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Wireless Sensor Network Technology and Networking Algorithms for Wireless Sensor Network Applications: A Survey

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Abstract: ***Recent advances in the electronics technologies results into revolutionary developments in fields of science and technology. Due to relentless efforts of scientists and technologists the fields such as Embedded Technology, Integration technology, communication technology, smart sensor design technology etc are pervasively growing and evolving innovative fields for research and developments. On confluence of embedded technology and communication technology with computer technology, a novel field called Wireless Sensor Network is emerged. Wireless sensor network provides new paradigm for sensing and disseminating information from various environments with a great potential to serve many and diverse applications. The monitoring of various physical parameters such as temperature, fluid level, relative humidity, intensity of light, concentration of gasses dissolved in the atmosphere, vibrations, strain, soil moisture, industrial process parameters, pH and salinity of water etc plays commendable role in various sectors such as environmental pollution monitoring, high-tech agriculture, structural engineering, chemical and physical industries, transportation, military and defense, healthcare, forestry etc. The WSN is the network of smart sensor nodes, wherein the standard protocols such as Zigbee, Bluetooth, wifi, GSM etc technologies are employed to establish the RF communication. The distributed sensor nodes must be routed in the network to ensure cooperative collection of the data. Different routing protocols have been studied for their suitability to use in the WSN. It is found that, to establish the WSN, different routing protocols have been reported. Therefore, in present paper wireless sensor network technology and networking algorithms used in wireless sensor network for diverse applications are discussed.***
Keywords- Wireless Sensor Node, Wireless Sensor Networks, Network Protocols, Base Station.

I. INTRODUCTION

Recent advances in the electronics technologies results into revolutionary developments in fields of science and technology. Due to relentless efforts of scientists and technologists the fields such as Embedded Technology, Integration technology, communication technology, smart sensor design technology etc are pervasively growing and evolving innovative fields for research and developments [1-2]. On confluence of embedded technology and communication technology with computer technology, a novel field called Wireless Sensor Network is emerged [3]. Wireless sensor network provides new paradigm for sensing and disseminating information from various environments with a great potential to serve many and diverse applications [4]. The monitoring of various physical parameters such as temperature, fluid level, relative humidity, intensity of light, concentration of gasses dissolved in the atmosphere, vibrations, strain, soil moisture, industrial process parameters, pH and salinity of water etc plays commendable role in various sectors such as environmental pollution monitoring, high-tech agriculture, structural engineering, chemical and physical industries, transportation, military and defense, healthcare, forestry etc [5-9]. These physico-chemical parameters are depicting Site Specific Variability (SSV) and monitoring of such widely distributed parameters is challenging task. During early days, the wired networks have been deployed for monitoring of such parameters. However, the wired networks are not only infeasible for typical environment but also shows high cost, hardware complexity, hard to debug and upgrade. The wireless sensor network provides suitable solution to overcome the limitations of the wired system. The WSN is the application specific establishment of smart sensor nodes. The sensor nodes are systematically distributed over a geographical area of interest. The sensor nodes are intelligent and have capabilities such as sensing of physical environment, signal processing and wireless communication. Recently, an embedded technology, wherein smart devices such as microcontrollers of promising features are deployed as computing unit, helps to enhance the intelligence of the sensor nodes. Therefore, it becomes possible to design the intelligent, autonomous and energy efficient sensor nodes to facilitate the desired WSN. Moreover, dramatic reduction in the cost of design and deployment the WSN shows wide

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spectrum of applications. Deployment of advanced microcontrollers helps to design the sensor nodes of high preciseness and great reliability in assimilating and disseminating the data of spatio-temporal variance [10]. On extensive study of the literature and survey of the industries, such as Sugar industry, Alcohol industry, Textile industry, milk processing, food processing industry, paper and pulp making industries etc, it is found that, the sophisticated industries are demanding an electronic system of a great preciseness and reliability to monitor and control the various parameters. Typical industries such as power generation plants are availing DCS or SCADA systems of networking to collect the information of the parameters. However, these are wired networks. Such architecture depicts the complexity in the hardware and hence hard to debug the faults. Moreover, the power consumption and power loss is also significantly high. To overcome the problems of wired networking and to ensure sophistication in data collection and dissemination, the industries are demanding Wireless Sensor Network.

II. REVIEW OF LITERATURE

Indeed, the Wireless Sensor Network (WSN) is an emerging field of electronics, ensuring research of applied nature. The salient features of wireless sensor network motivate to undertake the research work in this field. According to the architecture, the wireless sensor network (WSN) consists of a thousands of self-organizing, lightweight sensor nodes, which are used to monitor physical or environmental conditions. Normally, the parameters considered for monitoring include temperature, sound, humidity, vibration, pressure, gases, motion etc [11]. Each sensor node in a WSN is equipped with a RF module, an array of sensors, a battery unit and a Central Processing Unit (CPU). Although, research in the field of WSN was initially motivated by military applications. Now days, it is deserving a key position in many industrial and public service areas including traffic monitoring, weather conditions monitoring, video surveillance, industrial automation and healthcare applications [12]. The node communicates wirelessly and self organize after being deployed in an ad hoc network. The WSN realizes the deployment of IEEE 802.15.4 standard for wireless communication. The Zigbee technology is playing vital role in establishment of WSN for dedicated applications. Currently, wireless sensor networks are widely deployed in diverse areas. It is expected that, within few years the world may be connected with wireless sensor network and provides accession with the internet, to realize the concept of Internet of Things (IOT) [13-15]. In establishment of WSN, the nodes are autonomously operating at remote places. Therefore, the minimizing the power consumption is one of the key issues [16]. Therefore, precise and low power nodes are required for development of wireless sensor network. In facts, the nodes can be designed with microcontrollers of prominent features. The features of the nodes vary with the designing issues of hardware and firmware. Therefore, designing of nodes of prominent features is one of the challenging jobs. Therefore, many

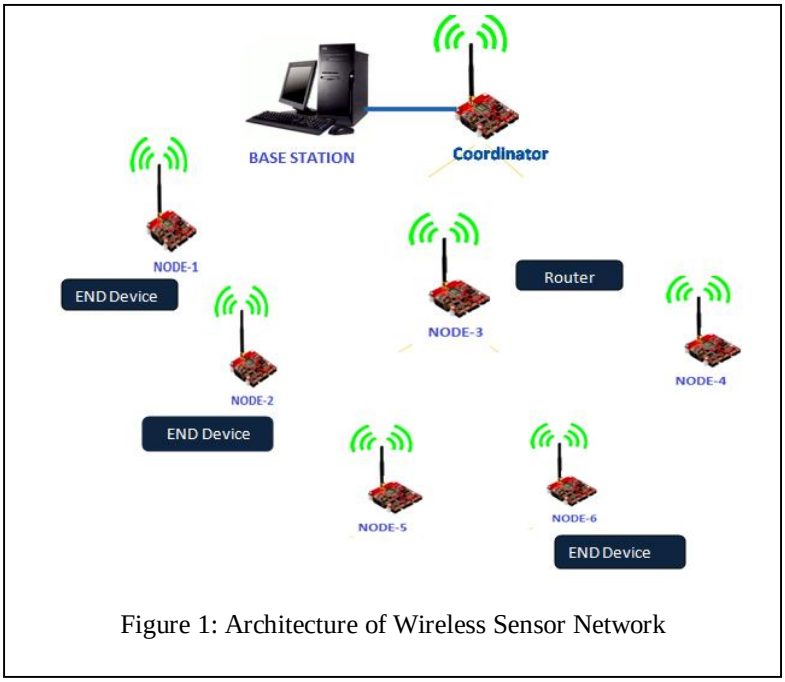


Figure 1: Architecture of Wireless Sensor Network

researchers are exhibiting significant interest in developing wireless sensor node and wireless sensor network for dedicated applications.

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III. WIRELESS SENSOR NETWORKS (WSN)

A. Introduction

Wireless Sensor Network (WSN) is the realization of confluence of sophisticated electronics technologies with information technology [17]. It is the establishment of distributed devices linked with wireless means [18]. The WSN is an innovative field and depicts wide spectrum of applications in diverse sectors. Recently, the Site Specific Data Management (SSDM) is challenging task, wherein data depicts the spacio-temporal variations. For collection and processing of such data, the WSN is most suitable. Therefore, WSN plays commendable role in agricultural, military, defense, environmental protection, infrastructural monitoring, domestic appliances etc fields [19-25]. Now days, the Wireless Sensor Network also deployed to facilitate the industrial processes. The Wireless Sensor Network (WSN) may be described as the collection of nodes organized into co-operative network. Due its salient features, the WSN is becoming significant area of research of global relevance. Due to their several popular applications, efficient design and implementation, wireless sensor networks [26-27] have become an area of current research. Sensing, processing and communication are key elements, whose combination in one tiny device gives rise to a vast number of remote sensing applications [28-29]. The Sensor Nodes in a WSN operate with small and limited battery power and usually non-renewable resource. Since communication among nodes consumes most of the energy [30], it is important to design the network with less communication among the nodes to estimate the required parameter vector.

The revolutionary field, Wireless Sensor Network (WSN) is playing vital role in the development of an electronic instrumentation, particularly for monitoring and control of industrial as well as environmental parameters. A sensor node consists of microcontroller as a computing unit, which performs manipulation and administration. A radio transceiver is used to transmit and receive data packets, whose contents depend upon type of sensor and network topology [31]. The important factor in designing of the sensor network is the reduction of the cost of the node without compromise in the performance. Due to low cost of the nodes the denser deployment can be ensured. Recently, to establish a wireless sensor network, the use of Zigbee technology is suggested [32]. Moreover, IEEE has also laid down the standards, IEEE802.15.4 standards for WSN [33] and allowed to works at 2.4 GHz of ISM frequency band. A significant research and development is going on for designing of robust and effective wireless sensor network with promising routing protocols. The researchers are putting significant contribution to enhance the features of WSN. Extensive research work is going on to minimize power consumption and hence to increase a node`s lifetime. The deployment of microcontrollers of promising features or configurable devices such as PSoC or CSoC, may results into not only miniaturization but also reduction of power consumption. Thus, for development of present WSN, along with an embedded technology, the fundamentals of Zigbee technology and IEEE 802.15.4 standards have been intensively studied and briefly presented in this report.

B. An Architecture Of Wireless Sensor Network (Wsn)

Wireless sensor network (WSN) is the distributed network of large number of wirelessly connected autonomous devices, called Wireless Sensor Nodes, which collaboratively collects the information about physical world and disseminates the same towards the monitoring stations called Base Station (BS) for the deterministic analysis and presentation [34-37]. The general architecture of wireless sensor network is shown in figure 1. The WSN is an infrastructure comprised of sensing, computing and communication elements, which provides the information about area and process of interest to the administrator, to ensure the sustainable management. As depicted in figure 1, the WSN comprises following four components.

1) An assembly of distributed Wireless Sensor Nodes.
2) An interconnecting wireless network in suitable protocol.
3) A smart base station.
4) A set of computing devices required for data computation, co-relation, event, trending, status querying and actuations etc.

C. Types of the Wireless Sensor Network

According to architecture, the WSN can be classified into two groups such as Type 1 WSN and Type 2 WSN.

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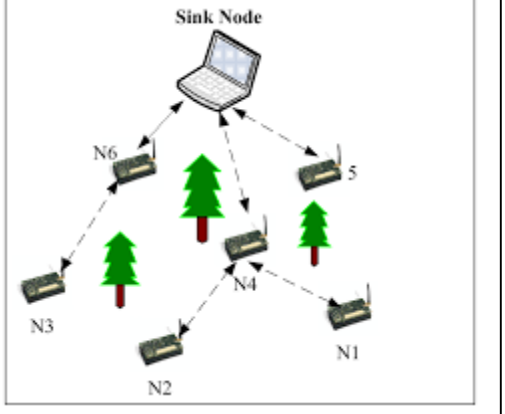


Figure 2: Type-1 WSN

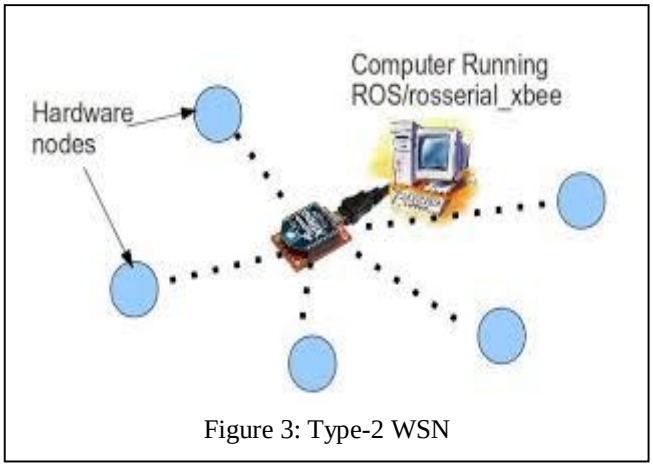


Figure 3: Type-2 WSN

1) *Type 1 WSN:* Emphasizes mesh-based systems with multi-hop radio connectivity among the Wireless Sensor Nodes and realizes dynamic routing of nodes within the establishment of wireless sensor network.
2) *Type-2 WSN:* The WSN of this category ensures point-to-point connectivity between sensor nodes with single-hop technique. These networks reveal static routing of the sensor nodes.

Figure 2 and 3 depict the schematic of Type 1 WSN and Type 2 WSN respectively.

D. Features of Wireless Sensor Network

Following are the salient features of the wireless sensor network.

1) *Scalability:* The scalability is nothing but the capability of the WSN to increase or reduce the sensor nodes from establishment. The routing protocol should be flexible to accommodate the changes in the topology of network.
2) *Self-organization:* In wireless sensor network, each sensor node should be self-organized. The wireless sensor network is composed of sensor nodes. Therefore, each sensor node should be capable to individually respond to local stimulus. All sensor nodes should work together to distribute the load of the network. Moreover, the sensor network should work efficiently to achieve goal of the network.
3) *Self-Healing:* The long term use of wireless sensor network depends on the availability of the sensor node in a network. Damage in the node may depict inconvenience in the collaborative operation. This may be due to technical damage, low RSSI, foreign attack etc. Therefore, such node must be self-healed from the establishment. The architecture of the WSN depicts the capability of the self-healing.
4) *Energy Efficiency:* The design of sustainable wireless sensor network is a very complex issue. The energy constrained sensor nodes are expected to run autonomously for several hours. Therefore, the energy saving in WSN is most essential. The various techniques have been employed to reduce the energy consumption of the sensor nodes. The Rault et al have reported different techniques to increase energy efficiency of the WSN. Deployment of cluster based networking protocols is also suggested by the researchers. The use of solar cell to update the battery is the suitable solution for energy scavenging.
5) *Communication among nodes:* In wireless sensor network, after collecting the data from implementation site, sensor node needs to transmit the collected data to the base station (BS). It is important to ensure that each node can communicate to the base station as well as with node to node. For the better connectivity the large number of sensor nodes canbe used. A network is said to be fully connected if each pair of sensor nodes can communicate with each other. While establishment of the communication the limitations such as flooding, packet loss, data rate, use of frequency bands, infrastructural interferences etc should be considered and attempted to minimize the same.
6) *Low Complexity:* In comparison with the wired network, the wireless sensor network is depicting rather lower complexity. Even though for dense deployment, the complexity can be minimized by proper routing of the nodes and encoding of the data. The routing protocols can reduce the complexity of the WSN. The configuration of PHY and MAC layers would reduce the complexity in the deployment.

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7) Low Cost: The wireless sensor network is affordable as compared to wired network. If the network density, the number of sensor nodes deployed in given area, is increased then the cost may be enhanced. The cost of the sensor node depends on energy, memory, computational speed and communication medium. However, cost of each sensor node can be reduced by optimization in the hardware design.

8) *Size of the nodes:* A sensor node may vary in size from that of shoebox down to the grain of dust. However, the size of the sensor nodes can be reduced by deploying VLSI devices, wherein the philosophy of the System-on-chip is ensured

IV. NETWORK PROTOCOLS

The WSN is the network of smart sensor nodes, wherein the standard protocols such as Zigbee, Bluetooth, wifi, GSM etc technologies are employed to establish the RF communication. The distributed sensor nodes must be routed in the network to ensure cooperative collection of the data. Different routing protocols have been studied for their suitability to use in the WSN. It is found that, to establish the WSN, different routing protocols have been reported [38-40]. These protocols are presented in figure 4. To achieve the better connectivity, reduction in the energy consumption, minimization in complexity, ease of deployment the protocols are playing significant role. As presented in the figure 4, the protocols can be grouped into four different groups such as Attributed Based, Geographical Routing, Hierarchical Based, multi path routing etc. These protocols have their own advantages and limitations as well. Many routing protocols have been proposed [41-44], where the network topology changes frequently because of node failure and communication conditions. Helmy et al. [45] proposed an architecture that is geared towards one shot frequent queries in sensor networks. Their approach aims at reducing the total energy consumption. Trakadas et al. [46] classify selection of algorithms proposed for ad hoc networks according to their relevance and efficiency. A spatial position node from GPS or other coordination mechanisms can be used for geographic routing and there have been many proposals using this, such as [47-50]. Basically, the data routing approaches in WSNs fall into three main categories, namely data centric, hierarchical and location based. A few other protocols follow the traditional network flow. Typical routing protocols are described.

A. Data Centric Protocols

1) *Flooding and Gossiping:* Flooding and gossiping [51] are two classical mechanisms to relay data in sensor networks without the need for any routing algorithms and topology maintenance. In flooding, each sensor node, receiving a data packet, broadcasts it to all of its neighbors and this process continues until the packet arrives at the destination or the maximum number of hops for the packet is reached. On the other hand, gossiping is a slightly enhanced version of flooding, where the receiving node sends the packet to a randomly selected neighbor, which picks another random neighbor to forward the packet. Although flooding is very easy to implement, it has several drawbacks such as implosion and overlap. It may be due to duplication of messages sent to same node, overlap when two nodes sensing the same region send similar packets to the same neighbor and resource blindness by consuming large amount of energy without consideration for the energy constraints. Gossiping avoids the problem of implosion by just selecting a random node to send the packet rather than broadcasting. However, this cause delays in propagation of data through the nodes.

2) *SPIN(Sensor Protocols for Information via Negotiation):*The SPIN is a common protocol may be employed efficiently to

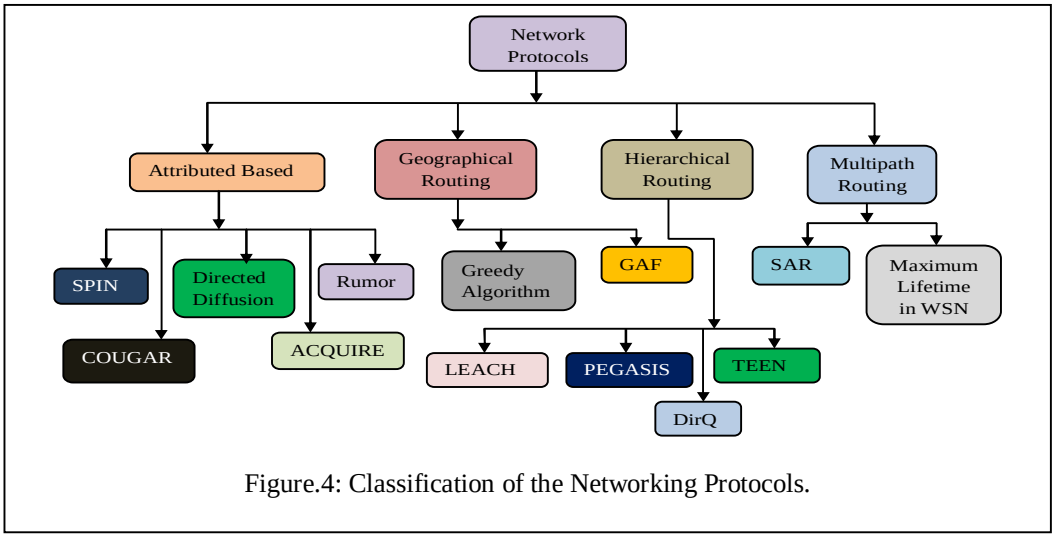


Figure.4: Classification of the Networking Protocols.

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disseminate information in a wireless sensor network [52]. The traditional data transmission approaches like flooding and gossiping waste valuable communication and energy resources transmitting redundant information in entire network. However, these protocols are not resource aware. Therefore, SPIN removes these drawbacks of conventional approaches using data negotiation and resources adaptive algorithm. Node running SPIN gives a high level tagto their information called as meta-data and performs meta-data negotiation before any data is transmitted. Therefore, SPIN ensures that no redundant data sent through entire network.

3) *Directed Diffusion:* Directed diffusion is a classic data centric routing protocol [53] in wireless sensor network. In directed diffusion based wireless sensor networks, data generated by sensor nodes is named by attribute value pairs. A sink node requests a data by sending message. The information that matches the message is then passing down towards the sink node. The intermediate sensor nodes transform data and give the direction to the message based on previously cached data.
4) *Rumor:* In rumor routing [54] queries are generated by the sink node are propagated among the sensor nodes that have observed an event related to the queries. A sensor node that observes an event sends a packet. The packet is propagated in the network so distant node acknowledge about its path.
5) *COUGAR:* In this routing protocol, the network is foreseen as distributed database, wherein some sensor nodes having the information [55]. The sensor nodes stores the past values and networks behaves as the data warehouse. Moreover, unhealthy propagation condition may lead to the storage of erroneous data in the sensor nodes. According to above situation, COUGAR provides a MySQL like interface extended to incorporate some clauses to model the probability distribution. The sink node is responsible for generating a query plan which gives the idea to select a special sensor node called leader. The network leader performs aggregation and disseminates the results to the sink node.
6) *ACQUIRE: The* data centric technique for querying sensor networks is Active Query forwardingin Sensor Network. In [56], the protocol viewed as the sensor network as a distributed database is well suited for complex queries which consist of hundreds of sub-queries. In this routing protocol, the query is forwarded by the sink node and each sensor node in a network receives the query and tries to acknowledge partially by using its pre-cached data and forward it to another sensor node. If the pre-cached data is not up to date then sensor nodes collect information from its neighbors within a hop. After the resolving of query, it is sent back through either the reverse to the sink node.

B. Geographical Routing Protocols

The geographical routing protocols take benefit of the location information to make routing technique more efficiently. The most popular forwarding techniques in geographical routing protocols are as follows.

1) *Greedy Algorithm:* In this algorithm [57] sensor node decides the transmission path based on the position of its neighbors. The source compares the localization of the destination with the coordinates of its neighbors. Then it propagates the message to the neighbor which is closest to the final destination. This process is repeated until the packet reaches the desired destination.
2) *GAF (Geographic Adaptive Fidelity):*Under this approach [58], energy aware location based routing algorithm is designed basically for mobile ad hoc networks. However, it is used in sensor networks as well. The GAF is employed to optimize the performance of wireless sensor networks by identifying the equivalent nodes with respect to forwarding packets. In GAF routing protocol, each sensor node uses location information based on GPS to associate itself with a virtual grid. Therefore, the entire area is divided into several grids and sensor node with the highest residual energy within each grid becomes master of the grid.

C. Hierarchical Routing Protocols

The main aim of the hierarchical routing is to reduce power consumption by classifying nodes into clusters. In each cluster, a sensor node is selected as the leader or cluster head. The some hierarchical routing protocols are described.

1) *LEACH (Low Energy Adaptive Clustering Hierarchy):*LEACH is the one of the most popular distributed cluster based routing protocol in wireless sensor network [59]. LEACH performs self-organizing and re-clustering function for energy consideration. Sensor nodes organized it to cluster into LEACH routing protocol. LEACH maximizes the lifetime of the network and reduces the power consumption by compressing the data before disseminating to cluster head. The LEACH routing protocol operates in two rounds called as set-up phase and steady phase. In set-up phase, sensor nodes inform the base station about their positions and about their energy level. With the help of this information, the base station decides the structure of clusters and their corresponding cluster heads. In fact the cluster head is self-elected. In steady phase data aggregation is done within the different

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clusters of the network, compressed sensed data within a cluster and transmission of compressed data to the sink node via different cluster heads. Here, the parameter such as received signal strength indicator (RSSI) is playing commendable role.

2) *PEGASIS(Power Efficient Gathering in Sensor Information Systems):*This approach is based on optimization of the LEACH routing protocol. Instead of clustering nodes in cluster, the PEGASIS [60] forms chains of the sensor nodes. Based on this structure, each sensor node transmits to and receives from only one closest sensor node of its neighbors. The sensor nodes perform data aggregation and forwards it to the node in the chain that communicate with the sink node. In each round, one sensor node in the chain is elected to communicate with the sink node. The greedy algorithm is employed to construct the chain.
3) *TEEN (Threshold Sensitive Energy Efficient Sensor Network Protocols):*The TEEN [61] is the first protocol developed for reactive networks used in temperature sensing application. Based on LEACH, TEEN also divides sensor nodes twice for grouping cluster in order to detect the scene of sudden changes in the sensed attributes such as temperature. After forming the cluster head TEEN separates the cluster head into the second level cluster head and uses hard-threshold and soft-threshold to detect the sudden changes. The hard-threshold tries to reduce the number of transmission by allowing the nodes to transmit when sensed attributes is in the range. The soft-threshold also reduces the number of transmission and only sends when small changes in the sensor attributes.
4) *DirQ (Directed Query Dissemination):*The main objective of the DirQ [62] is to optimize the propagation of queries in a wireless sensor network. In this approach quires are just propagated by the minimum number of nodes that ensure that the queries arrive at the nodes that are able to service the query, to do so, certain information is exchanged in the network. The interval of the update message depends on the rate of variation of the physical parameters that the network is sensing.

D. Multipath Routing Protocols

In these routing protocols, a source sensor node knows the multiple routes to destination. The most used routing protocols are as follows.

1) *SAR (Sequential Assignment Routing):*The SAR [63] is based on the association of a priority level to each packet. In this routing, first creation of multiple trees is done. The root of each tree manages a single hop distance from sink node. Dissemination of the packets is based on priority of the packet. If sensor node contains low priority packets, then SAR chooses longer path to reach sink node otherwise it chooses shortest distant to the sink node. The main objective of SAR is to maintain quality service along the network.
2) Maximum Lifetime Routing in WSN: This algorithm [64] is a combination of the energy consumption optimization with the use of multiple routes. In this routing, an active route is monitored to control its residual energy, at the backend, other routes can be discovered. If energy of the active route is less than the energy of the alternative route, then the corresponding route is used.

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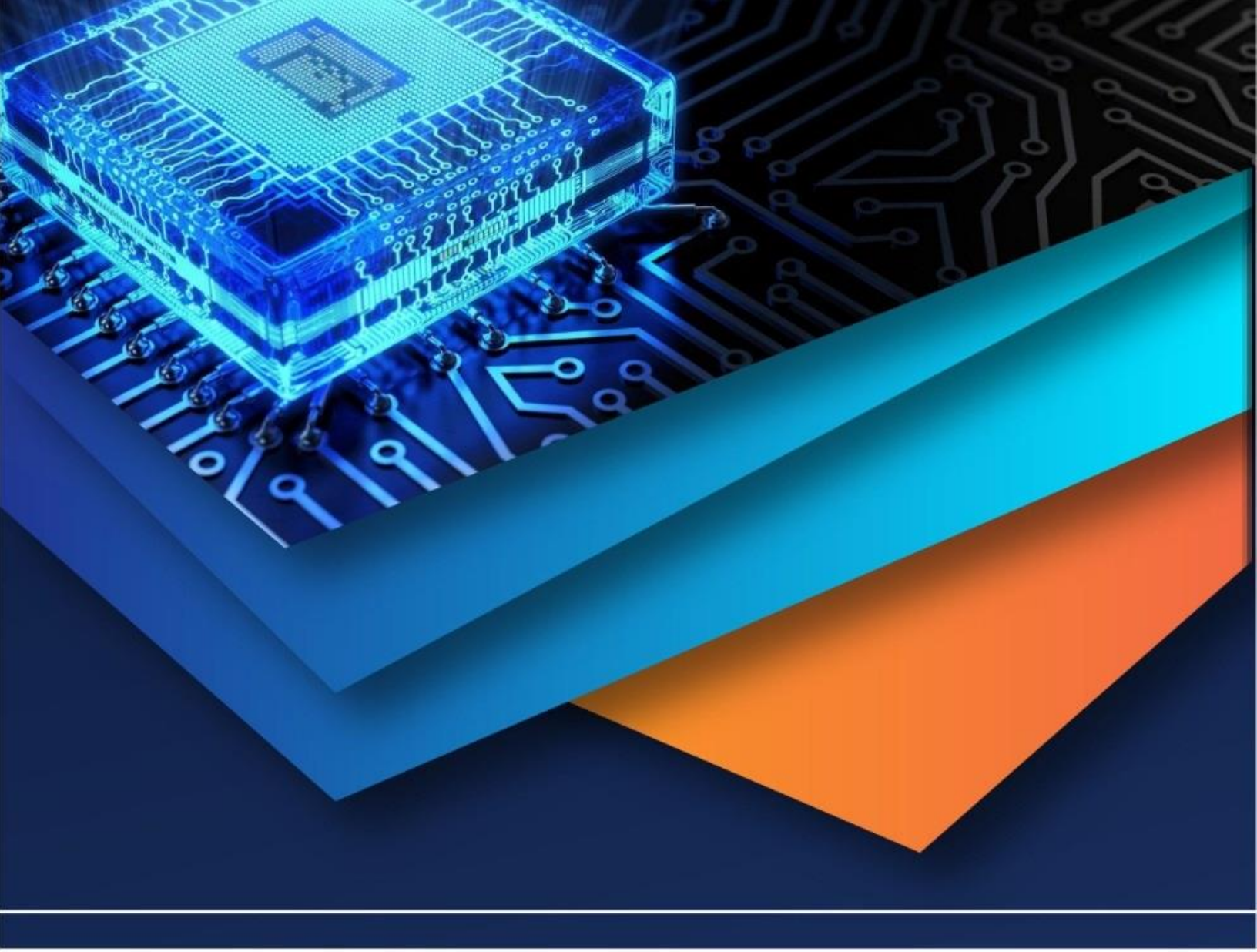
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