Impact of Beacon Packet Losses to RSSI-Signature-Based Indoor Localization Sensor Networks

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1. INTRODUCTION
Localization has drawn a great deal of attentions from the sensor network research community. Among the various approaches proposed, RSSI-signature-based solution is particularly popular for indoor localization. The idea is to exploit the uniqueness of the radio signal strength indicators (RSSI) received from a set of pre-deployed beacons at a certain location, referred to as the RSSI signature. Most existing works have focused on devising methods to ensure the mapping between the measured RSSI vector and the pre-recorded RSSI signature is robust. These methods, statistics-based or learning-based, help minimize location estimation errors induced by the instability of RSSI readings. One problem often overlooked is that in our average everyday environment, the beacon packets containing the RSSI information may be lost and how these beacon packet losses are handled play a significant role to the overall localization accuracy. In other words, the proposed statistical or learning-based methods will be able to discover the mapping between the input and output only when there are sufficient evidences to support the existence of such mapping. “Garbage in; garbage out,” so to speak.

In this work, we present an experimental study, in which we deploy a 14-node 802.15.4-based sensor network in our department building. Using the k-nearest-neighbor (KNN) method to the estimation of location, we implement an RSSI-signature-based localization system on top of the network. The two major findings are: (1) whether the sensor network runs on a busy or clean channel makes a dramatic difference. Switching from a clean channel to a busy one, we observe, in our experiments, a 300% increase in the 80-percentile location estimation error. An interesting message revealed is that frequency hopping may be necessary for localization in a spectrum-jammed environment; (2) even when the packet reception rate is high, beacon packet losses are still unavoidable. Many RSSI-signature-based systems fill the lost RSSI reading in with the minimum value. This implicitly assumes that a lost beacon packet must carry a low RSSI value. The RSSI value and packet reception rate, however, are not linearly correlated. By properly filtering out the lost RSSI reading, we observe an approximately 50% reduction in the 80-percentile location estimation error.

2. EXPERIMENTAL TESTBED
The localization system consists of 14 telos motes \cite{1} deployed 10 meters apart along the corridor of our department building. These 14 motes serve as beacon nodes, periodically broadcasting messages containing RSSI values with a 200ms interval. The system adapts a fingerprint-based approach similar to MoteTrack \cite{2} to estimate locations, for which the estimation is based on a reference RSSI signature map. The tracking area is surveyed first to construct the reference RSSI signature per sampled location. In this case study, one side of the corridor (51.3m x 2.5m) is surveyed with the sample points taken every 30.5cm away. In the tracking phase, the system compares the collected RSSI vector to the reference RSSI signatures using the KNN method. In that, we select the top K sample points whose RSSI signatures are the closest in Euclidean distance in the RSSI vector space. The final location is an average of the top K locations weighted by the distances.

3. A CASE OF FREQUENCY HOPPING FOR BEACON NODES
We collected RSSI traces at 4 locations evenly distributed along the corridor in two different channels, one clean and the other busy. Each trace is taken for 5 minutes long. The clean channel operates at center frequency 2.475GHz with bandwidth 5MHz (channel 25 of 802.15.4). This channel does not overlap with any 802.11b/g channels and there are no other 802.15.4 traffic presented during the experiment. For the busy channel, we choose the one (channel 22 of 802.15.4) that overlaps with the center frequency of 802.11b/g channel 11. We deliberately associated a laptop with an access point operating at channel 11 nearby and continuously transferred a large file to generate interference. CDF of the resulting location estimation errors is shown in Figure 1. In the busy channel, the location accuracy drops significantly; the 80th percentile estimated error is 13.7m while in the clean channel the system can achieve an accuracy of 4.5m error, about 3 times lower. We found that the cause of such a big difference is beacon packet losses. The average packet loss rate over all beacons is 42% in the clean channel, but rises up to 83% in the busy channel. The loss of beacon packets leads to insufficient RSSI input to the estimator, and therefore the poor estimations.

To see how the 802.15.4 packets are dropped in an everyday environment, we ran an experiment measuring the packet reception rates on the testbed through all 802.15.4 channels. The experiment is configured to have one sender and all others as receivers. The sender broadcasts a packet every 60ms round-robinly from channel 11 to 26. Here we show typical changes of packet reception rate over a 3-hour period in Figure 2. We can see that some channels are busy in which the packet reception rates are low. The busy periods are usually 20-30 minutes long and the packet reception rate can go down to only 20%. Although several channels seem to remain stable, these channels can still suffer from the beacon packet loss problem if WLAN is deployed denser or other 802.15.4-based sensor networks are constructed in the environment. Configuring the beacons to run on a particular channel will not be a robust
solution in a long run. In the meantime, the busy channels do not stay busy all the time. When the busy channels are stable, they can serve as alternative channels to operate the system just fine. Frequency hopping is widely used to explore available capacity over multiple wireless channels [3][4][5]. Our ultimate goal is to extend this poster work with a design, implementation, and evaluation of a frequency hopping mechanism for indoor localization.

4. HANDLING BEACON PACKET LOSS

We observe also that even when the channel is clean, the packet reception rate is not going to be perfect all the time. I.e., the mobile tag does not always receive the complete RSSI vector. For the computation of KNN, the missing values are traditionally filled in with the minimum RSSI, which is -100 dBm in CC2420. However, our measurement results (Figure 3) show that the relationship between RSSI and packet reception rate is not linear. A higher RSSI does not necessarily imply a higher probability to successfully receive the packet. Instead, for all RSSI above a certain threshold (-85dBm in our experiments), the packet reception rates are all similar. Similar results are reported by Srinivasan et al. [6]. Setting the missing RSSI values to the minimum gives bias to sample points with lower RSSI values. To remove such bias, we filter out the missing values from the location estimation computation. The proposed method is referred to as the normalized KNN (NKNN), in which the Euclidean distance is further divided by the number of beacons from which RSSI values are indeed received. Note that if a beacon RSSI value is missing in both the reference signatures and tracking vector, that beacon is still considered and the distance is set to 0 to prevent under-estimations.

The accuracy of location estimates applying NKNN is shown in Figure 4. In clean and busy channels, NKNN can reduce the 80th percentile error by 53% and 45% respectively. One can have the mobile tag listen for a longer period of time to ensure the completeness of RSSI vectors, but this trades off the timeliness of the location estimation. The NKNN approach is complementary and can add to the effect of a longer listening period. If the application demands very timely location updates, NKNN will be able to improve the localization accuracy under the circumstance.

5. CONCLUSION AND FUTURE WORKS

Our preliminary results show that even in a clean channel, the unreliable beacon packet transmissions can affect the location accuracy and need to be handled carefully. Nevertheless, if the operating channel is heavily interfered by other spectrum users, e.g. 802.11b/g, the performance of beacon packet delivery can be so bad that no good estimations can be made. The beacons should seek for another clean channel to continue operation. One of immediate tasks to pursue is the design and implementation of a frequency hopping mechanism for indoor localization sensor networks. The system will be robust and resilient to beacon packet losses in arbitrary environment, spectrum-busy or not.

REFERENCES


Figure 1. CDF of location estimation errors. Clean channel v.s. busy channel
Figure 3. RSSI vs. packet reception rate. Each data point is a wireless link in the testbed measured over 10 hours
Figure 4. CDF of location estimation errors. KNN v.s. NKNN

Figure 2. The variation of packet reception rate over time in 802.15.4 channels 11-26 in a typical 3-hour period.