RF Mesh Communication Between Smart Meters and a Data Concentrator Unit for Smart Metering Applications

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Abstract

This paper investigates the adoption of RF Mesh communication in smart metering systems, evaluating its efficiency, scalability and reliability for data transmission between smart meters and a Data Concentrator Unit (DCU). Unlike point-to-point schemes, RF Mesh networks use a decentralized, self-healing topology in which each meter acts as a node that relays data through neighbouring meters until it reaches the DCU, extending coverage for large-scale smart-grid deployments. The network operates in the 865-867 MHz band using Frequency Hopping Spread Spectrum (FHSS) to reduce interference while enabling multi-hop, low-power communication. A hardware setup comprising a smart meter, RF NIC modules and a Rugged Board DCU (A5D2x, i.MX6UL) was implemented and tested; the system achieved a measured latency of 50-150 ms and a packet delivery ratio (PDR) of 98.7%, confirming RF Mesh as an efficient, self-healing and cost-effective communication technology for modern smart-grid infrastructure.

Index Terms— *RF Mesh, smart meter, Data Concentrator Unit (DCU), AMI, ZigBee, LoRa, packet delivery ratio, self-healing network, smart grid.*

I. Introduction

The modernization of power distribution systems has driven widespread adoption of smart metering, which enables real-time monitoring, efficient energy management and accurate billing in place of manual, error-prone readings. RF Mesh communication has emerged as a reliable, scalable solution for exchanging data between smart meters and a Data Concentrator Unit (DCU).

RF Mesh networks operate on a decentralized architecture in which smart meters act as nodes that communicate with one another, forming a self-healing and robust network that removes dependence on a single communication path. Compared with Power Line Communication (PLC), ZigBee and LoRa, RF Mesh offers superior scalability and resilience for smart-grid applications. The DCU aggregates data from many meters, filters it and forwards it to the central server; Rugged Board DCUs, built for industrial and utility use, add processing power, storage and security for large-scale deployments.

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This paper presents the design, implementation and performance evaluation of an RF Mesh communication network connecting smart meters to a Rugged Board DCU, analysing latency, packet delivery ratio, scalability and security to assess the feasibility of RF Mesh in modern power distribution networks.

II. Literature Review

Smart metering infrastructure combines smart meters, a communication network and a Data Concentrator Unit to support automated meter reading, demand response, outage detection and energy-theft detection, while facing challenges in data security, network scalability and reliability. Communication technologies for Advanced Metering Infrastructure (AMI) evolved from one-way PLC and basic RF links to two-way ZigBee, cellular (3G/4G/5G) and RF Mesh networks, the last of which is self-forming, self-healing and well suited to large deployments.

Table I summarizes the trade-offs among the four communication technologies most commonly used in smart metering.

Tech.	Advantages	Limitations
PLC	Uses existing power lines; low cost	High electrical-noise interference; low bandwidth
ZigBee	Energy-efficient; low cost, short range	Range ~10-100 m; low data rate
LoRa	Very long range (up to 10 km); low power	Low data rate; higher latency
RF Mesh	Self-healing; scalable; low latency; high reliability	Needs careful network planning; higher initial cost

TABLE I. Comparison of smart-metering communication technologies

III. Smart Meter and DCU Overview

A. Smart Meter

A smart meter is an electronic device that records voltage, current, power and energy consumption and supports two-way communication with the utility, replacing electromechanical and simple electronic meters. Smart-meter architecture comprises metering, load-switch, metering-protocol and communication-module functional zones, with communication realized as a Neighbourhood Area Network (NAN) or Wide Area Network (WAN) module. Meters are further classed as Whole Current (Class 1) or CT-operated (Class 0.5/0.2), each available in single- or three-phase variants.

B. Data Concentrator Unit (DCU)

The DCU collects data from multiple smart meters, validates and preprocesses it, and forwards it to a central server, reducing server load and communication cost relative to each meter reporting individually. In this work the DCU is realized on an A5D2x Rugged Board (SAMA5D2x / ARM Cortex-A5, 500 MHz, 64 MB RAM, 32 MB NOR flash, Linux kernel 4.9) chosen for its ruggedized I/O (Ethernet, RS-232/RS-485, CAN, USB, micro-BUS, SIM slot) and support for RF mesh, Wi-Fi, LoRa and Zigbee radios.

IV. RF Mesh Communication Architecture

RF Mesh is a self-healing, self-organizing wireless network in which each smart meter acts as both a data source and a relay node. Data travels through multiple nodes (multi-hop communication) before reaching the DCU, with adaptive routing selecting the best available path and automatic rerouting if a node fails.

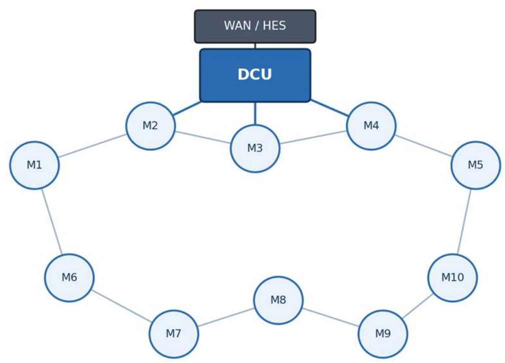

Fig. 1. RF Mesh network architecture: meters relay data through neighbouring nodes to the DCU, which forwards it to the HES over WAN.

Each Network Interface Card (NIC) attached to a meter operates in the 865-867 MHz Sub-GHz ISM band with Frequency Hopping Spread Spectrum (FHSS) and AES-128/256 encryption, giving low-interference, long-range and low-power communication in a self-forming topology.

V. System Implementation

A. Hardware Setup

The implemented system consists of a smart meter (El Sewedy Electrometer EM101-2), RF NIC modules operating at 865-867 MHz, an A5D2x Rugged Board DCU, a Quectel EC25 4G LTE module for backhaul to the Head End System (HES), and a Windows PC running Gurux DLMS Director for reading and analysing meter data.

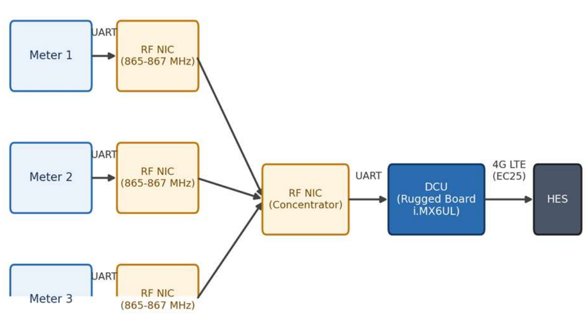

Fig. 2. Block diagram of the RF Mesh link between smart meters and the DCU.

B. Test Procedure

- Connect the DCU to a PC using a USB cable.
- Open PuTTY and configure the port: baud rate 115200, connection type Serial.
- On the DCU's Linux terminal, stop the existing UART daemon service and start /usr/bin/uart_daemon on /dev/ttymxc2 at 115200 baud.
- Power on the smart meter after 20 seconds and observe the serial number and assigned IP address in PuTTY.
- Verify data transmission every 10 seconds, including energy readings and timestamps.

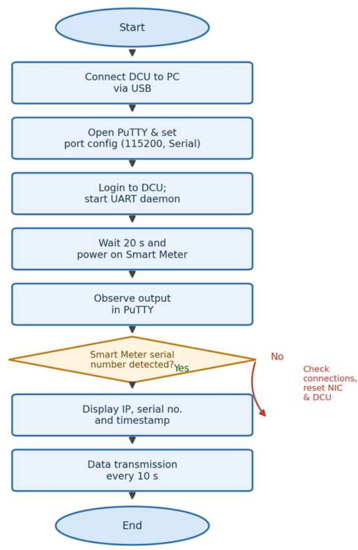

Fig. 4. Test and data-acquisition procedure for the RF Mesh link.

C. Optimization Techniques

Adaptive transmission power control adjusts RF signal strength according to distance and congestion, reducing interference and meter power consumption, while multi-hop routing optimization and self-healing rerouting maintain delivery when a node fails. AES-256 encryption and tamper-detection mechanisms protect data in transit and flag unauthorized physical access.

VI. Results and Analysis

Performance was evaluated in terms of latency, reliability and Packet Delivery Ratio (PDR). Measured latency ranged from 50-150 ms depending on network congestion and hop count; the error rate was below 1%, indicating high data integrity; and the achieved PDR was 98.7% under normal conditions, dropping to about 95% under high interference but remaining stable due to multi-hop routing.

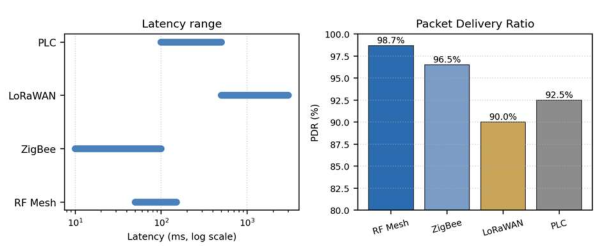

Fig. 3. Comparative latency and PDR of RF Mesh against ZigBee, LoRaWAN and PLC.

Technology	Latency (ms)	PDR (%)
RF Mesh (multi-hop)	50-150	98.7
ZigBee	10-100	95-98
LoRaWAN	500-3000	85-95
PLC	100-500	90-95

TABLE II. Latency and packet delivery ratio by technology

Scalability testing with 1,000+ simulated smart meters communicating with a single DCU showed no performance degradation: adaptive multi-hop routing sustained smooth data transmission and latency stayed under 150 ms. Resilience testing, which simulated node failures and interference, confirmed automatic rerouting via alternate paths, with PDR remaining above 95% and the network recovering within 5-10 seconds of a node failure.

A cost-benefit comparison shows RF Mesh has a moderate initial setup cost but a self-forming infrastructure, high scalability, low maintenance (owing to self-healing) and high long-term ROI, outperforming ZigBee, LoRaWAN and PLC on reliability (98.7% PDR) while remaining more cost-effective than gateway-dependent LoRaWAN deployments.

VII. Conclusion

This work demonstrates RF Mesh communication as an effective technology for modern smart metering, enabling real-time data transfer, efficient energy monitoring and seamless integration with utility infrastructure. Built around a smart meter, a Rugged Board DCU, RF NIC modules and a USB/PuTTY verification interface, the system achieved low latency (50-150 ms) and a high packet delivery ratio (98.7%). Its self-healing, scalable topology handles large numbers of meters while remaining more cost-effective and reliable than LoRaWAN, ZigBee and PLC for urban and suburban deployment. Remaining challenges include validating performance at larger scale, mitigating interference in dense urban environments, and addressing cybersecurity risks; RF Mesh may also extend to smart street lighting, industrial automation and smart agriculture. With continued advances in security and optimization, RF Mesh communication is well positioned to underpin future smart-grid infrastructure.

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