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An Investigation into Clustering Routing Protocols for Wireless Sensor Networks

Abdulazeez F. SALAMI, Farhat ANWAR and Akhmad Unggul PRIANTORO
International Islamic University Malaysia (IIUM)
P. O. Box 53100 Gombak, Malaysia.
E-mail: kermkerm1@yahoo.com

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Abstract: Recent advances in wireless sensor technology have led to the evolvement of new protocols specially designed for wireless sensor networks where energy conservation is of utmost importance. Most of research effort and focus, however, has been concentrated on routing protocols since they might differ depending on the application and network architecture used in their design. Cluster-based routing protocols for large-scale wireless sensor networks are more advantageous compared to flat-based routing protocols. Clustering minimizes the number of messages that are propagated throughout the network whenever an event is sensed. In this paper, an investigation into clustering routing protocols for wireless sensor networks is presented together with a highlight of their key features for comparison. *Copyright © 2009 IFSA.*

Keywords: Wireless sensor networks, Cluster-based routing protocol, Flat-based routing protocol

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1. Introduction

Recent advances in micro-electro-mechanical systems technology, wireless communications and digital electronics have led to the proliferation of smart and miniaturized sensors which leveraged the idea of wireless sensor networks and their versatility for remotely monitoring events [2], [3], [4]. Applications of wireless sensor networks include tracking migration of animals, monitoring wild fires, security and tactical surveillance, weather monitoring, intrusion detection, distributed computing, inventory control, detecting ambient conditions such as temperature, movement, sound, light, or presence of certain objects and other numerous uses [1], [2], [3], [5]. Sensor networks contain hundreds or thousands of sensor nodes that work in a collaborative manner to achieve a sensing task.

Wireless sensor network architecture comprises of a sink and other sensors. These sensors communicate with each other to forward messages to the sink, which is the entity interested in monitoring one or more event in the network. A sensor node has limited sensing, computing and communication capabilities [1], [3], [4].

Sensor networks have only a limited amount of energy available to them as they derive their energy from an in-built battery and not from a constant power supply. Moreover, because these nodes are deployed in places where it is difficult to replace the nodes or batteries, it is desirable to increase network lifetime. Reception and transmission of data is the most energy-consuming operation in a sensor node. In order to conserve energy, the sensor nodes should use low duty cycling by turning off their radio but at the same time still have the ability to sense their environment for desired events. Data aggregation, data compression, data fusion, data filtering and other in-network processing functions are all ways to minimize transmission of redundant data to the sink and hence preserving energy [2], [3], [4].

A large number of routing protocols have been recently developed for wireless sensor networks [5], [6]. Due to the energy constraints in sensor nodes, developing energy-efficient routing algorithms has been a challenging issue in the field of wireless sensor networks. Recently, clustering routing protocols have been developed with the aim of conserving energy by reducing the traffic toward the sink [3], [7], [8], [9], [10], [12], [13]. Although clustering may introduce overhead as a result of cluster configuration and their maintenance, earlier research work has shown that clustering routing protocols possess better energy consumption and performance than flat network topologies in wireless sensor networks [3], [4].

In this paper, an investigation into clustering routing protocols for wireless sensor networks is presented. The aim is to foster better understanding of the current clustering routing protocols and to point out areas of improvement which can be further researched upon. The remainder of the paper is organized as follows: In Section 2, investigation into selected clustering routing protocol is carried out. Section 3 summarizes the key features of these protocols and section 4 concludes this paper.

2. Clustering Routing Protocols

In this section, selected clustering routing protocols for wireless sensor networks are surveyed and examined.

2.1. Low-Energy Adaptive Clustering Hierarchy

The Low-Energy Adaptive Clustering Hierarchy (LEACH) is a self-organizing, adaptive clustering-based routing protocol that minimizes energy dissipation in sensor networks [2], [7]. It is one of the most popular hierarchical routing algorithms and it was one of the pioneering clustering-based techniques for wireless sensor networks [3], [4], [5]. The fundamental idea behind LEACH is the utilization of randomized rotation of cluster heads so that the high energy dissipation in communicating with the sink is distributed evenly to all sensor nodes in the sensor network [2], [3], [4], [6].

Mode of Operation: The operation of LEACH is separated into two phases, namely; the set-up phase and the steady phase. During the set-up phase, a sensor node chooses a random number between 0 and 1. If this random number is less than the threshold T(n), the sensor node is a cluster head. T(n) is calculated as:

$$T(n)=\begin{cases}\dfrac{P}{1-P[r \bmod (1/P)]} & \text{if} \quad n \in G,\\ 0 & \text{otherwise}\end{cases}$$

where P is the desired percentage to become cluster head (in this protocol, the optimal number of cluster head is estimated to be 5% of the total sensor nodes); r is the current round; and G is the set of nodes that have not been selected as cluster heads in the last 1/P rounds [3], [5], [6], [7].

After the selection of the cluster heads, they advertise to all nodes in the sensor network that they are the new cluster heads. Once the nodes receive this advertisement, they determine which cluster they want to belong to based on the signal strength of the advertisement. The stronger the signal strength, the closer is the cluster head to the node, thus, requiring minimum communication energy. The nodes then inform the closest cluster heads that they will be a member of the cluster. Afterwards, the cluster heads assign the time in which the nodes can send data to the cluster heads based on a TDMA approach. During the steady phase, the nodes begin sensing and transmitting data to cluster heads. The cluster heads also aggregate data from the member nodes in their cluster before sending these data to the sink. After certain duration in the steady phase, the network goes into the set-up phase again and it enters another round of selecting new cluster heads. It must also be mentioned that LEACH uses single-hop communication from the nodes to the cluster heads and from the cluster heads to the sink [3], [5], [6], [7]. A description of the LEACH protocol is as shown in Fig. 1.

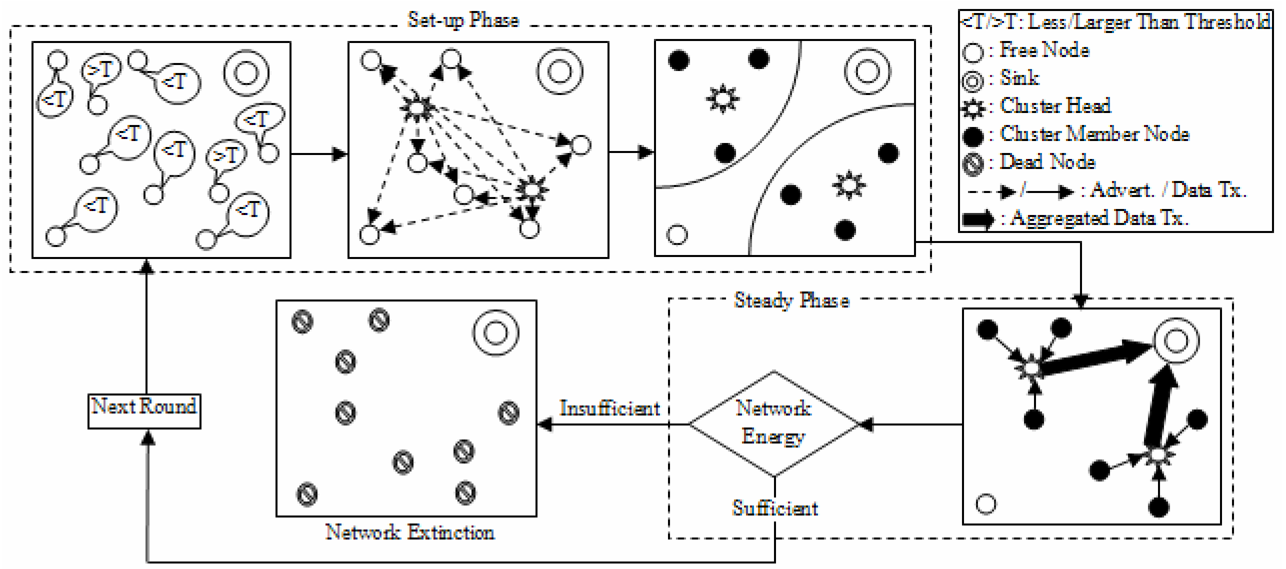

Fig. 1. LEACH Protocol.

Performance: The simulation results presented in [7] have shown that the sensor nodes reach energy depletion randomly and the dynamic clustering increases the network lifetime. These simulations have also shown that LEACH can achieve as much as a factor of 8 in terms of reduction in energy dissipation compared to conventional routing protocols like direct communication and minimum-energy multi-hop routing protocol.

The randomized rotation of the cluster head maximizes the power usage for each and every node. LEACH performs local data aggregation in the cluster heads to reduce the amount of data being sent from the clusters to the Sink, which further reduces energy dissipation and enhances the network lifetime. The LEACH protocol is completely distributed and requires no global knowledge of network.

The clustering operations are negotiation-based and LEACH uses a TDMA/CDMA MAC scheme to reduce inter-cluster and intra-cluster collisions.

LEACH uses single-hop communication as shown in Fig. 1. Therefore, the LEACH protocol faces scalability problems from large-scale networks when the sensed data is to be relayed in long distance communications. The idea of dynamic clustering brings extra overhead such as cluster head changes, advertisements which may diminish the gain in energy consumption. Data collection is centralized and it is performed periodically but a user may not need all the data immediately. Hence, periodic data transmissions are unnecessary which may drain the limited energy of the sensor nodes. It is not obvious how the number of the predetermined cluster heads is going to be uniformly distributed throughout the network because there is the possibility that the elected cluster heads will be concentrated in one part of the network. Hence, some nodes will not have any cluster heads in their vicinity.

2.2. Threshold-Sensitive Energy-Efficient Sensor Network Protocol

Two hierarchical routing protocols called TEEN (Threshold-Sensitive Energy-Efficient Sensor Network) and APTEEN (Adaptive Periodic Threshold-Sensitive Energy-Efficient Sensor Network) were proposed in [8] and [9] respectively for time-critical applications. TEEN is essentially a hybrid of hierarchical clustering and data-centric mechanisms and it is also a protocol designed to be responsive to sudden changes in the sensed attributes such as temperature in the sensor network [3], [4], [5].

Mode of Operation: The algorithm first goes through cluster formation by grouping nodes which are closer to each other as clusters with nth level cluster heads. The nearer the cluster to the sink, the higher the level attached to the cluster head and the reverse goes for clusters farther from the sink. Hence, the farthest cluster from the sink will have a 1st level cluster head and the nearest cluster to the sink will have an nth level cluster head where n is the maximum distance it takes to traverse the hierarchical tree from the farthest cluster head to the sink through the other cluster heads [1], [3], [5], [6], [8].

After cluster formation, the cluster heads broadcast two thresholds to their member nodes which are namely; hard and soft threshold for the sensed attributes. Hard threshold is the minimum possible value of the monitored attribute which will trigger the nodes to turn their radio on and transmit to their cluster heads. The nodes sense their environment periodically continuously. The first time a parameter from the attribute set reaches its hard threshold value, the node switches its transmitter on and sends the sensed data. In this algorithm, the sensed value is stored in an internal variable, called sensed value. The nodes will transmit data in the current cluster period only when the following conditions are true: (1) The current value of the sensed attribute is greater than the hard threshold (2) The current value of the sensed attribute differs from SV by an amount equal to or greater than the soft threshold. Consequently, soft threshold will help reduce transmissions if there is little or no change in the sensed attributes [1], [3], [4], [5], [6], [8].

APTEEN is an extension of the TEEN protocol which aims at capturing periodic data collections and at the same time reacting to time-critical events. It is a hybrid protocol that changes the periodicity or threshold values used in the TEEN protocol according to the user needs and the type of the application. The architecture is the same with TEEN but here, the base station forms the clusters and the cluster heads broadcast the following parameters, (1) Attributes (a set of physical parameters which the user is interested in obtaining information about), (2) Thresholds (this parameter consists of the hard and soft threshold), (3) Schedule (a TDMA schedule assigning a slot to each node) and (4) Count Time (the maximum time period between two successive reports sent by a node). In APTEEN, the node senses the environment continuously, and only those nodes which sense a data value at or beyond the hard threshold transmit. Once a node senses a value beyond HT, it transmits data only when the value of that attributes changes by an amount equal to or greater than the soft threshold just like in TEEN protocol. If a node does not send data for duration equal to the count time, it is forced to sense and retransmit the data. A TDMA schedule is used for assigning a transmission slot to each node. It must also be mentioned that cluster heads perform data aggregation to save energy [1], [3], [4], [5], [6], [9]. A description of the TEEN protocol is as shown in Fig. 2.

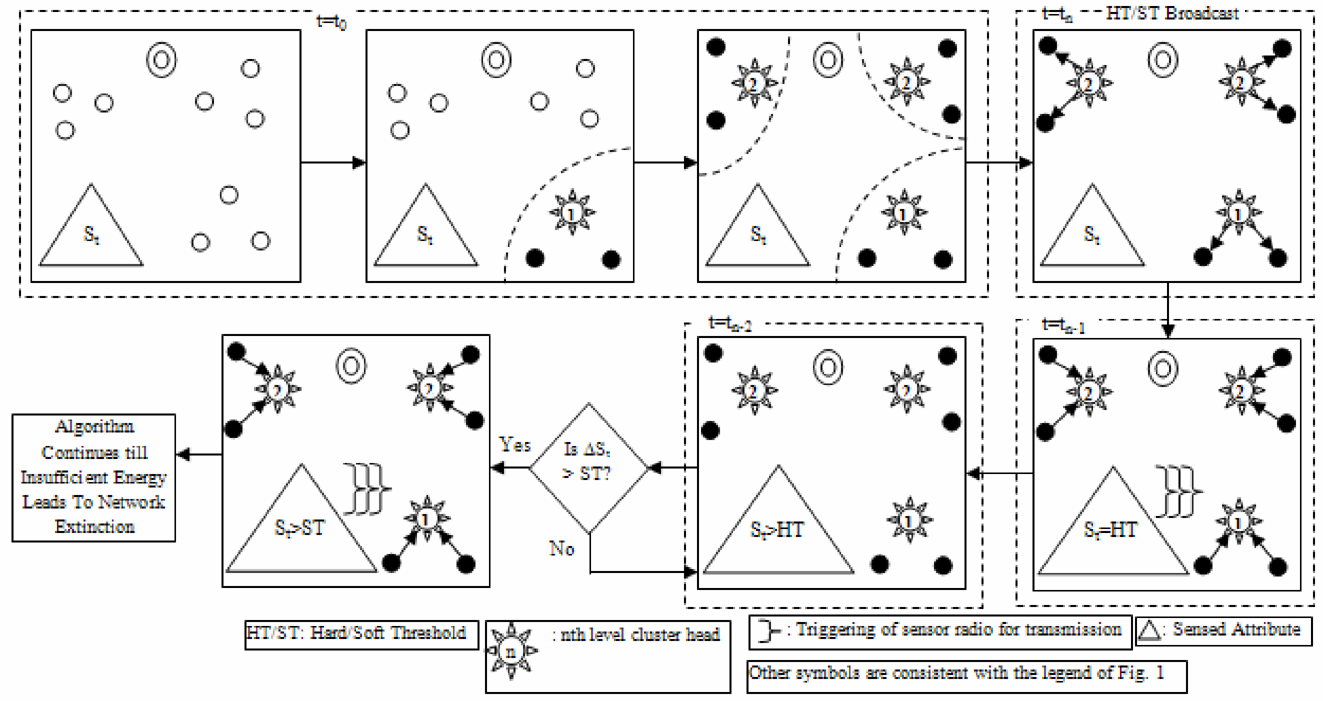

Fig. 2. TEEN Protocol.

Performance: The simulations presented in [8] and [9] shows that both TEEN and APTEEN perform better than LEACH protocol. The results show that APTEEN's performance is between that of LEACH and TEEN in terms of energy dissipation and network lifetime. TEEN gives the best performance since it decreases the number of transmissions.

The hard threshold reduces the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest and the soft threshold further reduces the number of transmissions that might occur if there is little or no change in the sensed attribute. Hence, reducing the number of transmissions leads to energy saving. TEEN is suitable for time-critical sensing applications and the energy consumption in this protocol is less than that of other proactive networks. APTEEN combines proactive and reactive policies; it offers a lot of flexibility by allowing the user to set the count time interval (which is the maximum time period between two successive reports sent by a node); and energy consumption is controlled using the threshold values and the count time.

The major drawback of the TEEN algorithm is that if the thresholds are not received, the nodes will never communicate and the user will not get any data from the network. TEEN cannot be applied for types of sensor networks where periodic sensor readings should be delivered to the sink because the values of the attributes may not reach the threshold at all. Another limitation of the protocol is that the message propagation is accomplished by cluster heads only and if cluster heads are not in each other's transmission radius, the messages will be lost. Another drawback is the additional complexity required to implement the threshold functions and the count time.

What limits the ability of both TEEN and APTEEN are the overhead and complexity associated with (1) forming clusters at multiple levels because the sink is engaged in forming the clusters which creates a lot of network traffic and (2) implementing the threshold-based functions and query handling.

2.3. Geographic Adaptive Fidelity Protocol

Geographic Adaptive Fidelity (GAF) is an energy-conscious location-based routing protocol designed in the first place for mobile ad hoc networks but found applicable to wireless sensor networks as well [3], [5], [10]. In spite of the fact that GAF is a location-based routing algorithm, it may also be categorized as a hierarchical protocol, where the clusters are associated with the geographic location. The uniqueness of GAF lies in the fact that for each grid area, a representative node acts as a leader to transmit data to other nodes but these leader nodes do not perform data aggregation as in other clustering routing algorithms [4], [6], [10].

Mode of Operation: The algorithm starts with forming a virtual grid for the covered area. Each node uses its location indicated by a Global Positioning System (GPS) to associate itself with a point in the virtual grid. Nodes which are associated with the same point in the virtual grid are called equivalent nodes when viewed from the cost of packet routing perspective. From the Fig. 3, node 1 can reach nodes 2, 3 and 4 while nodes 2, 3 and 4 can reach node 5. Therefore, nodes 2, 3 and 4 are equivalent and any two of them can be put in sleep state [3], [4], [5], [10].

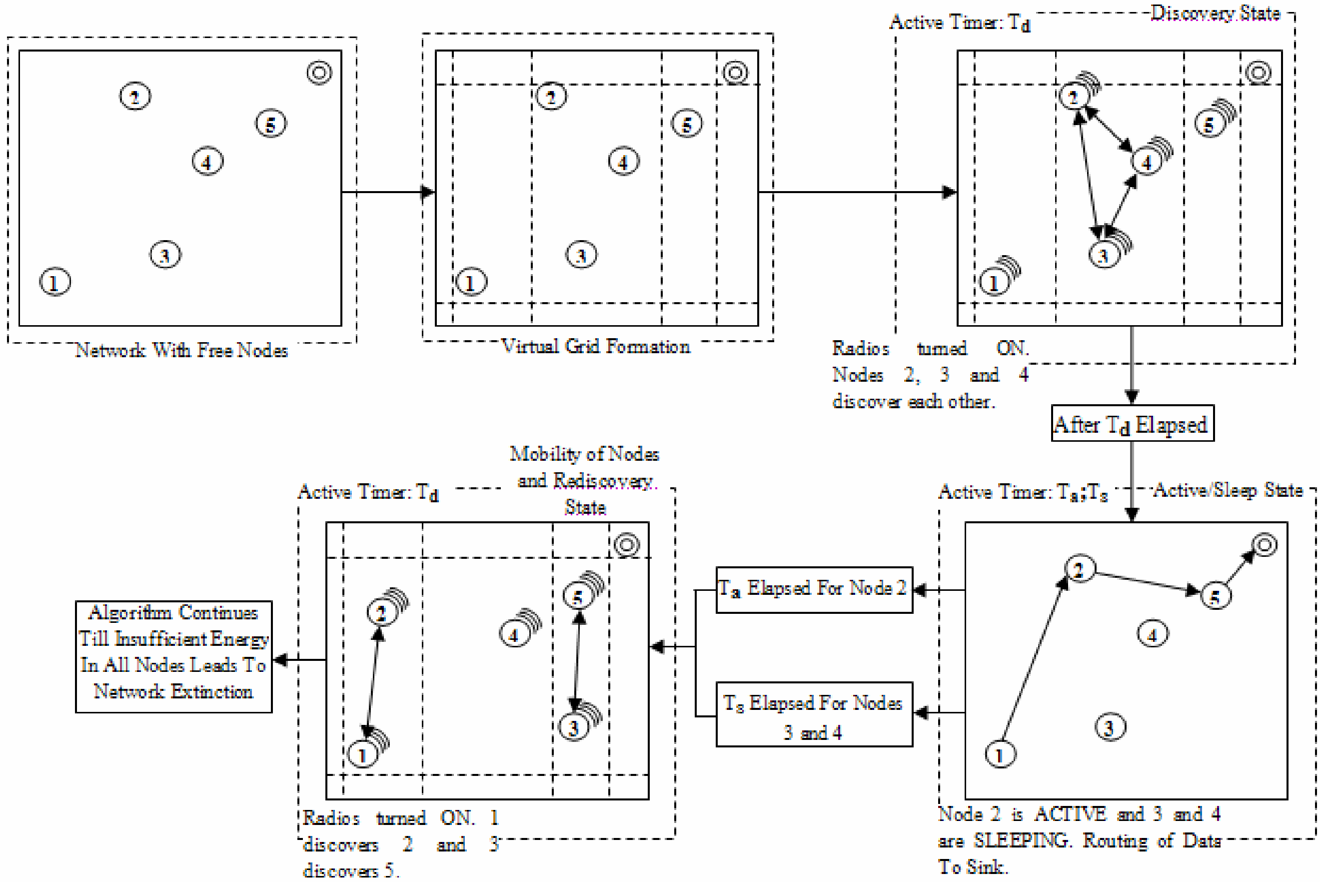

Fig. 3. GAF Protocol.

There are three states in GAF, namely; discovery, active and sleeping state. In the discovery state, nodes find out neighboring nodes in their grid by exchanging messages for a discovery time period Td.

Nodes participate in routing during the active state during the allotted active time Ta and the radios of appropriate nodes are turned off during the sleeping state for an allotted sleeping period Ts. Nodes change states from sleeping to active in turn to ensure load balancing. In order to support mobility, this algorithm ensures that each node in the grid estimate it’s leaving time from the grid and sends this to its neighbors. The sleeping neighbors adjust their sleeping time in such a way that the routing fidelity (uninterrupted connectivity between communicating nodes) of the entire network is sustained. Before the leaving time of the active node expires, sleeping nodes wake up and one of them becomes active. GAF is implemented both for non-mobility (GAF-basic) and mobility (GAF-mobility adaptation) of nodes [3], [4], [5], [6], [10]. A description of the GAF protocol is as shown in Fig. 3.

Performance: The analysis and simulation presented in [10] shows that GAF can consume 40 % to 60 % less energy than an unmodified ad hoc routing protocol. These simulations suggest an increase in network lifetime with increasing node density. In summary, GAF performs at least as well as a normal ad hoc routing protocol in terms of latency and packet loss and increases the lifetime of the network by saving energy.

This algorithm conserves energy by identifying equivalent nodes and then turning off unnecessary nodes, keeping a constant level of routing fidelity. Consequently, GAF can substantially increase the network lifetime as the number of nodes increases.

In this algorithm, the nodes use GPS for indicating their position. However, GPS technology is energy-expensive and costly when it comes to using it in sensor networks where energy is a scarce resource. The algorithm accounts for travel time for determining the frequent changes in distance between mobile nodes communicating with each other. This kind of communication requires a line of sight propagation which might be difficult to attain in sensor networks where nodes are deployed in areas with unfavorable environmental conditions.

2.4. Periodic, Event-driven and Query-based Routing Protocol

Periodic, event-driven and query-based (PEQ) routing protocol is designed to meet the demands of sensor networks when they are deployed as surveillance and monitoring applications operating under critical conditions. The fundamental idea behind the PEQ algorithm is simply the use of the hop level of the sensor nodes to minimize data transmission. Generally, the PEQ protocol consists of three steps, namely; the construction of the hop tree, propagation of subscriptions and data delivery to the sink [3], [4], [12].

Mode of Operation: The algorithm starts with configuring the whole sensor network by finding the shortest distance to the sink from each sensor node. The configuration process is initiated by the sink by broadcasting a packet that contains a hop value, a time-stamp, and the source address to every node which is one hop away from it. After this, each node will store, increment and transmit the hop level to the next neighboring nodes which are a hop away from them. Upon receiving the configuration packet, each node compares its local hop value with the one contained in the packet. If the local hop value is greater the received hop value, update is carried out by incrementing hop value of received packet and re-transmitting it to the next neighboring node. On the other hand, if the local hop value is less than or equal to the hop value of the received packet, no update and retransmission will be done. This process continues until the entire network is fully configured with appropriate hop levels. During this configuration process, each node will also learn and store the source address in a routing table that will be used for forwarding of data to the sink [3], [4], [12].

The Publish/Subscribe concept introduced [11] was implemented for the subscription phase of this protocol. The sink subscribes to the network by setting one or more criteria for a desired event like temperature above 100°C. The sink disseminates subscription message through the network in the same manner as in the configuration process. When a node senses an event that matches the sink's interest, the node sends the event packet to the forwarding address of its neighboring node. The forwarding address has been previously learned during the configuration process. After the neighbor node has received the packet, it performs the same algorithm and sends the data to its next forwarding neighboring node. The event notification/data delivery process ends when the event or data reaches the sink [3], [4], [12].

This protocol also implements an ACK-based repair mechanism. Each node sets a time-out timer after it has forwarded a packet and waits for the neighbor's ACK before the time elapse. The absence of ACK after the time elapse means that the neighboring node is dead. Consequently, the node broadcasts a SEARCH packet to find a new forwarding node. The neighbor nodes will reply with a packet that contains their hop level and address. From all these volunteering nodes, the node elects the neighboring node with the lowest hop level as the new forwarding node [3], [4], [12]. A description of the PEQ protocol is as shown in the Fig. 4.

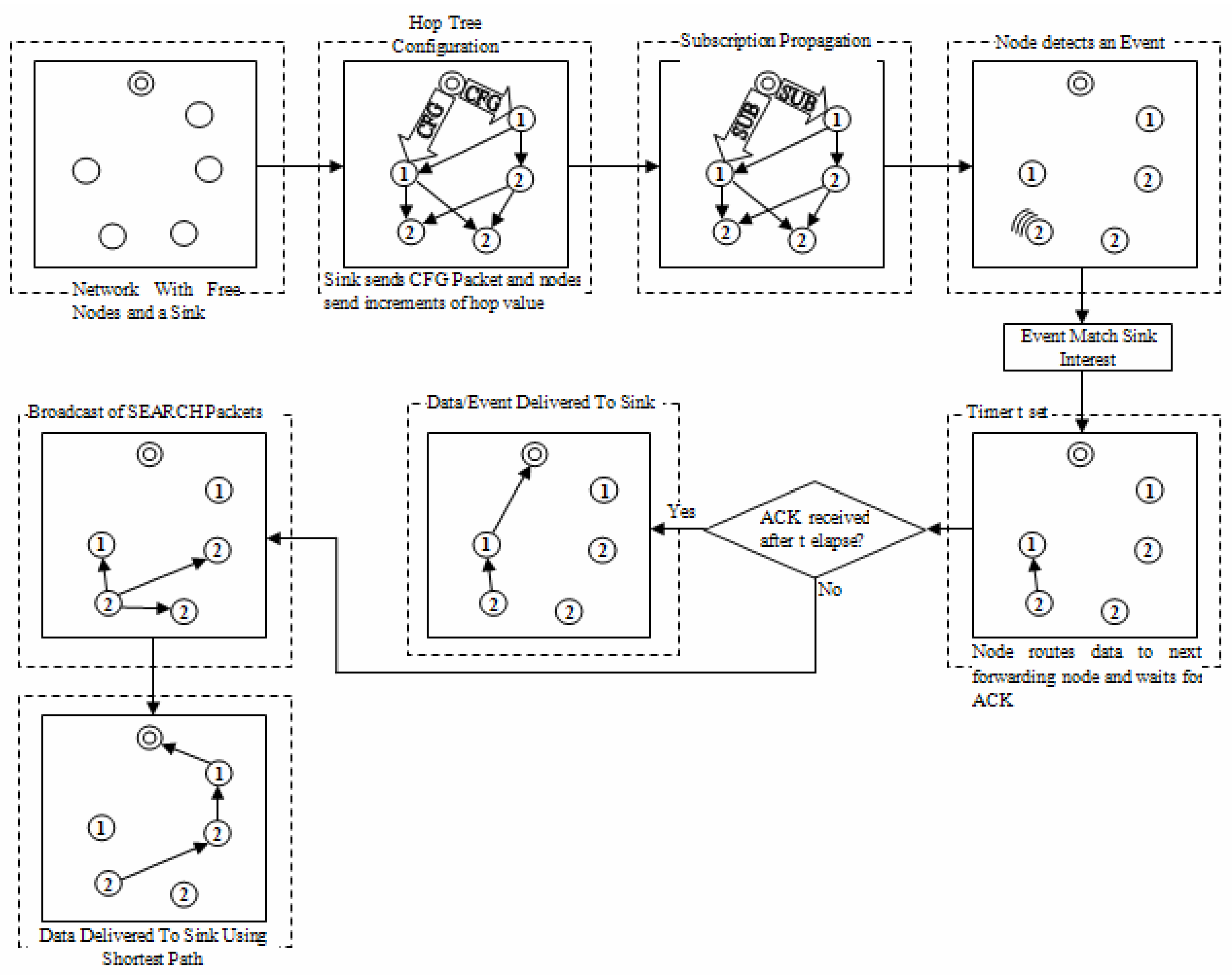

Fig. 4. PEQ Protocol.

Performance: The PEQ protocol uses multi-hop communication which is simple and at the same time efficient due to the fact that long distance communication can be carried out in a situation where the size of the sensor network is large. The network configuration process ensures that the path from each node to the sink is the shortest path hence this algorithm achieves low energy consumption and it promotes quick dissemination of data to support low latency. The ACK-based repair mechanism is a means to ensure reliability and robustness of the network. A major concern is the flooding and broadcasting of configuration (hop values) and subscription message to neighboring nodes. There is a possibility of redundant transmission and reception of data here and for large scale networks, a considerable amount of energy will be wasted listening to redundant data. Clustering PEQ addresses the problem of redundancy. Storing and updating of the subscription, configuration and routing details can be costly and challenging in a scenario where there the sensor nodes are mobile and numerous.

2.5. Clustering Periodic, Event-driven and Query-based Routing Protocol

The Clustering Periodic, Event-driven and Query-based (CPEQ) protocol is an improvement over the PEQ algorithm by adopting a cluster-based approach in which sensor nodes with more residual energy are selected as cluster heads (CH). The cluster heads forms a cluster and the nodes within each cluster send their events to their respective cluster heads. It is the task of the cluster head to compress all these data by an aggregation function before forwarding it to the sink [3], [4], [12].

Mode of Operation: The algorithm starts with configuring the entire sensor network just like in the PEQ protocol to form a network of hop tree. The only modification here is the broadcast of an additional field together with the configuration packet which signifies the percentage of nodes that can become cluster heads. This is to ensure that any node in the sensor network can become a cluster head with a certain probability p [3], [4], [12].

The cluster head selection is based on LEACH [7]. It begins by each node generating a random number p between 0 and 1. If this number is less than the probability p, the node will initiate the cluster head selection process. The nodes initiating this selection process are called elector nodes. The elector nodes request the energy level from its immediate neighbors by broadcasting a packet to them. After receiving the reply packets from its neighbors, the elector nodes elect the neighbor with the highest residual energy as the cluster heads. A node remains in the cluster head state for a specific period of time until its tenure expires. This selection process is carried out periodically [3], [4], [12].

After the selection process, the next phase is the cluster configuration stage where each cluster head will form its cluster by broadcasting notification packets. This process is the same as the initial configuration phase of the PEQ algorithm. In order to limit the size of a cluster, a time-to-live field is included with the notification packet. This is to make provision for a scenario whereby a node receives notification from more than one cluster head. In this case, the node will simply choose the notification with the least time-to-live value [3], [4], [12].

Event notification is also an important phase in this algorithm. When nodes sense an event, they simply forward their events to their respective cluster heads. From the nodes’ point of view, the cluster heads are their sinks. The data routing scheme employed for this task is the same as the one used in PEQ algorithm for routing data from nodes to sink. It must also be mentioned that CPEQ inherits the ACK-based path repair mechanism of the PEQ protocol [3], [4], [12].

After receiving data from their member nodes, the cluster heads will perform data aggregation on the multiple data coming in to reduce redundancy. Afterwards, the cluster heads will relay the aggregated data to the sink through the shortest path. The event/data delivery process is the same one employed in the PEQ protocol, in which nodes use the forwarding addresses of their nearest neighbor which was learned during the initial configuration step. There is a possibility of having nodes which do not belong to any cluster after cluster configuration phase. For their case, they will use routes learned during the initial configuration phase to route data to the sink in case they sense an event [3], [4], [12]. A description of the CPEQ routing protocol is as shown in Fig. 5.

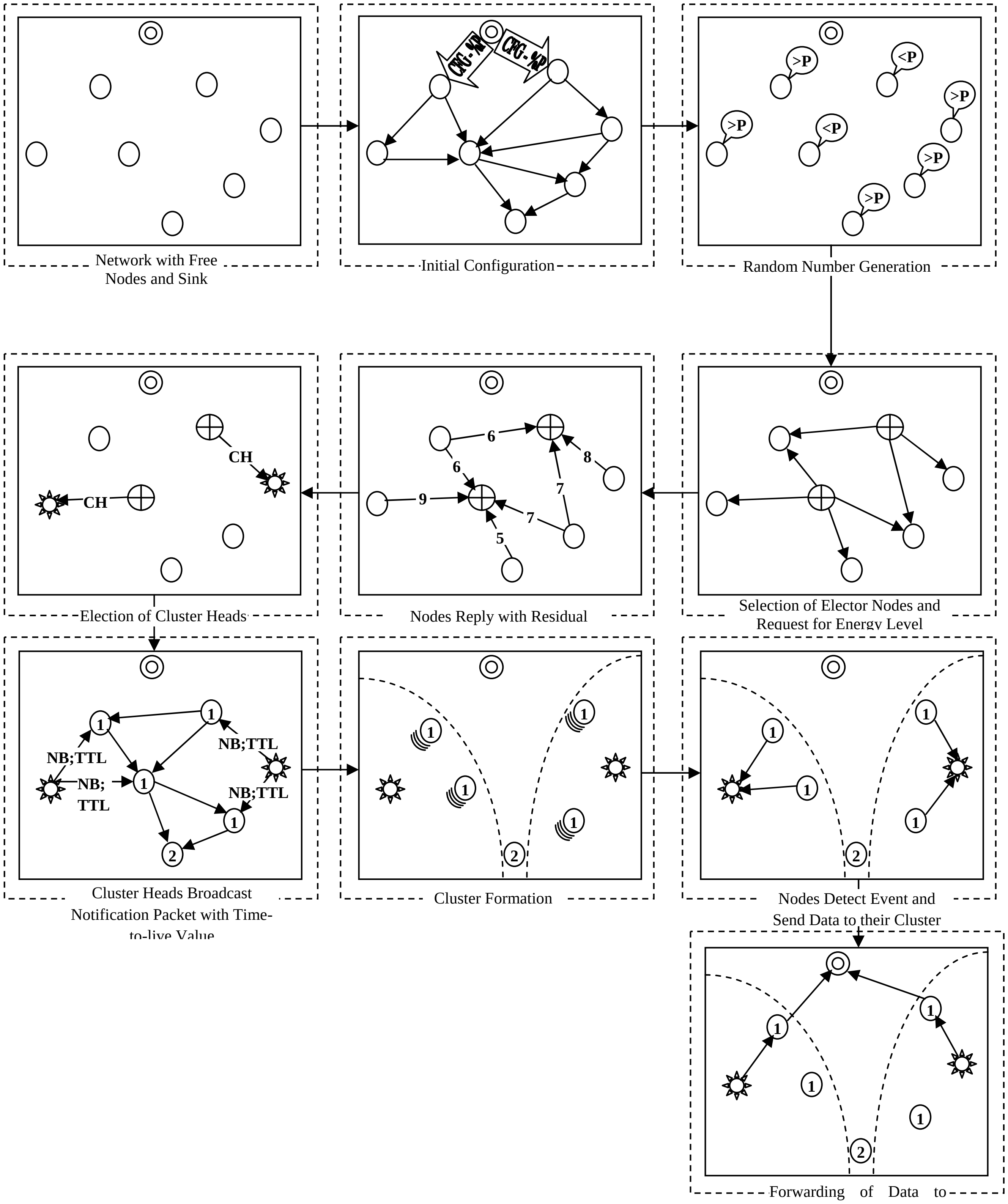

Fig. 5. CPEQ Protocol.

Performance: The simulations presented in [12] shows that the CPEQ algorithm has lower event delivery delay, better average event delivery ratio and lower energy dissipation when compared to directed diffusion and the PEQ protocol. The CPEQ protocol enjoys all the benefits of PEQ algorithm, namely; low energy consumption due to multi-hop communication, quick data dissemination via shortest route to support low latency; support for reliability and robustness by the use of ACK-based path repair mechanism and simplicity of algorithm implementation. Another major advantage of the CPEQ algorithm is the data aggregation function performed by the cluster heads which saves energy by reducing the unnecessary listening time to repetitive notifications from the nodes. A major concern is the redundant transmission and reception of packets in some phases of the CPEQ algorithm where the data are flooded to neighboring nodes just like in the configuration process of the PEQ algorithm. In a scenario where the network is highly-dense with sensor nodes, a considerable amount of energy will be wasted in transmitting and listening to unwanted or unnecessary packets. Some of these problems are carefully addressed in the Energy Efficient Inter-cluster Communication based (ICE) routing protocol. Storing and updating of the initial configuration, cluster configuration and routing details can be costly and challenging in a scenario where there the sensor nodes are mobile and numerous.

2.6. Energy Efficient Inter-cluster Communication based Routing Protocol

Energy Efficient Inter-cluster Communication based (ICE) algorithm is a QoS-aware routing protocol developed for periodic, event-driven and query-based wireless sensor networks. Just like in the PEQ and CPEQ algorithm, this protocol employs the publish/subscribe concept too. Routing of messages in the network is done via cluster heads and the nodes closest to each other within two neighboring clusters. Consequently, message propagation through the entire sensor network is accomplished through short transmissions [3], [4], [13].

Mode of Operation: The algorithm comprises of three parts, namely; setup, subscription propagation and event notification propagation. In the setup phase, the entire sensor network is configured just like in the PEQ and CPEQ protocol to form a network of hop tree. The objective of this is to know the distance or number of hops each node is from the sink. The cluster head selection is based on LEACH [7]. It begins by each node generating a random number p between 0 and 1. In this algorithm, the nodes with probability less than 0.05 will initiate the cluster head selection process. The nodes initiating this selection process are called beacon nodes. The beacon nodes request the energy level from its neighboring nodes which are one hop away from it by broadcasting a packet to them. After receiving the reply packets from its neighbors, the beacon nodes elect the neighbor with the highest residual energy as the cluster heads. A node remains in the cluster head state for a specific period of time until its tenure expires [3], [4], [13].

Another part of the setup phase is the cluster configuration process where each cluster head will form its cluster by broadcasting notification packets to its neighboring nodes. This process is similar to the cluster generation process of the CPEQ algorithm. The next part of the setup phase is to learn about neighboring clusters through the beacon nodes. The beacon nodes broadcast the cluster heads they have elected in its transmission radius. Once a cluster head receives this information, it finds the nearest neighbors (NNs) to the neighboring clusters it has been informed about. The way the cluster heads finds the nearest neighbors is by (1) drawing a logical line between itself and other cluster heads, (2) projecting the nodes in the cluster to these logical lines and (3) storing the first two nodes in its neighboring clusters that are nearest in distance to it with reference to these logical lines. The last part of the setup phase is the discovery of nodes that do not belong to any cluster. These nodes are called free nodes. The free node broadcast a notification and location message to all nodes that are one hop away from them. Out of its neighboring nodes, the ones belonging to a cluster will forward that message to their cluster heads [3], [4], [13].

The subscription propagation phase starts with the sink broadcasting its subscription message to the network through the constructed clusters. When a subscription message leaves a cluster, the nodes that are not nearest neighbors will go to sleep. The nodes will stay asleep unless they detect an event or wake up according to the TDMA schedule broadcasted to them by the cluster heads. When a cluster node hears the subscription message, it relays it to its cluster head. It is the job of the cluster head to identify whether the subscription is intended for any of its nodes. If so, the message propagation ends when the cluster head relays the subscription message to the appropriate node. Otherwise, the message will be further forwarded to other clusters using nearest neighbors and intermediate nodes (free nodes that can be easily employed for communication between clusters). Whenever a subscription message propagates through the clusters, the cluster head checks also if the subscription is intended for any free node that it is aware of. If this is so, the free node will learn of the sink's interest through the cluster head and with the help of its cluster nodes. The ICE algorithm implements an improved version of the ACK-based path repair mechanism used in PEQ and CPEQ protocol. Whenever a message leaves a cluster, a timer is set. If the sending node does not receive an ACK message from a node in the destination cluster, the algorithm uses intermediate nodes for further relaying of the message [3], [4], [13].

For the event notification propagation phase, whenever a cluster has a message to send to the sink, it chooses one of its neighboring clusters which it has learned about from the beacon node. Once the message reaches a node belonging to a cluster, the message is forwarded to its respective cluster head. On the other hand, an intermediate node will be used when a nearest neighbor node relays a message to its nearest neighbor from a neighboring cluster and an ACK message is not received. Due to the fact that each node will have stored the node from which it had received subscription message from, the reverse path of subscription propagation will simply be used for event notification to the sink [3], [4], [13]. A description of the ICE protocol is shown in Fig. 6 from after the cluster formation phase to the rest of the algorithm since the earlier part of the protocol is similar to the CPEQ algorithm as shown in Fig. 5.

Performance: The analysis presented in [13] shows that this algorithm caters for energy-efficiency, fault tolerance, quality of service (QoS) and network connectivity. The ICE algorithm is a marked improvement over the CPEQ and PEQ protocol and as a result it inherits their strengths like data aggregation, reliability, simplicity and quick data dissemination. This algorithm employs short-range transmissions by using nearest neighbors among the clusters for the purpose of energy conservation. Even energy dissipation among the nodes is achieved by alternating the routes used to relay messages to the sink. By adopting this multi-path routing approach, loads on nodes are balanced, network lifetime is increased and fault tolerance is provided. QoS is provided by prioritizing event notifications and selecting the path with the least cost in terms of low delay and high residual energy for event notifications with high priority. As a result, the issue of congestion is taken care of. The algorithm offers network connectivity by ensuring that neighboring clusters can communicate anytime. Whenever clusters cannot communicate, free nodes otherwise known as intermediate nodes are used for forwarding the message until it reaches a node belonging to a cluster. Redundant messages are dropped by using cluster heads to relay event notifications and hence unnecessary network traffic is minimized.

The major drawback of this protocol is if the cluster nodes are positioned in such a way that they cannot be projected to the logical line in a cluster. This will mean that no nearest neighbors will be found and message propagation will be considerably affected since data transmission in this algorithm relies on these nearest neighbors. This scenario is likely to occur in a situation where the nodes deployed randomly, mobile and self-configurable depending on the environmental conditions. This algorithm inherits the problem associated with using the configuration process just like the CPEQ and PEQ protocol. Redundant transmission and reception of packets are still bound to happen during the formation of hop tree but to a lesser degree in this algorithm. Constructing, storing and updating of the nearest neighbor table, subscription table, ACK messages and other notification and routing messages can be costly and challenging in a scenario where there the sensor nodes are mobile and hugely-dense.

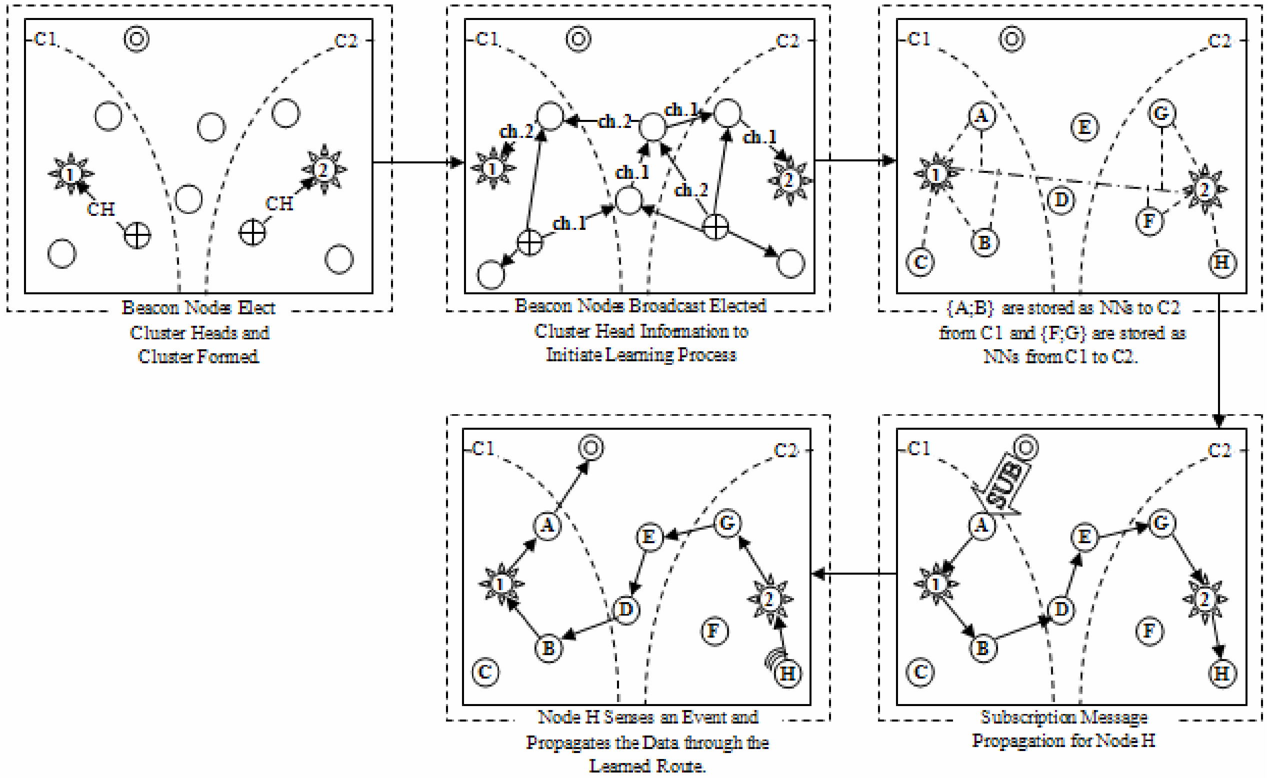

Fig. 6. ICE Protocol.

3. Summary of Features

In this section, a summary and comparison of the key features of the investigated clustering routing protocols is presented in the Table 1:

Table 1. Comparison of Features.

	Mobility	Multi-Hop Routing	Data Aggregation	Multi path	Query-based	QoS	Energy Awareness	Sink Involved in Cluster Formation	Only CH are Relay Nodes	Optimal Route	Fault Tolerance
LEACH	NO	NO	YES	NO	NO	NO	YES	NO	YES	NO	NO
TEEN	NO	YES	YES	NO	NO	NO	YES	YES	YES	NO	NO
APTEEN	NO	YES	YES	NO	NO	NO	YES	YES	YES	NO	NO
GAF	YES	YES	NO	NO	NO	NO	YES	NO	NO	NO	NO
PEQ	NO	YES	YES	YES	YES	NO	YES	NO	NO	YES	YES
CPEQ	NO	YES	YES	YES	YES	NO	YES	NO	NO	YES	YES
ICE	NO	YES	YES	YES	YES	YES	YES	NO	NO	YES	YES

4. Conclusion

Routing in wireless sensor networks has attracted the attention of researchers recently and it has also posed interesting and important challenges. Clustering routing protocols group sensor nodes in such a manner that propagation of sensed data to the sink is done with minimum energy. Nodes that are less energy-constrained are often chosen as cluster heads which are tasked with the responsibility of aggregating data and transmitting that data to the sink. In this paper, selected clustering routing protocols for wireless sensor networks are investigated and their features are highlighted. The pioneering routing protocol LEACH is not applicable for large-scale wireless sensor networks due to the fact that cluster heads communicate with the sink by single-hop communication which is unsuitable for large-scale sensor networks. Succeeding routing protocols address this challenging issue of scalability in wireless sensor networks by using multi-hop communication. In TEEN and APTEEN, only cluster heads are used as relay nodes during the multi-hop propagation of data to the sink whereas in PEQ, CPEQ and ICE, cluster nodes, cluster heads and free nodes are employed for relaying data to sink. The approach used in PEQ, CPEQ and ICE where the responsibility of message delivery is shared by all nodes in the sensor network achieves load balancing which in turn helps to conserve energy. Energy-efficient cluster formation, minimization of nodes' database operations (constructing, storing and updating of routing and clustering information), effective data aggregation and fusion techniques, provisioning for fault tolerance and specific QoS requirements are key research openings in clustering routing protocols for wireless sensor networks.

References

[1]. Mohammad Ilyas (Editor) and Imad Mahgoub (Editor), Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems, *CRC Press*, LLC, 2005, pp. 120-138.

[2]. I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, Wireless Sensor Networks: A Survey, *Elsevier Computer Networks Journal*, Vol. 38, Issue 4, 2002, pp. 393-422.

[3]. A. Martirosyan, A. Boukerche and R. W. N. Pazzi, A Taxonomy of Cluster-Based Routing Protocols For Wireless Sensor Networks, The International Symposium on Parallel Architectures, *Algorithms and Networks, I-SPAN 2008*, pp. 247-253.

[4]. A. Martirosyan, A. Boukerche and R. W. N. Pazzi, Energy-Aware and Cluster-Based Routing Protocols For Large-Scale Ambient Sensor Networks, *in Proceedings of the 1st International Conference on Ambient Media and Systems*, Quebec, Canada, 2008, Article No. 18.

[5]. K. Akkaya and M. Younis, A Survey on Routing Protocols For Wireless Sensor Networks, *Elsevier Ad Hoc Network Journal*, Vol. 3, 2005, pp. 325-349.

[6]. Jamal N. Al-Karaki and Ahmed E. Kamal, Routing Techniques in Wireless Sensor Networks: A Survey, *IEEE Wireless Communications Journal*, Vol. 11, Issue 6, December 2004, pp. 6-28.

[7]. W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, Energy-Efficient Communication Protocol For Wireless Microsensor Networks, *in Proceedings of the 33rd Hawaii International Conference on System Sciences (HICSS '00)*, Vol. 2, 10, January 2000, pp. 4-7.

[8]. A. Manjeshwar and D. P. Agarwal, TEEN: A Routing Protocol For Enhanced Efficiency In Wireless Sensor Networks, *in Proceedings of the 15th International Symposium on Parallel Distributed Computing*, April 2001, pp. 2009-2015.

[9]. A. Manjeshwar and D. P. Agarwal, APTEEN: A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks, *in Proceedings of the 16th International Symposium on Parallel Distributed Computing*, 2002, pp. 195-202.

[10]. Y. Xu, J. Heidemann and D. Estrin, Geography-Informed Energy Conservation For Ad Hoc Routing, *in Proceedings of the International Conference on Mobile Computing and Networking*, Rome, Italy, 2001, pp. 70-84.

[11]. P. T. Eugster, P. A. Felber, R. Guerraoui and A. M. Kermarrec, The Many Faces of Publish/Subscribe, *ACM Computing Surveys (CSUR)*, Vol. 35, Issue 2, June 2003, pp. 114-131.

[12]. A. Boukerche, R. W. N. Pazzi and R. B. Araujo, HPEQ – A Hierarchical Periodic, Event-driven and Query-based Wireless Sensor Network Protocol, *in Proceedings of the IEEE Conference on Local Computer Networks*, 15-17 November 2005, pp. 560-567.

[13]. A. Boukerche and A. Martirosyan, An Energy-Aware and Fault-Tolerant Inter-cluster Communication based Protocol for Wireless Sensor Networks, *in Proceedings of the IEEE Global Telecommunications Conference (GLOBECOM '07)*, 26-30 November 2007, pp. 1164-1168.

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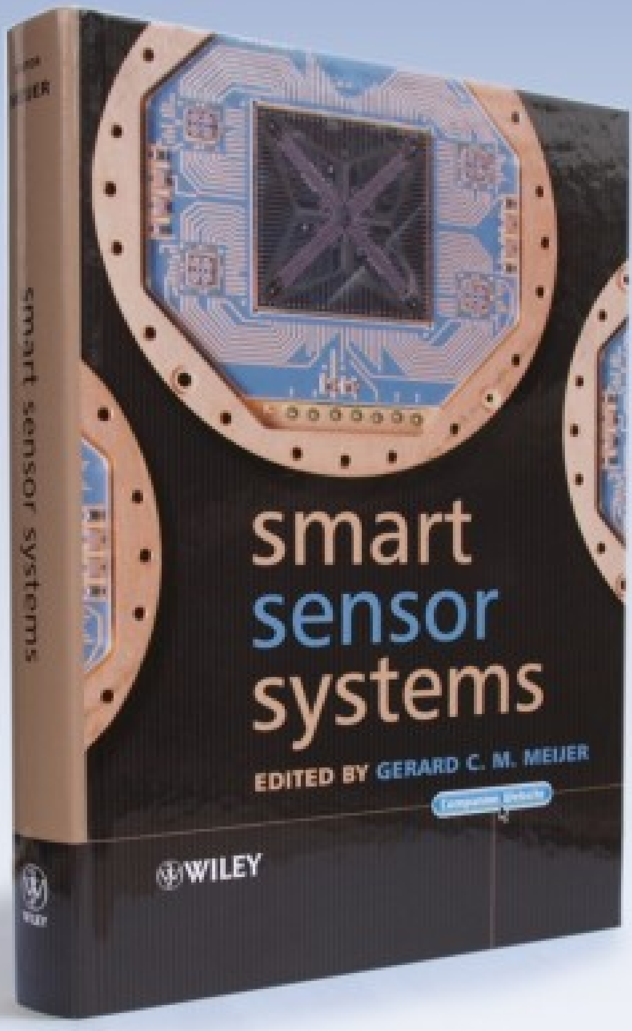
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