Poster: Mitigating Erroneous Wake-ups

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ABSTRACT

We propose a novel method for mitigating erroneous wake-ups that are commonly associated with ultra-low power wake-up receivers. Recent research in low-power protocols has demonstrated significant improvements in energy-efficiency by employing ultra-low power wake-up receivers. However, due to the low-complexity receiver structures adopted, wake-up receivers are susceptible to external interference, which can cause the detection of non-existent wake-ups. The occurrence of these erroneous wake-ups wastes precious energy resources, thereby negating the potential energy savings in employing wake-up receivers. We address this challenging problem by extracting time-domain features from the output of the wake-up receiver, and construct a classifier to distinguish between correct and erroneous wake-ups. We describe the design of the proposed wake-up classifier and present preliminary results.

CCS CONCEPTS

• **Networks → Network protocol design**;

KEYWORDS

wake-up receiver; wake-up radio; false wake-ups

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1 INTRODUCTION

Motivation. RF-based wake-up receivers are ultra-low power receiver circuits that are capable of detecting a modulated RF signal. They are typically designed to demodulate low-complexity modulation schemes such as On-Off Keying (OOK), which lends itself to receiver structures exhibiting ultra-low power dissipation, *e.g.*, on the order of microwatts or less. This level of power dissipation makes it feasible to operate wake-up receivers continuously, and therefore facilitate asynchronous rendezvous between wireless nodes without having to duty-cycle a high-powered transceiver. For example, equipping wireless nodes with a wake-up receiver, as illustrated in Fig. 1, node *A* can initiate communication with node *B* by transmitting a *wake-up preamble*. The preamble is detected by the always-on wake-up receiver at node *B*, causing the output of the wake-up receiver, *i.e.*, the *DATA* line, to awaken the attached microcontroller from a low-power sleep state, and turn on the high-powered transceiver for bi-directional communication. Since the high-powered transceiver is turned off during periods of inactivity, significant energy resources are conserved, making it possible to achieve operational lifetime of several years using a low-capacity battery.

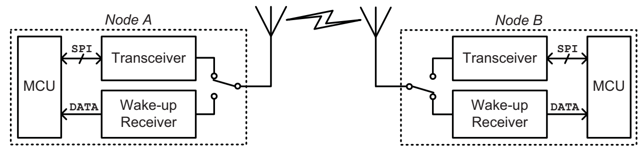

Figure 1: Example of asynchronous rendezvous using wake-up receiver-enabled wireless sensor platforms.

As recently surveyed in [8], a number of wake-up receiver-based protocols have been proposed that exhibit significant improvements in energy efficiency compared to state-of-the-art duty-cycled protocols. However, it is well known that due to the low-complexity receiver structures employed, wake-up receivers are susceptible to in-band and out-of-band interference sources [2]. This in turn leads to the detection of non-existent wake-up preambles, which we term *erroneous wake-ups*. An erroneous wake-up is detrimental to the energy efficiency of the node since it will trigger unnecessary communication using the high-powered transceiver. This problem is further exacerbated when using asynchronous wake-up flooding techniques, as used in Zippy [9] and BLITZ [10], since the detection of one erroneous wake-up will result in all nodes in the network awakening unnecessarily.

Challenges. While out-of-band interference may be rejected using passive, *e.g.*, [3] or active, *e.g.*, [1] filtering techniques, in-band interference is more difficult to mitigate against. The most common approach is to append an address to the wake-up preamble. By extending the wake-up receiver hardware with a correlator, *e.g.*, [5], the wake-up receiver only indicates the detection of the preamble if the decoded address matches the preconfigured address of the wake-up receiver.

While this approach works well in single-hop networks, it is not a robust approach in multi-hop networks. When several nearby nodes wish to wake-up their neighbor, for example during a wake-up flood using BLITZ [10], the address of the wake-up preamble will likely be corrupted, therefore preventing the wake-up of the intended node. The reason for this behavior is a combination of two fundamental characteristics of OOK-based wake-up receivers. First, the time to detect a wake-up preamble is non-deterministic [9]. This means that during a flooding sequence, several nearby nodes will transmit a wake-up preamble with a non-negligible relative time offset. Secondly, using OOK modulation, a 0-bit will be decoded as 1-bit if a nearby node simultaneously transmits a 1-bit. This results in time-shifted overlapping transmissions of the preamble address

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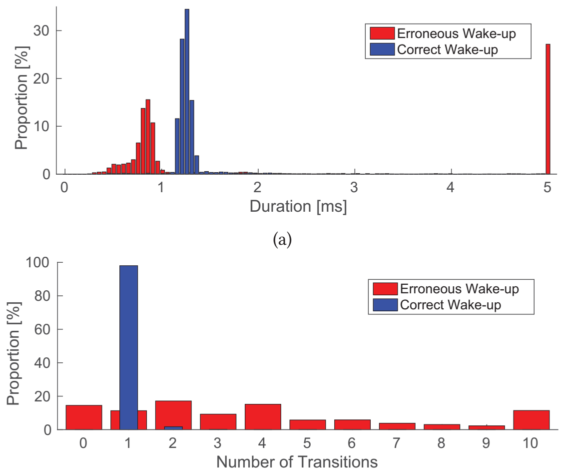

(a)

(b)

Figure 2: Histogram of (a) the duration of the first pulse, and (b) the number of transitions observed in the *DATA* signal.

that will likely corrupt address decoding, and therefore prevent the wake-up of the intended node. It is worth noting that novel schemes such as time-separated wake-ups [6], multi-band addressing [7], and adaptive decision thresholding [5] do not circumvent this fundamental problem. In summary, there is a need for an alternative scheme that can mitigate erroneous wake-ups, without adversely impacting the detection of correct wake-ups.

Proposed Solution. We propose to exploit the inherent structure of the wake-up receiver's digital output to determine if a received wake-up preamble represents a correct or an erroneous wake-up. When the *DATA* line activates, we observe the level of the digital line for a short period of time, and then extract appropriate features from the signal. We then use a pattern classifier to determine, within some probabilistic bounds, if the detected wake-up is correct, *i.e.*, the high-powered transceiver is turned on and communication commences, or if the wake-up is erroneous, *i.e.*, the microcontroller returns to a low-power sleep state.

2 WAKE-UP CLASSIFIER

Methodology. In order to investigate the time-domain characteristics of the wake-up receiver digital output, we performed a series of experiments on the FlockLab [4] testbed using a network of Zippy [9] nodes that each integrate an OOK-based wake-up receiver operating on the 434 MHz ISM band. We first collected erroneous wake-ups by turning on each wake-up receiver and awaiting for the *DATA* line to activate. Once an erroneous wake-up was detected, the level of the *DATA* line was recorded for 50 ms before the wake-up receiver was reset. We then collected correct wake-ups by performing controlled periodic flooding of wake-up preambles. When a correct wake-up was detected, the level of the *DATA* line was recorded for 50 ms before the flooding continued. A total of 6700 *DATA* signal traces were collected for each wake-up class.

Feature Selection. An inspection of the signal traces revealed that correct wake-ups typically exhibit only a single pulse with a duration similar to the length of the wake-up preamble, while erroneous wake-ups typically exhibit a shorter first pulse followed by several pulses of varying duration. Fig. 2(a) illustrates the histogram of the first pulse duration, and Fig. 2(b) illustrates the histogram of the number of transitions for each class. Due to the visible separation of the histograms, we select these two features to build a classifier.

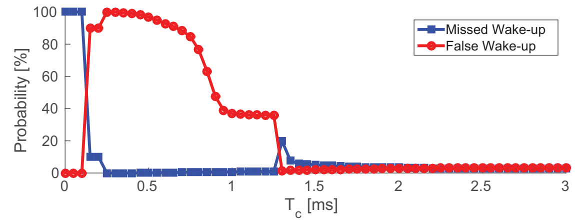

Figure 3: Performance of the wake-up classifier.

3 PRELIMINARY RESULTS

Simulation Setup. Using MATLAB, we trained a decision tree classifier using the two aforementioned continuous features, and applied 10-fold cross-validation. From the confusion matrix, we evaluated the *missed wake-up* and *false wake-up* probabilities based on the *DATA* signal observation window T_c. In an ideal design, the wake-up classifier should minimize both missed wake-up and false wake-up probabilities.

Results. The results of the classifier performance evaluation are illustrated in Fig. 3. As is evident in the figure, the performance of the wake-up classifier is dependent on how long the *DATA* signal is observed. However, if the observation window T_c is longer than the wake-up preamble, *i.e.*, 1.4 ms in this case, both missed wake-up and false wake-up probabilities converge to below 5%. Specifically, for $T_c = 2.2$ ms, the wake-up classifier exhibits a missed wake-up and false wake-up probability of approximately 3%.

Future Work. We plan to implement a low-complexity decision tree classifier using a set of binary features, integrate the wake-up classifier into the BLITZ [10] network architecture, and experimentally evaluate its performance in a testbed deployment.

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