Network design for the LOG-a-TEC outdoor testbed

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***Abstract*—We present steps involved in planning a wireless sensor network for the LOG-a-TEC outdoor testbed, part of the CREW federation for cognitive radio experiments. Based on initial testbed requirements and estimates of the management network load we have selected two clusters of locations from a large pool of possible locations. We have then performed a verification step. By measuring signal strength and packet loss with a mobile setup we have verified that nodes in the chosen testbed configuration would be able to form a usable mesh network. Finally, we compare our initial estimates of network performance with measurements obtained from the deployed testbed.**

I. Introduction

We are witness to a rapid increase in the number of deployed devices employing radio-frequency wireless communications and increasing requirements for data transfer bandwidth by existing devices. On the other hand we see a shortage of spectrum available for exclusive licensing to new users[1] and strong signs that existing technologies are not efficient at using frequency bands allocated to them[2]. These and similar observations have recently motivated research into novel approaches to radio communications technologies.

FP7 CREW project[1] aims to facilitate this research by creating testbeds for practical experimentation with communication protocols, spectrum sensing, cognitive radio and cognitive networking technologies. CREW testbeds are representative of various real-life environments and provide instrumentation allowing execution of various communication scenarios using experimental protocols and evaluation of their performance.

Research into more efficient use of radio spectrum and coexistence of a large number of heterogeneous devices operating in the same frequency band touches the interest of our research group for wireless sensor networks. Hence the Jožef Stefan Institute has joined the CREW consortium to provide an out-door testbed focused on wireless sensor applications of cognitive radio technologies and low-cost spectrum sensing hardware.

This paper presents the approach we took at designing the geographical configuration of the testbed from the stand point of radio frequency communications. First, an overview and basic requirements are given in Section II. Next, we describe steps leading to selection of node locations in Section III. Section IV describes how we verified the proposed testbed configuration by performing measurements and estimating quality of radio links within the network. Section V presents measurement results obtained from the deployed testbed and compares them with initial estimates. Finally, conclusions are drawn in Section VI.

[1]http://www.crew-project.eu

II. Overview of the LOG-a-TEC testbed

The testbed, named LOG-a-TEC, was to be situated in the city of Logatec, Slovenia. Here, through an agreement with the local authorities, we were able to secure the use of the street lighting infrastructure for mounting and power supply of our equipment. This provided us with approximately 1000 possible locations for sensor nodes, consisting mostly of lamp posts but also occasionally other parts of public infrastructure like switching stations.

The testbed was to be based on the VESNA wireless sensor network platform[3]. VESNA is an embedded system developed at Jožef Stefan Institute based on a 32-bit microcontroller with a modular structure. Testbed requirements called for a total of 50 sensor nodes which would comprise the permanently mounted part of the testbed. Hence we were faced with the task of selecting 50 sensor node locations out of a much bigger pool of possible mounting locations.

The overall design of the testbed followed a pattern we have successfully employed in the past[4]: sensor nodes participate in a management wireless mesh network for remote control and over-the-air reprogramming while a coordinator node serves as a gateway between the mesh network and the Internet. VESNA platform offers a number of options for the management network based on the IEEE 802.15.4 standard, operating at sub-1 GHz or 2.4 GHz bands.

It was decided that the LOG-a-TEC testbed must cover cognitive radio experiments in the 2.4 GHz international ISM band, 868 MHz European short range device band and the white-spaces in the UHF broadcast band. For this purpose, VESNA sensor nodes were equipped with a custom-designed expansion that contains spectrum sensing equipment and software-reconfigurable digital transceivers operating on these frequencies. These radios operate independently from the management network and form the experimental part of the testbed.

III. Selection of node locations

Since it was impractical to do effective optimization on locations covering the whole municipality, our first step was to narrow down considerably the list of candidate locations.

Physical size of the sensor network depends on the range of the radio frequency links that will be used in the network. An early decision was to base the management network in the 868 MHz band because it was expected that most experiments in the testbed will be performed in other bands. This minimized the number of cases where the operation of the management network would interfere with experiments. Compared to 2.4 GHz this frequency also has propagation properties that better fit our predicted network size, which we estimated to be in the range between 500 m and 1000 m based on street light spacing and the number of nodes.

A consideration affecting the distribution of nodes was the desired network topology. Here, two conflicting requirements came into play:

From the standpoint of the management network it was desired to have the smallest number of hops in the network to improve reliability and performance. Compared to most other sensor networks where only small amounts of sensor data is generated, our testbed would often require larger transfers. One example was over-the-air reprogramming. Due to the experimental nature of the testbed, firmware images in the 100 kB range would often need to be uploaded to nodes. Second example is spectrum sensing data. Our radio equipment can generate up to 400 bytes of spectrogram data per second which again often has to be transferred over the management network to the computer controlling the experiment.

On the other hand, the testbed should allow experiments that involve different network topologies, including multi-hop scenarios where different nodes are well outside of the range of others. From this standpoint, a geographically diverse network is desired.

Also because of the second consideration, it was decided to provide coverage of two distinct sub-urban environments available at the location: immediate city center and an industrial zone. It was expected that these two locations will have different properties regarding propagation and interference and hence enable more diverse experiments to be performed.

Other factors affecting our choice of locations were availability of a wired Internet connection for the coordinator node and number of street light switching stations that would require rewiring due to testbed installation.

Based on these constraints we have selected 64 sensor node locations and 2 coordinator locations for further study. A map of the industrial zone and city center clusters can be seen in Figure 1 and Figure 2 respectively. Each location was assigned a numerical identifier. We chose more locations than the number of available sensor nodes to give us a margin for error in case some turned out unusable in the field.

IV. Preliminary measurements

A. Methods

Before we started permanently mounting equipment we had to verify that sensor nodes in the proposed configuration will be able to form a usable management network. We performed this verification experimentally, by measuring radio link quality between possible locations of devices with a mobile setup.

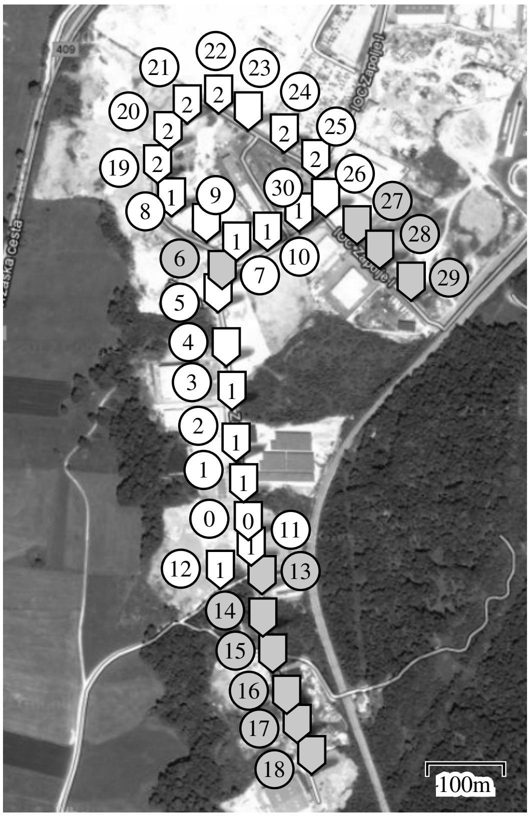

Fig. 1. Map of the industrial zone cluster. Arrows point to sensor node locations. Numbers in circles are location identifiers. Number of hops to the coordinator in deployed network is shown in the arrow. Shaded locations were not deployed.

We assumed that measurement results so obtained are a good estimate of the situation in the deployed testbed.

The mobile setup consisted of two VESNA sensor nodes, both equipped with Atmel ATZB-900-B0 wireless modules[5]. Modules were configured to form a two-node mesh network at 868.300 MHz central frequency, using O-QPSK modulation at 100 kbps and 11 dBm transmit power. Both nodes were using an omni-directional vertical antenna.

One node has been programmed to act as an echoing device (denoted with E), sending any received packet back to its sender. This node was mounted together with a battery in a portable plastic box that could be temporarily fixed to a light-pole in a way similar to the final deployment. A photograph of the mounted box can be seen in Figure 3.

The other node (denoted with T/R) has been transmitting one packet per second to the first one, receiving the responses and recording the received signal strength (RSSI). Transmitted packets included a sequence number and a checksum, allowing the node to also reliably detect packet loss or corruption. This node was mounted on a mobile platform with the antenna 150 cm from the ground. A laptop computer provided power for the node through an USB connection and also stored RSSI measurements on a hard drive for later processing. A photograph of the platform can be seen in Figure 4.

During measurements, node E has been fixed to a light pole

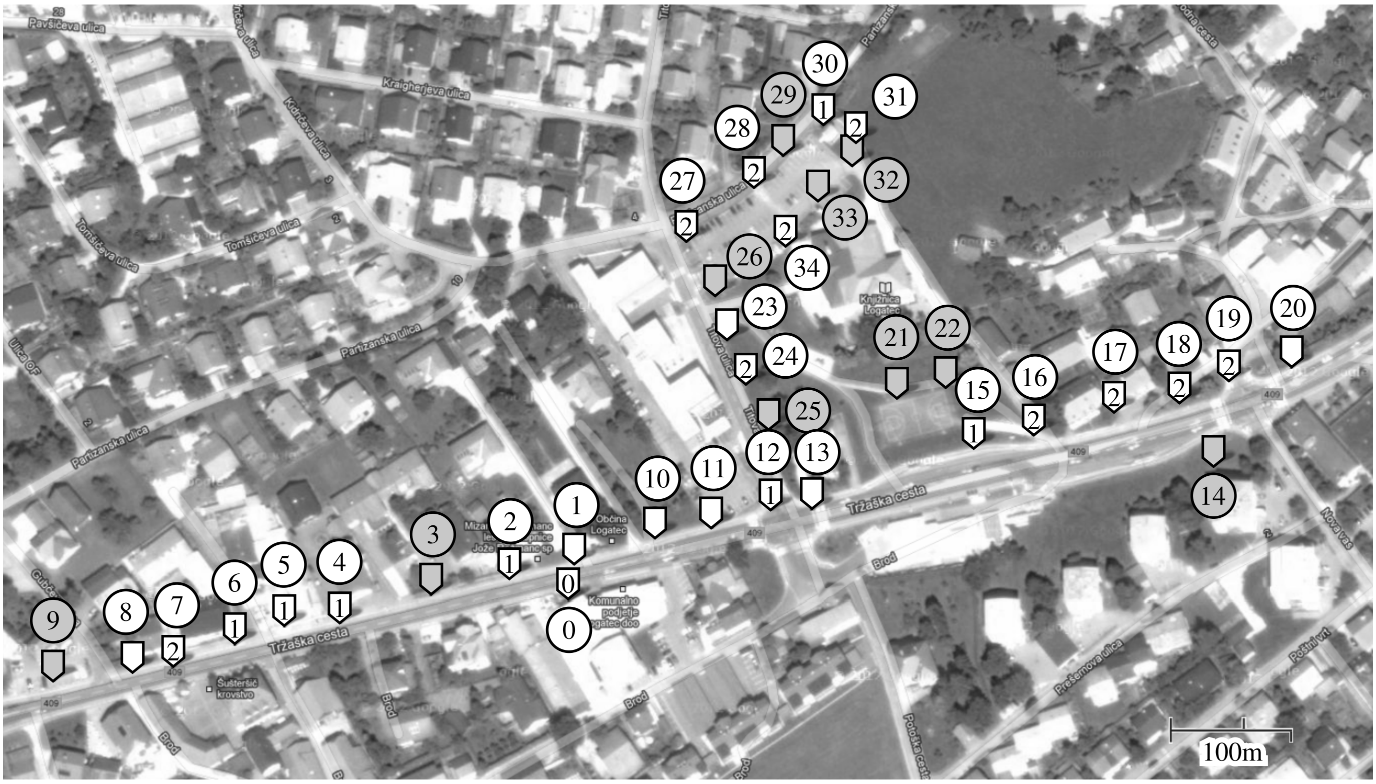

Fig. 2. Map of the city center cluster. Arrows point to sensor node locations. Numbers in circles are location identifiers. Number of hops to the coordinator in deployed network is shown in the arrow. Shaded locations were not deployed.

Fig. 3. VESNA node (E) temporarily mounted on a light pole.

at each proposed coordinator location (designated 0 in Figure 1 and Figure 2) with the antenna 170 cm from the ground.

The platform with node T/R has then been moved to each of the proposed sensor node locations in the corresponding cluster. At each location RSSI and packet loss were recorded for 150 seconds, yielding data for approximately 150 packets. Additionally the GPS coordinates of each location have been recorded manually using a hand-held Garmin GPSMAP 60CS device.

B. Results

Results of measurements of radio link properties from the coordinator location to each individual location in the industrial zone can be seen in Figure 5. Distances have been calculated based on GPS coordinates. Locations where link to the coordinator could not be established (100% packet loss) are not shown.

Locations roughly fall into three categories: up to 150 m the recorded signal strength is falling exponentially. Between 150 m and 300 m signal strength remains approximately constant at around -80 dBm with minimum packet loss. Nodes beyond 300 m have high levels of packet loss. These nodes (6, 7, 8, 9, 10) are located outside the direct line-of-sight along the main street.

From these results we have concluded that the range of our radio links in the industrial zone environment is at least 300 m and that direct communication is mostly limited to line-of-sight. We predicted that nodes up to location 5 will fall with-in the first network hop from the coordinator. Based on the line-of-sight requirement we also estimated that the network will be at most 3 hops deep. Node at location 5 will most likely provide connectivity to nodes 6, 7, 8, 9, 10, 19, 26 and 30 in the second hop, with the rest of the nodes being three network hops away from the coordinator.

Similarly, results of measurements of radio link properties for the city center cluster can be seen in Figure 6.

The results again show division of locations into two

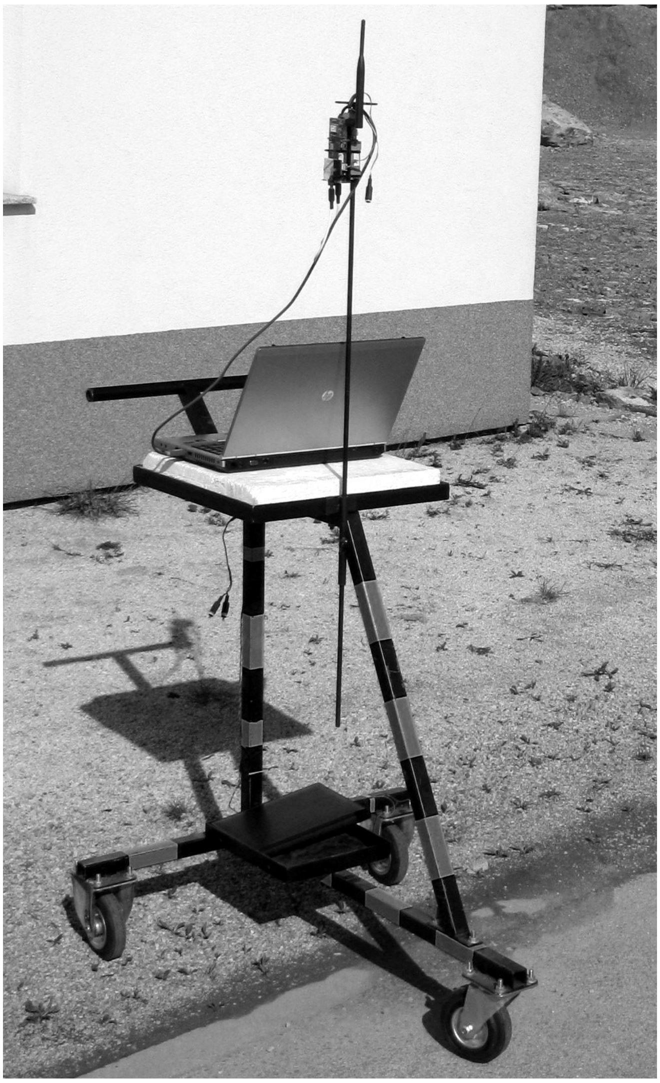

Fig. 4. VESNA node (T/R) mounted on a mobile measurement platform.

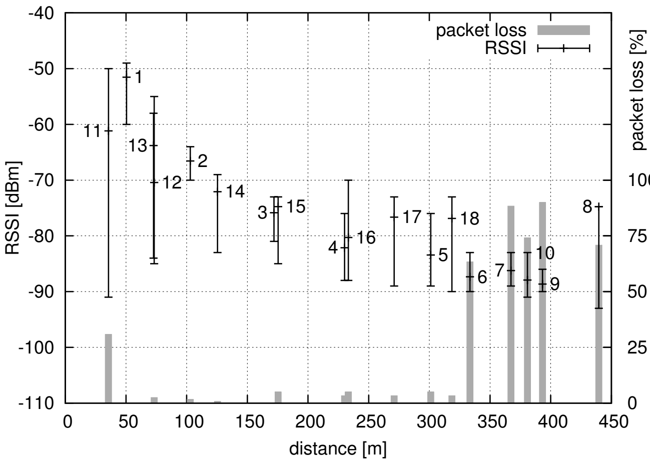

Fig. 5. Observed RSSI values and packet loss in the industrial zone cluster, measured between node locations and the coordinator

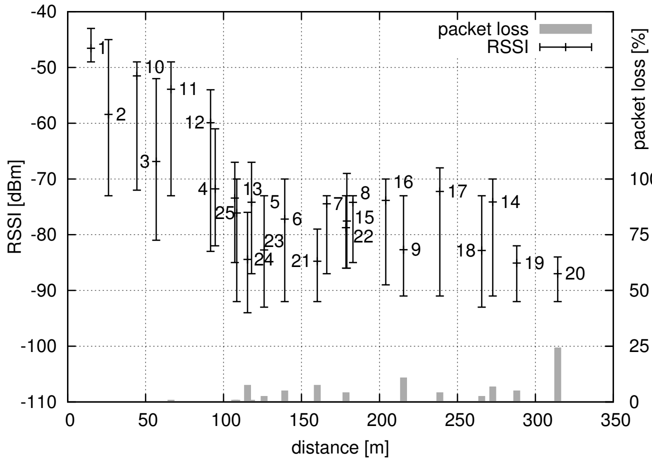

Fig. 6. Observed RSSI values and packet loss in the city center cluster, measured between node locations and the coordinator

categories: falling signal strength up to approximately 150 m and a constant signal strength beyond that distance. Due to greater density of street lights in this cluster we have not reached distances beyond 300 m. Again, reachable nodes have direct line-of-sight with the coordinator with the exception of nodes 23 and 24.

From these measurements we predicted that all locations along the main street will fall with-in the first hop from the coordinator. Nodes in the northern part of the cluster (26 and above) will not be in range of the coordinator. Since all of them are with-in 100 m of a node in the first hop, we predicted that they will be able to communicate with the coordinator through one additional network hop, most likely through node at location 25. Hence the mesh network in the city center would be at most two hops deep.

V. MEASUREMENTS IN DEPLOYED TESTBED

After preliminary measurements indicated that the wireless sensor network would work as desired, we have mounted 20 nodes on previously selected locations in the industrial zone cluster and 24 nodes in the city center cluster. 6 nodes have also been installed on locations not covered in preliminary measurements. These have not been included in this study. Possible locations included in preliminary measurements that were not used in deployment are shaded gray in Figure 1 and Figure 2.

Compared to our mobile measurement setup the permanently mounted nodes include identically configured Atmel ATZB-900-B0 radio modules and use similar, vertically-mounted omni-directional antennas. Sensor nodes were mounted in weather-proof plastic boxes approximately 8 m above ground.

As predicted, the mounted sensor nodes successfully formed a wireless mesh network. Network distance between each node in the deployed network and the coordinator in its cluster is noted in Figure 1 and Figure 2. For technical reasons a number of sensor nodes have not been available for measurements after deployment. Network distance is not shown for these nodes.

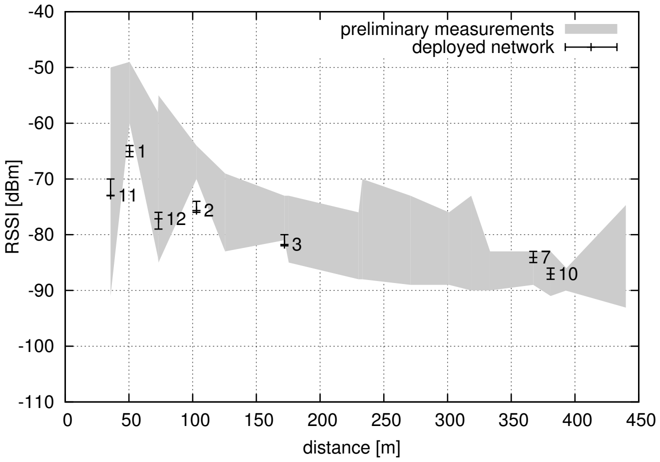

Fig. 7. Observed RSSI values in the deployed network in industrial zone cluster, measured between sensor node with-in first hop and the coordinator

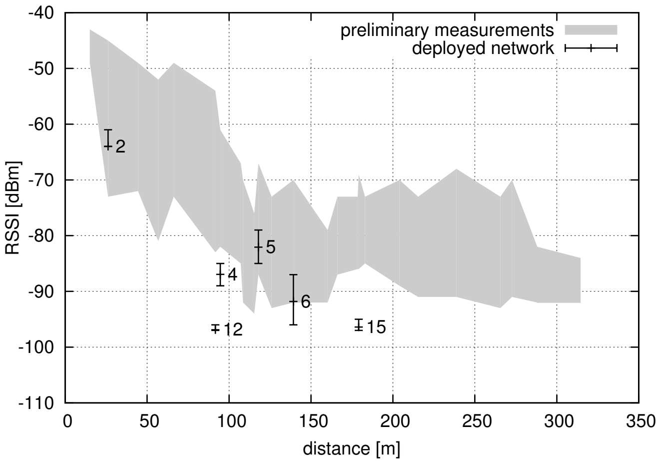

Fig. 8. Observed RSSI values in the deployed network in city center cluster, measured between sensor node with-in first hop and the coordinator

In both clusters, all nodes are reachable with two network hops. This is an improvement over our initial estimate for the industrial zone. We have also observed that the network stack used by Atmel radio modules has a maximum of 10 network neighbors, meaning that some nodes require two hops even if they are in reach of a direct radio link to the coordinator.

To measure signal strength between two nodes on the deployed network, a method similar to the method used in preliminary measurements has been used. Coordinator has been setup to send packets to all nodes with-in the first network hop. It then recorded received signal strength of replies. This time measurements were done remotely and collected through the coordinator's Internet connection. RSSI values in deployed network compared to preliminary results for industrial zone and city center clusters are shown in Figure 8 and Figure 7 respectively.

While measurements in the industrial zone fit relatively well in predicted ranges, nodes in city center see lower than expected signal strength.

VI. Conclusions

Our method of preliminary measurements turned out to be pessimistic regarding network topology in the industrial zone, where only two network hops were necessary to reach all sensor nodes in the deployed network. We can contribute that to the fact that the sensor nodes in the deployed network are mounted significantly higher than the antenna on our mobile measurement platform. This height was sufficient to reach above the metal fences surrounding individual blocks (although not above buildings themselves) and hence might have opened additional line-of-sight links (e.g. to nodes 7, 10 30).

On the other hand our predictions regarding network topology in city center were too optimistic. Although RSSI measurements show that signal strength is also lower than predicted, we believe the limiting factor was the proprietary software implementation of the mesh networking stack in the radio modules used in the network. Would the software be able to track more than 10 neighboring nodes, more nodes should be able to have direct links with the coordinator. Additional experiments would be necessary to confirm that.

Our measurements show that at 868 MHz band and 11 dBm transmit power, the range of a single radio link in the sensor network is at least 300 m. We have observed that in both studied environments the signal strength falls exponentially during the first 150 m and then stays approximately constant at -80 dBm.

We have also seen a much higher variation of RSSI values reported by the radio module with preliminary measurements than when using the deployed testbed. Again we can attribute that to lower antenna height and hence larger influence of ground activity on the radio link (e. g. moving cars and people in the space around the devices).

Regardless of these shortcomings, the preliminary measurements were accurate enough to predict a network with essentially the same properties as one observed in the deployed testbed.

Acknowledgments

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