Poster Abstract: On the Spatial Characteristics of the Gray Region for 802.15.4 Radios

Yin Chen Andreas Terzis
Department of Computer Science
Johns Hopkins University
{yinchen,terzis}@cs.jhu.edu

ABSTRACT
Packet loss and energy consumption in sensor networks depend critically on the quality of the network’s wireless links. In turn, link quality depends on the environment in which the RF signals propagate and the locations of the link’s endpoints. Experimental results have shown that a low-power wireless link can be in one of three states or ‘regions’, as the inter-node distance increases: connected, transitional (gray), and disconnected. The gray region is characterized by extreme variability, whereby small differences in distance or endpoint locations can lead to pronounced differences in loss rates. However, not all is lost. This work investigates the spatial characteristics of the gray region and experimentally shows that one can efficiently identify links with low loss rates within the radio’s gray region. One of the possible applications of this finding is in the design of sparse, yet low-loss network deployments.

1. INTRODUCTION
High device costs and limited energy resources (i.e., batteries) motivate the deployment of efficient sensor networks. Efficiency in this context encompasses frugal use of all resources, including employing as few motes as possible to achieve the user-defined tasks and economical use of energy. In turn, radio link quality and the packet loss associated with it directly affect energy use as sensor measurements must be reliably collected for many applications (e.g., environmental monitoring [3]).

Several studies have classified low-power wireless links into three distinct reception regions: connected, transitional, and disconnected [7]. Links in the connected region exhibit consistent low loss and are symmetric [1]. In contrast, the transitional or gray region is characterized by the presence of unreliable and asymmetric links. Given these conditions, algorithms that determine a sensor network’s layout select relay point locations that limit inter-node distances to the radio’s connected region in order to ensure low packet loss rates [2]. However, doing so severely limits the maximum inter-node distance as the radio’s transitional (gray) region can span up to 50% of the radio’s range [7].

In this work we show that it is possible to exploit this oft-cited feature of low-power radios to our advantage. Specifically, using extensive measurements from diverse environments we show that one can leverage the spatial characteristics of the gray region to find locations which have persistently low loss. Depending on the environment, the proposed method requires two to six trials to construct a link that is 100% longer than the extent of the connected region for a 802.15.4 radio.

2. MECHANISM DESCRIPTION
We conducted experiments in four increasingly complex RF environments: an open parking lot spanning approximately 600 m², an open grassy area, a building hallway with line-of-sight transmissions, and finally an indoors testbed deployed over multiple offices. All experiments used TelosB motes [5], equipped with IEEE 802.15.4-compliant TI/Chipcon CC2420 radios.

Figure 1 shows the variation of packet reception ratios (PRRs) as the distance between a transmitter and six receivers increases at 5 cm intervals in the hallway environment. It is evident that PRRs fluctuate significantly even within short distances. This variation is the defining signature of the gray region.

Figure 2 presents the same small-scale spatial PRR variation over a two-dimensional grid using data collected from one of the parking lot experiments. The gray cells correspond to locations with PRR ≥ 85% (good locations), whereas the dark cells have PRR < 85% (coverage holes). The interlacing of good locations and coverage holes in the gray region is in fact good news.
Rather than avoiding the gray region completely due to its coverage holes, network planners can use the existence of multiple good locations to their advantage. While Figure 2 suggests that multiple good locations exist in the gray area, it does not provide an efficient way for identifying them. Next, we outline an analytical method for experimentally locating good locations.

The log-normal path loss model describes the wireless signal strength as a Gaussian random variable whose mean decreases with distance [6]. This model also assumes that the received signal strengths (RSSI) at all equidistant locations from the transmitter are independent and identically distributed. This is not true for locations very close to each other, as Figure 2 also suggests. This inaccuracy was identified by Patwari and Agrawal who proposed a correlation model for RSSI at different positions [4]. Nevertheless, the i.i.d. assumption is a reasonable approximation for positions further away from each other. In practice, we found that across the four environments we tested, any two locations that were more than one meter apart from each other had insignificant RSSI and PRR correlations.

We use this independence property to sample positions that are separated by at least 1 m. Then if the probability for each position to be good is $p$, the expected number of trials to find a good location is $1/p$ according to the geometric distribution. In turn, $p$ is a function of the inter-node distance and can be calculated using a site-specific log-normal path loss model and the radio’s PRR-SNR curve [6].

3. EVALUATION

As the first step, we experimentally derived the parameters of the log-normal path loss model and the SNR-PRR curve for each environment. Using these parameters, we calculated $p$ for locations in the radio’s gray region. Finally, we compared the actual number of trials ($\hat{t}$) necessary to identify a good location to $1/p$. The results for the parking lot, hallway, and office experiments are $(\hat{t}, 1/p) = (2.21, 2.79), (6.66, 5.43),$ and $(1.81, 1.81)$ respectively, suggesting a good correspondence between model and experimental results. In future work, we will incorporate the proposed mechanism to existing relay node placement algorithms (e.g., [2]) to investigate whether the increased link lengths translate to a reduction in the number of required relay nodes.

4. REFERENCES