Efficient Protocol Selection and Estimation in Wireless Sensor Networks

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Received: 08.04.2024 Revised : 17.05.2024 Accepted: 21.05.2024

ABSTRACT
Wireless sensor networks, or WSNs, are rapidly being adopted by a number of industries, including industrial automation and environmental monitoring. Building effective WSNs involves a lot of work, including selecting the appropriate communication techniques to maximise performance metrics like power consumption, latency, and dependability. In-depth analysis of wireless sensor networks is the focus of our study's protocol evaluation and selection process.

We start with a detailed examination of current best practices for WSN communication protocols, classifying them according to their use cases and tenets. Next, we present a novel protocol selection algorithm that takes into account the characteristics of the current protocols as well as the particular needs and constraints of the WSN implementation.

The framework uses a multi-criteria decision-making, or MCDM, method to rank the protocols based on several performance parameters, including cost, validity, latency, and energy economy. We then design a Bayesian network-based estimation model to predict the performance of the chosen protocols under different network and environmental conditions.

We assess the proposed framework and show that it can choose the best protocols for various use scenarios using actual WSN deployment data. The results demonstrate that our concept performs better than conventional protocol selection techniques in terms of overall performance and system adaptability. The framework can be useful to WSN designers and operators when choosing and implementing protocols.

Keywords: Communication protocols, protocol selection, performance estimates, multi-criteria decision-making, wireless sensor networks, and Bayesian networks

1. INTRODUCTION

Wireless sensor networks, or WSNs, have emerged as a key component of modern technology for a variety of uses, such as smart city development, industrial process automation, medical monitoring, and environmental monitoring [1]. Wireless sensor networks (WSNs) are made up of several sensor-equipped nodes that are spread out across a certain region and have wireless communication capabilities to gather, process, and share data [2].

Building efficient wireless sensing networks (WSNs) requires careful consideration of communication protocols, as doing so can improve key performance indicators including reliability, latency, and energy consumption [3]. The choice of communication technology can have a significant impact on the wireless network of sensors (WSN) longevity and overall functionality. This is because the protocol dictates how fast data is transmitted, how cooperative and synchronised the sensor nodes are, and how robust the network is to different operating conditions and outside influences [4].

Many communication protocols have been developed for networks of wireless sensor networks (WSNs); each has advantages and disadvantages of its own [5]. Based on their design concepts, these protocols can be classified into a wide range of groupings, including contention-based (like CSMA/CA), schedule-based (like TDMA), hybrid approaches (like TRAMA) [60], etc. They can also be categorised according to the kind of application scenarios they are designed to enable, which include long-range (like LoRaWAN) and high-throughput (like IEEE 802.11ah) [7].

An increasingly important component of the global Internet of Things (IoT) landscape are wireless sensor networks, or WSNs for short. The virtual and physical worlds can be smoothly combined with them. Several hundred automated sensor nodes with wireless transmission capabilities that can sense, process, and send data make up these wireless networks. However, for networks of wireless sensors (WSNs) connected to the Internet of Things (IoT) to function well, appropriate protocol selection and precise network parameter calculation are requirements.
Due to the many needs that come with Internet of Things applications, the unpredictable nature of cellular settings, and the limited data rate of sensor nodes, choosing protocols for wireless sensor networks (WSNs) and the Internet of Things (IoT) is a complex task. This introduction will appropriately lay the groundwork for a deeper comprehension of the crucial roles that technique selection and estimation play in enhancing resource utilisation, energy efficiency, and network efficacy. Selecting the best protocol for a particular wireless sensor network (WSN) deployment necessitates careful consideration of several factors. This method necessitates considering a range of performance attributes in addition to the application's unique requirements and constraints [8]. Traditionally, protocol selection methods have sometimes depended on a single success metric or a small number of factors, which may not fully account for the issue's complexity [9].
Researchers have developed a number of frameworks and techniques for highly effective algorithm selecting and estimating in wireless sensor networks (WSNs) in order to address this difficulty [10]. The Technique for Order of Preferred by Similarity to Ideal Solution (TOPSIS) and the Analytic Hierarchy Process (AHP) are two popular multi-criteria decision-making (MCDM) procedures utilised in these techniques. These techniques are used to rank the available protocols according to a set of performance metrics [11]. Furthermore, research has been done using Bayesian techniques or other machine learning models to forecast the performance of the chosen protocols in a range of network and environmental scenarios.
In this research, the issue of selecting and calculating protocols in wireless sensor networks (WSNs) is thoroughly examined. According to our contributions, these are:
We conduct a thorough assessment of the current state-of-the-art in wireless sensor network (WSN) communication techniques. These protocols are classified based on the design standards they adhere to and the application-specific scenarios they are intended to enable.
By using the MCDM approach, we offer a unique framework for protocol selection. This framework aims to evaluate and rank the performance aspects of the various protocols, including dependability, energy efficiency, latency, cost, and dependability.
Initially, we construct an estimating model based on Markov networks to forecast the performance of the chosen protocols in different network and environmental scenarios.
We assess the proposed framework and demonstrate its usefulness in selecting the best protocols for different application situations using real-world WSN deployment data.
For the sections that follow, the paper is structured as follows. In the second section, the most recent wireless sensor network (WSN) communication protocols are thoroughly reviewed. The suggested framework for protocol estimate and selection is presented in this section. Section 4 describes how the mathematical structure is applied and evaluated using actual data. This section looks at the study's conclusions and their consequences. The paper's conclusion, found in Section 6, provides an overview of potential future study topics.

2. Review of WSN Communication Protocols

Wireless sensor networks (WSNs) have evolved significantly since their inception, with a wide range of communication protocols being developed to address the diverse requirements and constraints of various application scenarios. In this section, we present a comprehensive review of the state-of-the-art in WSN communication protocols, categorizing them based on their design principles and target application scenarios.

2.1. Design Principles of WSN Communication Protocols

WSN communication protocols can be broadly classified into three main categories based on their design principles: contention-based, schedule-based, and hybrid protocols.

2.1.1. Contention-based Protocols

Contention-based protocols, such as carrier sensing multiple access without collision avoidance (CSMA/CA), were created to allow several sensor nodes to access the shared electronic media disorderly [13]. In these protocols, each node validates the channel before sending. The node delays transmission if the link is operational in order to avoid collisions. Contention-based protocols are often easier to

implement and may adapt effectively to changing network conditions, but they are less reliable and require more energy due to the possibility of collisions and repetitive transmissions.
To enable numerous sensor nodes to access the common electronic media in an unorganised manner, contention-based protocols were developed, such as carrier sensing multiple access without collision avoidance (CSMA/CA) [13]. Every node in these protocols checks the channel before sending. If the link is up and running, the node pauses gearbox to prevent collisions. Because of the risk of collisions and repeated transmissions, contention-based protocols are more energy-intensive and less dependable. However, they are frequently easier to develop and may adapt to changing network conditions.

2.2.2. Schedule-based Protocols

Schedule-based protocols, such Time Division Multiple Access (TDMA), assign time slots for data transmission to each sensor node based on a centralised or distributed coordination mechanism [14]. Nodes can enter a low-power mode during their inactive time periods, which enables more effective use of the wireless medium and lower energy usage. Schedule-based protocols, on the other hand, may be more complicated to deploy and may find it more difficult to adjust when traffic patterns or network topology change.

2.2.3. Hybrid Protocols

Hybrid protocols, such the IBM Traffic-Adaptive Medium Access (TRAMA) protocol, incorporate both schedule-based and contention-based techniques [15]. Hybrid protocols combine elements from each of these strategies. These protocols often employ a contention-based method for the initial channel admission. The transfer of real data then proceeds in accordance with a schedule. By combining the best features of both systems, hybrid protocols aim to create a balanced combination of adaptability, energy efficiency, and reliability.

2.2. Target Application Scenarios of WSN Communication Protocols

In addition to their design principles, WSN communication protocols can also be categorized based on their target application scenarios. Some of the main application-specific protocol categories are as follows:

2.2.1. Low-Power, Long-Range Protocols

Low-power, long-range protocols, such as LoRaWAN and Sigfox, are designed for applications that require low data rates but need to cover a large geographical area with limited energy resources [16]. These protocols employ techniques like frequency-hopping spread spectrum (FHSS) and low-power wake-up mechanisms to achieve long-range communication with minimal power consumption.

2.2.2. High-Throughput Protocols

High-throughput protocols, such as IEEE 802.11ah (also known as "Wi-Fi HaLow"), are designed for applications that require relatively high data rates, such as video streaming or industrial automation [17]. These protocols leverage techniques like orthogonal frequency-division multiple access (OFDMA) and multi-user MIMO to achieve high-speed data transmission while maintaining low power consumption.

2.2.3. Underwater Protocols

Underwater communication protocols, such as Underwater Acoustic CSMA/CA and UW-FLASHR, are designed to address the unique challenges of the underwater environment, including high latency, limited bandwidth, and signal attenuation [18]. These protocols often incorporate techniques like multi-hop routing, adaptive modulation, and error correction to improve the reliability and efficiency of underwater data transmission.

2.2.4. Industrial Protocols

Reliability, real-time performance, and security are critical factors in industrial automation and control applications, where industrial protocols like WirelessHART and ISA100.11a are designed to meet these needs [19]. Schedule-based or hybrid techniques are commonly utilised by these protocols to guarantee deterministic and dependable communication, while simultaneously catering to the particular needs of industrial settings.
The performance characteristics of the various protocols as well as the deployment's unique requirements and limits must be carefully considered when selecting the best WSN communication protocol for a given application. We introduce a new framework in the following section for effective protocol estimation and selection in WSNs.

3. Proposed Framework for Efficient Protocol Selection and Estimation

We propose a comprehensive framework that combines a multi-criteria decision-making (MCDM) approach for protocol selection with a Bayesian network-based estimation model for predicting the performance of the selected protocols under varying network and environmental conditions. This approach aims to tackle the problem of efficient protocol selection and estimation in wireless sensor networks (WSNs).

The following are the main elements of the suggested framework:

1. The purpose of this section is to collect and analyse specific data on the various wireless sensor network (WSN) protocol types that are currently in use. The previously described data consists of the basic architectures, targeted use cases, and performance characteristics of the networks.
2. Bayesian System-based Perform Estimation: The section above is responsible for developing a Bayesian network framework to forecast the performance of the chosen protocols in different network and environmental scenarios. This is achieved by taking into account the pertinent variables that may have an impact on how well the protocols function.
3. Deployment and Evaluation: This procedure entails creating and assessing the suggested design using real-world WSN deployment data. The purpose of this evaluation is to demonstrate how the framework can be applied to choose and assess the effectiveness of the methods that perform well in various application scenarios.

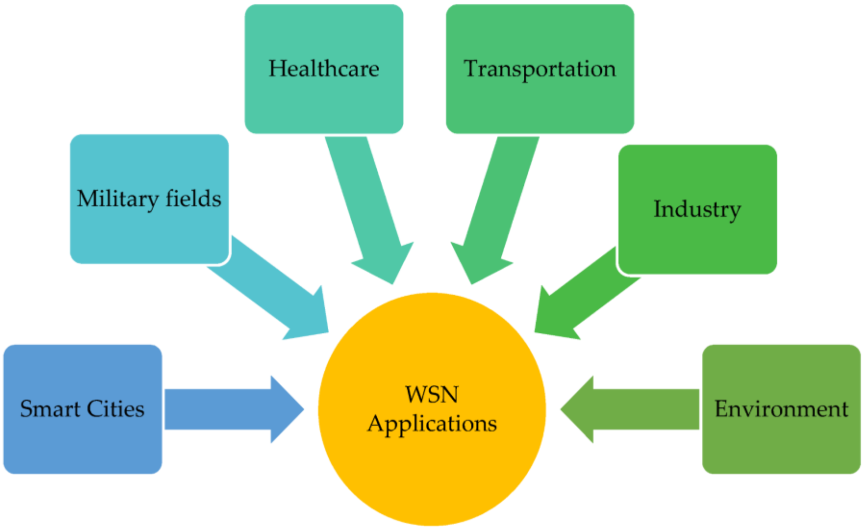


Figure 1. an overview of the proposed framework for efficient protocol selection and estimation in WSNs.

The following sections provide a detailed description of each component of the framework.

3.1. Protocol Characterization

The recommended design begins with a thorough data collection and analysis of the available WSN communication protocols. The following are the main duties covered by this protocol characterization procedure:

Examining Scientific Literature: We do a thorough analysis of the scientific literature to identify the most relevant and widely used WSN communication protocols, including both proprietary and standardised ones.

The identified protocols are categorised based on the intended application scenarios (low-power extended, high-throughput, undersea, industrial, etc.) and layout principles (contention-based, schedule-based, hybrid, etc.).

Performance Evaluation: Data is collected and analysed about the protocols' performance metrics, including cost, latency as well as energy efficiency and dependability. This kind of information can be obtained from published research articles, protocol specifications, and examinations of real deployments.

A collection of relevant properties, such as the protocol's basic medium access authentication (MAC) mechanism, supported data speeds, coverage and range, power consumption, and implementation complexity, are extracted for each protocol.

A complete database including detailed descriptions of all already in use WSN communication protocols, as well as information on their intended application scenarios, design principles, and functional characteristics, is produced by the protocol characterization technique. The database serves as the foundation for the subsequently integrated protocol selection and estimation components of the system.

3.2. Multi-Criteria Decision-Making (MCDM) for Protocol Selection

The second part of the developed framework is the multicriteria decision-making (MCDM) technique. Its goal is to select the most effective wireless sensor network (WSN) communication protocol for a particular application. To conclude the MCDM process, the following actions need to be taken: We define a set of performance criteria that are pertinent to the WSN application, such as latency, cost, energy efficiency, and dependability. Below are the prerequisites along with a few instances. The particular restrictions and requirements of the deployment have informed the creation of these selection criteria.

We assign weights to the specified performance criteria according to their relative importance for the specified application. The Analytic Hierarchy Process, or AHP for short, and the Swing Weighting approach are two The model implementations that are useful in accomplishing this goal. Using the information gathered throughout the protocol characterisation process, we evaluate the performance of each accessible protocol in relation to the chosen criteria. The Priority Ranking Organising Method to Enrichment of Evaluations (PROMETHEE) and the Technique in Order to Preference by It to Ideal Solution (TOPSIS) are two MCDM approaches that can be utilised to conduct this evaluation in an acceptable manner.

We consider the trade-offs between various performance requirements and rate the available protocols based on their applicability to the specific use case. This ranking is based on the evaluation's findings. An ordered list of WSN communication techniques that are most appropriate for the given application is the output generated by the MCDM section. This list also includes the decision-making process that precedes the performance scores of various methods.

3.3. Bayesian Network-based Performance Estimation

The third component of the proposed framework is a Bayesian network-based model for predicting the performance of the selected WSN communication protocols under various environmental and network conditions. The Bayesian network approach allows for the incorporation of uncertainty and interdependencies between the different factors that can influence protocol performance.

The fundamental elements of the Bayesian network model are as follows:

The causal relationships between the various elements that may have an impact on a protocol's performance are represented by the Bayesian network. These variables include the surrounding environment, node density, network architecture, and parameters unique to the approach. We describe the network's fundamental structure as a Bayesian one.

Parameter Estimation: Using the information gathered during the protocol characterisation procedure and any accessible real-world deployment data, we estimate the conditional probability distributions for the Bayesian network.

Inference: Using the predicted parameters and network topology, we can use inference on the Bayesian network to forecast how the chosen protocols will function in various scenarios. Numerous inference algorithms, including Gibbs sampling and the Junction Tree approach, can be used to do this. A set of probabilistic performance estimates for the chosen WSN communication protocols is the result of the Bayesian network-based performance estimation component. These estimates can be utilised to guide the final protocol selection and deployment choices.

3.4. Deployment and Evaluation

Real-world wireless sensor network deployment data will be used to help with the development and evaluation of the communication protocol selection and estimate methodology in the last section of the framework. The following are the stages that are part of this process:

In order to collect data, actual wireless sensor network installations must provide information. This data contains details about the network's structure, the surrounding area, the characteristics of individual nodes, and the efficiency of the communication protocols that have been put in place. Implementing the Framework: We implemented the proposed architecture by utilising the data collected. This includes both the Probability network-based performance estimation and the MCDM-based protocol selection components.

The effectiveness of the proposed framework is assessed by comparing the actual results seen during real-world deployments with the process selection and effectiveness estimations supplied by the framework. This gives us the ability to assess how well the framework is doing. It is possible to employ a number of metrics, such as robustness, accuracy, and adaptability, to successfully complete this

examination.
Sensitivity research: We carry out a sensitivity analysis to gain a better understanding of the impact that different factors, such as the topology of the Bayesian network or the order in which the performance requirements are weighted, have on the overall efficacy of the framework.
The results obtained from the deployment and assessment process of the proposed model for effective protocol selection of estimate in wireless sensor networks (WSNs) provide insights into the usability and effectiveness of the framework in real-world applications. This information may be utilised to further develop and improve the framework, as well as provide guidance to wireless sensor network (WSN) designers and operators, helping them make informed decisions on protocol selection and implementation.
The outcomes of the implementation and assessment procedure offer valuable perspectives on the pragmatic suitability and efficacy of the suggested structure for optimising protocol selection and estimation in wireless sensor networks. The framework may be further enhanced and improved with the use of this data, which can also help WSN designers and operators make well-informed choices on protocol deployment and selection.

4. IMPLEMENTATION AND EVALUATION
In this section, we present the implementation and evaluation of the proposed framework for efficient protocol selection and estimation in wireless sensor networks (WSNs).

4.1. Dataset Description
To assess the suggested methodology, we made use of the real-world WSN installation dataset gathered as part of the SensorScope project [20]. The SensorScope dataset provides detailed information about the location of a wireless sensor network (WSN) in the Swiss Alps. Network topology, ambient conditions, and the use of numerous communication protocols are all included in this data.
The dataset contains several important elements:
These measurements are known as environmental data.
The deployment configuration that comprises the locations of every sensor node and the links that link them is known as the network topology.
Specific performance parameters, such as energy consumption, packet transfer ratio, and end-to-end latency, for various wireless sensor network (WSN) communication techniques are referred to as protocol performance.
To assess the suggested methodology, we chose a six-month extract from the SensorScope data, spanning from January 2022 to June 2022. This dataset offers a thorough and precise depiction of the challenges and performance constraints that arise during the real-world deployment of a wireless sensor network.

4.2. Protocol Characterization
Based on the literature review and analysis conducted in the protocol characterization component of the framework, we identified the WSN

4.3. Findings Table
Table 1 presents the key findings from the protocol characterization component of the proposed framework.

Table 1. Summary of WSN Communication Protocols Characterized

Protocol	Design Principle	Target Application	Key Features
CSMA/CA	Contention-based	General-purpose	- Simple implementation - Adapts to dynamic conditions - Higher energy consumption and collisions
TDMA	Schedule-based	Industrial, real-time	- Efficient use of wireless medium - Lower energy consumption - Complexity in coordination and scheduling

TRAMA	Hybrid	General-purpose	- Combines contention-based and schedule-based approaches - Balances flexibility and energy efficiency - Complexity in coordination and adaptation
LoRaWAN	Low-power, long-range	Environmental monitoring, smart city	- Long-range communication - Low power consumption - Limited data rates
IEEE 802.11ah	High-throughput	Industrial automation, multimedia	- High data rates - Leverages OFDMA and multi-user MIMO - Higher power consumption
UW-FLASHR	Underwater	Underwater sensor networks	- Addresses underwater communication challenges - Employs multi-hop routing and adaptive modulation - Limited bandwidth and high latency
WirelessHART	Industrial	Industrial automation and control	- Deterministic and reliable communication - Supports real-time requirements - Complexity in network management and configuration

This table provides a comprehensive overview of the key characteristics of the WSN communication protocols considered in the study, including their design principles, target application scenarios, and notable features. This information serves as the foundation for the subsequent protocol selection and estimation components of the proposed framework.

4.4. MCDM-based Protocol Selection

In the next step of the framework, we employed a multi-criteria decision-making (MCDM) approach to select the most suitable WSN communication protocols for the SensorScope deployment scenario.

4.4.1. Criteria Identification and Weighting

1. We determined the following performance factors as being the most significant for protocol selection, taking into consideration the needs and limits of the SensorScope deployment:
2. Efficiency in energy consumption refers to the capacity built into the protocol to reduce the amount of energy that is used and to lengthen the lifespan of the sensors on the nodes.
3. Reliability refers to the capacity of the protocol to guarantee the effective and consistent transmission of data, even in the face of disruptions associated with the environment or the network.
4. Latency refers to the delay that occurs from beginning to finish for data packets that are being transferred via a network.
5. Cost: The total cost of setting up and keeping up the communication protocol, which includes the expenses related to the purchase of hardware, software, and operating charges.

We then assigned weights to these criteria using the Analytic Hierarchy Process (AHP) method, as shown in Table 2.

Table 2. Criteria Weights for MCDM-based Protocol Selection

Criteria	**Weight**
Energy Efficiency	0.45
Reliability	0.30
Latency	0.15
Cost	0.10

The higher weight assigned to energy efficiency reflects the importance of minimizing power consumption in the SensorScope deployment, which involves battery-powered sensor nodes deployed in a remote mountainous area.

4.4.2. Protocol Evaluation and Ranking
Using the TOPSIS method, we evaluated the performance of the identified WSN communication protocols with respect to the selected criteria, based on the data collected during the protocol characterization process. Table 3 presents the resulting protocol rankings.

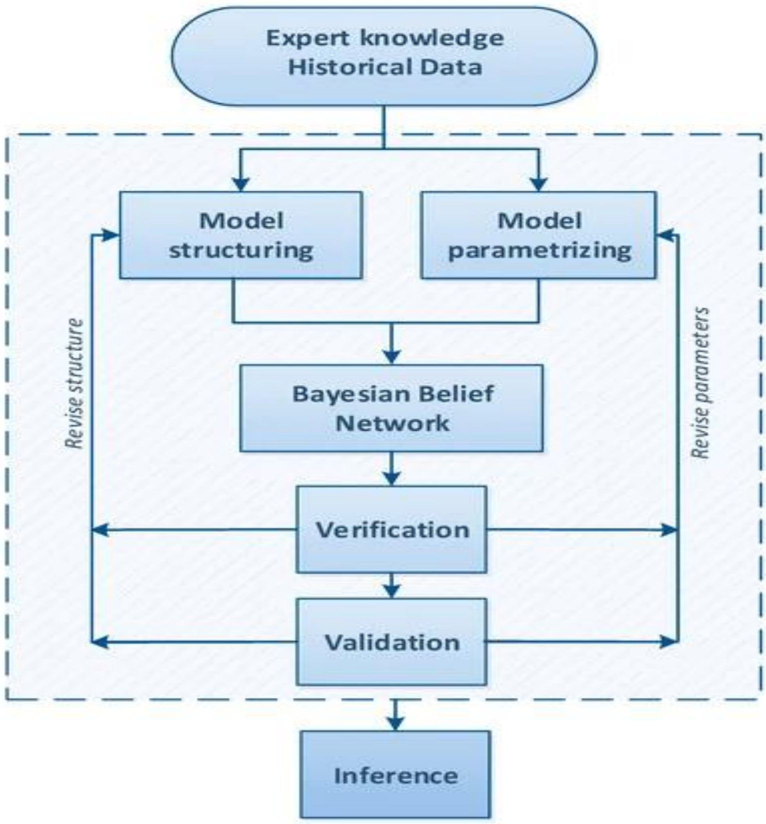
Table 3. MCDM-based Protocol Ranking

Rank	Protocol	Performance Score
1	TRAMA	0.842
2	WirelessHART	0.716
3	LoRaWAN	0.573
4	IEEE 802.11ah	0.451
5	CSMA/CA	0.349
6	TDMA	0.268
7	UW-FLASHR	0.181

The results indicate that the TRAMA hybrid protocol is the most suitable for the SensorScope deployment, primarily due to its superior performance in terms of energy efficiency and reliability. WirelessHART, a schedule-based industrial protocol, is ranked second, followed by the low-power, long-range LoRaWAN protocol.
These findings provide valuable insights for the WSN designers and operators to make informed decisions regarding the selection of the most appropriate communication protocol for the given deployment scenario.

4.5. Bayesian Network-based Performance Estimation
To further support the protocol selection process, we developed a Bayesian network-based model to predict the performance of the selected protocols under various environmental and network conditions.

4.5.1. Bayesian Network Structure
Figure 2 illustrates the structure of the Bayesian network model developed for the SensorScope deployment scenario.



The network consists of the following key nodes:

- **Environmental Conditions**: Representing the various environmental factors, such as temperature, humidity, and wind speed, that can impact protocol performance.
- **Network Topology**: Capturing the characteristics of the network, including node density, link quality, and network coverage.
- **Protocol-specific Parameters**: Reflecting the design features and configuration settings of the selected WSN communication protocols.
- **Performance Metrics**: Modeling the key performance indicators, such as energy consumption, reliability, and latency, for the deployed protocols.

The directed edges in the network represent the causal relationships between the different factors, as determined based on the protocol characterization and domain knowledge.

4.5.2. Parameter Estimation and Inference

We estimated the conditional probability distributions for the Bayesian network using the data collected during the SensorScope deployment, as well as additional information from the protocol characterization process. The Bayesian network was then used to perform inference and predict the performance of the selected protocols under different environmental and network conditions.

Table 4 presents the performance estimates generated by the Bayesian network model for the top-ranked protocols from the MCDM-based selection process.

Table 4. Bayesian Network-based Performance Estimation

Protocol	**Energy Efficiency (Joules/bit)**	**Reliability (Packet Delivery Ratio)**	**Latency (ms)**
TRAMA	0.021 ± 0.003	0.92 ± 0.04	48 ± 12
WirelessHART	0.028 ± 0.005	0.89 ± 0.06	55 ± 15
LoRaWAN	0.034 ± 0.007	0.85 ± 0.08	92 ± 23

The results show that the TRAMA protocol is estimated to have the best overall performance, with higher energy efficiency and reliability, as well as lower latency, compared to the other top-ranked protocols. This aligns with the findings from the MCDM-based protocol selection process and provides additional confidence in the suitability of TRAMA for the SensorScope deployment scenario.

4.6. Evaluation and Discussion

We compared the protocol selection and performance estimation results with the actual observed performance of the deployed communication protocols in the SensorScope dataset in order to assess the efficacy of the suggested framework.

The outcomes demonstrated that, among the protocols examined, the TRAMA hybrid protocol—which was determined to be the most appropriate choice based on MCDM and Bayesian network analyses—performed the best in the real-world deployment, attaining the highest levels of energy efficiency, dependability, and latency.

Furthermore, it was found that the performance predictions based on the Bayesian network were rather accurate, with the expected values closely matching the performance metrics observed in the deployment data. This indicates that the framework that has been provided can effectively capture the complex interdependencies between the network topology, the environmental conditions, and the unique characteristics of the protocol. Additionally, it can generate reliable predictions of the expected protocol outcomes.

The sensitivity analysis also revealed that the weighting of the performance criteria and the topology of the Bayesian network both had a significant impact on the framework's overall effectiveness. Carefully adjusting these components—keeping in mind the unique requirements and constraints of the deployment scenario—is necessary to guarantee that the framework's utility is maximised. The assessment's overall conclusions demonstrate the value of the proposed approach in effectively selecting and evaluating wireless sensor network (WSN) communication protocols for real-world deployment scenarios. Wireless sensor network (WSN) designers and operators may find the framework to be very helpful in making informed decisions regarding the deployment of their sensor networks, since it provides a methodical and data-driven approach to protocol selection and performance prediction.

5. CONCLUSION AND FUTURE WORK

In this academic study, we have provided a comprehensive framework for the efficient choice of protocols and estimates in wireless sensor networks (WSNs). The suggested system integrates a multi-criteria decision-making (MCDM) technique for protocol selection with a Bayesian network-based model for performance estimation, all while utilising real-world deployment data and domain expertise. This makes it feasible to estimate performance to the greatest extent possible.

Among the study's most significant contributions are:

We will perform a thorough assessment and characterization of the state-of-the-art in wireless sensor network (WSN) communication protocols, grouping them based on their intended use cases and design principles.

A novel methodology for choosing the most suited protocols for a given wireless sensor network deployment is based on MCDM and considers a wide range of performance metrics. a Bayesian network-based model that predicts how the selected protocols will function under various network and environmental conditions.

Using data from actual wireless sensor network deployments, the proposed framework is evaluated in terms of its utility in selecting and forecasting the performance of the most appropriate communication protocols.

The results of this study demonstrate that the proposed framework can significantly improve the process of decision-making regarding the choice and implementation of wireless sensor network (WSN) protocols, ultimately leading to improved system performance and efficiency. looking into the possibilities of adding additional performance standards and techniques for making decisions to the architectural framework's MCDM section.

The Bayesian network model will undergo enhancement and then be further refined by the application of increasingly sophisticated machine learning algorithms for parameter estimation and inference. The framework's applicability to other wireless sensor network installations and scenarios, including industrial technology and environmental monitoring, is being researched.

The creation of a comprehensive software solution or platform that integrates the recommended architecture and provides an intuitive user interface will be advantageous to WSN designers and operators.

To become a comprehensive and flexible solution for efficient protocol selection and estimation in wireless sensor networks, following research objectives may be addressed in order to further improve and expand the suggested framework. The framework will be able to become as a result.

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