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Link Quality Metrics in Large Scale Indoor Wireless Sensor Networks

Ana Bildea, Olivier Alphand, Andrzej Duda

Grenoble Institute of Technology, CNRS Grenoble Informatics Laboratory UMR 5217, France.
`firstname.lastname@imag.fr`

Pouvoir estimer la qualité d'un lien sur la base d'un minimum de paquets est essentiel pour un réseau de capteur sans fil multisaut en environnement "indoor" compte tenu du coût énergétique de cette estimation et de ses conséquences sur la stabilité des routes construites sur ces liens. Notre étude s'appuie ainsi sur des expérimentations intensives menées sur une plateforme Senslab ([Sen]) qui nous ont permis de trouver des lois de distribution suivies par les métriques physiques (RSSI, LQI) pour 3 catégories de liens (bons, mauvais, intermédiaires) regroupés par plage de PRR (Packet Reception Ratio). Sur la base de ces distributions, nous observons comment elles peuvent nous aider à discriminer les différents liens et ainsi les utiliser dans de futures expérimentations pour améliorer l'efficacité de protocoles de routage de réseaux de capteurs dans le choix des liens.

Keywords: Received Signal Strength indicator (RSSI), Link quality indicator (LQI), Wireless sensor networks (WSN)

1 Introduction

Much research has considered the problem of characterizing wireless links to derive metrics allowing finding the best routes in wireless networks. In this paper, we report on the results of measurements on a indoor wireless sensor network testbed that we use to characterize wireless links. Our goal is to find a way of detecting *good* links in comparison to *weak* ones, a recent approach in routing metrics.

We have done extensive experiments on the SensLab platform and recorded two main hardware metrics: RSSI (Received Signal Strength Indicator) and LQI (Link Quality Indicator). LQI gives *"an estimate of how easily a received signal can be demodulated by accumulating the magnitude of the error between ideal constellations and the received signal over the 64 symbols immediately following the sync word"* [TI]. In a typical indoor environment, the metrics fluctuate due to reflections, fading, diffraction, and interference so that we need to characterize the quality of reception in terms of RSSI and LQI in a statistical way.

2 Experimental Set Up

We have run experiments on the Strasbourg platform of Senslab [Sen] composed of 240 WSN430 nodes distributed across 3 trays at different heights. Each tray contains 80 nodes arranged in a regular grid (10x8) with a distance between each node of about 1m (cf. the topology of the testbed in Fig. 1). A node is composed of a MSP430F1611 CPU (48KB ROM, 10KB RAM) and a CC1101 radio operating at 868MHz. Its transmission power ranges between -30dBm and 10dBm, and the reception sensitivity is set to -88dBm.

In a single experiment, we use one tray at a time, i.e. 80 nodes. We observe the quality of transmission of a node that broadcasts a total of 5000 packets of 110 bytes each 0.5s. There is no other ongoing transmissions so there is no interference nor contention between nodes. When one node broadcasts its packet, the other 79 nodes are active and ready to receive—they log LQI and RSSI of the received packet. The receiver nodes do not acknowledge frames so that the MAC layer does not retransmit frames in case of failed transmissions. At the end of the experiment, we compute the average Packet Reception Ratio (PRR) of each link as the proportion between the number of correctly received packets to the total number of sent packets. We assume that all nodes can potentially communicate so that the number of unidirectional links is 6320 (80 sender nodes times 79 receiver nodes). We run the experiments with two levels of the transmission

power: 0dBm and -10dBm. The bit rate is 60kb/s and nodes use the 2FSK modulation. Table 1 summarizes the parameters of the experiments.

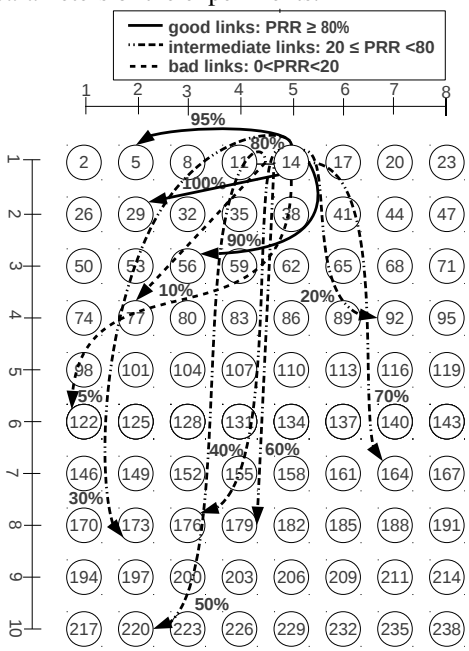


Figure 1: Topology of the second tray of Senslab testbed in Strasbourg. An example of the measured PRR for Node 14 (transmission power: 0dBm): an arrow represents a link labeled with the measured PRR (only links with non null PRR are shown).

Experiment area	10m x 8m x 3m
Number of nodes	3 x 80
Traffic type, interpacket interval	broadcast, 0.5s
Number of packets	5000
Packet size	110 bytes
Transmission power	0dBm, -10dBm
Topology	grid

Table 1: Parameters of the experiments.

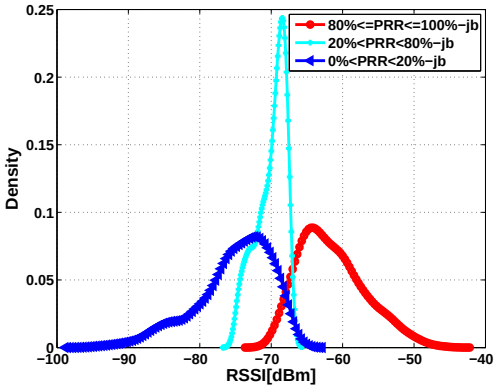


Figure 2: Probability density functions fitting RSSI.

Fig. 1 presents some example links of Node 14 labeled with the measured PRR (the figure does not present all links of the node).

3 Link Characterization

We consider three main categories of link quality: *good* links with a PRR above the 80%, *intermediate* with the PRR between 20% and 80%, and *bad* ones with PRR below 20% (such categories appear in previous studies [WLMP10, SDTL10] and the thresholds may be more strict, e.g. 90%–10%). Table below gives the proportion of links in each category (over all 6320 unidirectional links).

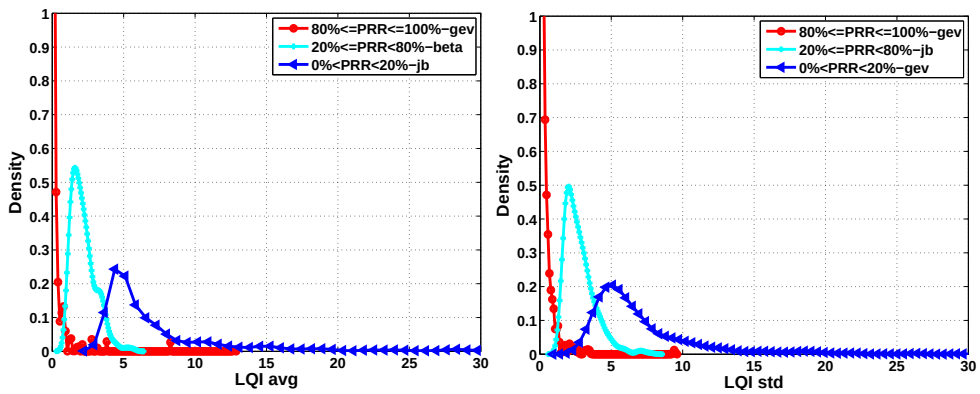
Table 2: Proportion of links in each category

Transmission power	good	intermediate	bad	$PRR = 0\%$
0dBm	49%	8%	10%	33%
-10dBm	44%	6%	9%	41%

$PRR = 0\%$ corresponds to the case in which a given node did not receive any packet. We can observe that there is a large proportion of good links and decreasing the transmission power to -10dBm only slightly affects the proportion of good links.

To further characterize PRR in function of RSSI and LQI, we look for continuous distributions that fit the best the measured values of PRR. The goal is to predict PRR or at least the link category based on the observed values of RSSI and LQI. We have considered as candidate distributions the most common fifty continuous distributions with a bounded, semi-infinite, variable support or unbounded. The distributions

that fitted the best are the following: *Log-logistic* ($F(x;\alpha,\beta,\gamma) = (1+(\beta/(x-\gamma)^{\alpha})^{-1}$), *Johnson SB* ($F(x) = \phi(\gamma+\delta ln(z/(1-z)))$, where ϕ is the Laplace integral and z is defined as $(x-\xi)/\lambda$), *Beta* ($F(x;\alpha,\beta) = B(x;\alpha,\beta)/B(\alpha,\beta)$), *Generalized Extreme Value* ($F(x;\mu,\sigma,\xi) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$). We have used



(a) Probability density functions fitting LQI

(b) Probability density functions fitting the standard deviation of LQI

Figure 3: Density functions fitting LQI for each link category.

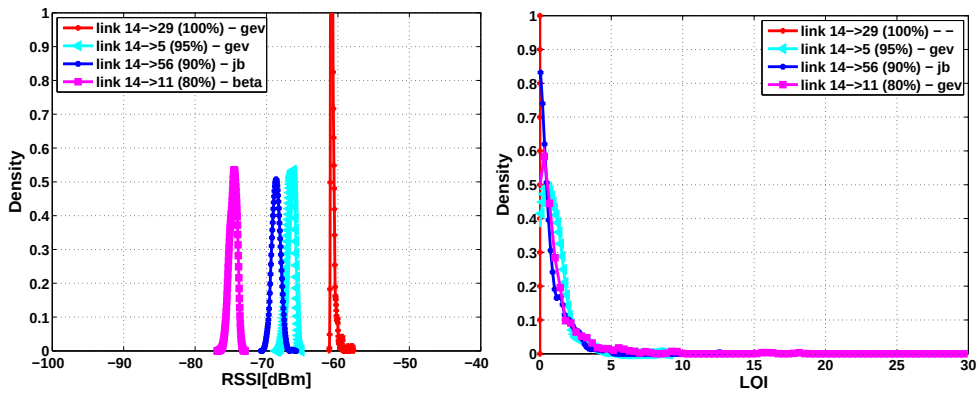
three common statistical tests: Kolmogorov-Smirnov, Chi-Square, and Anderson-Darling [Hub04] to find the best distributions for LQI and RSSI. We first categorize the measured values into three categories (good, intermediate, and bad) and run fit tests on candidate distributions. To decrease the number of samples to handle, we average the measured values of LQI and RSSI for each link. We eliminate the measurements of two nodes as outliers, because their RSSI values are clearly outside the range of all other nodes. The observed values of RSSI do not present variations, so we have not analyzed the standard variation of RSSI.

Figs. 2 and 3 show the best density functions for each category: Johnson SB for RSSI and Generalized Extreme Value as well as Beta, and Johnson SB for LQI. We can observe that RSSI is not a good discriminator of link categories, because the functions overlap. Even the bad category overlaps the category of good links. The average LQI better discriminates between the categories, especially it can distinguish good from intermediate links. We can also observe that the standard variation of LQI is also a good discriminator of the categories.

Fig. 4 presents the density functions for the links in the good category of a chosen node (14) that exhibit PRR of 100%, 95%, 90%, and 80%, respectively. We can now observe that RSSI can fairly well discriminate between links with the respective values of PRR while all the links except 100% show the same values of LQI.

4 Related Work

Much work considered the problem of characterizing wireless link quality. Researchers identified three zones: the connected, the transitional, and the disconnected one [ZNB08, Be11]. They reported that the links in the connected zone are stable contrary to the transitional zone. Our measurements also showed that bad links are also highly variable. Srinivasan et al. [SL06] observed that the RSSI value can differentiate very good links ($PRR > 99\%$). In a later study, the authors [SDTL10] argued that LQI is a good indicator for transitional (intermediate) links if it is averaged over a certain number of packets. However, the question of how to distinguish links with PRR below 99% is still open and our study provides some answers.



(a) Probability density functions fitting RSSI

(b) Probability density functions fitting LQI

Figure 4: Density functions fitting RSSI and LQI for specific links: 14 → 29 (PRR=100%), 14 → 5 (PRR=95%), 14 → 56 (PRR=90%), 14 → 11 (PRR=80%)

5 Conclusion and future work

In this work, we report on the results of measurements of PRR, RSSI, and LQI on a indoor wireless sensor network testbed. We have found the density functions that fit the observed values when we consider three categories of links. The analysis shows that the network benefits from a large proportion of good links with respect to intermediate and bad links. In addition, the decrease of the transmission power to -10dBm only slightly affects the proportion of good links. Furthermore, we can conclude that RSSI is not a good discriminator of the link category, but it can help to eliminate nodes that present anomalies. LQI is a better discriminator between good and intermediate links.

We continue our analysis of the results in an incoming paper by i) fitting a function to the observed relationship between PRR and the values of RSSI, the average and the standard deviation of LQI, ii) use the function of RSSI to detect nodes with abnormal behavior, iii) use the functions of LQI as estimators of PRR based a few observed values and derive relevant routing metrics.

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