Demo: The Embedded Orchestra

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***Abstract*—Time synchronization is an important building block for deterministic low-power wireless networks such as IETF 6TiSCH. The synchronized nature of this class of networks can be used by the application running on it, including to start/stop actions in a coordinated fashion across different nodes. This is called "orchestration" in 6TiSCH parlance. This demo proposes to interpret this term literally, by turning each low-power wireless device into an embedded musician. The network of 20 of these wireless musicians deployed across the demo space becomes an embedded orchestra, which plays John Williams' iconic orchestral arrangement of the Star Wars anthem.**

***Index Terms*—low-power wireless, synchronization, orchestral arrangements.**

I. Introduction

This is a highly entertaining demonstration of important networking concepts and advanced embedded programming techniques, resulting from recent research and standardization activities. We have designed the AIOT educational ecosystem: low-power wireless nodes which form a mesh network around a gateway, and which can be augmented with little electronic circuits. This demonstration is the first time, outside of the over twenty courses we have given with elements of it, that the AIOT ecosystem is being presented publicly. The demo itself consists of placing the matchbox-sized musicians around the ISCC demo area, and presenting the attendee with a button to start the 30 s tune.

This demo abstract is organized as follows. Section II provides background on the AIOT ecosystem which we use in this demo. Section III describes the demo itself: an orchestra of embedded musicians. Section IV provides details about the research results being showcased.

II. Background: the AIOT Educational Ecosystem

This demo is an entertaining way of using a synchronized low-power wireless network by turning it into an embedded orchestra. We showcase firmware written on the AIOT boards.

AIOT[1] is an ecosystem of toys and tools for hands-on learning about low-power wireless. The hardware and software are published under an open-source BSD license allowing users to build everything themselves. Alternatively, they can buy fully assembled hardware from startup company Falco[2].

Fig. 1 shows its different hardware elements. The AIOT Play (Fig. 1 left, Fig. 2) is a board which features a breadboard, a 2-AA battery holder and two modules: the green BC833M module the user programs and the white Dusty module which provides mesh networking capabilities. The user programs the BC833M which features a 32-bit nRF52833 ARM Cortex-M microcontroller. That program can interact with several external components through 14 available pins, which can be mounted on the convenient breadboard.

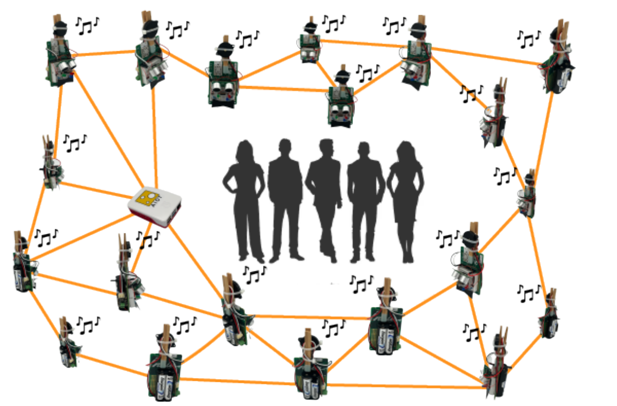

Fig. 1. The orchestral arrangement of Start Wars played by a 20-voice embedded orchestra, using the synchronized nature of the mesh network.

Several AIOT Play boards form a low-power wireless mesh network by using the Dusty module. The Dusty features the LTC58000 system-on-chip that implements Analog Devices best-in-class SmartMesh protocol stack. SmartMesh is very similar to the very recent 6TiSCH standards [1], [2]: nodes are tightly synchronized, time is cut into timeslots, and a communication schedule orchestrates what each node does in each timeslot: transmit, listen or sleep. This allows the nodes to keep their radio off over 99% of the time, resulting in a decade of lifetime on a pair of AA batteries.

The AIOT gateway is an assembly of a Raspberry Pi single-board computer with a custom daughter board featuring a Dusty module programmed as a SmartMesh manager. The gateway automatically connects to HiveMQ's public MQTT broker, allowing users to interact with their AIOT Play boards, over MQTT, minutes after unboxing.

We have used AIOT elements in over 20 courses, from half-day tutorials for high-school students to multiple week university courses. It allows students to touch upon aspects as diverse as basic circuits, embedded programming, low-power wireless networking, computer networks and cloud

[1] http://aiotsystems.org/
[2] https://wefalco.com/

infrastructure. In particular, the use of SmartMesh, a best-in-class networking product (rather than a best-effort open-source implementation) allows students to quickly build real end-to-end working systems that have all the components of a commercial solution.

III. Demonstration: the Embedded Orchestra

The demo consists of 20 AIOT Play boards and an AIOT Gateway. Each AIOT Play board is equipped with a small speaker, as shown in Fig. 2, transforming it in an embedded musician. Upon request, these musicians play the 20 parts of the orchestral arrangement of the Star Wars anthem.

The demo is part of the computer science museum at Inria. There, the musicians are attached to different elements of the computer exhibition in a large room at the museum. Using its ultra-sonic rangefinder, each musician detects whether someone is standing in front of it, and reports that to a central computer over the mesh network. If people are standing in front of the right combination of elements in the museum, the computer triggers the musicians to start playing the 30 s tune.

This demo replicates the museum setup in a format appropriate for a conference. We attach the musicians on different structures close to the booth. In the booth, we have the AIOT Gateway, a button to trigger the playing of the tune, pull-up posters to explain the concepts, and the printed sheet music that is being played. Attendees press the button and hear the musicians collectively play the different parts of John Williams' orchestral arrangement. Attendees feel fully immersed into the music, with sound coming from all directions.

This demo is a fantastic setup for the ISCC conference for at least three reasons. First, it builds upon cutting-edge scientific results and advanced embedded programming, as detailed in Section IV, including synchronized networking. Second, through its artistic side, its resonates with a good portion of the conference attendance. Third, because it is immensely entertaining, with the Star Wars anthem sounding from time to time, we have no doubt it will be one of the highlights of the ISCC demo sessions.

IV. Technical and Research Foundations

This demo is rooted in a deep technical foundation, consisting of recent research and standardization results, as well as advanced embedded programming techniques.

The key to the demo is ensuring tight synchronization between the nodes in the network. This is achieved by SmartMesh, which is synchronized in nature. Nodes in the network exchange messages every 15-30 s to resynchronize to neighboring nodes which naturally drift apart in time. The resulting synchronization scheme, borrowed from the 6TiSCH networking stack [2], achieves a synchronization accuracy better than 15 μs between any pair of nodes in the network. The 6TiSCH standardization activity concluded in 2023, making this a very timely demo.

Such high level of synchronization is not strictly needed for an embedded orchestra, as sound travels very slowly: 15 μs de-synchronization can be achieved by moving one of the musicians by only 5 mm. Good synchronization is however needed for example for localization using ultrasound, as previously published [3], [4]. This demo will trigger these discussions, and is an ideal illustration about the concept of "orchestrating" communications within a network, which is at the heart of 6TiSCH.

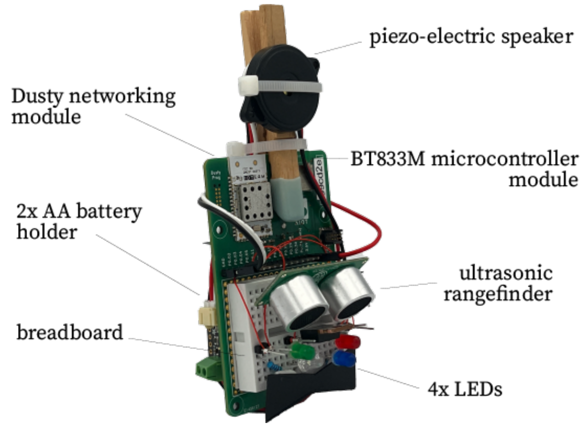

Fig. 2. The AIOT "Musician".

The demo uses firmware on the BC833M module which synchronizes to the Dusty over a serial port by periodically requesting the network time, and triggering a counter clocked by a 32 kHz crystal oscillator to keep an accurate sense of time. The firmware then follows a schedule that corresponds to the different notes in the score, and changes the output frequency of a Pulse-Width Modulation (PWM) pin at each new note. A piezo-electric speaker is connected to that pin.

We wrote a Python-based program which parses a multi-track MIDI file – Music Instruments Digital Interface, a popular format for digitally storing sheet music – and generates the header files that contain the sequence of notes and pauses which build up the different parts of an orchestral arrangement.

As an only addition to this paper, the code developed for this demo is published under and open-source license[3], including example videos of the demo.

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[3] https://github.com/aiotsystems/