Competition: Energy-Efficient Network Flooding with Channel-Hopping

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1 Abstract

We present a communication protocol for fast and reliable dissemination of event messages in short-range wireless networks. Our approach combines fast network flooding using Glossy with a pseudo-random channel-hopping scheme to increase its robustness against external interference. While a Glossy network flood can disseminate events within the wireless network within a few milliseconds, nodes need to be actively listening to the wireless channel in order to synchronize on the start of a Glossy flood. We therefore combine Glossy with a round-based radio duty-cycling scheme to reduce the energy consumption of our system at the expense of increased latency between detection of an event until a new network flood can be initiated.

2 Flooding-based Dissemination of Events

The main goal of our communication protocol is to report an event to the sink node as quickly as possible, for example a change in the status of the light bulb measured by the source node. We employ synchronized flooding using the Glossy protocol [3] implemented in Contiki with the source node as the originator. Each Glossy packet is sent with a preamble, the start of frame delimiter (SFD), length field, Glossy relay counter and the packet payload, which contains a bit field indicating the observed status of the light bulb (ON/OFF).

Glossy flooding is initiated by the source node and is based on the principle of tightly synchronized packet transmissions to exploit constructive interference and power capture effects at the receiving nodes. Since Glossy eliminates random delays between packet reception and re-transmission of the packet in order to achieve synchronous transmissions, it provides network-wide packet dissemination with very low latencies. Glossy flooding can reach all nodes within a few milliseconds in the case of wireless networks consisting of a small number of hops. Therefore, it is an ideal candidate for data dissemination applications requiring small end-to-end latencies.

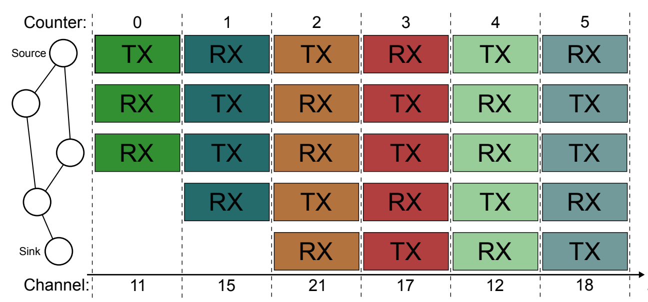

Figure 1. Example of single Glossy-based flooding with channel-hopping and $N = 3$ packet repetitions: The IEEE 802.15.4 radio channel used for each communication slot is derived from the relay counter and the packet sequence number.

3 Reliable End-to-End Packet Transmissions

During the competition phase, we expect strong radio interference on multiple channels of the IEEE 802.15.4 radio spectrum generated by an unknown number of JamLab [2] nodes placed in proximity to our wireless sensor nodes. As packets will be forwarded simultaneously along different paths between the source and the sink node, Glossy is very reliable against jamming of single links, as packets will be forwarded along other paths that are not affected by interference. In order to improve the reliability in case of strong interference affecting multiple nodes, we change the radio channel used for Glossy packets according to a pseudo-random hopping sequence, which can be derived from the packet relay counter and the packet sequence number (see Figure 1). Therefore, we can exploit frequency diversity on each link even during a single Glossy flood, as each packet is repeatedly transmitted on different radio channels.

Our approach provides best-effort packet delivery without end-to-end acknowledgments from the sink back to the source node, as this would require the sink node to initiate an additional Glossy flooding phase going into the opposite direction. Furthermore, we do not adapt our channel-hopping

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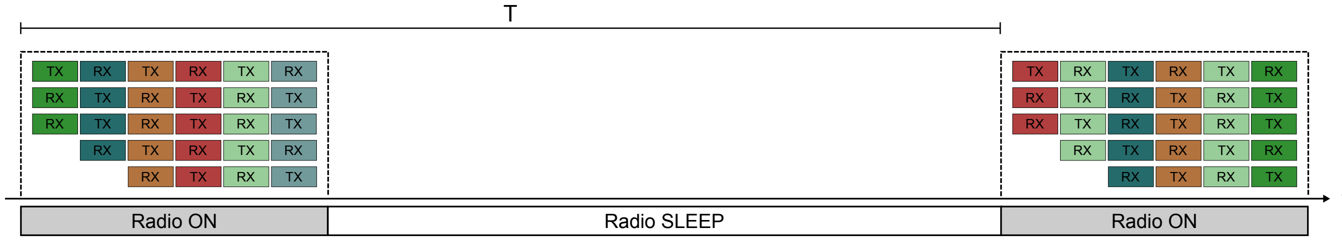

Figure 2. Timeline of round-based network flooding with synchronized pseudo-random channel hopping: Nodes wake up in a synchronized manner at the start of each Glossy flooding round and enable the radio transceiver for packet transmission (initiator node) or listening (all other nodes). Nodes receive or transmit radio packets according to a pseudo-random channel hopping scheme. At the end of each Glossy flooding round the CC2420 radio transceiver is put into power-down or idle mode until the start of the following round.

scheme to the experienced interference, as this would incur the transmission of additional messages (and thus consume more energy) and the interference pattern may change quickly.

4 Energy-Efficient Wireless Communication

We propose a round-based communication scheme where nodes wake up in a synchronized manner at the start of each Glossy flood. The CC2420 radio transceiver on the nodes can be put into idle or power-down mode between flooding phases to reduce the power consumption. However, nodes need to be synchronized in time so that the radio can be enabled again precisely at the start of the next flooding phase. The time interval T between flooding phases is constant and known to all nodes. Furthermore, nodes have to remain synchronized during the whole Glossy flood in order to keep receiving Glossy packets on the correct radio channel. In case a node has not successfully received a packet after a certain timeout has expired, it will switch to the radio channel on which the next packet is expected.

The CC2420 radio idle mode disables most parts of the receiver circuitry while the crystal oscillator remains active, which results in a current consumption of 426 µA compared to 18.8 mA in receive mode [1]. It is possible to further reduce the current consumption by entering radio power-down mode, which will also disable the crystal oscillator, resulting in a current draw of only 20 µA. However, it will take around 1 ms for the crystal oscillator to stabilize at the nominal frequency after entering idle mode again.

5 Bootstrapping Phase

After startup the Contiki application running on the sensor node will enter a bootstrapping phase until it has synchronized itself to the other nodes in the network. The source node can skip the bootstrapping phase and initiates periodic Glossy floods right from the beginning. All other nodes will select a random radio channel to listen for radio packets from other nodes. In order to reduce the energy consumption during the bootstrapping phase, nodes can duty-cycle the radio transceiver as long as the interval between receive slots is carefully chosen to eventually guarantee an overlap with the Glossy flood. After the first Glossy packet has been successfully received, the pseudo-random channel hopping sequence can be derived from the sequence number and slot counter contained in the packet. Furthermore, the node can calculate the start time of the next Glossy round and can remain in sleep mode until then to save energy. In order to account for clock drift between nodes, a small guard interval is employed so that a node will wake up shortly before the expected start of the next round. Nodes can estimate and compensate for the clock drift to the initiator node (source) by comparing the clock offset between the estimated and the actual start time of the next round, which allows to further reduce the duration of the guard interval.

6 Protocol Trade-offs

The proposed round-based wireless communication protocol can be adapted to the requirements of the application scenario in terms of end-to-end latency, reliability and energy consumption. The overall energy consumption of the sensor nodes is dominated by the duty-cycle of the radio transceiver. The radio duty-cycle of a node is proportional to the number of packet repetitions N transmitted by the initiator node during each Glossy flood and decreases when the time interval T between consecutive Glossy floods is increased. However, the worst-case source-to-sink latency depends mainly on the time interval T between consecutive floods and needs to be traded off against an increased power consumption when using shorter intervals. The reliability of a single Glossy round can be increased by repeating the packet N times on different radio channels to mitigate the effect of interference. Therefore, we can adapt the Glossy interval T and the number of packet repetitions N based on the available energy budget and requirements for reliability and latency.

7 References

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