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Research Article

Impact and Significance of Wireless Sensor Network in Health Care: A Systematic Analysis

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ABSTRACT

Wireless Sensor Networks (WSNs) have been used in various fields to monitor and collect data by connecting several nodes. This systematic review investigates the role and potential of WSNs in various fields such as environmental sensing, health care, manufacturing, and smart city. In comparison to wired networks, WSNs offer higher scalability, flexibility, and cost-effectiveness. Some of the areas that have been affected positively include; accuracy in data collection and gathering, response to events of importance, and efficiency in energy usage. Beyond this, the importance of WSNs is also in their suitability for enabling more complex applications such as IoT, as well as in their capacity to enable heterogeneity and integration between different devices. This analysis gives the recent developments in WSN technologies like low power communication protocols, security and robustness, and network management that improve the effectiveness of WSNs. This research also reveals some limitations, such as a lack of power, data privacy, and the absence of standards. The systematic analysis highlights the importance of WSNs in the enhancement of technology solutions, innovation, and handling of emerging issues in different fields.

Keywords: Energy consumption, security, heterogeneity, WSN, sensing, significance, and communication protocol.

1. INTRODUCTION

Recent developments in wireless networking, micro-fabrication and integration, and embedded microprocessors provide mass production of various WSNs that are highly viable and comply with every military requirement [1]. This expertise has the high potential to transform our lifestyle and deal with the living space. There is anticipation for small, affordable sensors that could be attached to roads, walls, house appliances, home appliances, and machines to create a digital covering. It detects a range of exciting physical activities like monitoring pedestrian/vehicle traffic in populated human surroundings and intelligent transportation grids, monitoring animal movements in the wild for environmental conservation, sensing forest fires to act immediately, and tracking work flow and supply chains in smart factories [2].

When compared to the new data facilities like the ones available on the internet, which store the data and turn them musty with no purpose, the WSNs assure us by bringing the users into direct contact with the sensor dimensions, thereby offering precise information in terms of when and where based on the user's requirements. Likewise, a WSN node depends on resource restraints like finite onboard battery power and restricted network communication bandwidth [3].

WSN is among the many wireless networks available, and it constitutes an enormous volume of circulated, self-directed, tiny, lowpowered devices called Sensor Nodes (SN). They are geographically spread, tiny, functioning on battery power, embedded devices so that the networks gather information with care, process it, and send it to the operators. They have measured the abilities of computing and processing. Miniature systems called ―nodes‖ constitute the networks [4]. A versatile SN is also an energysaving wireless device. Motes applications are quite popular in industries. A set of SNs gathers the information around them to achieve their goals. Transceivers are employed for the motes to communicate with one another. In a WSN, motes can range from a few hundred to a few thousand [5, 6]. When compared with SNs, ad hoc networks possess a minimal node's Storage Area Network (SAN) architecture [7].

For continuous monitoring, event ID, detection, and local control of actuators are, SNs are required. WSNs sometimes have various kinds, such as low sampling rate, seismic, magnetic, thermal, visual, infrared, radar, and acoustic. They are highly efficient in monitoring numerous known conditions. WSN technologies are highly advantageous with low installation costs, support distant communication, are user-friendly with the latest information, and are functionally optimal. Instead of being just time-based, they can also be event-based. This method is generally considered competent. Data obtained from sensors can be immediately joined with other data, like localization. There are also the possibility of having programs that are preemptive and practical [8]. In remote areas without any human habitation, WSNs can be installed as they are WSN enables quicker connection, commission, and reconfiguration. When it comes to performance ability, moving is the most significant aspect of WSN. For industries and commercial enterprises, the biggest hurdle is the cost involved in the installation.

The set up cost, maintenance, and reconfiguration in expensive projects are very economical. There are various sensor networks like seismic, low sampling rate magnetic, thermal, visual, infrared, acoustic, and radar [9]. These networks can oversee a range of changing settings like temperature, humidity, vehicular traffic, lightning conditions, pressure, soil composition, noise levels, the presence or absence of particular objects, mechanical stress levels of attached objects, and modern features like speed, direction, and object dimensions. Even though WSNs were first used for military activities like enemy movement detection, they are also used in day-to-day operations. They are also used to keep an eye on things like vanishing species, farming details, disasters, health and well-being, home appliances, making a safe and secure eco-system, giving advice, and more [10].

2. Taxonomy of Energy-Efficient Techniques

Five essential types of energy-efficient techniques have been identified. Data reduction, overhead protocol reduction, energy-efficient routing, duty cycling, and topology control [11, 12].

- Data Reduction: This aims to minimize information collection, processing, and transmission, for example, information reduction and collection.
- Protocol Overhead Reduction: Here, the focus is to enhance the quality of the technique by minimizing the overhead. This involves various methods. The time for transmitting information is revised according to how stable the network could be or the space between the target and source. Usually, an optimum communication method is possible because of a cross-layering approach considering the application needs. One more process called ―optimized flooding‖ could considerably reduce overhead.
- Energy-Efficient Routing: Increasing the shelf life has been the focus while designing routing protocols with less Energy Consumption (EC) during the back-and-forth data transmission while ignoring nodes with less residual energy. Specific methods do not miss the opportunity. They use the agility of nodes or the broadcasting feature of wireless communications to minimize energy costs during the broadcast to the sink. Some utilize the location details of nodes to build a path to the target node. At the same time, some create ranking nodes for ease of routing and to minimize overhead. Ultimately, the information-centric methods transmit information only too willing nodes to spare idle transmissions.
- Duty Cycling: It is the segment of time nodes that are lively in their lifetime. The docile/live pattern of nodes has to be synchronized and adjusted for the particular needs of applications. The above-said methodologies could still be subcategorized. High granularity methods aim to choose live nodes from among many sensors used in the network. While low granularity methods switch the radio of active nodes ON/OFF state when no transmission is required (similarly, if communication with that specific node is possible), they are mostly linked to the MAC protocol.
- Topology Control: Here, the attention is to minimize energy cost by altering transmit power without any change in the network connection. A novel minimized topology is generated according to the based-on data from the neighborhood-the class of energy-efficient methods managing energy loss.

3. Routing Challenges in WSN

The important aim of WSN in terms of design is to set up information transmission to happen in parallel, continuing the network's life and avoiding a downfall in connection by using energy control methods [13]. Despite various

WSN applications, the networks possess too many limitations, e.g., local energy sources, restricted computing power, and reduced bandwidth of the wireless links connecting SNs. There are some things that need to be thought about very sensibly when creating an optimized routing protocol [14, 15].

- Node Deployment: Using nodes in WSN is based on application and influences the efficiency of the routing protocol. The inclusion of nodes is either predetermined or random. In the predetermined case, the sensors are physically transferred, and information is directed via predetermined routes. In the random method, the nodes are dispersed arbitrarily, creating an ad hoc infrastructure. Because of this, there are a lot of things that need to be looked at because of the random process, such as coverage, optimal clustering, and so on.
- Energy Cost with No Loss in Accuracy: The restricted-energy in the SN can perform functions and transmit data in a wireless medium. In general, various means of energy-saving in communication and computation are essential. The life of the SN lifetime has a firm reliance on the battery shelf life. When it comes to multi-hop WSN, every node functions as a second task as a data transmitter and router. Defects in individual SNs because of no power could lead to drastic alterations in topology and may require routing packets once again in one more organization.
- Node/Link Heterogeneity: Certain WSN applications may need various SNs constituting different kinds of abilities that could be used. Each sensor generates data at an unprecedented rate. The network could choose any information-dispensing model and has the chance to face a range of QoS restrictions. This kind of mixed surroundings enables the routing of a complex one.
- Fault Tolerance: Certain SNs get lost/stopped because of unavailability of power, some device failures, or intrusions from the neighborhood. The downfall of SNs need not influence the entire mission of the WSN. If more nodes are lost, MAC and routing protocols must adjust new links and paths for the information gathering BS. If you want to keep energy costs down and send data packets through network zones that have much energy, you might have to control transmit power and signaling rates on the most common links very aggressively. Hence, numerous levels of redundancy may be required in a fault-tolerant WSN.
- Scalability: There might be 100 Sec to1000 Sec of SNs used in the zone. With this test number of nodes, all types of routings should work. Besides, we can also expand the routing process for attending the happenings in the neighborhood. Almost all sensors stay inert, with information from some leftover sensors offering a rough service unless something comes up.
- Network Dynamics: The majority of the network frameworks consider the SNs immobile. But the agility of the BS and SNs is, at times, necessary in many applications. Routed data from and toward mobile nodes are very tough when the routes become unstable, which is vital apart from other factors like energy, bandwidth, etc. Also, the concept of sense could be mobile/immobile based on the application. For example, in the case of locating a target, it is mobile, and for monitoring purposes, it is standing. Intensive observation of fixed procedures enables the network to perform in a responsive situation by creating more signals during the report. Current actions in the majority of applications need regular reports. Accordingly, a sufficient message is designed for routing to the BS.
- Transmission Media: In a multi-hop WSN, nodes that communicate are connected via cordless media. The cordless method is always associated with severe issues like diminishing, excess fault rate, etc. At times, this can also influence the functioning of the network. As a rule of thumb, the transmitting energy is directly proportional to the square of the distance; the apt network for energy conservation is a multi-hop network. Yet, many problems are created by the multi-hop network concerning the topology handling and controlling media usage. One mode of MAC design for WSNs uses CSMA-CA type procedures of IEEE 802.15.4 that save more energy than the contention-based procedures like CSMA (e.g., IEEE802.11). Hence, Zigbee, designed according to the IEEE 802.15.4 Low-power wide-area networks (LWPAN) technique, is presented to solve the problems.
- Connectivity: Radio signal reach is responsible for the WSN. The link is erratic when the WSN is suspended frequently and irregularly when the nodes are infrequently

within the communication signal range of the rest of the nodes. There is network connectivity only when there is uninterrupted multi-hop connectivity between any two nodes.

- Coverage: When it comes to coverage of the WSN node, it is either sensing or communication. Whether there is very little coverage of only some places or extensive coverage of the entire place, when the range is completed, there are several SN in the zone. Stereotypically, in radio communications, the range is suggestively more prominent than the sensing coverage. For an incident to be located in applications, a reliable assurance is given by the sensing coverage.
- Data Aggregation: Idle information is commonly formed by SN. For the sake of minimizing the transmitted counts, the same types of packets sent by different nodes could be collected. Combining information from various places based on a particular collection criterion is called ―data aggregation‖. Data aggregation is included in the routing procedures to minimize the data inflow from different places, thereby saving energy. On the other hand, it increases the intricacies and difficulties of incorporating the security methods into the protocol.

4. Comprehensive Analysis of WSN

Whatever the application, energy is the primary criterion. With a restricted timeframe, sensor batteries cannot get recharged, and hence, it is an expensive choice. Several trials to augment the timeline have been conducted via hardware-based solutions that were a failure. The major part of the energy is used for transmitting information/forwarding packets to the rest of the nodes. The energy cost can be reduced at the network level by effective routing and reliable communication among nodes [16]. Specific nodes regularly participate in sending data in the prevailing models, resulting in energy dissipation amid nodes and leading to nodes dead in beforehand, disconnecting connectivity in the network. With the limited energy situation in the nodes, it is necessary to make sure that the battery power is widely used to prolong the network shelf life. Therefore, energy-saving procedures are needed.

Energy conservation could be accomplished in two possibilities: (i) using procedures designed with minimal steps to consume less energy, and (ii) balancing the energy costs in multiple network devices. Preferably, every node present in the network must have a similar time frame, (ii) or else truncated portions of the network could exhaust quickly, disconnecting the network. When some critical portions of the network dry out of battery, it leads to faulty functioning throughout the network, even if the rest has some energy left [17, 18].

The near-optimal heuristic algorithm is based on backtracking (Pawan Singh Mehra 2021), which uses memorization to spurn the suboptimal schedules. These algorithms reduce the energy expenditure in each timeslot while avoiding revisiting the same timeslot [19].

A Fuzzy C-Mean Clustering (FCM) algorithm (Aqeel K Kadhim 2021) is one of the important methods adopted in the clustering field. Voronoi diagram method is contributed with FCM method to decrease the intra-clustering distance. Decision Tree Algorithm (DTA) is also a helpful technique for selecting high-specification SN a CH. This variety of algorithms and methods will have given impetus to progress network status and has an effective influence on the decreasing of consumed energy and increasing of network efficiency [20].

Due to battery drainage issues of the SN-WSN having a restricted network lifetime. An efficient way to increase the network lifetime of WSN is clustering, i.e., to group the SN of the whole network into the number of clusters, but it gives birth to a hot-spot problem. Unequal clustering is the best result to overcome such problems, in which SNs are grouped into clusters of unequal sizes, and the size varies according to the CH distance from the BS (Jatinder Pal Singh et al.2020) [21].

UDCH (Fang Zhu et al.2019) protocol aims to solve the challenges of high EC and unbalanced energy. It adopts unequal clustering technology to resolve the hot spots problem, in which the CH selection method and cluster size calculation method are improved [22].

Table 1: Systematic Analysis of WSN

Reference	Year and Author	Technique Used	Inference	Drawback
23.	2023, Kim et al.	Machine Learning-Based Congestion Control	Improved QoS and network lifetime through adaptive learning algorithms	High computational overhead
24.	2023, Zhang et al.	Energy-Efficient MAC Protocol	Enhanced energy efficiency and reduced delay	Complex implementation and high setup cost
25.	2022, Singh et al.	Fuzzy Logic-Based Congestion Control	Improved packet delivery ratio and network throughput	Requires fine-tuning of fuzzy rules
26.	2022, Wang et al.	Game Theory-Based Congestion Control	Balanced load distribution and improved network reliability	Complexity in strategy formulation
27.	2022, Patel et al.	Hybrid Congestion Control Scheme	Enhanced performance under variable network conditions	Increased system complexity
28.	2021, Lee et al.	Blockchain-Based Congestion Control	Secure and reliable data transmission	High energy consumption due to blockchain operations
29.	2021, Ahmed et al.	SDN-Based Congestion Management	Improved flexibility and efficient resource utilization	SDN controller bottleneck
30.	2021, Kumar et al.	Cross-Layer Congestion Control	Optimized network resources and reduced latency	Cross-layer dependencies can lead to complex debugging
31.	2020, Liu et al.	AI-Driven Congestion Control	Adaptive and intelligent routing for congestion mitigation	High training time for AI models
32.	2020, Gupta et al.	Bio-Inspired Congestion Control	Enhanced network resilience and fault tolerance	Limited by the computational power of sensor nodes
33.	2020, Hassan et al.	Adaptive Rate Contro	Dynamically adjusted data rates based on real-time congestion levels	Potentially high control message overhead
34.	2019, Chen et al.	Cluster-Based Congestion Control	Improved energy efficiency and network stability	Cluster head selection overhead
35.	2019, Park et al.	Context-Aware Congestion Control	Enhanced context-awareness leading to improved QoS	Context extraction and processing overhead
36.	2019, Reddy et al.	Priority-Based Congestion Control	Prioritized critical data transmission with improved reliability	May lead to starvation of lower priority packets
37.	2018, Ali et al.	Trust-Based Congestion Control	Improved security and reduced packet loss	Trust evaluation complexity
38.	2018, Zhao et al.	IoT-Based Congestion Control	Enhanced integration with IoT devices for better congestion management	High implementation complexity
39.	2018, Sun et al.	Real-Time	Improved real-time	High synchronization

		Congestion Control	data transmission performance	overhead
40.	2017, Brown et al.	Multi-Path Congestion Contro	Load balancing and improved fault tolerance	Increased path discovery overhead
41.	2017, Tang et al.	Cognitive Radio-Based Congestion Control	Efficient spectrum utilization and reduced congestion	Complex spectrum sensing requirements
42.	2017, Gao et al.	Delay-Tolerant Congestion Control	Improved performance in delay-tolerant applications	Limited applicability to real-time scenarios
43.	2016, White et al.	Heuristic-Based Congestion Control	Efficient heuristic solutions for dynamic congestion scenarios	Heuristic algorithms may not always provide optimal solutions
44.	2016, Xu et al.	Reinforcement Learning-Based Control	Self-adaptive and optimized congestion management through learning	Long convergence time for learning algorithms
45.	2016, Patel et al.	Swarm Intelligence-Based Control	Enhanced distributed decision-making for congestion management	High computational overhead
46.	2015, Li et al.	Geographic Routing-Based Control	Improved routing efficiency and reduced congestion	High dependency on accurate location information
47.	2015, Das et al.	Probabilistic Congestion Control	Reduced packet loss and improved network throughput	Complexity in probability calculation

5. CONCLUSION

This systematic analysis has comprehensively examined the impact and significance of wireless sensor networks (WSNs) with a focus on congestion and energy consumption. Our findings underscore the critical implications of these factors across various application domains. Congestion in WSNs can severely degrade network performance, leading to increased packet loss, latency, and reduced reliability. Moreover, congestion management techniques such as routing protocols and scheduling algorithms play pivotal roles in mitigating these effects. Energy consumption emerges as another pivotal concern, influencing network lifetime and operational sustainability. Efficient energy management strategies, including duty cycling, data aggregation, and energy-aware routing, are crucial for prolonging sensor node lifespan and enhancing network longevity. By synthesizing current research trends and methodologies, this analysis provides valuable insights for researchers and practitioners aiming to optimize WSN performance under real-world conditions. Addressing these challenges effectively promises to advance the deployment and utilization of WSNs across diverse applications, from environmental monitoring to smart healthcare systems, ensuring their continued relevance and effectiveness in the era of ubiquitous sensing technologies.

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