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Wireless Sensor Networks and Role of ML in Energy Management in WSN

Rama Bhardwaj¹, Urooj Sultana²

Assistant Professor, Department of Computer Science Engineering, Vivekananda Institute of Technology,
Jaipur, India¹⁻²

ABSTRACT: WSNs are handy, cost-effective, and reliable. They are composed of spatially distributed autonomic devices that use sensors to detect temperature, sound, and other parameters. The majority of WSNs today are used for civilian purposes, including condition monitoring, health care, and traffic control. In addition, wireless sensor nodes can be used to detect the presence of vehicles in parking garages using magnetometers. Micro radars and magnetometers can also be used to track vehicles. With the increasing usage of WSN in all areas, it is important to overcome the security issues of WSN. Machine learning, a subset of artificial intelligence, relies on data-driven algorithms and statistical analysis to modify the behavior of computers. Beyond initial programming, this technology can cause machines to do things they were not designed to do, such as dynamically update routing tables in WSNs-IoT, localize nodes in mobile ones, identify and remove defective nodes for network improvement and forecast energy harvesting in EH-WSNs. This paper focuses on the usage of machine learning algorithms in optimizing energy in WSN.

KEYWORDS: WSN Security, Wireless Sensor Networks, Sensor Nodes, Blockchain

I. INTRODUCTION

A wireless sensor network consists of specialized transducers with a communications infrastructure for monitoring and recording conditions across a wide area. The most commonly monitored parameters are temperature, humidity, pressure, wind direction and speed, illumination intensity, vibration intensity, sound intensity, power-line voltage, chemical concentrations, pollutant levels, and vital body functions. Sensor networks consist of multipledetection stations called sensor nodes. Each sensor node is equipped with a transducer, a microcomputer, a transceiver, and battery power.

Microcomputers process and store the sensor output generated by the transducer based on sensed physical effects and phenomena. Sensor nodes are powered by batteries and receive commands from a central computer. Sensor networks (WSNs) are composed of finite sets of sensor devices geographically distributed in a given indoor or outdoor environment (usually predefined). They gather environmental data, and the locations of the nodes may not be known in advance. A network node can be in actual or logical communication with all devices; this communication determines a topology based on the application. For example, a WSN can have both mesh and star topologies. For some applications, this may not be the case. Logical topology is mainly defined by the nodes' logical roles (tasks, etc.). Depending on the network's resources, the strategy can be either ad hoc or strategy-based (self-organization, clustering, pheromone tracking, etc.).

When the processing power capacity of a network depends primarily on a single device, centralized formation techniques are appropriate. It also forwards the sensed information data to a sink node, which is responsible for processing, coordinating, and managing the sensed information activities. In the past two decades, Wireless Sensor Networks (WSNs) have been the subject of many studies. WSNs collect, process, and distribute wireless data to designated database storage centers. Because these sensors are usually installed at remote sites, despite the recent advances in WSN technology, their applications still face significant challenges. A number of these are concerned with network security, network architecture, data collection, deployment, and coverage.

II. RELATED WORK

Bhatti et al. (2022) investigated the potential of Wireless Sensor Networks (WSNs) with solar energy harvesters, driven by an identification of the intermittent nature of solar energy. To this end, they developed ML algorithms that enable nodes of such networks to accurately predict solar irradiance and accordingly manage their own energy usage.

Evaluating their models using datasets from California (USA) and Delhi (India), covering between 2010 and 2020, the researchers implemented data pre-processing, feature engineering, outlier identification and grid search to determine the most optimized model. Comparison with a linear regression model has revealed that a Support Vector Regression (SVR) provided more accurate forecasting results. Moreover, relatively short periods were found to have much better outcomes than longer ones; for instance, Sacramento's Root Square Mean Error (RMSE) and Mean Absolute Error (MAE) with 1 year/month intervals were lower than 7%, respectively.

Mody, S., et al. (2021). Wireless Sensor Networks (WSNs) employ a group of sensors linked via a wireless network, distributed across different clusters with a single cluster head assigned to collect and send data back to the base station. The nodes are responsible for activities such as capturing, processing and transmitting data, all of which deplete energy quickly. Since these nodes are usually situated in remote locations where humans can't reach them easily, battery life is an important factor to consider in WSNs. This paper proposes the K-Means Energy Efficient Cluster Head Selection Algorithm (KE-CHSA), incorporating machine learning to create clusters and select cluster heads. An equation has been proposed that dynamically adjusts the number of clusters based on the number of active sensor nodes and a density parameter. Our algorithm decides on the most suitable node to serve as the cluster head taking into account both energy remaining and distance from other nodes resulting in improved lifespan of WSNs when compared to traditional LEACH or C-LEACH.

Okeke and Musa (2021) extensively studied the various concepts of condition and energy monitoring systems in manufacturing facilities related to enhancing the decision-making processes in industries. The utilization of Internet of Things (IoT) communication networks has further enabled machine connectivity for real time data, thus improving energy usage and condition monitoring for sustainable management. In their paper, they demonstrate the capability of their system to quickly ascertain the operational status of machines, with maintenance predictions being sent through user interface application Node-RED dashboards and Python Shell environment. Moreover, they integrated a portable and scalable wireless sensor network using IEEE 802.15.4e protocol with Machine Learning algorithm to evaluate anomalies detected in the condition and energy sensor datasets; this supervised learning model displayed an accuracy rate of 99.16% .

Roy, S., et al. (2021) proposed Software Defined Wireless Sensor Networks (SD-WSN), a promising paradigm in wireless communication that grants high flexibility in network management. The SDN controller has a centralized global view of the network, hence making it an ideal choice for data sensing in dynamic sensing environments. An adaptive topology control approach based on reinforcement learning (RL) (Roy et al., IEEE CCNC 2020) was introduced with mobility to incorporate various network objectives such as data delivery, latency, and energy efficiency. It was found that erratic mobility can strongly impact the learning of the RL module and lead to poor quality of service; thus, we came up with a customized simulation environment to capture performance variations in the proposed framework. To overcome this problem, we presented an alternative approach utilizing supervised machine learning which can detect periodic mobility and reduce its ill-effects.

III. ENERGY ISSUES IN WSN

This section focuses on energy management when designing or developing an algorithm for WSNs. Generally, a sensor network consists of connected sensor nodes that communicate via wireless protocol. This network typically includes different nodes with various capabilities (memory size, battery capacity, processor speed). For example, the ZigBee communication protocol contains three types of nodes: coordinator, router, and end-device. A single coordinator is mandatory to initiate and manage the WSN, while multiple routers are required to forward sensed data in the system by multihop communication. Additionally, a large number of end- devices might operate in the sleep mode. The importance of studying the field of energy management in order to minimize the power consumption for sensor networks is informed by the different levels of energy consumption derived from the type of sensor node employed. In terms of energy management, both energy consumption and energy provision need to be taken into account. Energy consumption relates to activities such as transmission, reception, and data processing that expend energy, while energy provision looks at various methods that can be utilized to provide sensor nodes with a reliable source of energy so they can remain operational for a long period.

Energy provision can be divided into three categories: battery-driven, transference, and harvesting. Batteries used for powering the sensor nodes may be replaceable, fixed, or rechargeable. When it comes to transference, microwaves and radio frequency energy can be used to transfer power from a source to the destination. Lastly, harvesting methods such

as solar, wind, and thermal energy can also provide energy for the sensor node [4]. Efficient energy management schemes have been designed and implemented to conserve the limited energy available for each sensor node. In order for sensor nodes to operate for as long as possible, energy management involves reducing their onboard energy usage. Based on the literature available, it is important to categorize energy management schemes into following categories. Schemes for managing batteries: To maximize the lifetime of sensor nodes, battery management utilizes the internal characteristics of batteries to evoke their charge. This section examines battery management schemes from two different perspectives: node energy management and energy balancing. Using node energy management, sensor nodes can be operated permanently in a wireless network. Dynamic Power Management (DPM) is a power management strategy for wireless networks, which establishes sleep and active modes. With the help of a micro-operating embedded system, DPM minimizes the energy consumption for each sensor node. Additionally, several research works have focused on the DPM as a way to maximize WSN throughput by reducing the energy consumption per sensor node. Energy balancing schemes, on the other hand, achieve a balance between the generation of energy and the consumption of it. For longer WSN lifetimes, efficient and balanced power consumption is crucial.

Schemes for managing transmission power: Compared to the other modules on a sensor node, data transmission consumes the most power. A transmission power management scheme can be classified into three main categories: Medium Access Control (MAC) layer management, routing policies, etc. As the bottom segment protocol for network communication in WSNs, the MAC protocol is used for MAC layer management schemes in order to minimize the power

consumption of sensor nodes. Several research works have explored the divergent MAC protocols for enormous applications of WSNs. The routing protocols on the other hand aim to create the best link between the source node and the destination node, without compromising some major performance characteristics. In order to forward data in WSN to reach its destination or sink node, several routing protocols and systems have been developed and implemented.

Schemes for system management: Power and device management strategies are employed in the processor unit to manage system power. The substantial drop in power consumption enables efficient hardware design. Moreover, some other features such as turning off the sensor node during idle situations or operating in power-saving mode may further minimize the power consumption. Power management and device management are part of the system management schemes. The processor power management strategy seeks to reduce the processor's power consumption by minimizing the number of executed commands and calculations. Several studies have explored various means of implementing this, such as utilizing a power saving mode for lessening a sensor node's energy usage in a WSN. Different parameters like the processor clock speed may also affect how much electricity is consumed. Using intelligent mobile sensor nodes, power management can be made more efficient. Design and development of the sensor node hardware have been proposed, which minimizes energy consumption. This technology features an operating system that adjusts the power usage based on the energy requirements of the node. There have been many device management systems proposed for WSNs with various features and results.

IV. MACHINE LEARNING FOR ENERGY MANAGEMENT IN WSN

Cluster heads are used to transmit data from sensor nodes to sink nodes in Wireless Sensor Networks (WSN). The emergence of new technologies has led to its widespread use in a wide range of applications, including habitat monitoring, health science, border surveillance, etc.. There are several issues in WSN such as Quality of Service (QoS), localization, routing and data aggregation. Sensor nodes have limited energy, so it is important to increase energy efficiency throughout the network. This paper examines two mechanisms of energy efficiency: energy consumption and energy harvesting [8] Energy consumption can be reduced through various Machine Learning (ML) techniques as well as energy harvesting. The latter provides two additional sources, namely an ambient source and an external source. Ambient sources involve renewable resources such as radio frequency, solar, thermal and flow-based energy harvesting. To elaborate, radio waves are transformed into electrical signals with radio frequency; solar rays become electrical signals with the solar mechanism; heat energy is converted to electrical energy by thermal mechanisms; and rotatory motion is changed into electric signal via flow techniques. Energy harvesting from external sources consists of mechanical and human methods. By applying ML techniques in energy efficient parameters, energy consumption across the network is reduced. These two mechanisms increase the energy efficiency parameter and network lifetime by using ML.



V. CONCLUSION

The energy efficiency is a key factor in the design of routing protocols for wireless sensor networks, as it will directly impact the life-time of each sensor node. Moreover, data-centric routing may be employed in order to prevent local optimum and uneven node energy consumption. To achieve an energy balanced routing in the required areas, machine learning algorithms can be used. By combining wireless sensor network nodes and energy factors based on ML algorithms, we can improve performance, network life cycle, energy distribution, node equilibrium, network delay and energy consumption.

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