Competition: Energy-Efficient Many-to-Many Communication with Channel-Hopping

Philipp Sommer, Yvonne-Anne Pignolet, Stevan Marinkovic,
Aurelien Monot, Maelle Kabir-Querrec, Robert Birke
ABB Corporate Research, Baden-Daettwil, Switzerland
{firstname.lastname}@ch.abb.com

1 Abstract

We present a communication protocol for fast and reliable dissemination of event messages from multiple sources in short-range wireless networks. Our approach combines round-based fast network flooding using Glossy with a pseudo-random channel-hopping scheme to increase its robustness against external interference. Using a deterministic round-robin schedule, we support multiple source nodes that initiate Glossy flooding in their corresponding round.

Furthermore, we combine Glossy with a synchronized 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 events sensed at multiple source nodes to the corresponding set of sink nodes as quickly as possible. We employ synchronized flooding using the Glossy protocol [4] implemented in Contiki. Glossy flooding is initiated by a source node (initiator) 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 retransmission 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 wireless networks with a small number of hops. Therefore, it is an ideal candidate for data dissemination applications requiring small end-to-end latencies. A deterministic round-robin scheme, inspired by the Low-power Wireless Bus [3], is used for communicating events from multiple source nodes to all other nodes. In each round, a single source node is selected as the initiator node for Glossy flooding. Although this round-robin mechanism introduces additional latency, it keeps the complexity of the system low. Nodes in the network will receive event messages from all source nodes and can then act accordingly (e.g. by combining information from multiple sources).

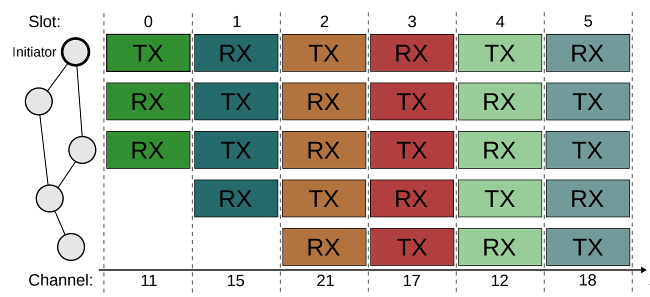

Figure 1. Example of single Glossy-based flooding round with channel-hopping and $N = 3$ packet repetitions: The radio channel used for each communication slot is derived from the relay counter and the packet sequence number. Nodes participating in Glossy flooding will switch between transmission (TX) and reception (RX) phases in each slot.

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. Glossy is very reliable against jamming of single links, as packets will be simultaneously forwarded along different non-interference paths between the source and the sink nodes. Furthermore, we change the radio channel according to a pseudo-random hopping sequence, which is derived from the packet relay counter and the packet sequence number (see Figure 1). This implies that each packet is repeatedly transmitted on different radio channels on each link to improve the flooding reliability. Our approach provides best-effort packet delivery without end-to-end acknowledgments from the sink nodes back to the source node, as this would require the sink nodes to initiate additional Glossy flooding phases going into the opposite direction.

International Conference on Embedded Wireless
Systems and Networks (EWSN) 2018
14–16 February, Madrid, Spain

ISBN: 978-0-9949886-2-1

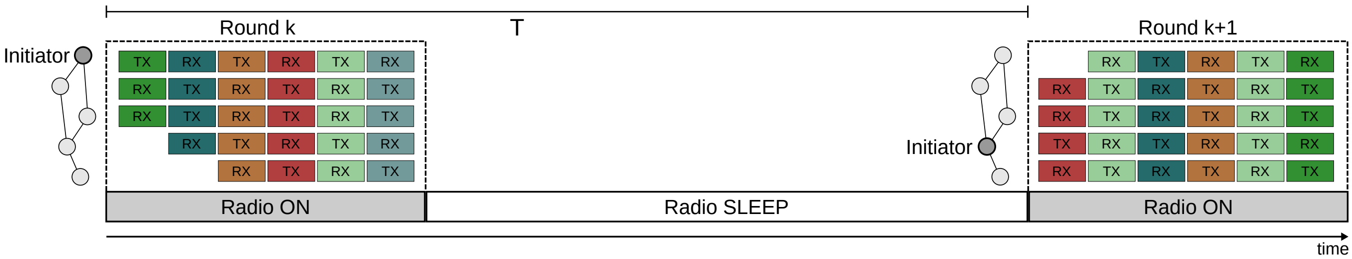

Figure 2. Timeline of round-based network flooding with synchronized pseudo-random channel hopping: Nodes wake up in a synchronized manner at the start of each Glossy flooding round and enable the radio transceiver for packet transmission (initiator node for this round) or listening (all other nodes).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

4 Synchronized Round-Robin Flooding

After startup, the Contiki application running on the sensor nodes will enter a bootstrapping phase until it has synchronized itself to the other nodes in the network. We select one of the source nodes as the leader, which initiates Glossy-flooding based on a deterministic round-robin schedule. 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, as shown in Figure 2. All other source nodes will start to initiate Glossy floods in their designated rounds, as soon as they become synchronized with the global round-robin schedule. We assign the source node to serve as initiator for a Glossy flood in the current round according to a deterministic schedule based on packet sequence numbers.

The time interval T between flooding phases is constant and known to all nodes. In order to account for clock drift between nodes, a small guard interval is employed to wake up shortly before the expected start of the next round. Nodes can estimate and compensate for the clock drift to the initiator node 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.

5 Energy-Efficient Wireless Communication

Our proposed round-robin based communication scheme allows nodes to wake up in a synchronized manner at the start of each Glossy flood so that the CC2420 radio transceiver on the nodes can remain in idle or power-down mode between flooding phases to reduce the power consumption. However, nodes need to be carefully synchronized in time so that the radio can be enabled again precisely at the start of the next flooding phase. Furthermore, nodes have to remain synchronized during a Glossy flood in order to keep receiving radio packets on the correct radio channel. In case a node has not successfully received a packet within a certain time after the start of a communication slot, 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.

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 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 number of source nodes and 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

[1] Texas Instruments: Chipcon CC2420 Datasheet (Revision C). `http://www.ti.com/lit/gpn/cc2420`, March 2012.

[2] C. Boano, T. Voigt, C. Noda, K. Romer, and M. Zuniga. JamLab: Augmenting sensornet testbeds with realistic and controlled interference generation. In *Proceedings of the 10th International Conference on Information Processing in Sensor Networks (IPSN)*, 2011.

[3] F. Ferrari, M. Zimmerling, L. Mottola, and L. Thiele. Low-power wireless bus. In *Proceedings of the 10th ACM Conference on Embedded Network Sensor Systems (SenSys)*, 2012.

[4] F. Ferrari, M. Zimmerling, L. Thiele, and O. Saukh. Efficient network flooding and time synchronization with Glossy. In *Proceedings of the 10th International Conference on Information Processing in Sensor Networks (IPSN)*, 2011.