Competition: RedFixHop

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1 Introduction

A constructive interference based flooding mechanism - using hardware-generated ACKs - is proposed to achieve highly reliable source-to-sink communication of very short critical packets in a wireless sensor network working in a harsh environment with potentially high levels of radio interference.

The basic strategy of the protocol is to minimize the number of relays (only one) as well as the number of retransmissions (ideally none) in order to minimize complexity as well as latency.

The reliability gain due to spatial diversity in wireless sensor networks has already been shown, e.g., in [1] and [2]. There, using multiple receivers instead of one decreased the packet error rate by several orders of magnitude while maintaining low delay. In case the sink is not reachable directly by the source, relays are necessary. Since each relay increases latency and also complexity, the number of relays should be minimal. On the other hand, the chance of reaching the sink increases with more relay nodes. Here, constructive interference is an elegant way to increase the chance of reception while maintaining low delay.

The exploitation of constructive interference in WSNs has already been demonstrated for instance in Glossy[3], Splash[4], Sparkle[5] and Disco[6]. It allows the simultaneous transmission of identical packets by multiple senders. However, constructive interference is only achieved if the senders synchronize their packet transmissions with sub-microsecond accuracy. For example, with an IEEE 802.15.4 radio working at 2.4 GHz, the maximum tolerable temporal displacement of distributed packet transmissions is 0.5 μs[3]. In order to achieve the required synchronization accuracy the distributed packet transmissions at the relay nodes are triggered by using the hardware acknowledgments of the transceiver; the micro-controller is thus bypassed.

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To keep the network complexity as low as possible, while further decreasing the energy consumption, an asynchronous sender-initiated radio duty cycling mechanism, like ContikiMAC[7], is also used.

Using a flooding mechanism allows the transmission of data packets with optimal latency and minimum complexity, since no previous knowledge of the network state is used. By combining flooding with an asynchronous radio duty cycling technique, energy consumption is also optimized.

2 RedFixHop

The protocol uses flooding with simultaneous transmissions triggered by hardware-ACKs exploiting constructive interference and a fixed number of repetitions (potentially on different channels). From this spatial redundancy and fixed repetition scheme the name RedFixHop is derived. The flooding scheme and duty cycling is explained in more detail in the following paragraphs.

Figure 2 shows a schematic view of RedFixHop with one hop. The relay nodes (blue) transmit simultaneously using constructive interference, which extends the transmission power (range), thus reaching the Sink node regardless of possible interfering jamming nodes (red). Since the jammers are not always active at the same time, the number and positions of the reachable relay nodes could change for each Source node broadcast. The assumption here is that each broadcast is received by more than 2 relay nodes most of the time. Also, as shown in the figure, the simultaneous transmissions of the relays add up (constructively) at the receiver. Nearby jammers will still overpower the summed up signal, if they are active at the same time. Thus, redundant transmissions on different channels seem necessary.

2.1 Flooding mechanism

The proposed flooding mechanism works as follows:

1. The source of the transmission sends the packet.
2. All forwarding nodes (relays) receiving the original packet from the source transmit it immediately using the hardware-acknowledgements, interfering constructively.
3. Back to 1. until a predefined number of burst repetitions to increase the reliability and ensure that all the potential receivers, in the range of the source, are awaken and cooperating to generate the constructive interference.

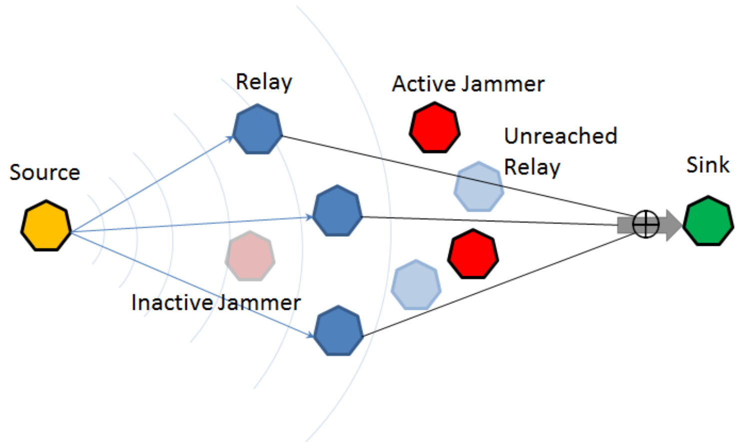

Figure 1. Schematic of RedFixHop with Relays using constructive interference

In wider area networks, in which more hops might be required, the robustness of the algorithm can be further improved if the nodes that do not receive the original packet from the source, but receive if from the forwarding nodes, restart the mechanism, acting as sources, after a random waiting time to decrease the probability of several nodes colliding by acting simultaneously as sources.

The accurate time synchronization needed for the constructive interference to work is achieved using the automatically generated hardware-ACKs from the radio transceivers. This way, the retransmissions are triggered simultaneously, independently of the tasks running in the nodes and avoiding errors due to different clock sources. For example, IEEE 802.15.4 2.4 GHz radio transceivers usually implement the automatic sending of an ACK after 12 symbol periods following the end of the received frame. This mechanism limits the maximum payload of the packets transmitted to 1 byte, since the information will be encoded in the Data Sequence Number field of the MAC Header.

2.2 Duty cycling

The implemented asynchronous radio duty cycling mechanism will use periodical wake-ups to listen for packet transmissions using an inexpensive Clear Channel Assessment (CCA). The mechanism works as follows:

- The forwarding nodes periodically perform a CCA. If radio signal is detected, the radio transceiver is kept on to receive the packet. If no valid packet transmission is detected after a certain time, the radio can go back to sleep.
- If a packet transmission is detected, the nodes must decode if the transmission is coming from the source or from the forwarding nodes. If the transmission is coming from the source, the radio is kept on to collaborate in the constructive interference during the burst interval. Otherwise the radio can go back to sleep.

Several time constraints must be fulfilled:

- The interval between each packet transmission from the source must be long enough to allow the retransmission of the packet by the forwarding nodes without colliding.
- The interval between each CCA performed by the forwarding nodes must be short enough to quickly and effectively detect the packet transmission without greatly increasing the latency.

An alternative duty cycling scheme is considered in order to fight the potential interference from the jamming nodes in the testbed, which could render the CCA useless. In that case, a TDMA based duty-cycling will be used to wake-up the nodes in a fixed interval for a fixed time. The actual wake and sleep periods are fixed (pre-defined) and will be defined during the development and test. The necessary clock synchronization for the periodic wake-up can be controlled by the transmission period of the source and the relays acknowledgements.

Furthermore, redundant or periodic transmissions from the source (triggering redundant/periodic transmissions from the relays) are considered to be done on different channels in order to exploit redundancy in time and frequency domains as well. The exact number of redundant transmissions (and possibly different channels) will also be defined during the development and testing stage.

3 References

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