Wireless Inference-based Notification (WIN) without Packet Decoding

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Abstract

We show that for extremely energy-efficient wireless transmission of notifications in sensor networks the conventional approach where a receiver decodes packets sent by a remote node to acquire its state is suboptimal. We propose an alternative approach where a receiver first (1) performs physical-layer match filtering on arrived packets without actually doing packet decoding at the medium access control (MAC) layer, and then (2) based on the matching results infers the sender's notification from the time-series pattern of packet arrivals. We argue that hierarchical multi-layer inference can be effective in coping with channel noise. Without requiring transmitted packets to be decodable at the MAC layer by the receiver, the sender can lower its transmit power to reach the receiver at the same distance, or, equivalently, a farther receiver at the same transmit power. We call our scheme Wireless Inference-based Notification (WIN) without Packet Decoding. We demonstrate by analysis and simulation WIN allows a sender to multiply its notification distance without increasing transmit power. We show how senders can realize these energy-efficiency benefits without changing their system and protocols; only receivers, which normally operate in the center and can have ample power, need to run WIN-specific systems.

1. Introduction

We consider a typical sensor network scenario where senders, such as sensors, transmit notifications about their states, such as events detected and remaining battery power, to some designated receivers over wireless channels. In such a scenario, it is often desirable that nodes draw only a small amount of power in transmitting notifications. This would allow transmitters to survive for a long time like years even operating on a small coin battery, in applications such as industrial monitoring and home automation.

Under a conventional approach we will adopt a low-power wireless network, e.g., Bluetooth or ZigBee, to send notifications. A sender will periodically transmit *normal packets* to report that it is in a *normal state*, and start transmitting *event packets* when it enters an *event state* upon noticing events of interest. A receiver will decode each received packet to determine if it is a normal or event packet, and in the latter case, may also examine packet payload to obtain further information about the event. In real-world applications, we expect that the bulk of the transmission is for normal packets and transmission of event packets is relatively infrequent. This means that it is especially important to minimize transmission energy for normal packets, but when the event of interest occurs the receiver needs to be alerted quickly.

We argue that for many sensor applications this conventional approach is suboptimal in terms of energy use. For example, there is no need for the sender to transmit at a relatively high power level to ensure packet decoding at the MAC layer by the receiver of all these normal packets, if their time-series arrival patterns can already reveal the normal status. Upon noticing events of interest a sender merely need to seek attention from the receiver about the new situation. To this end, the sender can just transmit packets with a different time-series pattern. The receiver can use a robust inference method to classify the sender in a normal or event state based on time-series patterns of arriving packets, without having to decode each packet for differentiating a normal or event packet.

In this paper we explore such inference-based approaches where no packet decoding is required. This enables the receiver to operate at a lowered signal-to-noise ratio (SNR). This, in turn, allows the sender to reach receiver at the same distance with lowered transmit power or, equivalently, farther receivers with the same transmit power. We call our approach Wireless Inference-based Notification (WIN) without Packet Decoding, or simply WIN.

2. Overview of the WIN Approach

We first review the conventional approach of notifications transmission, and then describe how WIN can

accomplish the same task with lowered energy consumption.

As depicted in Figure 1 (a), under the conventional approach a sender periodically transmits normal packets (in black) to a receiver to report that the sender is alive and it is in a normal state. Upon detecting events of interest, the sender starts transmitting event packets (in red). Usually event packets are transmitted multiple times or periodically to protect against possible packet corruptions over the wireless channel. The receiver will attempt to decode every received packet to determine the state of the sender.

Under a corresponding WIN approach, the sender in the normal state will periodically transmit copies of the same packet in some pre-agreed periodicity. This packet can be the normal packet in the conventional approach or a specially designed packet such as one including the network address of the sender (see a later section). When the sender enters the event state, it will transmit event packets periodically under a different arrangement on the lengths of packet burst and gap. Figure 1 (b) depicts of an example of such a WIN scheme using the time-series packet patters specified below:

Normal state: burst =1 and gap = 10
Event state: burst = 2 and gap = 9

The receiver uses physical-layer match filters to identify presence of packets bursts without decoding packets at the MAC layer and then use inference methods to infer the state of the sender (see later sections of this paper). As depicted in Figure 1 (c), a distant receiver may still be able to infer the state of the sender even when it cannot decode the event packet due to distance.

When a receiver detects that the sender is in the event state, if it happens to be mobile, it could move itself towards the sender to decode the event packet and learn about the event. It may also dispatch another procedure to locate the sender

Note that to support WIN, the sender does not need to change its protocol stack; all it needs to do is to change pattern transmission patterns.