Modular Data-Centric Tool for Wireless Sensor Network Monitoring and Managing

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***Abstract*—In the evolving landscape of Wireless Sensor Networks (WSNs), the ability to effectively monitor and manage network protocol parameters is critical for optimizing performance and ensuring reliability. This paper introduces the concept of a tool dedicated to sensing and controlling WSN protocol parameters. The proposed tool will integrate seamlessly with the network protocol to provide real-time insights into various protocol metrics, including connection states, packet status, neighboring node information, and routing paths. By employing adaptive mechanisms, the tool will capture essential data about the network's protocol operational parameters and facilitate dynamic network protocol management. This dual functionality enhances network efficiency, supports robust multi-hop communication, and enables proactive maintenance strategies. The tool will be based on tinyDSM middleware and will integrate Kangaroo Multi-Hop communication protocol for WSN to create a data-centric modular WSN management tool.**

***Index Terms*—WSN Monitoring, WSN Management, Wireless Sensor Networks, tinyDSM, Middleware, Data-centric, Modular**

I. Introduction

The growing complexity and scalability requirements of Wireless Sensor Networks (WSNs) [1] have driven the need for advanced mechanisms to monitor and manage WSN protocol. WSNs, characterized by numerous sensor nodes working collaboratively, are increasingly used in applications such as environmental monitoring or smart cities. These applications demand not only reliable data transmission but also efficient management of networks and node resources.

Traditionally, WSN protocols have focused on basic data transmission and routing. However, the dynamic nature of WSNs, influenced by varying node density, and environmental conditions, requires a more comprehensive approach to network protocol management. Effective monitoring of network protocol parameters, such as connection quality, packet integrity, and node interactions, is essential for maintaining optimal network performance and ensuring data reliability.

This paper presents a concept of a tool designed to address these challenges by sensing and managing WSN protocol parameters. The proposed tool will integrate with the existing network protocol to continuously gather and analyze data on network conditions, including the status of connections, packet delivery, neighbor node interactions, and routing paths. By providing real-time insights and enabling adaptive protocol adjustments, the tool may enhance the network's protocol ability to maintain robust multi-hop communication and efficiently manage its resources.

This tool employs a combination of sensing techniques and adaptive algorithms to provide a dual functionality: sensing crucial protocol parameters and managing the network protocol dynamically. This approach may not only improve the network's resilience to changes but also extend the lifespan and effectiveness of the network.

The presented tool will be based on the tinyDSM middleware platform for Wireless Sensor Network nodes [2] and will integrate the Kangaroo multi-hop protocol [3], designed for data transmission in WSNs. The tinyDSM platform enables the tool to be a modular and data-centric solution. Integrating it with the Kangaroo protocol will enhance the tool's capability to monitor and adaptively manage network protocol parameters by optimizing routing, improving connection reliability, and dynamically adjusting to network changes, which may significantly boosting overall network performance and resilience.

In this paper, we explore the conceptual framework and design of the proposed tool, highlighting its potential to improve network efficiency and resilience. We discuss the architectural components, operational principles, and the anticipated benefits of incorporating such a tool into modern WSN.

II. State of the Art

A wide array of tools exists for monitoring, configuring, and managing Wireless Sensor Networks and Internet of Things (IoT) Networks. These tools can be broadly classified based on their design objectives and requirements. In terms of design objectives, the primary classifications include network management protocols, cloud-based frameworks, software-defined networking (SDN) frameworks, semantic-based frameworks, and machine learning-based frameworks. Based on requirements, tools are categorized to handle network configuration, topology, Quality of Service (QoS), energy management, security, and maintenance.

The Lightweight M2M (LWM2M) [4] network management protocol exemplifies a client-server approach tailored for managing IoT low-power devices. Developed by the Open Mobile Alliance (OMA), it leverages protocols and security standards from the Internet Engineering Task Force (IETF). LWM2M supports features like connectivity and resource monitoring, as well as firmware upgrades. A cloud-based approach to managing IoT low-power devices was proposed in [5], focusing on energy efficiency. This model incorporates a predictive mechanism aimed at minimizing network transmission overhead. By utilizing cloud resources, the solution enhances the management capabilities of IoT networks, particularly in terms of energy conservation.

An SDN-based framework for IoT network management was introduced in [6], integrating reinforcement learning to optimize performance. This framework addresses control traffic overhead by filtering redundant information and implementing a load-balancing routing mechanism that adapts to data flows and QoS requirements. A semantic-based framework for managing heterogeneous IoT devices is discussed in [7]. This framework facilitates automatic discovery, provisioning of sensors, semantic reasoning on sensor data, and context-aware actuation. By leveraging semantic technologies, the framework aims to improve resource utilization and interoperability among diverse IoT devices.

In [8], a machine learning-based approach is presented for predicting link quality in WSNs. Using online supervised learning algorithms, this scheme predicts link quality, emphasizing the importance of balanced training samples for achieving higher accuracy and faster convergence.

The described tools each address different facets of network management, including network configuration, topology management, QoS, energy efficiency, security, and maintenance.

III. Monitoring and Managing Tool

The main idea of the presented tool is to collect network protocol information from nodes in a wireless sensor network and, on this basis, manage network protocol parameters to enable optimal and efficient data flow throughout the network, ensuring the longest possible operation of nodes without maintenance and fewer protocol or transmission errors.

The tool will be based on the tinyDSM middleware platform, making it modular and data-centric. This solution enables dynamic configuration and the creation of multiple services responsible for data processing, which can collaborate to facilitate management. Data is collected from various sensors or hardware components through adapters that translate data from different sources. The tinyDSM core communicates with adapters and services through data interfaces, providing access to the shared data and enabling reading and writing operations. The tool can consist of one or more services depending on the needs and distribution of functionality among given services.

In this approach, the network protocol is treated as a sensor and a managed module, serving as the main source of information for the tool. Thanks to its modular and data-centric nature, the tool will be able to use data from other sensors (e.g., battery level) and stored in various middleware services (e.g., energy storage management service) to perform network protocol management operations. The described solution converts the monolithic approach into a modular approach. This modularity allows for configuring how many and which services need to operate on various nodes or networks. This approach enables the tool to adjust to current network requirements and conditions. Fig. 1 shows tinyDSM architecture and simple examples of services and adapters that provide functionalities of the tool for network protocol monitoring and management.

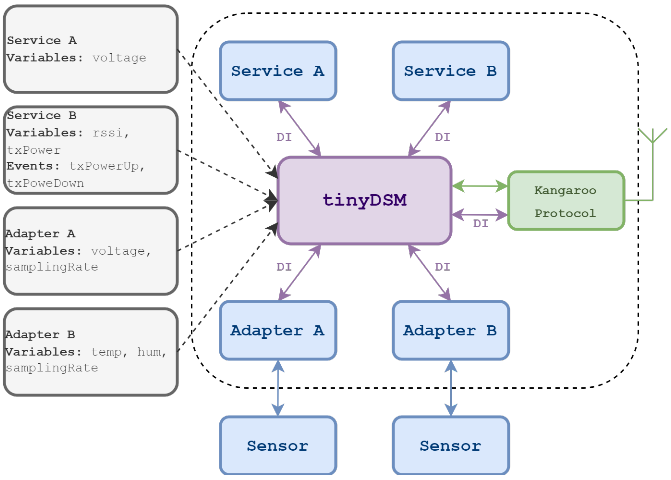

Fig. 1. Example of the simple architecture of Wireless Sensor Network monitoring and management tool.

The tool will be a hybrid solution in terms of the location of the management process. Management will be done locally on each node or in cooperation with neighbors to provide local real-time monitoring and management. Nodes will have ability transmit non-time-critical data to the gateway using the network itself to provide predictive or long-term operations or to provide chosen information to the administrator. In the future, a solution that manages a broader neighborhood area is also being considered, such as logical clustering of nodes and cooperation among nodes to manage entire clusters. Moreover, if the node supports a multi-radio or multi-protocol solution, the administrator will have the opportunity to retrieve stored information using a smartphone via Bluetooth communication. To avoid overloading the network, some low-priority information may be available only through Bluetooth.

To work with the described tool, the Kangaroo protocol must be appropriately adapted to collect and provide relevant information. The protocol will be able to deliver information about the network, nodes, and connections. All this information will be used to manage network protocol parameters based on the current state of the network, nodes, and connections. The described functionality is currently being implemented. The protocol can now provide some of the previously mentioned information, such as the RSSI information of neighboring nodes, outgoing packet statistics, and path information.

The first information monitored and relayed to the gateway are paths chosen during the network build phase. As nodes dynamically establish connections and routes during or after network initialization, the tool is meticulously track the path selection process. By relaying this information to the gateway, the tool will provide real-time insights into the evolving network topology and route preferences. This will ensure that the gateway remains aware of the network's structure, facilitating data processing, monitoring, and bottleneck detection.

The protocol already monitors packet transmission and reception, tracking the flow of packets, logging successful transmissions, and identifying instances of packet drops. Through packet loss analysis, the tool will determine the underlying causes of packet drops, such as protocol failures, transceiver module issues, or environmental interference, thus providing information to improve the packet transmission process. Additionally, the tool will meticulously monitor the machine state of each layer in the protocol stack. By continuously assessing the operational status of the MAC and network layers, the tool will detect anomalies and failures, enabling prompt issue identification and swift troubleshooting. After finding an issue, the tool can react accordingly, for example, by resetting the radio module or the entire device to resolve the error state.

RSSI, a key metric for connection quality, is continuously monitored by the protocol. It will assess connection strength and reliability between parent and child nodes by reading the RSSI values of received packets. Nodes will provide to the tool information about the last and average RSSI of packets received from parents and children. Additionally, the protocol will calculate link quality, a metric combining RSSI and hop count in the right proportion, which will be used for the selection and possible change of the parent node. Each node will also store and provide the number of currently stored parents and children in its tables, along with the RSSI information. This information, along with data on transmission and reception errors, can be used by the tool to change the priority of superior nodes or inform slave nodes about issues with receiving packets due to connection quality.

The transmission power of each node will also be a monitored parameter, allowing for dynamic adjustment as the network operates. This information, combined with RSSI, will enable the adjustment of transmission power to conserve node energy, ensuring successful data transmission without loss.

Moreover, additional services such as the energy management service will allow for control of the network topology by predicting the energy drop curve of a given node. It can be estimated when a node will lose the ability to transmit, enabling proactive measures to preserve its lifespan and the transmitted data. Consequently, nodes can be informed to use alternative routing routes, avoiding reliance on a weak node.

All described cases will enable autonomous management of network protocol parameters based on collected network information. This approach may help identify and automatically fix errors more quickly, extend node uptime, and reduce the likelihood of data loss.

IV. Conclusions

The development of advanced Wireless Sensor Networks necessitates innovative solutions for monitoring and managing networks and nodes' performance. This paper has introduced a concept of the tool designed to sense and manage protocol parameters within WSN, addressing the need for real-time network insights and adaptive network protocol control.

The proposed tool offers dual functionality: it acts as a sensor to provide detailed information about the network's operational status, including connection states, packet conditions, interactions with neighboring nodes, and routing paths. Simultaneously, it manages these protocol parameters to optimize network performance. By integrating this tool into network protocol, administrators can achieve more efficient and resilient operations, allowing the network protocol to adapt to varying conditions such as environmental changes.

Key advantages of the tool include its ability to facilitate dynamic protocol adjustments based on real-time data, enhance network reliability, and improve overall resource management. These capabilities are crucial for the effective deployment of WSN in diverse and challenging environments. Utilizing the tinyDSM platform will ensure that the solution is modular and data-centric, allowing for the dynamic addition of network monitoring and management functionalities.

While the conceptual framework and design principles of the tool have been thoroughly explored, future work will focus on implementing this tool in various WSN scenarios to validate its practical impact and refine its functionalities based on empirical findings. Integration with existing WSN protocol will enable practical tests and experiments, leveraging the protocols' capabilities to enhance data transmission efficiency and allow for a comprehensive evaluation of the tool's effectiveness in real-world scenarios.

In summary, the proposed tool's capabilities for real-time sensing and adaptive control enhance the network's efficiency and reliability, enabling it to better cope with dynamic operational conditions.

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