Poster Abstract: Are Those Trees Messing with My Wireless Sensor Network?

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ABSTRACT

We study what happens when the *same* wireless sensor network (WSN) is "immersed" in different outdoor environments, namely, two types of forests and an open field. Qualitative answers can be derived from existing results. Here, we aim to *quantify* the extent of changes, both at the physical and application layer, based on the combined effect of environmental parameters over daily and seasonal time-scales.

Categories and Subject Descriptors

C.4 [**Performance of Systems**]: Measurement techniques; C.2.1 [**Network Architecture and Design**]: Wireless communication

General Terms

Experimentation, measurements, performance

Keywords

IEEE 802.15.4, link quality, connectivity assessment

1. INTRODUCTION AND MOTIVATION

The performance of protocols and applications for wireless sensor networks (WSNs) depends on the quality of the underlying physical communication, which is deeply affected by the environment in which the WSN is immersed.

Several works studied the small-scale, short-term link behavior, to inform the design of network protocols capable of dealing effectively with these changes. In contrast, our goal is to inform the in-field *deployment* of a WSN, therefore *i)* we focus on large-scale changes, induced by different environmental conditions, and on the WSN as an *aggregate*, and *ii)* we assess the above *in vivo* (i.e., in an actual real-world environment) in contrast to the *in vitro* (i.e., in labs or controlled setups) experiences reported in the literature.

Driven by the requirements of a wildlife monitoring project, we focus on the outdoor environment representative of the habitat of our target species: two types of forests, respectively, evergreen (SPRUCE) and deciduous (BEECH), along with open field (OPEN). Further, to account for year-long monitoring, we assess daily and seasonal variations.

Our results focus on packet delivery rate (PDR, the ratio of packets received on a link over those sent), aggregated and analyzed to show the impact of several combinations of environmental factors. We consider both their impact on the physical layer and their indirect effect on the application layer, as the latter is directly relevant to end users.

An extended account of our study is available in [2], although here we include some more recent results.

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2. EXPERIMENTAL SETUP

We performed our experiments in the area of Mount Bondone, near Trento, Italy, using TMote Sky nodes, equipped with the CC2420 radio chip and on-board omni-directional antenna. The design and execution of the experiments relied on TRIDENT [1], a tool developed by our group to simplify in-field assessment of connectivity by automating the configuration and execution of the experiments, and the collection of their results. Nodes where placed at the height of 3 m. We investigated the effect of both high (-1 dBm) and low (-8 dBm) power settings. We used different network topologies for the experiments at the physical and application layers, the latter performed using the CTP protocol.

We first performed experiments during the winter and summer of 2011, to study the physical layer. We arranged the 8-node WSN in a "cross" topology, designed to cover several link distances between 7 m and 64 m. Experiments were performed over 2 days, divided in 30-minute rounds. No MAC was used, but we scheduled transmissions from each node (at the rate of 1 packet/s) to avoid collisions.

The application layer experiments relied instead on a 16-node grid, covering distances similar to the above. The experiments, performed during week-long campaigns in summer 2012 and winter 2013, used the default CTP and BoX-MAC configurations, with all nodes sending messages to the sink every 30 s. We also confirmed the findings of experiments at the physical layer on this different topology.

3. FINDINGS

Physical layer. The average PDR across all links provides an immediate and easy-to-compute macro-indicator of how the same network behaves, once immersed in different environments. Figure 1 shows that the quality of communication decreases as one goes from OPEN to SPRUCE then to

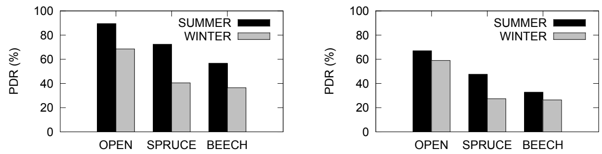
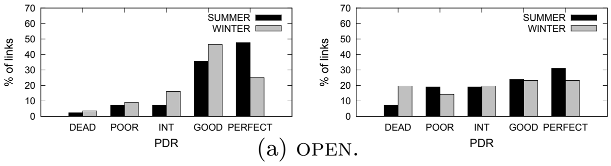
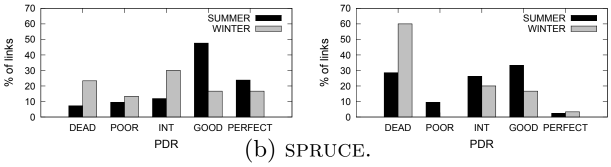


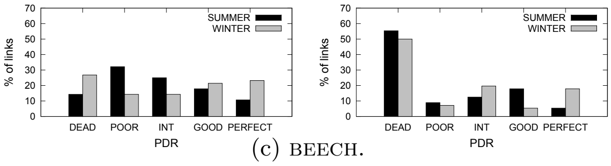
Figure 1: Average *PDR*, high (left) and low (right) power.



(a) OPEN.



(b) SPRUCE.



(c) BEECH.

Figure 2: Seasonal variations, at high power (left) and low power (right).

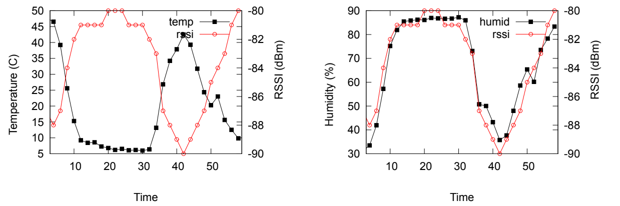
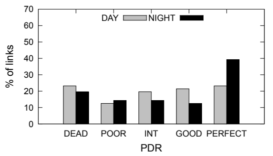
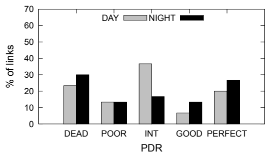


Figure 3: Impact on RSSI of temperature and humidity (open, summer, low power).



(a) OPEN winter low power.



(b) SPRUCE winter high power.

Figure 4: Day vs. night variations

BEECH, arguably due to the increased density of vegetation. Further, winter is consistently worse, due to the presence of snow. However, the difference between the two forests is almost negligible, due to the combination of snow and vegetation, and the decreased density in BEECH due to the loss of foliage. The same trends are observed at both powers.

Further, we classified links into perfect, good, intermediate, poor, and dead, with the same meaning as in [3]. As shown in Figure 2, this allows us to see where links "move" due to changes in environmental parameters. In winter, the presence of snow causes the transitional area to begin closer to the sender, and as a consequence, links to move towards the left (i.e., worse link classes) w.r.t. summer. An exception to this trend is BEECH, in which during winter foliage is not present, and communications less impaired.

Daily patterns between day and night are also present.

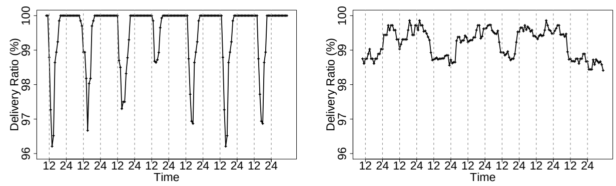


Figure 5: Delivery rate for CTP in open (left) and spruce (right), during summer at low power.

Figure 3 shows an example of how RSSI is negatively correlated with temperature and positively correlated with humidity. The effect of these variations, however, is different in OPEN and in the forests, as shown in Figure 4. In OPEN, links generally tend to improve. Instead, in the forests, daily patterns have the effect of "polarizing" the network into dead and perfect links, correspondingly reducing the number of intermediate links. This phenomenon is evident for SPRUCE in Figure 4(b); in contrast, in BEECH the higher density of foliage partially dampens this effect, essentially protecting links from environmental variations.

Application layer (CTP). An interesting question is whether and how these trends at the physical layer affect higher ones. Figure 5 shows the delivery rate of CTP in the summer. Daily patterns are evident, with the delivery rate stable at 100%, except during the central day hours, when it drops as low as 96% in summer and 93% in winter (consistent with the seasonal changes of Figure 2), at low power. The daily patterns are less marked in SPRUCE, due to the perturbing effect of foliage, with delivery still lower in winter (96%) than in summer (98.5%). This difference surfaces also when analyzing the number of CTP beacons exchanged. In SPRUCE, this is almost double that in OPEN, due to the lower link quality. Further, its number is invariant w.r.t. daily patterns. On the contrary, in OPEN there is a correlation of the number of beacons with daily patterns, with more exchanged during the day corresponding to the "dips" shown in Figure 5(a).

4. CONCLUSIONS

We presented results from outdoor experimental campaigns, where we observed the impact of the environment on the WSN physical and application layers, in terms of foliage, temperature, humidity, and snow, both on a daily and seasonal time-scale. Unlike most existing work, focused on the short-term behavior of individual links, we showed that peering at the long-term, *aggregate* WSN behavior provides important insights for its deployment.

5. REFERENCES

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