Extended abstract: UAV-assisted Multiband WSN Coverage Evaluation

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***Abstract*—Integration and deployment of Wireless Sensor Networks (WSNs) in the real world require the careful planning of node placement. The wireless link performance is an important factor for the deployment cost as it influences the number of nodes required to achieve the required coverage. Although the coverage can be simulated beforehand through various propagation models, modeling a complex real-world WSN deployment location is prone to omitting performance influencing factors.**

In this paper we present the usage of Unmanned Aerial Vehicles (UAVs) to determine the wireless link coverage based on actual measurements for WSN deployments. We show the challenges and exemplary results of our approach through measurements on an orchard in Italy for two different frequency bands.

I. INTRODUCTION

WSNs can be used for many different outdoor scenarios such as smart farming or smart cities. Most of these outdoor scenarios propose complex and unique challenges that need to be solved for a successful deployment. In order to do so, real-world testbed deployments can help to evaluate different approaches in a real scenario.

There are many practical challenges that are unique to a certain scenario and cannot be predicted beforehand. In outdoor scenarios, e.g., the wildlife or unpredicted change of the WSNs surroundings, can cause many different side effects that cannot easily be simulated. Thus, testbeds are valuable for research to close the gap between theoretic approaches and the real world.

To be able to successfully deploy an outdoor testbed, it is necessary to plan all node locations as precisely as possible before the actual deployment. This requires the consideration of many different factors such as the Radio-Frequency (RF) coverage, the physical conditions for mounting the nodes or the protection against harmful environment influences, e.g., rain. Some factors can be determined through a side survey and examination of the deployment side, but others, such as the RF coverage can only be determined with reasonable accuracy by doing the actual deployment of nodes.

To solve this problem and be able to base the deployment on measured values rather than estimations for the RF coverage, we propose the use of UAVs to assess the WSN coverage of an outdoor deployment side before the actual deployment of the sensor nodes. The UAV can be used to rapidly place a sensor node at candidate deployment locations to provide a measurement of the actual signal strength. This data can be used to enhance the planning of the sensor nodes locations and avoid connection problems through bad RF coverage.

II. RELATED WORK

Cao et al. [1] interpret the deployment of wireless sensor nodes as multi object optimization problem which considers reliability, coverage and lifetime as objectives. Their algorithm mainly uses the distance and number of relay nodes connected to each sensor node to determine the reliability compared to real world measurements. This could either be enhanced by using a more sophisticated path loss model, which in turn is a lot more complicated, or by using real measured values. Another downside of their approach is that the deployment side needs to be modeled as a 3D matrix before being able to optimize the deployment positions.

Krishnamurthy et al. [2] present experiences with designing and deploying a WSN in a semiconductor plant and in an oil tanker. They perform a temporary trial deployment with nodes placed close to the final positions and found that some nodes had to be re-positioned multiple times because the connectivity changed over the course of a few days. This process could be greatly simplified by the UAV approach shown here, which does not require the trial deployment of nodes. Yet, their experiences show some challenges, such as volatility in the time domain, that need to be considered for our approach as well.

A more comprehensive look at different path loss models to determine the RF coverage for a deployment is shown in Turner et al. [3]. Different models are used in an office scenario which is equipped with sensor nodes to measure the ground truth. Their evaluation of three different paths showed that the Root Mean Square Error (RMSE) is the lowest for the *RSSI Log-Model* and the *Log-Distance Path Loss Model*. However, the results still show a significant difference between the predicted Received Signal Strength Indicator (RSSI) and the ground truth, which can be eliminated with real-world measurements.

Olasupo and Otero [4] designed a framework to optimize the deployment of outdoor WSNs. Similarly to [1] they create a multi object optimization model to determine the deployment positions, but use terrain image recognition on aerial images to settle the appropriate RF model. Compared to using UAVs to measure the actual RF conditions this approach has several downsides. The framework needs an aerial image, which either can be collected with an UAV, which could also measure the RF conditions, or through satellites, which is more expensive to get a recent picture. Further, the framework still uses abstract propagation models for different terrains, which can only provide a rough estimation of the actual RF conditions.

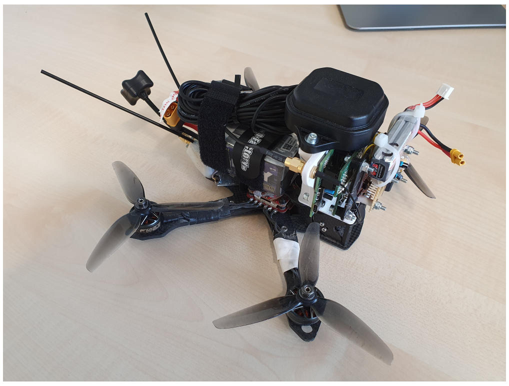

Figure 1. Drone equipped with GNSS receiver and dual-band sensor node

To close the gap between simulations and real-world deployments for performance measurements, we propose UAV-based measurements.

III. MEASUREMENT SETUP

Our measurement setup consists of two identical sensor nodes, one of which remains at a fixed location, in the following called the base station and the other, called the mobile node, is mounted to a UAV, as can be seen in Figure 1. The base station is placed at the location of the sink node in the final deployment. In order to obtain meaningful RF coverage data, the sensor node used for the coverage test should be identical to the one in the final deployment in terms of the wireless link performance. In this evaluation we use a sensor node equipped with a dual band AT86RF215 radio connected to Printed Circuit Board (PCB) antennas and an STM32F411 Microcontroller Unit (MCU). Hence, the sensor nodes can communicate using IEEE 802.15.4 in the 2.4 GHz and 868 MHz frequency bands. The mobile node on the UAV is mounted such that the main lobe of the PCB antennas faces forward, the setup can be seen in Figure 1. A First Person View (FPV) drone was used as the UAV platform in this evaluation to allow easy manual control of the flight path, but other types of drones can be used as well, i.e. in scenarios where automated flight paths are desired.

To collect wireless link performance data in relation to the mobile node and base station locations, these locations need to be known as accurately as possible. For this, the sensor nodes are equipped with a Global Navigation Satellite System (GNSS) receiver which can be operated in two different modes. In the base station configuration, the static sensor node operates in two phases. The first phase is used to observe the GNSS signals over a timespan of multiple hours or days during which a very accurate location is determined by means of averaging. Afterwards, this location is assumed fixed and is used as a basis for the calculation of Real-time kinematic (RTK) correction data. This data is sent to the mobile node using the node's wireless link. In the mobile node configuration the receiver determines its position very accurately based on GNSS signals and the RTK correction data received from the base station.

In this approach, the wireless link, the performance of which is to be determined for future WSN deployments, is also used to transfer the RTK correction data. Therefore, whenever a correction data packet is received at the mobile node, the RSSI is logged with the current location and the correction data is fed to the GNSS receiver. As a result, the mobile node collects datasets with RSSI and precise location information. In addition to the location of the mobile node, additional data such as the heading and the speed are logged, to allow filtering of the collected data.

Figure 2. WSN deployment location evaluated by UAV. The red "x" marks the location of the WSN sink, during the flights, the base station was positioned at this point.

For our evaluation, the wireless link performance in an orchard in Italy, which is used as a deployment location for a WSN, is studied. The orchard, which is shown in Figure 2, consists of multiple rows of trees, in which sensor nodes are to be placed. A sink node can be placed on the roof of a shed, which is located next to the trees. Therefore, the base station is placed at this position.

Since the sensor node can operate in two frequency bands, successive flights are used to evaluate the performance of both bands. In our tests, the flight path was chosen at random and, thus, not identical for both flights. Two sequential flights, one using the 2.4 GHz and another using the 868 MHz band have been performed at the orchard. During both flights, the base station remains fixed at the designated sink node location. During these flights the RSSI of received data packets is recorded in relation to the location data. Keep in mind that RSSI values are only reported by the radio and logged by the sensor node, if the transmission was successful. Hence, no RSSI samples are present for failed transmissions. Further, since the flights were performed manually and the flight path was not identical in the runs, the number of successful transmissions cannot be used as an indicator for the performance of the wireless link.

IV. MEASUREMENT RESULTS

A variety of factors is relevant when estimating the wireless link quality at any given location in a WSN deployment. Most notably, the Bit Error Rate (BER) is influenced by the Signal to Noise Ratio (SNR) in combination with the coding gain of the communication technology [5, 6]. The former is itself influenced by a variety of factors, such as the signal strength at the receiver, background noise levels and external interference.

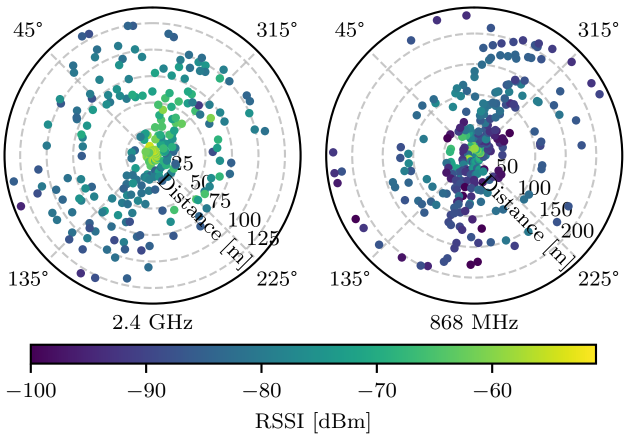

Figure 3. Measured RSSI values at the sensor node in relation to the distance from and bearing to the base station

While the latter can be selected depending on the hardware and communication technology in use.

The SNR can be a useful indicator for the link quality, but requires a sensor node to perform separate measurements of the signal and noise levels [7]. Considering the fact that the drone is not static and that the noise and especially the external interference might change over time, performing separate measurements at the exact same point is difficult. Hence, a single direct measurement is preferred. Since the RSSI is easily determined for any successfully received packet, and is not influenced by the coding gain, this metric is used in our evaluation. Additionally, as the RSSI is influenced by multipath effects [8], a coverage evaluation based on this metric has the potential of detecting these effects.

At any candidate deployment location, factors such as the distance to the transmitter and objects in the transmission path are influencing the received signal strength. These factors are relevant for comparing different candidate locations. Other factors influencing the RSSI include the transmission power and the antenna gain. These factors should be kept as constant as possible during the coverage test, to allow for comparison of the candidate locations based on the data collected.

While the transmission power is easily set to a fixed value in the transmitter's software, the antenna gain depends on the orientation of the sensor nodes relative to each other. Since the mobile node is mounted such that the main lobe of the antenna faces forward, the bearing of the signal depends on the heading of the UAV and the azimuth to the base station. Since the locations of the mobile node and the base station are known, the azimuth can be calculated and in combination with the heading information from the GNSS receiver the bearing is known. The bearing indicates the angle between the front of the UAV, and therefore the main lobe of the antenna, and the base station. A bearing of 0° indicates, that the base station is directly in front, whilst a bearing of 180° indicates that the base station is behind the UAV.

Figure 3 shows the RSSI in relation to the bearing and distance as seen from the mobile node for the flights with both frequency bands. In general, the signal strength of a wireless link in a WSN can be expected to reduce with increased distance. This tendency is also visible in Figure 3.

However, our evaluation of the influence of the bearing on the signal strength is much more pronounced: transmissions with the node oriented towards the base station tend to have a higher signal strength for any given distance. In addition to the antenna gain facing forward, the UAV blocks the signal behind the node which can be expected to reduce the signal strength. Keep in mind that nonuniform distribution of the samples are not a result of packet loss, but rather the selected flight pattern. As the measured RSSI varies greatly with the bearing, in order to obtain meaningful data for a deployment coverage evaluation, only data points within a certain bearing window should be considered.

For a WSN deployment, the coverage at the deployment site determines possible node locations. A coverage map from the data collected during the evaluation flights is given in Figure 4. To limit the effects from differences in the antenna gain on the RSSI relative to the bearing, only data points within ±20° bearing are displayed.

Comparing the results from the 2.4 GHz and the 868 MHz band it is obvious, that the higher frequency band produces a higher RSSI for a given range. This result is not expected, since the free space path loss for a given distance increases with shorter wavelengths. A possible explanation could be a difference in antenna efficiency between the two PCB antennas, which could be investigated in static test on the ground. Albeit the lower RSSI values, the 868 MHz link achieves longer range in this evaluation. However, since different flight paths are flown for the two frequency bands, this could be a result of the flight path and the filtering to a bearing of ±20°. Also it has to be kept in mind that the data rate in both frequency bands is identical, even though the bandwidth of the 868 MHz band is lower. To achieve this, the coding gain in the 868 MHz band is lower, therefore requiring a higher SNR for successful decoding compared to the 2.4 GHz link. However, the RSSI in both frequency bands is high enough that the whole orchard can be covered.

In this scenario no specific candidate locations have been considered prior to the evaluation flights. Hence, a coverage map spanning the whole orchard is desired to allow for the estimation of the number of nodes required to serve the full area. The flight path shows the approach taken in this evaluation. The UAV was used to fly over the orchard in multiple passes. Each path was offset by approximately the width of the trees, whilst facing the base station. The passes where flown directly above the trees, as well as in between trees, to examine whether the trees, which are approximately 2 m in height, influence the wireless link negatively.

The map in Figure 4 shows that the RSSI increases, as the distance to the base station reduces, which is expected. From the data in our evaluation, no significant negative effect of the trees is directly obvious. Whilst it is to be expected that trees in the wireless link could influence the RSSI negatively, the small size of the trees combined with the high base station antenna could reduce this effect. Further flights could investigate this

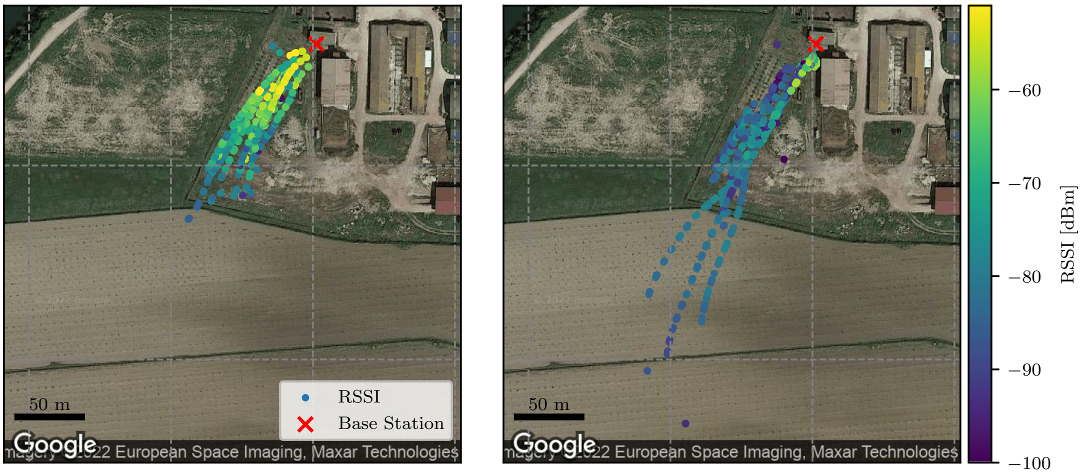

Figure 4. Average RSSI of received packets during the evaluation flights. Left: data from the 2.4 GHz band, Right: data from the 868 MHz band.

more closely.

As a result of the evaluation flights, the importance of careful flight path selection is obvious. To allow for a comparison of the achievable range between two frequency bands, the flight path should be identical. Also, tailoring the flight path more towards candidate deployment locations can help in interpreting the data points. A coverage map, as produced in this evaluation, could benefit from labeling of the data points during flight, to distinguish between conditions, i.e. above or in between rows of trees. Again, this could be done more easily with a pre-planned, automated flight path.

For WSNs using multi-hop communication, in addition to the coverage between the sink node location and a candidate deployment location, the expected link quality between candidate locations might also be interesting. Thus, in future evaluations, an extend measurement network could be considered.

V. CONCLUSION

Performing a coverage check with the actual sensor node hardware prior to a WSN deployment could potentially ease the roll-out process significantly. Using a UAV combined with a sensor node, many candidate locations can be checked rapidly and a coverage map can be produced. Our results show that channel metrics such as the RSSI can be measured at various locations and, hence, may aid in the deployment planning stage. While that approach offers great potential, our initial evaluation also offers some room for improvement. First, the results obtained here only include a single metric. Capturing multiple metrics, such as Link Quality Indicator (LQI), Packet Reception Rate (PRR) and SNR could improve the value of the measurement results. Second, for a comparison between different links, e.g., on different channels or frequency bands or with multiple technologies, following a selected flight path has obvious benefits. With an identical flight path, the absence of data points can be used to indicate areas with little to no coverage, which is not possible with a manual random flight path. Third, producing a coverage map of a whole deployment area leads to large amounts of data and identifying valid datapoints corresponding to candidate deployment locations can be hard. Using in flight labeling of data points by the pilot whenever the UAV is positioned at a candidate location could aid the process of analyzing candidate locations.

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