Poster: Edge-Level Event Detection for Wireless Livestock Monitoring under Intermittent Connectivity

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Abstract

Continuous monitoring of free-grazing livestock requires wearable sensor nodes operating under strict energy and connectivity constraints. We propose a delay-tolerant architecture with two communication paths: peer-to-peer exchange of lightweight state summaries for local detection of herd-level events, and store-and-forward data upload to a gateway when animals return to the stable. In-node feature extraction reduces transmission volume, while the gateway aggregates individual and herd-level information before Cloud upload. Preliminary simulations compare candidate technologies for both communication paths.

CCS Concepts

• **Computer systems organization → Embedded systems**.

Keywords

livestock monitoring, wearable sensor networks, edge-level event detection, delay-tolerant architecture

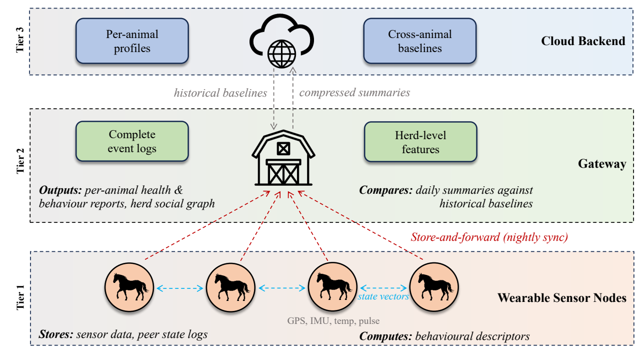

Figure 1: Livestock monitoring architecture

1 Introduction

Wireless sensor networks (WSNs) enable continuous monitoring of livestock health and behaviour through wearable sensor nodes that track location, activity, gait, and physiological indicators. They are particularly valuable for free-grazing herds, where animals roam large areas beyond the reach of frequent human observation. Horses are a good target for peer-aware, delay-tolerant sensing because of their daily return-to-stable routine, strong herd behaviour, and clinically significant social interactions. After grazing in open pastures for 8–12 hours, horses return to the stable, enabling a predictable store-and-forward cycle in which data processed locally during the day are uploaded overnight via a gateway with permanent power and reliable connectivity. This guarantees daily synchronization without relying on solar-powered gateways or mobile collectors while preventing excessive data backlogs. Herd dynamics provide valuable diagnostic information: early signs of colic, one of the leading causes of equine mortality, include social isolation, while reduced grazing synchronization, disrupted pair bonding, and coordinated flight are additional behavioural indicators that require observations and are overlooked by existing monitoring systems [5].

Deploying WSNs on free-grazing livestock presents communication challenges that existing solutions only partially address. LPWAN technologies such as LoRaWAN and Sigfox provide energy-efficient, long-range communication by operating in sub-GHz bands with very low duty cycles, making them the dominant choice for livestock monitoring [5]. However, they require gateway installations distributed across grazing areas and use a star topology that prevents direct communication between nodes. Short-range technologies such as Zigbee and Bluetooth Low Energy (BLE) support inter-node communication but have been used only for multi-hop forwarding to a central sink rather than peer-to-peer context exchange [1]. In practice, multi-hop routing performs poorly under sparse connectivity, leading to the adoption of mobile data collectors that opportunistically retrieve buffered data from nearby nodes [2, 3]. This concept was extended to continental-scale wildlife tracking by [6], but long synchronization intervals create large data backlogs, increasing communication time and energy cost. The approach also depends on solar-powered gateways whose fixed placement may become ineffective as animals change their movement patterns. Li et al. [4] classify such systems as Intermittently Connected Delay-Tolerant WSNs (ICDT-WSNs), arguing that neither traditional Delay-Tolerant Network protocols nor conventional WSN protocols adequately address the combination of intermittent connectivity and energy constraints. We address this dual constraint with an architecture that shifts event detection to the edge of the network and defers routine synchronization to the predictable nightly window, with the aim of minimizing energy cost and avoiding reliance on continuous connectivity.

2 Proposed Solution

The proposed system comprises wearable sensor nodes, a stable-mounted gateway, and a Cloud backend, connected through two communication paths: a peer-to-peer link for edge context exchange and a store-and-forward link for gateway synchronization (Figure 1). Its components, described below, support event detection at individual and herd level. The former (falls, abnormal gait, body temperature trend, irregular heart rate) needs only local feature extraction from each node's own sensor streams; the latter (isolation, fragmentation, coordinated flight) depends on the neighbours' relative state, requiring peer-to-peer state-vector exchange.

Wearable sensor nodes: Each collar-mounted node includes GPS, a 6-axis IMU, a temperature sensor, and a pulse sensor. An activity-aware duty-cycling scheme increases sampling during movement, reduces it during rest, and keeps the node in deep sleep between sampling periods.

Peer-to-peer context exchange: At regular intervals, each node broadcasts a compact state vector over a short-range link (e.g., BLE or Zigbee) containing its location, activity class, and alert status. Unlike existing systems, these messages are consumed by neighbouring nodes to detect herd-level events. To reduce false isolation alerts caused by intermittent connectivity, nodes also report their current neighbour count, enabling a consensus mechanism that distinguishes real isolation from communication disruptions. Concretely, if a node loses contact with all its peers, but the last received broadcast indicated that those peers were still detecting each other, the isolation is confirmed and the alert is prioritized. If, however, those broadcasts already show degraded connectivity across multiple nodes, the event is attributed to transient communication conditions and the alert remains tentative.

On-node feature extraction and data prioritization: Instead of storing raw sensor data, each node computes behavioural descriptors (e.g., activity, step count, gait regularity, temperature trend) and discards the raw samples. Summaries are prioritized, with critical events transferred immediately upon gateway contact and routine data uploaded during nightly synchronization.

Gateway processing: A gateway at the stable collects buffered data from returning nodes, computes per-animal and herd-level summaries, and uploads compressed results to the Cloud. Historical Cloud data provide a baseline for detecting gradual behavioural and health changes. The nightly sync assumes each animal is within range of the stable at synchronization time. One that misses this window defers routine upload to the next night, while priority-tagged critical events are forwarded the first time it passes within range of the stable gateway.

Cloud backend: The Cloud tier provides long-term storage, enabling the construction of per-animal behavioural profiles across weeks and seasons, as well as cross-animal comparative baselines for herd-wide health and dynamics assessment.

3 Preliminary Experiments

We evaluated Zigbee and BLE for both peer-to-peer communication and gateway synchronization through simulations in Cooja and ns-3, complemented by hardware power measurements to calibrate the simulation energy models before prototyping.

We model the peer-to-peer path as a periodic broadcast, by each of the 2 to 12 nodes, of a 50 byte state vector to all in-range peers, with the herd roaming a bounded pasture area of 300m×200m under a random-walk linear mobility model at grazing speeds of 0.5 - 2 m/s. Since the event detection and consensus logic consumes these broadcasts locally without generating additional traffic, radio performance can be assessed independently of the algorithm, and is a prerequisite to evaluating the performance of the complete system. The nightly sync path is modelled as a 70 KB close-range transfer of a day's buffered state summaries. Both paths use log-distance propagation model (exponent 2.5, reference loss 40.5 dB/m).

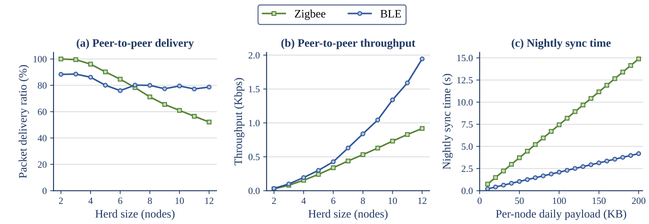

Figure 2: Simulation results over different herd sizes

Peer-to-peer path: BLE outperformed Zigbee in larger herds. While Zigbee achieved a higher packet delivery ratio (90.2% vs. 80.1%) with five nodes, its performance dropped to 52.1% with twelve nodes, whereas BLE maintained 78.7% and consistently provided higher throughput (Figure 2). The two protocols cross near seven nodes, making BLE the preferred choice for peer-to-peer communication in realistic herds.

Nightly sync path: Both Zigbee and BLE achieved near-perfect delivery, but BLE provided 3.6× higher throughput (382 vs. 107 Kbps), thus reducing synchronization time for an estimative daily payload of 70 KB from 5.3 s to 1.5 s. Using BLE for both communication paths also eliminates the need for dual-radio hardware, reducing cost, complexity, and energy consumption.

4 Conclusion

We presented a wireless livestock monitoring architecture integrating edge-level peer exchange for event detection with nightly gateway offload of on-node extracted features. Simulations across multiple realistic herd sizes identified BLE as the preferred technology for both communication paths. Future work will implement and evaluate peer-to-peer detection, consensus and store-and-forward logic atop this communication technology, as well as measure on-node processing performance and its impact on battery life, confirming that local feature extraction saves more energy for transmission than it consumes in computation.

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