Swarm Robotics is the Next Frontier in Cloud-to-Edge-to-IoT Research

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Motivation

There is a massive community in Europe of researchers doing some kind of work on IoT, focusing on developing communication **protocols**, **standardizing** those, **implementing** them, and **deploying** the resulting systems. The technology developed is now very mature with entire protocol stacks being standardized (6LoWPAN, CoAP, 6TiSCH…) and several large open-source projects running all these protocols (Contiki-NG, OpenWSN, RIOT…). You can now buy off-the-shelf commercial solutions such as Analog Devices' SmartMesh IP product line which offer >99.999% end-to-end reliability, <50uA average current draw even for routing nodes, and certified security. **The traditional low-power wireless aspect of (Industrial) IoT is solved**; starting research on MAC/routing protocol development is pointless. **So what is the next frontier?**

Current Status

Time Synchronized Channel Hopping (TSCH) is widely regarded as the right way of building networks for critical applications. These are networking which all devices synchronize to with a handful of micro-seconds, and a communication schedule orchestrates all communication. This results in very deterministic behavior, which is perfect for applications such as industrial process monitoring.

Thus networking technique is at the core of standards such as IEEE802.15.4e, 6TiSCH, Wireless, ISA100.11a and Bluetooth Low Energy. Hundreds of thousands of TSCH networks are running today.

That being said, there are a few caveats we need to understand:

- First, these networks are meant for static devices: they work great if the IoT devices are attached to static industrial machinery, but don't work if all nodes are constantly moving
- Second, while they pretty much guarantee that the data gets to its destination, they don't give any sort of guarantee in terms of when the data gets there

For many of the applications which are targeted by today's commercial networks, these caveats aren't a big deal. Yet, they do mean that these networks cannot be used in applications where nodes need be mobile, and communication needs to be real-time.

One application domain where these networks cannot be used at all is in swarm robotics. Imagine a team or firemen entering a factory where there is a fire; instead of entering, they open a backpack containing 1,000 cm-scale driving robots (the size of a toy car). This swarm coordinates at the robots collectively enter the building, explore the area in an efficient manner, and send back to the firemen waiting outside a map of the building and where the fire has propagated. While this example is very specific, this type of swarms of robots can be used for collaborative construction/repair, collective moving of objects in warehouses, or surveillance and mapping.

Research Challenges

There is a massive IoT community that is looking for the next frontier in research, now that IoT solutions are readily available off-the-shelf. And that frontier is swarm robotics as (1) it opens up massive application opportunities and (2) today's networking technology absolutely doesn't work for these systems. And for them to work, there are three research challenges.

Challenge 1: Supporting Mobility in Industrial IoT.

The network topology of a swarm of robots is dynamic because the robots move and have a short communication range. This is in stark contrast to traditional TSCH networks, which are static and stable. The question we need to answer is hence: *Can we use TSCH for networking a swarm of robots where each node in the network is mobile?* Because the state-of-the-art is very limited, answering this question requires us to reinvent both scheduling in a TSCH-based networking stack to support mobility.

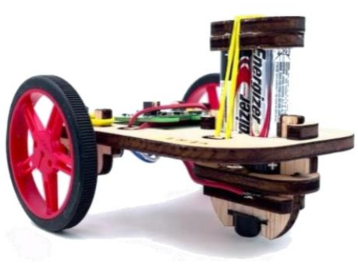
Challenge 2: Wireless Control Loops and Latency Predictability

Implementations of TSCH networks such as Analog Devices' SmartMesh IP guarantee delivery. That is, a TSCH network guarantees that data reaches the destination. The catch is that it does not guarantee when. Given the unreliable nature of wireless, this makes sense: if my neighbor did not get my frame, I retransmit until it does. One can even argue that, given an infnite amount of time and a connected network, only an implementation bug can justify not having 100% reliability. The next question is: *Can a TSCH network guarantee latency?* The answer to that is “no", since there is always a non-zero probability of an infinite amount of retries to happen on a link that has a packet delivery ratio strictly below 100%. The bold and ambitious is: *Can TSCH network offer predicable latency and be used to run control loops?*

Challenge 3: Constrained Localization

Localization is key to any robotic application, and many solutions have been developed. Out of those, lighthouse bearing measurement and ultrasonic range measurements are simple enough sensors that they can be integrated in a subset of robots relatively easily. The goal is to localize each robot, possibly in a coordinate system which is relative to the swarm. Yet, *what is the mathematical framework for turning local bearing and distance measurements into localization, and what is the resulting localization accuracy?*

DotBot: a cm-scale robot for swarm education and research



Within the Horizon Europe OpenSwarm project (www.openswarm.eu, 2023-2026), we are developing the DotBot (www.dotbots.org), an open-source robotic platform which features a printed circuit board and two motors installed on a laser-cut wooden chassis, with a lighthouse receiver for mm-accurate localization. As an open-source platform, DotBot is being designed for education and research. We are working on educational and research kits; we target students at the primary school, high school and university levels, with a particular focus on female students. The DotBot is a fantastic stepping stone for the community to embrace swarm communication, train the next generation of collaborative node experts and educate students, thereby significantly reinforcing Europe's position in the market of next generation smart system which incorporate decentralized orchestration, constrained AI and swarm programming.