Optimising WSN Battery Life using HARQ,TPC and Energy-Efficient Codes

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May 23, 2024

I. Abstract

This research addresses the pressing issue of energy constraints in wireless sensor networks (WSNs) [1], crucial for applications ranging from healthcare to military operations. Despite their significance, WSNs [1] face challenges due to limited battery capacity [2], hindering their efficiency and lifetime. This study aims to enhance WSN performance by implementing error reduction techniques to mitigate energy consumption. Specifically, the integration of Hybrid Automatic Repeat Request (HARQ) [3], Transmit Power Control (TPC), and advanced error-correcting codes like Reed-Solomon (RS) codes is proposed. By investigating the effectiveness of different error-correcting codes alongside HARQ and TPC [4], this research seeks to optimize battery life and overall energy efficiency in WSNs.

II. Introduction

Wireless sensor networks (WSNs) [1] play a crucial role in numerous applications, including healthcare monitoring, military operations, and home automation [5]. However, the widespread adoption of WSNs is hampered by energy limitations, primarily stemming from the reliance on small batteries to power sensor nodes. This limitation poses significant challenges in maintaining optimal performance while extending the network's lifetime. Additionally, ensuring data accuracy in the face of environmental changes, noise, and sensor faults further complicates the issue.

To address these challenges, this research proposes a comprehensive approach to enhance WSN performance by focusing on energy optimization. The integration of Hybrid Automatic Repeat Request (HARQ) and Transmit Power Control (TPC) [6] offers promising avenues to mitigate energy consumption in WSNs. Furthermore, the incorporation of advanced error-correcting Reed-Solomon (RS) [7] codes presents an opportunity to improve data reliability while minimizing energy expenditure.

Through systematic investigation and comparison of different error-correcting codes alongside HARQ and TPC, this study aims to identify the most effective strategies for optimizing battery life and overall energy efficiency in WSNs. By utilising these techniques, not only can the performance of WSNs be enhanced, but also their longevity can be significantly extended, leading to improved reliability and functionality in critical applications.

The rest of the paper is organised as follows: Literature presents the literature review of the papers; Design and Implementation 0.3 presents the overall design of the network along with its implementation; Results and Analysis 0.4 shows the analysis carried for the network for different ECC's; finally, Conclusion 0.4 concludes with the final attained results and Future Work 0.4 talks about the future prospects

III. Literature

0.1 Reliable and energy-efficient transmission scheme based on error correction codes and clustered routing protocol for WSN [8].

This article argues that [1] error correction codes should be used together with [7] to ensure efficient and reliable transmission in WSNs (Wireless Sensor Networks). This article examines the performance of RS (Reed Solomon) block numbers. They measure the value of RS in different environments. Finally, they integrated RS into the routing process to determine which strategy is best for LEACH. Simulation results show that LEACH using LDPC is better than LEACH using RS. Therefore, to establish reliable and efficient communication in WSN, LDPC strategy will be a suitable choice to adopt group routing protocol. However, in case of leaving the group, it would be more correct to use RS. [9]

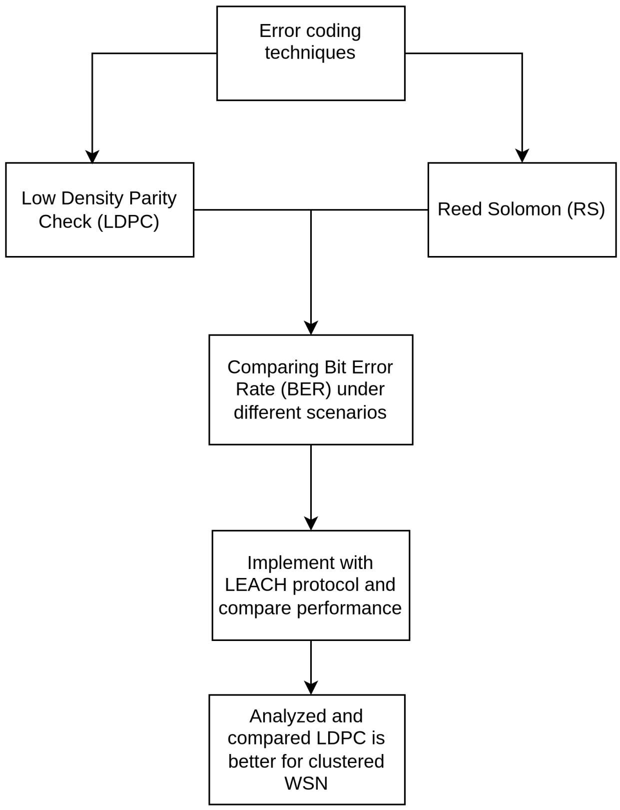

Figure 1: Suitability of LDPC for cluster WSN

Advantages:

- Improved Communication Reliability: The integration of error correction codes (ECCs), particularly the comparison between Reed Solomon (RS) and Low-Density Parity Check (LDPC) codes, improves the communication in WSNs. This is important for applications in harsh environments.
- Extended Battery Life: By implementing error correction codes, especially LDPC, this study aims to improve the Bit Error Rate (BER) performance with lower Signal-to-Noise Ratio (SNR) requirements. This can contribute to energy conservation in sensor nodes, thereby improving the battery life of the WSN.
- Efficient Routing Protocols: The research finds the performance of error correction codes with the context of the LEACH routing protocol, a clustering method. The results suggest that LDPC is more suitable for LEACH, indicating for efficient routing protocols that balance energy consumption and reliable communication.
- Flexibility in Code: The research provides a detailed analysis of different error correction situations, like varying code rates, lengths, and error correction capabilities. This allows for the selection of an appropriate error correction code based on WSN requirements.

Disadvantages:

- Complexity and Overhead: Implementing sophisticated error correction codes like LDPC may introduce computational drawbacks and communication overhead. The additional processing requirements could strain the limited resources of sensor nodes, eventually reducing the benefits gained from error correction.
- Energy Consumption during Decoding: While error correction improves communication reliability, the decoding process itself consumes energy. In energy-constrained WSNs, the trade-off between reliability and energy consumption must be considered, especially if the decoding process requires high computational resources.
- Real-World Challenges: The research is simulation-based, and the transition from simulation to real-world implementation may face challenges. Factors like environmental conditions, hardware constraints, and practical deployment issues could impact the real-world effectiveness of the proposed error correction strategies.

0.2 Performance Enhancement of Wireless Sensor Network (WSN) with the Implementation of Hybrid ARQ (HARQ) and Transmission Power Control (TPC)

This paper presents and proposes a battery-based approach to improve Wireless Sensor Networks (WSNs) by combining the Hybrid Automatic Repeat Request (HARQ) [3] and Transmission Power Control (TPC) [4]) Process. By successfully testing various parameters, significant improvements in WSN performance were achieved under different conditions. Their work not only complements existing research by addressing common issues with HARQ and TPC in wireless networks, but also provides insight into the concepts through experiments and investigations. In addition, this article provides a comprehensive review of relevant research and highlights the shortcomings of existing research. and suggests that better solutions are needed to improve efficiency when solving energy problems. Their contributions go beyond theoretical considerations and offer practical suggestions to improve WSN performance [10]. In addition, they laid the foundation for future research directions, including investigating the importance of collaboration, redesigning the implementation process, and reviewing electronic communication policies in wireless sensor networks. [6]

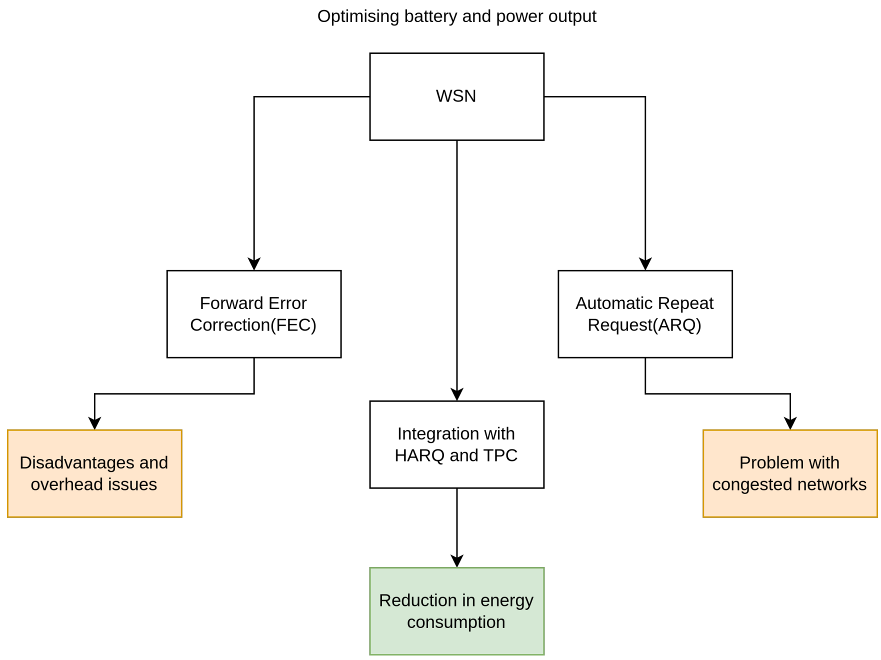

Figure 2: Battery efficiency of WSN in different scenarios

Advantages:

1. Energy Efficiency optimisation: Integrating HARQ with TPC offers drastic improvements in energy efficiency by optimizing transmission power levels, thereby extending the overall battery life of sensor nodes in WSNs.

2. Reduced Energy Consumption: The combination of HARQ and TPC minimizes energy consumption by controlling unnecessary retransmissions and optimizing transmission power based on network conditions, leading to longer operational lifetimes for battery-powered devices [11].

3. Enhanced Battery Management: By dynamically adjusting transmission power levels and employing efficient error control mechanisms, this research enables more effective management of battery resources in WSNs, ensuring longer network uptime and reduced maintenance.

Disadvantages:

1. Algorithm Overhead: The overhead associated with HARQ and TPC algorithms may consume more processing resources and memory in limiting their ability to perform other essential tasks and impacting overall system performance.

2. Trade-off Challenges: While the approach aims to optimize energy efficiency, there may be trade-offs between energy savings and other performance metrics such as latency or throughput.

3. Deployment Challenges: Implementing HARQ and TPC in real-world WSN deployments may face challenges related to scalability and adaptability to diverse environmental conditions, thus limiting its effectiveness in practical scenarios.

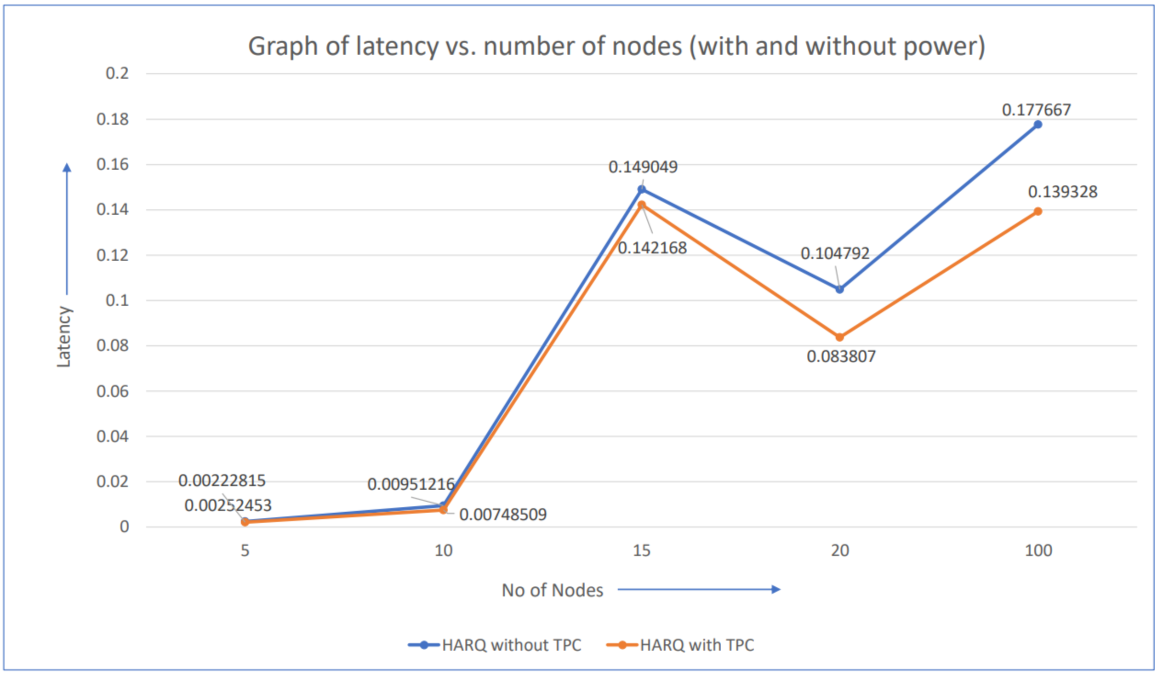

Figure 3: Analysis of HARQ with TPC vs without TPC [6]

0.3 Optimisation of energy efficiency in wireless sensor networks using error control codes

This paper contributes to the understanding and optimization of wireless sensor networks (WSNs) using error-correcting code (ECC) [7]. It helps in choosing the right power ECC [12] in WSN. This method takes into account many factors such as distance, bit error rate (BER), channel conditions, operating frequency and ECC. Considering the trade-offs between using ECC and increasing power transmission, it is recommended to choose ECC techniques in WSNs. It refers to the need to control the bit error rate (BER) for an application to achieve quality of service (QoS) [2]. Contains a detailed analysis of various ECCs, including Hamming and RS. The evaluation is based on BER's error correction ability and coding gain. This analysis provides information on the performance of different ECCs. [13]

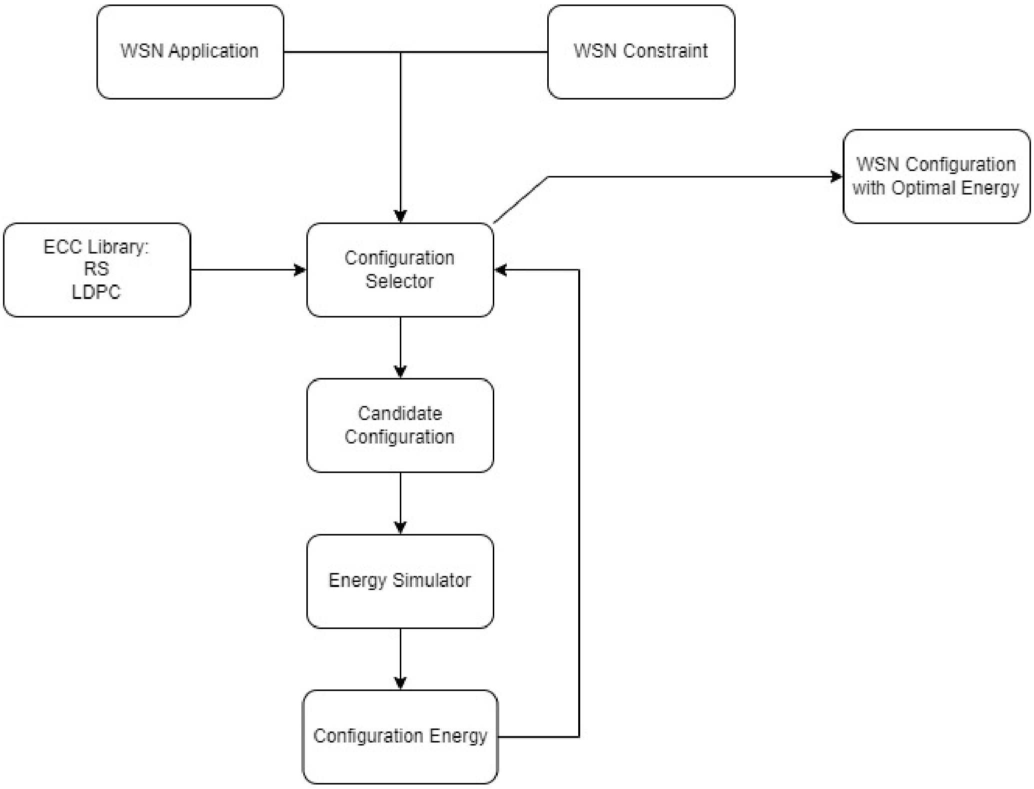

Figure 4: ECC selector

Advantages:

- Performance Analysis: This paper presents a complete analysis of various ECCs, including RS and Hamming Codes. This result is helpful to determine the type of ECC required for some purpose.
- Error Correction Capability: RS codes offer strong error correction capabilities, determined by the minimum distance parameter (dmin=N-K+1), ensuring reliable data transmission.
- Energy Model : Considering a standard energy model, the provided a detailed explanation of error correcting codes and which performs better for what situations.

Disadvantages:

- Limited ECC Scope: The paper focuses on a specific set of ECCs potentially limiting the findings. The exclusion of other ECCs may overlook potential alternatives that could be relevant in different situations.
- Simplified Energy Model: The energy model presented in this paper, while informative, hasnt suggested for energy efficiency in real-world WSNs.

Table 1: Comparison of Approaches

Metrics	**Approach-1**	**Approach-2**	**Approach-3**
Communication Reliability	High	High	High
Energy Efficiency	High	High	High
Battery Life	Extended	Extended	Extended
Routing Protocol Efficiency	Efficient with LDPC	Not Applicable	Not Applicable
Processing Complexity	Moderate	Moderate	Low
Energy Consumption during Decoding	Considerable	Moderate	Low
Real-World Implementation Challenges	Yes	Yes	Yes
Performance Enhancement	Moderate	Significant	Moderate
Battery Management	Effective	Effective	Effective
Algorithm Overhead	Moderate	High	Low
Trade-off Challenges	Moderate	High	Low
Deployment Challenges	Yes	Yes	Yes
Performance Analysis of ECCs	Detailed	Not Applicable	Detailed
Error Correction Capability of ECCs	RS and LDPC demonstrated	Not Applicable	RS highlighted
Energy Model Explanation	Not provided	Not provided	Simplified
Scope of ECCs Analyzed	RS and LDPC	Not Applicable	Hamming, RS

- Approach-1 : Reliable and Energy-Efficient Transmission Scheme
- Approach-2 : Performance Enhancement with HARQ and TPC
- Approach-3 : Optimization of Energy Efficiency with ECCs

IV. Design and Implementation

To implement this analysis we created a python script to simulate the WSN environment by making the following assumptions 2. We used the reedsolo library available in python to encode and decode the data to simulate using the ECC(Error correcting Code). We plotted the graphs using python's matplotlib library.

The pseudocode has been provided for reference. Python was used as the programming language to setup the WSN environment with the below mentioned variables 2.

To design this approach, we first considered the graph of what would happen if we just consider using RS as the ECC for the entire process along with HARQ and TPC. Upon reviewing the results we tried to build a hybrid approach which would use RS only under certain situations so that we can ensure that battery is not simply being consumed and also ensure good tradeoff between battery and the data reliability.

0.4 Psuedocode

Algorithm 1 Wireless Sensor Network Simulation

```
Initialize parameters: SNR, HARQ max retransmissions, number of transmissions, packet sizes, power levels
Create Wireless Sensor Network instance with packet sizes
Run simulation with the following steps:
for all power level in power levels do
    Initialize arrays for energy consumption without and with RS
    for all packet size in packet sizes do
        Decide whether to use RS based on packet size, power level, and SNR threshold
        Calculate energy consumption for the configuration
        Store energy consumption based on RS usage
    end for
    Calculate average energy consumption for both cases
    Calculate energy consumption per bit for both methods
    Plot energy consumption per bit vs packet size for both methods
end for
Define methods:
generate_snr: Calculate SNR mean based on power level and generate random SNR with normal distribution

transmit_with_tpc: Determine SNR threshold, adjust data based on power level if SNR exceeds threshold, encode data using RS if necessary, and return transmitted data
simulate_transmission: Initialize energy consumed variables, loop for number of transmissions, generate random SNR, transmit data with TPC, update energy consumed based on success or failure
choose_use_rs: Decide whether to use RS based on packet size, power level, and SNR threshold
calculate_energy_consumption: Initialize total energy consumed, loop for number of transmissions, simulate a single transmission, add consumed energy to total, return average energy consumption
```

Variables	Values
Packet Sizes	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 (Bytes)
Power Levels	0.2, 0.34, 0.5, 1.64, 2.0, 2.36 (W)
Error Control Protocol	HARQ
Max HARQ simulation retransmissions	5
Error Control Codes	Reed Solomon(RS-31)
Number Of Transmissions	10
SNR simulation threshold	20

Table 2: The defined variables that were used in experiments

V. Result and Analysis

After running the WSN environment with random data for some iterations we found that HARQ TPC with RS was using more energy that compared to without RS. This was because of the large overhead introduced by using the RS algorithm. 5 Hence we decided to come up with a hybrid approach which doesnt use RS whenever the packet sizes are smaller than a fixed constant and will use RS when the packet sizes are more than the constant.

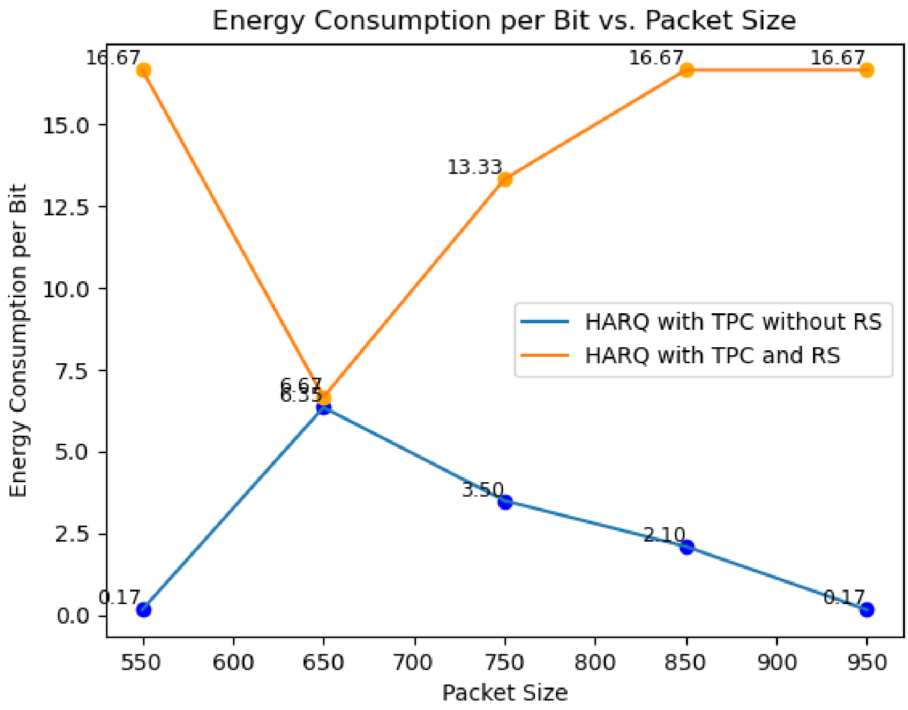

Figure 5: For packet sizes above 500

From the below graph 5, we observe that for packet sizes greater than 500 we are getting HARQ with TPC and RS consuming more energy per bit. This is because RS introduces way too much overhead resulting in higher energy consumption. This is however not the required approach as it would lead to more battery being consumed faster. However using RS here ensures reliable transmission of data packets due to error correction capabilities. This is a tradeoff between reliable communication and the battery consumption of the WSN network. To fix the above issue we modified this approach to create the hybrid approach which doesnt use RS whenever the packet sizes are small based on a certain contant value (determined based on the WSN conditions), these can be cured with HARQ retransmissions for small errors as the amount of battery consumed would be less in comparision. For larger packet sizes we will use RS in order to reduce retransmissions and ability to correct at receiver side at the cost of battery life to ensure that the tradeoff between battery and error correction is maintained.

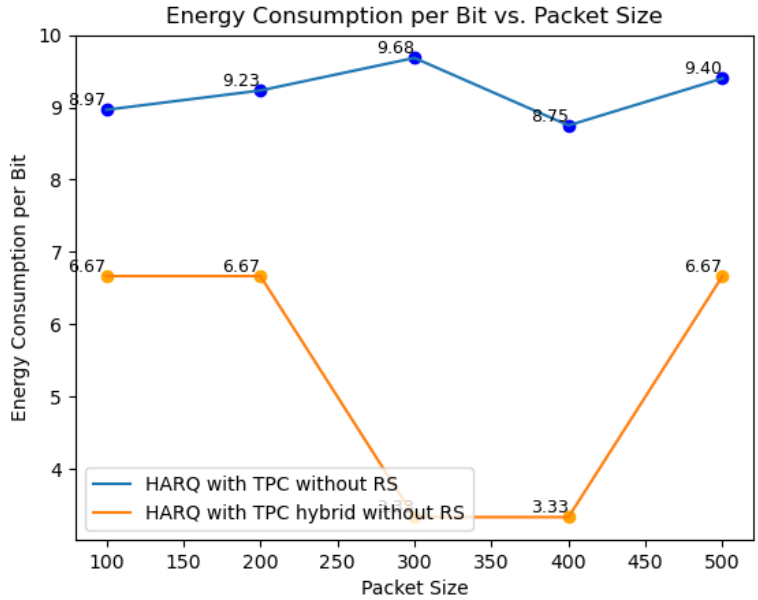

Figure 6: For packet sizes below 500

From the above graph 6, we observe that for packet sizes of less than 500 we get our hybrid approach which adjusts according to power levels dynamically adjusts the SNR, consumes less energy of the battery as compared to the traditional approach. However since we are not simulating the environment and are just using certain fixed values we dont get an accurate representation of the actual WSN environment. This is because of which the graphs are not a perfect representation of what they are supposed to be.

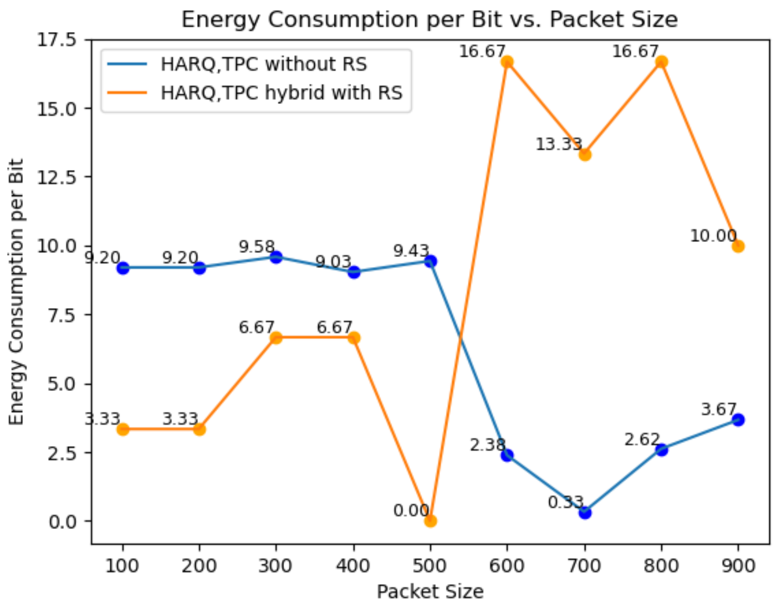

Figure 7: Choosing for packet sizes below 500

The above graph 7 is the overall idea of the hybrid approach which we have conducted based on our research. In this graph as we see, for packet sizes less than a certain constant which we need to set based off the WSN environment, HARQ with TPC [14] consumes more power than the hybrid approach this optimises the overall battery efficiency of the WSN. Since smaller packets may contain small errors which can be retransmitted using the HARQ protocol [3] not consuming enough battery in comparision the larger packets which may contain errors need more energy for transmission hence we use the ECC RS code here. This ensures that even if there is more energy consumption after the fixed constant size, the data packets are correctly received. The graph slightly deviates from our project idea as we could not dynamically change the RS code length based on packet sizes. This is again because currently we have fixed the RS code length to RS(31) [7] but we need to infact dynamically change the length of the code as we increase the packet sizes to make sure proper behaviour to be expected.

VI. Conclusion

This concludes with the idea that an implementation of HARQ TPC with RS by itself just consumes a lot of battery. To maintain the tradeoff between the battery and also ensure that reliable communication takes place, merged the two ideas to ensure that we use RS as our ECC [4] only in cases where packet sizes are small and use RS as ECC in cases where packet sizes are big. This ensures that the tradeoff is maintained while also slightly increasing the battery life. The code currently uses a fixed RS code length. Implementing dynamic code length selection based on packet size has the potential to further improve performance, especially for varying packet sizes. This would require defining a logic for how the code length changes and careful consideration of the trade-off between error correction overhead and energy efficiency.

VII. Future Work

We plan to further extend our research by validating it using a simulator like NS2/NS3 [15]. This would help further build the verification needed for our ideas to ensure the method works. Also by using a simulator we would be able to properly replicate a decent WSN instead of just using a very trivial one.

We would also like to dynamically change the RS code length based on the packet sizes instead of just using a particular RS code length for all the sitations wherever the packet sizes are higher than the constant value.

If possible, consider integrating the simulation code with actual WSN hardware to validate the simulation results under real-world conditions. This would provide valuable insights into the accuracy of the model and potential discrepancies.

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