-to-peer communication and diagnostics. LinkSmart-enabled devices offer secure and trustworthy communication through distributed security and social trust components of the middleware. The Hydra Software Development Kit (SDK), Device Development Kit (DDK) and IDE (Integrated Development Environment allows developers to create new networked embedded AmI applications and devices quickly and cost effectively.

In Hydra Ambient Intelligence (AmI) applications, any physical device, sensor, actuator or subsystem can be considered as a unique web service. A major novelty in the Hydra approach is that the middleware provides support for using devices as services both by embedding services in devices and by proxy services for devices. Another novelty is that the middleware supports dynamic reconfiguration and self-configuration, which are indispensable properties in any AmI application [4], [5]. To assist application developers in addressing a wide variety of mobile and stationary devices and networks, the LinkSmart middleware hides device-dependent and network-dependent details and provides comprehensive open interfaces to the display, communication port, input facilities and memory management of each class of device.

A novel implementation in the LinkSmart middleware is the use of peer-to-peer (P2P) network technologies to identify and utilize the services available in the network, even if they are behind firewalls or NATs, [6]. P2P pipes are used as an alternative to WS communication between Hydra-enabled devices.

III. Energy Efficiency in Home Automation

The presented application [8] aims at integrating energy efficiency into a smart home infrastructure, providing intuitive user interfaces for monitoring and controlling the smart environment. The user can interact with the system via both, stationary and mobile interfaces. Cumulative and comparative views on devices and energy consumption are presented on a large scale display like a TV, etc.

The interface provides easy-to-compare per device information including current consumption in watts, costs per hour, and costs projected over one year using an adjustable average per-day usage time. Costs are calculated taking into account the electricity price, which depends on the daytime. Cumulated consumption and cost data of all devices are shown as well. All values are updated every second. On their mobile devices, users can directly access appliances using UbiLense.

Figure 1 shows an example of the UbiLense interaction concept. It recognizes objects using image processing methods and displays energy consumption information about that device.

Figure 1. Mobile device

In future smart homes, energy efficiency will be a major issue, when considering advancements in the area of smart metering and smart grids [7]. Energy providers will have to react to liberalized markets, micro energy generation and resulting user requirements. For example, time-of-use and real-time pricing may help both, consumers to save energy costs in households and energy providers to improve load management [2]. We believe that an energy aware smart home application has to find a balance between supporting the user in saving energy and at the same time not decreasing convenience. Thus, besides pure monitoring of energy consumption, we provide novel control functions on device level for increasing energy efficiency in households. On the stationary control device, users can manually change the energy price and are continuously informed by the system regarding changing energy costs. It is vital to provide control on device level in order to take full advantage of the energy saving potential of appliances already present in the household. To demonstrate features of future energy usage, we integrate a washing machine into the smart home application. Users can individually program this virtual washing machine by setting a limit for the energy price. If the price falls below this limit, the washing machine starts.

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Invited Poster: EUCLID Project
Strengthening EU-India Collaboration in Networked Monitoring and Control Systems Technologies

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Abstract - **This poster presents the recently launched EUCLID support action project "Strengthening EU-India collaboration in networked monitoring and control systems technologies", funded by the European Commission under the 7th Framework Programme. Wireless Sensor Networks and Cooperating Objects is one of the major topics of the project, also identified as a research priority in the FP7 ICT Work Programme.**

I. Introduction

NOWADAYS, India and the European Union face common challenges in many fields of the citizens' life and in particular in the development of the ICT.

Economic and societal problems in India exist in different domains, such as transportation, industrial automation, and healthcare. All of these areas represent applications for networked monitoring and control system technologies and particularly for the very important and developing field of Wireless Sensor Networks and give ground for hand-in-hand work between Europe and India.

As the EU has a rich history in monitoring technologies development, many things in India and Europe have followed common models. Consequently, India benefits from the European experience in all sectors thanks to the large EU research community.

The current situation creates a favourable environment for strategic collaboration and mutual learning for both the EU and India. In addition to serving as a source of challenging problems, India represents a huge economic opportunity for the European Union: the market sizes and opportunities for monitoring and control applications are in the billions of Euros, and European companies need to gain a competitive advantage in order to pursue these opportunities. Furthermore, India represents an incredible pool of talented and motivated people who are willing to collaborate.

In this context, the European Commission has decided to support the EUCLID project (www.euclid-india.eu), under the FP7 Theme 3 "Information and Communication Technologies (ICT)" in order to stimulate the cooperation between the European Union and India in the field of Engineering of Networked Monitoring and Control systems.

Started on 1st June, 2010, the ambitious two-year EUCLID project aims to explore new opportunities and strengthen the EU-Indian cooperation in the networked monitoring and control systems, in order to support Europe's leading position in monitoring and control, focusing on the research priorities identified in the FP7 ICT Work Programme 2009, such as the **Wireless Sensor Networks and Cooperation Objects**, while ensuring mutual benefits for both Europe and India. Furthermore, EUCLID addresses areas of crucial importance to Indian citizens. Several domains, such as healthcare, transportation, and industrial automation are covered by the project.

II. Societal and Industrial Needs in India: Focus on Transportation, Industrial Automation and HealthCare

A. Healthcare

Healthcare services need sophisticated medical instruments that make use of multiple varied sensors to monitor vital health parameters. An infrastructure that can effectively store this heterogeneous data in a form that supports efficient re-trieval could be put to great use. Such a database would constitute a key component in the creation of a decision-support platform that would provide the healthcare services with an instantaneous, sensor-based snapshot of a patient's condition that would aid in the diagnosis. Here, information technology is initially used to pool together the various heterogeneous sensor data collected to provide an instant, consolidated picture of the patient's condition. The display platform can utilise information stored in a healthcare database, and provide decision support. The platform will also possess a wireless communication capability, thereby permitting the opinion of a remote healthcare expert to be sought. Where one network alone will not suffice or prove sufficiently reliable, can non homogeneous wireless networks (e.g., cellular, WiMaX, WiFi, and wireless personal area networks) be used in an ad-hoc manner to transport information? This will require technologies such as software defined radios and cognitive radio algorithms to determine which among the various available networks to operate on. Research is also needed on higher-level networking protocols that will facilitate the setting up of connections across non-ho-mogeneous technologies and in maintaining quality of service.

B. Transportation

India's road (and air) traffic has grown enormously, keeping in pace with its growing economy. This has led to significant problems in traffic management. The data collected by varied sensors placed all across the city needs to be transmitted to a central traffic management centre(s). In the near future vehicles would be integrated with traffic control centres and information would pass back and forth. These demand highly reliable communication technologies, and wireless systems holds great promise for this. A national collaborative program on Intelligent Transportation System (ITS), covering various technology modules, has been formally launched, 8 ITS Sub projects developing a Wireless Traffic control system, Second Generation Area Traffic Control System, Intelligent Traffic Congestion Management System using RFID, Intelligent Transit Trip Planner have been and funded. Wireless enabled systems are a prime enabler.

C. *Industrial Automation*

Wireless solutions/products are gaining strong interest in the Indian market. There is also a societal aspect to this; India is expected to leapfrog wired communications and jump directly to wireless communications for the vast rural population as well. The expected future trend in India for industrial wireless systems are towards a large number of sensors which will be connected with wireless links and form sensor networks. These self powered wireless sensors and networks can be used for remote monitoring of industrial equipment. These types of communications systems (e.g. low cost, low power) will drive this trend in India. Furthermore, the standard problems in wireless, e.g. optimal coverage of an area with sensor networks, security of the network etc are also issues that need to be addressed for the Indian market.

The ground for development of the Wireless Sensor Networks in India is continuously growing. Many Indian organisations, including academic institutes & companies have strong teams working in this field, in particular:

- IIT- Delhi, led by Professor B.N.Jain
- IIT- Bombay, led by Professor B.N.Jain and Professor U.B. Desai
- IIT- Kharagpur, led by Professor R.V. Raj Kumar and Professor Saswat Chakraborthy.
- IISc, led by Professor K.V.S Hari, Professor R. Vijaykumar, Mr. T.V Prabhakar
- TCS, Mr Balamurali- Head, Wireless and Embedded Systems Research
- Wipro, led by Mr Ramachandra Budhihal
- HTS, led by Mr Arun Mahasenan, Head, Wireless Systems Research

The EUCLID project is currently undertaking a "mapping" of Indian organisations (including those specialised in wireless sensors networks and cooperating objects) who are willing to cooperate with European research organisations. The "catalogue "with cooperation opportunities will be available on line on the EUCLID project web-site in 2011.

III. EUCLID Project Support: Opportunities and First Results

The EUCLID project has been running for six months only, but the first results have already been achieved and new cooperation opportunities for the EU and Indian specialists have already been offered for example:

A. *Customized hands-on support*

The project team helps Indian and European organisations to identify relevant competencies and skills, complementing their FP7 consortia and teams, and helping them to achieve successful collaborative research. 3 Indian organisations are already being supported in order to integrate with the European research consortia, to submit FP7 ICT proposals. A workshop explaining FP7 cooperation opportunities for Indian colleagues has been recently organised in Bangalore, India.

B. *Prospecting and Partnership Visit to India*

Seven European monitoring and control specialists participate in the visit to India organised by the EUCLID project on 18-22 April 2011 in Bangalore and Mumbai. The goal is to bring potential research partners from the EU and India together and to help EU specialists build up win-win research partnerships with Indian partners..

C. *Promotion of post-doc and PhD opportunities in Europe in India*

EUCLID promotes PhD and post-doctoral opportunities for Indian young researchers in the EU, and has publicised them widely in India. The team welcomes new enquiries.

D. *Set up of panel discussions and workshops*

EUCLID prepares two workshops/panel discussions:

⇒ Energy and Environmental Challenges in Emerging Regions - Opportunities for Control and Monitoring Technologies (IFAC WC, August 2011), to inform the audience about issues associated with increasing energy use and its environmental impact, with special reference to emerging regions, and to discuss how monitoring, control, and optimisation technologies can address these issues.

⇒ Foundations and future perspectives to cooperate in monitoring and control with India (ECC-CDC-2011, December 2011), to remind foundations and Indian contributions about monitoring, systems and control research, to highlight cooperation experience with India in monitoring and control and to present collaboration opportunities and to discuss cooperation prospects EU-India.

IV. Conclusion

Thanks to the support of the European Union' 7th Framework programme, the EUCLID project offers discussion panels and numerous cooperation opportunities for monitoring and control specialists and will continue its actions until May 2012. The project team has adapted a flexible pro-active approach and welcomes cooperation enquiries and new ideas that would aim to support Indian participation in European research, in particular in WSN, and to reinforce EU-Indian R&D cooperation in monitoring and control systems technologies. The EUCLID team, through its website www.euclid-india.eu welcomes enquiries from monitoring and control systems researchers from EU and India and all interested parties, and is ready to provide relevant support to reinforce EU-India cooperation.

Invited Poster: EMMON: A System Architecture for Large-Scale, Dense and Real-Time WSNs

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***Abstract*—In spite of the significant amount of scientific work in Wireless Sensor Networks (WSNs), there is a clear lack of effective, feasible and usable WSN system architectures that address both functional and non-functional requirements in an integrated fashion. This poster abstract outlines the EMMON system architecture for large-scale, dense, real-time embedded monitoring. EMMON relies on a hierarchical network architecture together with integrated middleware and command&control mechanisms. It has been designed to use standard commercially–available technologies, while maintaining as much flexibility as possible to meet specific applications' requirements. The EMMON WSN architecture has been validated through extensive simulation and experimental evaluation, including through a 300+ node test-bed, the largest WSN test-bed in Europe to date.**

I. Introduction

Wireless Sensor Networks (WSNs) have been emerging as underlying infrastructures for new classes of large-scale and dense networked embedded systems. While there has been a plethora of scientific publications on WSNs, the vast majority focuses on protocol design (e.g. medium access control, routing, data aggregation) while only a scarce number of papers report real(istic) applications [1]. This might be due to the following facts: (i) WSN technology is extremely expensive for large-scale systems, contradicting the initial "less than 1$ per node" vision; (ii) WSN technology is still very limited and unreliable, particularly in what concerns communications; (iii) difficulty on finding "killer" applications with a good cost/benefit trade–off; (iv) unavailability of standard, application-adequate, mature and commercially available technology; (v) lack of complete and ready-to-use WSN system architectures, able to fulfill both functional and non-functional applications' and users' requirements.

Despite relevant work on WSN architectures proposed so far (e.g. [2] – [8]), to the best of our knowledge, none of them fulfills all requirements for large–scale and dense real–time monitoring [9], [10]. The EMMON system architecture [11] outlined in this poster abstract pushes the state-of-the-art by combining the following aspects:

- it encompasses all system components: Command and Control (C&C) graphical user interface, communication network architecture, middleware over a standard and commercially available hardware platform;
- it considers several Quality–of–Service (QoS) properties simultaneously, e.g. scalability, timeliness (including real–time support), energy–efficiency and reliability;
- it builds upon a deep analysis of specific user/application requirements [12], problems to address [9] and previous work [10], ranking solutions/technologies according to a set of criteria;
- it is based on the most widely-used standard and COTS technologies for WSNs - IEEE 802.15.4 and ZigBee, which is good for system designers and end–users;
- it augments IEEE 802.15.4 and ZigBee with important add–ons, such as traffic differentiation, time–division cluster scheduling, dynamically adaptable duty-cycling, mitigation of the hidden–node problem and downstream geographical routing;
- the baseline IEEE 802.15.4 and ZigBee protocol stack is supported by a solid critical mass, developed in synergy with the TinyOS 15.4 and ZigBee Working Groups;
- it is supported by a unique and complete planning, dimensioning, simulation and analysis toolset;
- it has been tested and validated by extensive simulation and experimental evaluation, including through a 300+ nodes test-bed (DEMMON1 [11]). This first prototype serves as a baseline pilot experiment to support development of more system functionalities in the near future.

II. Outline of the EMMON system architecture

The EMMON system architecture aims at supporting scalability and QoS support through a hierarchical network, middleware and command and control design, as outlined next.

A. WSN architecture

Building on the alternatives identified in [10], the main features of the WSN architecture are (Fig. 1):

- Tier 0: IEEE 802.15.4 operating in synchronous mode, supporting traffic differentiation (e.g. best-effort and real-time) and duty–cycling.

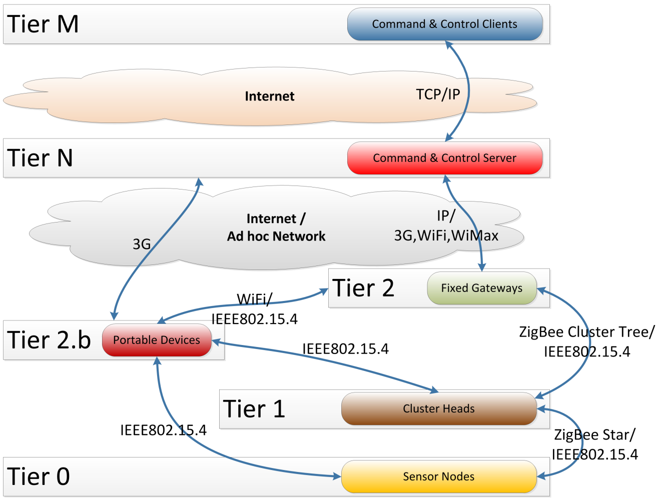

Fig. 1. EMMON High Level Multi–Tiered System Architecture.

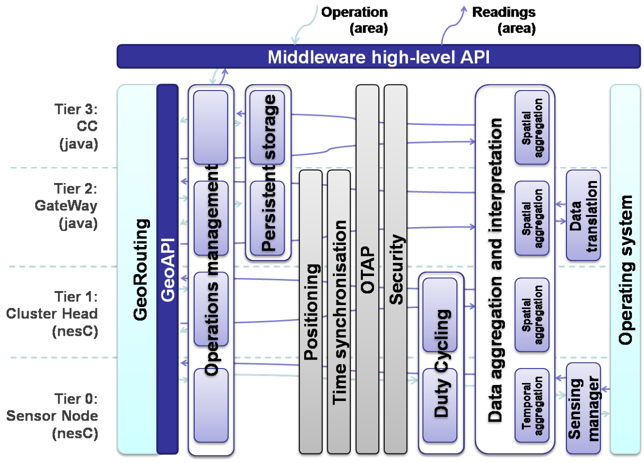

Fig. 2. EMW architecture: the light blue boxes are components from other software layers. White boxes were implemented for DEMMON1.

- Tier 1: Cluster–Tree network model (ZigBee-like) supporting distributed synchronization, time division cluster scheduling, convergecast routing upstream and geographical based routing downstream.
- Tier 2: Fixed gateways enable the interface between the WSN and the command and control over long range IP-based communication technologies.

Fig. 1 also includes an optional element of the EMMON network architecture, the Portable Device (e.g., PDA). It is indicated as belonging to an intermediate Tier2.b, since it plays a special role of mobile gateway and diagnosis element.

B. EMW: EMMON Middleware

A novel EMMON–specific middleware (Fig. 2) facilitates the development of environmental monitoring applications by abstracting away the details of the network via a geographical API. It runs on all the elements of the system and glues all the components together, from the C&C Clients to the Sensor Nodes, allowing them to work properly over the heterogeneous communication technologies (Fig. 1). The middleware distributes intelligence as low as possible in the network (given hardware restrictions) to reduce traffic generated and simplify system management.

C. C&C: EMMON Command and Control

The EMMON C&C subsystem is the most visible part of the whole system. It aims to collect readings and provide all the functionalities to the end-users. It encompasses a C&C server and multiple C&C clients, where the Graphical User Interface is implemented. Conversely to traditional C&C applications, the EMMON C&C Clients do not interact with each node individually, but with monitoring objects (e.g. a room), which can group several sensor nodes.

III. Conclusions

We outlined the EMMON system architecture aiming at enabling large-scale, dense and real-time WSN applications. It is a fully integrated and innovative system, where communication protocol stack, middleware and command and control mechanisms are combined to maintain as much as flexibility as possible, while meeting specific applications' requirements. This architecture is supported by a complete planning, dimensioning, simulation and analysis toolset and has been validated through extensive simulation and experimental evaluation. Future work will address improvements to fault–tolerance and data aggregation.

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