

ACCESS graduate course

Wireless sensor network programming: an introduction

Book of abstracts

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Foreword. This report contains the poster abstracts resulting from the course “Wireless sensor network programming: an introduction”, given as a 2-week intensive ACCESS graduate course in the fall of 2008. The course consisted of an initial day of lectures and tutorials on networked embedded systems programming in the operating system Contiki, but was otherwise centered around a mini-project which was presented both orally and as the abstracts contained in this report.

Table of Contents

Enabling automated measurements for indoor sensor networks

Azadeh Abdolrazaghi

Performance monitoring in wireless sensor networks

Ibrahim Orhan and Jonas Wåhslén

Light detecting wireless sensor network

Dennis Sundman and Petter Wirfält

Distributed polling in wireless sensor networks

Fetahi Wuhib

Explore energy efficiency in wireless sensor networks based on RSSI

Liping Wang and Huimin She

Experimental study of cooperative spectrum sensing to support dynamic spectrum access

Ioannis Glaropoulos

Feasibility of using Contiki and TmoteSky for spectrum sensing

Ali Özyağci

Power control algorithms for wireless sensor networks

Pangun Park

Semi random protocol approach for wireless sensor networks

Piergiuseppe Di Marco

Measuring parameters of multipath fading

Magnus Lindhé

Detection of packet-based interference

Luca Stabellini

Identifying spectrum availability based on RSSI analysis using wireless sensor network

Saltanat Khamit and Pamela González

Mobility in wireless sensor networks to support health care applications

António Oliveira Gongga

Channel quality estimation in indoor wireless sensor networks

Carlo Alberto Boano

Investigating throughputs dependency on packet size in lossy networks

David Gustafsson and Jesper Karlsson

Experimental measurement of RSSI and LQI in WSN using Tmote-Sky device

Miurel Tercero V.

Enabling Automated Measurements for Indoor Sensor Networks

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ABSTRACT

Towards developing protocols and applications for sensor networks, one of the difficult tasks is to perform measurements in order to evaluate networks performance in reality.

Due to high sensitivity and limited resources of sensor nodes, radio communication can be influenced by many environmental parameters which respectively complicates preparing the radio propagation models.

In order to carry out continuous and automated measurements, employing toy cars moving on special tracks in a closed loop is proposed.

Using this approach saves time and energy in the process of radio measurements and also the experiment can be repeated over and over with minimum effort.

1.INTRODUCTION

In the area of Wireless Sensor Networks, radio measurements specially indoor have always been of great concern and also error prone. There are many factors influencing indoor radio propagation models such as different types of objects like walls, roofs, doors and furniture causing all types of radio wave changes (i.e. reflections, diffraction and scattering), human noises, external devices like micro wave oven and so on.

Another alternative method [1], a localization algorithm in indoor sensor networks is suggested.

In [2] instead of a moving car, the sensor is carried by a human inside a building.

The contributions of this paper are:

Introducing a measurement method for indoor sensor networks using mobile nodes and discussing challenges involved with the radio modeling.

2.DESIGN

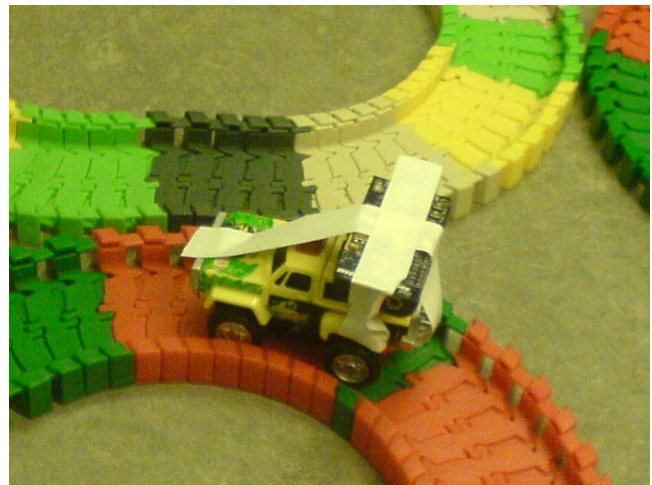
Our system consists of three Tmote Sky motes and one FLEXI TRAX path with one small car. Experiments are done in a 9 m corridor. The sender mote is installed on the car to move in the track, receiver mote is put with 0.3 m distance of the track

at the height of 0.5 m. And the sink node is connected to a laptop. The sender transmits one byte packets continuously. The receiver calculates the RSSI of the packets correctly received every half a second and sends the average value of RSSI and the number of collected samples to the sink node.

Since the experiment is done in an indoor environment with free line of sight between the transmitter and receiver, transmitter power is reduced to half. And as it is shown in the Evaluation section, this does not have effect on the quality of measurements.

In order to avoid interference between the communication of sender and receiver with the transmission of receiver to sink, receiver switches channels for the sender and sink.

The tests are done at night not to be affected by the sources of noise like human beings.



3.EVALUATION

In this section, we illustrate the average RSSI measured in different distances between sender and receiver, shown in Figure 1.

As it can be seen in Figure 1, the small changes in the distance in the scale of 0.5 m affects the RSSI values considerably.

The interesting observation of this graph is nonlinear changes of RSSI with distance although it is expected that RSSI should decrease as the sender goes further away, this is not always the

case. When the distance is more than 3 meters, RSSI graph is semi-sinusoidal.

One of the observation to be mentioned is that in the same distance from the receiver if transmitter changes its antenna direction towards the receiver (e.g. horizontal changes about 0.3 m or when car turns) the RSSI is not fixed so this can confirm the fact that Tmote Sky antennas are not ideally omnidirectional as it is mentioned in the Tmote Sky datasheet as well [3].

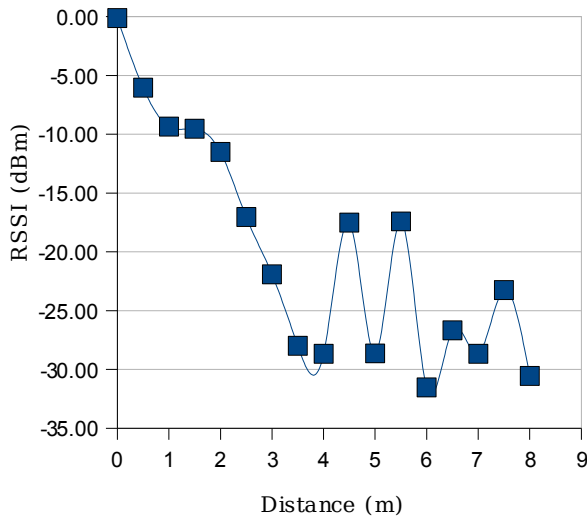


Figure 1. RSSI versus Distance

Several repeated tests with both fixed and moving car show that in order to get reliable measurements, the car's speed should be very slow and also some means of isolation between the mote and the car is needed to avoid the noises from electromagnetic field of the car's engine.

Experiments also demonstrate that very close distances to the transmitter have negative effect on received signal strength while the other way is expected so a minimum distance of 0.3 m is recommended.

Tests are performed at different distances from the receiver by both stopping the moving car using the remote controller and also manually placing the car. Results are very similar but it should be considered that the initial values before and after car brake should be removed due to the effect of brake which causes high variation from the average.

4.CONCLUSIONS

In this paper we showed that creating an accurate radio model is very hard and crucial. And this issue is discussed in [4] as well.

Employing FLEXI TRAX with cars eases radio measurements but two important issues to be mentioned: first, the car engine

effect should be reduced and second, cars with highly tunable speed are needed.

As future work, the experiment can be done with finer steps of changing the distance (e.g. 1cm) to get more precise values. And since fulfilling this goal manually is not efficient, using mobile cars can be very useful.

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Performance Monitoring in Wireless Sensor Networks

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ABSTRACT

Higher packet frequency generally gives higher data throughput. This is however not the case in wireless environment. In an unreliable data transmission protocol, there is no mechanism to detect the performance of the transmission link. In this paper, we present a monitoring method which is able to measure the performance of the link. It could be used to detect the optimal packet frequency that will minimize the packet loss. Our implementation of the monitoring method can successfully measure the throughput at any given frequency.

1. Introduction

Wireless sensor networks are rapidly becoming a common infrastructure for exchange in many areas like real-time surveillance, sport or medical applications. In video surveillance applications, it is desired to get a high data throughput and at the same time no or low packet loss.

An alternative solution is to use reliable data sending protocols that mimics the behavior like TCP sliding windows and packet acknowledgement. However a reliable data protocol will resend packets and thus have a negative impact on real-time applications.

This paper presents a measurement method that provides online transmission quality feedback to the sending application.

2. Design

A. The Measurement Testbed

The first testbed scenario contains three Tmote Sky nodes and one of them is connected to a laptop as seen in Figure 1. The second scenario only uses a sending node and a base station. The application is written in Contiki[1] and uses the RIME[2] communication stack. The sending node transmits packets of 30byte in single-hop unicast mode to the middle node. It also sends a monitoring packet after every 100 sent data packets. The monitoring method

is described in the next section. The middle node receives and sends the packets immediately to the base station. The base station receives both the data and monitoring packets and sends the information collected by the monitoring method to the directly connected laptop for storage and processing

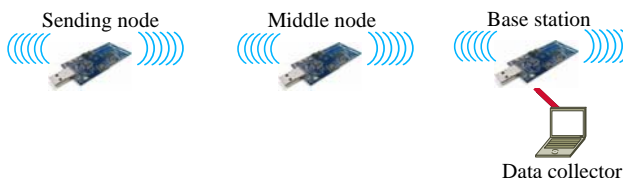


Figure 1: The testbed used for measuring the packet loss.

B. The Performance Meter

The monitoring method used in this work is inspired by the results from measurements in wireline networks in [3] and [4]. A light-weight performance meter is implemented in each node. The meter consists of two counters of the number of sent and received packets and bytes, and a function that can insert monitoring packets. These dedicated measurement packets are inserted between blocks of ordinary data packets as seen in Figure 2. They contain an ID, a timestamp and the cumulative number of packets and bytes transmitted from the sending node to the receiving node.

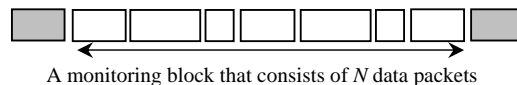


Figure 2: A monitoring block surrounded by two monitoring packets.

The interval between the monitoring packets, i.e. the size of the monitoring block, is the number of packets. When a monitoring packet arrives at the received node stores a timestamp and the current cumulative counter values of the number of received packets and bytes from the sending

node. The packet loss is measured passively using the counters described above.

The results from the performance meter can be used in a management and control system for optimizing the throughput by providing the sending node statistics of the performance of the transmission link.

3. Results and Evaluation

The evaluations were done as described in Figure 1, and without using the middle node. The reason was that we wanted to show how different networks environments affect the total throughput. Our choices of packet frequencies were done to detect changes in packet drop. The measurement period is 30 minutes.

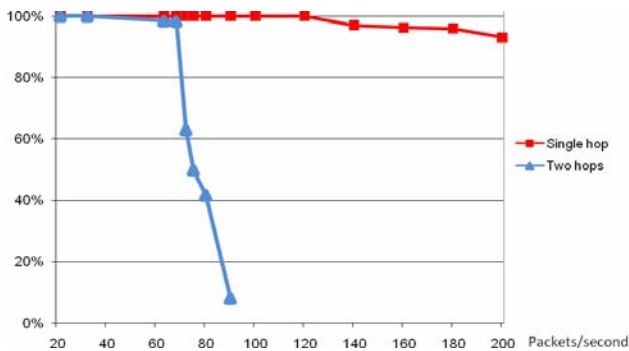


Figure 3: Successfully received packets in percent of totally sent packet for different packet frequencies for 1 and 2 hops.

As showed in Figure 3, there is a big difference in packet loss when the packet frequency increases for one hop and two hops. Given a packet frequency of 90 packets per second in a single hop environment, would in our case give an excellent throughput. However, sending at 90 packets per second in a multi-hop environment would in our case result in almost zero throughput.

One obvious conclusion is to analyze the reason behind this result and improve the performance in the middle node see e.g.[5]. Another conclusion is that “UDP-like” applications would benefit a lot from a simple feedback mechanism to improve performance. This would make it possible for the sender to optimize the packet frequency, to one that will minimize the losses. Figure 3 is based on the monitor packets received by the base station. It shows that the receiver have enough information to send relevant

feedback information about optimal frequency to the sending node. An example where this is useful is in real-time measurement sensor data in for example sport-applications. Measuring of the intensity of soccer players using accelerometers, would require multiple nodes, one for every player. There is also possible that multiple hops are required to send data from any sending node to the base station node. Based on the information feedback from the receiving base station, the sender could adapt its packet frequencies to the best possible data throughput in the given network.

4. Future Work

Implementation of an algorithm that enables the receiver node to send feedback to the sending node is for future work. The algorithm would be used for controlling the packet frequency of the sending node in order to minimize packet loss.

5. Conclusions

We have presented a monitor system that gives the receiver transmission link quality feedback on the data throughput. This could be used to minimize the packet losses between the sending and receiving nodes depending on the network environment.

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Light Detecting Wireless Sensor Network

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Abstract—Tracking an object given some noisy distance data is not a trivial task. The tracking problem is encountered quite frequently today, with GPS-devices being integrated in more and more consumer products, e.g. cellphones. We present a solution to the more general problem of, with a limited number of sensors, finding an emitter position relying more on signal processing than amassing data. We conclude that by deploying a number of relatively cheap distance-sensors, we manage to track an object precisely by careful analysis of tracking data, allowing cheap robust wireless tracking networks.

I. INTRODUCTION

TRACKING objects have been an important task for a long time. Thousands of years ago people used the sun and the stars to find their position, especially while at sea. Since then tracking implementations have involved radar, satellites, and most recently sensor networks. In this paper we will focus on a method of detecting moving objects given some sort of distance data. This can be seen as the inverse of what is done in a GPS-navigation system; rather than at one node relying on broadcast signals from a number of sources (satellites), we collect information from a single source (a moving lamp) at several nodes.

In tracking application, the fundamental strengths of sensor networks are that they are cheap, efficient, and robust. A typical application would be to fly by some area of interest, deploy the required number of sensors and then collect the information at a location of the deployer's choice. Through optimal power usage, the sensors can be configured to last during the time of interest, and through a somewhat redundant deployment the failure of some nodes can be made to insignificantly affect the target tracking capabilities.

In this paper we will focus on the objective to track a light source moving around an area. Similar scenarios have been tried by others. In a Master's thesis from Luleå University [1], a protocol is constructed for synchronization of communication between nodes in order to solve the task of light-source tracking. The result presented in that master thesis does not seem very promising.

A de-centralized algorithm for calculating a source-position using a sensor network is presented in [2], which is attractive due to its lack of central computation requirements. The method however suffers from the limitation that the source needs to be surrounded by nodes on all sides, which presents a significant limitation of applicability – e.g. if the source ventures outside the sensor array in any dimension, the tracking breaks down.

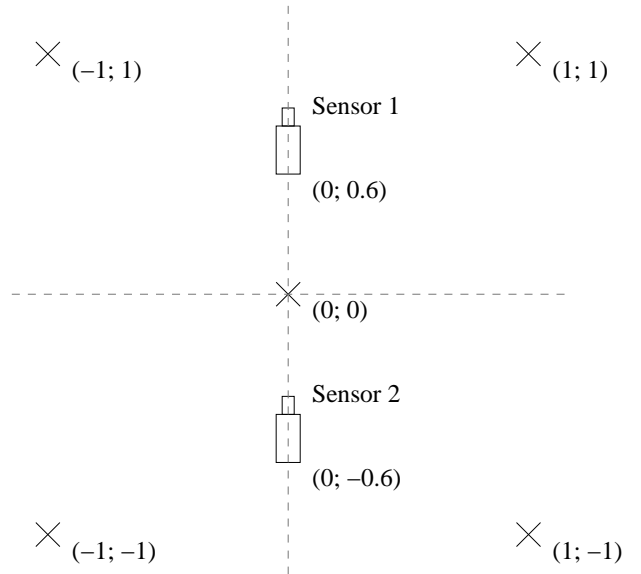


Fig. 1. An overview of the setup. Distances in meters [m].

We show, on the contrary, that by using fewer sensors but more sophisticated data-analysis, tracking can become, relative to the sensor properties, both precise and efficient. This is done by careful calibration and state-of-the-art implementation of a Kalman filter.

II. DESIGN

The problem setup is depicted in Figure 1. Two sensor nodes are placed at a specified location, monitoring received light intensity at a rate of 10Hz. Communication is implemented by sending default Contiki data packages containing sender id and sensor information.

This data is mapped towards sensor calibration data in order to get the true sensor-to-source distance. The initial sensor-calibration is done by fixing light intensities to predetermined distances, which is then interpolated using cubic splines. This calibration is essential to the accuracy of the sensor network, but could be overcome with different sensor hardware. Further, the received data is relatively noisy – it fluctuates around a mean (true) value by about 10%.

A moving average filter is implemented in order to remove the high frequency content of this noise. The low-pass filtering introduces a small delay in the computation procedure which is tolerable due to the relative, to the scenario, high sampling rate.

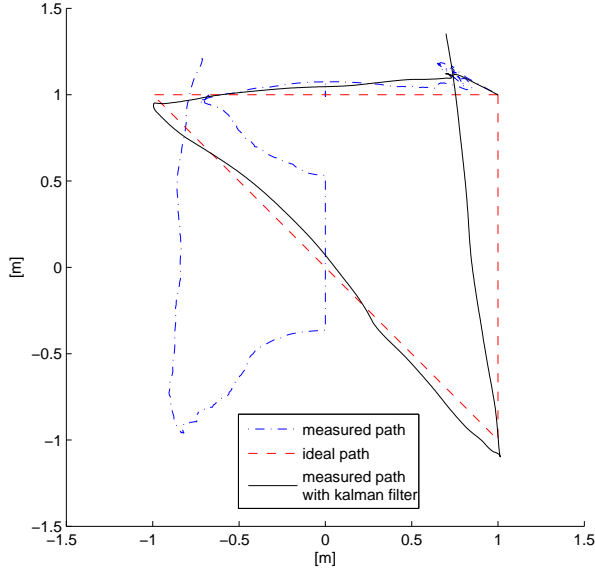


Fig. 2. One of the experiments showing a "real" path and the, from data, reconstructed path.

III. EVALUATION

Based on the manner in which the source position is found from the data – i.e. as the intersection of two circles, with each circle corresponding to a sensor's perceived distance to the source – the locating algorithm is very sensitive to measurement errors. For example, with a setup as the one in Figure 1, a seemingly plausible least squares solver will in the event the two circles do not intersect produce a solution along the system y -axis. While being correct in the least squares sense, such a solution does not correctly emulate the true source movement and, further, cannot determine on which side of the y -axis the source is located. In order to overcome such limitations and to further decrease the dependence of measurement noise, a Kalman filter is implemented according to

$$\mathbf{x}_{n+1} = \mathbf{F}\mathbf{x}_n + \mathbf{G}\mathbf{w}_n \quad (1a)$$

$$\mathbf{y}_n = \mathbf{H}\mathbf{x}_n + \mathbf{v}_n \quad (1b)$$

where

$$\mathbf{x}_n \triangleq (x_n \quad \dot{x}_n \quad \ddot{x}_n \quad y_n \quad \dot{y}_n \quad \ddot{y}_n)^T \quad (2)$$

represents the true state at time n , \mathbf{F} describes the evolution from state \mathbf{x}_n to \mathbf{x}_{n+1} , \mathbf{G} specifies how the *model* noise \mathbf{w}_n enters the system, \mathbf{y}_n represents what is actually measured at time n , \mathbf{H} how this relates to the true state \mathbf{x}_n , and finally \mathbf{v}_n accounts for measurement noise. Equation (1a) follows from the assumption that the source movement follows the regular equations of motion,

$$\begin{aligned} x_{n+1} &= x_n + \dot{x}_n \Delta + \ddot{x}_n \frac{\Delta^2}{2} \\ \dot{x}_{n+1} &= \dot{x}_n + \ddot{x}_n \Delta \\ \ddot{x}_{n+1} &= \ddot{x}_n + w_n \end{aligned} \quad (3)$$

with the addition of noise in the \ddot{x} -term, corresponding to changes in movement direction, etc. The source y -coordinate translates according to a similar set of equations. Further we define the measurement $\mathbf{y}_n = (x_n \quad y_n)^T$ as the least squares solution to the circle intersecting problem based on the sensor distance data.

A Kalman filter relies to different extents on the model or the actual measurements, depending on the noise covariances. Thus in the present implementation the measurement noise covariance is kept considerably higher than the model noise as the measurements are known to show significant errors. This will allow the filter to ignore sudden changes in input data, but still allowing gradual changes in the system behavior.

The improved performance of the detecting algorithm with the implemented Kalman filter can be seen in Figure 2. The detected path without the implemented filter can also be seen, and the previously mentioned lumping around the y -axis is evident. For the situation depicted, it is hard to formulate such a guess without creating too many situation-specific conditions. The Kalman filter solves the issue of determine what side of the y -axis the source is located very effectively and is computationally insignificant compared to the least squares estimator. The trick is to design the model accurately and to choose the noise covariances correctly to attain the right mix between model propagation and measurement data. This is very feasible to do based on the sensor positions and system geometry.

An interesting phenomenon in Figure 2 is that the data indicates that the object being tracked moves away from the ideal straight path between $(1, -1)$ to $(1, 1)$. This can be seen both in the raw data and in the data manipulated with a Kalman filter. This is due to a white wall which was located close (about 1 meter). It is also important to remember that the ideal path is not necessarily the actual path, as it is created with the precision of a person walking with a light in his hand.

IV. CONCLUSION

We have constructed a method for measuring light intensities with t-motes, analyzing the received data and reconstructing the travel-path with good precision. This has been done through careful low-pass filtering, interpolation, synchronization, and Kalman filtering. We can see, in analogy with Figure 2, that the result presents a significant improvement compared to unfiltered data.

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Explore Energy Efficiency in Wireless Sensor Networks based on Received Signal Strength Indicator

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Abstract

Energy efficiency is one of the most crucial issues in wireless sensor networks (WSN). In this paper, the energy efficiency property of WSNs is studied by investigating the received signal strength indicator (RSSI) at various deployment environments. The experiments are conducted to investigate the RSSI values with respect to transmission power level, radio channel, and alignment of the transmitter and receiver. The results indicate that energy consumption can be reduced by choosing proper transmission power and alignment techniques without sacrificing the quality of communications.

Keywords

Wireless Sensor Network, Energy Efficiency, RSSI

1 Introduction

Recently, wireless sensor network has become a promising technology with a variety of applications, including environment surveillance, remote health-care, supply chain management, and military assistance, etc[2]. A wireless sensor network usually consists of a large number of battery-powered sensor nodes with sensing, computation, and wireless communication capabilities. As the number of nodes is large, battery replacements are difficult or impossible. Moreover, the total power consumption in sensor networks is dominated by the communication circuitry [4]. So reducing energy consumption of the transceiver circuitry is of great importance.

With popularly used radio such as CC1000, CC2420 and CC2520, the transmission power control technique has been widely adopted for reducing the energy consumption in wireless sensor networks [5]. However, under a constrained energy budget, energy efficiency is at odds with the transmission quality, which can be evaluated by RSSI. On the other hand, the configuration of a sensor network also has a significant impact on transmission quality and energy efficiency. In order to study the trade-off between link quality and energy consumption at different deployment aspects of sensor networks, we conduct experiments to measure the RSSI values with respect to transmission power level, radio channel and alignments of transmitter and receiver. From the results, we show that by appropriately configuring the network, such as choosing a proper transmission power level and radio channel, and adjusting the alignment of transmitter and receiver, the energy efficiency can be improved without sacrificing the

communication quality.

The remaining paper is organized as follows: Section 2 provides four alignments of transmitter and receiver. Section 3 gives the experimental results for RSSI investigation under different configurations. Finally, section 4 concludes the paper and provides directions for future work.

2 Alignment of Transmitter and Receiver

As we know, the antennas of sensor nodes may be not homogeneous in all directions. With the same transmission power, the communication quality between two pairs of transmitter-receiver could be different because of different alignment of the transmitter and receiver. Therefore, it is beneficial to deploy the nodes so that a transmitter and a receiver can communicate in the optimal direction. As shown in figure 1, we define four kinds of transmitter-receiver alignments: Tx-Rx parallel-1, Tx-Rx parallel-2, Tx-Rx Vertical-1, and Tx-Rx Vertical-2. In the next section, the RSSI values are measured with each alignment.

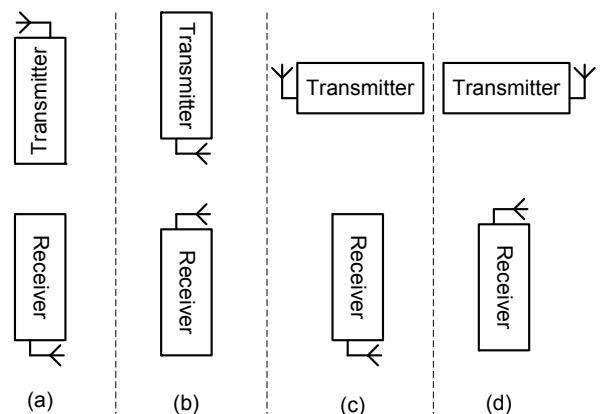


Figure 1. Alignment of transmitter and receiver: (a) Tx-Rx Parallel-1; (b) Tx-Rx Parallel-2; (c) Tx-Rx Vertical-1; (d) Tx-Rx Vertical-2.

3 Experiment Results

Experiments are conducted in an indoor environment using the Sentilla's Tmote Sky sensor mote [1], which is an MSP430-based board with an 802.15.4-compatible CC 2420 radio chip. The operating system for the mote is Contiki 2.2.1[3]. We deploy two motes which act as the transmitter

and the receiver, respectively. The RSSI values are measured with respect to transmission power level, radio channel, and alignment of transmitter and receiver.

3.1 RSSI VS. transmission power levels

In this experiment, we investigate the relations of RSSI values and transmission powers on different radio channels, which are channel 11, 16, 21, and 26. In each of these channels, 500 packets are sent on each transmission power level (ranging from 1 to 31), and the average RSSI values are calculated. The distance between the transmitter and the receiver is fixed to be 1 m.

From figure 2, we can see that the average RSSI value increases as the transmission power enhances. With the same transmission power, the RSSI values are different on different radio channels. On the whole, channel 26 has the best quality from our experiment. Another interesting thing we noticed from our experiment is that when RSSI is less than -45 dBm, the packet loss rate is very high, and it almost equals zero when RSSI is larger than -45 dBm. In order to reduce the packet loss rate, a higher transmission power level should be chosen. However, on the other hand, higher transmission power will lead to higher power consumption and thus reduce the lifetime of the network. Therefore, energy efficiency can be improved by choosing proper radio channels and transmission powers according to various requirements and constraints.

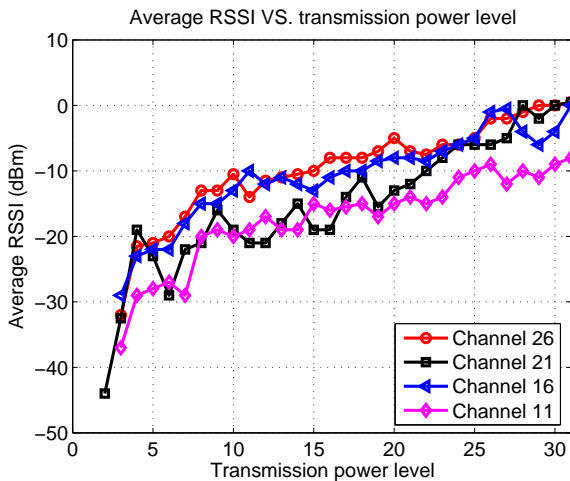


Figure 2. Average RSSI VS. transmission power levels on different radio channels

3.2 RSSI VS. transmitter-receiver alignment

In this experiment, we fix the distance between the transmitter and the receiver to be 0.5 m, and change the direction of the transmitter and the receiver so that they have different alignments. We study the RSSI values with four transmitter-receiver alignments as shown figure 1. An average RSSI is taken from the measurements of 500 packets. The radio channel is set to 26.

In this figure, the alignment of transmitter and receiver has a significant impact on the RSSI value. With the same transmission power, the alignment "Tx-Rx Parallel-1" can achieve the biggest RSSI values, while "Tx-Rx Vertical-2"

has the smallest RSSI values. This means that by appropriately adjusting the direction of transmitter or receiver, power consumption can be reduced without losing the quality of communications. The results indicate that the antenna of our mote is not homogeneous in all directions. Therefore, the assumption of "homogeneous antennas" is may not accurate as many literature stated in their simulations.

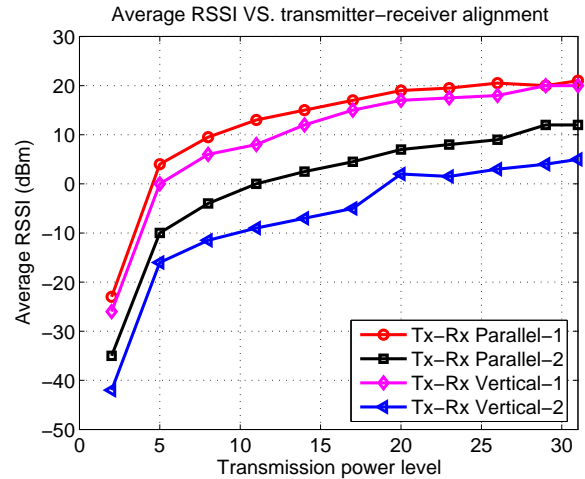


Figure 3. Average RSSI VS. transmission power levels with different transmitter-receiver alignments

4 Conclusions and Future Work

Since sensor nodes are powered by small limited batteries and may be difficult or impossible to refill, energy efficient is crucial in wireless sensor networks. In this paper, we conducted experiments with Moteiv's Tmote Sky motes to investigate the RSSI values with respect to transmission power, radio channel, and transmitter-receiver alignment. The results show that energy efficiency in wireless sensor networks can be improved by appropriate deployment of the networks. In future work, we plan to study the relations among transmission power, RSSI and link distance. Moreover, it is interesting to investigate the path loss effect at different environments with interference and obstacles.

5 References

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Experimental study of cooperative spectrum sensing to support dynamic spectrum access

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Abstract

Opportunistic spectrum access has been proposed to dynamically utilize spectrum holes that are left unused by the primary system, which has acquired the license for the spectrum, adapting the transmission parameters in such a way that the interference between the two systems is limited. The challenge for dynamic spectrum access (DSA) is to be able to detect weak primary signals often prone to severe signal attenuation due to fading and shadowing phenomena. In this paper we propose a cooperative detection scheme where the detection of primary signals is distributed among several sensing devices. We experimentally evaluate the performance gain of the cooperative scheme compared to a non-cooperative one in terms of interference between the primary system and the secondary (DSA) system.

Keywords

Spectrum Sensing, Opportunistic Spectrum Access, Wireless Sensor Networks

1 Introduction

DSA has been proposed as a possible solution to the problem of spectrum scarcity, originating from the fact that the demand for spectrum has grown and is expected to grow more because of the introduction of new services and applications based on mobile Internet access. As most of the licensed bands have been found to be under-utilized [1], DSA offers a great opportunity for low priority communication within these bands, improving in this way the total spectrum utilization. Opportunistic spectrum access requires that the interference between the primary system that owns the license of the band and the secondary system that employs dynamic spectrum access be kept under a predefined level specified by the licensed system. The secondary system therefore needs to operate in such a way, so it can detect the primary transmitted signals and occupy the radio channel only in case it is not used by the primary system. The reliability of signal detection is, however, limited due to path loss and fading phenomena. This reliability can be improved by increasing the time during which the sensing devices "hear" the channel for primary transmissions.

The idea of opportunistic spectrum access is presented in [2] and [3] which introduce the concept of a protected region inside which no secondary operation is allowed. The size of this region depends on transmission power of both primary and secondary users, the acceptable interference level between the two systems and the sensing quality interpreted as a missed signal detection probability. Cooperation among several sensing devices has been proposed as a solution to improve the quality of sensing [4]. The sensors form a wireless sensor network that replies to secondary users' request regarding spectrum availability.

The remainder of the paper is organized as follows. In Section 2 we provide a description of the above system. In Section 3 we

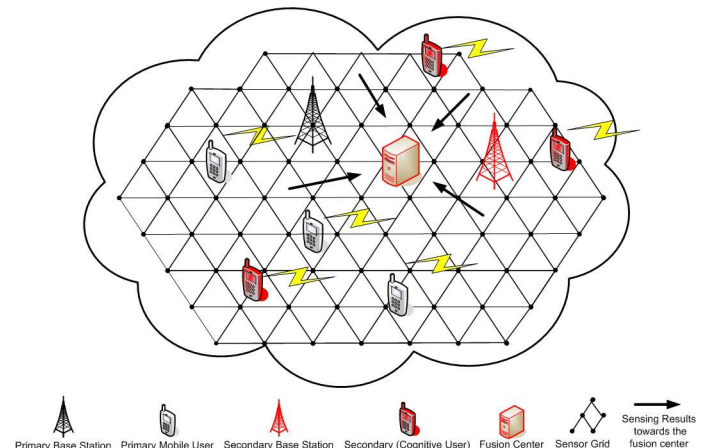


Figure 1. Detailed description of the addressed scenario.

conduct real experiments in our effort to reveal and quantify the gain originating from sensor cooperation. We conclude the paper in Section 4.

2 Design

In this section we first present the basic idea and afterwards we provide a more detailed description of the system design and implementation.

2.1 Scenario Description

Figure 1 describes the addressed scenario. The primary transmitters (PT) that are the owners of the license communicate with the primary receivers (PR). The secondary users (SU) that desire to access the spectrum may not interfere with the primary transmissions. Therefore, they may use the channel only in case there is no active primary transmitter. SUs can either rely on sensing information from the sensor network (WSN) that is dedicated to "hear" the channel on a continuous mode or act independently, which means that they try to detect primary transmissions and they access the radio channel in case they do not detect any. WSN consists of a set of sensors that continuously monitor the radio environment and report their sensing information to an entity called Fusion Center (FS). FS concludes whether or not there is an active primary user based on the information from the whole set of sensing devices. SUs access the radio channel only if they are informed by the FC that the channel is free.

2.2 Design and Implementation

We deploy a single set of PT and PR in a distance d between them so for a standard Tx power and if no secondary operation is active, packet loss rate is negligible. PT duty cycle consists of ON

and OFF times exponentially distributed. During the ON period PT continuously sends *Unicast* or *Broadcast* packets with *Rime* to the receiver using *nullmac* protocol. We also deploy a single SU with higher transmission power that tries to access the same channel in an opportunistic way.

2.2.1 Non-cooperative case

In this case SU also has integrated sensing capabilities. Its duty cycle consists of a silent (OFF) period where he tries to listen for transmissions in the radio environment and an ON period with fixed duration when it continuously transmits packets also using *nullmac* protocol. If it detects transmissions during the OFF period, then another OFF period starts. SU duty cycle is quite shorter than PU's cycle.

2.2.2 Cooperative sensing

In this case we deploy a set of nodes, S , that are dedicated to sense the desired channel. They monitor the environment for packet transmissions and they broadcast their (hard) detection information to the FS, using a different channel as control channel (C). Packet collisions are avoided using a random back-off time for broadcast transmissions. FS decides based on OR decision rule and sends this information to the SU through a feedback channel (F). The SU waits for instructions from the PU during the OFF period and uses the ON period for transmission if no active PU was detected.

3 Evaluation

3.1 Performance Metric

Clearly in case PT and SU transmit simultaneously, a collision should occur and this will result in a packet loss. The primary receiver (PR) produces long term statistics regarding the packet loss rate. This packet loss rate is directly associated with the missed detection probability that is our performance objective. In our experimental setup we measure the packet loss rate for different distances between the PU and the SU in the non-cooperating case or the sensors in the cooperating scenario. What we expect to see is the packet loss rate to increase while this distance increases.

3.2 Experimental Setup

The primary user operates on a first order Markov (ON-OFF) mode with ON and OFF times exponentially distributed with average values of 200msec and 400msec respectively. The SU operates in a much shorter, deterministic duty cycle of a sensing (or silent) OFF period of 10msec and a transmission (ON) period of 20msec. Dedicated sensors operate in the same cycle. It is obvious that these arbitrarily selected values affect the performance of the system in terms of PU packet loss rate. The higher the SU ON period is, the more packets will be lost in case of a missed detection of an active primary user. PT uses a medium signal power for transmission (16) while the SU transmits with higher power (31), so it will always interfere with the PR. We select the default channel (11) for primary and secondary transmission and channel (26) for the common control channel required for inter-sensor cooperation. We use the T-mote Sky sensors for the transmission, reception and sensing operations. The non-cooperative and cooperative sensing schemes are implemented on the Contiki OS. We place the motes in such a way that no line of sight (LOS) transmission is possible, in order to make communication prone to multipath fading and shadowing. The nominal distance between PT and PR is chosen to be 10m.

3.3 Results

We measure the packet loss rate for different spatial distances between the primary transmitter and the sensing devices. In case we examine the performance of the cooperative scheme we place the PT in the center of a canonical triangle, so the distances between the sensors and the PT are the same. We investigate the performance of the system for different levels of sensor cooperation. Figure 2 depicts the measurement results.

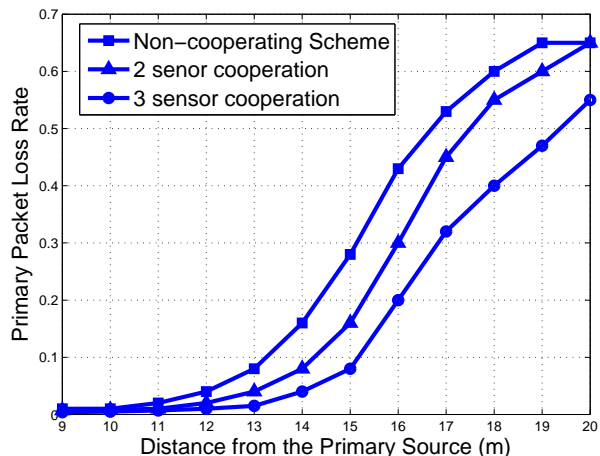


Figure 2. Primary User packet loss rate with respect to sensor or SU distance from the primary transmitter.

It is clear that for a distance compared to the nominal distance between the primary users the performance of the system is not improved by the introduction of the cooperative sensing scheme. This happens because even single sensor detection is highly reliable as signal strength is enough for a sensor or SU to detect the primary transmission. As this distance exceeds a certain threshold, the single SU misses a large percentage of primary transmissions, which results in a high packet loss rate, since SU tries to transmit in the same channel (and higher power) with the PT. The cooperative scheme outperforms the single sensor detection up to the point that no scheme can actually detect the primary transmissions.

The point at which the curves converges is determined by the specific properties of the primary and secondary users' duty cycles. This point would be different if different values for the ON and OFF periods were used.

4 Conclusions

In this paper we investigated the performance gain of cooperative spectrum sensing which is employed to support dynamic spectrum access. We have shown that with only a few cooperating sensor nodes the probability of a missed detection can be significantly improved compared to the non-cooperating case.

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Feasibility of Using Contiki and TmoteSky for Spectrum Sensing

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Abstract

Measuring the spectrum usage accurately is crucial for dynamic spectrum allocation algorithms to work. Sensing the spectrum accurately is not trivial and poor sensing performance may result in interference or underutilization of spectrum. We evaluate the feasibility of using TmoteSky to sense spectrum usage in dynamic spectrum allocation applications. Results show that the TmoteSky platform provides good sensing accuracy to be used in long term dynamic spectrum allocation applications.

1 Introduction

Spectrum is a resource which is becoming increasingly scarce paralleling the advancement in radio communications, therefore finding more efficient ways of utilizing the spectrum has gained attention. One approach to solve the spectrum scarcity issue is to dynamically allocate spectrum to users who need it. One class of dynamic spectrum allocation applications is the so-called “overlay” use, where primary users of the spectrum access it at will and the rest of the users (“secondary users”) may access the parts of the spectrum which is not used by the primary users at a given time (“spectrum whitespace”). In order to utilize the spectrum whitespace efficiently, it is crucial to measure the use of spectrum by the primary users. Measuring the spectrum usage poorly will cause secondary users to interfere with primary users, or cause the spectrum whitespace to remain unused.

In dynamic spectrum allocation literature, spectrum usage information is almost always assumed given, and is thus abstracted away. One project that addresses the problem of measuring the spectrum use is the Sendora project [1]. Incidentally, this project also proposes the utilization of sensor networks to aid in the task of sensing the spectrum.

The contributions of this paper are measuring the spectrum sensing performance of the TmoteSky platform and measuring the correlation of sensing results across different motes. Our results show that the TmoteSky platform is well suited for sensing the spectrum to aid long term dynamic spectrum allocation applications.

2 Design

For the experiments we used TmoteSky sensor motes running Contiki 2.2.1 operating system. In all the experiment cases we connected the motes via USB to a computer where we collect the sensing data. We perform our measurements in the 2.4GHz frequency band, mainly because the antenna of TmoteSky is designed to operate in this frequency. Also, a number of radio technologies use this band, and because it is license-free there is a large potential for interference in this band.

For sensing activity of users at a certain frequency, RSSI (Received Signal Strength Indicator) measure is widely used, therefore we focus on this parameter in our evaluation. For our feasibility analysis of the TmoteSky platform for spectrum sensing applications we measure the spectrum sensing performance of the motes in number of RSSI samples collected per second, and the in terms of the correlation of the sensing results across different TmoteSky motes. For visualization purposes we also implement a program which receives sensing information from two motes and emulates a spectrum analyzer.

3 Evaluation

As we mentioned before, evaluation is in terms of sensing performance and correlation between results from different motes.

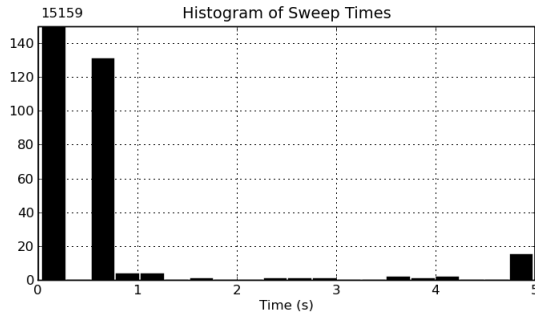
3.1 Sensing Performance

In order to obtain an accurate picture of instantaneous spectrum use, the rate of sweeping the spectrum is important. Therefore, we measure the highest rate at which we can sense the spectrum band between 2400MHz and 2500MHz. TmoteSky can set the frequency of its transceiver in increments of 1MHz [2], so we collect 100 samples to sense this interval. In our experiments, TmoteSky is able to sweep this interval for 20 times per second, that is, we can collect 2000 samples per second. This rate may be adequate for long term dynamic spectrum allocation, which can last for upwards of several minutes, however it would not be enough for very short term spectrum allocation which would last for a fraction of a second.

Although the platform can sample the spectrum about 2000 times per second, we are able to extract only around 400 samples from the sensor mote because the act of printing to the terminal through the serial port is very inefficient (because integer RSSI values are converted to ASCII char-

acters first). Instead, if a binary protocol (like SLIP) is used, data can be transferred from the mote to the host computer at potentially 115200bps (14.4kBps). This has no effect on the bottleneck of 2000 RSSI samples per second, however.

We observed other glitches in the system which may reduce the reliability of the sensing results. The histogram in Fig.3.1 shows the time it takes to obtain one full sweep of the 100MHz band (100 RSSI samples). One sweep may take as much as 5 seconds, which also makes the TmoteSky platform inappropriate for applications with strict interference requirements.



3.2 Mote Correlation

As Fig.1 shows, correlation of RSSI readings from the same mote is high between adjacent frequencies.

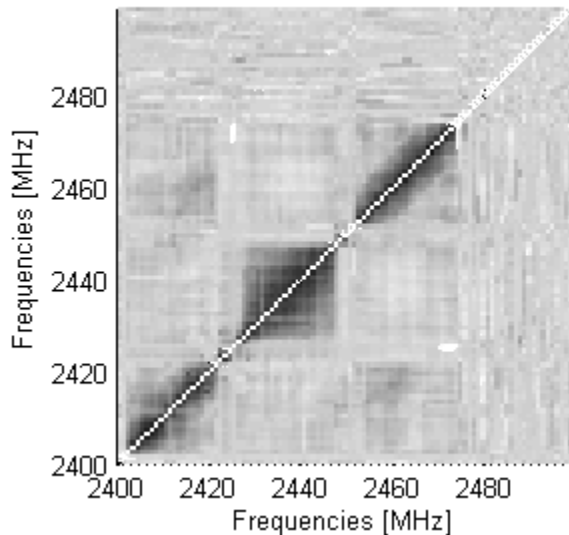


Figure 1. Correlation between frequencies measured on same mote, for 1000 samples.

The correlation across different sensors placed adjacently is very weak for short measurement durations on the other hand. The reason for this follows from the results in performance section. Considering maximum packet size and minimum bitrate, transmission of one ethernet frame will take $1500\text{Bytes} \cdot 8(\text{bits/Byte}) / 11\text{Mbps} = 1.1\text{msec}$. On the

other hand, sensing of 100MHz takes at least 50msec. However, for longer durations in the order of seconds, we observe high correlation between the envelopes of the spectrum measured on different motes.

To observe the dependence of correlation of RSSI measurements on distance between motes, This experiment was repeated for another setup where the motes were two meters apart and in different corners of the same room. The correlation of the results did not show much variance compared to that of adjacent motes, however.

We observe that the floor value of RSSI readings from two different motes may differ significantly. Although this will not affect the correlation, such uncalibrated input is likely to cause problems for algorithms which fuse the input from several motes. In our experiments RSSI readings differed as much as 6dB between two motes. This difference could be offset using the `RSSI_OFFSET` macro in Contiki source, but currently Contiki does not use this parameter although it is defined in the source code [3].

4 Conclusions

We evaluate the feasibility of using TmoteSky platform for spectrum sensing. We measure sensing performance and correlation across different motes. Using sensor motes to sense the spectrum is viable for applications where sensing duration is longer than several seconds and interference requirements are not very strict.

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Power control algorithms for wireless sensor networks

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Abstract

The main contribution of this paper is the implementation and experimental evaluation of three radio power control algorithms for wireless sensor networks. We illustrate the necessity of lightweight radio power control algorithms for the deployment of wireless sensor networks in realistic situations. Furthermore, based on a simple loss model, we develop an algorithm that optimizes the transmit power while guaranteeing a desired packet error probability. The simple power control strategy is also compared with two other strategies in experiments using Tmote. A component-based software implementation in the Contiki operating system is used.

1 Introduction

Wireless sensor networks (WSNs) are characterized by mobile nodes that can communicate with each other without a fixed infrastructure using multi-hop paths. The topology of the network may vary rapidly and unpredictably, because of fast and shadow fading.

Energy saving techniques through routing schemes are proposed in [1]. However, these routing protocols perform radio power control using an accurate topology knowledge, and often neglect the burden of signaling overhead. Many ad-hoc routing protocols (e.g., AODV, DSR, DSDV, and TORA) do not support power control, i.e., they assume to have fixed transmit radio power for the wireless communication. In [2], and [3], it was shown that the energy consumption associated radio power plays a critical role in WSNs.

Sensor nodes have limited resources in terms of memory usage and micro-controller capabilities, hence power control algorithms that require heavy computations cannot be efficiently implemented. Most of the ad-hoc routing protocols use an acknowledgment in order to guarantee a required packet reception rate. Hence, it is possible to use these messages to carry the information related to channel estimation for radio power control.

2 Problem Formulation

The problem we are targeting is finding suitable power control algorithms for the control structure. The algorithms should meet two requirements in addition to providing a low power consumption for the wireless transmission: (i) minimizing the overhead used by power control; (ii) be implementable through a component-based software design.

3 Three Power Control Algorithms

In this section, we discuss three power control algorithms, Multiplicative-Increase Additive-Decrease Power Control (MIAD), Packet Error Rate Power Control (PER) and Simple Channel Model Power Control (SCM).

3.1 MIAD Power Control

The MIAD is based on the following mechanism to set the transmission power level. When an erroneous packet is detected, the power P_i of node i is increased by $\alpha(t)\Delta$, where $\alpha(t)$ is an integer and Δ the step size. Each correctly received packet imposes a decrease of the transmit power by $\beta(t)\Delta$. The parameters $\alpha(t)$, $\beta(t)$ and Δ obviously influence performance of the packet error rate process and the power consumption, see [2] for details.

3.2 PER Power Control

The PER is based on an analytical model of the wireless channel to estimate the Signal to Interference plus Noise Ratio (SINR). By setting a constraint PRR_d , the optimal transmit power can be derived for each wireless link considering the channel condition. Furthermore, the packet error probability can be computed according to the modulation scheme and the wireless propagation model. After each node receives a packet, it derives the SINR based on the RSSI, which is a link performance metric provided by the Tmote, see [2] for details.

3.3 SCM Power Control

The SCM is based on the simple Additive white Gaussian noise (AWGN) model of the wireless channel to derive the transmit power instead of estimating the SINR of the received signal. The channel attenuations can be derived using the RSSI of the received signal and the transmit power level. Let us denote the received signal power $y(t)$ at time t , the transmit radio power $u(t)$ and channel attenuation with $P_{\text{loss}}(t)$. Then, the received power is given by $y(t) = u(t) + P_{\text{loss}}(t)$. The received power can be successfully detected only if $y(t) \geq P_{\text{thr}}$. Therefore, a simple algorithm can be derived to find a suitable transmit power for each link:

$$u(t) = P_{\text{thr}} - P_{\text{loss}}(t) + \varepsilon \quad (1)$$

where the ε is the offset considering fading wireless condition and the $P_{\text{loss}}(t)$ is approximated as follows $P_{\text{loss}}(t) \approx$

Table 1. Gain and packet error rate for two different propagation conditions.

	AWGN		Rayleigh	
	ρ_i	PRR %	ρ_i	PRR %
MAX	1	100	1	100
MIAD	1.6662	97.1	1.5247	88.5
PER	1.8114	99.6	1.2206	100
SCM	1.9974	99.7	1.5368	95.8

$y(t-1) - u(t-1)$. Note that $\varepsilon = \sigma Q^{-1}(1 - P_s)$, where σ is the standard deviation of shadow fading, Q function and P_s denotes the required packet receiving rate, see [4] for details.

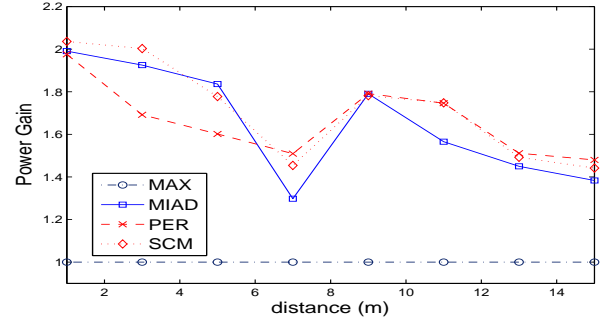
4 Experimental results

This section presents an experimental evaluation of three power control algorithms. The algorithms are implemented on Contiki OS using Tmote. We first compare the algorithms for a fixed position of the transmitter and receiver within Line of Sight (LOS) and Non Line of Sight (NLOS), and then for different distances within LOS. Note that we compared them with the case of fixed maximum power level (0 dBm). The signaling packets sent by the sink node to the source node are beacons with a periodicity. We considered static and time-varying conditions of the wireless channel. The static case corresponds to a fixed position of the sink, which is located in LOS with the source (AWGN) In the time-varying case, the sink node is let to move around its initial position. Furthermore, a metal object is put in front of the sink, so the source and the sink are not in line-of-sight.

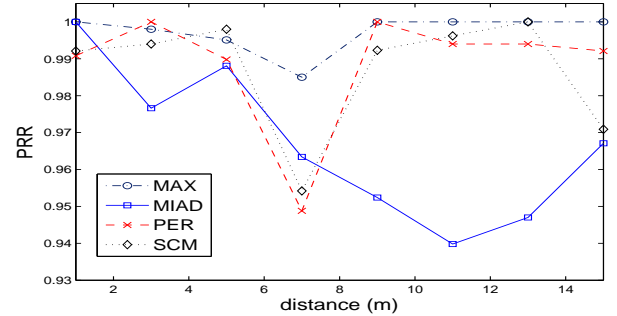
To characterize quantitatively the power consumption, we define the gain from using power control for node i as $\rho_i = \frac{P_{\max}}{P_{\text{avg},i}}$ where $P_{\max} = 0$ dBm is the maximum power level in Tmote, and $P_{\text{avg},i}$ is the average power consumed by node i . A high ρ_i and a low packet error rate indicate a good behavior of the power control algorithm.

In Tab. 1, we report the energy gain and the PRR for power control algorithms in both the cases of AWGN and Rayleigh environment. It is interesting to observe that the Rayleigh fading requires more radio power with respect to the AWGN case. The gain of power control increases for SCM when it is compared to PER and MIAD, whereas the packet reception rate is over 97% for all algorithms. On the contrary, considering MIAD and SCM in Rayleigh fading channel, the MIAD has higher packet error rate and, at the same time, higher energy consumption. The PER has higher energy consumption than the others, but highest PRR.

In Fig. 1, the experimental results as function of distance in AWGN are reported. It is interesting to observe that MIAD has lower PRR with respect to the PER and SCM and, at the same time, lower power gain. This is due to the fact that in MAID PC, the packet loss is compensated after estimating the PRR in certain period. The PER has similar PRR as SCM, whereas the power gain is lower than SCM. SCM has higher packet reception rates and, at the same time, higher power gain through the whole measuring range.



(a) Power gain of the power control algorithms.



(b) Packet Reception Rate (PRR) of the power control algorithms.

Figure 1. Performance of three power control algorithms at different distances in AWGN environment.

5 Conclusions

Simple feedback control systems for radio power control in WSNs have been implemented and evaluated in this paper. We have reviewed two power control mechanisms: one based on a MIAD mechanism, and another one based on the packet loss probability. Furthermore, we have studied a simple power control algorithm which is based on AWGN model. We have compared the performance of the three algorithms in terms of packet error rate and power gain in AWGN and Rayleigh environment. The experimental results show that SCM have good performance in terms of energy consumption and packet error rate than PER and MIAD in AWGN. Furthermore, PER may be recommended in Rayleigh environment because of stable PRR than SCM.

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Semi Random Protocol Approach for Wireless Sensor Networks

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Abstract

Designing energy-efficient, reliable, and timely communication protocols for real-time control and actuation applications by wireless sensor networks (WSNs) is a challenging task, due to the variability of the environment. We present SERAN, a cross-layer solution that embraces a semi-random routing algorithm, MAC, data aggregation, and radio power control for clustered WSNs. The protocol leverages the combination of a randomized and a deterministic approach to ensure robustness over unreliable channels and low packet losses. As relevant contribution, SERAN is implemented on a test-bed using both TinyOS and Contiki. Experimental results validate our analysis and show excellent performance in terms of packet reception rate, end-to-end delay, and low node duty cycle.

1 Introduction

Wireless sensor network (WSN) technology is allowing us to exploit sensing, control, and actuation via wireless communication with potential revolutionary effects in industrial and consumer applications. Given the lack of cabling and power supply that characterize WSNs, and the tiny dimensions of the nodes, industrial control and automation is one of the areas where WSNs are having a significant impact [1], since WSNs permit engineers to embed control and actuation at locations that were out of reach for traditional solutions. However, the scarce computation, communication, and energy resources of the nodes, and the fact that they must perform real-time tasks, pose several challenges for the effective application of WSN technology in this area. Indeed, a lively standardization activity is ongoing, particularly in the industrial domain [2].

Most of the existing protocols for WSNs are not optimized to maximize the overall network performance while minimizing the energy consumption and ensuring reliability and delay requirements [3]. The central idea of SERAN is a cross-layer design to achieve significant performance improvements by exploiting the interactions among various protocol layers (routing, MAC, and physical) and application requirements.

Our work is related to [4], where a relevant design methodology has been presented for industrial applications. However, in [4] no reliability requirements and load balancing were considered, and only a partial implementation of the protocol was performed. We extend the design approach sig-

nificantly by considering a collision avoidance mechanism, reliability constraints and packet aggregation to ensure a load balancing. Finally, as a relevant contribution, the protocol we present in this paper is completely implemented on a hardware platform. The experimental results allow us to assess the theoretical analysis and the protocol performance.

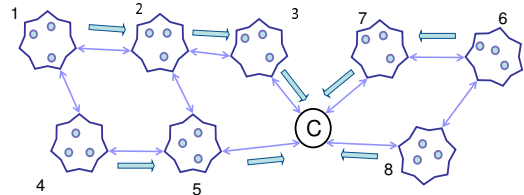


Figure 1. Connectivity graph

2 SERAN Design

We consider a WSN for monitoring the state of some plant, where source information are distributed into a few specific regions. A group of sensors deployed on a region is associated to a cluster. Information taken by sensors, which are uniformly deployed in the clusters, are sent to a sink node, linked to a controller, by multi-hop communication. In Fig. 1 we report the system model. Each star is a cluster of nodes. The connectivity between two clusters is denoted by a double arrow. The thick arrows indicate data flow. The network controller (C) is the sink node, which is assumed to be equipped with light computing resources. The protocol is based on the simultaneous optimization of routing and MAC layer, as we see next.

Semi-Random Routing

In [5], the idea of a semi-random routing is introduced to reduce inter-cluster and intra-cluster collisions. SERAN routing is hierarchically subdivided into two parts: a static route scheduling performed at cluster level and a dynamical routing algorithm at node level. A transmitter node has knowledge of the cluster to which the packet will be forwarded, but the actual choice of forwarding node is made at random. Such a random choice is not performed at network layer, but it is a result of a contention scheme performed at MAC layer by all the candidate receivers.

Hybrid MAC

A deterministic MAC with a weighted TDMA scheme regulates channel access among clusters. Nodes are awake to transmit and receive only during the TDMA slot associated to the cluster for transmission and reception, respectively, thus achieving consistent energy savings. A random MAC with a p-persistent CSMA/CA scheme manages the communication between nodes during a TDMA-slot. The MAC we adopt offers flexibility to the introduction of new nodes, robustness to node failures, to packet collisions and low energy consumption. Furthermore, it supports a procedure for the random selection of next-hop node.

3 Protocol Implementation

In [6] a complete implementation of SERAN by using TinyOS [7] is presented. In this paper we introduce a basic implementation in Contiki [8], to validate and compare the performance of the protocol using a different implementation environment. We cast SERAN protocol stack to the Rime stack layers embedded in Contiki [9]. As a result, the existing XMAC code has been disabled and the MAC rewritten according to the hybrid TDMA/CSMA of SERAN. We consider a simple setup with single hop communication, where each cluster is composed by 3 Tmote Sky [10] node sensors, deployed at random within a circle with one meter radius.

We evaluate experimentally the Packet Reception Rate (PRR) varying TDMA-slot duration S , and compare the TinyOS and the Contiki implementations (see Fig. 2) to the theoretical behavior from the mathematical analysis of the protocol. Fig. 2 shows that the PRR of SERAN as achieved by experiments well follows the theoretical analysis. The slight difference is mainly due to the acknowledgement mechanism, which introduces extra collisions with respect to the theoretical model. As S increases, SERAN gives a PRR near 100%. The Contiki implementation shows some problem with low values of S . It might depend on a imperfect synchronization among the nodes.

In Fig. 3, we report the analysis on the delay by comparing experimental and analytical results on the cluster evacuation time. A good agreement can be observed.

4 Conclusions

We propose SERAN, a new cross-layer solution for control and automation applications which satisfies system level requirements while minimizing energy consumption.

Performance are analyzed by a complete implementation over Tmote Sky sensors by using TinyOS 2.x. and a partial but effective implementation on Contiki. The theoretical model is validated in terms of reliability (PRR) and latency. Moreover, there is a substantial agreement between Contiki and TinyOS implementations.

Future work includes a comprehensive implementation in Contiki and an experimental evaluation of SERAN in severe scenarios of traffic load, node clustering, channel conditions, and performance requirements.

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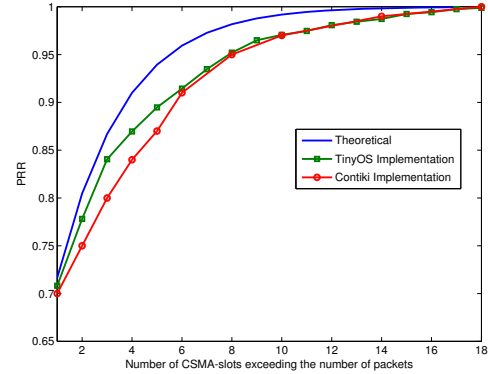


Figure 2. Packet Reception Rate vs. the number of CSMA-slots S exceeding the number of packets k , $k = 3$

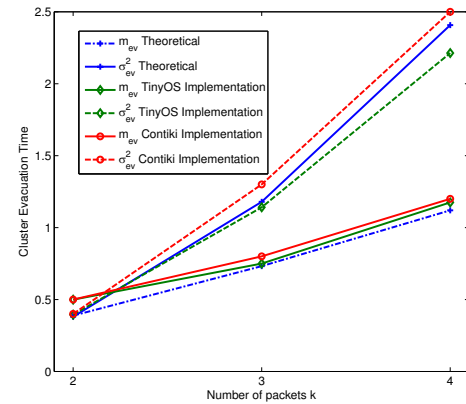


Figure 3. Cluster evacuation time vs. number of packets

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Measuring Parameters of Multipath Fading

By Magnus Lindhé, PhD student at KTH/EE, Automatic Control Lab

Background

Multipath fading happens when a radio signal is reflected by obstacles. The signal at the receiver is the sum of many reflections that sometimes interfere constructively, and sometimes destructively. This makes the received signal strength fluctuate when the receiver or transmitter is moving fractions of a wavelength of the signal.

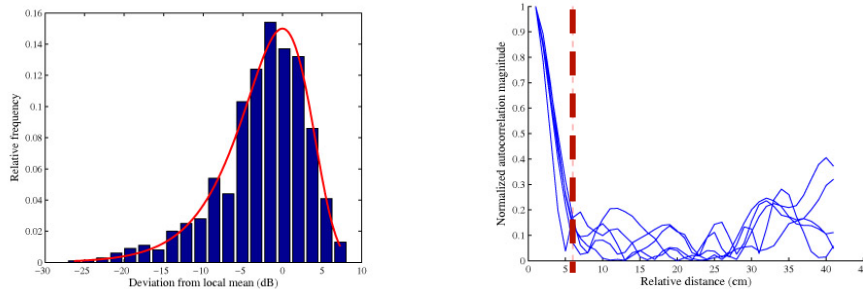
Project goal

Measure parameters of the multipath fading (such as the pdf of the fading and the autocorrelation over space and time) in our tank lab. This will later allow us to develop algorithms for a robot to exploit the fading while moving, to improve the capacity of a radio link.

Solution method

A TMote Sky was used as a base station, sending data to another TMote Sky, connected to a laptop on a moving robot platform. The transmitter sends 64 packets/s, with 50 bytes/packet, at 0 dBm. The receiver listens for 1 s, then moves 1 cm and listens again. For each position, it records the average RSSI.

Results



The RSSI histogram (above, left) matches the expected pdf (solid line) very well. The spatial autocorrelation (above, right) reaches the noise floor at an inter-sample distance of about 6 cm, so this is our estimate of the coherence distance. The correlation in time is very high, due to the static environment.

Contiki was suitable for this measurement, since it allowed low-level access to the CC2420 radio. It also made communication to/from Matlab simple, using the USB as a virtual serial port. But some part of the OS turns the radio on/off periodically, which may have interfered with the measurements.

Detection of Packet-Based Interference

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Abstract

Detecting in an energy efficient way the presence of interference is an important issue in wireless sensor networks: sensor communications might be corrupted by packet transmissions of other devices which might increase data delay and energy consumption of sensor nodes; to prevent such performance degradation interfered channels must be avoided. Interference detection is normally carried out by means of spectrum sensing: this requires extensive usage of the radio unit and it is therefore an energy demanding task. In this paper we present a new algorithm suitable for identifying frequency spectrum opportunities and designed in order to meet energy and complexity constraints of wireless sensor networks. A preliminary performance evaluation shows that our scheme is most effective in detecting interfered channels.

1 Introduction

Interference is today a serious concern in the context of wireless sensor networks. Transmissions of low-power and complexity constrained sensor nodes are easily corrupted by packets generated by other wireless devices operating in the same frequency band: this induces loss of information that might have to be retransmitted eventually increasing data delay and energy consumption. A clear example of this scenario is provided by the problem of coexistence among the IEEE 802.15.4 and IEEE 802.11 radio standards in the 2.4 GHz ISM band. In order to overcome these problems, interference avoidance schemes exploiting the cognitive radio paradigm have been recently proposed. The basic idea of these schemes is to enable frequency agile systems that avoid channels experiencing high interference levels. A key issue that needs to be addressed in order to implement these algorithms involves the identification of those channels that are unsuitable for sensors communications. Such a task normally requires nodes to sense the medium, looking for packet transmissions of other devices and it is therefore an expensive procedure that needs to be accurately designed in order to meet the energy limitations of wireless sensor networks.

Spectrum sensing has been widely studied in the literature; many of the proposed algorithms however focus on the detection of continuous signals such as for instance TV or radio broadcasts ([3]) and this makes them unsuitable for detecting packetized transmissions. Other schemes ([4], [5]) aim at opportunistically exploiting on a very short time perspective temporal spectrum holes: this approach however re-

quires frequent spectrum monitoring and might not be a feasible solution for power limited sensor devices.

In this paper we present a new sensing scheme that overcomes the limitations outlined above and it is expressly designed for identifying frequency spectrum holes and detect in an energy efficient manner packetized transmissions. We tested this algorithm in the 2.4 GHz ISM band under several channel conditions: experimental results show that our scheme is most effective in identifying the presence of packet transmissions and outperforms other sensing schemes that does not account for the packetized nature of typical sources of interference in the considered unlicensed band.

2 The Sensing Scheme

The sensing scheme we propose, which skeleton is outlined in Figure 1, aims at estimating the presence on a certain channel of a level of interference greater than a maximum tolerable threshold defined in terms of average channel occupancy ρ and average power of the interfering transmissions σ_1^2 .

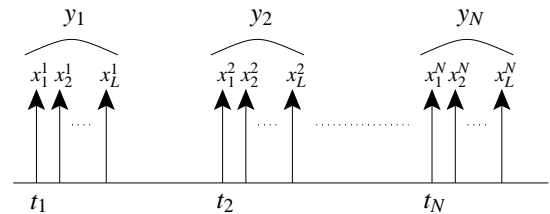


Figure 1. Sketch of the considered sensing scheme.

To this purpose, the node executing the algorithm collects N channel macro-samples y_1, \dots, y_N at time instant t_1, \dots, t_N : each macro-sample consists of L micro-samples: for instance at time t_i we will have x_1^i, \dots, x_L^i . The presence of a modulated signal is then estimated by comparing the power of the collected micro-samples $\sum_{k=1}^L |x_k^i|^2$ with an opportune threshold. Finally the algorithm classifies the sensed channel based on the number of macro-samples that have given positive outcome. More details on how to choose the algorithm parameters L and N , the decision thresholds and the temporal pattern of the sensing procedure can be found in [6]. While implementing our scheme we have assumed $N = 80$, $L = 8$ micro-samples per macro-sample and periodic sensing with intra-sample time equal to $\delta_t = 5[\text{ms}]$. Spectrum sensing has been performed by means of energy detection.

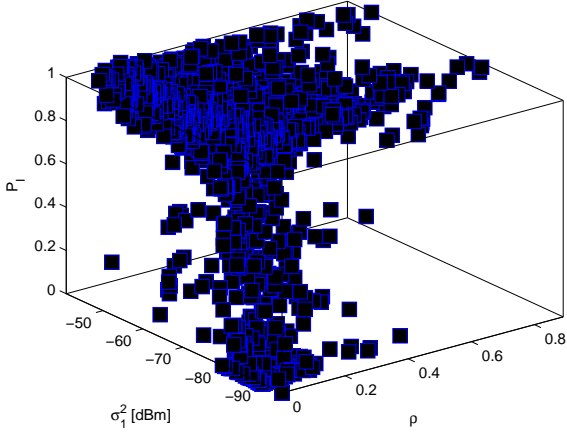


Figure 2. P_I as a function of ρ and σ_1^2 for our intermittent-sensing approach.

3 Evaluation

In this section we present a preliminary performance evaluation of our algorithm. We ran the interference detection scheme over the 16 IEEE 802.15.4 channels in the 2.4 GHz ISM band, carrying out experiments in both office and residential areas in order to fully capture the algorithm behavior under different channel conditions. The figure that we have chosen in order to quantify performance is the probability P_I of classifying a channel as interfered. This was obtained by running several times the algorithm under the same channel conditions and computing the rate among the number of iterations that have lead to the identification of interference and the total number of performed iterations. Results are presented in Figure 2 where we show P_I for different channel occupancy ρ and interfering power σ_1^2 : the parameter $\rho \in [0, 1]$ is defined as the fraction of time during which the measured power level over the channel was 3 [dB] above the noise level (that was around $\sigma_0^2 = -95$ [dBm]). σ_1^2 instead denotes the average power of the interfering signal. For instance for the channel presented in Figure 3 we have $\rho \approx 0.23$ and $\sigma_1^2 \approx -45.2$ [dBm].

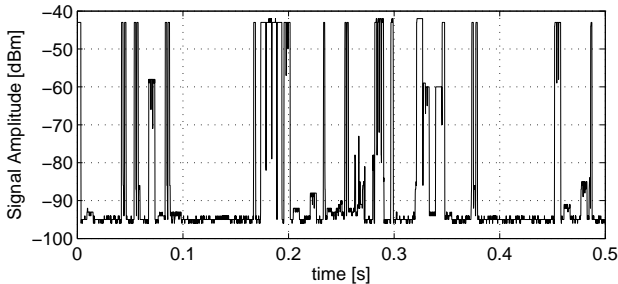


Figure 3. Example of channel considered for our experiments.

It can be clearly seen from Figure 2 that channels with low interference levels (i.e. both low channel occupancy and interfering power) are correctly classified as clear. Higher packet activities are also correctly handled by our scheme

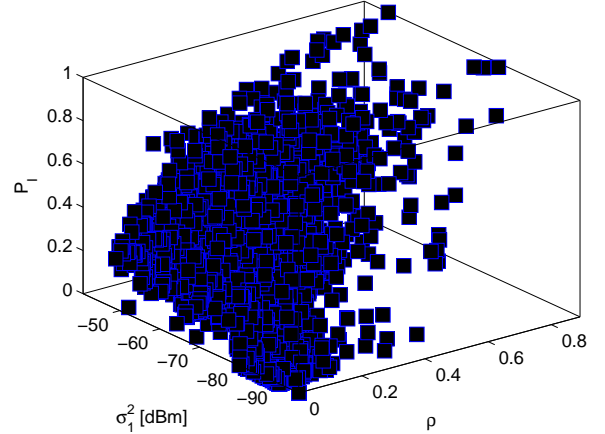


Figure 4. P_I as a function of ρ and σ_1^2 for a continuous-sensing approach.

that is able to promptly detect the presence of other users transmissions. For the same energy budget, i.e. for the same value of N , we compared the performance of our algorithm to the ones achieved by a continuous-sensing scheme, that collects all the N macro-samples in a row, without accounting for the packetized nature of the considered interference. Results for this second scheme are presented in Figure 4: it should be noted how this second algorithm fails with high probability in detecting bad channel conditions and in order to achieve the same performance of our scheme would require a much higher number of channel samples.

4 Conclusions

In this paper we presented a new sensing scheme designed for detecting packet-based interference: this scheme can be exploited in order to allow energy constrained sensor nodes to identify frequency spectrum opportunities. A preliminary performance evaluation of our algorithm in different channel scenarios has shown good performance.

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Identifying Spectrum Availability Based on RSSI Analysis using Wireless Sensor Network

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ABSTRACT

A spectrum sensing helps to do efficient spectrum utilization by providing information about available channels that can be exploited in space and time. In our case, we implemented a method of identifying spectrum availability based on analysis of RSSI values collected with Tmote Sky sensors in an indoor environment. We have conducted measurement campaigns and evaluated the proof of concept. Our analytical and empirical results have shown a potential of this approach.

Keywords: Spectrum Sensing, Wireless Sensor Network, Energy Detection, RSSI.

1. INTRODUCTION

Wireless Sensor Network (WSN) has enabled the development of applications in data collection to detect energy level of radio frequency spectrum. Spectrum sensing helps for efficient spectrum utilization by providing information about available channels that can be exploited in space and time. [1]. It's important to examine the capability of a WSN to detect unused frequencies for the wireless network currently in use. Observing the real time spectrum occupancy is a challenging task to learn the behavior of the spectrum usage under some considerations. This information can be used to predict future spectrum opportunities [2] and to encourage dynamic spectrum access strategies.

In current work, we have studied the occupancy of frequencies by indoor wireless system applying a statistical method based on RSSI (received signal strength indicator) readings via Tmote Sky wireless sensors that use CC2420 Radio [3]. CC2420 operates in 2.4 GHz band and provides two key indicators of the signal power transmission, such as RSSI and LQI (link quality indicator). The technical specifications of CC2420 radio can be revisited more in details in [3].

In this paper, the concept of feasibility to identify spectrum availability by using wireless sensor network is main scope

of our studies. We conducted our experiments in order to see validity of existing techniques. Our proposed method consists of theoretical and empirical analyses of collected RSSI measurements in an indoor environment.

2. OUR APPROACH

Since Tmote Sky provides useful estimator of signal power by RSS indicator, we carried out experiments based on its values. From previous studies we found out that "there is a general belief in WSN community that RSSI is a bad estimator... in spite of this (even so) there is so far no extensive evaluations of CC2420 to validate this claim" [4].

In our model, we proposed a sensing system that is consisted of two nodes; each of them detects energy at receiver side of an indoor wireless network. The system is static and connected to wired backhaul in order to solve the time synchronization problem. All nodes transfer the collected data to central server, where all data can be analyzed. The system operates in the unlicensed 2.4 GHz ISM band. The sensing is performed on a channel domain, which is similar to channel clear assessment (CCA) method done for the IEEE wireless standards.

The motes were programmed with a simple code implemented in Contiki OS [5]. The sensing procedure was modeled for taking measurements at a certain channel for one sampling period, $T_{sampling} = T_{RSSI} + T_{switch}$. The collection of RSSI value is an average of 8 symbols with period of $128\mu s$, T_{RSSI} . The duration of time to switch a channel is about $40\mu s$ [3]. Thus, one $T_{sampling}$ of collection data for all considered channels (ZigBee) equals to 2.68ms.

Furthermore, to see the correlation between two motes decreases, while the distance between them increases for indoor scenario, by placing at a certain line-of-sight location at the office space.

For our method of identifying spectrum availability, to define a decision threshold that could reveal the spectrum occupancy is a crucial task. If the measured RSS in a certain channel is below this threshold, then a channel is considered as available and could be used as spectrum opportunity.

3. EVALUATION

In this section, the proposed method has been implemented and used to analyze a system performance. In order to evaluate the respective probabilities for each channel, we had conducted the time series measurement campaigns within 10000 samples per trace. First we have assessed RSSI values for indoor environment, in order to parameterize the system with two motes (Figure.1).

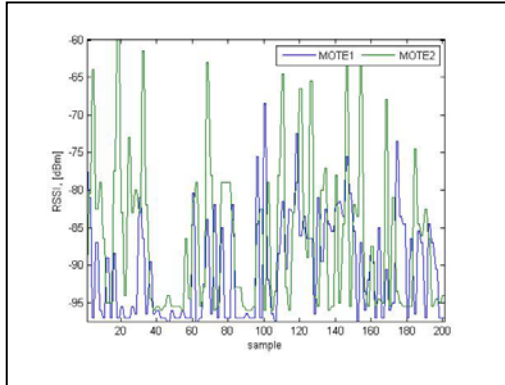


Figure 1. RSSI variance for a certain channel.

Assuming the decision threshold, called CCA_{thresh} , equals to $-77dBm$ and $-83dBm$ [3], the expected availability channel rate, $EACR$, was proposed to investigate the channel occupancy state. (Figure2.) By using this method, we could identify those channels with the highest probability of being available over the sampling time. Figure 3 shows the effect of distance between two motes, there were collected by four sequential sets of measurements at each trace. However, due to lack of time, we could testify results only within a close proximity of motes (up to 10m).

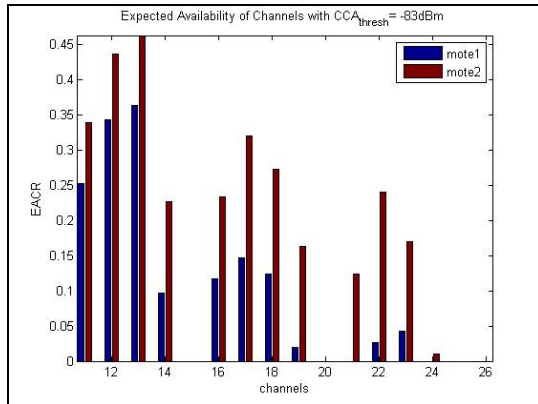


Figure 2. The expected availability channel rate versus channels with distance between 2 motes 8m.

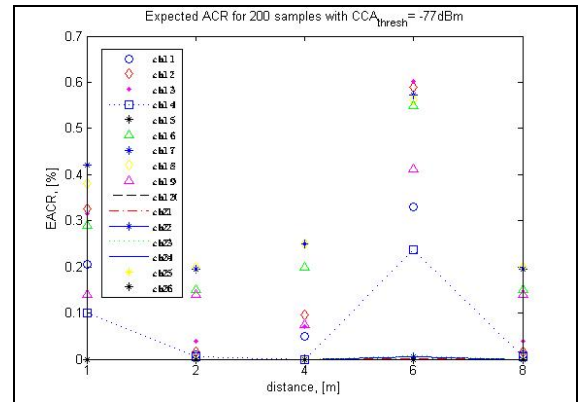


Figure 3. The expected availability channel rate vs. distance between 2 motes for 200 samples.

4. CONCLUSIONS

In our study, we consider problem of the spectrum sensing based on RSSI analysis model for indoor environment. We have proposed a simple method to detect spectrum opportunities by using Tmote Sky sensors. We have conducted extensive measurement campaigns and evaluated the proof of concept. Our solution takes advantages from the existing technologies, WSN; therefore it could be applicable immediately. However, for indoor environment the more extensive measurements require to have a better knowledge of underlying factors in particular for the overcrowded ISM band. The effect of sensors density and searching for an optimal decision threshold can be addressed for the further considerations of the current work.

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Mobility in Wireless Sensor Networks to support Health Care Applications

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November 11, 2008

Abstract

Early research papers have presented architectures in order to support mobility in Wireless Sensor Networks (WSN). Similarly in cellular networks, is very important that an ongoing call proceed when a mobile unit transits from one Base Station (BS) to another, in the same way, we would like a mobile sensor node continuously send its data while it moves through the area covered by the sensor network. On this paper we propose an architecture based in Multihop routing to be used in elderly health care applications in order to support mobility of mobile sensor units attached to the patients. To do so, we propose that static sensors that implement routing (transport network) and aggregate data are referred to as routers, while the no static sensors that are source of data are designed by mobile units. When joining the network, a mobile node merely selects as its parent, the router that gives the best received signal strength indicator. In this way, a mobile unit does not need to implement any routing protocol neither to send advertisement messages in order discover routes to the destination. Our primary results suggest that handover can be performed in WSN, and the experienced packet loss is below 10% if the sender packet rate is 50pkts/sec. This is independent to the handover time.

Keywords: Mobility in Wireless Sensor Networks, multihop communication.

1 Introduction

It is necessarily important that current research results in WSN can be applied to lifetime applications. In this paper work we focus on use of mobility in WSN to support elderly health care applications. Like in cellular networks, is very important that an ongoing call proceed when a mobile unit transits from one Base Station (BS) to another. In the same way we propose architecture in which for example a mobile unit monitoring a patient's blood pressure can continuously send its data to the central monitoring center by using nearby routers while the patient walks on the area covered by our WSN. To do so, we propose architecture in which sensors are classified into two categories: routers and mobile units'. The sensors implement one or two of these modules according to the responsibilities.

Recent proposals such us [1] uses a mobile element that visits nodes that aggregate data. This architecture is inadequate due to the fact that if the size of the network increases, the mobile element would take hours to visit all nodes that aggregates data

The main contribution of this paper is to analyze how we can easily perform handover in WSN and its impact on packet losses. Our architecture is designed in order to divide the tasks that a specific sensor executes in the network.

2 Proposed architecture design

The proposed architecture is based on the cellular networks on which the BSs are static while the cell phones are mobile. We classify the sensor according to the role in the network; as routers, and as mobile nodes respectively. A router is a sensor that is part of the transport network whose purpose is not primarily source of any data; they merely relay received data from mobile units or from other routers to the destination using multihop routing algorithm. A router implements two modules: the routing and the mobility modules respectively. The routing module is responsible for routing the received data to the destination, while the mobility module on the routers is responsible for; advertising router's position so that mobile units can find it, receiving data from mobile sensors and transfer it to the routing module in order to be relayed, to act as a gateway from other routers in the network, and replying to mobile units requests. On the mobile units, the mobility module is responsible to receive beacons messages from routers, and to select the closest router.

When a mobile node moves around the area covered by the transport network, its mobility module continuously monitors the received signal from surrounding routers and then selects as its parent the router which gives the best received signal strength indicator (rssi). In this case, the selected router acts as the cluster head for mobile sensors that might have chosen it as their parent. For this light version of the architecture, no congestion is checked at the selected router. The aim is to guarantee that at any time a mobile sensor can always send its data to the monitoring center. The data and request messages from mobile units to the routers, and request replies from routers to mobile units use unicast communication, while beacons message sent from routers to the mobile units use broadcast. Figure 1 depicts the position of Mobility on the Rime partial stack [3] when implemented on the routers and on the mobile

units. When sending a packet, the mobility module on the mobile units appends the routing header to the payload in order to speed up the forwarding of the packets on the routers.

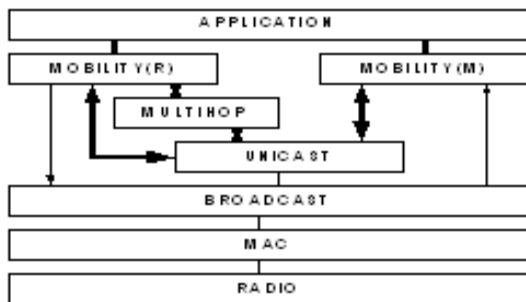


Figure 1: Position of Mobility on the Rime partial stack

3 Evaluation

The system is evaluated using one BS (attached to a PC and acting as a monitoring station), two intermediate routers and a mobile unit. The goal is to evaluate the packet loss when increasing the sender packet rate while at the same time the mobile unit moves in the building following the path depicted on the testbed (see Figure 2).

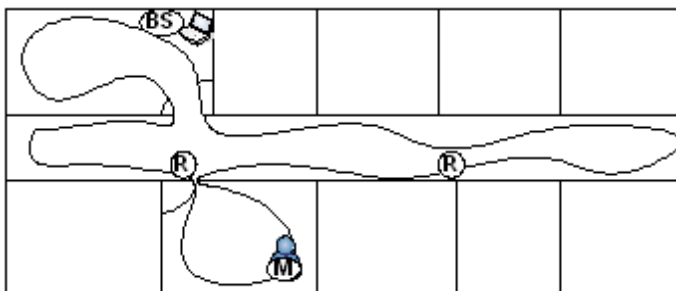


Figure 2: The Test bed depicting the BS, routers and the path that the mobile unit follows.

A. Effect of Handover time on Packet loss

The primary result is that the packet loss is independent to the time that a mobile unit takes to select another router. This conclusion is made due to the fact that we have not verified any gap in the received packet sequence number whenever a mobile unit selects another router. This result is also true even increasing the sending rate. To reinforce this conclusion, on the present architecture we do not check if the selected router is congested neither extra messages are exchanged before a mobile unit performs the handover so that no handover delay is experienced by packets.

B. Effect of Packet Frequency

When increasing the packet rate at the sender, it results in the loss of several beacon messages due to the fact that the

mobile unit is not able to receive many beacon messages from routers and as a consequence, it does not update the rssi value for the neighbor routers. In many cases we have observed that the selected router will still be serving the mobile unit even when the mobile unit is closed to another router. However, as a possible solution is to force the mobile unit to send blocks of packets separated by the beacon interval hopping that the mobile unit has time to receive beacon messages and to update the rssi values.

As we have mentioned earlier, the increase of packet loss is only dependent on the sender packet rate; neither the number of hops can be considered a key factor. On the Figure 3, we can observe that when the for packet frequencies behind 20packets/second, the loss per block is negligible (around 1%) even increasing the speed of the mobile unit. When increasing the sender packet rate to 50packets/sec, we get packet loss values around 7%, and for the sender packet rate values over 75packets/second, the losses are above 45%. These results suggests us that to maintain some accuracy on the received data, the health care application running on the mobile unit should not be configured to send over 50packets/second.

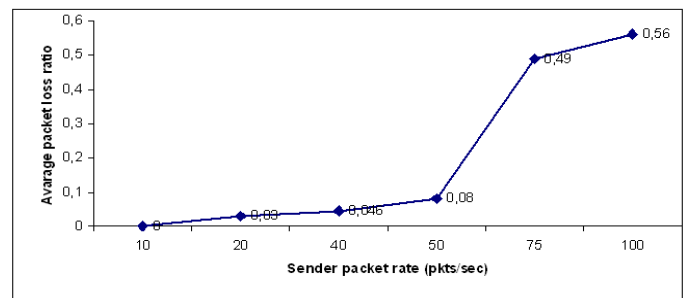


Figure 3: Packet loss evaluation

4 Conclusion

We have presented an architecture that uses multihop routing algorithm to support mobility in WSN. Our results suggest that, its possible to implement mobility in WSN, however, our solution is not reliable enough yet to support elderly health care applications especially when the sender packet rate is up to 50packets/sec. Some improvements such as congestion check at the selected router will be carried out as future work.

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Poster abstract: Channel quality estimation in indoor Wireless Sensor Networks

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ABSTRACT

Link quality estimation is a critical issue in Wireless Sensor Networks (WSN), since it can both affect network protocol performances and lead to a better usage of the limited amount of the available energy.

When a WSN is used or deployed in indoor environments it is prominent the ability of the network to reliably estimate the available wireless channels quality and self-configure on the best one.

Therefore, find indicators for the channel performance that are both reliable and swift to be obtained is an interesting research topic, as well as the target of this paper.

The results of the conducted study indicate that it is possible to measure with a discrete accuracy the quality of the indoor channel, exploiting parameters such as noise and Link Quality Indicator (LQI).

Categories and Subject Descriptors

C.2.1 [Network Architecture and Design]: Wireless communication.

General Terms

Experimentation, Measurement, Performance.

Keywords

Wireless Sensor Networks, Tmote Sky platform, CC2420 radio chip, indoor channel selection, RSSI, LQI, Noise.

1. INTRODUCTION

Indoor channel quality selection is a critical issue for Wireless Sensor Networks. A wrong decision can lead to extremely bad performance or interruption of connectivity. Therefore, a good channel quality estimation is vital for the general design and performance of a Wireless Sensor Network.

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Many current platforms such as the micaZ and the Sentilla Tmote Sky use the CC2420 radio chip [2] that provides as hardware indicators both Received Signal Strength Indicator (RSSI) and LQI.

If on one hand RSSI is known to be a reliable and efficient indicator of the link quality and has been proven to vary coherently with the distance between the nodes [1], it may not represent the best choice when looking for a channel quality estimator with fixed distance nodes.

The experiments carried out during this study proves that RSSI and LQI values are not the best metrics for indoor wireless channel quality estimation with fixed distance nodes. Indeed, their correlation with the Packet Reception Rate (PRR) in such scenario is despicable. Although the experiment result suggested this disconnection, they have also shown that it is possible to estimate how good a channel is with a fairly better accuracy exploiting repeated noise and LQI measurements.

The rest of the paper is organized as follows. Section 2 briefly explains the methodology followed in the experiment; Section 3 present the experimental results and Section 4 the possible approaches for indoor channel selection. Acknowledgments and conclusions complete the paper.

2. EXPERIMENTAL METHOD

The study was made on Sentilla Tmote Sky platforms and consisted in collecting data in a sink node from a sending node located at a fixed distance of 2 meters. The data collection run over 48 hours in a working environment. The nodes were using the Contiki Operating System.

The sink node measured the noise level on the channel for 5 seconds. After that it triggered the sender to send 100 packets and collected for each received packet the RSSI and LQI values. The PRR was computed on the number of packets received over the 100 that were sent. Each packet has a length of 12 bytes. The same procedure was subsequently iterated over all the 16 channels for the whole 48 hours.

3. EXPERIMENTAL RESULTS

The data retrieved in the experiment by the sink node have been analyzed and average values and standard deviation have been computed for RSSI, LQI, noise and PRR.

A good channel can be defined as a channel with acceptable average packet received rate (or alternatively low packet loss rate). But also variance of the PRR is desirable to be as low as possible, especially during the different hours of the day. In the experiment that was run, the difference of the 4 retrieved parameters in the different hours of the day was evident, especially the difference between working hours and night. Since a WSN is expected to run under every condition, low PRR variance is thus an important factor.

From the experimental data it is possible to gather that the average values of both LQI and RSSI does not reflect the actual accuracy of PRR: some of the worst channels in term of packet loss have fairly higher LQI values than the best channels. The same observation can be done with the RSSI average values for each channel.

Table 1 shows the results of the experiment. Data are ordered based on the PRR average. Avg stands for average, Dev for standard deviation and Min is the minimum value registered among all the data collection. LQI values are scaled on 1100.

If on one hand the average values does not give any information, there is a very high relationship between the goodness of the PRR and the LQI and noise standard deviation over time.

LQI variance increases as it increases the standard deviation of the PRR. The more is the variance and the peaks of packet loss during time, the higher will be the LQI standard deviation. This can be evinced from the data in Table 1, as well as that also the noise standard deviation seems to be related to the goodness of the PRR rate: with the exception of channel 19, it increases proportionally with the packet lost rate. Values between 25 and 45 refers to the worst channels, whereas values lower than 10 refers to the best channels.

The obtained results seem also to be coherent with respect to the existing interference between Wi-Fi and 802.15.4 channels: in fact the channels that do not suffer Wi-Fi interference, such as number 25 and 26, are two of the channels with the best average PRR.

CH	PRR			NOISE LEV.		RSSI	LQI	
	Avg	Dev	Min	Avg	Dev	Avg	Avg	Dev
17	95,19	10,30	17	-498,5	42,2	-172,2	1072,3	12,1
22	95,31	4,72	32	-437,5	28,7	-114,6	1057,9	7,1
12	95,74	4,21	43	-442,8	25,0	-118,5	1056,1	8,1
18	96,25	9,21	27	-494,7	33,6	-137,6	1074,2	9,5
21	97,02	4,71	28	-466,0	22,3	-106,5	1061,6	8,2
16	97,85	4,55	35	-498,8	27,8	-155,0	1066,9	11,5
23	98,45	2,82	19	-501,9	14,4	-119,4	1062,4	12,1
13	98,65	1,38	69	-498,4	10,5	-117,4	1063,1	6,9
24	98,77	2,34	79	-487,1	19,5	-134,5	1055,5	4,8
14	98,85	0,85	92	-513,7	5,1	-104,6	1067,0	1,8
15	98,98	0,75	95	-518,0	2,4	-126,6	1069,5	1,6
19	99,32	0,92	80	-500,6	24,1	-104,5	1073,1	2,6
26	99,46	1,56	83	-515,8	4,9	-105,6	1067,2	6,0
20	99,57	0,53	96	-510,7	6,2	-108,3	1069,4	1,5
25	99,95	0,25	97	-514,4	4,9	-126,7	1058,3	3,0
11	99,99	0,16	97	-510,8	8,2	-109,2	1059,0	1,7

Table 1. Experimental results. Noise and RSSI are expressed in dB*10 without the 45 dB offset.

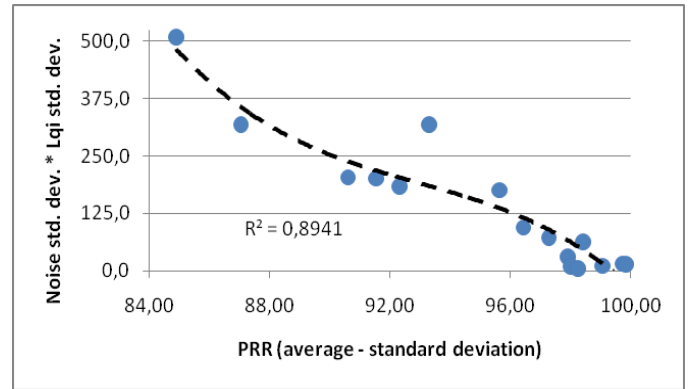


Figure 2. Relation between PRR and the combination of noise standard deviation and LQI standard deviation.

4. POSSIBLE APPROACHES FOR CHANNEL SELECTION

Figure 1 shows the relationship between PRR and the combination of noise and LQI standard deviations. As it can be appreciated, the curve progress is descendent and follows an almost linear trend. Values close to zero indicate a good channel PRR, whereas higher values indicate high packet loss rates. As it can be evinced from the values in table 1, pure RSSI values would not constitute such a good metric. This implies that a good estimation on the channel quality can be made based on repeated measurements on LQI and noise.

In a deployment phase this observation would be very useful to select in a short time on which channel the WSN should operate. If time is not a constraint, different techniques may be used to obtain more fine-grained estimations, for example the file system may be used to store a chronology of the channel quality, so to obtain a larger view of noise and LQI variance over time.

5. CONCLUSIONS

The preliminary evaluation suggests that noise and LQI variance can be used as channel quality estimator with better accuracy than RSSI. If these results would hold true after a more thorough evaluation, more sophisticated channel selection techniques will be studied and developed.

6. ACKNOWLEDGMENTS

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Poster Abstract: Investigating Throughputs Dependency on Packet Size in Lossy Networks

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Abstract

The majority of network protocols for wireless sensor networks transmit packets with their size fixed to the maximum transmission unit without considering the consequences on the overall throughput. This can severely affect network performance, lowering the overall throughput of a network deployed in a noisy environment. We suggest changing the packet size according to channel conditions, thus limiting the impact of packet loss on the overall throughput. We show that by changing the packet size from the maximum transmission unit to the most optimal we will get an increase in overall throughput of approximately 100%.

1 Introduction

A majority of the currently available wireless sensor network protocol stacks utilizes the IEEE 802.15.4 standard for their physical and medium access control layers e.g. [1, 7]. In wireless sensor networks the most common practice is to fill each packet with the maximum amount of data that the underlying network allows. This approach gives the best throughput in a perfect network where packet loss is almost nonexistent. Whenever a packet is lost or corrupted a retransmission is necessary and this lowers the overall throughput. The problem in the case when using large packets is that whenever a packet is lost it will heavily influence the performance in a negative way. If instead the packet size is smaller the loss of a packet does not affect the throughput as much.

In wireless sensor networks packet loss is particularly important since sending and receiving packets is very power consuming [10]. The nodes in a wireless sensor network usually have a limited power source, normally batteries. This in turn can lead to a higher maintenance cost as the power source need to be replaced more often. Sensor nodes might be deployed in hostile and remote environments. In these conditions changing batteries is a painstaking process or at worst not even possible.

An alternative approach would be to use error correction as suggest in [9, 6]. This approach appends extra data to the header so that a limited amount of corrupted data can be reconstructed. The amount of corrupted data that can be reconstructed depends mainly on the algorithm and the amount of extra data in the header. The receiver of a cor-

rupted packet use the error correction algorithm to recreate the packet that was initially sent. The pros of error correction might not over shadow the cons introduced by the extra data in the header. One example would be wireless sensor networks where a packet is relatively small and where a retransmission might be cheaper than always sending the extra data in the header.

The solution illustrated in this paper shows that by lowering the packet size one can increase the overall throughput in a lossy network. The results show that by switching the packet size from the maximum transmission unit size to the optimal size the increase will be as high as 100%.

2 Design

To illustrate our argument we implemented a test application in Contiki [3]. It utilizes anonymous broadcast from the Rime communication stack [2]. This protocol was selected due to its low complexity and lack of retransmission mechanism. The source sends X packets each with a payload size Y to the sink. The total amount of traffic sent for each packet size is a fixed value and thus both X and Y varies. The sink keeps track of the number of received packets and since the total amount is fixed the packet loss can easily be calculated. From the collected data the throughput is calculated for each payload size.

For each packet an anonymous broadcast header of 9 bytes are added and a single byte is appended by the radio driver. Payloads between 1 and 118 bytes was used during the test.

3 Evaluation

To evaluate the system, we run the application on a Tmote sky [8] that is equipped with a CC2420 radio that utilizes the 2.4 GHz ISM band for transmitting. The tests are performed on two separate channels, one channel that uses the same frequency spectrum as IEEE 802.11 and therefore suffers from more interference and one that does not and thus will experience less interference.

In the environment where the experiment is carried out there is a wireless IEEE 802.11b network that run on channels 1, 6 and 11, these correspond to the IEEE802.15.4 channels 11–14, 16–19 and 21–24 respectively [5]. This means that IEEE 802.15.4 channels 15, 20 and 25–26 are likely to suffer from less interference than the others and therefore we arbitrarily choose 15 as our less noisy channel and 23 as our more noisy channel.

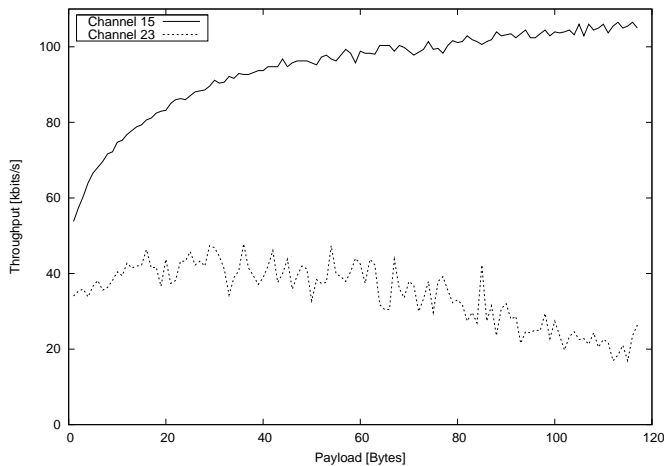


Figure 1. Throughput versus payload size

The code is compiled for the Tmote sky platform using the msp430-gcc-3.2.3 compiler and the CVS version of Contiki retrieved 2008-10-30. X-MAC has been disabled in favor for NULLMAC as the medium access control protocol. As X-MAC limits the maximum throughput in favor of greatly lowering the power consumption of the nodes [4].

From this we calculate the throughput by taking the total sum of bytes received and the time it took to transfer them for each payload size. The distance between the nodes during the experiment was 15 meters in an office environment with an median RSSI values of -39 dBm and -41 dBm for the less and more noisy channels respectively, we run the test for 50 iterations. The results of the experiment can be seen in Figure 1. As shown in the figure the throughput rises until the payload size reaches about 40 bytes and then drops down, this is due to the fact that when the payload size is small the headers give a large overhead, and when the payload size is larger the loss of a packet presents a more severe loss in overall throughput.

4 Conclusions

As we can see in Figure 1 the overall throughput first rises when the payload size is increased as one would expect, but if the channel is experiencing high amounts of noise, which is the case for channel 23, the throughput drops when the payload size grows even further. In our experiment we experienced that when using the largest payload size the overall throughput is only half that of the highest throughput. This would suggest that it is more efficient to use a smaller payload size when transmitting on a channel that is experiencing a lot of noise. The generally accepted notion that a larger payload gives a higher throughput is true when there is less noise on the channel.

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Distributed Polling in Wireless Sensor Networks

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Abstract

When computing aggregates, the traditional centralized approach is slow, wasteful, not scalable and not robust. This is primarily due to the fact that all local data has to be moved to a sink before being aggregated. In this work, we extend, implement and evaluate Echo: a distributed protocol for polling aggregates. The results of our evaluation show that Echo has a much lower overhead compared to a centralized protocol.

Keywords

distributed polling, ECHO, WSN, wireless sensor networks, aggregation

1 Introduction

In many distributed systems, aggregates are usually more important than individual values when it comes to describing the state of the system. In wireless sensor networks (WSNs), the number of nodes, the maximum, minimum, average, histograms of the values being sensed, bottom-k nodes with the least battery level, etc. are all aggregate values that are more interesting than individual values that are being sensed or the property of individual nodes.

There are two paradigms to computing to computing aggregates: the centralized and distributed paradigms. Traditionally, aggregates are computed in a centralized fashion, with a central node (usually called a sink in WSNs), collecting values from all nodes and aggregating them. Though this approach is simple, it has a number of well known drawbacks. The load on the sink and nodes close to it is large and increases usually linearly with the system size, making it not scalable. Also, the centralized node introduces a single point of failure in this system making it not robust.

Recently, another paradigm that leverages the distributed nature of the aggregation problem has been proposed. This paradigm generally offloads some or the entire task of computing the aggregate to the nodes that are holding the individual values. In general such distributed aggregation mechanisms are scalable and robust.

In this work, we propose an extended version of a light-weight distributed polling protocol called Echo that was originally proposed in [1] and extended in [7]. Specifically, the protocol of [1] is not robust to node failures in that if, during the execution of the protocol, a node fails, then the protocol will 'hang' forever. In [7], the authors propose an extension called 'skip Echo' that allows the protocol to 'skip' over failed nodes. The main contribution of this work is extending skip echo for WSNs such that neighbor discovery and failure detection are done in a straight-forward way by the protocol itself so that the overhead associated to the protocol is minimized.

2 Protocol Design

2.1 The Echo protocol

Echo is a tree-based algorithm that can be used, to compute commutative and associative aggregation functions over the values held by all nodes in the system. The protocol has two phases. In the first phase (called the *expansion* phase), the protocol starts at a root node by sending out a token to all neighbors. When a node receives a token the first time, it marks the sender as its parent and then sends out tokens to its neighbors. By the time all nodes receive the token, the parent pointers on the nodes create a BFS tree. When all nodes have received the token, then the expansion phase ends and the *contraction* phase begins. During the contraction phase, nodes wait for tokens from all neighbors before sending a token to their parent. This goes on until the root node receives all tokens from its neighbors to complete the protocol. During this phase, if leaf nodes send their local values while all other nodes send the result of computing the aggregation function over all values received from children, the result of the aggregation at the root node would give the value of the aggregation function evaluated on all local values on all nodes. Figure 1 gives the Echo algorithm.

```
var rec    :integer;  
    parent: neighbor;
```

Algorithm for the initiator:

```
rec:= 0;  
forall v in Neigh do send [echo] to v;  
while rec < |Neigh| do  
    begin receive [echo]; rec:= rec+1 end
```

Algorithms for other nodes:

```
receive [echo] from w; parent:=w; rec:= 1;  
forall v in Neigh-{w} do send [echo] to v;  
while rec<|Neigh| do  
    begin receive [echo]; rec:= rec+1 end;  
send [echo] to father
```

Figure 1. The echo protocol

3 Extending the Echo protocol

The protocol presented above is not robust to node failures or message losses. Specifically, if a node fails before sending a token to its parent or if the token gets lost, then the parent deadlocks the protocol waiting for an echo that never comes.

In [7], the authors propose a solution whereby a node that detects a failed child skips it and sends up the partial aggregate without the value of the failed node (consequently, the subtree rooted at the failed node).

The goal of our protocol design is to send as little messages as possible. This is particularly important in WSNs as sending

and receiving messages are the leading causes of power drain. To this end, our protocol does neighbor discovery and failure detection with $2n$ messages where n is the number of nodes. Note that the echo protocol of Figure 1 has an overhead of $\geq 2n$ messages (being equal when run on a tree) and it assumes that neighbors of the node are known (while our protocol does not). Our protocol uses two timers together with the broadcast capability of WSNs to implement neighbor discovery and robustness (to node failure and message loss).

The protocol is extended as follows. Explorer messages (token sent during the expansion phase) are extended so that nodes also send out id of their parent along with an explorer message. When a node receives an explorer for the first time it marks the node as parent¹. After receiving an explorer, a node waits for a time uniformly distributed between 0 and a parameter t_{tx} before sending out an explorer (this is to implement random backoff). If a node receives an explorer which specifies it as parent, then it marks the sender as its child. After sending out an explorer, a node waits for $1.5t_{tx}$ time units listening for neighbors. If by this time, the node has no children, it sends an echo to its parent that holds its local value to its parent. Otherwise, it waits for messages from all its children or for $t_{to,root} - d * t_{dec}$ ² time units, whichever comes first, before sending an echo to the parent.

4 Evaluation

We implement the extended Echo protocol described above in the Contiki OS on Tmote Sky wireless sensor board using the Rime communication stack on top of null MAC. The protocol uses event timers to implement timeouts. The radio transmission power was set to level 3 so that the communication range of the nodes was around 3 meters. 13 nodes were randomly distributed in a hall 2mx26m. A random node was chosen as the root node and echo was started periodically on this node.

The goal of this evaluation is to compare the protocol overhead for Echo and a centralized polling protocol. The overhead for the case of centralized polling is computed using the *star pattern* [5] which computes the overhead assuming packets are routed via the BFS tree of the Echo protocol. Figure 2 shows the total and maximum overhead of the Echo protocol and a centralized protocol. The protocol overhead is measured as the number of messages sent.

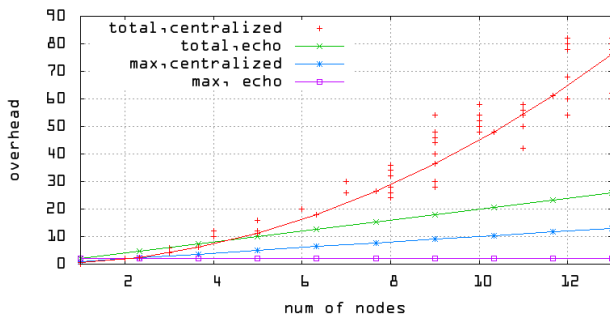


Figure 2. Protocol overhead: Echo vs. a centralized protocol.

The graph clearly shows the advantage of using a distributed protocol. For example, for the case of the total overhead, we see it increases linearly for the case of Echo while it increases with the square of the system size for the case of the centralized system. In

¹Can be improved to choose a closer node, for example.

² $t_{to,root}$ is the timeout at the root node, d is the distance in hops of the node from the root, t_{dec} is the decrement every hop. Note that $t_{dec} > t_{tx}$ and $t_{to,root}$ should be chosen such that $(t_{to,root} - d * t_{dec}) > t_{tx}$ for all nodes

addition, the maximum protocol overhead also is independent of the system size for the case of Echo while it increases linearly with the system size for the centralized protocol.

5 Conclusion and future work

In this work, we presented an extended version of the Echo protocol, a protocol that is used to compute a snapshot of an aggregate in a distributed manner in WSNs. Echo can be used to compute commutative and associative aggregation functions using incremental aggregation on an aggregation tree that is created on the fly. The performance evaluation demonstrates that the protocol overhead is much lesser than that of a centralized protocol and this gain increases with system size.

Our protocol is extremely frugal and the computation load is evenly distributed. Specifically, each node sends out only 2 messages (one explorer and one echo) throughout the computation of the aggregate. This frugality, however comes at an expense. Specifically, if a node's message to its parent gets lost, then the aggregate computed from the subtree of this node gets lost. As message losses are common in WSNs, this is rather a serious issue. A simple extension is to send multiple echo messages instead of a single one so that the probability of reception is higher. Another extension is to use acknowledgements though this would make the protocol more complex.

For the sake of simplicity, our protocol uses null MAC. However, null MAC is not suitable for WSNs as its power consumption is high. The protocol should be implemented with a power saving MAC protocol like XMAC. This, however, requires that the protocol implementation tolerate message loss and duplicate messages.

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Experimental measurement of RSSI and LQI in WSN using Tmote-Sky device

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ABSTRACT

This paper presents two different metrics of measurement (RSSI and LQI) in wireless link quality for different channels in the 2.4 GHz band. The determination of the link quality in the channels could be useful in order for the users to know the performance and use of each channel. We present results of experimental measurement using Tmotes with Contiki operating system. The results show that for both metrics the channels that performance better are between 16 and 22.

Keywords: Wireless Sensor Networks, Latency, RSSI, LQI

1. INTRODUCTION

The use of Wireless sensors network (WSN) is becoming popular especially because a proper alignment and sending power level can reduce the energy consumption, in order to increase the network life time [1], beside that this use small and cheap wireless sensing device that can run on battery power for several months or years. The link quality measurement could provide important information in the network in order for the users to choose a proper channel for a communication and use the resources (energy and frequency) in a efficient mode, this is beneficial for rural areas where the energy is expensive and in urban areas where the spectrum is becoming scarce.

Many studies in wireless link quality measurement have been done specially using the Received Signal Strength Indicator (RSSI) as a metric. In [1], [2] and [3] investigate the variation in RSSI with respect to distance between transmitter and receiver, non circular radio communications and alignment of transmitter and receiver using Tmote Sky devices, the authors in [4] exploring several factors that are relevant for the link layer performance like the effect of interference from simultaneous transmissions and the use of calibrated RSSI measurement. While in [5] they conducted an evaluation of the RSSI as a good estimator of the link quality and compared with the Link Quality Indicator (LQI) parameter. Furthermore [6] is a study of the Link Quality as a metric for the 915 MHz ISM band.

The studies mentioned previously were develop under a single channel, this paper study the RSSI and LQI metrics in multi-channels, the CC2420 radio [7] that use Tmote Sky board [8], already provide multiples frequency (16 Channels with 5MHz spacing) working with the IEEE Standard 802.15.4 [9]. A similar study can be found in [10], where they look in to the Channels versus Packet Reception Ratio and related with the RSSI with and without interference.

2. SYSTEM DESIGN

The experiments are conducted in an indoor environment using Tmote Sky. The two Tmote are aligned and the distance between then is 10 meters. The Tmotes are programmed using Contiki an open source, highly portable and multi-tasking operating system [11]. The two Tmotes send 40 unicast messages each other. The data in the message contains the RSSI and LQI measurement in different channels; a raw idea of the Program is explain in Fig.1.

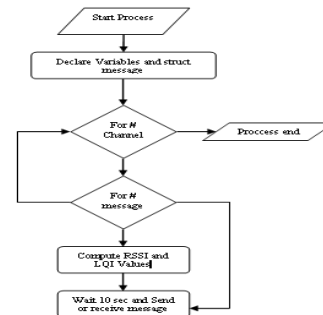


Fig.1. Flowchart of the program made in Contiki.

3. EVALUATION

In order to evaluate the system we are interested in the RSSI and LQI parameters that are extend as follow.

3.1. RSSI Parameter

The RSSI values in one channel are not the same even when the location of the two transceivers is fixed, the values of it

is limited to the range of 60 to -60 for the CC2420. Fig.2. Show the RSSI values for the 16 different channels, each point correspond an average of 40 different values. Each line corresponds to the measurement of different Tmotes, but is notice that in both measurements the better channels are the ones between 16 (2.43GHz) and 22 (2.48GHz). The Fig.3 represent the correlation between the measurements of each Tmote, where we can see that there is a linear correlation.

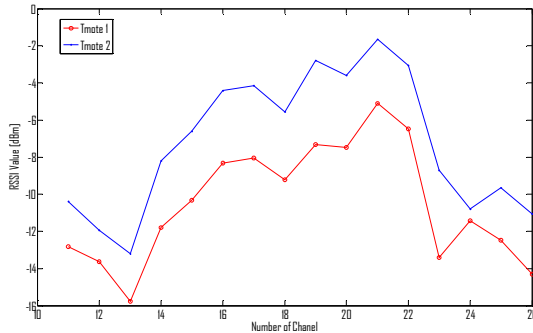


Fig.2. RSSI Values for different Channels, each graft correspond to the measurement of different Tmotes

Note that trough the RSSI parameter we can also take care of the input power by the expression [7]:

$$P = \text{RSSI_VAL} + \text{RSSI_OFFSET} \text{ [dBm]} \quad (1)$$

Where RSSI_VAL is compute by the device and the RSSI_OFFSET is approximately -45.

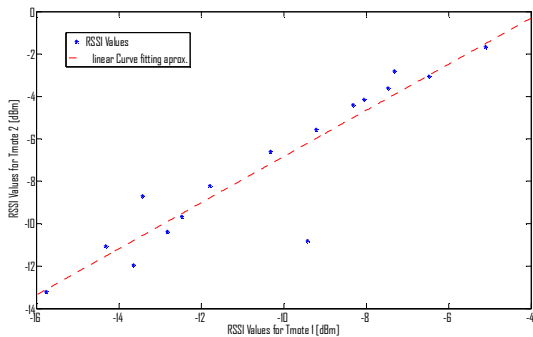


Fig.3. Correlation between the measurements of RSSI values in each Tmote.

3.2. LQI Parameter

The LQI is a metric that is compute for the CC2420 for each received packet, this is limited to the range of 0-255 and is defined according the following expression [7]:

$$\text{LQI} = (\text{CORR} - a) \cdot b \quad (2)$$

Where the average correlation value (CORR) is appended to each received frame together with the RSSI value. The

“a” and “b” values are calculates empirically based on PER measurement as a function of the correlation values.

Measurements of the LQI are present in Fig.4. We can see that the curve for the Tmote 2 is the one that make sense according with the RSSI values, each point is as well an average of 40 LQI values, because the middles channels have a better performance with values grater that 105dBm.

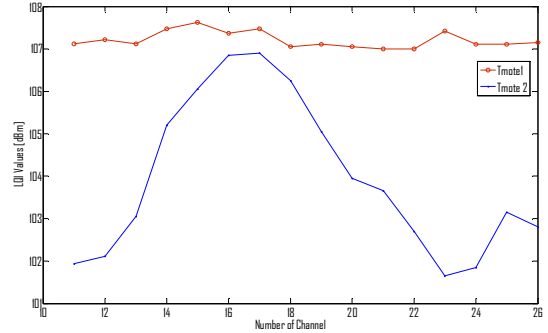


Fig.4. LQI Values for different Channels, each graft correspond to the measurement of different Tmotes

The correlation between the measurement take for the Tmotes for the LQI parameter is show in Fig.4. Note that from a 107.4 downwards the LQI for Tmotes 1 and 2 seems correlated.

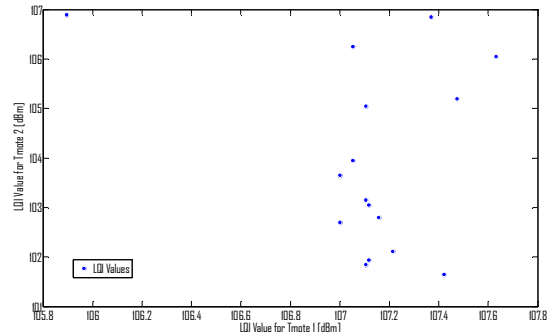


Fig.3. Correlation between the measurements of LQI values in each Tmote.

4. CONCLUSION

In this paper we show that through unicast message the Tmotes can share information about the RSSI and LQI parameters in order to choose a proper channel for a communication. The range of channels between 16 and 22 are the ones that performance better according with both metric. We believe that this result is helpful in networks design where resources like energy consumption and spectrum are scarce.

5. ACKNOWLEDGEMENT

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