Poster Abstract: Cross-Layer Optimization for Low-power Wireless Coexistence

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ABSTRACT

We present a system that leverages physical layer features to combat *Cross-Technology Interference* (CTI) in low-power wireless networks. Our system incorporates: *(i)* a lightweight interference detection mechanism for low-power radios that recognizes the type of interference in the received signal, *(ii)* a lightweight error detection mechanism to estimate and characterize error patterns within interfered packets, and *(iii)* a CTI-aware protocol that dynamically adapts transmission and recovery mode to the current interference patterns. We implement a prototype of our system for the low-power IEEE 802.15.4 in software defined radios (SDR). Our early results of the system components demonstrate that we can achieve a high accuracy in error detection and interference type identification. Moreover, we observed a significant performance improvement compared to the standard 802.15.4 systems without interference-awareness.

Categories and Subject Descriptors

C.2.1 [**Computer Communication Networks**]: Network Architecture and Design—*Wireless communication*

Keywords

Low-power Wireless; Coexistence; CTI; Cross-Layer Design

1. INTRODUCTION

Embedded computing devices are increasingly integrated in objects and environments surrounding us, paving the way for the Internet of Things' vision of digitizing the physical world. These devices utilize low-power sensors and RF transceivers for a range of performance-sensitive applications, such as health systems, general monitoring and tracking, home automation, etc. Emerging low-power wireless technologies (e.g., BLE, 802.15.4, and backscatter) are expected to endure interference from other radio technologies. The CTI problem is exacerbated for these networks [1], where energy and complexity constraints prohibit the use of sophisticated interference suppression and cancellation techniques that are finding their ways into unconstrained wireless systems [4, 5]. CTI has not been adequately addressed in low-power wireless networks. This is mainly because diagnosing the type of interference in received signal is non-trivial. Current low-power networks treat CTI as collision, hence, perform exponential backoff and continuously defer their transmission. With the existing power asymmetry in the unlicensed bands, such handling imposes significant coexistence problems, where high-power interferers can completely starve low-power technologies.

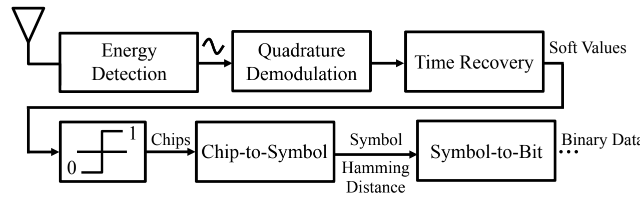

Figure 1: Considered physical layer hints at the 802.15.4 receiver.

Approach In this project, we thoroughly investigate how to best exploit physical layer (PHY) information in low-power radios and consequently make insightful adaptation decisions when subject to CTI. In particular, we focus on discerning *Intra-* and *Cross-Technology Interference*, estimating, localizing, and recovering errors. We propose a reactive and adaptive recovery scheme, which observes error characteristics harnessed from PHY hints to adjust the recovery settings. The recovery mechanism primarily runs an adaptive coding which derives optimal coding redundancy based on the observed error meta-data for different CTI patterns. For packets received with long error bursts which are beyond adaptive coding recovery capabilities, our diversity combining-based packet merging recovery is applied.

2. SCOPE AND DESIGN

With our system we present a cross-layer solution that allows low-power wireless nodes to communicate in interfered environments by getting the most out of received signals. In the following, we briefly highlight relevant aspects and components of our system.

Physical Layer Hints: When an interfered signal is received, besides standard processing, such as demodulation, chip-to-symbol mapping, and delivering decoded symbols to data-link layer, physical layer also accommodates further hints that can be exploited to boost the performance of wireless systems. In our design, we leverage distinctive features of the 802.15.4 PHY such as, uniform signal amplitude and the unique signal shaping, to discern *Intra-* and *Cross-Technology Interference* and to estimate the confidence of received symbols in interfered packets (see Figure 1). We

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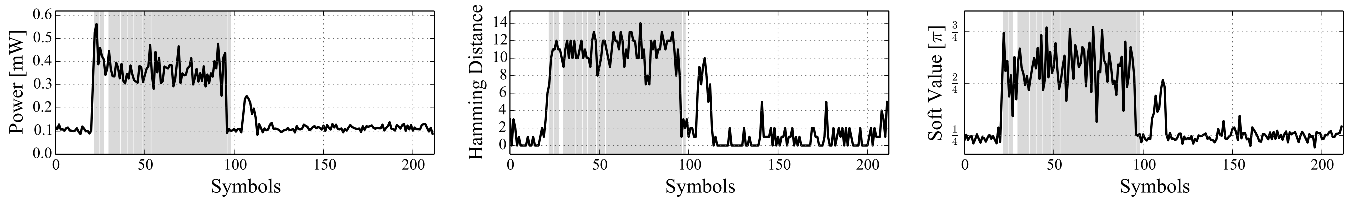

(a) Power. (b) Hamming distance. (c) Soft values.

Figure 2: Considered PHY hints in the presence of interference. The gray area indicates erroneous symbols.

consider the following PHY hints (see Figure 2): *(a) Signal Power:* when two signals interfere, their energies add up. Therefore interfered segments of the received signal experience larger power than the rest of the signal. The interfered segment of the signal exhibits lower SINR, thus experiences a higher error rate. *(b) Hamming Distance:* in the 802.15.4 PHY, symbols are spread to a 32-chip codeword ahead of transmission. The de-spreading is performed by mapping the received codeword to the symbol with the highest correlation. The distance between the input and output codewords of the chip-to-symbol mapper can serve as a direct indicator for the confidence of symbol decoding. *(c) Demodulation Soft Values: Soft Values* (SV) of demodulated bits are float numbers output by the demodulator. The binary demodulated bits are retrieved after passing the soft values through a binary slicer. However, besides the bit value, SV also contains the confidence information about the demodulation [3], and serves as indicator on the similarity between the received signal and ideal signal shape.

Interference Type Identification. We exploit variations in SV for interference type detection. The core idea is to inspect the modulation and signature shape of the interfered signal, which is reflected on the soft values. In case the signal shape is similar to the ideal shape this would translate into smaller variations to the ideal soft value. Note that when subject to *Intra-Technology Interference*, the baseband signal passed to the quadrature demodulator eventually is a 802.15.4 signal (i.e., OQPSK with half sine shaped). Hence, the quadrature demodulator output will be close to the ideal soft value. In contrast with CTI, the baseband signal passed to the quadrature demodulator is of different shape and this consequently reflects on the demodulator output being distanced from the ideal output.

Error Estimation and Localization. The previously mentioned PHY hints expose statistical differences between interfered and non-interfered symbols, which render them suitable candidates to detect erroneous symbols. However, designing practical symbol error detection algorithms based on these PHY hints with acceptable false positive and false negative rates is challenging. We propose an error estimation algorithm that jointly uses the number of unmatched bits of decoding results and received signal power.

CTI-aware Protocol. Our system recovers from a variety of interference patterns. The receiver estimates errors in interfered packets. The derived error meta-data is then used to choose a suitable recovery mechanism; currently alternating between two primary recovery mechanisms: *(a)* adaptive FEC to deal with transient interference with errors limited to few bytes, and *(b)* diversity combining-based packet merging to recover bursty errors. For such bursty error patterns, we expect diversity combining to decrease the ratio of erroneous symbols to a level where FEC can fully recover the packet. Our diversity combining is based on *Maximum Ratio Combining* (MRC) [2].

3. PRELIMINARY RESULTS

Prototype Implementation. We build a prototype of our system using SDR (i.e., USRP N210 and GnuRadio).

Experimental Setup. We expose an 802.15.4 link to the following four interfering technologies: 802.11, 802.15.4, wireless camera, microwave oven, and Bluetooth. Our traces include the complex signal of 35875 corrupted packets by interference.

Results. Now we discuss the early results of our performance evaluation of interference type diagnosing and error estimation mechanisms. We estimate the effectiveness of our interference type identification scheme in detecting the occurrence of *Intra-* and *Cross-Technology Interference*. For low SINR, we can identify the type of interference with high accuracy. In case of *Intra-Technology Interference* and very low SINR, the capture effect takes place. Thus, the interference signal can be accurately demodulated and this is reflected into lower variations of the soft values. Therefore, we can achieve high detection accuracy in these ranges. However, the accuracy decreases when the interference becomes weaker. Our symbol error estimation approach yields a stable performance with a precision and recall of 82% and 92%, respectively. The average achieved accuracy is $94.3\% \pm 2.4$. Moreover initial experiments indicate a significant performance improvement on a system-level performance compared to 802.15.4 systems without interference-awareness.

4. FUTURE WORK

We propose a cross-layer solution that allows low-power wireless links to develop a better cognition of the CTI patterns in the channel. We harness physical layer information to allow a better estimation, detection, and recovery of interference. We will show the practically, adaptability, and performance of our system through an enhanced prototype implementation and thorough evaluation considering both micro-benchmarking and system performance.

5. REFERENCES

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