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Investigating Power-Aware Protocols for Wireless Sensor Network Durability

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Abstract- The paper reviews existing literature, analysing the strengths and limitations of different power-aware protocols deployed in WSNs. It explores how these protocols impact overall network durability, considering energy efficiency, communication overhead, and adaptability to dynamic environmental conditions. Furthermore, the research assesses the practical implications of implementing power-aware protocols in real-world scenarios, offering insights into their performance, reliability, and potential challenges. Case studies and experimental results are presented to illustrate the impact of these protocols on the longevity and sustained functionality of wireless sensor networks. The findings of this investigation contribute valuable knowledge to the field, offering guidance for researchers, engineers, and practitioners seeking to optimise power-aware protocols for prolonged durability in wireless sensor networks.

Keywords- Wireless Sensor Networks, Power-Aware Protocols, Energy Efficiency, Network Durability, Sensor Technologies

INTRODUCTION

A Wireless Sensor Network (WSN) is a wireless device that uses sensors. It autonomously works to monitor physical or environmental conditions such as light, heat, pressure, pollution, humidity, sound, noise degree, vibration, and movement of assets in different environments [1, 2]. WSNs use sensors to monitor physical and environmental conditions. These are wireless networks consisting of autonomous devices distributed depending on the location. These autonomous devices or sensor nodes (SN) combine with routers and a gateway to form a unique WSN system. Each node consists of a processing capacity (microcontroller), can contain multiple types of memory, contains a Radio Frequency (RF) transceiver and power supply (battery), and various sensors and actuators. Nodes communicate wirelessly and become self-organised after propagating in ad hoc mode. WSN systems can be said to be a revolution when looking at the way they live and work. A WSN system is an ideal application to provide a solution by spreading the findings to be obtained due to the physical conditions of the environment and climate measurements over the long term. Wireless sensors for utilities such as electricity and water grid streetlights offer low-cost methods by collecting healthy data to reduce energy use and better manage resources [3–5]. In addition, WSNs are used to monitor highways, bridges and tunnels effectively. A typical UCA consists of dozens of small but effective ADs that self-organise in wireless environments, provide interconnection and exchange data [6, 7]. With the advancement of technology, small, energy-consuming and multifunctional ADs have been developed. One of the most important problems encountered when designing UWA is energy waste. Energy waste can be seen as the soft belly of WSNs because the battery can run out at any moment.

Moreover, ADs, whose power source is a battery, have minimal energy. Therefore, preserving, maximising and saving this energy is the most critical issue in WSNs. Media Access Control (MAC, Medium Access Control) protocols have been developed to deal with this situation [8, 9] because the energy expenditures of ADs are also affected by the existence of the WSNs. Therefore, the most beneficial use of the energies of ADs is vital to the continuation of the tasks of the WSNs. Numerous studies have been conducted in the literature on efficient and effective energy use. The main purpose of this study is to contribute to the management of increasing energy efficiency.

WIRELESS SENSOR NETWORK

WSN consists of many distributed small ADs created to measure physical parameters such as temperature, pressure or relative humidity and monitor the system. ADs have limited computing power, memory capacity, and communication capability. WSNs are highly preferred because of their ease of use and ability to reach everywhere [10, 11]. Advances in wireless systems have made it possible to create low-cost, less energy-consuming, multifunctional small detection devices. Through thousands of tools mentioned above, ”ad-hoc” networks are occurring. These devices are scattered over an immense area, resulting in an ”ad-hoc” environment merger without a physical connection. The randomly placed “ad-hoc” and the sensor forming the network create a detection network system by cooperating [1, 8, 12]. Sensor networks make it possible to access data instantly and comfortably from anywhere. It performs these by performing various operations on the data. In this way, WSNs are used very effectively. UCAs can consist of many SNs that do not need maintenance and repair, do not require human intervention, and can work independently from each other Col- lectively. Even if the coverage area of only a single node is small, densely distributed SNs work simultaneously and on the principle of cooperation, thus extending the scope of the network [13].

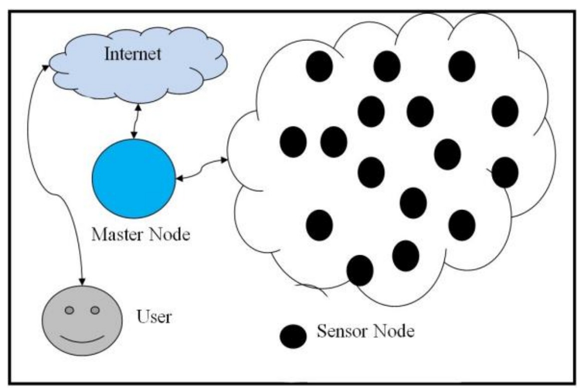

Figure 1. Wireless Sensor Network

A UCA architecture can be seen in Figure 1, in which SNs spread around the environment and create an automatic topology. ADs flow data to the main node (sink) and the base station via the gateway. The network infrastructure is directly connected to the application. SN’s large macro detectors provide excellent efficiency, unlike conventional sensor systems, because in traditional systems, cables have to be used until the user. That, if a macro sensor fails or its work is interrupted, While the sensor's function completely collapses in the area where the sensor is located in the traditional system, SNs continue to create data even if a small part of the micro-sensor in the same area fails; because fault tolerance is possible in SNs. In addition, each SN is built competently with wireless connectivity and hardware that is enough to transmit data with signal processing. Due to the limited energy, processing power and communication resources, it is essential to use many SNs for high efficiency regardless of the area [14, 15]. Assuming that the battery of an SN is depleted or broken, or another obstacle intervenes, or communication is interrupted due to this obstacle after the sensor network setup is made, other sensors sending or waiting for data to that SN will understand the situation and organise the reorganisation of the topology in that area. In other words, all information passing through the corrupted SN is redirected, and all connections with the broken SN are broken.

LITERATURE REVIEW

This literature survey aims to understand the MAC protocol's diverse and dynamic nature for energy-efficient sensor networks. Further, this literature survey also focuses on multichip and other routing protocols that benefit the longer network survival. A literature survey was conducted to recognise energy-efficient sensor network routing protocols. Finally, this literature survey identifies a recent research gap by analysing power-aware routing protocol. Shafiq et al.(2020) [1] proposed a novel Quorum time slot adaptive condensing (QTSAC)--based medium access control protocol is proposed for achieving delay minimisation and energy efficiency for wireless sensor networks (WSNs). The QTSAC protocol has two main innovations: One is the condensing of the Quorum time slot (QTS) to the data transmission period according to the characteristic of WSNs data transmission, which consequently prolongs the duty cycle of the nodes and reduces the network latency. The other is utilising the remaining energy in the area far from the sink to increase the QTS, prolong the duty cycle and reduce the network latency. The SO-grid Quorum system for condensed matrix QTS has also been designed and proposed in this work. Both theoretical analyses and experimental comparisons are carried out to evaluate the performance of the QTSAC protocol. The results demonstrate that it outperforms the existing protocols. More importantly, the QTSAC-based MAC protocol prolongs the network lifetime while dramatically reducing the network latency, which is not achieved by previous protocols. Thus, the QTSAC-based MAC protocol is of great significance.

Shao et al.(2018)[2] consider a hybrid framework that combines the advantages of wireless charging and solar energy harvesting technologies. The authors study a three-level network consisting of SNs, WNs and MCs levels. First, the authors study how to minimise the total cost of deploying a set of SNs. The solution is further improved using the intra-cluster Weiszfeld algorithm in continuous space. Second, the Author examines the network's energy balance and develops a distributed head re-selection algorithm to designate some WNs as cluster heads when solar energy is unavailable during rainy/cloudy days. Third, the Author focuses on optimising the joint tour to consist of wireless charging and data-gathering sites for the MCs. They proposed a linear-time algorithm that can approach the exact solution very closely and reduce at least 5% of MC's moving energy compared to previous solutions. The authors also propose partially refilling sensors' energy to reduce battery depletion further and develop an efficient algorithm to solve the problem with high accuracy. Finally, based on real weather data, the Author demonstrates through simulations the effectiveness and efficiency of the hybrid framework that can improve network performance significantly. Alabdali et al.(2021)[3] proposed a novel resource allocation solution for heterogeneous cognitive radio sensor networks (HCRSNs) has been proposed. The proposed solution assigns channels to spectrum sensors to maximise the channels' detected available time.

Furthermore, it efficiently allocates the available channels to the data sensors and the transmission time and power to prolong their lifetime. Extensive simulation results have demonstrated the optimality and efficiency of the proposed algorithms. The solution presented in this work enables the efficient use of primary network channels while adapting to the availability of harvested energy in real-time. It optimises the allocation of the scarce resources of battery-powered data sensors. This yields significantly higher spectral and energy-efficient HCRSNs. For future work, authors plan to investigate the channel allocation and routing protocol design in EH-aided multi-hop HCRSNs, considering the time-varying EH rate and the adaptive detection threshold of sensors.

Ozger et al.(2022)[4] present an energy-efficient scheme for reporting event packets to mobile nodes for data collection in the position-free network. The essential trait of the scheme is that it does not depend on global position system devices. Moreover, it considers four energy-saving techniques in selecting the next forwarding node downstream and leverages the transmission power adjustment capability of nodes upstream. Combining energy-saving techniques in calling the mobile node for data collection uniquely contributes to the EPR scheme. The performance of the EPR scheme is demonstrated by simulation. The results showed that EPR outperformed other existing schemes regarding power consumption, lifetime, packet delay, packet delivery ratio, and the number of packets sent into the network. The EPR can be implemented cheaply as it does not require GPS devices.

Moreover, it can operate longer since sensor nodes only utilise their energy to sense and report event packets to mobile nodes. This means the EPR scheme can support navigation operations longer than the existing schemes. Future research will explore the actual navigation strategy of mobile nodes in position-free hybrid wireless sensor networks. The EPR scheme will support single and multiple mobile node(s) navigation. Moreover, even though simulation results showed better performance for EPR, experimental analysis is necessary for validation, which remains an open issue.

Olatinwo et al.(2019)[5] proposed an implementation of cognitive sensor networks, where a cluster of unlicensed sensors opportunistically transmit their measurement samples to a common sink node by exploiting the vacancies of a shared channel. An adaptive framing policy is developed by assessing the impact of packet lengths on energy efficiency and information age. The idea is to regularise packet lengths for secondary nodes based on the sensing parameters (sensing rate alpha and the number of bits per sample N), communication parameters (the number of header bits per packet H, and channel rate Rch) as well as the current channel quality factors (channel utilisation process parameters by primary nodes u, v and channel error rate β). As a general trend, longer packets are desired for error-free channels since they improve energy efficiency by reducing the average header bits per sample. In erroneous channels, however, longer packets increase the packet discard rate. This proposed joint framing and scheduling policy can be used to implement a low-cost and optimised network of cognitive sensor networks for a wide range of applications with dynamic channel quality conditions and opportunistic access to shared channels. If the channel variation is much slower than the single packet transmission rate, this scheme can adaptively adjust the framing policy for time-varying shared channels.

Othman et al.(2012) [6] propose an analytical model for analysing the available energy in the network. The next step is to analyse the overall energy consumption as a k-median facility location problem, its solution corresponding to the location of k sinks in the network. This work revisited the energy consumption problem in wireless sensor networks through analytical investigation and formulation as a facility location problem. This work presents an analytical model. It is analytically demonstrated that when the sinks are placed according to the solution of the k-median problem, the overall energy consumption in the network is minimised (i.e., green use), thus allowing for subsequent network lifetime prolongation. The presented simulation results validate the proposed analytical model, thus revealing a significant gain concerning energy savings and network lifetime.

COMPARATIVE ANALYSIS

Comparative analysis of power-aware protocols is vital for understanding their efficacy in enhancing the durability of Wireless Sensor Networks (WSNs). Two prominent protocols, Protocol 1 and Protocol 2, are evaluated based on several key parameters. Protocol 1 prioritises energy-efficient routing mechanisms and employs data aggregation and sleep scheduling strategies to conserve power. In contrast, Protocol 2 focuses on dynamic power management techniques tailored to adapt to fluctuating network conditions. A critical examination of these protocols reveals nuanced differences in their approaches and performance. While Protocol 1 demonstrates robustness in scenarios with static node configurations and predictable traffic patterns, Protocol 2 excels in handling dynamic environments and mitigating the impact of node failures or environmental changes.

Moreover, comparative power consumption, reliability, and scalability assessments underscore the trade-offs inherent in protocol selection. Protocol 1 exhibits lower energy consumption per packet under specific conditions, leading to prolonged node lifetimes. In contrast, Protocol 2 showcases superior resilience and adaptability, particularly in large-scale deployments or volatile network environments. Ultimately, the choice between these protocols hinges on the specific requirements and constraints of the WSN application, emphasising the need for tailored solutions to optimise durability while balancing energy efficiency, reliability, and scalability.

DISCUSSION AND FINDINGS

The investigation into power-aware protocols for Wireless Sensor Network (WSN) durability yields several key findings and insights, which are pivotal for understanding and improving the performance of WSNs in various applications. Here's a discussion of the findings:

Energy Efficiency vs. Adaptability: One of the primary trade-offs observed in power-aware protocols is between energy efficiency and adaptability. Protocol 1, focusing on energy-efficient routing and conservative power management, demonstrates excellent performance in scenarios with static node configurations and predictable traffic patterns. In contrast, Protocol 2, with its dynamic power management techniques, excels in adapting to changing network conditions, making it more resilient and adaptable in dynamic or large-scale deployments.

Resilience to Node Failures and Environmental Changes: Protocol 2 showcases superior resilience to node failures and environmental changes due to its dynamic power management mechanisms. By dynamically adjusting power consumption based on network conditions, Protocol 2 can mitigate the impact of node failures or environmental changes, ensuring continuous operation and data integrity in volatile network environments.

Scalability and Network Dynamics: Another crucial aspect highlighted in the investigation is the scalability and adaptability of power-aware protocols to dynamic network topologies. Protocol 2 demonstrates better scalability by efficiently handling network expansions, contractions, or node mobility. This scalability is essential for accommodating the growing number of sensor nodes in large-scale deployments and ensuring seamless communication in dynamic environments.

Power Consumption Optimisation: The investigation reveals the importance of optimising power consumption to prolong node lifetimes and enhance overall network durability. While Protocol 1 may offer lower energy consumption per packet under certain conditions, Protocol 2's dynamic power management techniques contribute to prolonged node lifetimes and improved energy efficiency in dynamic environments.

Application-specific Considerations: It becomes evident that the choice between power-aware protocols depends heavily on the specific requirements and constraints of the WSN application. For applications with static node configurations and predictable traffic patterns, Protocol 1 may be more suitable due to its emphasis on energy efficiency. In contrast, applications operating in dynamic or volatile environments may benefit more from Protocol 2's adaptability and resilience.

CONCLUSION

The investigation into power-aware protocols for Wireless Sensor Network (WSN) durability underscores the critical role of efficient power management in prolonging network lifespan and enhancing overall performance. Through a comparative analysis of two prominent protocols, Protocol 1 and Protocol 2, it becomes evident that each offers distinct advantages and trade-offs. Protocol 1 prioritises energy-efficient routing and conservative power usage strategies, making it well-suited for scenarios with static node configurations and predictable traffic patterns. On the other hand, Protocol 2's dynamic power management techniques excel in adapting to fluctuating network conditions, bolstering resilience and adaptability, particularly in dynamic or large-scale deployments. Furthermore, evaluating power consumption, reliability, and scalability reveals the nuanced differences between these protocols, emphasising the importance of informed protocol selection based on specific application requirements. While

Protocol 1 may offer prolonged node lifetimes and lower energy consumption per packet under certain conditions, Protocol 2 demonstrates superior resilience and adaptability, which are crucial for mitigating the impact of node failures or environmental changes in volatile network environments.

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