Competition: CRYSTAL

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Abstract

CRYSTAL enters the 2019 dependability competition in both categories: data collection and dissemination. This requires extensions for point to multi-point delivery and tuning to address competition challenges. In both cases, we maintain the core CRYSTAL protocol, showing how it performs in the challenging competition conditions.

1 Core Approach: The CRYSTAL System

In the last decade, a new technique has taken the research field by storm, building on the notion of synchronous transmissions. In a counter-intuitive manner, synchronous transmissions embrace interference to construct extremely fast and reliable network flooding by relying on two wireless phenomena: constructive interference and the capture effect.

Glossy [1] pioneered the use of synchronous transmissions in WSNs. In Glossy, a flood is initiated by a node broadcasting a packet. The initiator's neighbors receive the packet and promptly retransmit it, with their neighbors repeating the same actions. In this way, Glossy provides network-wide time-synchronization and constructs floods that are extremely *i) fast*, as upon receiving a packet each node immediately rebroadcasts it, keeping the required tight timing; and *ii) reliable*, due to the above PHY-level properties and the inherent spatio-temporal redundancy of flooding.

To further increase reliability, packets are retransmitted N times by each node; the value of N is the main knob for controlling the trade-off between reliability and energy consumption.

The CRYSTAL [2] system builds a flexible schedule atop Glossy to collect, with near-perfect reliability, low latency, and ultra-low power consumption, aperiodic and sparse data traffic, such as those obtained from applying data prediction to periodic transmissions.

CRYSTAL builds a network-wide transport protocol in which synchronized transmissions (T) and acknowledgment (A) slots are organized in pairs. As illustrated in Figure 1, where a simplified setting with only 2 nodes and the sink is considered, a CRYSTAL epoch starts with a synchronizing Glossy flood (S) from the sink, ensuring all the network is time synchronized and ready to participate in data collection. Subsequently, a transmission slot (T) is exploited by all the senders to disseminate their data packet via Glossy floods. Due to the capture effect and the redundancy of Glossy, one of these floods reaches the sink with high probability. In the subsequent A slot, the sink acknowledges the received packet, if any, using a contention-free Glossy flood. The senders are highly likely to receive the acknowledgement message; if their packet was not correctly delivered, they simply retransmit in the next T slot. All communication occurs via the aforementioned TA pairs, which repeat until all senders have successfully transmitted their packet and the entire network goes to sleep for the rest of the epoch. CRYSTAL detects the termination condition after R consecutive silent pairs, namely after R T slots without transmissions and whose A contain negative acknowledgements.

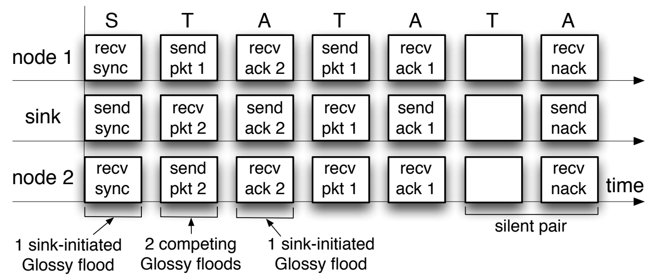

Figure 1. CRYSTAL in a nutshell.

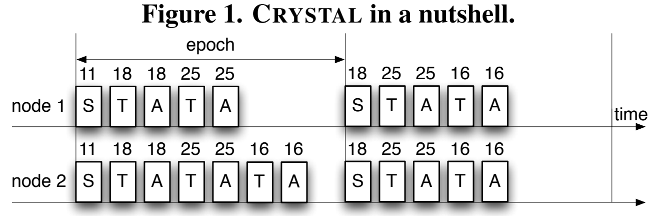

Figure 2. Channel hopping in CRYSTAL.

Interference resilience. To make our protocol resilient to noise, in [3] we endowed CRYSTAL with two techniques known to mitigate interference: frequency diversity and noise detection. As depicted in Figure 2, since interference usually affects only some of the 16 channels available in

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IEEE 802.15.4, each transmission-acknowledgement pair is executed on a different channel, following a network-wide hopping sequence. This prevents consecutive transmissions from being exposed to the same frequency-localized source of interference, effectively turning a long-lasting jamming signal into an intermittent one. The second technique fights interference, providing a "safety net" when channel hopping alone is insufficient. Relying on the ability to detect radio frequency noise, CRYSTAL dynamically changes the termination condition in function of the observed noise levels. If high and persistent noise is detected, extra transmissions are scheduled in a decentralized way increasing the chances that a packet is delivered; under low noise no additional overhead is introduced.

2 CRYSTAL for the Competition

To compete in both categories of the competition, data collection and dissemination, we added some information inside the normal CRYSTAL packets. Further, the peculiarities of the competition environment require extensions, outlined below.

2.1 Data Collection

CRYSTAL was initially designed for data collection, but its ability to achieve extremely low consumption with fast delivery arises from matching the period of the protocol to an analogous application-level period, e.g., collecting data from all sources within a 30 s frame. Instead, the competition takes a source-centric perspective, with unsynchronized nodes generating data at a given rate an latency computed from the moment of generation. The resulting network-wide data traffic is thus more similar to a random, event-driven one, requiring CRYSTAL to react quickly to the arrival of data at a node. Put another way, we cannot match the CRYSTAL period to the period of the data, as this would unreasonably increase the competition-defined notion of latency. Therefore, for this scenario, we trade-off energy efficiency for latency, making the CRYSTAL period much shorter than the packet generation period.

Knowing that the maximum number of sources in the competition is eight, we added a simple optimisation w.r.t. the original protocol. Instead of indicating the source ID and the sequence number in the acknowledgement, the sink uses a bitmap with one bit per source to indicate the parity of the last seen sequence number for all sources. A source node keeps sending its packet in T slots until it sees that the parity matches. This reduces the probability of making repetitive send attempts when acknowledgements are lost. Unfortunately, this requires the use of FIFO sending on all sources as they cannot progress to the next packet until the previous one has been acknowledged, increasing latency.

2.2 Multiple Destinations

Delivery of events to multiple actuators requires some extensions. As acknowledgements from the CRYSTAL sink provide the high reliability of the system, a sink must be identified even for the multiple destination case. By colocating this sink with one of the actuators, ideally a well-connected node, the standard CRYSTAL mechanisms ensure delivery to this node. Since we do not know the destination node IDs used in the final evaluation, we cannot a priori select *the best* of them as the sink, therefore we arbitrarily choose the first actuator listed in the injected experiment settings.

Delivery to all other actuators can occur in one of two ways. When a sensor node has data, it is put into a T slot until acknowledged by the sink. Thanks to the broadcast nature of T floods, some actuators will receive the packet directly from the source, reducing the latency of reception. To further increase delivery, the data is also placed into the A slot. Therefore, if direct source-to-destination delivery does not occur due to interference, the data can be recovered at the actuator with the reception of the packet in the A slot, flooded by the sink.

CRYSTAL has no mechanisms to reliably detect reception at actuators. We considered the trade-off between the cost of such an operation and its benefits, and did not further extend CRYSTAL. Nevertheless, the sink rotates among the most recent packets from all sources, ideally filling in gaps of packet reception at the actuators and incurring little overhead.

2.3 Competition Peculiarities

CRYSTAL requires nodes to be synchronized and, without external interference, making the S and A slots synchronizing at the Glossy level is sufficient. Unfortunately, under interference, when a node loses synchronization it must turn on its radio continuously in the hopes of receiving a packet to synchronize to. Further, if a node never manages to synchronize during a competition run, it responds similarly. In both cases, this drives up the network-wide consumption. To mitigate this, we use the one-minute setup time before a competition run to synchronize all nodes at the maximum rate, repeatedly sending pure Glossy floods in the hopes of reaching, and synchronizing all nodes. Nevertheless, in the highest interference settings, achieving and maintaining synchronization remains a challenge.

Finally, it is worth noting that one of the challenges of the competition is identifying a configuration that is *good enough* to perform well in *most* of the scenarios. In CRYSTAL, this principally amounts to identifying the period and the redundancy parameters of CRYSTAL and the underlying Glossy. Further, identifying a *good quality* sink node can make a significant difference in the reliability of CRYSTAL. Unfortunately, all these operations are challenging under competition rules. Interestingly, in contrast, real deployments pose other challenges, but they also provide concrete, clear requirements allowing protocols to be tuned for success.

3 Summary

With extensions for delivery to multiple destination and to address the peculiarities of both competition scenarios, CRYSTAL offers a general purpose transport protocol suitable to the aperiodic transmission scenarios expected at the EWSN 2019 dependability competition.

4 References

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