# Competition: CROWN – Concurrent ReceptiOns in Wireless Sensor and Actuator Networks

Usman Raza, Yichao Jin, Aleksandar Stanoev, Michael Baddeley, Mahesh Sooryiabandara
Telecommunications Research Labarotary
Toshiba Research Europe Limited, Bristol, United Kingdom
usman.raza@toshiba-trel.com

## Abstract

In wireless sensors and actuator networks, different data sources such as sensors are often required to report data to different destinations such as actuators. In this paper, we ask if the destination diversity, presence of multiple destinations, can enable multiple successful receptions when the sensors transmit their distinctly different data packets over a shared wireless channel in a multi-hop mesh network at the same time. To answer this, we present CROWN, a network protocol that exploits the destination diversity, capture effect, and spatially-separated multi-hop paths between source-destination pairs to enable robust, fast, and energy efficient many-to-many communication between sensors and actuators.

## 1 Introduction

Industrial control applications often pose very stringent requirements on latency and reliability. This is also a reason why wired solutions are more popular despite their much higher cost than industrial wireless technologies. The industry does see clear cost benefits in moving from wired technologies to more flexible, low maintenance, and easily deployable wireless technologies. Nevertheless, operation of wireless solutions in the shared Industrial, Scientific, and Medical (ISM) radio bands attract skepticism due to a number of factors such as high levels of interference caused by the co-existing technologies. Apart from the inherent unreliability of wireless channels, most wireless solutions are designed for converge-cast traffic from multiple nodes to a single node ( a.k.a *the sink*). The deployments in the Factories of Future will have more complex communication needs. It may be desired that multiple sensors connect directly to actuators and vice versa so to achieve low latency in order of (tens of) milliseconds and high reliability of five-nines (i.e., 99.999%) and above. In this paper, we propose CROWN protocol for wireless mesh networks. It enables low-latency communication by enabling sensors to flood their distinct data packets to reach actuators *exactly* at the same time over a shared channel.

This paper is organized as follows. In Section 2, we first briefly present the scenario of *Dependability Competition* [4] in which our protocol will be tested for its reliability, latency and energy consumption. Section 3 highlights the features of CROWN and how these will help it in achieving low-latency and highly reliable communication. Section 4 concludes this paper.

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

ISBN: 978-0-9949886-2-1

## 2 Dependability Competition: Scenario

The Dependability Competition aims to evaluate the performance of multiple low-power mesh communication protocols under external interference. Some peculiarities of the scenario are highlighted below to understand to design our protocol.

**Unpredictability of Application Data:** The sensing nodes generate data in response to changes in the values of their multiple discrete binary sensors. This data is relayed through the set of forwarding nodes to reach the actuators. Neither the timing nor the frequency of the data packets is known *a priori*. The unpredictability of data generation poses extra challenges to the protocol design. For example, if a protocol dedicates radio resources to individual sensing nodes that end up generating useful data only rarely then most resources would be wasted, resulting in high energy consumption and latency. More flexible protocols that allow the nodes to share the radio resources among themselves and access them only when needed are much desired in this case.

**Pattern of Communication:** The sensors need to report changes to one or multiple actuators. Moreover, actuators also require the sensed values from multiple sensors to perform their required actions. It does mean that protocol should support many-to-many communication, ideally allowing multiple sensors to communicate to the actuators at the same time (i.e., in parallel) so to keep the latency very low.

**Radio Environment:** The network running our protocol would be subjected to a high level of external interference coming from Wi-Fi and other IEEE 802.15.4 based devices. Thus, the proposed protocol should embed interference resilient mechanisms such as channel hopping or error correction codes.

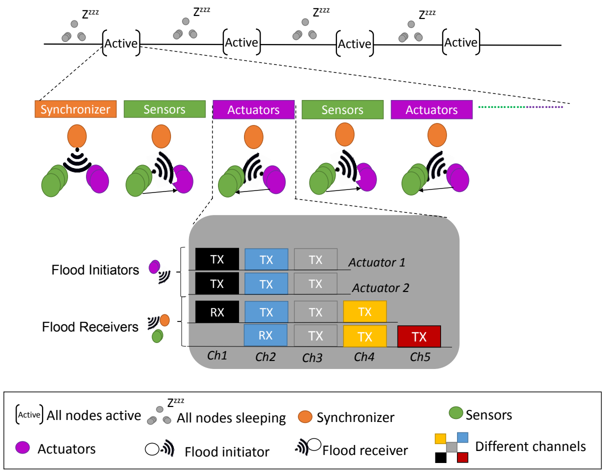


**Figure 1. CROWN: Protocol operation**

# 3 CROWN: A Many-to-Many Protocol

CROWN is a full network protocol stack that supports robust and interference-resilient many-to-many communication of unpredictable volume of traffic between sensors and actuators. It exploits a Glossy [1]-like synchronous transmission based flooding protocol named FOCUS [3] to achieve network-wide time synchronization as well as multi-hop communication. In FOCUS, an initiator node injects the data into the network. On receiving this data packet, other nodes transmit it multiple times in a back-to-back fashion without listening in between any two consecutive transmissions. The capture effect and constructive interference help in disseminating the packet to the entire network. Nodes change channels from one transmission to next to fight against cross-technology interference and frequency-selective multipath fading.

Figure 1 shows the duty-cycled operation of CROWN protocol. All network nodes turn on their transceivers periodically in the *Active* phase only. First, a dedicated node in the network, referred to as *Synchronizer*, floods the network to help the network achieve time synchronization based on the packet receptions. Then all the sensing nodes, which experience any changes in their values, share a single flooding round to transmit their updated status to their intended actuators. Multiple sensing nodes may initiate multiple floods by injecting their own distinct packets. Thanks to the previous flooding round initiated by *Synchronizer*, different sensors are able to transmit their packets over the air very precisely in time. This helps receivers to benefit from the capture effect. In [2], Istomin et al. have shown that capture effect in the converge-cast (many-to-one) scenario enables at least one sensing node to reach to the single destination with very high probability. Our solution is inspired by the same work but tailored to not one but multiple destinations (actuators) that enables multiple receptions of packets from different source nodes in a single flooding round.

In next flooding round, each actuator that has heard data destined to itself from a sensing node will echo back the received packet including its own ID and that of the sensing node. The sensing nodes and the *Synchronizer* listen to learn the IDs of pairs of sensors and actuators that have successfully communicated in the previous flooding round. This way, individual sensors can determine if they are able to successfully communicate their changes to all the actuators. If so, the sensing nodes can avoid participating in the subsequent floods as initiators until any further changes in their sensor values. This mechanism enables CROWN to transmit packets only when needed and also suppress the number of data sources trying to reach their destinations. The resulting reduction in the number of transmissions improves the performance of capture effect and thus overall communication reliability.

The consecutive flooding rounds initiated first by the sensing nodes and then by the actuators can be repeated multiple times before network nodes sleep to conclude the *Active* phase. Any non-reported changes are sent in the next *Active* phase(s). The actual number of these repetitions should be carefully adjusted to balance the trade-off between energy consumption and communication reliability.

At the start of each *Active* phase, the *Synchronizer* is required to initiate a flood to achieve network-wide synchronization. This flooding round can also be used to send the information that the *Synchronizer* has learned about the pairs of sensors and actuators which communicated in the previous *Active* phase. It may help sensing nodes to learn bit more about their successful transmissions so to suppress any unnecessary and redundant transmissions.

To mitigate the effects of external interference and frequency-selective fading, FOCUS floods, which are used by CROWN, will be realized using aggressive channel hopping using multiple different channels.

# 4 Conclusion

We present CROWN, a synchronous transmissions based network stack for the many-to-many communication that exploits capture effect, destination diversity and aggressive channel-hopping scheme to deliver an unpredictable volume of traffic from multiple sensors to multiple actuators.

# 5 References

[1] F. Ferrari, M. Zimmerling, L. Thiele, and O. Saukh. Efficient network flooding and time synchronization with glossy. In *Information Processing in Sensor Networks (IPSN), 2011 10th International Conference on*, pages 73–84. IEEE, 2011.

[2] T. Istomin, A. L. Murphy, G. P. Picco, and U. Raza. Data prediction+ synchronous transmissions= ultra-low power wireless sensor networks. In *Proceedings of the 14th ACM Conference on Embedded Network Sensor Systems CD-ROM*, pages 83–95. ACM, 2016.

[3] U. Raza, Y. Jin, and M. Sooriyabandara. Competition: Synchronous transmissions based flooding for dependable internet of things.

[4] M. Schuß, C. A. Boano, M. Weber, and K. U. Römer. A competition to push the dependability of low-power wireless protocols to the edge. In *Proceedings of the European Conference on Wireless Sensor Networks (EWSN)*, 2017.