Poster Abstract: Could a Wireless Stack Based on Synchronous Transmissions Challenge 6TiSCH?

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***Abstract*—Synchronous transmissions (STX) and routing represent two distinct approaches to communication in low-power wireless networks. Over time, increasingly sophisticated networking architectures have emerged from both paradigms, including solutions with complete IPv6 support. 6TiSCH and 6Mixer are network stacks representing routing and STX, respectively. In this work, we evaluate how these modern stacks compare under identical, real-world conditions. We discuss the steps required to establish a fair experimental setup and present preliminary results for one of the defined scenario groups, namely a wireless sensor network. We observe that 6TiSCH offers a better trade-off between latency and duty cycle. However, it also exhibits recurring stability issues, manifested by drops in reliability below 70%, which become more frequent as the traffic load increases. In contrast, 6Mixer maintains a 100% reliability, as well as predictable latency values, regardless of the imposed load.**

***Index Terms*—Low-power wireless networks, IPv6, routing, synchronous transmissions, 6TiSCH, RPL, Mixer.**

I. Motivation

Wireless communication primitives such as Glossy [1], Crystal [2], or Mixer [3] represent a noteworthy alternative to the conventional routing-based approach to low-power mesh networking, which is commonly exemplified by the RPL protocol [4]. Rather than constructing communication paths based on the abstraction of neighbor links, they operate in a largely topology-agnostic manner. To this end, these primitives rely on flooding-based dissemination mechanisms combined with *synchronous transmissions* (STX), a technique enabling multiple nodes to transmit simultaneously. It has been shown that this inherently broadcast-based paradigm can serve as a fast, highly robust, and yet energy-efficient foundation for the design of wireless network stacks [3], [5], [6].

The trade-offs between routing and synchronous flooding have been extensively investigated in a wide range of insightful experimental studies and competitions, such as in [6], [7]. However, most of this prior work has focused on different protocols and distinct application scenarios. Meanwhile, the proposed solutions have evolved into increasingly complex and integrated protocol stacks that also support IPv6 networking, in line with the vision of the *Internet of Things* (IoT). For instance, the routing paradigm represented by RPL has been incorporated into the 6TiSCH architecture [4], a set of IETF-standardized protocols built on top of IEEE 802.15.4. On the side of STX, similar efforts have aimed at establishing a mature architecture, including the OSF framework [5], or the recently launched OpenSTX standardization initiative [8].

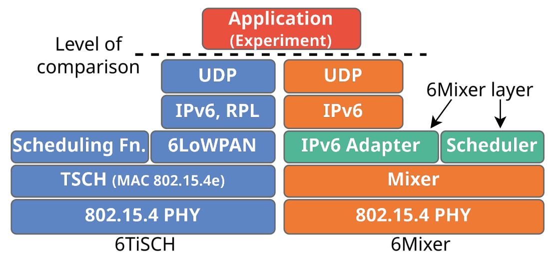

Fig. 1. Simplified depiction of 6TiSCH and 6Mixer.

We believe that these developments should be complemented by new experimental studies comparing the strengths and weaknesses of routing and STX approaches incorporated into complete IPv6 protocol stacks. Such comparisons should also consider a diverse range of IoT application scenarios, encompassing different requirements and traffic characteristics. Addressing the current lack of comprehensive performance evaluations of state-of-the-art solutions would provide valuable input for protocol designers and application developers.

Contributions. We experimentally compare two IPv6 stacks representing routing- and STX-based wireless communication, respectively. For routing, we employ Contiki-NG's 6TiSCH implementation [9]; for STX, we use 6Mixer, our own stack built on Mixer [3], a many-to-all broadcast primitive. For the comparison, we:

1) Define a set of metrics and evaluation scenarios reflecting the requirements and workload characteristics of different IoT applications.
2) Run our experiments on D-Cube [7], an established real-world testbed, and discuss the obtained results.

II. Towards a fair comparison

We discuss three key aspects that must be considered to ensure a fair comparison.

Protocol stacks. Figure 1 illustrates the evaluated stacks. Both operate with the IEEE 802.15.4 physical layer. 6TiSCH provides a complete stack offering the standard IP socket abstraction. The existing work of Mixer defines an STX-based primitive that allows to broadcast multiple messages within a communication round. To establish a common ground, we

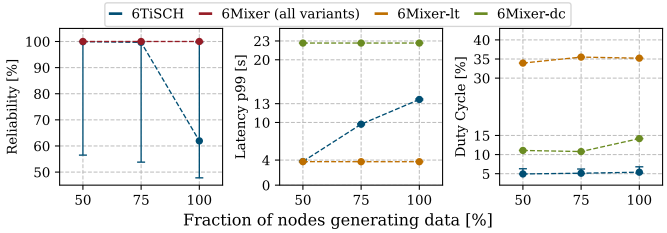

Fig. 2. Performance results for the WSN scenario over increasing load. 6Mixer-lt and 6Mixer-dc optimize for latency and duty cycle, respectively.

implemented 6Mixer as a layer on top of Mixer, which enables universal IPv6 communication across rounds. We further reused components of the lightweight IP stack [10] to process IPv6 packets and provide the socket abstraction. As a result, our setup allows us to directly compare representatives of the routing-based and STX-based communication paradigms at a common level, namely an application running over UDP.

6TiSCH builds on the TSCH MAC protocol, which arranges transmissions into time slots to enable collision-free communication between neighbors. The scheduling function determines the slot assignment and can be tailored to application traffic. In Contiki-NG, this is provided either by the negotiation-based Minimal Scheduling Function (MSF) [4] or by Orchestra [11], in which nodes compute the schedule autonomously.

Mixer simultaneously disseminates messages originating from multiple nodes within each communication round. The 6Mixer scheduler assigns the round's message slots according to each node's traffic demand and decides when rounds are executed. By tuning the number of message slots and the round frequency, the system can balance latency and energy efficiency. Similar to 6LoWPAN in 6TiSCH, the 6Mixer IPv6 adapter compresses packet headers to minimize their overhead within the 127-byte payload size limit.

Scenarios. To investigate the universal networking capabilities of both stacks, we consider three representative classes of low-power mesh applications: (1) Wireless Sensor Networks (WSN), a fundamental use case where sensor data generated by distributed nodes are collected at one or multiple sinks; (2) Cyber-Physical Systems (CPS), capturing industrial automation scenarios with closed-loop control and strict timeliness requirements; and (3) IoT, representing heterogeneous applications running concurrently in the context of so-called smart buildings, factories, or cities.

Metrics. We evaluate (1) the *end-to-end reliability* (percentage of datagrams successfully delivered at the destination), (2) the 99th percentile of the *end-to-end latency*, and (3) the *duty cycle* (fraction of cumulated radio on-time over the total runtime).

III. Preliminary Experimental Results

In this initial study we focus on the classical WSN scenario. Nodes send 16-byte UDP datagrams at 15s intervals with +/- 1.5s randomized jitter to a sink. We let 50%, 75%, and 100% of the nodes generate data to test three different traffic loads.

Testbed and Methology. We conduct our experiments on the D-Cube [7] testbed, equipped with 48 nodes with nRF52840 SoCs. Each experiment runs for 1 hour and is repeated seven times. We report the median, minimum, and maximum values for both reliability and duty cycle, and use the 99th percentile over all runs for latency.

Results. Figure 2 shows the performance of 6TiSCH and 6Mixer under three traffic loads. At the lowest load, both stacks achieve similar latency, at approximately 3.8s. 6TiSCH performs better in terms of duty cycle, achieving 4.93% compared to 11.08% for Mixer-dc. However, 6TiSCH exhibits less predictable behavior, as indicated by the wide error bars in the reliability results. In more than half of the runs at the highest load, 48–62% of datagrams were delivered. Conversely, 6Mixer repeatedly achieves a 100% reliability and high predictability (almost no variance across runs for all metrics), which are common strengths of STX-based networking.

IV. Ongoing Work

Further performance trade-offs between the two stacks remain to be explored. We plan to extend our experiments to the full set of scenarios outlined in Section II. These scenarios involve one-to-one and one-to-many communication patterns, for which 6TiSCH is less optimized than for the many-to-one data collection in WSNs. In contrast, 6Mixer's topology-agnostic design does not favor any specific pattern, and further improvements of its round scheduling could support applications with strict timeliness requirements.

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References

[1] F. Ferrari, M. Zimmerling, L. Thiele, and O. Saukh, "Efficient network flooding and time synchronization with Glossy," in *Proceedings of the ACM/IEEE IPSN*, 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 ACM SenSys*, 2016.
[3] C. Herrmann, F. Mager, and M. Zimmerling, "Mixer: Efficient Many-to-All Broadcast in Dynamic Wireless Mesh Networks," in *Proceedings of ACM SenSys*, 2018.
[4] X. Vilajosana, T. Watteyne, M. Vučinić, T. Chang, and K. S. Pister, "6TiSCH: Industrial performance for IPv6 Internet-of-Things Networks," *Proceedings of the IEEE*, vol. 107, no. 6, pp. 1153–1165, 2019.
[5] M. Baddeley, Y. Gyl, M. Schuß, X. Ma, and C. A. Boano, "OSF: An Open-Source Framework for Synchronous Flooding over Multiple Physical Layers," in *Proceedings of EWSN*, Oct. 2022.
[6] F. Ferrari, M. Zimmerling, L. Mottola, and L. Thiele, "Low-power wireless bus," in *Proceedings of the 10th ACM SenSys*, 2012.
[7] M. Schuß, C. A. Boano, M. Weber, and K. Römer, "A competition to push the dependability of low-power wireless protocols to the edge," in *Proceedings of the EWSN*, Feb. 2017.
[8] OpenSTX Foundation. https://openstxfoundation.org.
[9] G. Oikonomou, S. Duquennoy, A. Elsts, J. Eriksson, Y. Tanaka, and N. Tsiftes, "The contiki-ng open source operating system for next generation iot devices," *SoftwareX*, vol. 18, p. 101089, 2022.
[10] A. Dunkels, "Design and implementation of the lwip tcp/ip stack," *Swedish Institute of Computer Science*, vol. 2, no. 77, 2001.
[11] S. Duquennoy, B. Al Nahas, O. Landsiedel, and T. Watteyne, "Orchestra: Robust Mesh Networks Through Autonomously Scheduled TSCH," in *Proceedings of ACM SenSys*, 2015.