Poster Abstract: On the Scaling Properties of Low Power Wireless Links

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ABSTRACT

We study the time-scaling characteristics of low-power wireless communication at the physical and link layers. We observe that links are bursty at many time scales: the packet reception rate (PRR) varies regardless of the length of the time scale considered. Using wavelet analysis, we find that RSSI variations in many wireless sensor network (WSN) links are consistent with statistical self-similarity but not with long range dependence, which can explain burstiness at many scales. We relate RSSI variance to the probability that the physical layer is consistent with self-similarity. Current simulation models and protocols do not take these characteristics into account, leading to inaccurate simulation and sub-optimal protocol performance.

Categories and Subject Descriptors

C.4 [**Performance of Systems**]: Modeling techniques; G.3 [**Probability and Statistics**]: Time series analysis; I.6.1 [**Simulation and Modeling**]: Simulation Theory

General Terms

Measurement, Performance, Experimentation

Keywords

Wireless sensor networks, Wavelet analysis

1. LINK-LAYER BURSTINESS

Heuristically, a link is bursty if it has periods of good reception and periods of bad reception. Srinivasan et al. [7] study various 802.15.4 and 802.11 links and define a metric, β, that quantifies the burstiness at the level of individual packets—the shortest possible time scale. Likewise, Aguayo et al. [2] study the Allan deviation of 802.11 mesh network links to find characteristic burst lengths.

To study burstiness in 802.15.4 networks, we ran long-term packet delivery experiments (6–96 hours at 10 ms inter-packet interval) in three environments: the Intel Mirage testbed [3], Stanford's Gates Hall, and an apartment. In Figure 1, we consider the number of packets received over different time windows, an approach used to study Ethernet traffic [4]. For most intermediate links, we cannot identify a characteristic length for bursts—burstiness is observed at all time scales studied. Understanding this property is vital for simulation and may lead to new insights on protocol design.

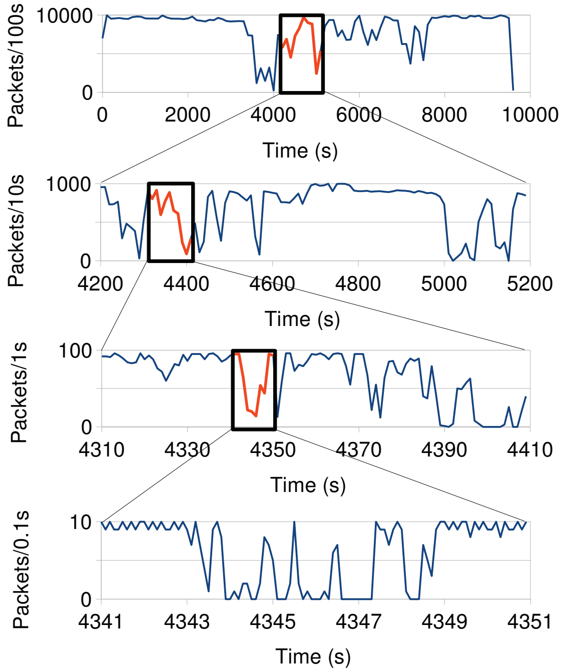

Figure 1: The number of packets received over different time scales in an 802.15.4 link. Each diagram is a zoomed-in version of the boxed, highlighted section of the preceding trace. The heuristic similarity between the plots—including periods of good and bad receptions over a wide range of time scales—suggests an underlying self-similar process at the physical layer.

2. WAVELET ANALYSIS OF RSSI SCALING

Signal power, which can be approximated by RSSI (total RF power at packet reception in dBm), is correlated with PRR characteristics [5, 6]. Thus, the observations made in Section 1 suggest scaling characteristics in RSSI measurements at the physical layer.[1] To investigate such charac-

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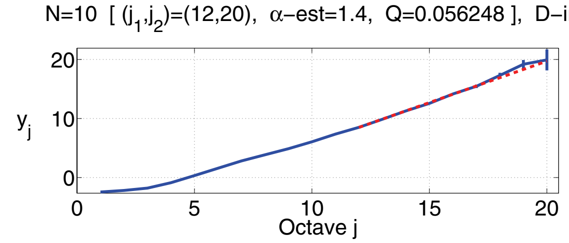
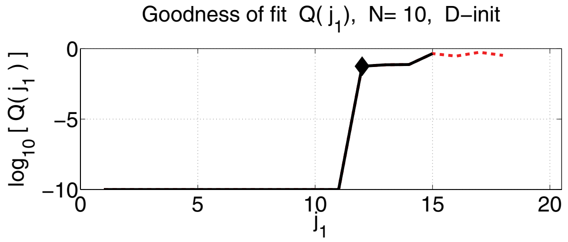
[1] We also investigated scaling at the link layer (PRR over different time scales). Here we detail our investigation of scaling at the physical layer.



(a) Logscale diagram of RSSI value scaling in a 802.15.4 link in the Apartment testbed. The solid line is the wavelet estimation of y_j [1] and the dotted line is a fit over the estimated region of scaling.



(b) The corresponding estimator for the point of onset of scaling j_1. The diamond symbol is the estimate for j_1, the solid line shows the region of non-decreasing Q, a goodness of fit metric, and the dotted line shows the Q value for octaves beyond the non-decreasing region [8].

Figure 2: Wavelet estimator for scaling.

teristics of RSSI traces, we follow the approach of Abry et al. [1] and create *logscale diagrams*, such as Figure 2(a). The horizontal axes of these plots correspond to *octaves*, a base-2 logarithmic time scale. The slope of a linear region on the logscale diagram, α, can be used to categorize scaling in the data trace [1]. In imperfect links, this trace is lossy—an RSSI sample is available only when a packet is received.

To determine the type of scaling present in RSSI traces of 802.15.4 networks, we conducted a similar analysis on all long-term links studied. A surprisingly large number of links in all three testbeds show $\alpha > 1$ when including the largest octaves, as in Figure 2(a). Estimation of the lower bound—the *onset point* of scaling [8]—is shown in Figure 2(b). This value for α indicates possible consistency of the RSSI traces with statistical self-similarity or asymptotic self-similarity but not with long range dependence [1].

We find, however, that not all links have $\alpha > 1$. In Figure 3 we plot the probability of $\alpha > 1$ (i.e., consistency with self-similarity but not with long range dependence) versus the base-10 logarithm of the average variance of RSSI values over groups of traces. We observe a phase transition between variances which have $\alpha \leq 1$ and those that have $\alpha > 1$—above a certain critical point in the variance value, virtually all links in this experiment can qualify for self-similarity based on the α parameter.

3. IMPLICATIONS FOR SIMULATORS AND PROTOCOLS

WSN simulators today do not use self-similar processes for physical or link layer models. Simulators could take into account the variance of RSSI values in an experimental trace

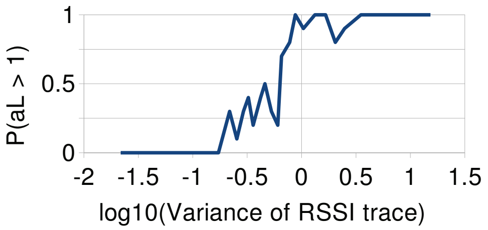


Figure 3: This plot considers groups of 10 Mirage links each, sorted by order of increasing variance, and plots the probability that in each group $aL > 1$ versus the base-10 logarithm of the average variance, where aL is the lower bound of the 95% confidence interval of α. This plot shows that beyond a certain critical point, virtually all links in these experiments are consistent with self-similarity but not with long range dependence. Outliers in this plot, in particular for $\log_{10}(\text{variance}) \approx 0.4$, may be due to an incorrect estimate of the onset scale.

(as in Figure 3) to determine whether a self-similar process is needed for synthesized traces. Figure 2(b) shows the onset estimator for scaling. This suggests a self-similar or related process may be needed to model large scale RSSI variations beyond the onset scale, while short term variations may be modeled based on the seed value. We previously suggested methods for modeling signal power at shorter time scales [5].

The onset point may be related to phenomena considered for protocol design. For example, it was observed that waiting 500 ms before retransmitting lost packets substantially improves link reliability [7]. This time scale may correspond to the onset point of scaling for the links in that study.

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