

# Chapter 3

## Literature Review

### 3.1 Introduction

Due to potentially harsh, uncertain, and dynamic environments, WSNs are envisioned to operate in an autonomous and untethered fashion. The main task of WSN is to sense and collect data from a target domain, process the data, and forwarding data directly to the target node, but this task would not be feasible as the required transmission energy increases proportionally to the square of the distance. Therefore, data is routed using multi-hop communication. Achieving this task efficiently requires the development of an energy efficient routing protocol to set up paths between sensor nodes and the data sink. As several alternative routes to a destination node may exist, the routing decision has a significant effect on load balancing, end-to-end reliability and latency. The path selection must be such that the lifetime of the network is maximized. Due to resource constraints, WSN poses considerable challenges ranging through network organization, topology discovery, communication scheduling, routing control and signal processing. Also, tight energy budgets enforce energy efficient designs for hardware components, network stacks and application algorithms [13].

Data routing in WSNs can be made robust and energy-efficient by taking into account a number of pieces of state information available locally within the network [11] such as link quality, link distance, residual energy, location information and mobility information.

The basic service of a routing protocol is the multi-hop forwarding a packet from a source to a destination. However, a routing protocol may also provide end to end latency, reliability, or energy usage (QoS metrics), efficient packet delivery to several nodes at once (multicasting or broadcasting) and node mobility [13].

## 3.2 Routing Protocols in WSNs

The routing protocols are responsible for all aspects of end-to-end packet delivery, including logical message addressing and routing packets between different networks. The main goal of a routing technique is to efficiently deliver data from the source to the destination. Although all routing protocols share this goal, each protocol adopts a different approach to achieve it.

Routing paths for transmission of data packets from one node to another can be established in one of three ways, namely proactive, reactive or hybrid.

In proactive routing [35], all the routes are computed in advance and maintain consistent up-to-date routing information from each node to every other node in the network. Every node in the network maintains one or more routing tables that store the routing information. This is also called table driven routing and is preferably used in the application where the sensor nodes are static. Proactive routing protocols periodically monitor the changes in the topology to ensure the ready availability of any path amongst active nodes. When a topology changes due to the failure of nodes, the change has to be propagated throughout the network as updates so that the network view remains consistent. The protocols vary in the number of routing tables maintained and the

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method by which the routing updates are propagated.

In reactive routing, routes are discovered only when desired. This means that protocols don't make the nodes initiate a route discovery process until a route to a destination is required. Route discovery can be initiated either by source or destination. Source-initiated routing means that it is the source node that begins the discovery process, while destination-initiated is the opposite. Once a route has been established, the route discovery process ends and a maintenance procedure preserves it until the route breaks down or is no longer desired. The main disadvantage of reactive protocol is that, significant amount of energy is expended in route discovery and setup.

Hybrid routing combines characteristics of both reactive and proactive routing protocols to make routing more scalable and efficient.

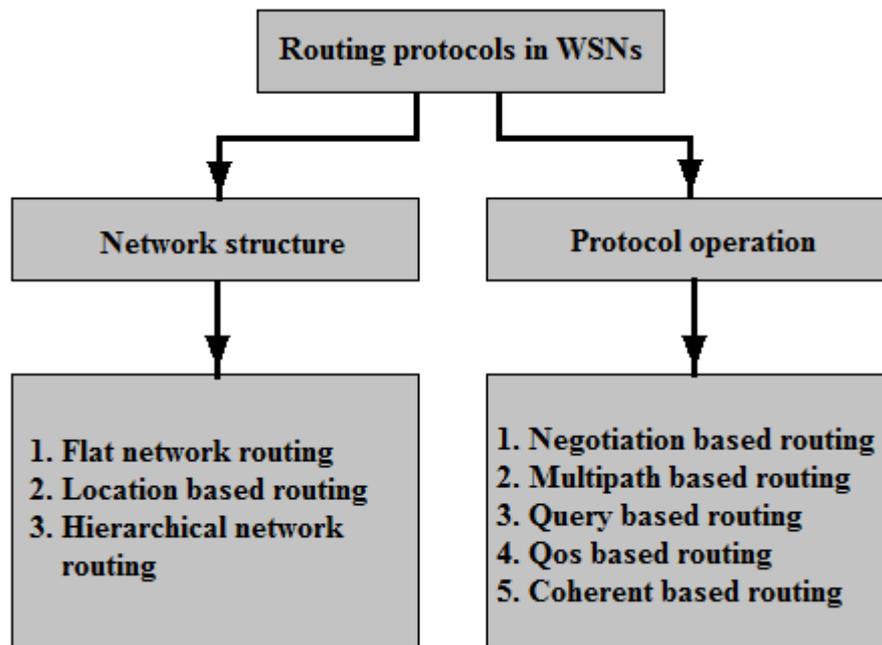


Figure 3.1: Classification of Routing Protocols in Wireless Sensor Network

In general, the routing protocols in WSNs are classified into different types based on network structure (i.e network architecture) and protocol operation(i.e application) [36]. The Figure 3.1 shows the classification of routing protocols in WSNs. Depending on the network structure, the routing

protocols are divided into flat-based routing, hierarchical based routing, and localization-based routing. Generally, in flat-based routing, the same functionality is assigned to every node in the network. However, in hierarchical-based routing, the nodes play different roles in the network. In localization-based routing, the location information is used to adequately route the data.

A routing protocol will be considered adaptive if it can adapt to the current network conditions and available energy levels. Depending on the protocol functioning, these can be classified as multi-path based routing, query based, negotiation based, quality of service based or coherent based.

### **3.3 Network-Structure based protocols**

The network structure can play significant role in routing the data from the nodes to the base station. Depending on the network structure, routing in WSNs can be classified [36] as mentioned below.

#### **3.3.1 Flat based routing**

In a flat network topology, each node plays the same role and has the same functionality as other sensor nodes in the network. When a sensor node needs to send data, a flat network routing protocols attempt to find a route to the sink hop by hop using some form of flooding. Since the sensor networks composed of large number of sensor nodes, it is not feasible to assign a global identifier to each node in the network. The most popular flat-based routing in WSN are data-centric protocols, where the base station collects the data from the selected regions by sending queries. Most of the protocols use attribute based naming to specify the characteristics of data. The advantage of data-centric protocols is that these save energy through data negotiation and elimination of redundant data and also, that all the nodes can reach the BS irrespective of their position. The following paragraphs describe some of the

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flat network routing protocols.

The TinyOS embedded sensor network platform [37] employs a very simple ad-hoc routing protocol. The BS broadcasts a route update beacon message into the network periodically. The nodes near the BS receive this beacon message and store BS as their parent. These nodes rebroadcast the beacon to their neighboring nodes and the node hears from it, and marks the first node as its parent. The beacon is thus flooded throughout the network, setting up a breadth-first spanning tree rooted at the BS. This process is repeated at regular intervals known as epochs. Each node in the network periodically collects its sensor data and forwards the data packet to their parent in the spanning tree. The parent node in turn forwards the packet to its parent and so on. This process is repeated until the data finally reaches the BS.

Directed diffusion is a data-centric (DC) communication protocol for sensor networks has been proposed in [38]. It is an application-aware paradigm in the sense that all sensor data are characterized by attribute-value pairs. The BS requests data by broadcasting interest into the network, and then interests are diffused through the network hop by hop towards the nodes that are capable of responding.

The destination initiated reactive protocol called Energy Aware Routing proposed in [35] uses sub-optimal communication paths occasionally to increase the lifetime. Although this protocol is similar to Ad hoc On-Demand Distance Vector (AODV) and directed diffusion, it differs in the sense that it does not find a single path for information flow; instead that it maintains a set of good paths and chosen by a certain probabilistic function. The probability depends on how low the energy consumption is that each path can achieve. The protocol maintains several paths; the communication paths will be chosen at different times, thus the energy of any single path will not exhaust quickly. This can achieve the longer network lifetime as energy dissipation is more equally balanced among all nodes. Network survivability is the main

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performance metric of this protocol.

The Pulse protocol [39] is similar to the beaconing protocol addresses the three parameters; routing, energy consumption and time synchronization in sensor networks. The routing paths and time synchronization are provided by flooding the periodic pulse signal by a pulse source. As the pulse propagates through the nodes in the network, a spanning tree rooted at the pulse source is constructed. If a node wants to transmit a data packet, sends a reservation packet to the pulse generator. The reservation packet contains the address of the node transmitting the packet and is used to set up reverse routes for data packets. To keep the route fresh, the active nodes need to keep sending reservation packets in response to the periodic pulse signals. Idle nodes that do not have data to communicate and that are not needed for forwarding packets can switch off their radios till the next pulse signal arrives and thereby save energy.

Further to minimize energy consumption, intermediate wake-up periods are incorporated in the modified Pulse protocol. The motivation behind this modification is that the routes in the network are established by the flooding of the pulse signal, which is an expensive process. Instead, nodes are permitted to send reservation packets during intermediate wake-up periods which can occur several times between two pulse floods. This enables faster path activations with lesser energy expenditure.

Flooding [40] is an old classical technique that can also be used for data routing in sensor networks without the need of any complex routing algorithm and expensive topology management. In flooding a node broadcast a data packet or a network management packet to all its neighbors except the one which sent the packet to it. This process continues till the node itself destination or the maximum number of hops for the packet is reached. In spite of its simplicity, the algorithm has some disadvantages such as implosion, overlap and resource blindness. Flooding do not check whether a node already

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received a data packet or not, so nodes receive the duplicate copy of the same packet from the neighboring nodes, this is called implosion and this consumes more energy. In a densely deployed network, nodes very close to each other, may sense the same environment. The neighboring nodes may receive the data packet from more than one nodes may contain similar information is called overlap. The resource blindness in flooding means, the protocols do not distinguish the nodes with high energy and nodes with low energy for data routing.

Gossiping [41] is similar to classic flooding in which energy is conserved by reducing the number of packets in the network. When a node receives a packet, it forwards the packet to a randomly selected neighbor in the network but not to all the neighbors as in classic flooding. The neighboring node in turn transmits the packet to one of its randomly selected neighbor, this continues until the packet reaches its destination. Gossiping chooses a single random node to transmit the data, no implosion is observed in the network. The propagation of packet through randomly selected nodes increases the delay to reach the destination.

Sensor Protocols for Information via. Negotiation (SPIN) [42] is the first data-centric protocol that was designed to reduce the redundant data and minimizes energy consumption in wireless sensor networks. These protocols are designed to address the deficiency of flooding (i.e. implosion, overlap and resource blindness) before transmitting data via negotiation and resource adaptation.

SPIN assign a high-level name to their data, called meta-data, which describes the characteristics of the data or information that needs to be shared. Three types of meta-data messages are exchanged between the nodes before transmitting the data: ADV, REQ and DATA. When a SPIN node has some piece of information, either from its own sensors or from a neighbor that it would like to share or exchange with other nodes in the network, the node

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broadcast ADV message to each neighbor. The nodes that are interested in this data will send back REQ message to ADV sender requesting the data. Once the transmitting node receives the REQ message, the data is disseminated to the interested nodes through DATA messages that contain the data. In this fashion, all data packets are propagated throughout the entire network.

The SPIN family includes four protocols, SPIN-PP, SPIN-BC, SPIN-RL, and SPIN-EC proposed in [43]. SPIN-PP and SPIN-EC for point-to-point communication networks and SPIN-BC and SPIN-RL for broadcast communication networks. SPIN-EC is an energy conserving version of SPIN-PP and SPIN-RL is a reliable version of SPIN-BC.

Energy-Aware Data-Centric Routing (EAD) [44] is a distributed routing protocol, which constructs a virtual backbone made of active sensors that are responsible for in network data processing and traffic relaying. EAD is a heuristic that builds a tree spanning all sensors in the network with maximum number of leaves and rooted at the sink. This way a virtual backbone infrastructure is responsible for routing the messages that are formed. All the leaf nodes can enter the sleep mode by turning off their transceiver and all other nodes corresponds to active sensors turn their transceiver on, only when events that should be reported to happen.

COUGAR [45] is a data-centric protocol which considers the network as a huge distributed database system and maximizes the energy saving by performing the in-network data aggregation. The COUGAR approach provides user and application programs with declarative queries of the sensed data generated by the source sensors. The COUGAR provides abstraction through an additional query layer that lies between the network and application layers.

COUGAR has some drawbacks. (a) the addition of a query layer on each sensor node may add extra overhead in terms of energy consumption and memory storage. (b) to obtain successful in-network data computation, synchronization among nodes is required (not all data are received at the same

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time from incoming sources) before sending the data to the leader node.

Active Query Forwarding in Sensor Networks (ACQUIRE) proposed in [46] is used for querying named data and considers the network as a database system. It provides excellent query optimization to answer specific types of queries, called one-shot complex queries for replicated data. ACQUIRE query consists of several sub queries for which several simple responses are provided by several relevant sensors. Each sub-query is answered based on the currently stored data at its relevant sensor. ACQUIRE allows a sensor to bring in an active query in a network following either a random or a specified trajectory until the query gets answered by some sensors on the path using a localized update mechanism. Unlike other query techniques, ACQUIRE allows the user to introduce a complex query into the network to be forwarded stepwise through a sequence of sensors.

An energy efficient flat routing protocol for WSN was proposed in [47]. SEER (A Simple Energy Efficient Routing Protocol) combines the metrics such as hop count, residual energy of the nodes to route a data to the BS. The protocol also uses the distances to the BS to make a routing decision to forward the data using shortest path. The results shows that the significant energy efficiency can be achieved if the sink node is based at the center of the network and all the sensor nodes are uniformly distributed from the BS.

The GRAdient Broadcast (GRAB) [48] protocol designed to handle robust data delivery in large sensor networks. The protocol constructs and maintains cost field, which provides direction to each sensor nodes to forward sensed data. It uses a band of interleaved mesh from each source to the receiver to forward the data. The width of the band controlled based on the amount of data carried in each data message by allowing the sender to adjust the robustness of data delivery. The results show that the GRAB can deliver 90 percent of the packets with relatively low energy consumption.

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### 3.3.2 Location based routing

Routing algorithms based on geographical location of the nodes in a sensor field is most important to make routing decision, as sensor measurements usually relate to a specific location. They use location information to guide routing discovery and maintenance as well as packet forwarding, thus enabling the best routing to be selected, reducing energy consumption and optimizing the whole network. The location information is useful to estimate the energy consumption by calculating the distance between any two of the particular nodes. Generally two techniques are used to find location, one is to find the coordinate of the neighboring node and other is to use GPS. Since, there is no addressing scheme for sensor networks like IP-addresses and they are spatially deployed on a region, location information can be utilized in routing data in an energy efficient way.

The Geographic and Energy Aware Routing (GEAR) protocol proposed in [49] uses a technique to disseminate queries, which include geographic attributes to appropriate regions of a network. The protocol takes nodes geographical position and energy consumption into account when nodes are selected for routing. Similar to directed diffusion, GEAR disseminates particular interests through the network. These interests are disseminated only to a specific region and not to the whole network, thus maximizing the energy saving than directed diffusion. In GEAR each node stores information about several parameters, essentially the distance, energy, and density of the areas that the data must cross. With these parameters, an estimation of the costs to reach a destination can be computed.

An energy aware localized routing protocol, called Localized Energy-Aware Restricted Neighborhood routing (LEARN) [50], which guarantee the energy efficiency of the route. The node selects the neighbor inside a restricted neighborhood that has the highest energy to travel long distance i.e. to the next

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hop node. If the largest energy node does not present in the restricted neighborhood, then LEARN fails. The protocol operation is also extended to three-dimensional (3D) networks, where it can derive its critical transmission radius in 3D random networks.

A localized power-aware routing algorithm is proposed in [51]. The protocol combines the power and cost for localized routing to minimize the energy consumption to extend the node lifetime. The transmission power can be made linear by placing the additional node between any two nodes based on the optimal power needed for transmission. This provides basis for the cost, power and the power-cost localized routing algorithms make routing decisions solely on the basis of location of their neighbors and destination. The power-aware routing attempts to minimize the total power needed to route a message between a source and a destination.

The SPAN proposed in [52] is a position based algorithm selects some nodes as coordinating nodes based on their locations. These coordinators form a network backbone and forward messages. The coordinators are selected only if two neighbors of a non-coordinator node cannot reach each other directly or via one or two coordinators. New and present coordinators are not necessarily neighbors, which in effect make the design less energy-efficient because of the need to maintain the positions of two or three-hop neighbors in the complicated SPAN algorithm.

### 3.3.3 Hierarchical based routing

Hierarchical routing techniques have become widely popular to achieve network scalability and energy efficiency. The energy-efficient routing in WSNs can be achieved by grouping sensor nodes into clusters. In a hierarchical routing, nodes with higher-energy can be used to process and transmit the data packets, while low-energy nodes can be used to perform the sensing in the

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proximity of the target. The creation of clusters and assigning special tasks to CHs can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster, performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. The detailed survey of hierarchical routing protocols are described in section 3.5.

## 3.4 Routing based on protocol operation

Depending on the protocol operation, routing in WSNs can be divided into five types: *Negotiation-based routing*, *Multi-path-based routing*, *Query-based routing*, *QoS-based routing* and *Non-coherent and Coherent data-processing based routing* [36].

### 3.4.1 Negotiation-based routing

Negotiation-based routing protocols exchange messages before actual data transmission begins, this helps in elimination of redundant data transmissions. The node in the network makes a decision whether the actual data is needed or not. This method reduces the number of transmissions and thus saves energy. The detection and elimination of redundant data are achieved by using high-level data descriptors to distinguish data. The overheads due to negotiation and size of data-descriptor must be smaller than the actual data size.

The flooding is not preferred for data dissemination, since it produces implosion and overlap between the sent data, hence nodes will receive duplicate copies of the same data. This consumes more energy and more processing by sending the same data to different sensor nodes. So, the main idea of negotiation based routing in WSNs is to suppress duplicate information and prevent redundant data from being sent to the next sensor node or the base-station by

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conducting a series of negotiation before the real data transmission begins.

The negotiation based protocol known as SPAM (Scalable Protocol for Anytime Multi-level negotiation) proposed in [53]. It has been used to manage a set of distributed sensor nodes in order to solve the problem of multiple target tracking. The main objective of the multiple-target tracking problem is distributing sensors to obtain the corresponding measurements for optimal tracking quality.

The data centric protocols like DD (Directed Diffusion) [38,54], SPIN (Sensor Protocols for Information via Negotiation) [42, 43] and GRAB [48] algorithms were shown to save energy through data negotiation and elimination of redundant data. These protocols have motivated the design of many other protocols with similar mechanism.

### 3.4.2 Multi-path based routing

Multi-path routing allows building and use of multiple paths for routing between a source-destination pair. The multi-path routing increases network performance by utilizing alternate paths between a source and a destination when the primary path fails. The multi-path routing provides benefits such as increased fault tolerance, load balancing, bandwidth aggregation, enhancing reliability, load balancing and improvement in QoS minimizing end-to-end delay. These are achieved at the cost of increased overhead in maintaining the alternate path.

SEIF is a secure and efficient intrusion-fault tolerant routing protocol for WSNs proposed in [55]. The protocol uses branch-aware flooding and constructs node-disjoint paths. The alternate paths are constructed starting at the 2-hops neighbors of the sink node instead of the actual sink neighbors. Each node considers new disjoint paths that come from nodes in different sub-branches. Each sensor nodes locally constructs routing tables without the

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need to depend on the sink. The data are forwarded by randomly chosen path among the discovered alternative paths to the BS. In this way, it avoids to use the same path, thus distributing the energy load among the sensor nodes.

The distributed secure multi-path routing [56] address the problem of how to choose secure and reliable paths in order to minimize the maximum damage that can be caused by a single-link attack. The routing decisions are made locally by nodes in the network, which minimize throughput loss under a single-link attack. Two algorithms are defined named the Bound-Control algorithm and the Lex-Control algorithm, to identify the alternative paths that can maximize the packet security and reliability. The Bound-Control algorithm is more effective to prevent the worst-case single-link attack when compared to the single-path approach, and that the Lex-Control algorithm further enhances the Bound-Control algorithm by countering severe single-link attacks and various types of multi-link attacks.

The Secure and Energy-Efficient Multi-path routing protocol (SEEM) [57] designed to effectively make the best use of the severely limited resource such as energy and security to the application as possible. In this protocol sink computes the alternative paths to reach each node and periodically selects a new path which consumes the minimum sum of energy to route the packet from the source to destination node. The modified Breadth First Search algorithm used to construct both disjoint and braided paths. SEEM is effectively resistive to some specific attacks that have the characteristics of pulling all traffic through the malicious nodes by advertising an attractive route to the destination. Since the sink is the one that decides on the route selection, attacks such as the sinkhole and wormhole which are no longer applicable.

The reliability of WSNs is enhanced by the multi-path routing proposed in [58] and useful for delivering data in unreliable environments. The protocol maintains several paths from source to destination to provide higher reliability and sends the same packet on each path. This technique will increase traffic

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significantly. Hence, there is a trade-off between the amount of traffic and the reliability of the network. This trade-off is studied using a redundancy function that is dependent on the multi-path degree and failing probabilities of the available paths.

The algorithm proposed in [59] routes data through a highest energy path i.e. nodes with largest residual energy. The protocol changes the path whenever a better path is discovered. The primary path will be used until its energy falls below the energy of the backup path, at which time the backup path is used. Using this technique, the nodes in the primary path will not deplete their energy resources through continuous use of the same route, hence achieving longer life.

### 3.4.3 Query-based routing

In query based routing all the nodes may store the sensed information locally, and only transmit in response to a query issued by the sink or nodes which needs the data. Therefore, the querying of sensors for desired information is a fundamental networking operation in WSNs. In this kind of routing, the queries are transmitted by destination nodes through the network, and a node matches with this query sends the data back to the node that initiated the query. Usually these queries are described in natural language or high-level query languages.

Rumor routing [60] is a variation of directed diffusion and used in applications where geographic routing is not feasible. Flooding is not feasible when there is only a small amount of data requested from the nodes. Flooding is preferred if the number of events is small and the number of queries is large. The main idea is to forward the queries to the nodes that have observed a particular event rather than flooding the entire network to retrieve information about the occurring events. The rumor routing algorithm tries to fit in

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between query flooding and event flooding.

The QBDCS (Query-Based Data Collection Scheme) [61] is designed to collect data from sensor nodes in the network with mobile sinks. Due to the mobility of sink, the Query and Response packets travel in the different routes. The minimization of energy consumption and packet delivery latency, the protocol estimates the time to deliver the packet and predicts the packet-sink meeting position. The optimal query time is defined by the QBDCS to send the Query packet and tailors the routing mechanism for partial node participation in a WSN.

In Multi-tier Grid Routing Protocol (MGRP) [62] a special hybrid multi-tier structure is introduced for data dissemination. The observations are divided into square grids of same size or different size. The optimized clusters are formed within each grid, which sends reliable data packets to its next higher CH. The uppermost CH from the neighbor grids further negotiates to construct the data d-tree from which the mobile sink can be reached and transmit queries.

### 3.4.4 QoS based routing

The quality-of-service in WSNs refers to the capacity of a network to deliver data both reliably and timely. Generally, a large amount of resources such as high throughput or transport capacity is not enough to satisfy an application's delay requirements. Consequently, the speed with which to propagate information could be as important as the throughput speed. The route selection is based on different QoS metrics such as end-to-end latency, reliability, energy usage or bandwidth.

An energy efficient and QoS aware multi-path routing protocol for WSN (EQSR) [63] was designed to satisfy the reliability and delay requirements of real time applications. The protocol maximizes the network lifetime through

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balancing energy consumption across multiple nodes. The end to end delay of each path is computed during path construction phase and then the paths with smaller delay are assigned more data than the other paths. The end to end delay is reduced by spreading out the traffic across multiple paths and increases the throughput by introducing data redundancy. The initial packet is split into several sub-packets, error correction codes are added and then the sub-packets are transmitted over the available multiple paths taking end to end delay into account.

The Multi-path and Multi-Speed routing protocol (MMSPEED) [64] is designed using cross layer approach between network and MAC layer to provide QoS differentiation in terms of reliability and timeliness. For reliability, protocol uses probabilistic multi-path forwarding to control the number of packet delivery paths depending on the required end-to-end reaching probability. The timeliness is provided with multiple network-wide speed options so that various traffic types can dynamically choose the proper speed options for their packets depending on their end-to-end deadlines. These two methods are desirable for scalability and adaptability in a large scale networks.

The SPEED protocol [65] provides soft real-time end-to-end guaranteed packet delivery. Each node maintains information about its neighbors and uses geographic forwarding to find the paths to reach BS. The SPEED ensures a certain speed for each packet so that each application can estimate the end-to-end delay for the packets by dividing the distance to the BS by the speed of the packet before making an admission decision. Each node estimates time delay by calculating the elapsed time before acknowledgment received from a neighboring node in response to a transmitted data packet. The SPEED performs better compared to DSR and AODV in terms of end-to-end delay and miss ratio. SPEED also offers low reliability since it does not transmit any redundant data packets and uses a single route for data delivery.

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### 3.4.5 Non-coherent and Coherent routing

The sensor nodes deployed in the WSNs are used to collect the data of the surrounding environment. So the processing of gathered data is the most important task and required at each node. The collaborative effort among the sensor nodes is required to process this data. In WSNs, data processing is divided into two methods, namely coherent and non-coherent data processing based routing.

In *Coherent Data processing-based routing*, the minimum data processing is carried out by each node and then the data is forwarded to the next level nodes called aggregators for further processing. The minimum processing includes tasks such as time stamping or duplicate suppression. This technique is energy efficient as all the processing is done by the nodes, which reduces the total time and energy consumption.

In *Non Coherent Data processing-based routing*, the sensor nodes locally process the raw data and then transmit it to the other nodes for further processing. The nodes that perform further processing are called the aggregators.

The complex processing is done by a single aggregator node in the Single Winner Election (SWE) algorithm proposed in [66]. This node is selected based on the residual energy and computational capability, known as Central Node (CN). In order to decide the CN node each node in the network broadcast an elect message and announces itself as a candidate for the same. After receiving the first batch of elect messages, the nodes will start comparing the proposed CN candidates with itself and respond with a second batch of elect messages that carries the result of this initial comparison. The second batch of message passing will generate further exchange of messages. The message that presents a better candidate, is recorded in the registry and then forwarded to all neighbors, otherwise the message is discarded.

The Multiple Winner Election (MWE) algorithm is an extension to SWE

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proposed in [66]. When all nodes are sources and transmit their data to the central aggregator node, a large amount of energy will be consumed; hence, this process has a high cost. The energy cost may be smaller only fewer number of sources that can send data to the central aggregator node. Instead of keeping a record of only the best candidate node (master aggregator node), each node will keep a record of up to  $n$  nodes of those candidates. The MWE process makes each sensor in the network to have a set of minimum-energy paths to each Source Node (SN). After that, SWE is used to find the node that yields the minimum energy consumption. This node can then serve as the central node for coherent processing.

### 3.5 Cluster based routing protocols

Recent years have witnessed the use of WSNs in many applications due to their ability to operate in unattended, harsh and inaccessible terrains. Based on this critical expectation, the sensor nodes are randomly deployed in the area of interest by relatively uncontrolled manner and the nodes form a network in an ad-hoc manner. The random deployment may cause damage to the sensor nodes and also to cover the wider area, large number of sensor nodes is expected. In addition, several applications of WSN require only the aggregate value, in such cases sensor nodes in different regions of the field can collaborate to aggregate their data and provide more accurate results about their local regions. Therefore it is required to design energy aware routing and data gathering protocols which offer scalability and long lifetime of the network.

In order to achieve scalability and data aggregation, grouping sensor nodes into clusters has been widely adopted by the research community. In clustered network, sensor nodes are partitioned into small group called *clusters*, each cluster has a leader/coordinator called as *cluster head (CH)* and a number of *member nodes*. Clustering results in a two-tier hierarchy in which CHs form

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the higher tier while the member nodes form the lower tier. The data flow in a clustered sensor network is shown in Figure 3.2 [67].

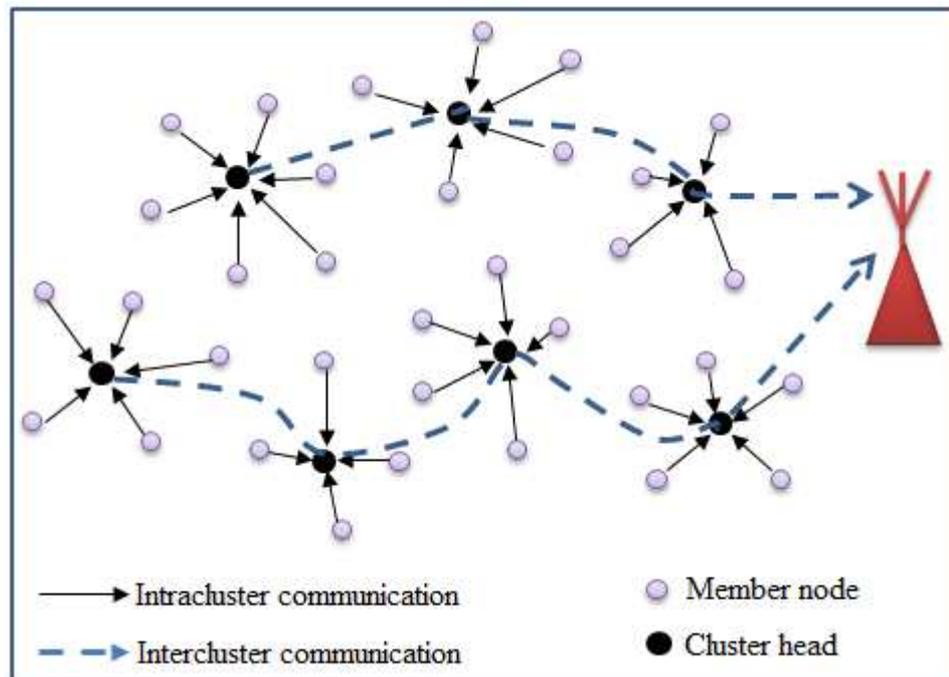


Figure 3.2: Data flow in clustered network

The member nodes do not communicate directly with the sink node, but they have to transmit their data to the respective CHs. The CHs will aggregate the data received and transmit them to the BS directly or using multi-hop communication via other CHs. This reduces the number of transmissions to the BS, thus minimizes the energy consumption. The CHs receive the data from member nodes, process it and transmit to the higher distances, all the CHs eventually spends more energy compared to member nodes. In order to balance the energy consumption evenly among the sensor nodes, the network is re-clustered periodically.

The BS is the data collection center, which receives data from all the CHs and it provides the access to the end user. Generally, the BS is considered to be fixed and away from the sensor nodes. The CH nodes actually act as gateways between the sensor nodes and the BS. The CHs are responsible for aggregating the data received from the member nodes, transmission of aggregated data to

the sink/BS and schedule creation in clusters etc. Ultimately, the clustering the network greatly minimizes number of communication to the BS, thereby increases the network lifetime.

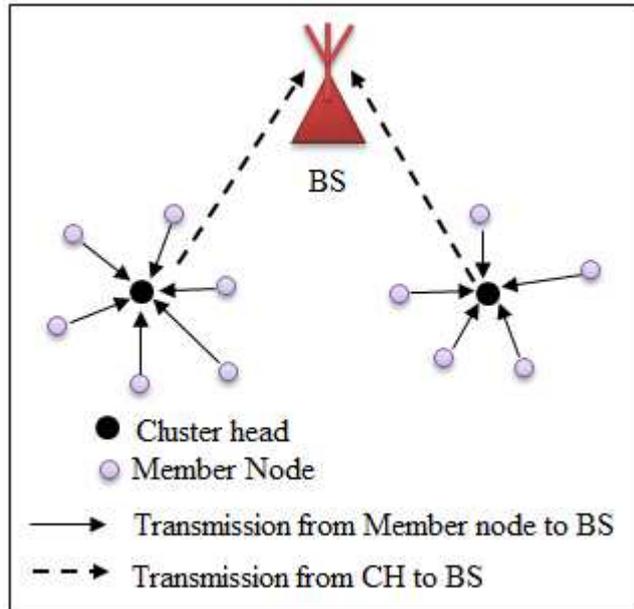


Figure 3.3: Single-hop clustering architecture

Usually WSNs contain large number of sensor nodes in a wide area and the BS may be located far from the sensor nodes. Thus, partitioning the entire network into distinct clusters replaces the one-hop long-distance transmission by multi-hop short-distance data forwarding. This would minimize the energy expenditure for data communications, provides load balancing and scalability when the network size grows. Based on the mode of communication, the clustering strategy could be single-hop cluster or multi-hop cluster [68] as shown in Figure 3.3 and Figure 3.4 respectively. In single-hop cluster the CHs directly communicates with the BS. This leads to the higher energy consumption in CHs, since BS is far away from the sensor field. In order to achieve energy efficiency, multi-hop communication architecture is preferred. The data is forwarded to BS using intermediate CHs. Based on the hierarchy of clusters, the clustering strategies can also be divided into single-level or multilevel clustering. The system architecture of multilevel hierarchical clustering [68] is

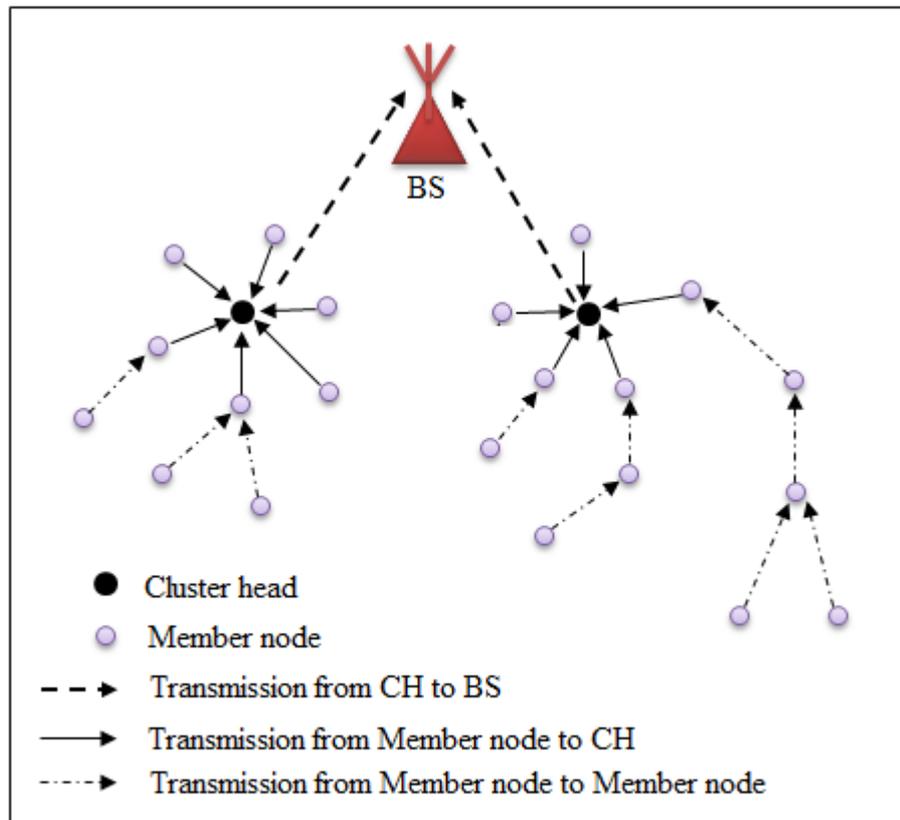


Figure 3.4: Multihop clustering architecture

illustrated in Figure 3.5.

In the past few years, WSNs gained increased interest in the applications such as disaster management, combat field reconnaissance, border protection and security surveillance. In most of the applications sensors are expected to be remotely deployed in large numbers and to operate autonomously in unattended environments. To support scalability, data aggregation and prolonging the network lifetime, several energy efficient cluster based routing [1, 69–88] techniques have been proposed by many research communities for ad hoc and WSNs.

One of the first and most popular clustering protocols proposed for WSNs was LEACH (Low Energy Adaptive Clustering Hierarchy) [1, 69]. It was the first cluster based protocol for WSN that includes distributed cluster formation. The primary objectives of the protocol are to reduce energy consumption and distribute energy load evenly among the sensor nodes in the network.

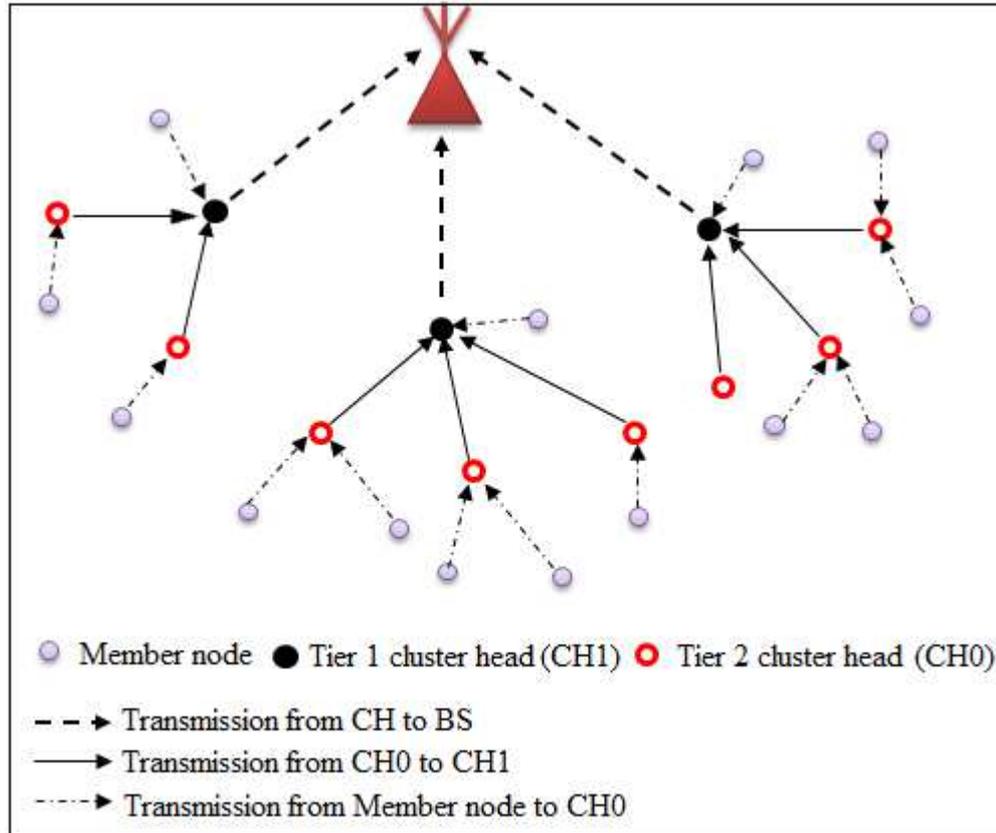


Figure 3.5: Multilevel hierarchical clustering architecture

The load balancing is achieved by adaptive clustering, i.e., re-clustering after a given interval with a randomized rotation of the energy-constrained CH so that energy dissipation in the sensor network is uniform.

LEACH operation is divided into number of rounds, each round starts with setup phase followed by steady state phase. In the setup phase, the clusters are organized and CHs are selected. In the steady state phase, the actual data transfer to the BS takes place. In order to minimize the energy consumption the steady state phase is made longer than the duration of the setup phase.

During the setup phase, algorithm predetermines the  $p$  number of nodes being elected as CHs. The CHs are selected as follows: a sensor node chooses a random number,  $r$ , between 0 and 1. If this random number is less than a threshold value,  $T(n)$ , the node becomes a CH for the current round. The threshold value is calculated based on the desired percentage of nodes to become a CH, the current round, and the set of nodes that have not been selected

as a CH in the last  $(1/P)$  rounds, denoted by  $G$ . This is given by:

$$T(n) = \begin{cases} \frac{p}{1-p*(r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{Otherwise} \end{cases} \quad (3.1)$$

where  $G$  is the set of nodes that have not been CHs in the last  $1/p$  rounds.

After the CHs have been elected, an advertisement message is broadcasted to the rest of the member nodes in the network that they are the new CHs. The member nodes inform the appropriate CHs that they will be members of the cluster based on the signal strength of the advertisement message received. After receiving all the messages from the nodes that would like to be included in the cluster and based on the number of nodes in the cluster, the CH node creates a TDMA (Time Division Multiple Access) schedule and assigns each node a time slot when it can transmit. This schedule is broadcasted to all the nodes in the cluster.

During the steady state phase, the sensor nodes can begin sensing and transmitting data to the CHs. The CH node, after receiving all the data, aggregates them before transmitting to the BS. After a certain time, which is determined *a priori*, the network goes back into the setup phase again and enters another round of selecting new CHs.

LEACH-centralized (LEACH-C) is proposed as an improvement of LEACH which uses a centralized clustering algorithm to create the clusters [69]. In LEACH-C, the BS collects the information of the position and energy level from all sensor nodes in the networks. Based on this information, the BS calculates the number of CH nodes and configures the network into clusters.

Power-efficient gathering in sensor information systems (PEGASIS) is an enhancement over the LEACH protocol was proposed in [70]. It is chain based protocol, in which nodes need to communicate with their closest neighbors and take turns in communicating with BS. Each node in the network uses signal strength to locate the closest neighbor. The chain in PEGASIS consist of

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nodes closest to each other that forms a path to the BS. The aggregated form of the data will be sent to the BS by any node in the chain and the nodes in the chain will take turns sending to the BS. This reduces the power required to transmit data per round because the power draining is spread uniformly over all nodes.

However, the assumptions in PEGASIS may not always be realistic. a) PEGASIS assumes that each sensor node is able to communicate with the BS directly. In practical cases, sensor nodes use multi-hop communication to reach the BS. b) it assumes that all nodes maintain a complete database about the location of all other nodes in the network, but the method by which the node locations are obtained is not outlined. c) it assumes that all sensor nodes have the same level of energy and are likely to die at the same time. Fourth, although in most scenarios sensors will be fixed or immobile as assumed in PEGASIS, some sensors may be allowed to move and thus affect the protocol functions.

The Concentric Clustering Scheme (CCS) [72] proposed to maximize the network lifetime by reducing the energy consumption loopholes in PEGASIS. The protocol divides the network into number of concentric circular tracks, each track represents a cluster and have assigned a level. The level number is assigned from the BS in increasing order. Thus, each node in the network is assigned with its own level. Similar to PEGASIS, chains are constructed within each circular track. The protocol selects a CH in each level based on the value  $i \bmod ML$ , where  $ML$  is the number of nodes in the cluster and  $i$  is the round number. All the nodes in each cluster transmits the data to the nearest node, the received data is fused with its own data and forwarded to the next node along the chain. At the end the CH node receives at the most two messages and transmit it to the lower level CHs. The data is forwarded from higher level to lower level and finally, the CH in level 1 transmit it to BS. Compared to PEGASIS, CCS reduces the distance over which the data can be

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transmitted to BS and the reverse data flow from the BS is also reduced.

Energy Efficient Hierarchical Clustering (EEHC) proposed in [71] is a distributed,  $k$ -hop hierarchical clustering algorithm aiming at the maximization of the network lifetime. Initially, algorithm selects *volunteer* CHs with a certain probability  $p$  and advertises its election to the neighboring nodes within its communication range. Next, nodes which are  $k$ -hop away from the *volunteer* CH receive the election message either directly or through intermediate nodes. All the nodes which receive election message and are not CH, becomes a member of the closest CH. In addition, if the election messages do not reach a node within a certain time interval  $t$  (i.e. those are not within  $k$ -hops of all *volunteer* CHs), the node becomes a *forced* CH that are neither CHs nor belong to a cluster. The algorithm runs initial clustering process recursively to build multiple levels of cluster hierarchy. The data from the CHs belongs lower level hierarchy are transmitted to the BS through the next level CHs using multi-hop communication. The energy consumption in EEHC for network operations such as data gathering, aggregation, transmission to the BS, etc. clearly depends on the parameters  $p$  and  $k$  of the algorithm.

The first unequal clustering model was proposed in [73], called Unequal Clustering Size (UCS) to balance energy consumption. The sensor field is divided into two concentric circles called layers and each layer has some number of clusters of same size. The size and shapes of the clusters of two layers are different. The protocol assumes that the BS is located in the center of the network and CHs locations are determined “p priori” which are positioned symmetrically in concentric circles around the BS. To minimize the energy consumption within the clusters, every CH should be placed at the center of the cluster. CHs are deterministically deployed in the network and are assumed to be super nodes which are much more expensive than member nodes. The coverage of the clusters can be varied by varying the radius of the first layer around the BS, so the number of nodes in a particular cluster also changed.

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Every CH transmit data to BS by choosing the closest CH in the direction of BS.

The UCS has two advantages compared to LEACH. First, the UCS can maintain uniform energy consumption among CHs. This can be achieved by varying the number of nodes in every cluster with respect to the expected communication load. Secondly, protocol creates two layered network model and two-hop inter-cluster communication method, this results in a shorter average transmission distance compared with LEACH, thus effectively reduces the total energy consumption.

The flow-balanced routing (FBR) protocol proposed in [74] for multi-hop clustered WSNs. The protocol attempts to achieve both power efficiency and coverage preservation. The protocol consists of four phases: network clustering, multi-hop backbone construction, flow-balanced transmission, and rerouting. The several nodes are grouped into one cluster on the basis of overlapping degrees of sensors. In backbone construction phase, a novel multi-level backbone is constructed using the CHs and the BS. The flow-balanced routing assigns the transferred data over multiple paths from the sensors to the BS in order to equalize the power consumption of sensors. When the CH ran out of energy, the CH drops out from the backbone and in such places the network topology is reconfigured in rerouting phase. The two metrics called the network lifetime and the coverage lifetime are considered to evaluate the performance of FBR protocol. The simulation results show that FBR yields both much longer lifetime and better coverage preservation.

An Energy Efficient Clustering Scheme (EECS) for the periodical data gathering applications was proposed in [75]. In EECS, the network is partitioned into several clusters and uses single-hop communication between the CH and the BS. In EECS, CH candidates compete for the ability to elevate to CH for a given round. Each CH candidates broadcast their residual energy to neighboring candidates. If a given node does not find a node with more

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residual energy, it becomes a CH. EECS extends LEACH by dynamic sizing of clusters based on cluster distance from the BS. The intra-cluster communication cost is reduced by choosing the closest CH.

The hierarchical protocol Threshold sensitive Energy Efficient sensor Network protocol (TEEN) [76] proposed to cope with sudden changes in the sensed attributes such as temperature. It combines the hierarchical technique in line with a data-centric approach. The nodes sense their medium continuously, but the transmission is done less frequently. This can reduce the energy consumption potentially be much less than that in the proactive network.

In TEEN, a CH broadcast its members a hard threshold (HT) and a soft threshold (ST). The HT tries to reduce data communications by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The ST further reduces data communications by not transmitting data when there is little or no change in the sensed attribute. At the expense of increased energy consumption, a smaller value of the ST generates more accurate information of the network, thus users can control the trade-off between energy efficiency and data accuracy by the parameters adjustment. Moreover, the ST can be varied and the users can change the fresh parameters as required at every cluster change time.

Adaptive Periodic Threshold-sensitive Energy Efficient Sensor Network protocol (APTEEN) [77] is an extension to TEEN and aims at both sending periodic data and react to time critical events. On the other hand, APTEEN combines the feature of proactive and reactive networks and transmits data in adjustable time intervals while it still responds to sudden changes in attribute values. APTEEN is based on a query system which allows three types of queries: historical, on-time, and persistent which can be used in a hybrid network. The CH selection procedure is based on the method used in LEACH-C.

In APTEEN, CHs broadcast the four parameters: Attributes (a set of physical parameters which the user is interested in obtaining data about),

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Thresholds ( consists of the HT and ST ), Schedule (a TDMA schedule telling each node when it can transmit) and Count time (CT) (the maximum time period between two successive reports sent by a node).

All nodes in APTEEN sense the environment continuously, but the data transmission happens only when sensed data value is at or greater than HT. For a node, if a data transmission does not take place in time period equal to the count time, it must sense and transmit the data again. In APTEEN, each CH aggregates the data from the member nodes within its cluster and transmits the aggregated data to the BS. The protocol assumes that the data received from member nodes are sufficiently correlated, thus it reduces a large amount of redundancy of the data to be forwarded to the BS. Moreover, a modified TDMA schedule helps to implement the hybrid network by assigning transmission slot to each node in the cluster. In addition, APTEEN offers a lot of flexibility by allowing the user to set the CT interval and the threshold values for energy consumption can be controlled by changing the CT as well as the threshold values.

Hybrid Energy-Efficient Distributed clustering (HEED) [78] is a multi-hop, distributed clustering scheme in which CH nodes are selected from the deployed sensors. HEED do not select CHs randomly as in LEACH, but considers residual energy of nodes and communication cost for the construction of clusters. In general, the CHs nodes have high residual energy compared to member nodes of the cluster. The probability of selecting two CHs within each other's communication range is very small in HEED and ensures that CHs are well distributed in the network. The operations in HEED are divided into following three phases:

*Initialization phase:* The algorithm first sets an initial percentage (i.e.  $C_{prob}$ ) of nodes to become CHs among all sensors, this limit the initial CH announcements to the other sensors. Each sensor sets its probability (i.e.  $CH_{prob}$ ) of

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becoming a CHs as follows:

$$CH_{prob} = C_{prob} * \frac{E_{residual}}{E_{max}} \quad (3.2)$$

where  $E_{residual}$  is the current energy in the sensor, and  $E_{max}$  is the maximum energy, which corresponds to a fully charged battery.  $CH_{prob}$  is not allowed to fall below a certain threshold  $p_{min}$ , which is selected to be inversely proportional to  $E_{max}$ .

*Repetition phase:* During this phase, each sensor nodes goes through several iterations until it finds the CH that it can transmit with least transmission power (cost). If the nodes do not hear from any of CH, the sensor node elects itself to be a CH and transmit an announcement message to its neighbors informing them about the change of status. Finally, each sensor doubles its  $CH_{prob}$  value and goes to the next iteration of this phase. HEED terminates this phase when its  $CH_{prob}$  value equals 1.

A sensor node could announce two types of CH status to its neighbors namely Tentative status and Final status. The node becomes a tentative CH if its  $CH_{prob}$  is less than 1. It can change its status to a regular node at a later iteration if it finds a lower cost CH. The node permanently becomes a CH if its  $CH_{prob}$  has reached 1.

*Finalization phase:* During this phase, each sensor makes a final decision on its status. It either picks the least cost CH or pronounces itself as CH.

Power-Efficient and Adaptive Clustering Hierarchy (PEACH) [79] protocol is proposed for WSNs to extend network lifetime by reducing the energy consumption. The nodes in the network can recognize the source and destination of the data packets by overhearing characteristics of wireless communication. In PEACH, the clusters are formed without additional transmission overhead such as advertisement, announcement, joining, and scheduling messages. PEACH is probabilistic routing protocol and provide an adaptive multi-level clustering. PEACH is scalable and very efficient under various circumstances

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than the existing clustering protocols.

PEACH may be suitable to both location unaware and location aware WSNs. In certain applications, the location information of the node is unavailable. In such applications, location-unaware PEACH protocol can be used. The location-aware PEACH operates when the localization mechanism such as a GPS-like hardware is available on sensor nodes.

A Distributed Weight-based Energy-efficient Hierarchical Clustering protocol (DWEHC) [80], is a distributed clustering algorithm to improve performance of HEED by constructing balanced cluster sizes and optimizing the intra cluster topology using location awareness of the sensor nodes. DWEHC used the same assumptions similar to HEED, such as network size, node density and residual energy for the selection of CH.

The DWEHC uses the locally calculated parameter weight for the selection of CH. After discovering the neighboring nodes, each sensor calculates its weight. Weight is the function of residual energy, initial energy, cluster range and the distance between the nodes. In a neighborhood, the node with largest weight would be selected as a CH and the remaining nodes become members of the cluster. At this stage, all the member nodes become first level nodes, since they have a direct link to the CH. A node progressively adjusts such membership to reach a CH using the least amount of energy. Basically, a node checks with its non-CH neighbors to find out their minimal cost for reaching a CH. Given the node's knowledge of the distance to its neighbors, it can assess whether it is better to stay a first-level member or become a second-level one reaching the CH over a two-hop path. Compared to HEED, the DWEHC algorithm has been shown to generate more well-balanced clusters as well as to achieve significantly lower energy consumption in intra-cluster and inter-cluster communication.

In [81], author proposed a two routing protocols to enhance the network lifetime: Two Tier Cluster Based Routing Protocol (TTCRP) and power con-

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trol algorithm (PCA). TTCRP configures the nodes in the form of clusters at two levels. At the first level sensor nodes join pre designated resource rich CHs. These CHs form the second level of clusters to deliver data to the BS. The CHs are equipped with dual channels in which different channels are used for communication at both tiers. The CHs receive data from their members at one channel and use second channel to send it to the BS through other CHs. The proposed scheme implements a power control algorithm to allow the isolated sensor nodes as well as cluster-heads to dynamically change their transmission power for connecting sensor nodes with unreachable clusters and hence provides network robustness.

In cluster based WSNs, the energy consumption among nodes are more imbalanced due to the non-uniform distribution of sensors. In [82] an energy-aware clustering and a cluster-based routing algorithms are proposed. The clusters of even sizes are constructed by using competition range. The energy consumption among CHs is balanced by adjusting intra-cluster and inter-cluster energy consumption. Each CH chooses a CH with higher residual energy and fewer cluster members as its next hop. The imbalanced energy consumption caused by non-uniform node distribution is solved by increasing forwarding task of the CHs in sparse areas.

Energy-efficient Clustering (EC) is a scalable, distributed, and energy-aware clustering algorithm proposed in [83]. EC determines suitable cluster sizes depending on their hop distances to the data sink. The algorithm aims to achieve approximate equalization of node lifetimes and reduced energy consumption levels. By tuning the probability that a node becomes a CH, EC effectively controls cluster sizes, which allows an approximately uniform use of the overall energy resources of a WSN. An energy-efficient multi-hop data collection protocol was proposed to evaluate the performance of EC and calculate its energy consumption amounts. The protocol targets at low signaling overhead and an overall low level of energy consumption. The results demon-

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strate that EC extends network lifetime and achieves energy equalization more effectively than two well-known clustering algorithms, HEED and UCR.

A new clustering algorithm based on the optimum parameters is proposed in [84]. The protocol is adopted to prolong the network lifetime by minimizing the energy consumption for inter-cluster and intra-cluster communication. The algorithm divides all the nodes into static clusters with the optimum parameters. The clusters near to the BS have smaller size than those farther away from the BS. The different sizes of the clusters assure that the CHs closer to the BS have enough energy to transmit the fused data comes from other CHs farther away from the BS. In intra-cluster, the current CH continuously acts as the local control center to reduce the frequency of updating cluster and the energy consumption for new CH set-up. In this clustering algorithm, the energy consumption for communication between the inter-cluster and the intra-cluster is reduced.

An Energy Efficient Heterogeneous Clustered Scheme (EEHC) [85] is proposed for heterogeneous WSNs. The election probabilities of CHs are weighted by the residual energy of a node relative to that of other nodes in the network. The algorithm is based on LEACH and works on the election processes of the CH in presence of heterogeneity of nodes in hierarchal WSN. In the EEHC algorithm, there is an optimal percentage of nodes have to become CH in each round. Simulations results show that EEHC is more effective in prolonging the network lifetime compared with LEACH.

Distributed Linear Regression based Data Gathering (DLRDG) [86] is a framework for cluster based data gathering in WSNs. The distributed linear regression model is used to implement the subtle trade-off between communication and calculation cost. It uses the concept of approximation based on linear regression by less than a pre specified threshold. After distributed regression computing, CH node has the coefficients of the estimate model to predict the approximation of the monitoring event. By less communication

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energy consumption, the network system can provide queries about the distant past or future by storing regression model coefficients, which determine a compact summary of sensor readings at a given point in time. For the sensor readings with linear character in WSN, a simple polynomial model is sufficient to represent the monitoring data.

Distance Aware Intelligent Clustering (DAIC) [87] is a hierarchical routing protocol proposed to minimize the energy consumption and extend the network lifetime. The protocol divides the network into two tiers: primary and secondary. The CHs of the primary tier are selected by considering the distance between the CH nodes and BS. The protocol determines the number of CHs dynamically based on the number of alive nodes in the network, which avoids the selection of unnecessarily large number of CHs. The non-CH nodes transmit the data to the primary CHs and the CH nodes at the secondary tier transmit the data to the BS. For uniform distribution of energy load in the network, DAIC uses rotation of CH roles in each round of communication and selects CHs on the basis of residual energy.

In [88], author proposed a cluster-based routing protocol called Base Station Controlled Dynamic Clustering Protocol (BCDCP), which uses BS to perform energy intensive tasks. The high-energy BS used to set up clusters, identifying routing paths and performs randomized rotation of CHs. In BCDCP, approximately equal number of member nodes is assigned to each CH. This avoids CH overload, uniform placement of the CHs in the network and utilizes the CH-to-CH routing to transfer the data to the BS.

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