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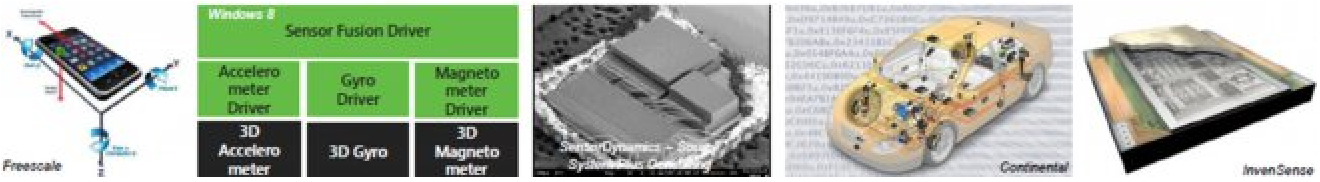

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Comparative Analysis of Energy-efficient Cluster-based Routing Protocols for Wireless Sensor Networks

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Abstract: Wireless sensor networks continue to get tremendous popularity, as evidenced by the increasing number of applications. Sophistication of wireless communications had enabled the development of low-cost, low-power wireless sensor networks (WSNs) with wide applicability, including environment and vehicle-health monitoring system. WSN reduce the energy consumption and hence maximize the lifetime of the network which are the key requirements in the design of optimum sensor networking protocols and algorithms. The limiting factors of the sensor nodes, such as their finite energy supplies and their moderate processing abilities, as well as the unreliable wireless medium restrict the performance of wireless sensor networks. Several routing protocols with different objectives have been proposed for energy-efficient WSNs applications. This article surveys a sample of existing energy-efficient cluster-based protocols PEGASIS, LEACH, EEHC, HEED, DWEHC, BMA, BCDCP, THEEM and highlights their key features, including merits and limitations.

Keywords: Wireless sensor networks, Routing protocols, Energy-efficient cluster-based protocols.

1. Introduction

Advances in wireless networking, micro-fabrication and integration, embedded microprocessors have enabled a new generation of massive-scale sensor networks suitable for a range of commercial and military applications. The technology promises to revolutionize the way we live, work, and interact with the physical environment. Wireless Sensor Networks (WSNs) are networks made up of tiny embedded devices. Each sensor node in a WSN is capable of sensing, processing and communicating the local information. Each node device has some level of intelligence to collect data and route them to the sink node to enhance operational efficiency. The networks can be made up of hundreds or thousands of devices that work together to communicate the information that they obtain. A sensor node in a WSN comprises mainly a sensing unit, a processing unit, a radio transceiver unit and a power unit. Due to sensor node's placement with respect to the operational environment and quantity, it is not usually easy or even feasible to replace individual sensor nodes or their energy frequently. Energy efficiency, low latency, data accuracy, high estimation accuracy, and fast convergence are important goals for any sensor network. Hence the network needs to ensure quality of service (QoS) besides ease of deployment, energy efficiency and low cost.

One of the major design goals of WSNs is reliable data communication under minimum energy depletion to extend the lifetime of the network. This may be achieved via aggressive energy management techniques. Owing to their poor energy conservation, traditional routing protocols are not suitable for WSN applications. It is highly desirable to employ an energy-efficient route discovery and data relaying techniques to transfer data between the sensor nodes and the base station (BS), the data aggregation point. Some of the routing challenges and design issues that affect the routing process in WSN are: node deployment, data reporting method, node/link heterogeneity, fault tolerance, scalability, transmission media, data aggregation, connectivity, coverage and QoS [1-3].

In this article, we survey energy-efficient routing protocols for WSNs, which exploits the concept of clustering. The concept of clustering is exciting with unlimited potential for numerous application areas including environmental, medical, and military, transportation, entertainment, home automation and traffic control crisis management, homeland defense, smart spaces and .railway infrastructure monitoring [4]. The rest of this article is organized as follows. Section 2 classifies routing protocols. Section 3 discusses existing popular cluster-based routing protocols for WSNs. Section 4 tabulates the merits and limitations of cluster-based routing protocols. Section 5 concludes the article.

2. Routing Protocols for Wireless Sensor Networks

Data gathering and processing are important functions of sensor networks and all data from individual sensor nodes need to be sent to the BS, where the end user can access the data. Several routing techniques introduced for WSNs' are based on special features like, data aggregation and processing, in network processing, clustering, nodes' role assignment, and position of node. Therefore, routing protocols for WSNs can be classified into data-centric or flat-based, hierarchical or cluster-based and location-based, depending on the network structure. Routing protocols can also be divided into multipath based, QoS-based, query-based, and coherent-based, depending on how the protocol operates.

All nodes in a flat routing protocol are assigned equal roles or functionality and the nodes collaborate to perform the sensing tasks. The BS sends queries to certain regions within the WSN and awaits data from the sensors located in that region. SPIN [5] and directed diffusion [6] are examples of flat routing protocols. Location or position information of sensor nodes is essential to calculate the distance between neighboring nodes. If the location of sensor nodes are known then data transmission only occurs on that region to reduce the number of transmissions. GAF [7] and GEAR [8] are examples of location-based energy-efficient routing protocols. In the cluster-based routing approach the network is divided into clusters and nodes play multiple roles in the network. Nodes in a cluster communicate with a cluster-head (CH) and the CH transmits the data to the global BS. This reduces the transmission range of normal nodes to conserve energy.

The routing protocol that uses multipath instead of a single path to increase reliability is called multipath routing protocol. Directed diffusion [6] and proposal [9] are examples of multipath routing. QoS-aware routing protocols minimize the end-to-end delay, energy consumption and bandwidth requirements of WSNs during data communication. In query-based routing, the destination nodes initiate a query for data from a node through the network. The nodes having the answer to the query send the data back to the parent nodes that initiated the query. Examples of query-based routing protocols are directed diffusion [6] and RUMOR [10]. Based on data processing techniques, routing protocols for WSNs comprise coherent based and non-coherent-based. Proposal [11] and directed diffusion [6] are examples of coherent and non-coherent routing protocols [2, 3].

3. Cluster-based Routing Protocols

Single-gateway architecture is not suitable for a large sensor network covering a huge area of interest. Clustering approach is a suitable solution for a sensor network with heavy load and wide coverage area. Cluster-based routing reduces energy consumption within a cluster, performs data aggregation and fusion to reduce the number of transmitted messages to the BS. In hierarchical-based routing, nodes play different roles in the network and typically are organized into clusters. Clustering is the method by which sensor nodes in a network organize themselves into groups according to specific requirements. A cluster-based topology is illustrated in Fig. 1. Each group or cluster has a leader referred to as cluster-head (CH) and other ordinary member nodes (MNs). The cluster-heads can be organized into further hierarchical levels. As opposed to a flat organization, clustering allows a hierarchical architecture with more scalability, less consumed energy and thus longer lifetime for the whole network. This is due mainly to the fact that most of the sensing, data processing and communication activities can be performed within clusters. Numerous are WSN applications that require simply an aggregate value to be reported to the sink. In such applications, data aggregation at the cluster-heads helps to alleviate congestion and save energy.

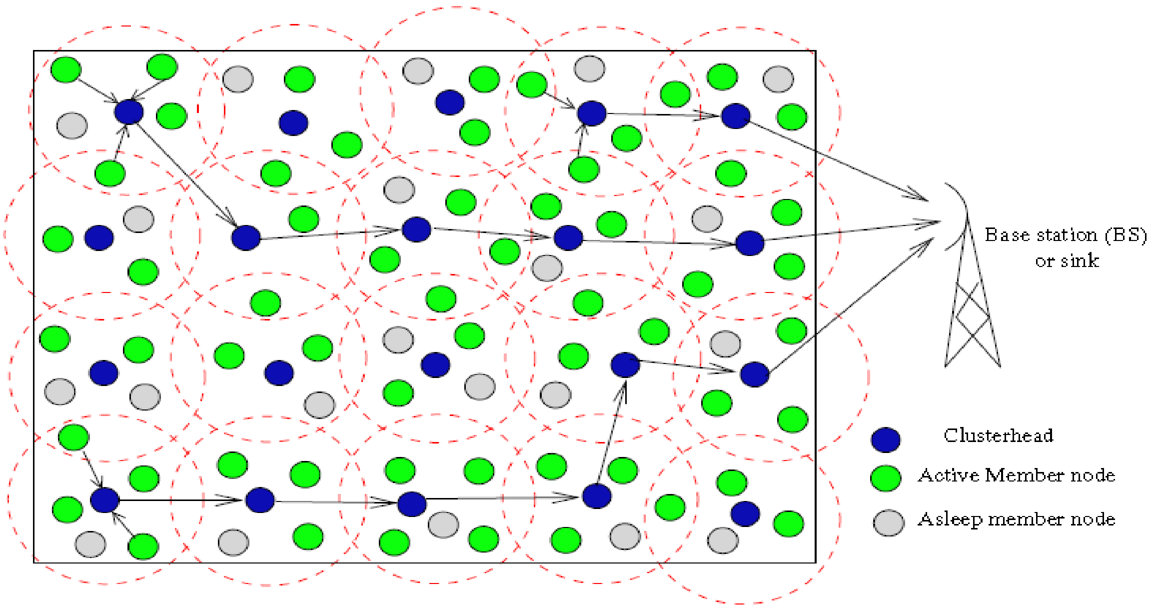

Fig. 1. Cluster-based wireless sensor network.

Clustering allows intra-cluster and inter-cluster routing which reduces the number of nodes taking part in a long distance communication, thus allowing significant energy saving in addition to smaller dissemination latency. Cluster-based routing, due to its salient features, is a promising area and hence has been widely studied on several fronts including: cluster formation, CH election, node to CH data communication and CH to BS data communication [2, 3]. We review some popular cluster-based routing protocols.

3.1. Power-efficient Gathering in Sensor Information Systems (PEGASIS)

The main idea in PEGASIS is for each node to receive from and transmit to close neighbors and take turns being the leader for transmission to the BS [12]. This approach will distribute the energy load evenly among the sensor nodes in the network. The nodes will be organized to form a chain, which can either be accomplished by the sensor nodes themselves using a greedy algorithm starting from some node. Gathered data move from node to node, get fused and finally a designated node transmits the data to the BS. The nodes in the network are organized to form a chain, which can either be computed in a centralized manner by the BS or broadcast to all nodes. It could also be accomplished by the sensor nodes themselves by using the greedy algorithm. The chain construction process starts with the farthest node from the BS. The farthest node is chosen to ensure that nodes farther from the BS have close neighbours. As in the greedy algorithm, the neighbour distances increase gradually since nodes already in the chain cannot be revisited. The chain is reconstructed in the same manner to bypass any dead node in the network.

In each round, each node receives data from its neighbour node, fuses the data with its own and then transmits to the neighbour node in the chain. In turn, nodes transmit fused data to the BS. In this approach in round i the total number of nodes used is i mod N (N represents the number of nodes) that transmit to the BS. Therefore, the leader in each communication round is at a random position in the chain and nodes die at random locations, making the sensor network robust to failures. Each round of data collection can be initiated by the BS with a beacon signal which synchronizes all sensor nodes. A time slot approach for transmitting data is employed as all the nodes in the chain know their positions. Data fusion takes place at every node except the end nodes in the chain. Therefore, in PEGASIS each node, except the two end nodes and the leader node, receive and transmit one data packet in each round and becomes the leader once every N rounds. There are some nodes which are far away along the chain and dissipate more energy in each round. These nodes cannot act as leaders in this protocol. Reference [12] introduce a chain-based binary scheme for sensor networks with CDMA nodes and a chain-based 3-level scheme for sensor networks with non-CDMA nodes to reduce the energy and delay for data gathering in WSNs.

3.2. Low-energy Adaptive Clustering Hierarchy (LEACH)

LEACH [13] combines cluster-based routing and MAC protocol to serve wireless micro-sensor networks which achieve low energy dissipation and latency without sacrificing application-specific quality. LEACH is a cluster-based protocol with distributed cluster formation with random cluster-head election. A sensor node chooses a random number between 0 and 1. If this random number is less than a threshold value, T (n) the node becomes a cluster-head for the current round. This threshold value is calculated using:

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

where P is the desired fraction of nodes to be cluster-heads, r is the current round and G is the set of nodes that have not been cluster-heads in the last 1/P round. The elected cluster-heads broadcast an advertisement message to inform other nodes about their states. Based on the received signal strength of the advertisement, a non-cluster-head node decides to which cluster it will belong for this round and sends a membership message to its cluster-head. Based on the number of nodes in the cluster, a cluster-head creates a TDMA schedule and assigns each node a time slot in which it can transmit. This schedule is broadcast to all the cluster nodes. This is the end of the so-called advertisement or setup phase of LEACH. Then begins the steady state where different nodes can transmit their sensed data. In order to save energy, in the steady phase, the radio of each member node can be turned off until the node's allocated transmission time. Moreover, cluster-heads can perform data processing such as fusion and aggregation before relaying to the base station. To evenly distribute energy load among nodes, cluster-heads rotation is insured at each round by entering a new advertisement phase and by using equation (1).LEACH is completely distributed and requires no global knowledge of network. However, it forms one-hop intra and inter cluster topology, which is not applicable to large region networks. Cluster-heads are assumed to have a long communication range so they can reach the sink directly. This is not always a realistic assumption since the cluster-heads are regular sensors and the sink is often located far away. Furthermore, dynamic clustering brings extra overhead due to the advertisements phase at the beginning of each round, which may diminish the gain in energy. Since the decision to elect a cluster-head is probabilistic without energy considerations, LEACH cluster-head rotation assume a homogeneous network and cannot ensure real load-balancing in case of nodes initially with different amount of energy. A node with very low energy becomes a cluster-head for the same number of rounds as other nodes with higher energy and will die prematurely. This could affect network coverage and connectivity.

The key design goals of LEACH are: adaptive cluster formation, energy-efficient MAC, and application specific data processing. Reference [13] also introduces a centralized control algorithm called LEACH-C to form clusters by dispersing up the CH nodes in the network. Each node sends a message including its ID, location and energy level to the BS. The BS computes the energy levels of nodes and the node which has above average energy level can act as the CH. Simulated annealing algorithm [14] is used to find the CH for the rounds and the associated clusters. Minimum energy is required to transmit information from node to the CH. After formation of the cluster and the CH, the BS transmits this information to all nodes by sending a broadcast message that contains CH ID to each node. If the CH ID matches with a node's ID, then it acts as the CH, unless the node determines its TDMA slot for data transmission. Steady state phase of LEACH-C is the same as LEACH. LEACH-F is another protocol proposed in [13], in which the cluster is fixed throughout the network but the CH selection is rotational.

3.2.1. Energy Efficient Hierarchical Clustering (EEHC)

EEHC [15] can be seen as an extension of LEACH with multi-hop intra clusters and a hierarchy of cluster-heads to route data to the sink. In the single-level clustering of EEHC, each sensor in the network becomes a Volunteer cluster-head with probability p. It announces this to the sensors within k hops radio range. Any sensor that receives such advertisements and is not itself a cluster-head joins the closest cluster. If a sensor does not receive a cluster-head advertisement within certain time duration it can infer that it is not within k hops of any volunteer cluster-head and hence becomes a forced cluster-head. Data transmission to the sink can be performed using multi-hop routing through cluster-heads organization in a multi-level hierarchy rooted at the sink.

3.3. Hybrid Energy-efficient Distributed Clustering (HEED)

Both EEHC and LEACH do not consider energy in selecting cluster-heads. HEED [15] brings one more step toward energy-efficient cluster-based routing with explicit consideration of energy. Selected cluster-heads in HEED have relatively high average residual energy compared to member nodes.

Additionally, HEED aims to get a well-distributed cluster-heads set over the sensor field. Indeed, in HEED, the probability that two nodes within the transmission range of each other to be cluster-heads is small. It is worth mentioning that the main drawback of LEACH is that the random election of cluster-heads does not ensure their even distribution in the sensing field. It is quite possible to get multiple cluster-heads concentrated in a small area. In this case, these area sensors are likely to exhaust their energy more quickly which may lead to insufficient coverage and network disconnection. Distributing cluster-heads evenly in the sensing area is one important goal to be met in order to ensure load balancing and hence longer network lifetime. HEED periodically selects cluster-heads according to a hybrid of their residual energy and intra-cluster communication cost. HEED outperforms LEACH with respect to the network lifetime and energy consumption distribution. However, HEED suffers from a consequent overhead since it needs several iterations to form clusters.

3.4. Distributed Energy Efficient Hierarchical Clustering (DWEHC)

DWEHC [16] aims to improve HEED by generating balanced cluster sizes and optimizing the intra-cluster topology due to its location awareness. DWEHC creates a multi-level instead of one-hop structure for intra-cluster communication and limits a parent node's number of children. Even if HEED considers energy reserve in cluster-head selection and aims to a well distributed cluster-heads, the clusters generated by DWEHC are more well-balanced and that DWEHC achieves significantly lower energy consumption in intra-cluster and inter-cluster communication than HEED. However, location information required by DWEHC is not necessarily and easily available.

3.5. Bit-map Assisted (BMA)

BMA [17] is a schedule-based MAC protocol for intra-cluster communications. The main objective of Bit-Map-Assisted (BMA) MAC protocol was to reduce the energy wastes due to idle listening and collisions while maintaining a good low-latency performance. In BMA sensor nodes forward data to the cluster-head (CH) only if a significant event has been observed, i.e., dealing only with event-driven networks. BMA protocol reduces energy consumption occurring in conventional TDMA systems due to idle listening in the absence of data in any node in their allocated scheduled time slots. The cluster setup phase is identical to the LEACH [13] protocol.

Each node in the cluster keeps its radio on in the contention period and transmits a 1-bit control message during its allocated slot if it has data to transmit, otherwise the slot remains empty. The nodes which have data to transmit are called source nodes and the rest are non-source nodes. After completion of the contention period the CH sets up and broadcasts a transmission schedule only for the source nodes. During data transmission period, each source node turns on its radio and sends its data to the CH over its allocated slot and turns off its radio at all other times. Non-source nodes keep their radios off during the data transmission period. If there is no source node, the system proceeds directly to an idle period. Analytical models are developed for BMA, TDMA and energy-efficient TDMA (E-TDMA) to validate their energy-efficient features.

3.6. Base-station Controlled Dynamic Clustering Protocol (BCDCP)

BCDCP [18] is a centralized clustering-based routing protocol in which network lifetime is improved by distributing the energy dissipation among nodes in the network. BCDCP distributes the energy dissipation evenly among all sensor nodes to improve network lifetime and average energy savings. The method assumes that the properties of a given sensor network model are a fixed base station, sensor nodes with energy constraints, nodes equipped with power control capabilities, and stationary nodes. It operates in two major phases, i.e., the setup phase and data communication phase. BCDCP uses class based addressing which gives identifications to each node in a network.

In the setup phase of BCDCP, the main activities are cluster setup, cluster-heads selection, cluster-head-to-cluster-head (CH-to-CH) routing path formation, and schedule creation for each cluster. During each setup phase, the base station receives information on the current energy status from all the nodes in the network. The base station computes the average energy level after receiving information from each node and decides which nodes are appointed as cluster-heads. The base station sends information back to the nodes which include identification for each node. Each node holds two identifications which represent the identification for each node and identification of cluster-head. Each cluster-head is connected to the other cluster-heads and uses a minimum spanning tree to create a routing path.

In the transmission phase, each sensor node transmits the sensed information to its cluster-head. Since sensor nodes are geographically grouped into clusters, these transmissions consume minimal energy due to small spatial separations between the cluster-head and the sensing nodes. Once the data from all sensor nodes has been received, the cluster-head performs data fusion on the collected data, and reduces the amount of raw data that needs to be sent to the base station.

Balanced clustering technique is used to distribute evenly the load on all cluster-heads. After selecting clusters and their CHs using the spanning tree algorithm [19], the BS forwards the lowest-energy routing path information to the sensor nodes with information on the cluster and the CH. TDMA scheduling approach is used to transmit data from sensor nodes to the CH. Data gathering, fusion and data routing activities are involved in the data communication phase. To prevent radio interference caused by neighbouring nodes, BCDCP uses CDMA codes during CH-to-CH multihop routing [18].

3.7. Two-hop Energy-efficient Mesh Protocol (THEEM)

THEEM is a hierarchical cluster-based energy-efficient protocol. The main goals of this protocol are to achieve energy-efficiency, high QoS, low latency, and equilibrium energy dissipation. The network is divided uniformly into clusters or meshes by using a centrally organized method to eliminate the mesh setup overheads. Residual energy of each mesh is calculated at the beginning of each round and, based on the energy levels the mesh-head (MH) is chosen. The MH is rotated and any node can act as MH.

In each round there are setup and assignment phases in THEEM. Nodes send out short message with their location and energy level to the BS at the initial stage of the setup phase. The BS broadcasts control packets to the network and all sensor nodes synchronize their clocks and update their tables. Assignment phase is composed of the start beacon, energy reporting form and control packet. The start beacon is sent by the BS to inform the network about the start of the current round. After receiving node location and energy level the BS selects the MH for the current round according to their residual energy. The BS then makes a TDMA schedule for each node and broadcasts a control packet to the network. THEEM introduces a two-hop scheme to transmit data from a node to the MH and hence reduces energy consumption. Meshes are divided into two portions, the portion which is far from the MH is called source node and the portion which is closer to the MH is called intermediate node. As MH is changed with rounds, source and intermediate nodes also change with rounds. In the first hop, source nodes send data to intermediate nodes using the minimum transmission energy (MTE) [21] routing approach. In the second hop, the intermediate node fuses the data and sends it to the MH. A multi-hop scheme is used to transmit data from the MH to the BS. CDMA code is used to reduce interference between meshes. The farthest mesh layer transmits data to the adjacent layer and this layer sends accumulated data to the next adjacent layer and finally to the BS. Reduced overhead and CH-to-CH routing makes this an energy-efficient protocol [20].

4. Comparison

Comparative analysis of Cluster-based routing protocols is shown in Table 1.

Table 1. Comparative analysis of Cluster-based routing protocols.

Proposal	Merits	Limitations
PEGASIS[12]	1. Each node communicates only with a close neighbor and takes turns transmitting to the base station, thus reducing the amount of energy spent per round. 2. Distributing the energy load among the nodes increases the lifetime and quality of the network.	1. High latency for distant nodes on the chain and overhead associated due to topology adjustment. 2. If there are N nodes in the network the BS makes N data jumps to acquire all the data from the network which introduces time delay.
LEACH [13]	1. Overall throughput of the network increases as latency is reduced and system life increases. 2. Collision and interference are overcome by using TDMA and CDMA protocol respectively. 3. Data aggregation mechanism reduces the amount of data that must be transmitted to a BS, hence reduces energy consumption.	1. Due to its distributed cluster formation algorithm, it cannot ensure the coverage of entire network. 2. TDMA schedule introduces time delay and comparatively it has more setup overhead.
HEED[15]	1. HEED aims to get a well-distributed cluster-heads set over the sensor field.	1. HEED suffers from a consequent overhead since it needs several iterations to form clusters.
DWEHC[16]	1. DWEHC creates a multi-level instead of one-hop structure for intra-cluster communication and limits a parent node's number of children. 2. Achieves significantly lower energy consumption in intra-cluster and inter-cluster communication.	1. Location information required by DWEHC is not necessarily and easily available.
BMA[17]	1. BMA is intended for event-driven applications, where sensor nodes transmit data to the cluster-head only if significant events are observed. 2. BMA has low complexity, reduces energy wastes due to idle listening and low packet latency.	1. BMA is superior only for the cases of low and medium traffic loads, relatively few sensor nodes per cluster, and relatively large data packet sizes. 2. Data may arrive in empty node at any time during node to the CH data transmission.
BCDCP[18]	1. Balanced clustering techniques, CH-to-CH routing scheme makes BCDCP an energy-efficient protocol. 2. BCDCP reduces energy expenditure and increases network lifetime over its rivals (LEACH, LEACH-C and PEGASIS).	1. BS needs more energy to perform most of the tasks. 2. BCDCP chooses the leader node only based on the energy of head nodes.
THEEM [20]	1. Eliminate cluster setup overhead in each round as cluster is fixed throughout the network. 2. TDMA schedule and CSMA techniques are used to reduce collision and interference respectively.	1. Fixed cluster protocol is unable to adapt to new conditions. 2. A node may need to transmit data in a far way and needs more energy to communicate with its MH when there is another cluster's MH nearby.

5. Conclusion

This article concludes with a concise survey of energy-efficient cluster-based routing protocols. Hierarchical cluster-based routing protocols hold a great potential toward energy efficiency in WSN. Managing energy consumption individually at each sensor is far from being sufficient to maximize the

WSN lifetime. A global management strategy with load balancing feature is required. To do so, clustering techniques have to provide low overhead cluster-head rotation as well as optimal traffic distribution among cluster-heads while keeping network connectivity and coverage. The basic idea of PEGASIS is to extend network lifetime and to reduce the bandwidth. LEACH is most appropriate when there is a need for constant monitoring by the sensor network. EEHC can be seen as an extension of LEACH with multi-hop intra clusters. HEED outperforms LEACH with respect to the network lifetime and energy consumption distribution. DWEHC aims to improve HEED by generating balanced cluster sizes and optimizing the intra-cluster topology. BMA is intended for event-driven applications, where sensor nodes transmit data to the cluster-head only if significant events are observed. BCDCP is a centralized routing protocol, which distributes the energy dissipation evenly among all sensor nodes to improve network lifetime and average energy savings. THEEM achieve energy-efficiency, high QoS, low latency, and equilibrium energy dissipation. THEEM adopts centralized mesh (cluster) formation method along with other design innovations, such as the concepts of mesh layer/column, power-aware mesh head assignment and a low-energy media access protocol, to achieve energy efficiency. Clustering allows a hierarchical architecture with more scalability, less consumed energy and thus longer lifetime for the whole network. This is due mainly to the fact that most of the sensing, data processing and communication activities can be performed within clusters. Numerous are WSN applications that require simply an aggregate value to be reported to the sink. In such applications, data aggregation at the cluster-heads helps to alleviate congestion and save energy. Clustering allows intra-cluster and inter-cluster routing which reduces the number of nodes taking part in a long distance communication, thus allowing significant energy saving in addition to smaller dissemination latency.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

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