Demo: MooNet — Enabling Outdoor Cattle Monitoring via IEEE 802.11-Based Low-Power Mesh Networks

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Abstract

Cattle farmers rely on the early detection of health issues in order to intervene in time. To this end, a wireless sensor bolus in the cow's rumen is typically used. Despite the use of highly effective radio technologies such as subGhz LoRa, the range between bolus and gateways is severely limited because of the cow body's attenuation of radio signals. The power consumption of commercial off-the-shelf gateways requires wall-powered operation or large solar panels, which limits them to indoor deployment in practice. This demo presents a mesh network of low-power anchor nodes that can cover large outdoor farmlands and can be powered by reasonably small solar panels. The anchor nodes and bolus LoRa radios use clock synchronization to reduce the anchor's power consumption. Received bolus messages are forwarded from all anchors to an Internet gateway via a duty-cycled IEEE 802.11-based custom mesh protocol. The demonstrator visualizes the routing topology, device and radio duty cycling, and transmitted bolus messages.

CCS Concepts

• **Networks** → **Network protocol design**; **Routing protocols**; **Link-layer protocols**.

1 Introduction

Cattle farmers rely on the early detection of health issues in order to intervene in time. One of the most effective health monitoring methods are wireless sensors in the cow's rumen stomach. These measure, for example, inner body temperature, rumination activity, movement activity, drinking cycles, and pH level. Normal measurements can be transmitted rarely, for example once in 15 minutes and may be accumulated for later transmission. However, when a critical condition is detected, alarm messages need to be transmitted promptly and reliably, so the farmer can react directly.

Such bolus sensors are offered by various companies, such as SmaXtec, Dropnostix, Moonsyst, Cattle Scan, and HKT. They are typically around 13x3 cm and weight around 200 g such that they stay in the rumen on their own. For communication, radios based on the Semtech LoRa modulation in the 868/915 MHz band are commonly used. Because of the RF signal attenuation caused by the cow's body, the distance between bolus and receiver is severely limited. Existing base stations based on simple LoRa transceivers recommend a range of 100 m or less and have to be configured in advance for the modulation parameters used by the bolus' radios.

In contrast, high-end LoRa gateways support up to 500 m in exchange for slower bitrates and are able to determine the modulation parameters automatically. However, they require power cables or large solar panels and backup batteries because of their high power consumption. Even the power consumption of the simple LoRa transceivers is quite high because the receiver needs to listen continuously for bolus messages. Hence, practical deployments use only wall-powered indoor gateways.

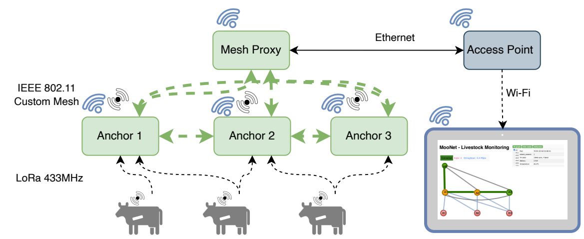

Figure 1: Demonstrator setup for MooNet network

This demo presents a mesh network of anchor nodes that enables covering large outdoor farmlands. The principal network structure is depicted in Figure 1. The power consumption of the anchors' LoRa receiver is reduced by synchronizing the duty cycles across all devices. All received bolus messages are forwarded from all anchors to a central gateway. In order to overcome the subGHz airtime limitations, an IEEE 802.11-based backbone mesh is introduced. Its power consumption is reduced by exploiting the efficient sleep states of a low-power Wi-Fi SoC through a custom duty-cycled mesh protocol. In combination this reduces the needed size of the solar panels significantly, which simplifies the anchors' deployment.

2 Related Work

The anchor nodes could use the LoRa radio to forward all received bolus messages. A popular choice is the Meshtastic protocol [2]. However, the current revisions do not integrate duty cycling, which complicates the coexistence with the bolus transmissions. In addition, the airtime is restricted on subGHz bands for fairness between users, which limits the number of bolus sensors and anchors.

In contrast, the 2.4 GHz band provides more channels, higher bitrates, and CSMA-based fairness. Typical choices are 6LoWPAN (IPv6 over IEEE 802.15.4) and RPL (Routing Protocol for Low-Power and Lossy Networks). However, IEEE 802.11-based networks are an interesting alternative because the higher bitrates can improve the energy efficiency through shorter activity times. The typical communication range of IEEE 802.11 radios is sufficient because of the constrained anchor to bolus distance. IEEE 802.11ax (Wi-Fi 6E) increased the range through ERSU (Extended Range Single User) and DCM (Dual Carrier Modulation) extensions [4].

IEEE 802.11s standardized multi-hop networking on OSI layer 2 and defines the HWMP (Hybrid Wireless Mesh Protocol) protocol [3]. Unfortunately, its beacon collision avoidance and the

Figure 2: The battery-powered anchor module that contains a LoRa radio with integrated microcontroller (top) and low-power IEEE 802.11 radio with integrated microprocessor (bottom).

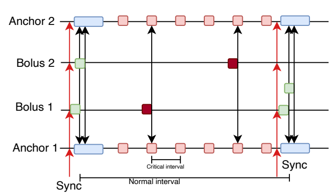

Figure 3: Protocol flow with global schedule for normal messages and short intervals for receiving alarm messages using TDMA slots.

MCCA (Mesh Coordinated Channel Access) are designed for improved throughput instead of low-power operation with long sleep intervals. B.A.T.M.A.N.-V is the other widely used layer-2 protocol [1]. However, until recently, no implementations were available for resource-constrained low-power micro-processors. This demo is based on our modified BATMAN-V implementation [5] for Espressif ESP32 SoCs.

3 Design of MooNet

In this section we give a brief description of the overall MooNet communication design. First we describe the physical layer protocol between bolus sensor and anchor mesh using 433MHz LoRa modulation. Then we discuss the custom Anchor mesh network that uses IEEE 802.11 standard Wi-Fi followed by application level protocol design with TDMA slots that has a global schedule.

3.1 Bolus to Anchors Communication

The power consumption of the LoRa communication is dominated by the receiver listening time because regular operation requires just a single short message every 15 minutes per bolus. In order to reduce the listening time on the anchors, it is therefore necessary to know when the bolus sensors will transmit their messages. In order to implement a coarse location tracing based on signal strength, each anchor within radio range has to receive these messages. Both objectives are achieved by maintaining a globally synchronized clock and TDMA schedule between all nodes.

As LoRa radios, we selected the RAK wireless RAK3172 modules as shown in Figure 2. These are based on the STM32WLE5CC low-power microcontroller, which enables autonomous processing of the communication protocol. The proposed TDMA scheme is depicted in Figure 3. The anchor nodes use dedicated periodic timeslots to broadcast synchronization beacons. Based on this, an exclusive time slot is used by each bolus for its normal status messages every 15 minutes. The alarm messages can be transmitted once per minute but are very rare. For these, very short shared time slots are introduced and alarm collisions are reduced through LoRa Channel Activity Detection.

3.2 Anchor Backbone Network

The backbone network has to maintain multi-hop routes from all anchors to an Internet gateway and timely forward all bolus messages and alarms. The expected network load is very small compared to typical uses of IEEE 802.11 networks. Thus, again the receiver listening time is dominating the power consumption. In order to reduce the listening time, a globally synchronized clock between the anchors is introduced.

Figure 2 shows an anchor node based on the Espressif ESP32-C6 microprocessor. The BATMAN-V implementation for ESP32 [5] was extended to introduce TDMA schemes. The transmission of frames is delayed until their respective time slots. A shared time slot once per minute is used to exchange beacon broadcasts in order to maintain the neighbour and routing tables. Collisions are avoided by the IEEE 802.11 PCF mechanism and additional randomized delays. Then, a shared time slot or exclusive time slots are used for forwarding of the data frames. One challenge in the BATMAN-V protocol is the OGM interval used for the flooding of route discovery messages. These are aggregated into larger frames before forwarding in the next beacon time slot. In consequence, the OGM interval needs to be a multiple of the beacon time slot interval. This makes global route repairs very slow.

4 Conclusions

This demo presents a cattle monitoring for large outdoor farmlands. Solar-powered outdoor operation is enabled by the use of low-power microprocessors. Based on measurements and modelling, we predicted an average power consumption of 6mW for the LoRa+Wi-Fi communication with a cattle of 1000 bolus sensors.

Acknowledgments

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References

[1] Simon Wunderlich Antonio Quartulli, Marek Lindner. 2016. B.A.T.M.A.N. V. https://www.open-mesh.org/projects/batman-adv/wiki/BATMAN_V. Accessed:2024-04-02.

[2] Kevin Hester. 2020. Meshtastic. https://meshtastic.org/docs/overview/mesh-algo/. Accessed:2026-07-16.

[3] Guido R. Hiertz, Dee Denteneer, Sebastian Max, Rakesh Taori, Javier Cardona, Lars Berlemann, and Bernhard Walke. 2010. IEEE 802.11s: The WLAN Mesh Standard. *IEEE Wireless Communications* 17, 1 (2010), 104–111. doi:10.1109/MWC.2010.5416357

[4] Evgeny Khorov, Anton Kiryanov, Andrey Lyakhov, and Giuseppe Bianchi. 2019. A Tutorial on IEEE 802.11ax High Efficiency WLANs. *IEEE Communications Surveys & Tutorials* 21, 1 (2019), 197–216. doi:10.1109/COMST.2018.2871099

[5] Randolf Rotta, Julius Schulz, Billy Naumann, Navya Sneha Chatharajupalli, Jörg Nolte, and Matthias Werner. 2024. B.A.T.M.A.N. Mesh Networking on ESP32's 802.11. In *2024 IEEE 49th Conference on Local Computer Networks (LCN)*. 1–7. doi:10.1109/LCN60385.2024.10639698