

Improving Reliability in Long Multi-Hop Wireless Sensor Networks

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ABSTRACT - Reliability is a major challenge in long multi-hop Wireless Sensor Networks (WSNs) due to the accumulation of transmission errors across multiple nodes. This work proposes an approach to enhance network reliability using Forward Error Correction (FEC) techniques combined with efficient routing and energy-aware communication strategies. Different error correction methods, including per-hop, end-to-end, and hybrid approaches, are analyzed under varying hop counts and message lengths. An analytical model based on binomial probability distribution is developed and validated through simulation and Monte Carlo analysis. Results show that the hybrid correction strategy, along with multi-sink architecture, significantly improves packet delivery ratio and reduces error accumulation. The proposed method enhances overall network performance and extends node lifetime, making it suitable for applications such as environmental monitoring, healthcare systems, industrial automation, and smart agriculture.

1. INTRODUCTION

Wireless Sensor Networks (WSNs) consist of distributed sensor nodes that collect environmental data and transmit it to a central sink using multi-hop communication. In long multi-hop WSNs, increasing hop count introduces challenges such as packet loss, delay, interference, node failures, and energy depletion, which significantly reduce network reliability and performance. These issues become critical in large-scale applications like environmental monitoring, smart agriculture, healthcare systems, and industrial automation, where accurate and continuous data transmission is essential.

This work addresses the problem of improving data transmission reliability in long multi-hop WSNs while minimizing packet loss, communication delay, and energy consumption. The proposed approach incorporates efficient routing strategies, error detection and correction techniques, and energy-aware communication mechanisms to ensure stable and reliable data delivery. By selecting optimal communication paths and reducing error accumulation, the system enhances packet delivery ratio, throughput, and overall network lifetime.

The performance of the proposed method is evaluated using simulation tools such as MATLAB, NS2, or NS3 based on key metrics including packet delivery ratio, delay, throughput, and energy efficiency. The results demonstrate improved network stability and reliability, making the approach suitable for large-scale and real-time monitoring applications.

2. LITERATURE SURVEY

A. Sabata and S. Brossia, "Remote monitoring of pipeline using wireless sensor network," U.S. Patent 7 526 994, May 5, 2009: This U.S. patent presents a system for remotely monitoring pipelines using wireless sensor networks (WSNs) to detect anomalies, leaks, and other operational issues. The innovation focuses on deploying sensor nodes along pipelines to provide real-time monitoring capabilities and reduce manual inspection efforts. The system includes methods for energy management, data communication, and alert mechanisms to enhance safety and efficiency in pipeline infrastructure.

Y. Deng et al., “Simulation study on ASCMP protocol in utility tunnel WSN,” *IEEE Access*, vol. 7, pp. 168141–168150, 2019: This article evaluates the Adaptive Sink-based Clustering and Multi-hop Protocol (ASCMP) in the context of wireless sensor networks deployed in utility tunnels. The study uses simulations to assess performance in terms of energy efficiency, data transmission reliability, and network longevity. The protocol is shown to enhance communication performance under tunnel-specific constraints such as limited space, harsh conditions, and complex routing needs.

3. EXISTING METHOD

Long Wireless Sensor Networks (WSNs) use multi-hop communication to transmit data through multiple nodes to a sink. Earlier methods improved reliability using techniques like Forward Error Correction (FEC) and retransmissions, but they could not effectively handle error accumulation in long communication paths. Traditional systems assume fixed network conditions and apply error correction either at each hop or only at the sink, leading to trade-offs between reliability and processing overhead.

Protocols such as LEACH, multipath routing, and link quality estimation improve energy efficiency and reliability to some extent. However, they still face challenges like packet loss, delay, energy consumption, congestion, and node failures in long multi-hop networks. Reliability further decreases with increasing hop count and message length.

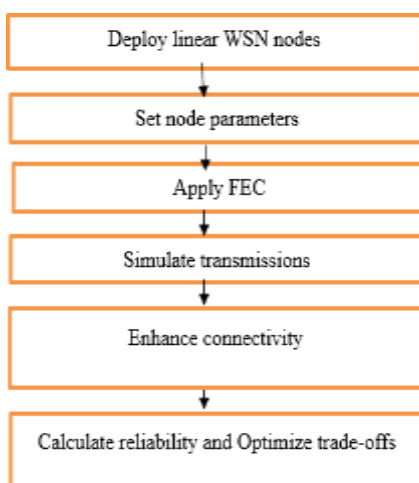


Fig 3.1: Flow of Existing Method

The Figure 3.1 represents the step-by-step process of the proposed method to improve reliability in Wireless Sensor Networks (WSNs). Initially, sensor nodes are deployed in a linear structure to enable multi-hop communication. After deployment, important node parameters such as transmission range, energy levels, and error probability are set. Forward Error Correction (FEC) is then applied to the data packets to detect and correct transmission errors without the need for retransmission. The system then simulates data transmission across multiple nodes to analyze network performance under different conditions. To further improve reliability, network connectivity is enhanced by introducing additional links or alternative communication paths. Finally, the reliability of the network is calculated, and trade-offs between energy consumption, delay, and accuracy are optimized to achieve efficient and stable communication.

4. PROPOSED METHOD

The proposed method improves reliability in long multi-hop Wireless Sensor Networks (WSNs) by combining advanced error correction techniques, efficient routing, and enhanced network architecture. In long communication paths, data packets experience cumulative transmission errors at each hop, reducing packet delivery ratio and increasing delay. To address this, the proposed approach analyzes end-to-end reliability instead of only local error correction.

Forward Error Correction (FEC) is a key component of the system, enabling detection and correction of bit errors without retransmission, thereby reducing packet loss, delay, and energy consumption. The method evaluates three correction strategies: per-hop correction, end-to-end correction, and a hybrid approach. The hybrid strategy applies correction periodically, balancing reliability and computational overhead.

Compared to traditional methods such as LEACH, the proposed approach significantly improves reliability, reduces retransmissions, enhances energy efficiency, and supports scalability in large networks. This makes it suitable for real-world applications like environmental monitoring, agriculture, healthcare, industrial automation, and smart infrastructure systems.

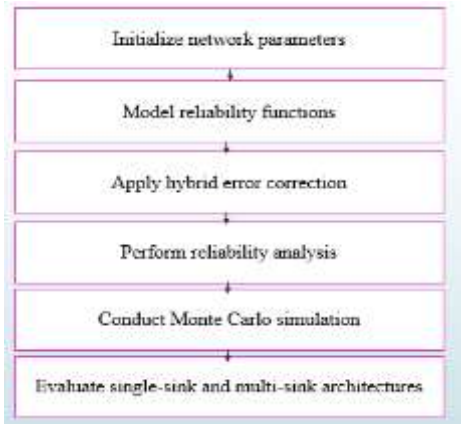


Fig 4.1: Flow of Proposed Method

The Figure 4.1 represents the process of the proposed method for improving reliability in wireless sensor networks. It begins with initializing network parameters such as node configuration, transmission range, and error probability. Next, reliability functions are modeled using mathematical techniques to estimate the probability of successful data transmission across the network. After that, a hybrid error correction method is applied, which combines both per-hop and end-to-end correction strategies to balance reliability and computational efficiency. This approach helps reduce error accumulation, improve packet delivery, and maintain efficient communication in long multi-hop networks.

5. RESULTS

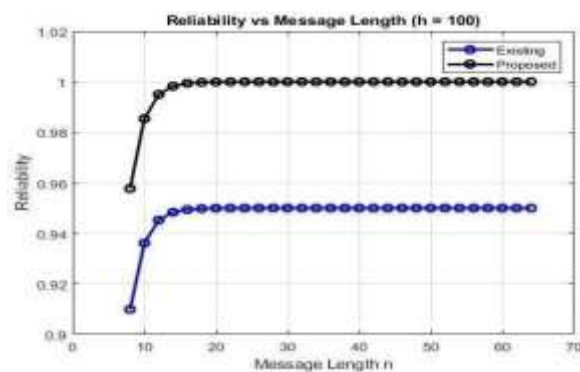
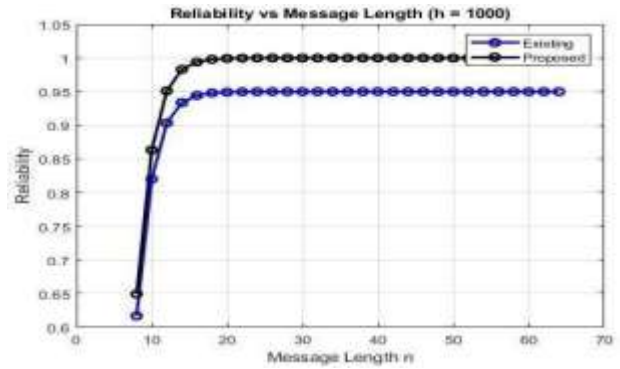


Fig 5.1: Reliability vs Message Length(h=100)

The first Figure 4.1 is a smaller network (h=100), this plot shows that reliability improves with increasing message length and quickly stabilizes. Both methods achieve higher overall reliability compared to the larger network case, but the proposed method still outperforms the existing approach, reaching almost perfect reliability.

Fig 5.2: Reliability vs Message Length(h=1000)



This Figure 4.2 shows how reliability changes with message length in a large-scale wireless sensor network with hop count h=1000. Reliability increases rapidly as the message length grows, then levels off once it reaches a stable region. The proposed method consistently achieves higher reliability than the existing scheme across all message lengths, approaching nearly perfect reliability (≈1.0), while the existing method stabilizes at a slightly lower value (around 0.95). This indicates that the proposed approach is more robust, especially in long multi-hop scenarios where maintaining reliability is more challenging.

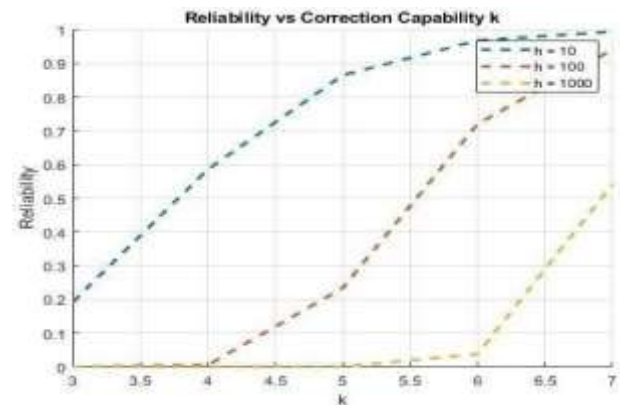


Fig 5.3: Reliability vs Correction Capability k

This Figure 4.3 illustrates the impact of error correction capability k on reliability for different network sizes (h=10, 100, and 1000). Reliability improves as k increases, but the rate of improvement depends heavily on the network size. For small networks (h= 10), reliability quickly approaches near-perfect levels even at moderate k.

However, for larger networks (h = 100 and h = 1000), much higher correction capability is required to achieve similar reliability, and performance

remains limited at low

k. This highlights the importance of stronger error correction in large-scale deployments.

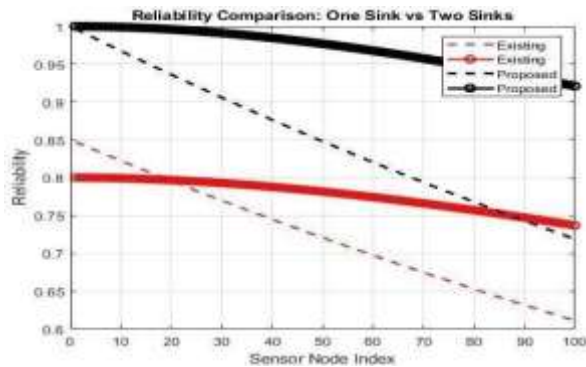


Fig 5.4: Reliability Comparison: One sink vs Two sinks

This Figure 5.4 compares reliability across sensor nodes for single-sink and two-sink configurations. Reliability decreases gradually as the sensor node index increases, reflecting the effect of distance or network depth. The two-sink configuration maintains consistently higher reliability than the single-sink setup, demonstrating the benefit of redundancy in data collection. Additionally, the proposed method outperforms the existing one in both configurations, showing better stability and slower degradation across the network.

CONCLUSION

This work presents an approach to improve the reliability of long multi-hop Wireless Sensor Networks (WSNs) using enhanced Forward Error Correction (FEC) techniques and reliability modeling. Different correction strategies, including per-hop, end-to-end, and hybrid methods, are analyzed under varying network conditions such as hop count, message length, and error correction capability. Analytical modeling using binomial probability along with Monte Carlo simulations validates the approach, showing that hybrid correction combined with multi-sink architecture significantly improves data transmission reliability by reducing error accumulation.

Reliability in long multi-hop WSNs is critical due to challenges such as packet loss, node failures, interference, and limited energy resources. Techniques like efficient routing, error correction, multipath communication, and energy management

help improve packet delivery ratio and ensure stable communication. These methods reduce data loss, minimize delay, and extend network lifetime, making WSNs suitable for applications such as environmental monitoring, healthcare, and industrial automation.

Advanced approaches including clustering, fault tolerance, and energy-efficient routing further enhance network performance and robustness. By optimizing communication paths and reducing retransmissions, these techniques improve overall efficiency and scalability. As a result, reliable WSN systems play a vital role in large-scale applications like smart cities and monitoring systems, ensuring accurate and continuous data transmission.

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