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A Theoretical Review of Topological Organization for Wireless Sensor Network

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***Abstract*—The recent decades have seen the growth in the fields of wireless communication technologies, which has made it possible to produce components with a rational cost of a few cubic millimeters of volume, called sensors. The collaboration of many of these wireless sensors with a basic base station gives birth to a network of wireless sensors. The latter faces numerous problems related to application requirements and the inadequate abilities of sensor nodes, particularly in terms of energy. In order to integrate the different models describing the characteristics of the nodes of a WSN, this paper presents the topological organization strategies to structure its communication. For large networks, partitioning into sub-networks (clusters) is a technique used to reduce consumption, improve network stability and facilitate scalability.**

***Keywords*—clustering algorithms, DEBC, heterogeneous networks, LEACH, Wireless Sensor Network**

I. Introduction

THE use of wireless sensor network (WSN) is often correlated with the lack of infrastructure. Thus their operation requires the use of collaborative protocols. To best manage these networks, it is essential to discover cooperation between the constraints inherent to the sensors and the needs expressed by the applications. The literature describes two approaches, namely: either the flat network in which one directly deploys adapted communication protocols or a self-organized structure that will offer effective support for a great variety of protocols like the routing, the localization, discovery of services, etc. [1-3].

After this short introduction, we discuss in Part 2the main generic models and definitions describing the communication components (sensor node model, communication model, detection model, consumption model). Section 3 is then devoted to the specific architectures needed by large WSNs. It is particularly developing the principles of network partitioning (or "clustering") as well as the main algorithms adapted to the topological organization of such networks. Finally, the last section provides a summary of the different approaches in the literature and their shortcomings concerning our issues. This makes it possible to position the work and to introduce it in the following heading.

II. Nodes and their Communication

To better understand the physical systems and, subsequently, the different strategies adopted to size and architect a WSN, we will use models as simple as possible. This section defines numerous prototypes that are used in the WSN. For example, we use node models, communication models, detection or acquisition models, and energy consumption models.

A. Node Model

Depending on the application and structure chosen, a WSN contains different types of nodes:

- A regular node is a node with a transmission unit and a data processing unit. The data transmission unit is responsible for all data transmissions and receptions via a wireless communication medium that can be of optical type (as in Smart Dust nodes) or radiofrequency type (as in Stargate nodes) [4]. The data processing unit is composed of a memory, a microcontroller and a specific operating system (such as Tiny OS, developed at the University of Berkeley and currently used by more than 500 universities and research centers worldwide [5]). It is responsible for the processing of data from or transmission. Depending on the field of application, a node can be equipped with additional or optional units such as a GPS to determine its position, or an energy generating system (photovoltaic cell, etc.), or a mobile system to allow it to change its position or configuration if necessary.
- A sensor node or source node is a regular node equipped with an acquisition or detection unit. The acquisition unit is equipped with a sensor or several sensors that obtain analog measurements (physical and physiological) and an Analog / Digital converter that converts the information recorded into a digital signal understandable by the unit of treatment [6].
- An actuator node or robot is a regular node with a unit allowing it to perform specific tasks such as mechanical tasks (moving, fighting a fire, driving a PLC, etc.).
- A sink node is a regular node with a serial converter connected to a second communication unit (GPRS, Wi-Fi, WiMax, etc.). The second communication unit provides transparent retransmission of data from sensor nodes to an end-user or other networks such as the internet [7].
- A gateway node is a regular node for relaying traffic in the network on the same communication channel [8].
- For optimizing network lifetime or data delivery time parameters, some work focused on the architecture (flat, hierarchical, multilevel) of the WSN. These architectures most often define the roles played by the nodes in a WSN [9-10].
- Source Node (NS): whose main role is to detect the physical or physiological phenomena occurring in its immediate environment to transmit them, directly or via multiple nodes, to an end-user. It's a sensor node [11].

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B. Detection Model

The simplest of the detection models are also the "binary disc" model. This model assumes that a node can detect only the phenomena found in its detection range (and not outside). In this model, the detection range of each node is confined in a circular disk of radiusr_d is called radius or detection range [12].

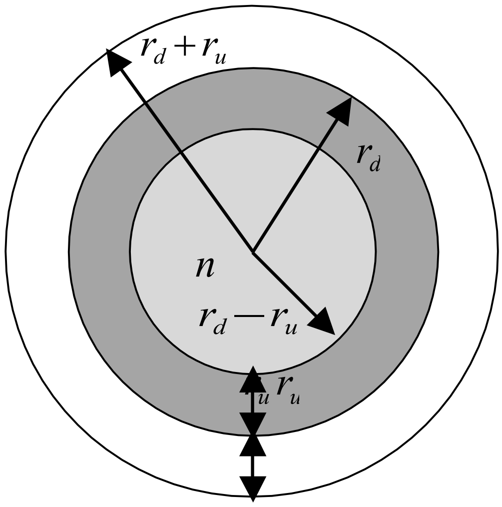

Fig. 1. Detection model: "Probabilistic sensing model" [13]

A more realistic extension of the "binary disc" model is the "probabilistic sensing model" (see Figure 1), proposed by [13]. This probabilistic model reflects the uncertain behavior of the detection of sensor nodes such as infrared or ultrasonic sensors. In such a model, if $r_u$defines an uncertain detection zone of a sensor$n$ such that $r_u < r_d$ then a node could detect with probability$P$ a point or an object lying in an interval between $r_d - r_u$ and $r_d + r_u$. The probability of coverage of a point $P(x_i, y_i)$by a sensor n_i is given as follows [13]:

$$C_{x_{iy_i}}(n_i) = \begin{cases} 0, & r_d + r_u \le d(n_i, P) \\ e^{-w\alpha^{\beta}}, & r_d - r_u < d(n,p) < r_d + r_u \\ 1, & r_d - r_u \ge d(n_i, P) \end{cases} \quad (1)$$

Where $\alpha = d(n_i, P) - (r_d - r_u)$, $w$and β are parameters that measure the probabilities of detecting an object at a distance from a sensor node. We can say that all points are 1-covered by a given sensor node if they are at a distance under $r_d - r_u$of this sensor node, and all those in the meantime $[r_d - r_u, r_d + r_u]$have a coverage (<1) that decreases exponentially with distance. Beyond a distance$r_d + r_u$, all points are 0-covered or uncovered.

Let $\Psi = \{n, i = 1,2, \dots\dots k\}$be the set of sensor nodes whose detection ranges cover the point$P(x_i, y_i)$. As $C_{x_{iy_i}}(n_i)$ is the probability of coverage of a point P by a node n_i, then the expression$(1 - C_{x_{iy_i}}(n_i)$defines the probability that point P is not covered by at least one of the neighboring nodes is defined by the expression:

$$\prod_{i=1}^{k}(1 - C_{x_{iy_i}}(n_i)). \quad (2)$$

As the probabilities of coverage of a point by the nodes are k independent of each other, so, the total coverage of a point P or the probability that the point P is covered by at least one of the neighboring nodes is defined by the expression

$$C_{x_{iy_i}}(\Psi) = \prod_{i=1}^{k}(1 - C_{x_{iy_i}}(n_i)) \quad (3)$$

C. Energy Consumption Model

Energy consumption strongly depends on the specific type of node. For example, in [14], the authors showed that the characteristics of a Mote-Class node are completely different from those of a Stargate node. However, whatever the node, the predominant dissipation of energy in a sensor node is generally during the detection, communication, and processing of data [15]. Thus, the model of energy consumption in a sensor node is defined as follows:

Event detection energy: this is the energy consumed by a sensor node during the activation of its acquisition and data collection unit. The cost of this energy depends on the specific type of sensor (image, sound, temperature, etc.) and tasks (sampling and conversion of physical signals into electrical signals, signal conditioning and analog-to-digital conversion, etc.) assigned.

Data processing energy: it is the energy consumed by a node during the activation of its data processing unit (operations, read/write in memory) [16].

The energy of the radio transmitter: it is the energy consumed by a node during the activation of its transmission unit. This energy is much higher than that dissipated by the processing unit. It has been demonstrated in [17] that the transmission of a bit of information can consume as much as the execution of a few thousand instructions. The simplest and most widely used model for estimating only the energy consumed by one node to transmit data to another node at a distance d is given as follows: $E(d) = d^{\alpha} + c$, where $\alpha \ge 2$ is the exponentiation of exponentiation depending on the environment, and $c \ge 0$ is a constant that represents the energy required to transmit a given amount of information [18] [19]. This simplistic model simply estimates transmission energy consumption while a node also consumes energy in reception and even when it is at rest or listening without reception. Therefore, the cost of the energy consumed by the transmission unit must depend on the operating mode (or state) of the radio transmitter. There are 4 modes of operation (transmission, reception, "idle" or listening without communication, and "sleep" or sleep) and a state of transition between the modes of operation.

III. TOPOLOGICAL ORGANIZATION OF A LARGE WSN

In a very large network, it is not possible to organize the network structure according to the centralized approach or flat approach. Because the centralized approach is too expensive in terms of energy and flat network structures has several issues in scaling up. Among other things, it aims to reduce [20] [21]:

- The size of the routing table per node.
- The number of (re-) transmissions.
- The bandwidth occupation.
- Energy consumption per node.

The role of each node cannot be defined a priori; the communication structure that we want to define must self-organize to make the service expected. It is, therefore, a question of introducing a hierarchy in the network by creating a virtual structure on the physical topology of the network. A virtual structure is most often formed from interactions or local rules. A partial solution to the problems mentioned above, and very well summarized in [22], is the topological control (see Figure 2). It consists of reducing the transmission power of the nodes and thus reducing their communication range.

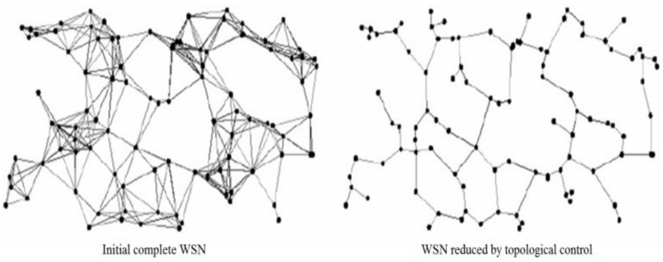

Fig. 2. Formation of a virtual structure by topological control [22]

In this kind of structure, the nodes try to join a BS by communicating gradually by diffusion. This approach, while simplifying routing and limiting interference and power consumption, maintains a flat structure. Clustering techniques are more adapted to our problem. After the major characteristics defining the principles of clustering, we will discuss the main strategies for forming clusters

A. Clustering Principles

The most common solution for organizing a very large WSN is to group the nodes into clusters (see Figure 3). This type of organization of communication-based on intra-cluster and inter-cluster routing reduces the number of nodes participating in long-distance communications. Each cluster of nodes is identified by a leader, called cluster leader or cluster-head, to coordinate the activities of their group, such as data routing, aggregation, synchronization, and so on. The nodes that are members of a cluster can be active or, on the contrary, sleepy (to preserve their energy). Upon detection of an event or on-demand, active members transmit their data (consisting of measured physical quantities) to the cluster-head with which they are associated. The cluster heads then form the higher hierarchical level structure relaying these data to the well. The entire communication structure represented by the arrows in Figure 3 is called the backbone [23].

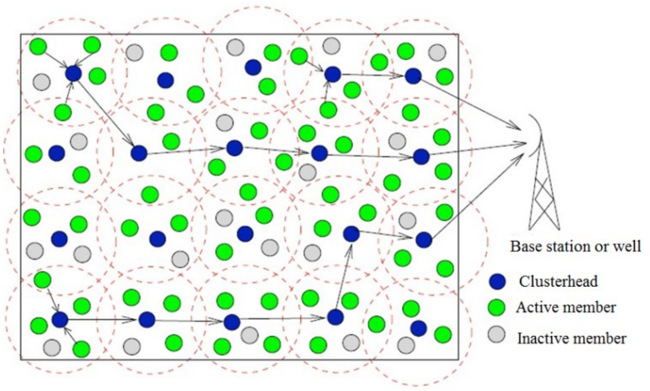

Fig. 3. Example of a cluster-based topology [23]

1) Building a Cluster Topology

Many clustering techniques have been proposed in the scientific literature. They vary according to the mode of deployment of the nodes (deterministic or random), the process of election of the cluster-heads, the size of the clusters, the model of functioning of the network, etc. The general principle of building a self-organized cluster structure is described in Figure 4. After a neighborhood discovery phase (b), the WSN constructs its structure into groups of nodes (d) and a dominant communication path called dorsal (c). Note that steps (c) and (d) are chronologically interchangeable and can even be performed at the same time. Classically a simple clustering algorithm can be described as:

- Each node discovers its neighborhood through the "Hellos" messages it broadcasts to its neighborhood. This will allow him to calculate his metric (Figure 4b).
- Except for cluster-head pre-designation, a node determines whether it is cluster-head or not depending on its metric and that of its neighborhood (immediate or not) (Figure 4c).
- A node chosen as cluster-head broadcasts it's status to its neighborhood to notify its desire to form a cluster and invite its unaffiliated neighbors to join it in its cluster (Figure 4d).
- Any change in status is notified by a message broadcast.

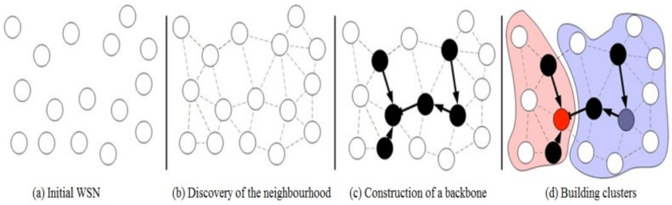

Fig. 4. Steps for building a cluster topology [24]

The groups formed may have different characteristics depending on the strategy adopted: clusters of homogeneous or non-overlapping sizes, overlapping or not, passive or active, etc. If the clusters are overlapping, then a node can belong to several clusters (this is the case in Figure 3). In general, these nodes will have a gateway role in the communication between clusters. Otherwise, a node is associated with only one group (Figure 4). In a cluster, any member can be at most one node or k breaks from its cluster-head (see Figure 5). In a node-1 cluster, the cluster-head is directly connected to any member node. This choice, as we will see later, proves to be important to have a satisfactory data delivery time. Indeed, while the backbone can be likened to a highway for information, the competition for access to the medium and a high number of nodes closer together the intra-cluster communication of a city center at peak times (with k intersections) [24].

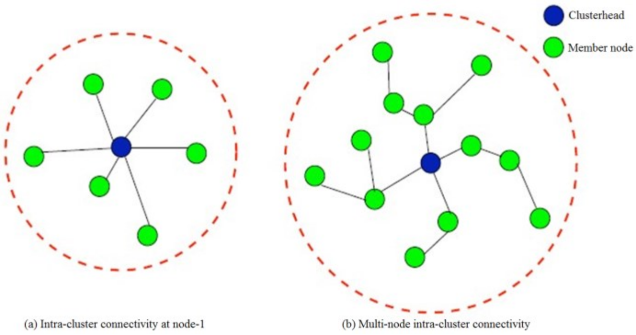

Fig. 5. 1-node or k-node clusters [24]

2) Maintenance of the Communication Structure

Maintenance of the structure is particularly necessary for overlapping clusters (some nodes can belong to several clusters) where a local restructuring of the topology can cause a chain reaction constantly questioning the whole of the communication structure and inducing a significant load. Some authors propose to create completely dissociated clusters to avoid chain reactions as a result of a local restructuring of the structure and to offer more stability to the cluster structure. To further optimize the persistence of clusters and minimize the number of changes in the virtual topology, some propose to keep the state of a cluster-head as long as possible even if it does not have the highest weight in its cluster. Others propose to adapt the frequency of the questioning of the structure: do not spend more energy than necessary, especially if the service is rendered. Some works propose to make "rotate" the role of cluster manager to balance the energy expenditure between the nodes[25].

To avoid maintenance and avoid the traffic that follows, some research has proposed to initiate the construction of the cluster each time a node wants to disseminate information. The main idea is to identify the set of nodes to participate in the routing of the information as the information spreads in the network. However, such a mechanism cannot be applied in large networks because the number of broadcast messages and the latency to discover the routes can be enormous. And this could be in contradiction to the requirements of certain applications such as emergency applications where the delivery time is essential.

In the following section, we present a state of the art review of the main clustering techniques proposed in the literature.

B. Clustering Strategies

There are several ways to classify clustering algorithms: depending on whether the deployed nodes are homogeneous or heterogeneous, that the intra-cluster communication is one or k nodes, according to the criteria that determine the cluster-heads, according to the policy maintenance of the structure. In order to introduce the positioning of our proposal, we have chosen to structure this part by answering the following question: How is a node defined as cluster-head? The first possibility is that this decision stems from an elective process. Another strategy is that it is the very nature of the node that defines it as cluster-head.

1) Cluster Election Process

Cluster heads are chosen through an election process using a decision criterion. The latter is usually a metric or a combination of metrics such as the node identifier, the degree, density of neighboring nodes[27], the residual energy of the node, the mobility of the nodes [28], a weighted sum of all these elements or still a probabilistic function [28].

The process of electing a cluster-head in a k-node cluster is as follows:

- If the node u has the strongest metric in its k-neighborhood, then it declares itself cluster-head and spreads its status to its k-neighbors in order to invite them to join it in its cluster.
- Otherwise, the node u waits for all its k-neighbors to broadcast their status.
  - If one of them declares itself cluster-head, then the node u attaches itself to it and declares itself an ordinary node. Then, it diffuses its status to its k-neighborhood
  - If several of its k-neighbors have declared themselves cluster-heads, the node u declares itself a gateway node and diffuses its status to its k-neighborhood
  - Otherwise, the node u declares itself cluster-head and spreads its status to its k-neighborhood

One way to classify clustering algorithms is, for example, to differentiate construction metrics that consider energy from those that do not.

a. Algorithms that do not take into account energy

Historically, clustering algorithms formed node-1 clusters. One of the oldest is "the algorithm of the smallest identifier" or Lowest Common Ancestor (LCA) proposed by [29]. The ability of a node to become cluster-head is based on its own identifier and those of its direct neighborhood. In LCA, nodes can have three different states: cluster-head, gateway (node belonging to multiple clusters), or ordinary node (default state of a node) [30]. In the formed virtual structure, only cluster-heads nodes and gateway nodes are used to relay control and data messages.

To provide more stability to the virtual structure formed by the LCA algorithm, the authors in [31] proposed the connectivity-based LEACH-MEEC routing protocol, which uses the degree of the nodes as the criterion of the election of the cluster -heads. This metric favors the nodes with the most neighbors to become cluster-heads. In case of conflict, it is the weaker identifier that is elected. In [32], the authors propose a generalization to k nodes of the HCC algorithm.

Another variant of the LCA algorithm called WCA (Weight Clustering Algorithm) [33]. WCA uses the same principle as LCA but with a different metric referenced as a weight. This weight is a weighted sum of several metrics such as degree, Euclidean distance, relative mobility, and time of service as cluster-head. The node with the lowest weight among its neighborhood becomes cluster-head. The weight of a node u is defined as follows [33]:

$$Weight(u) = \frac{\alpha.D_u+\beta.P_u+\lambda.M_u}{+\sigma.T_u\ with\ \alpha+\beta+\sigma} = 1 \quad (4)$$

- D_u is the difference between the degree of the node u and the maximum size of a cluster;
- P_u is the sum of the distances between the node u and its neighbors;
- M_u is the average relative mobility of the node u ;
- T_u are the service time as a cluster-head.

Cluster maintenance in WCA considers only the node identifier and not the main metric. This increases the temporal persistence of cluster heads. This heuristic is very complex because it requires the nodes to calculate their weight before initiating the clustering process. Weight calculation requires a lot of traffic. Also, it uses GPS for calculating distances (expensive and very energy-intensive). Such a heuristic cannot be used in a WSN where, in most applications, it is impossible to replace the node batteries.

In [34], the authors propose the 3hbac algorithm (node-2 between adjacent cluster-heads) which impose 3 nodes between neighboring cluster-heads. Compared to overlapping 1-cluster algorithms, the 3hBAC algorithm minimizes the average number of clusters, reduces inter-cluster communication and delivery time. Also, it optimizes the temporal persistence of the clusters because a local reconstruction does not generate the total reconstruction of the structure. In the same vein, [36] propose the Min-Max d-cluster algorithm that requires each node to be at most d breaks from its cluster-head. It optimizes inter-cluster routing by reducing the number of clusters and building non-overlapping d-clusters. The algorithm is based on the identifier of the nodes for the election of cluster-heads. The resulting clusters are more robust than those of the two 1-clustering algorithms (LCA and HCC). Nevertheless, they introduce latency and exchanges of messages not insignificant because they require a knowledge of the neighborhood with nodes. Also, no maintenance is proposed for the latter approach.

In [37], the authors rely on the k-density metric of nodes for the election of cluster-heads. The k -density of a node u is the ratio of the number of links by the number of nodes in his k-neighborhood. The resulting clusters, non-overlapping and of varying sizes, are more robust and adapt to small changes that may occur in the vicinity of a node. This reduces maintenance costs and provides more stability to the structure (this metric promotes the re-election of old cluster-heads when possible). Moreover, these authors have shown that among the various k-densities, the most robust and least expensive in terms of exchange of control messages is that of 1 - density since it requires only the knowledge of 2 - density. neighborhood.

Some authors like [38] propose to build k-clusters after creating a dorsal. A backbone is by definition a connected set of strong nodes called "dominant" whose function is to collect data traffic and relay it to an end-user. There are several types of backbones, namely the CDS (Connected dominant set) [39], and variants such as MCDS (Minimum connected dominating set) [40], the k -CDS (k -connected dominant set) [41]. The authors in [38] propose to create the k -CDS backbone. The authors define four different states (dominant: a member of the dorsal, dominated: node at most k dominant, active: node competing to be elected dominant, ordinary: the default state of a node) and a stability weight associated with each node. This weight for a node is a nonlinear combination of three metrics: its relative mobility is given by:

$$M = \frac{||N_{t+\Delta t}/N_t| + N_t/N_{t+\Delta t}|}{|N_t \cup N_{t+\Delta t}|} \quad (5)$$

If N_t is the set of neighbors of a node N at time t, its reserve of energy (ξ), its distance with an optimal degree of connectivity Δ (equal to the difference between the number of real neighbors and an optimal degree chosen for the application). The weight of a Node is thus defined by weights.

$$P_{stability} = \xi(\alpha.(1+\Delta)^{-1} + \beta.(1+M)^{-1} \quad (6)$$

Where α *and* β are weighting coefficients.

Due to the historical context of ad hoc networks that are not necessarily large but have strong mobility constraints, the algorithms presented so far take very little account of the energy of the nodes for the designation of cluster heads. The large WSNs do not necessarily have this constraint of taking mobility into account but require, in order to improve their lifetime, to be able to optimize energy expenditure.

b. Algorithms based on the node's residual energy

Energy consumption is minimized by several clustering techniques suggested in the literature, and LEACH is widely used among them. The random selection of cluster heads in the LEACH algorithm for some time and according to a "Round-Robin" policy to maintain the energy dissipation between the nodes [42]. The resulting topology of this algorithm is shown in Figure 6.

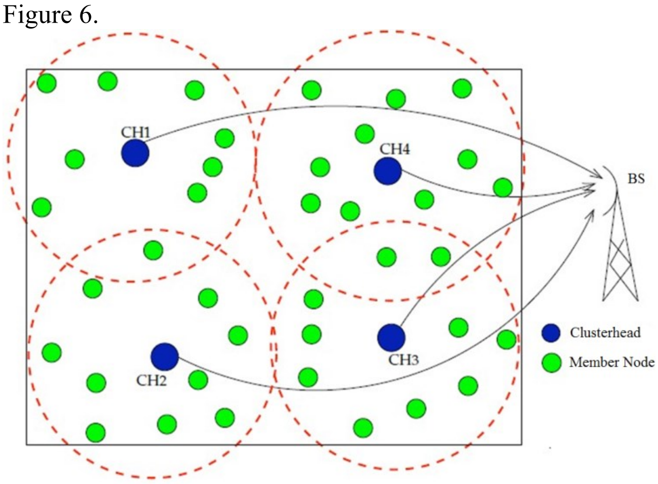

Fig. 6. Topology based on LEACH: 1 intra-cluster node and 1 node to the sink [42]

The HEED protocol proposed in [43] uses the cluster radius which is responsible for the transmission power required in the intra-cluster distribution. The degree and residual energy of a node decide the probability of becoming a cluster-head. The goal of HEED is to standardize the distribution of cluster heads in the network to generate clusters balanced in size, and therefore to balance energy consumption.

Several improvements have been made to LEACH. We can cite the M-LEACH algorithm (Multi-node LEACH) [44]. M-LEACH assumes that members of a cluster can be more than 1 node from its cluster-head. Also, it allows for inter-cluster multi-node communications (see Figure 7). The goal of M-LEACH is to increase the stability of the structure compared to LEACH by reducing the energy dissipated by cluster-head. Nevertheless, M-LEACH does not solve the problem of a low energy node that can become cluster-head and thus weaken the robustness of the structure. To remedy this, another LEACH variant called LEACH-C has been proposed [44]. LEACH-C involves the amount of residual energy of the nodes in the election measure of cluster-heads. However, this approach is centralized because the base station governs the entire clustering approach.

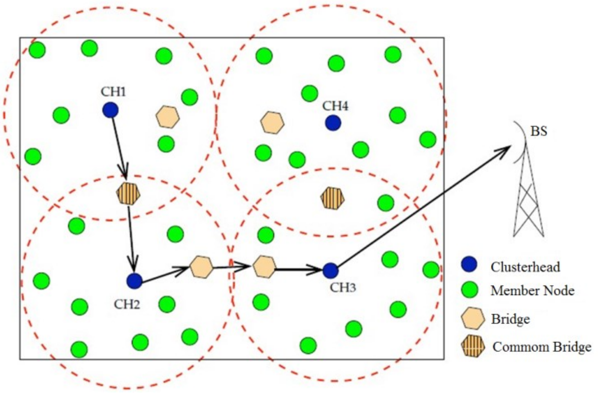

Fig. 7. Multi-node topology intra- and inter-cluster [44]

The authors in [45] proposed EEHC (Energy Efficient Heterogeneous Clustered), an energy-efficient clustering algorithm. Like LEACH, the criterion of cluster-head election is probabilistic. However, the election process incorporates the residual energy of the nodes. It thus makes it possible to standardize the energy consumption between the nodes and thus to prolong the lifetime of the network.

In [46] [47], the authors propose, respectively, the DEEC (Distributed Energy-Efficient Clustering) and DEBC (Distributed Energy Balance Clustering) algorithms, also based on LEACH. The criterion for selecting cluster heads is probabilistic. The idea is to allow each node to dissipate its energy uniformly by distributing, in turn, the cluster-head function. Any node can pretend to become cluster-head if its probability is greater than a threshold. This probability is calculated based on initial energy, average energy and the energy reserve of the network. The authors assume that the value of the average energy of the network is estimated and broadcast at each turn by the base station to all the nodes of the network. This centralized operation increases the complexity of the algorithm in terms of message exchange and makes it difficult to use for large networks.

An improved version of DEEC called SDEEC (Stochastic DEEC) has been proposed in [48] to reduce intra-cluster communications. For that, it proposes a strategy to put to sleep the non-chosen nodes like cluster-head. This policy requires that any member node sends its data to the cluster-head within a defined time interval. Then, they can fall asleep to conserve their energy while cluster-heads nodes aggregate all data.

2) Cluster heads are different nodes (heterogeneous network)

Nodes with higher capabilities than basic nodes are "by nature" intended to be cluster-heads. It is called hardware heterogeneity: these nodes differ in terms of processor, processing capacity, transmission power, bandwidth, and so on. Given the technological advances and for certain types of applications, it is more and more common to integrate these "super-nodes" to improve performance network. The communication network thus defined is a hierarchical structure with two levels as in Figure 8. A study by [49] showed that a properly deployed heterogeneous network could triple the average delivery rate and can extend network lifetime by up to five times. The use of super-nodes in large WSNs is therefore seen as a possible way to facilitate the management and to scale-up of the network, to shorten transmission delays, but also to improve connectivity and network lifetime. Such WSNs are usually partitioned into subnets with one super-node per cluster. They perform specific tasks such as aggregating and relaying data, or coordinate the activities of their members, and so on. Cluster formation strategies in such networks are numerous and vary according to the purpose. For example, in [50], the authors propose a Scalable Self-configuration and Self-healing (GS3) algorithm to self-configure and provide spatial coverage of the network of super-mobile nodes and ordinary nodes. The resulting structure is similar to a hexagonal cell structure.

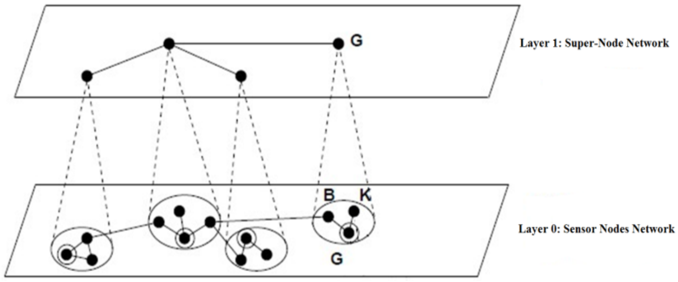

Fig. 8. Hierarchical communication architecture at 2 levels [50]

The clustering process is initiated by one of the super-nodes that chooses the cluster-heads of the neighboring hexagonal cells. Unselected super-nodes then become cell members. Super-nodes selected as cluster-heads are relocated to the center of their cells and then start selecting neighboring cluster-heads. This process is repeated until there are no more cells to add. GS3 uses the geographic radius of the cluster instead of the logical radius. This increases the spatial coverage by increasing the number of clusters in areas where the degree of connectivity is high. However, changes in the topology of the super-nodes require a total reconstruction of the clusters, and therefore a cost of not insignificant communication. Also, GS3 requires supernodes to be equipped with a directional antenna to allow them to reposition themselves in the center of their hexagonal cell. Such hypotheses (mobility + directional antenna) are complex and expensive, and therefore excluded for most conventional applications.

For load balancing, several clustering techniques have been proposed. The Load Balanced Clustering (LBC) [51] and GLBCA (Greedy Load Balanced Clustering Algorithm) [52] algorithms are proposed. GLBCA and LBC control the network load distribution between the super-nodes by creating clusters. Each cluster is connected with a super-node that acts as a cluster-head. They use an offline and centralized method to find the ideal size of the clusters. For this, the super-nodes must collect the information of all the nodes of the network. LBC uses the energy reserve and the geographical position of the nodes. Then, the super-nodes must transmit the partitioning information so that the nodes can join their respective cluster. This approach is not flexible because nodes can be subject to temporary or permanent failures. It leads to problems because, at each change, the super-nodes must recalculate the best partitioning and retransmit these decisions to the nodes. This generates a significant protocol overhead in terms of messages and latency. Also, GLBCA and LBC are not "scalable" (not suitable for very large dimensions) because they require super-nodes to have a universal understanding of the network at all times (to balance the network load in case of topological changes). And this requires a lot of information gathering time especially if the network is large. Besides, GLBCA and LBC require nodes to be able to determine their geographic position through a location system (such as GPS) that is financially costly [53]. Table 1 shows the comparative analysis of different clustering algorithms based on various parameters.

TABLE I

COMPARISON OF VARIOUS CLUSTERING ALGORITHMS

Algorithm	**Abbreviation**	**Heterogeneity**	**Advantages**	**Parameters of CH selection**	**Clustering Approach**
Balanced Centroids Clustering Algorithm	BCCA [54]	No	Network Lifetime	Node ID	Analytical
Base station Controlled Dynamic Clustering protocol	BCDCP [55]	No	Energy Saving, Network Lifetime	Initial Energy	Iterative
Cluster optimized cooperative MIMO transmission scheme	COC-MIMO [56]	No	Energy Saving	Residual Energy	Analytical
Cross-layer approach	CROSS [57]	No	Energy Saving, Network Lifetime	N/A	Analytical
Dynamic Clustering-binary Multi PSO algorithm	DCBMPSO [58]	No	Energy Saving	Residual Energy	Analytical
Distributed Source Coding based algorithm	DSCB [59]	No	Efficient Data Correlation	Max-Min Hop Number	Analytical
Gustafson-Kessel clustering	GK-Clustering [62]	No	Energy Saving	N/A	Fuzzy Clustering
Hybrid, Energy-Efficient, and Distributed Clustering Approach	HEED [63]	No	Energy Saving	Residual Energy	Iterative
Low Energy Adaptive Clustering Hierarchy	LEACH [64]	No	Energy Saving	Residual Energy	Analytical
Improved LEACH	I-LEACH [65]	No	Energy Saving	Residual Energy	Experimental
Optimal Placement of Cluster heads algorithms	OPC [43]	No	Network Lifetime	Initial Energy	Analytical
Particle Swarm Optimization algorithm	PSO [68]	No	Energy Saving	Residual Energy	Theoretical
Step Wise Adaptive Clustering Hierarchy	SWATCH [70]	No	Energy Saving	Residual Energy	Analytical
Time Controlled Clustering Algorithms	TCCA [71]	No	Energy Saving	Residual Energy	Analytical
Virtual Grid-Based Clustering Routing protocol	VGCR [72]	No	Energy Saving, Network Lifetime	Residual Energy	Analytical
Energy-Efficient Heterogeneous Clustered Scheme	EEHC [60]	Yes	Energy Saving	Residual Energy	Analytical
Energy-Efficient Cluster Head Election Method	EECHE [61]	Yes	Energy Saving	Residual Energy	Analytical
A level Based Clustering algorithm	LBC [66]	Yes	Energy Saving	Residual Energy	Analytical
Stable Election Protocol	SEP [69]	Yes	Provides Network Stable Region	Residual Energy	Analytical
Distributed Energy Efficient Clustering	DEEC[46]	Yes	Increased stable region	Residual Energy	Analytical

IV. CONCLUSION

The algorithms (LCA, WCA, HCC, 3hBAC, etc.) do not take (or very little) into account the energy of the nodes in the construction of the clusters, despite the fact that this is a strong constraint for embedded systems. They are, therefore, unsuited to our needs because the main branches of our communication tree must not be too weak or unstable.

The algorithms (LEACH-C, LEACH-M, HEED, DEBC, etc.) use the residual energy of the nodes in their topological organization policy. But they were designed for WSN involving homogeneous nodes. However, given technological advances and application needs, it is increasingly common to use heterogeneous nodes (energy and/or physical capabilities). Also, they deliver overlapping clusters, which can be problematic in terms of the temporal persistence of the communication structure.

The heuristics proposed algorithms (GS3, GLBCA / LBC) are based on structures hierarchical involving multiple levels and nodes with different capabilities (heterogeneous networks). Cluster leaders are here named because of their very nature (the notion of "super-nodes"). This structuring of the communication brings undeniable benefits to the overall performance of the quality of service of the network. Still, the proposed variations are not extensible to the very large WSN. This is due to their protocol complexity in terms of messages exchanged or the fact that these heuristics are based on a centralized approach. Also, some algorithms require super-nodes to know, at any time, the geographical position of all the nodes of the network. The collection of this information can be very long and very expensive in terms of message exchange and therefore energy consumption particularly if the network is large. The GLBCA / LBC approach assumes that collectors can be mobile. This is not always applicable in large networks as it is difficult for a collector to move throughout the surveillance zone. And while they may have access to the set, the sink travel time could result in significant communication latency and data loss caused by the limited storage capacity.

This study allowed us to highlight the need for a new approach taking advantage of the assets considered in the different categories of algorithms.

REFERENCES

[1]. Rawat, Priyanka, Kamal Deep Singh, HakimaChaouchi, and Jean Marie Bonnin. "Wireless sensor networks: a survey on recent developments and potential synergies." *The Journal of supercomputing* 68, no. 1 (2014): 1-48.

[2]. Ang, Li-Minn, KahPhooiSeng, Li Wern Chew, Lee SengYeong, and Wai Chong Chia. "Wireless multimedia sensor network technology." In *Wireless multimedia sensor networks on reconfigurable hardware*, pp. 5-38. Springer, Berlin, Heidelberg, 2013.

[3]. Levis, Philip, Sam Madden, Joseph Polastre, Robert Szewczyk, Kamin Whitehouse, Alec Woo, David Gay, et al. "TinyOS: An operating system for sensor networks." In *Ambient Intelligence*, pp. 115-148. Springer, Berlin, Heidelberg, 2005.

[4]. Akyildiz, Ian F., Weilian Su, YogeshSankarasubramaniam, and ErdalCayirci. "A survey on sensor networks." *IEEE Communications Magazine* 40, no. 8 (2002): 102-114.

[5]. Curiac, Daniel-Ioan. "Towards wireless sensor, actuator and robot networks: Conceptual framework, challenges, and perspectives." *Journal of Network and Computer Applications* 63 (2016): 14-23.

[6]. Bouk, SafdarHussain, Iwao Sasase, Syed Hassan Ahmed, and Nadeem Javaid. "Gateway discovery algorithm based on multiple QoS path parameters between a mobile node and gateway node." *journal of communications and networks* 14, no. 4 (2012): 434-442.

[7]. Liu, Anfeng, ZhongmingZheng, Chao Zhang, Zhigang Chen, and XueminShen. "Secure and energy-efficient disjoint multipath routing for WSNs." *IEEE Transactions on Vehicular Technology* 61, no. 7 (2012): 3255-3265.

[8]. Garcia, Miguel, Sandra Sendra, Jaime Lloret, and Alejandro Canovas. "Saving energy and improving communications using cooperative group-based wireless sensor networks." *Telecommunication Systems* 52, no. 4 (2013): 2489-2502.

[9]. Abdollahzadeh, Sanay, and NimaJafariNavimipour. "Deployment strategies in the wireless sensor network: A comprehensive review." *Computer Communications* 91 (2016): 1-16.

[10]. AlSayyari, Abdulaziz, IvicaKostanic, and Carlos E. Otero. "An empirical path loss model for wireless sensor network deployment in an artificial turf environment." In *Proceedings of the 11th IEEE International Conference on Networking, Sensing and Control*, pp. 637-642. IEEE, 2014.

[11]. Kurt, Sinan, and BulentTavli. "Path-Loss Modeling for Wireless Sensor Networks: A review of models and comparative evaluations." *IEEE Antennas and Propagation Magazine* 59, no. 1 (2017): 18-37.

[12]. Chen, Jiming, Junkun Li, Shibo He, Youxian Sun, and Hsiao-Hwa Chen. "Energy-efficient coverage based on probabilistic sensing model in wireless sensor networks." *IEEE Communications Letters* 14, no. 9 (2010): 833-835.

[13]. Akbarzadeh, Vahab, Christian Gagne, Marc Parizeau, MeysamArgany, and Mir AbolfazlMostafavi. "Probabilistic sensing model for sensor placement optimization based on line-of-sight coverage." *IEEE Transactions on Instrumentation and Measurement* 62, no. 2 (2012): 293-303.

[14]. Zhang, Yuhong, and Wei Li. "Modeling and energy consumption evaluation of a stochastic wireless sensor network." *EURASIP Journal on Wireless Communications and Networking* 2012, no. 1 (2012): 282.

[15]. Abo-Zahhad, Mohammed, Mohammed Farrag, Abdelhay Ali, and Osama Amin. "An energy consumption model for wireless sensor networks." In *5th International Conference on Energy-Aware Computing Systems & Applications*, pp. 1-4. IEEE, 2015.

[16]. Latif, Kamran, NadeemJavaid, Malik NajmusSaqib, Zahoor Ali Khan, and Nabil Alrajeh. "Energy consumption model for density controlled divide-and-rule scheme for energy-efficient routing in wireless sensor networks." *International Journal of Ad Hoc and Ubiquitous Computing* 21, no. 2 (2016): 130-139.

[17]. Pottie, Gregory J., and William J. Kaiser. "Wireless integrated network sensors." *Communications of the ACM* 43, no. 5 (2000): 51-58.

[18]. Li, Li, and Joseph Y. Halpern. "Minimum-energy mobile wireless networks revisited." In *ICC 2001. IEEE International Conference on Communications. Conference Record (Cat. No. 01CH37240)*, vol. 1, pp. 278-283. IEEE, 2001.

[19]. Das, Arindam Kumar, Robert J. Marks, Mohamed El-Sharkawi, PaymanArabshahi, and Andrew Gray. "Minimum power broadcast trees for wireless networks: integer programming formulations." In *IEEE INFOCOM 2003. Twenty-second Annual Joint Conference of the IEEE Computer and Communications Societies (IEEE Cat. No. 03CH37428)*, vol. 2, pp. 1001-1010. IEEE, 2003.

[20]. Kröller, Alexander, Sándor P. Fekete, Dennis Pfisterer, and Stefan Fischer. "Deterministic boundary recognition and topology extraction for large sensor networks." In *Proceedings of the seventeenth annual ACM-SIAM symposium on Discrete algorithm*, pp. 1000-1009. Society for Industrial and Applied Mathematics, 2006.

[21]. Huang, Zuming, Guangliang Cheng, Hongzhen Wang, Haichang Li, Limin Shi, and Chunhong Pan. "Building extraction from multi-source remote sensing images via deep deconvolution neural networks." In *2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pp. 1835-1838. IEEE, 2016.

[22]. Santi, Paolo. "Topology control in wireless ad hoc and sensor networks." *ACM computing surveys (CSUR)* 37, no. 2 (2005): 164-194.

[23]. Singh, Santar Pal, and S. C. Sharma. "A survey on cluster-based routing protocols in wireless sensor networks." *Procedia computer science* 45 (2015): 687-695.

[24]. Desai, S. Sundeep, and Manisha J. Nene. "node-level trust evaluation in wireless sensor networks." *IEEE Transactions on Information Forensics and Security* 14, no. 8 (2019): 2139-2152.

[25]. Liu, Zhen, and Don Towsley. "Optimality of the round-robin routing policy." *Journal of applied probability* 31, no. 2 (1994): 466-475.

[26]. Younis, Ossama, Marwan Krunz, and Srinivasan Ramasubramanian. "Node clustering in wireless sensor networks: recent developments and deployment challenges." *IEEE Network* 20, no. 3 (2006): 20-25.

[27]. Intanagonwiwat, Chalermek, Deborah Estrin, Ramesh Govindan, and John Heidemann. "Impact of network density on data aggregation in wireless sensor networks." In *ICDCS*, vol. 2, p. 457. 2002.

[28]. Bouaziz, Maha, and AbderrezakRachedi. "A survey on mobility management protocols in Wireless Sensor Networks based on 6LoWPAN technology." *Computer Communications* 74 (2016): 3-15.

[29]. Ephremides, Anthony, Jeffrey E. Wieselthier, and Dennis J. Baker. "A design concept for reliable mobile radio networks with frequency hopping signaling." *Proceedings of the IEEE* 75, no. 1 (1987): 56-73.

[30]. Singh, DeveshPratap, and R. H. Goudar. "Energy-efficient clearance routing in WSN." *International Journal of System Assurance Engineering and Management* 8, no. 2 (2017): 555-575.

[31]. Ahmad, Muqeet, Tianrui Li, Zahid Khan, Faisal Khurshid, and Mushtaq Ahmad. "A Novel Connectivity-Based LEACH-MEEC Routing Protocol for Mobile Wireless Sensor Network." *Sensors* 18, no. 12 (2018): 4278.

[32]. Takabatake, Toshinori, Keiichi Kaneko, and Hideo Ito. "HCC: generalized hierarchical completely-connected networks." *IEICE TRANSACTIONS on Information and Systems* 83, no. 6 (2000): 1216-1224.

[33]. Dahane, Amine, AbdelhamidLoukil, BouabdellahKechar, and Nasr-EddineBerrached. "Energy-efficient and safe weighted clustering algorithm for mobile wireless sensor networks." *Mobile information systems* 2015 (2015).

[34]. Yu, J. Y., and Peter HJ Chong. "3hbac (3-hop between adjacent cluster heads): a novel non-overlapping clustering algorithm for mobile ad hoc networks." In *2003 IEEE Pacific Rim Conference on Communications Computers and Signal Processing (PACRIM 2003)(Cat. No. 03CH37490)*, vol. 1, pp. 318-321. IEEE, 2003.

[35]. Azizian, Meysam, SoumayaCherkaoui, and AbdelhakimSenhajiHafid. "A distributed d-hop cluster formation for VANET." In *2016 IEEE Wireless Communications and Networking Conference*, pp. 1-6. IEEE, 2016.

[36]. Amis, Alan D., Ravi Prakash, Thai HP Vuong, and Dung T. Huynh. "Max-min d-cluster formation in wireless ad hoc networks." In *Proceedings IEEE INFOCOM 2000. Conference on Computer Communications. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies (Cat. No. 00CH37064)*, vol. 1, pp. 32-41. IEEE, 2000.

[37]. Chidean, Mihaela I., Eduardo Morgado, Eduardo del Arco, Julio Ramiro-Bargueno, and Antonio J. Caamaño. "Scalable data-coupled clustering for large scale WSN." *IEEE Transactions on Wireless Communications* 14, no. 9 (2015): 4681-4694.

[38]. Theoleyre, Fabrice, and Fabrice Valois. "A self-organization structure for hybrid networks." *Ad Hoc Networks* 6, no. 3 (2008): 393-407.

[39]. Zhao, Yaxiong, Jie Wu, Feng Li, and Sanglu Lu. "On maximizing the lifetime of wireless sensor networks using virtual backbone

scheduling." *IEEE transactions on parallel and distributed systems* 23, no. 8 (2011): 1528-1535.

[40]. Jovanovic, Raka, and Milan Tuba. "Ant colony optimization algorithm with pheromone correction strategy for the minimum connected dominating set problem." *Comput. Sci. Inf. Syst.* 10, no. 1 (2013): 133-149.

[41]. Pan, Jeng-Shyang, Lingping Kong, Tien-Wen Sung, Pei-Wei Tsai, and VáclavSnášel. "A clustering scheme for wireless sensor networks based on genetic algorithm and dominating set." *Journal of Internet Technology* 19, no. 4 (2018): 1111-1118.

[42]. Sohn, Illsoo, Jong-Ho Lee, and Sang Hyun Lee. "Low-energy adaptive clustering hierarchy using affinity propagation for wireless sensor networks." *IEEE Communications Letters* 20, no. 3 (2016): 558-561.

[43]. Chand, Satish, Samayveer Singh, and Bijendra Kumar. "Heterogeneous HEED protocol for wireless sensor networks." *Wireless personal communications* 77, no. 3 (2014): 2117-2139.

[44]. Das, Abhijeet, and Parma NandAstya. "A relative survey of various LEACH based routing protocols in wireless sensor networks." In *2017 International Conference on Computing, Communication, and Automation (ICCCA)*, pp. 630-636. IEEE, 2017.

[45]. Kumar, Dilip, Trilok C. Aseri, and R. B. Patel. "EEHC: Energy efficient heterogeneous clustered scheme for wireless sensor networks." *Computer Communications* 32, no. 4 (2009): 662-667.

[46]. Qing, Li, Qingxin Zhu, and Mingwen Wang. "Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks." *Computer communications* 29, no. 12 (2006): 2230-2237.

[47]. Duan, Changmin, and Hong Fan. "A distributed energy balance clustering protocol for heterogeneous wireless sensor networks." In *2007 International Conference on Wireless Communications, Networking and Mobile Computing*, pp. 2469-2473. IEEE, 2007.

[48]. Brahim, Elbhiri, SaadaneRachid, Alba-Pages Zamora, and DrissAboutajdine. "Stochastic Distributed Energy-Efficient Clustering (SDEEC) for heterogeneous WSNs." *ICGST-CNIR Journal* 9, no. 2 (2009).

[49]. Yan, Jingjing, Mengchu Zhou, and Zhijun Ding. "Recent advances in energy-efficient routing protocols for wireless sensor networks: A review." *IEEE Access* 4 (2016): 5673-5686.

[50]. Zhang, Hongwei, and Anish Arora. "GS3: scalable self-configuration and self-healing in wireless sensor networks." *Computer Networks* 43, no. 4 (2003): 459-480.

[51]. Siavoshi, Saman, Yousef S. Kavian, and Hamid Sharif. "Load-balanced energy-efficient clustering protocol for wireless sensor networks." *IET Wireless Sensor Systems* 6, no. 3 (2016): 67-73.

[52]. Low, Chor Ping, Can Fang, Jim Mee Ng, and Yew Hock Ang. "Efficient load-balanced clustering algorithms for wireless sensor networks." *Computer Communications* 31, no. 4 (2008): 750-759.

[53]. Esmaeeli, Mahnaz, and Seyed Ali HosseiniGhahroudi. "Improving energy efficiency using a new game theory algorithm for wireless sensor networks." *International Journal of Computer Applications* 136, no. 12 (2016).

[54]. Gupta, Shivani. "A survey on balanced data clustering algorithms." *International Journal for Women Researchers in Engineering, Science and Management* 2, no. 9 (2017): 2611-2614.

[55]. Dawood, M. Sheik, S. Sadasivam, and G. Athisha. "Energy-efficient wireless sensor networks based on QoS enhanced base station controlled dynamic clustering protocol." *International Journal of Computer Applications* 975, no. 8887 (2011): 44-49.

[56]. Pillutla, Laxminarayana S., and Vikram Krishnamurthy. "Joint rate and cluster optimization in cooperative MIMO sensor networks." In *IEEE 6th Workshop on Signal Processing Advances in Wireless Communications, 2005.*, pp. 265-269. IEEE, 2005.

[57]. Mammu, Aboobeker, Unai Hernandez-Jayo, NekaneSainz, and Idoia de la Iglesia. "Cross-layer cluster-based energy-efficient protocol for wireless sensor networks." *Sensors* 15, no. 4 (2015): 8314-8336.

[58]. Latiff, NM Abdul, C. C. Tsimenidis, Bayan S. Sharif, and CassimLadha. "Dynamic clustering using binary multi-objective particle swarm optimization for wireless sensor networks." In *2008 IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 1-5. IEEE, 2008.

[59]. Wang, Honggang, DongmingPeng, Wei Wang, Hamid Sharif, and Hsiao-Hwa Chen. "Cross-layer routing optimization in multi-rate wireless sensor networks for distributed source coding based applications." *IEEE Transactions on Wireless Communications* 7, no. 10 (2008): 3999-4009.

[60]. Kumar, Dilip, Trilok C. Aseri, and R. B. Patel. "EEHC: Energy efficient heterogeneous clustered scheme for wireless sensor networks." *Computer Communications* 32, no. 4 (2009): 662-667.

[61]. Lee, Kyounghwa, Joohyun Lee, Minsu Park, Jaeho Kim, and Yongtae Shin. "EECHE: an energy-efficient cluster head election algorithm in sensor networks." In *Asia-Pacific Network Operations and Management Symposium*, pp. 486-489. Springer, Berlin, Heidelberg, 2009.

[62]. Raghuvanshi, A. S., S. Tiwari, R. Tripathi, and NandKishor. "GK clustering approach to determine the optimal number of clusters for Wireless Sensor Networks." In *2009 Fifth International Conference on Wireless Communication and Sensor Networks (WCSN)*, pp. 1-6. IEEE, 2009.

[63]. Younis, Ossama, and Sonia Fahmy. "HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks." *IEEE Transactions on mobile computing* 4 (2004): 366-379.

[64]. Handy, M. J., Marc Haase, and Dirk Timmermann. "Low energy adaptive clustering hierarchy with deterministic cluster-head selection." In *4th international workshop on mobile and wireless communications network*, pp. 368-372. IEEE, 2002.

[65]. Kumar, Naveen, and Jasbir Kaur. "Improved leach protocol for wireless sensor networks." In *2011 7th International Conference on Wireless Communications, Networking and Mobile Computing*, pp. 1-5. IEEE, 2011.

[66]. Diwakar, Meenakshi, and Sushil Kumar. "An energy-efficient level based clustering routing protocol for wireless sensor networks." *International Journal Of Advanced Smart Sensor Network Systems (IJASSN)* 2, no. 2 (2012): 55-65.

[67]. Dhanaraj, Marudachalam, and C. Siva Ram Murthy. "On achieving maximum network lifetime through optimal placement of cluster-heads in wireless sensor networks." In *2007 IEEE International Conference on Communications*, pp. 3142-3147. IEEE, 2007.

[68]. Kulkarni, Raghavendra V., and Ganesh Kumar Venayagamoorthy. "Particle swarm optimization in wireless sensor networks: A brief survey." *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 41, no. 2 (2010): 262-267.

[69]. Smaragdakis, Georgios, Ibrahim Matta, and AzerBestavros. *SEP: A stable election protocol for clustered heterogeneous wireless sensor networks*. Boston University Computer Science Department, 2004.

[70]. Wang, Quanhong, Kenan Xu, HossamHassanein, and Glen Takahara. "Swatch: A stepwise adaptive clustering hierarchy in wireless sensor networks." In *International Conference on Research in Networking*, pp. 1422-1425. Springer, Berlin, Heidelberg, 2005.

[71]. Selvakennedy, S., and SukunesanSinnappan. "The time-controlled clustering algorithm for optimized data dissemination in a wireless sensor network." *The IEEE Conference on Local Computer Networks 30th Anniversary (LCN'05) l*, pp. 2-pp. IEEE, 2005.

[72]. Li, Hong, XuShunjie, Wang Guoqiang, and JiZhe. "Uneven virtual grid-based clustering routing protocol for wireless sensor networks." In *2009 International Conference on Information and Automation*, pp. 397-402. IEEE, 2009.