Chapter 1

INTRODUCTION
Wider use of sensors in varieties of complex and real-time networked applications brought Wireless Ad hoc Sensor Network (WASN) into the picture. Recent advancement in WASN has proven itself as one of the desired technology for people. Sensors are likely to be remotely positioned in unattended network settings and this becomes the reason of development of many routing protocols. Routing is one of the key exercises that any network performs for better quality of service and it is impossible that a single routing protocol for all applications. This is the region why strategic routing and packet communication are becoming the point of attention in WASN research. However, limited power source, bandwidth and wireless medium with node mobility still remain as fundamental constraints in protocol designing in WASN.

1.1. Routing in WASN

Routing is very challenging in WASN, where data and information moves from a source point to a destination point through intermediate nodes, called multi hopping in packet routing. But, collecting and gathering data at some universal destination point is quite difficult as there is always a chance of unpredictable power depletion, resulting packet loss and network delay. That leads to early breakdown of the whole network structure. Ad hoc capability in real time network setting makes wireless routing critical due to ever changing routing path with respect to different instance of time. Active research in wireless ad hoc and mobile sensor kind of network is being carried out in the field of routing, resource management, power control, security, etc. The consideration of energy for making the routing process efficient is the best way to deal with any of these issues by extending network operation. There are several more considerations that make the designing of WASN protocol a tough task.

Hierarchical routing with clustering brings a noticeable development among the sensor nodes, in consideration of energy consumption and data gathering in a static environment. A network hierarchy and clustering of sensor nodes provides network scalability, robustness, well-organized resource utilization and lower power consumption.
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The essential objectives for sensor networks are reliability, accuracy, flexibility, cost and energy effective deployment, packet routing, etc. The limited battery power is likely to be the most critical resource bottleneck in most WASN applications. Based on the applications, networked devices with sensors can be connected together in a number of ways. In basic data-gathering applications, for instance, there is a node referred to as the sink to which all data from source sensor nodes are directed. The modest logical topology for communication of data is a single-hop star topology, where all nodes send their data directly to the sink. In networks with lower transmission power settings or where nodes are positioned over a large region, a multi-hop network structure may be used for data-gathering. In this case, some nodes may act both as source node, as well as routers for other end nodes. One interesting characteristic of WASN is that they often allow for the possibility of smart in-network processing. Intermediate nodes along the path not only act as packet forwarders, but also may examine and process the content of the packets going through them. This is often done for the purpose of data compression or for signal processing to increase the quality of the collected information. But, with mobility in WASN environment the activities of existing network becomes different and conventional cluster routing protocols need to be analyzed in terms of energy complexity and other factors, which is the prime focus of this work.

As WASN, has been aimed for locations with zero human interference where geographical changes are continuous and dynamic. An enhancement in the capabilities of existing sensor network is a critical need to deal with dynamic and real life wireless network scenarios. Hence, construction of improved energy aware cluster routing in WASN become essential. To do so, incorporate mobility in the sensor nodes is one of the ways. The inclusion of such realistic behavior in the current WASN helps to draw a distinct line between static and dynamic states in terms of random node mobility. To deal with power problems with such network settings several protocols are developed. Data aggregation and data fusion methods in clusters inspire non redundant bulk of packet transfer at a quicker pace to the base station with lower routing overhead. Hence, it is always desirable an effectual routing protocol, that has low routing overhead and well organized data capturing mechanisms. However, the performance of the cluster routing requires optimization when WASN becomes heterogeneous with mobility. Severe power depletion strongly affects the existence of active nodes and the network operation too. In
order to prolong the network utilization, several power management approaches are available that efficiently reduce the energy consumption individually in each sensor as well as in the whole network. Several studies say, due to real time dynamic behaviors and complexities of ad hoc wireless nodes, the use of traditional methods for enhancing quality and durability in the process of routing becomes a challenging job. Optimization is very helpful in creating the appropriate trade-off between different conflicting parameters to get the best possible outcome. The potential paradigms of evolutionary computation, soft-computing based heuristics and multi objective meta-heuristics can be compatible with such network setting to overwhelm the complexities. Two major issues in wireless sensor networks are energy efficiency and quality of service. Bio-inspired evolutionary meta-heuristics can be able to optimize current clustering and routing protocols to maximize quality of services and efficiency in terms of energy.

Moreover unpredictable node displacement causes frequent topology change and network partitioning. The short range and variable capability link makes the chance of packet loss higher. Additionally, the mobility of sensor nodes draws more power and makes the routing process, power hungry that, affects the sustainability of routing path prior to the packets reaches to its intended destination. Techniques like multicasting, broadcasting, flooding, clustering provides significant support in routing and continuously providing a base for further optimization in modeling new energy aware routing protocols. The traditional approaches applied on current WASN to enhance the quality of the network become a challenging job due to a rise of complexity with real time and application specific features in the current setting. As the problem size increases the computational complexity of an existing method grows exponentially. Hence, new approaches need to be proposed and optimized over the conventional one.

1.2 Design Challenge and Requirements of WASN

WASN has created new opportunities across the spectrum of human endeavors ranging from engineering, designing and manufacturing, monitoring and control of environmental systems, forecasting, event tracking, health care and health informatics, battlefield surveillance, disaster management, infrastructure protection, etc. But, there are
many design issues and requirements devoid of which designing of WASN network system are quite impossible; and these are as follows,

1.2.1 Sensor Network Topology

The topology of a network impacts many of its characteristics like; latency, capacity, and robustness. Also, the complexity of data routing and processing depends on the network topology. Densely positioning of thousands of sensor nodes in a sensor field requires careful handling of network topology maintenance [148]. The topology of WASN can be fall under any of these three phases,

- Pre-deployment and deployment phase.
- Post deployment phase.
- Redeployment of supplementary nodes phase.

1.2.2 Energy Consumption

One of the critical modules in sensor node is the power module which is limited. A sensor node is battery-operated. Hence; lifetime of a sensor node depends strongly on the battery lifetime, especially where no power source replenishment is possible in some application scenarios. The lifetime of a sensor node plays a key role on energy efficiency and robustness of sensor nodes. Hence; distinguished research works are still being done on designing of power-aware protocols and algorithms for WSN with the goal of minimization of energy expenditure as much as possible [148].

1.2.3 Data Aggregation and Fusion

It is the task of minimizing data size by summarizing the collected data into a set of significant information via intelligent computation for further propagation through the WSN. As sensor networks made up of a large number of sensor nodes; this can easily congest the network and flooding it with information [150]. Hence, a solution to data congestion in sensor networks is to use computation to aggregate and fuse data in-place at sensors and then transmit the aggregated data to the BS.
1.2.4 Security

Security aspects in WSNs have been focused on the centralized communications approaches. Some of the threats to a WSN are described in [146,149] and are categorized as Passive Information Gathering, False Node, Node Outage, and Supervision of a Node, Node Malfunction, Message Corruption, Denial of Service, and Traffic Analysis and others. There is a need to develop distributed security approaches for wireless sensor network what the current network demands.

1.2.5 Self Configuration

It is essential for WSN to be self-organizing and self-forming. The densely deployed sensor nodes in a sensor field may fail due to many reasons like, Lack of energy, physical destruction, environment interference, communications problem, inactivity, etc. and new nodes may join the network at any point of time. On the other hand; sensor nodes in most of the applications work unattended in a dynamic environment; so they need to be self-configuration to establish a topology that supports communications under severe energy constraints. It is worthy to mention that self-configuration in WSN is an essential factor to maintain the network functions properly and serve its purpose.

1.2.6 Self Optimization and Adaptation

Traditionally, most engineering systems are optimized a priori to function professionally in the face of expected or well modeled operating conditions. In WSN, there may often be significant uncertainty about operating conditions prior to deployment. Under such circumstances, it is significant that there need to be inbuilt mechanisms to autonomously learn from sensors and network measurements collected over time and to use this learning to continually increase performance. Also, besides being uncertain a priori, the environment in which the sensor network operates can change drastically over time. WSN protocols should also be able to adapt to such environmental dynamics over time.

1.2.7 Network Dynamics

In many applications, the movement of sensor nodes or the base station (sink) is essential. This means that sensor nodes are most probably non-static movable nodes in real time network setting. This brings the routing stability issues as well as energy, bandwidth,
etc. Moreover, the specific sensed phenomenon may be either dynamic in applications like, target detection/ tracking or stationary applications like, forest monitoring, etc. depending on requirements.

1.2.8 Heterogeneity

The meaning is the presence of networked devices with heterogeneous capabilities with respect to computation, communication, sensing or any functional capabilities in realistic network settings. This heterogeneity can have many significant design consequences. For instance, the incidence of a small number of devices with higher computational competence along with a large number of low-capability devices can dictate a two-tier, cluster-based network architecture, and the existence of multiple sensing modalities requires pertinent sensor fusion techniques. A crucial challenge is to control the right combination of heterogeneous devices with varied capabilities, according to a given application requirements.

1.2.9 Mobility

Communication devices with mobility do not have access to unlimited power. On the other hand mobile devices use batteries for displacement as well as accessing to network coverage with limited power source. Higher the power usage lowers the battery life. Efforts are to be made in device and protocol designing that can consume less power and adjust the strength of communication signal based on the distance, velocity, mobility patterns and others in WASN.

1.2.10 Quality of Service

In network applications, data delivery within a bounded latency is of great importance; otherwise, the sensed data that delivered after certain latency will be of no use. Hence; there is a trade-off between the quality of service or the quality of data transmission and the energy consumption and conservations depending on the application domain [151].

1.2.11 Coverage
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The sensor node’s view of the environment that it is situated in is limited both in range and in accuracy. This means the ability of sensor nodes to cover the physical area of the environment is limited [148].

1.2.12 Connectivity

The connection between individual sensor nodes that are densely deployed in a sensor network defines the network connectivity. The connectivity is of great importance, since it influences communications protocols’ design and data dissemination techniques. But, under ad hoc and dynamic WASN environment, maintaining connectivity among sensors is challenging. On the other hand death or failure of some sensor nodes due technical or environmental reasons also affects the network connectivity [148].

1.2.13 Scalability

The combination of fine granularity sensing and large coverage area implies that wireless sensor networks have the potential to be extremely large scale. Protocols will have to be inherently distributed, involving, localized communication, and sensor networks must utilize hierarchical architectures in order to provide better scalability. However, visions of large numbers of nodes will remain unrealized in practice until some fundamental problems, such as failure handlings are addressed even in small settings involving tens to hundreds of nodes. There are also some important limits on the throughput and capacity that impact the scalability of network performance.

1.3 Motivation

The rapid miniaturization process of wireless and device technologies impacts a lot in day to day lifestyle. Slowly but surely, with time wireless communication is becoming a fundamental important factor without which, imagining and envisioning the world is quite difficult. One of such smart communication system is Wireless Ad-hoc Sensor Network (WASN) [15] that can meet different application specific, complex, real life and practical challenges of civilization. WASN takes the combined and comprehensive features of Wireless Sensor Network (WSN) with Ad hoc networks. Ad hoc sensor networks are intended with autonomous sensors communicating through radio without any prebuilt infrastructure. WASN are kind of versatile self-configurable network that is used in many
different situations and wide range of applications. The sensor deployment varies with type of applications. Recent improvement in wireless communications and electronics technology has allowed the engineers to develop low-cost, low power, multifunctional miniature devices for use in real time and remote sensing kind of applications. Sensor networks are composed of a good number of networked nodes, with sensing, data processing and communication capabilities, are deployed in hares, dynamic, unattended and unfriendly environment. In ad hoc networking scenarios such as WASN it is tough to forecast the instance to deploy the nodes and which random topology the network will follow in the next instance due to impulsive node movement. Due to such scenarios, one cannot predict random topology of the network at different instances of time, hence designing routing protocols becomes crucial for such networks. Hence, to cope-up, each networked nodes incorporated with built-in capabilities; including communication elements on board that work round the clock.

In typical network scenario, each node requires a power source to do all device operations, including data capturing, processing trans-receiving etc. For remote operations, installing a battery on each sensor node is a better option; however battery replacement is a challenge. Though, gradual advancement in battery technology is added day by day, but battery source is always limited. Hence, one of the primary issues is the prolonged availability of battery energy to the sensor nodes to face the genuine constraints like geographical terrains, mobility, cost, device size and weight of each deployed sensor node, etc. Therefore, it is needed to monitor and manage power exhaustion uniformly across the network to get the best use of the network. To enhance WASN life span, it is needed to give emphasis on algorithms, protocols, and circuitries that can bring maximum functionality by scaling the consumption of inadequate power source. Therefore, there is always a need to minimize energy consumption in WASNs. Sensing, processing and packet communication with minute sensors with power restriction is not that simple task. Any technology that is in the course of its development, offers a lot of challenges. In the same way, WASN also brings a lot of challenges and issues towards its improvement. The key challenge in sensor networks is to minimize the energy consumption of sensor nodes due to the fact that it is quite infeasible to replace or refill the batteries of thousands of sensor nodes. Therefore, communication protocols used essentially need be made as energy
efficient as possible. Data transmission protocols have much more significant in terms of energy, since the energy required for data transmission takes nearly 70% of the total battery consumption of a WSN [147]. The conventional single-hop approach is costly with high communication overhead that affect the lifetime of the network. Particularly, in wireless multi hop network scenario; for effective performance; its protocol has to act very competently in parallel with any change in network settings. In multi-hop scenarios intermediate nodes participate in packet forwarding and multi-hopping principle is one of the backbones of routing in a large scale network. Several protocols have been developed to deal with a power problem in sensor networks. FAF-EBRM (Forward Aware Factor) [183], is one of the multi-hop energy aware routing method which mainly deals with selection of the next hop node according to the link weight and forward energy density. It tells how all packets will move towards the sink direction by choosing efficient link. Most of the routing algorithms that are available for wireless and ad hoc networks can be classified into three kinds i.e., Direct transmission algorithms, hop to hop transmission algorithms and cluster based algorithms under both proactive and reactive network patterns.

Coverage and data aggregation procedures can greatly help conserve the scarce energy resources by eliminating data redundancy and minimizing the number of data transmissions. Therefore, data aggregation methods in sensor networks are extensively discussed and investigated in many of the literatures [147, 153, 152]. Sensor networks are mostly data centric rather than address-centric. So, sensed data are directed to an area containing a cluster of sensors rather than particular sensor addresses. Clustering is one of the effective techniques among others, used to save energy in WASN as shown in figure 1.1. Clustering is one of the network structures where the total network is divided into different logical network segments according to certain rules or metrics with different behaviors for nodes incorporated in a cluster from those left out from the cluster. Clustering provides a three level hierarchical architecture normally with a head node called cluster head normally serves as a leader and sink for its cluster and responsible for intra-cluster communication, data forwarding to other CH, etc. A gateway is a node that is present in two or more clusters with inter-cluster links, so that it can able to access neighboring clusters
and forward information between them. A member node in a cluster is usually an ordinary node or leaf node without any inter-cluster links [186,187].

![Conventional Clustering and Hierarchical Clustering](image)

(a)

(b)

### Figure 1.1 Conventional Clustering and Hierarchical Clustering

The operational implementation of a clustering approach helps the communication network to reduce the volume as well as frequency of transmission by accomplishing data aggregation and data fusion at the cluster heads [85]. Data aggregation and data fusion method have been used in clusters to inspire non-redundant packet transmission at a quicker pace to the Base Station with lower routing overhead. The local data is organized
by an aggregator node within the cluster, reduces the communication and bandwidth overhead. Clustering is largely favorable for routing, due to the presence of set of cluster heads and cluster gateways which form a virtual infrastructure for inter-cluster communication, and hence limit the spreading of routing information freely in the network. The structure of conventional clustering and hierarchical clustering has been shown in the figure 1.1.

Most of the work in WSN is concerned with the network with stationary nodes. Due to which nodes in particular locations in the network drain out energy in the routing process. For example, nodes nearer to the base station deplete their energy rapidly by keeping ON their transceiver round the clock for packet routing. If the node becomes weaker and died near the sink, then it blocks the packets to be reached to the base station leads to network break down and discourage long distance communication by the distant end nodes which resulting extra communication and energy overhead. So node displacement is essential to escape the network from early breakdown. On the other hand, there are critical applications nodes can never be operated static and mobility brings considerable improvement in the network performance a quality of service. Cluster based hierarchical routing protocols proven energy efficient due to its network architecture and mode of operation, where the high energy nodes can be used to sense, process and send the packets as compared to low energy nodes sensing at remote target endpoints on the network [190,191].

LEACH [24, 14] is one of the hierarchical cluster based protocol for energy efficient routing under static environment with no multi-hop concept. Several other protocols also designed over LEACH under node mobility framework. LEACH-Mobile [56] is a protocol that used the membership declaration concept upon nodes to keep them to be included within the cluster and the node not able to receive a request during consecutive frames moved out of the cluster and the node able to perform cluster join request to reunion with the new cluster. LEACH-Mobile [56], enhances the successful packet delivery rate, but also increases the control overhead on the whole network. LEACH-ME [67] is another protocol that has tried to minimize the control overhead by introducing mobility metric in terms of the remoteness of the node with respect to cluster head. The node with minimum mobility in the network or moving in group with respect to other node get more chance to
be cluster head. But in reality than cannot be the network parameters to design a dynamic WASN. This protocol forgot to take parameters like remaining energy and total number of nodes under a cluster head.

The current categories of WASN are becoming useful for solving a number of dynamic and complex real time tasks. Integration of inexpensive, power efficient and reliable sensors with significant communication and computation resources opens new research directions. However, there are many challenges like efficient use of limited bandwidth, communication capacity, mechanism for reducing power consumption with extended battery life, mobility management of networked wireless node, information security, reliable routing, etc. Particularly, routing has a vital role to meet the challenges in WASN.

1.4 Objective

There is a growing need for energy aware routing protocols for different application based Wireless Ad hoc Sensor Network as wireless nodes are having limited battery resources. This is very much interesting and challenging area of research. The work mainly focuses on to study, analyze and investigate the potential energy aware routing protocols under real time environment. The objective of the work covers the study of the routing protocols based on energy and their challenges in WASN. It also investigates their limitations, for further enhancement with new routing strategy based on energy awareness. The effect of heterogeneity, dynamic, clustering, and others on routing protocols has been analyzed to model new energy efficient routing protocol. To evaluate the comparative performance of the proposed approach with that of the existing approaches and to optimize the protocol performance, different optimization strategies along with multi-objective meta-heuristic approaches have been analyzed and studied for optimizing the routing protocol in terms of energy and throughput in the wireless ad hoc sensor network. To Analyze the Link Quality of nodes in real time WASN environment for assessing of the network’s power consumption pattern the test bed has been implemented. The work mainly focuses on power saving routing protocol and network lifetime in a dynamic network environment by taking different aspects and prospects of the network and compare and
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contrast the different existing and proposed algorithms for relative advantages and disadvantages.

1.5 Thesis Outline

The thesis is structured out as follows; the current chapter has presented a brief overview of the work carried out.

Chapter 2 conducts a review of primeval and contemporary research findings in the light of adopted methods, algorithms, mechanisms and their usage. The pros and cons of existing methods and protocols have enlightened and arranged in-place for better understanding.

Chapter 3 presents about Energy Complexity and wireless network topology management under a dynamic network with the hierarchical cluster routing process of experimental analysis.

Chapter 4 describes a Hybrid Multi-hop Mobility Assisted Heterogeneous Energy Efficient Cluster Routing Protocol for performance enhancement of WASN in terms of energy efficiency and system throughput under heterogeneous real time mobile environment and the results are compared with existing protocol.

Chapter 5 deals with Pareto-optimization of energy throughput model with multi-objective function under NSGA-II framework with a new set of equations and the results are compared with existing one.

Chapter 6 offers a real time assessment of Link Quality in data routing process with hands on Test bed under different network scenarios. Again the chapter briefly discussed the energy consumption pattern and the effect of environmental factors upon wireless links.

Lastly, Chapter 7 presents a discussion on conclusion with further scope for knowledge workers and researchers.