MoteFinder: A Deployment Tool For Sensor Networks

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Abstract

The support for the actual deployment of wireless sensor networks is, notwithstanding an increased interest and work in this field, still an underdeveloped area of research. We discuss the use of two simple objects built from household materials – a cantenna and a tinfoil cylinder – to increase the directivity of an antenna of a standard mote. This *MoteFinder* can be used in a variety of applications including node localization and as a tool for selective communication with groups of nodes. We show in our evaluation that both devices provide a good sense of direction in indoor and outdoor scenarios and provide a foundation for future research.

Categories and Subject Descriptors

B.4.1 [**Input/Output and Data Communications**]: Data Communications Devices; C.2.3 [**Computer-Communication Networks**]: Network Operations

General Terms

Experimentation, Measurement

Keywords

WSN, directed antennas, deployment, experiments

1 Introduction

Wireless sensor networks (WSN) have been proposed as a new technology enabling cost-effective and non-intrusive long-term monitoring of ambient characteristics. Application scenarios include environmental monitoring, structural health monitoring, facility management, safety applications and rescue scenarios. The research in the field of WSN has concentrated on a large number of issues including efficient MAC and routing protocols, adaptive systems, localization and hardware designs.

However, the number of practical operations of sensor networks is still limited and real deployments often raise unexpected problems not addressed in the development phase [7, 13]. Additionally, we are still far away from the use of cheap "throw-away" sensor nodes as envisioned at the beginning of WSN research under the term "smart-dust". Although research specifically targeted at the simplification of the deployment phase is underway, a lot of work has still to be done in this area to realize the stated goal of wireless sensor networks of ubiquitous non-intrusive and cost-efficient monitoring.

In this paper, we present "MoteFinder", a helpful tool for supporting the deployment of motes. We present two very simple devices – a so-called cantenna and a tinfoil cylinder – to increase the directivity of the radio reception of a standard mote. Applications for this system include the collection of motes after an experiment, important not only due to the still sizable cost but also due to environmental considerations, and also the tracking down of malicious nodes that actively disturb the operation of the network. However, by far the most important application is the support of the deployment phase. The tool can be used to selectively communicate with a number of nodes, e.g., for the assignment of groups, to measure the signal strength of individual nodes, as a node localization tool, for performance assessments and to find malfunctioning nodes. For the future we envision the integration with robots which would enable a sense of direction to motes, for example, to exchange batteries, to collect faulty motes and for fully automatic node localization. We evaluate the performance of the cantenna and the tinfoil cylinder for indoor and outdoor scenarios and show that both devices provide a good sense of direction.

The rest of this paper is structured as follows. After describing the hardware and software of the MoteFinder in Section 2, we present performance metrics in Section 3. We discuss related work in Section 4 and complete this paper with our conclusions and an outlook to future work.

2 MoteFinder

2.1 Hardware

We use two different objects to increase the antenna directivity of our motes. Both approaches use Telos motes as the base platform. On the one hand, we use a home-made antenna following the popular *"cantenna"* approach (depicted in Fig. 1). This antenna is then used as an external antenna with the Telos mote, which requires a slight modification to deactivate the on-board antenna and attach the external one. On the other hand, we use an even simpler device as shown in Fig. 2: we coated a half-open cylinder built of paper and cardboard with simple household aluminium foil found in supermarkets. We then inserted a mote at the bottom of the cylinder without changing the mote at all. Therefore, still the on-board antenna is used for this *tinfoil cylinder*.

2.1.1 Cantenna

Cantennas have become popular in recent years with the widespread proliferation of WiFi networks. A cantenna, the name originally derived from the use of a tin can, is a home-built directional antenna based on the principle of Yagi-Uda directional antenna [14]. The uses of this antenna ranges from extending the range of a wireless network, over connecting multiple wire-

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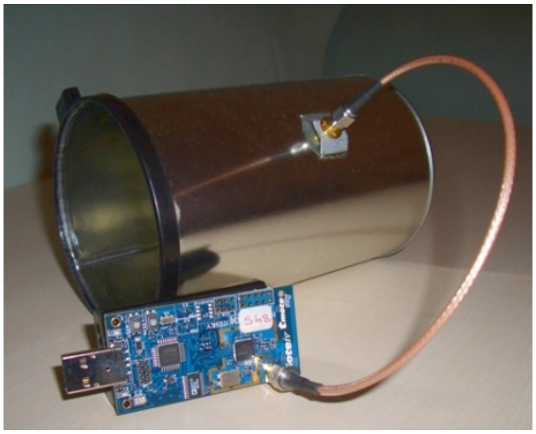


Figure 1. Cantenna

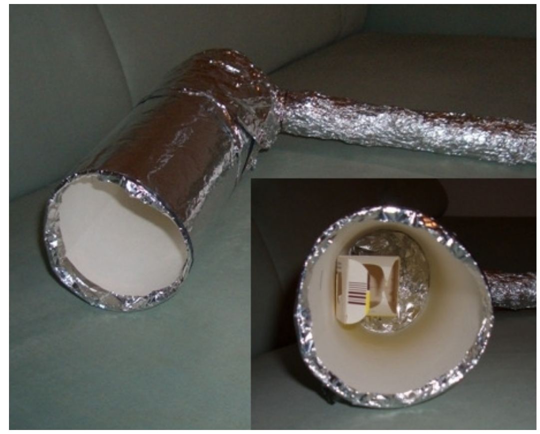


Figure 2. Tinfoil Cylinder

less routers to form larger networks to the so-called "wardriving", searching open Wi-Fi access points with the help of a mobile device. A cantenna is usually employed to extend the range of a device, where increasing the directivity is only a side-effect. However, more related to our approach, a cantenna can also be used as part of a point-to-point radio system.

A cantenna [11] is built around a half-open cylinder, in our case a part of a coffee pot. To obtain a good performance, the length and diameter of the cylinder may vary, but should lie within some limits with respect to the wave length – in our case corresponding to 2.4 GHz. Important is a smooth surface of the cylinder particularly the bottom. In addition to the cylinder only a few small parts are required. The most challenging part of the construction is the exact drilling of a small hole for the injector, a little metallic rod connected to the antenna cable that must extend into the cylinder. The Telos mote is already set-up for the attachment of an external antenna. Only a SMA connector has to be installed and a capacitor has to be moved in order to switch from the on-board antenna to the external one.

2.1.2 Tinfoil Cylinder

As a second alternative, it was actually the first experiment we tried, we wanted to explore the possibility to increase the directivity of a mote with minimum effort. As explained above, our tinfoil cylinder constructed with materials readily found at home does not replace the on-board antenna. It rather acts as a reflector for the electromagnetic waves.

2.1.3 Cost

Besides the possibility to build a directional antenna yourself, the low cost is a major reason for the popularity of the cantenna concept. The tinfoil cylinder is even cheaper. For the use in sensor networks, it is noteworthy that both extensions do not require any additional energy and thus do not reduce the lifetime of a mote. The cantenna, however, diverts the energy to increase the range in a limited area of direction.

2.2 Software

Likewise to the hardware we prioritize simplicity and the use of existing components on the software side. For our tests, all nodes simultaneously send periodic beacon messages containing their IDs. The software on the MoteFinder records the RSSI values of received packets and transmits these to a base station for analysis.

For the future we envision several possibilities of interaction between the MoteFinder and its users – people or robots. First of all, using the intensity of the LEDs, the frequency of blinking and patterns allows using the MoteFinder autonomously from larger systems and without additional hardware. Mote platforms that provide the possibility to generate sound provide another mode for informing about the signal strength. Another possibility is the inclusion of a simple LCD display as found in many embedded applications, possibly even integrated with a few buttons which allows building a small self-contained device supporting, e.g., the interactive selection of the target node. On the other end of the spectrum are PDAs or even Notebooks which provide the usual capabilities of interaction.

3 Performance Measurements

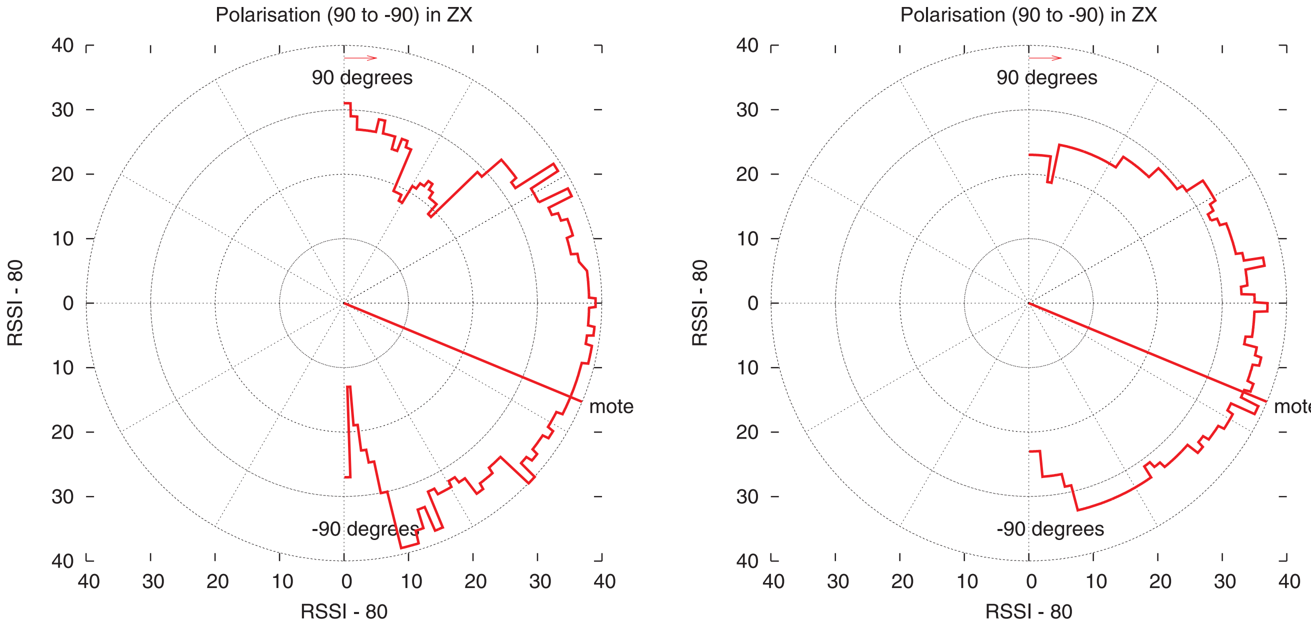
We evaluated our MoteFinder under a variety of settings with both the cantenna and the tinfoil cylinder, different values of the transmission power level (TPL), distances, number and orientation of motes and antennas and with 2D and 3D placement of nodes.

We considered the following coordinate system: The position of the MoteFinder always defines the 0 point of the X-axis and the Y-axis whereas the ground defines the 0 point for the Z axis. The starting direction of the MoteFinder defines the direction of the X-axis. Orthogonal to the X-axis and parallel to the ground is the direction of the Y-axis. The Z-axis is then the vertical direction. All tests were performed by rotating the MoteFinder in the XY-face. However, for evaluating the quality of the performance of the MoteFinder in 3D, we also study the radio propagation pattern rotating both antennas in the ZX face (see Fig. 3a,b)). Even if the antenna is not directed straight at a mote in the ZX face, a scan in the XY face always reveals in which direction the mote is located.

The test scenarios involved several beacon nodes that broadcast their IDs and the MoteFinder either with the cantenna or the tinfoil cylinder measured the RSSI value from every beacon it hears and forwards this information to the base station running the *Oscilloscope* application from the standard TinyOS distribution. For better presentation, all the evaluation figures in the paper use the polar coordinate system and we plot the values of RSSI minus 80 to highlight the differences.

The rotation of the MoteFinder during the tests was performed in regular discrete angle intervals with a granularity of 11.2° with 5 seconds time difference between the angle change. This results in a duration of 160 seconds for one entire rotation circle of the MoteFinder. The beacon nodes sent one beacon message per second.

In the tests several orientations of sensor nodes were considered and compared. We notice a slight difference in the RSSI values of the sensor node depending under the same conditions on its orientation, i.e. if it is located parallel to the XY-face, the YZ-face or the XZ-face. However, these changes in RSSI values are negligible compared to the changes in the RSSI values received from the sen-



(a) Cantenna ZX-Rotation (b) Tinfoil Cyl. ZX-Rotation

Figure 3. Indoor and outdoor settings; Antennas properties

sor node when rotating the directional antenna. This fact makes it possible to use the mote finder in all 3D and 2D scenarios without special consideration of the orientation of the beacon nodes.

Notice, that we do not consider any dependencies between the recorded RSSI values at different locations of the MoteFinder. Due to the fact, that there is little correlation between the value of RSSI and the distance only the "higher than" relation makes sense.

The main difference between the cantenna and the tinfoil cylinder is the much higher sensitivity of the cantenna due to the higher antenna gain. Therefore, for short-distance tests with high TPL one rotation round (0-360°) of cantenna results in only a slight difference in RSSI.

Two evaluation scenarios were evaluated to measure the performance of the MoteFinder: indoor and outdoor.

3.1 Indoor Scenario

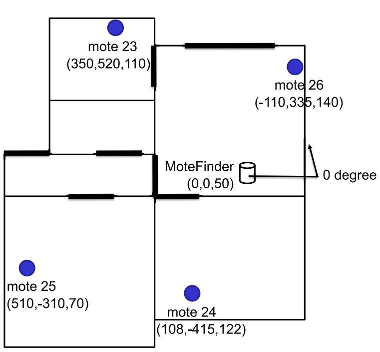


Figure 4. Indoor plan

In Fig. 4 the drawing of the indoor environment is presented. This test involved four beacon nodes located in different parts of an apartment. The walls of the apartment are made of bricks and are 42cm thick (old building). The beacon nodes were programmed with a TPL of 5 (with a maximum of 31 for the Tmote Sky). We experimented with both the cantenna and the tinfoil cylinder rotating in the XY-plane for one complete cycle. The resulting RSSI values are plotted in Fig. 6a,b). The figure presents the RSSI values received from one beacon node over time and, therefore, rotating angle. The straight lines from the center of the graph denote the actual direction to the beacon nodes. It is quite easy to identify different nodes on the graph by examining the position of the highest received RSSI values and derive the direction to it. The measurements show an error of about $\pm 30°$ for the cantenna in the indoor scenario. The cantenna performs smoother with the change of the angle compared to the tinfoil cylinder. The tinfoil cylinder also shows a good sense of directivity providing about $\pm$45-60° of error. However, these estimations are sensitive to the signal strength used by the beacon nodes. Experimenting with the maximum TPL at short distances gives better results for tinfoil cylinder than for the cantenna. This can be explained by the higher gain of the cantenna, which could result in the saturation of the input amplifier of the radio chip. However, the cantenna considerably outperforms the tinfoil cylinder in the following cases: if the TPL of beacon node is low, the distance to the beacon node is large or the RSSI value is low due to obstacles in the environment.

3.2 Outdoor Scenario

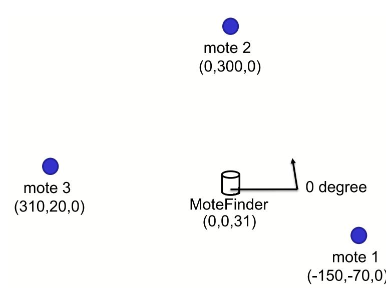
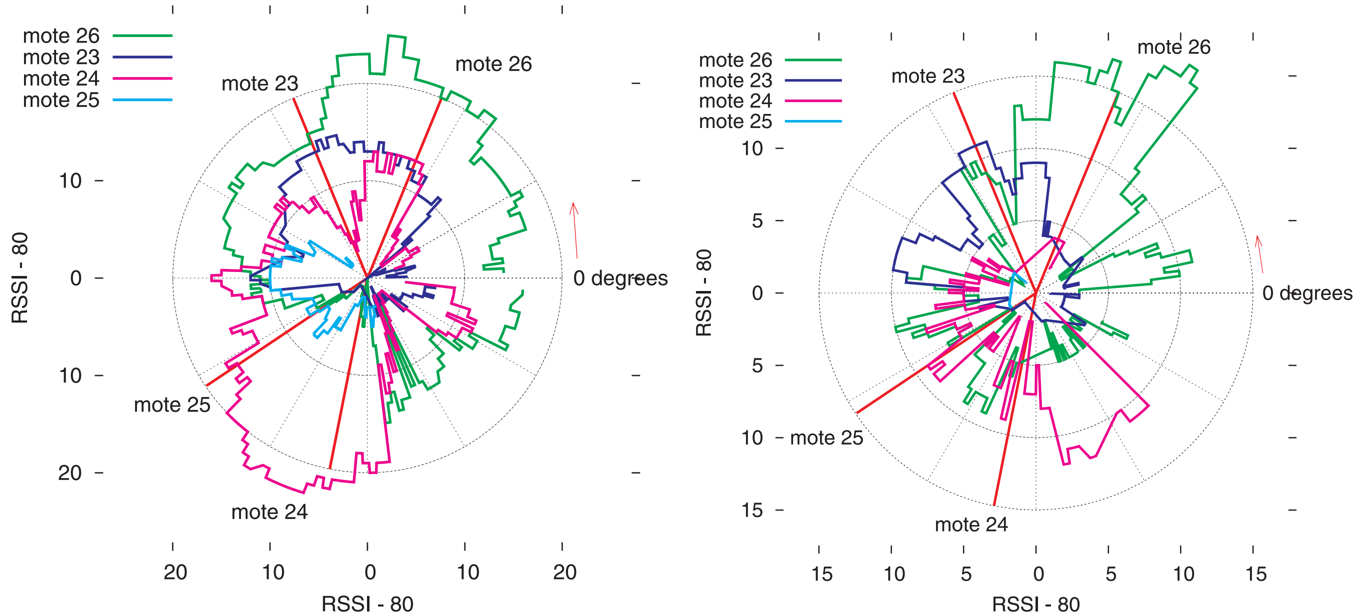


Figure 5. Outdoor plan

The second test scenario was performed outdoors. The tests in-



(a) Cantenna Test Indoor (b) Tinfoil Cylinder Test Indoor

Figure 6. Indoor tests with multiple motes

volved three beacon nodes as shown in Fig. 5. The nodes were programmed with the maximum level of the TPL (31). As in the previous test, we present the results using both discussed MoteFinders in Fig. 7. Due to the higher gain of the cantenna it provides generally higher RSSI values than those received using the tinfoil cylinder. Moreover, short distances to the beacon nodes and high TPL values result in a wider angle where the values of the RSSI achieve the maximum for both the cantenna and the tinfoil cylinder. The absence of obstacles in the outdoor scenarios considerably improves the smoothness of the performance of the tinfoil cylinder compared to the indoor results and reduces the error of the direction estimation.

3.3 Advantages and Limitations

One limitation of the current implementation is the requirement that all beacon nodes have to include their IDs in their message and, more generally, that the MoteFinder understands the message format of the deployed nodes. However, since the source ID of a message is a commonly used part of message formats and more specifically beacon messages are used in a lot of protocols and application, e.g., for neighborhood management, this is not a big limitation to the applicability of our approach. If no node IDs are available, the MoteFinder can still be used as a tracking device, however, not for a specific node.

If the goal is the detection of malicious nodes, the problem is harder, because even the sending of "garbage" messages by these nodes results in a strong disturbance of the network operation. This results in the paradox situation, that the sources of more advanced attacks that involve misleading but correctly formatted messages are more easily located than simple denial-of-service attacks by jamming the communication channel.

The main result of our tests is that a sense of direction is always obtained with the MoteFinder as well as the tinfoil cylinder. The exactness of the result, however, depends on several parameters: the distance, the number of obstacles, the TPL and of course the type of the MoteFinder itself. Both devices have their own area of optimum operation with respect to these parameters.

The evaluation shows the applicability of our approach for both indoor and outdoor scenarios and for both 2D and 3D settings. Moreover, the orientation of the motes does not negatively impact the results. Therefore, our approach is usable for a broad range of deployments and does not require special considerations.

4 Related Work

Cantennas have already been discussed in several publications, however, usually as a long range directed antenna and not as a localization device as in this approach. The authors of [2] evaluate the cantenna and other antennas for the use in long-distance WiFi links (in the range of several kilometers). In [1], the use of the cantenna is recommended to connect the network of schools in underdeveloped countries and in [5] a single rural mesh radio network, which is connected with a variety of antennas and devices including cantennas for some links, is evaluated.

As a direction for future research, we envision the design of a self-contained mote including interactive possibilities. The authors of [4] discuss the application of sensor networks in a workplace setting and present Mica-2 nodes integrated with a LCD and several control buttons. The work of [8] is even more closely related to our approach, as a mote equipped with a small multi-color TFT screen is used as a self-contained device for deployment validation. The system includes the possibility to run a variety of tests in local parts of a network, including connectivity, battery status and the initiation of self-tests to confirm the correct operation of a deployment. This system may be integrated with a directional antenna to better control the area of action and to find malfunctioning or even malicious nodes.

The use of directional antennas in general is discussed in several papers. The authors of [3] model the use of a directional antenna on the base station to increase network lifetime by increasing the range of the sink whereas in [12] the impact on a low-duty mac protocol is discussed. The authors of [6] examine the use of sensor networks to build "danger-maps" in order to guide robots or people safely through hazardous areas in rescue scenarios. While at the moment the nodes have to know their positions, the authors discuss the use of a directional antenna on the robot to allow determining a bearing to the next goal node. A number of papers discuss the use of

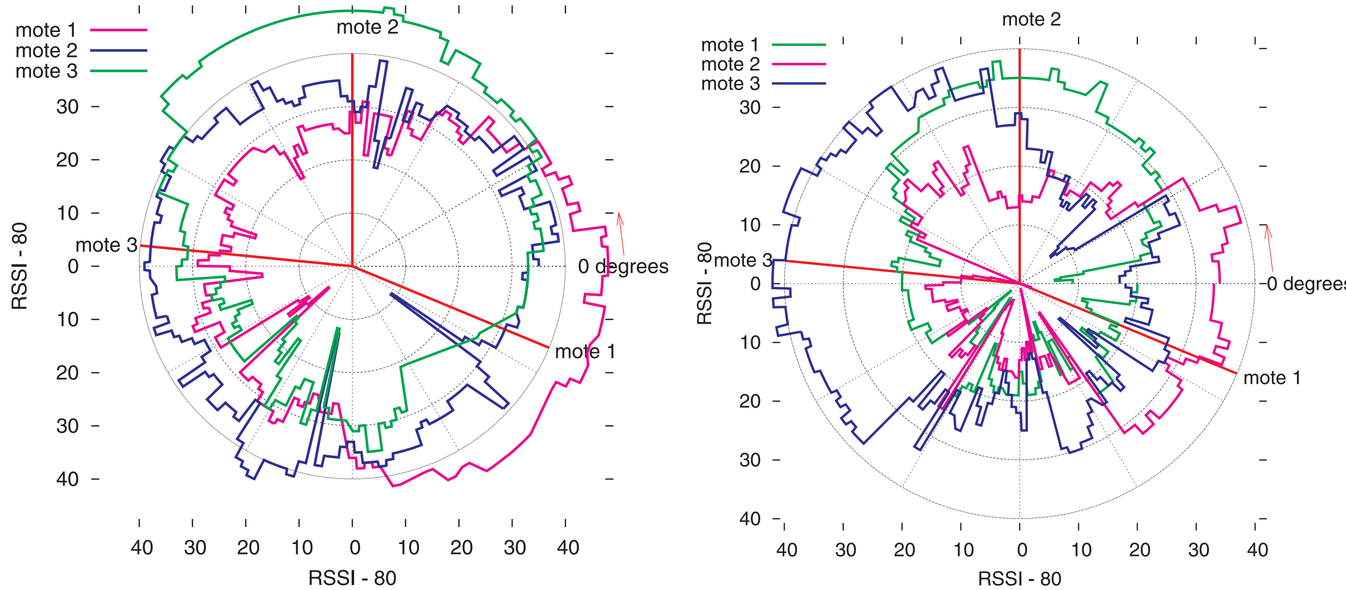


Figure 7. Outdoor tests: Multiple nodes

directional antennas for angle-of-arrival localization including [9] which discusses the use on sinks and [10] using motes equipped with directional antennas.

5 Conclusions and Future Work

In this paper, we discuss the use of two simple objects to increase the directivity of antennas in wireless sensor networks. We evaluate the impact of using a cantenna as well as an even simpler tinfoil cylinder on the radio propagation of a mote. Our results show that even the tinfoil cylinder can be used as an efficient mean to obtain an approximate bearing to a sensor node. The cantenna provides an increased sense of direction coupled with a much higher range. Both objects have their own optimum operation in terms of the ration between the TPL and the distance to the beacon nodes.

For the future, we consider the integration of the MoteFinder with a small display or the use of a PDA to build a small self-contained tool for the targeted interaction with sensor nodes in deployments. The integration of an acceleration sensor and an electronic compass would allow the automatic determination of the polar angle of the antenna and, therefore, allow the easy use as a simple network localization tool.

6 References

[1] R. Beyers. The ulwazi concept: Virtual interactive and collaborative classrooms of the future. In *NADEOSA Conference 2006*, 2006.

[2] K. Chebrolu, B. Raman, and S. Sen. Long-distance 802.11b links: performance measurements and experience. In *MobiCom '06: Proc. of the 12th Int. Conf. on Mobile Computing and Networking*, 2006.

[3] J. Cho, J. Lee, T. Kwon, and Y. Choi. Directional antenna at sink (daas) to prolong network lifetime in wireless sensor networks. In *European Wireless 2006*, 2006.

[4] W. S. Conner, J. Heidemann, L. Krishnamurthy, X. Wang, and M. Yarvis. *Wireless Sensor Networks*, chapter Workplace Applications of Sensor Networks. Artech House, 2005.

[5] D. Johnson. Evaluation of a single radio rural mesh network in south africa. In *Information and Communication Technologies and Development*, 2007.

[6] K. Kotay, R. Peterson, and D. Rus. Experiments with robots and sensor networks for mapping and navigation. In *Int. Conf. on Field and Service Robotics*, 2005.

[7] K. Langendoen, A. Baggio, and O. Visser. Murphy loves potatoes: experiences from a pilot sensor network deployment in precision agriculture. In *Int. Parallel and Distributed Processing Symp.*, 2006.

[8] H. Liu, L. Selavo, and J. Stankovic. Seedtv: deployment-time validation for wireless sensor networks. In *EmNets '07: Proc. of the 4th Workshop on Embedded Networked Sensors*, 2007.

[9] A. Nasipuri and K. Li. A directionality based location discovery scheme for wireless sensor networks. In *WSNA '02: Proc. of the 1st ACM Int. Workshop on Wireless Sensor Networks and Applications*, 2002.

[10] P. Rong and M. L. Sichitiu. Angle of arrival localization for wireless sensor networks. In *Proc. of the 3rd Annual IEEE Conference on Sensor and Ad Hoc Communications and Networks*, 2006.

[11] C. Rütten and S. Dortmund. WLAN-Richtfunk mit Hausmitteln. c't, 2007.

[12] C. Santivanez and J. Redi. On the use of directional antennas for sensor networks. In *Military Communications Conference, 2003. MILCOM 2003. IEEE*, 2003.

[13] K. Srinivasan, P. Dutta, A. Tavakoli, and P. Levis. Understanding the causes of packet delivery success and failure in dense wireless sensor networks. In *SenSys'06: Proc. of the 4th Int. Conf. on Embedded Networked Sensor Systems*, 2006.

[14] S. Uda and Y. Mushiake. *Yagi-Uda Antenna*. Research Institute of Electrical Communication, Tohoku University, 1954.