Competition: Synchronous Transmissions based Flooding for Dependable Internet of Things

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Abstract

We present a reliable, fast, and ultra-low-power protocol stack to disseminate events in IEEE 802.15.4 based networks. Our stack is built on top of FOCUS, a new flooding primitive that exploits constructive interference and capture effect to provide higher energy efficiency, lower latency and higher reliability than state of the art flooding protocols. Our stack adapts key parameters of FOCUS and uses a time synchronized channel hopping scheme to mitigate interference and multipath fading.

1 Introduction

Industrial control applications rely mostly on expensive wired infrastructure for their ultra-high reliability and low latency communication. Exorbitant cost of installing and maintaining wiring motivates adoption of low cost and flexible wireless systems. However, low performance of wireless systems hindered their wide-spread adoption. Last decade, nevertheless, has seen improvements in network protocol stacks to enable dependable Internet of Things (IoT). More recent protocols inspired by synchronous transmissions based flooding primitives such as GLOSSY [2] outperform traditional protocols.

To flood wireless networks, GLOSSY exploits synchronous transmissions to harvest benefits of constructive interference and capture effect. Thanks to its fast flooding and sub-microsecond level time synchronisation, it has been used as a basic building block for multiple recent protocols [1, 3]. We, however, use even more energy efficient, faster and more reliable flooding primitive named Fast cOnCUrrent System (FOCUS), which is described in Section 2. Compared to GLOSSY, FOCUS reduces radio receptions and floods data more quickly by aggressively transmitting data multiple times to achieve high reliability. Faster flooding enables nodes to turn off their radios early to save energy. Our stack also adopts a time synchronized channel hopping described in Section 3.

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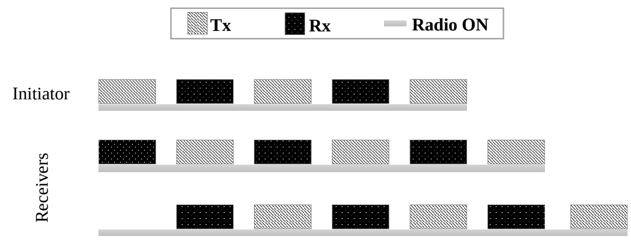
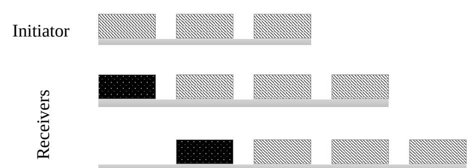


(a) GLOSSY: $\overline{RxTx}^{N_{tx}}$ structure.



(b) FOCUS: $Rx\overline{Tx}^{N_{tx}}$ strucuture.

Figure 1: GLOSSY vs. FOCUS with $N_{tx} = 3$

2 FOCUS: A New Flooding Primitive

FOCUS in Nutshell. FOCUS is a new synchronous transmissions based flooding primitive that exploits constructive interference and capture effect. It supports multiple communication modalities including ability for a single source (also referred to as *initiator*) to flood its information to the network. While FOCUS shares its design goals with GLOSSY, it is fundamentally different in the way in which each node packs Rx and Tx slots within a single flood. Figure 1 highlights these differences. In both GLOSSY and FOCUS, all network nodes are synchronized to wake-up at the same time to participate in flooding. Each GLOSSY node alternates between Rx and Tx slots unless it transmits N_{tx} times when radio is turned off. We express this slot structure as $\overline{RxTx}^{N_{tx}}$. In FOCUS, however, all nodes (except the initiator) start in Rx mode, receive their first packet successfully and then never switch back to reception mode again. Instead they transmit the received packet N_{tx} times one after another before turning off their radio to conclude the flooding round. We express slot structure of FOCUS with $Rx\overline{Tx}^{N_{tx}}$.

Advantages. With its *"listen less and speak more"* approach, Focus offers multiple advantages over Glossy.

- *Energy efficiency:* In $Rx\overline{Tx}^{N_{tx}}$ structure of Focus, nodes reduces receptions that are sometimes more power hungry than transmissions for example in case of CC2420 transceivers.
- *Low latency:* Data is flooded quickly in $Rx\overline{Tx}^{N_{tx}}$ than $\overline{RxTx}^{N_{tx}}$ structure because relay nodes prioritize quickly re-forwarding of the previously received packet rather than re-overhearing it again. Furthermore, if a node is not able to hear in a Tx slot of its neighbor due to interference, it can very well hear from the same neighbor in the very next time slot. This feature enables Focus to have a competitive advantage over Glossy in sparse deployments under heavy interference.
- *High Reliability:* Focus achieves higher reliability with help of multiple transmission retries within $Rx\overline{Tx}^{N_{tx}}$ structure. As Tx slots are more densely packed in Focus than Glossy, it enables Focus to offer higher transmission diversity (reliability), while decreasing radio on time (energy consumption).

Implementation. A reliable implementation of Focus on TelosB motes requires us to overcome some unique challenges. We need to assure that consecutive Tx slots of neighboring transmitters precisely overlap within a) 0.5 microseconds accuracy to benefit from constructive interference [2] or b) at least within 160 microseconds to benefit from the capture effect [4]. In Glossy, neighboring nodes synchronize their Tx slots by sharing their previous Rx slots. As each Tx slot immediately follows a Rx slot in Glossy's $\overline{RxTx}^{N_{tx}}$ structure, preserving accurate synchronization for each Tx slot among neighbors is easier in Glossy than Focus. With only single Rx slot in focus's $Rx\overline{Tx}^{N_{tx}}$ structure, neighboring nodes can precisely time their first Tx slot. But then they must make sure that the following Tx slots are also aligned very well. Firstly, Focus nodes executes minimal number of instructions after each Tx slot to schedule the next one. Secondly, Focus limits number of times data is transferred between the buffers of radio transceiver and microcontroller. Thirdly, any processing (if required) at the MCU is parallelized with radio activities (Rx, Tx). Last but not the least, like Glossy, Focus compensates for any delays caused by hardware variations or in executing interrupt service routines that schedule Tx slots. More challenges in implementing a reliable Focus based stack are omitted due to the space limitations of this paper.

3 Resilience to Interference

Our network stack shares its objective of providing ultra-high reliability with industrial wireless standards [5] such as WirelessHART and ISA100.11a, which employ Time Synchronized Channel Hopping (TSCH) to become resilient to external interference and multipath fading. Inspired by the same standards, nodes will exploit range of frequency channels with a mutually agreed channel hopping sequence. Consecutive Focus floods or the time slots within a Focus flood will operate on different channels to fight transient and persistence external interference on individual channels. Our implementation of the network stack should, however, ensure that the extra complexity added by TSCH mechanisms should not adversely affect timing of synchronous transmissions so to still harvest benefits of constructive interference and capture effect.

4 Conclusion

We described a network stack to disseminate events from a single source to rest of network in IEEE 802.15.4 mesh network. This stacks boosts on a new synchronous transmission based flooding primitive named Focus that supports faster, more reliable and cheaper network wide flooding than Glossy.

5 References

[1] 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*, pages 1–14. ACM, 2012.

[2] 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.

[3] 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*, pages 83–95. ACM, 2016.

[4] O. Landsiedel, F. Ferrari, and M. Zimmerling. Chaos: Versatile and efficient all-to-all data sharing and in-network processing at scale. In *Proceedings of the 11th ACM Conference on Embedded Networked Sensor Systems*, page 1. ACM, 2013.

[5] S. Petersen and S. Carlsen. Wirelesshart versus isa100. 11a: the format war hits the factory floor. *IEEE Industrial Electronics Magazine*, 5(4):23–34, 2011.