Experimental Analysis of Concurrent Packet Transmissions in Wireless Sensor Networks *

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Abstract

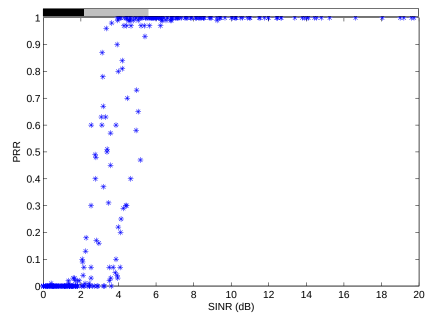
We undertake a systematic experimental study to analyze the effects of concurrent packet transmissions in wireless sensor networks. As expected, our measurements confirm that guaranteeing successful packet reception with high probability requires that the signal to interference plus noise ratio exceed a critical threshold. We also confirm that groups of radios show a 3 – 4 dB gray region that shows mixed reception. Unexpectedly, though, we find that this gray region is quite narrow for *individual radios*, and that the SINR threshold is not a constant, as was previously assumed. In practice, the critical SINR threshold varies significantly depending on the received signal power as well as individual radio hardware differences. Our study offers a better understanding of concurrent radio transmission and suggest new guidelines for enriching simulations as well as mathematical models to improve the design and analysis of sensor network protocols.

1 INTRODUCTION

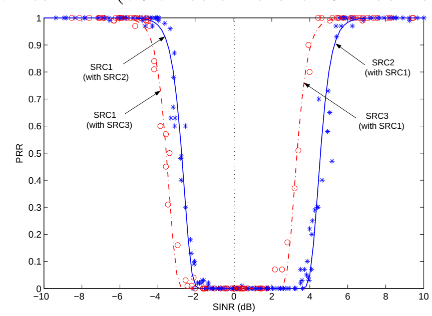
Realistic models of wireless links are essential for developing and evaluating protocols for sensor networks. Recent empirical studies have given us an understanding of the complex non-ideal behavior of wireless links without interference and shown how they can affect the design of efficient routing protocols. What is less well understood is the behavior of real wireless links in the presence of concurrent interfering transmissions. State of the art wireless network simulators typically assume that any concurrent transmissions within a given interference range result in packet loss, which significantly overestimates the likelihood of packet drop due to collisions because the capture effect [2] is not considered in their design. We perform systematic experimental study on a testbed of PC104 devices equipped with Mica2 Motes operating as radio interfaces, with CC1000 radios to understand the effects of concurrent packet transmissions.

2 SINR Threshold and Transmitter hardware

To verify the effect of tranceiver hardware, we perform experiments with two different pairs of nodes: SRC1-SRC2, SRC1-SRC3. For each pair of nodes, one node behaves as an intended sender and the other as an interferer. The sending node transmits at constant output power level while we vary the interfering signal strength. We adjust and set each sender's transmission power to get the same received signal strength (RSS) level for every sender at the receiver.



(a) SINR to PRR (w/ three different H/W combinatins)



(b) Separated Results for each H/W combination

Figure 1: Effects of different transmitter H/W combinations

Figure 1(a) presents the mapping from *signal to interference plus noise ratio (SINR)* to *packet reception rate (PRR)*. Three distinct regions based on the packet reception rate denoted as Black-Gray-White are indicated by a bar on the top of the figure. It shows 2.84 dB wide gray region where PRR is from 0.1 to 0.9 and where PRR is unpredictable with SINR value. We present a separated result for each transmitter hardware combination in figure 1(b). We find that, while across all hardware the gray region is fairly wide (in figure 1(a)), the gray region is quite narrow for each hardware combination (1.1 – 1.6 dB in figure 1(b)). We add regression lines to help the comparison

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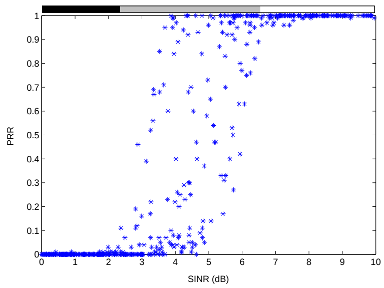

Figure 2: Effect of RSS change

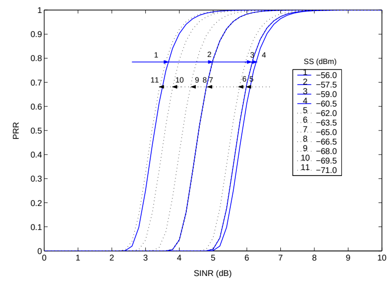

Figure 3: Fit lines for each RSS

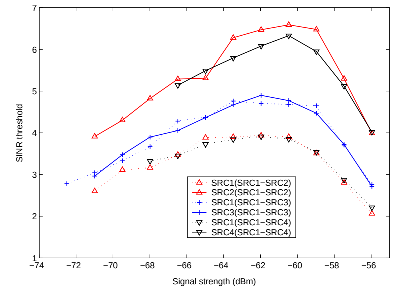

Figure 4: $SINR_\theta$ change

between the results. Our regression model is based on the link layer model [3] with extra parameters β_0 andβ_1. The new parameters are introduced to incorporate any real-world difference in the model.

$$PRR \quad = \quad (1 - \frac{1}{2} \exp^{-\beta_0 SINR + \beta_1})^{8(2f-l)} \qquad (1)$$

When we compare the critical *SINR threshold ($SINR_\theta$)* which guarantees successful packet reception with high probability, $SINR_\theta$ is different for different combination of hardwares. We can obeserve different $SINR_\theta$ for different sender (e.g., SRC1 and SRC2) and for the same sender with different interferer in figure 1(b). When we replace the interferer SRC2 with SRC3, we can clearly see the change of $SINR_\theta$ for the sender SRC1.

When we perform the same experiment after swapping the location between the sender and interferer, it does not make noticeable difference in $SINR_\theta$ for both node. This confirms that the difference in $SINR_\theta$ between two node is from the tranceiver hardware, not from the location difference.

Each transmitter may generate signal with different level of distortion from nonlinearity in the transfer function and this can be the reason why the signals from different transmitter hardware cause different effect even when we measure the same RSS value at the receiver. The effect of concurrent packet depends on both received signal strength and signal distortion level and distorted waveforms could result in inconsistent SINR threshold value for different transmitter hardware (i.e., for different packet sender and interferer combination).

3 Effect of *received signal strength (RSS)* level on SINR threshold and regression model

In section 2, we have identified the effect of different transmitter hardware. To see if the same hardware to have constant SINR to PRR relationship (or $SINR_\theta$), we perform extended experiments. This time we vary the transmission power level of both packet sender and interferer over the wider range. Experimental results are presented in SINR to PRR relationship in figure 2 where SRC1 is an interferer and SRC2 is a packet sender. We can still observe wide gray region of 4.19 dB width even the same packet sender and interferer hardware are used for entire experiments.

When we categorize experiment results based on the received sender signal strength by 1.5 dB interval, we can see very strong correlation from the SINR to PRR mapping in every category with higher than 0.96 R^2 value and distinct $SINR_\theta$ is identified for each category (shown in figure 3 with regression lines). This observation implies close relationship between the signal strength level and $SINR_\theta$.

We perform six experiments varying signal strength with three different pairs of nodes: SRC1-SRC2, SRC1-SRC3, SR1-SRC4. Figure 4 shows $SINR_\theta$ (for 0.9 PRR) value change at different signal strength level for each combination of sender and interferer. For every experiment, there is a $SINR_\theta$ value turning point around -61 dBm of RSS where highest $SINR_\theta$ is necessary for reliable communication. It seems like the effects of RF signal or implication of RSS measurement value change at different signal strength levels and some different factor dominates in each side of $SINR_\theta$ value turning point.

Like the different signal distortion level from different transmitter hardware leads to the changes in SINR to PRR relationship, we can reason from experiment results that the signal strength level is another factor that results in the change of $SINR_\theta$ value. These two identified causes of inconsistent $SINR_\theta$ can explain the high variation in SINR to PRR mapping observed in some previous experimental study [1] and the reason why simple, constant SINR to PRR mapping formula does not work well in every situation.

References

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