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Energy Efficient Routing In Wireless Sensor Networks: A Survey

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Abstract—**Technological advances in wireless communication paved way to the development of tiny low-cost, low-power and multifunctional sensor nodes in wireless sensor networks. Wireless Networks are becoming popular due to the concept of "3 any"- any person, anywhere and anytime. The design of sensor network is influenced by factors like scalability, energy consumption, environment etc. and depends on the application. Of the three activities: sensing, processing and communication, most of the energy is spent on communication purposes. Energy conservation is thus a dominant factor in wireless sensor networks. Routing strategy selection is very important for proper delivery of packets. Ongoing research aims in extending network lifetime by designing protocols that requires less energy during communication. An energy harvesting wireless sensor networks is a solution against the drainage of energy in battery powered networks since renewal of energy is too expensive. Energy harvesting make use of nodes that are able to harvest energy from the environment. This paper provides a survey on energy efficient routing in wireless sensor networks and introduces the concept of energy harvesting in wireless sensor networks.**

Index Terms— **Routing protocols, Energy efficiency, Wireless sensor networks, Cluster-based routing, Energy harvesting**

I. INTRODUCTION

Wireless Sensor Networks are becoming a need for the mankind due to the advancement in Micro-Electro-Mechanical Systems (MEMS) technology. A processing device, sensor or motes in wireless sensor networks can gather data, process it and transmit it to another device. Other device aggregate the data obtained in such a way that it is comprehensible to the humans. Wireless Sensor Networks (WSNs) is defined as a composition of a large number of sensor nodes which are densely deployed either inside a physical phenomenon or very close to it [1]. Sensors are tiny devices which monitor various conditions like temperature, humidity, pressure etc. and later convert it into electrical signal. These sensor devices communicate either directly to the Base Station (BS) or among each other. Each node hence requires a power source which can give a node maximum life in spite of its small size. The self-organizing capability of sensor nodes provides several challenges among researchers for designing the network protocols.

The communication architecture of WSN consists of sensor nodes scattered in a sensor field with each of these nodes capable of collecting and routing data back to sink and the end users as in Fig1 [1]. The communication protocol have five standard layers: application layer, transport layer, network layer, data link layer, physical layer and three management planes: power management plane, mobility management plane, and task management plane [2].

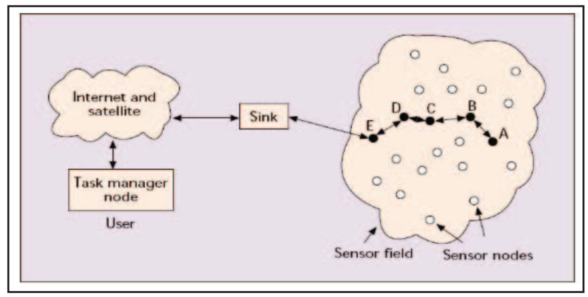

Fig.1. Communication Architecture

The hardware architecture of a sensor node shown in Fig.2 consists of four components: Sensing, Processing, Transmitter/Receiver and a Power Unit. They may also have location finding system and a mobilizer depending on the applications [2]. A power generator may be present as an external power supplier. The major concern for scientists and researchers is the power unit. To optimize life time of node, algorithms and protocols that makes maximum output with limited power resources should be designed.

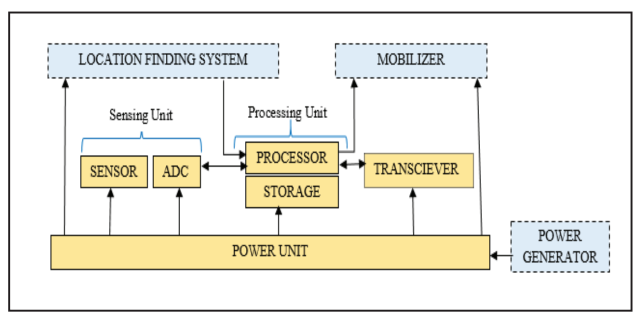

Fig.2. Hardware Architecture

WSN applications are mainly classified as monitoring and tracking as shown in the Fig 3. The potential applications include military sensing, air traffic control, traffic surveillance, industrial and manufacturing automation, environment, health, home and other commercial areas. The design of WSN is influenced by factors like fault tolerance, scalability, operating environment, hardware constraints, power etc. and depends significantly on the application. The network layer handles routing and aims in maximizing the lifetime by finding ways for energy efficient and reliable route establishment for data transmission from sensor nodes to sink. Many routing protocols have been proposed in order to route packets efficiently. The design of routing protocols is also affected by various factors such as deployment, energy consumption, security etc. Researchers thus focus more on designing energy efficient protocols.

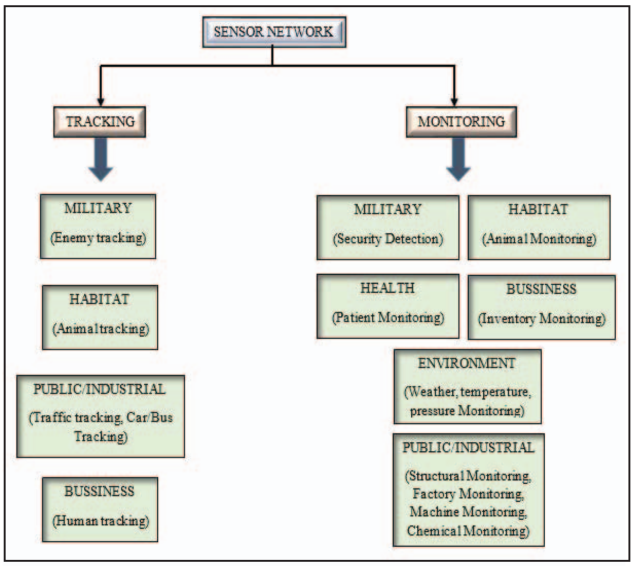

Fig.3. Applications of WSNs

This paper provides an overview on Wireless Sensor Networks and is organized as follows: Section II explains about the routing and its classification in WSNs. Section III gives brief idea on energy efficient routing. Section IV explains the basic concept of energy efficient hierarchical based routing and a few protocols. Section V compares LEACH and PEGASIS and also among its variants. Section VI introduces the concept of energy harvesting wireless sensor networks (EH-WSN). Finally Section VII concludes the paper.

II. ROUTING IN WSN

Sensor nodes have limited energy and bandwidth. The network layer as mentioned in the previous section aims in finding ways for energy efficient route setup and reliable relaying of data from sensor nodes to sink in order to maximize the lifetime. Selection of a proper routing method is a prudent issue in WSNs. All routing protocols share same goals [6] such as providing network survivability, availability and service; enhance sensor network lifetime; reduction of complexity; efficient energy consumption control; minimize delay of data transfer and improvement of WSN performance.

A. Classification and routing design issues

A detailed description about classification on routing techniques in WSNs is provided in [3, 4, 6]. Classification of routing protocols are done based on the network structure, communication scheme, topology schemes and reliable routing schemes as shown in Fig.4[6].

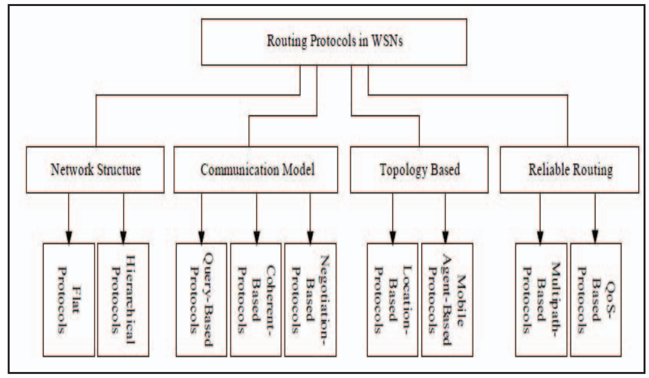

Fig.4. Classification of routing protocols

1) Network Structure

The schemes in this category address two types of node deployment or structures: nodes having a same level of organization and nodes with different clusters.

- Flat Protocols: all the nodes in the network are given equal roles to perform the sensing tasks. A data centric routing where base station sends queries to certain regions and waits for data from the sensors is followed. This architecture provides the advantage of minimal overhead to maintain the infrastructure between communicating nodes.
- Hierarchical Protocols: routing protocols in this scheme impose a structure that achieves energy efficiency, stability and scalability. In this class, the network is divided into several clusters where one node (with higher residual energy) becomes the cluster head (CH). CHs coordinate the activities of its cluster and transmit data among different clusters. Clustering significantly reduces energy consumption and extends the lifetime of the network.

2) Communication Scheme

The protocols in this category are related to how the packets are routed in the network and focus on delivering more data for a given amount of energy. Thus low delivery ratio for the data is a drawback in this scheme. The protocols are classified as follows:

- Query-based protocols: communication is made through propagation of queries.
- Coherent and non-coherent based protocols.
- Negotiation based protocols: negotiation messages are used in order to prevent the occurrence of redundant information.

3) Topology based Scheme:

In this scheme, the protocol operations depends on the topology of network. Every node in a network maintains topology information. The protocols under this scheme are:

- Location-based protocols: a node should know location of other nodes and take the advantage of it to drive received data only to certain region and not the entire network.
- Mobile agent-based protocols: this protocol provides flexibility to network. It has mobile agents migrating among the nodes in the network.

4) Reliable routing based scheme:

The protocols under this scheme achieve load balancing routes and satisfy certain QoS metrics such as delay, energy and bandwidth thereby recuperating from route failures. One of the drawbacks in this network is the overhead of routing tables. The two categories of protocols are:

- Multipath-based protocols: it achieves load balancing and enhances reliability thereby recover from failures.
- QoS-based protocols: data transmission has to meet a particular level of quality along with efficient energy consumption.

In order to design an efficient routing protocol several factors should be addressed such as node deployment, energy considerations, data reporting model, fault tolerance, scalability, network dynamics, transmission media, connectivity, coverage, data aggregation and quality of service.

III. ENERGY EFFICIENT ROUTING

Energy efficiency is a key factor in WSNs since the devices used in WSNs are resource constrained. Since the available energy resources limit the overall operation of sensors, energy consumption needs to be minimized for the network to be operated for a longer period. Even though main aim of WSN is to transmit data efficiently, the major design goal is to improve the network lifetime. The best way to achieve this goal is to incorporate energy efficient routing protocols. Performance of routing protocols are evaluated using several metrics such as Energy per packet, Energy and Reliability, Network Lifetime, Average Energy Dissipated, Low Energy Consumption, Total Number of Nodes Alive, etc. At present, research is being done for developing routing protocols that will consume less energy for extending the network lifetime.

A. Energy Saving Approaches

The paper [7] discusses certain approaches to tackle the energy consumption problem such as radio optimization, data reduction, sleep/wakeup schemes, battery repletion and energy efficient routing. We are interested in the energy efficient routing mechanisms and are categorized as follows:

- Cluster architectures: network is organized as clusters where each cluster is has a cluster head (CH) that takes the responsibility of coordinating the communication activities of members. CHs communicates with another CHs or to the base station. Clustering techniques enhance energy efficiency by limiting energy consumption of the nodes. Network scalability is also improved by the hierarchical structures in the network.
- Energy as a routing metric: the setup path phase considers energy as a metric. By doing so, routing algorithms can select the next hop by focusing not only the shortest paths but also on its residual energy.
- Multipath routing: single path routing rapidly drains energy of nodes on a selected path and when the node drains out of power, a new route must be reconstructed. Multipath routing in contrast, alternates forwarding nodes thereby balancing energy among the nodes. It enables the network to recover faster from failure and enhances the network reliability.
- Relay node placement: the early stage depletion of nodes can be avoided by the even distribution of nodes by placing a few relay nodes. This improves the energy equilibrium between nodes, coverage, and capacity and avoids sensor hot spots.
- Sink mobility: a huge workload is concentrated on the nodes closer to the sink (base station) since all the traffic is directed towards the sink through them. Hence their battery gets depleted faster than other sensor nodes. The load can be balanced by allowing a mobile base station which collects node information by moving in the network. Sink mobility improves connectivity, reliability and reduces collision, contention and message loss.

IV. ENERGY EFFICIENT HIERARCHICAL BASED ROUTING

Data transmission is the prominent energy consumer in WSNs. This demands a need for an architecture where the transmission to a Base Station (BS) is kept as small as possible and that all controls are made at node level. Also scalability proves to be salient as number of nodes grows and the size of network gets increased. A suitable approach is the hierarchical architecture. Here, the entire network is organized into some virtual layers (clusters) and nodes in the same layer are assigned with the same role. Some of the nodes are elected as head (CH) of each cluster in order to effectively manage tasks among the nodes. Clustering reduces the load on network by utilizing the correlation among the data. Then this information is aggregated, resulting in more efficient energy consumption. CHs are responsible for gathering and aggregating the data from nodes and finally transmit it to the BS. The Fig.5 provides an overview on typical clustered sensor network. In the figure the whole network is shown divided into three clusters centered by the base station. The sensor nodes transmit data to their corresponding cluster head (CH). The cluster heads aggregate the data and compress it. Later they forward these data to the base station.

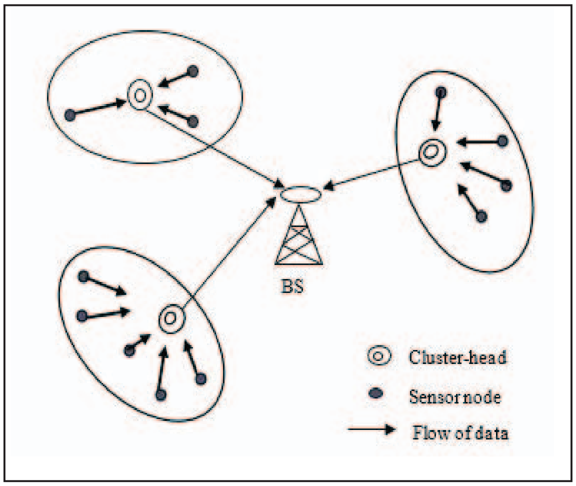

Fig.5. A typical clustered sensor network

The main goal of hierarchical based routing protocol is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink and transmission distance of sensor nodes. Each clustered network is said to have three characteristics: cluster properties, CH properties and clustering process properties. Cluster properties include number of clusters, cluster size, intra-cluster communication and inter-cluster communication. The CHs can be either stationary or mobile, the network can be homogenous or heterogeneous and the elected CHs have considerable effect on the clustering algorithm performance. The clustering algorithms can be either distributed or centralized and each algorithm has a unique CH election mechanism. There are several hierarchical protocols such as LEACH, LEACH-C, PEGASIS, TEEN, APTEEN, BCDCP, HEED, etc. [3,4,6,8] of which this paper compares the variants of LEACH and PEGASIS protocols in the next section.

V. LEACH AND PEGASIS PROTOCOLS WITH ITS VARIANTS

A. Low energy adaptive clustering hierarchy (LEACH)

LEACH is a self-organizing single hop hierarchical protocol where most of the nodes transmit data to the cluster heads. Operation of protocol consists of a setup and a steady state phase. In setup phase cluster organization and CH selection takes place whereas the data transmission takes place in steady state phase. Randomized rotation of CHs results in maximizing the lifetime of nodes. Compression of data before transmitting to CHs reduces energy dissipation. LEACH makes WSN scalable and robust [9]. The dynamic clustering property in LEACH leads to the extra overhead issues in the network.

B. LEACH-Centralized (LEACH-C)

LEACH-C is an improved version of LEACH where each node calculates its energy level and sends information about its location to BS. BS elects CHs considering the energy level of the node and distance between node and BS. Similar to LEACH this protocol has setup and steady state phases [5].

C. LEACH-MF

This protocol adopts method of multi-layer clustering in order to eliminate redundant information and saves the energy of CHs. Cluster heads form clusters among them called as super cluster heads and they send data to sink node. LEACH-MF improves lifetime of network with increase in scale of network [10].

D. Solar aware LEACH

In sLEACH, nodes that are equipped by solar power acts as CHs depending upon their solar status. CHs are selected using improved central control algorithm via BS. The nodes transmit solar status to BS along with their energy and nodes with higher energy are selected as CH. Lifetime of the network depends on sun duration and CH handover is performed if sun duration is small [11].

Comparison among LEACH variants based on energy efficiency and scalability is given in Table.I.

TABLE I. COMPARISON AMONG LEACH VARIANTS

Protocol	***Scalability***	***Energy efficiency***
LEACH	Poor	Poor
LEACH-C	Medium	Medium
LEACH-MF	High	High
sLEACH	Very high	Very high

E. Power efficient gathering in sensor information systems (PEGASIS)

PEGASIS is a chain-based protocol where each node communicates only with its immediate neighbors. Nodes take turn for transmitting data to the BS. The node number that forwards data to the BS is “i mod N” where i denote the current round and N is number of nodes. Construction of chain starts with farthest node from BS. Token passing is adopted to start data transmission and data fusion is performed at each node except at end nodes. Average energy spent by each node per round is reduced and network lifetime has improved up to 300% as compared to LEACH [12].

F. PEGASIS-for energy reduction

Here the nodes are arranged in a way that data packets arrive to destination through the shortest path reducing total energy consumption. The chain structure is modified such that distances between nodes will always remain minimized. Further, the data aggregation also reduces total energy consumption in the network [13].

G. Energy efficient PEGASIS based protocol (EEPB)

It is a chain based protocol that reduces the formation of long links (LL) by reckoning a threshold during the chain formation process. Since energy dissipation of nodes is proportional to transmission distance, the leader is selected by calculating both residual energy of nodes and distance between node and BS. Complexity and uncertainty in threshold are the drawbacks of EEPB [14].

H. Multi-chain based hybrid protocol (MHRP)

MHRP combines the concept of multi-chain formation as well as pre-chain leader (P-CL) selection in order to enhance the efficiency in terms of lifetime and delay. Chain formation is similar to PEGASIS and sink broadcasts a message after chain formation. The node that responds first is selected as P-CL. Data is formulated to sink by P-CL. MHRP minimizes data delivery delay and avoids redundant data transmission [15].

Comparison among LEACH variants based on energy efficiency and scalability is given in Table.II.

TABLE II. COMPARISON AMONG PEGASIS VARIANTS

Protocol	***Scalability***	***Energy efficiency***
PEGASIS	Good	Good
Energy reduction Algorithm	Very high	High
EEPB	Good	High
MHRP	High	Very high

VI. ENERGY HARVESTING WIRELESS SENSOR NETWORKS

Energy consumption is a critical issue directly related to network efficiently. WSNs use portable and constrained energy sources that may experience leakages in current. This drains the resources when not in use. A WSN has an infinite lifetime when it is not depending on limited power. Nowadays, renewable resources like solar, wind, water etc. are being used to generate electricity. Such resources outperform energy constrained resources especially when WSNs are expected to be functional for long period of time. Energy Harvesting Wireless Sensor Networks (EH-WSNs) converts ambient energy from the environment into electricity to power the sensor nodes. EH-WSNs can work perpetually without any maintenance and hence are useful in applications where human intervention is difficult. EH-WSNs are of two types. First, that treats the harvested energy as a supplement to the battery and other, which uses the harvested energy as the only source to the WSNs [17]. The factor that makes EH-WSNs different from battery-operated WSNs is the energy supplement module. The hardware architecture of Energy Harvesting WSNs node is shown in Fig.6.

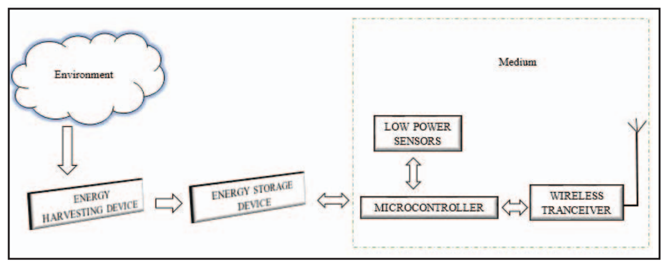

Fig.6. Hardware architecture of EH-WSNs node

While there has been extensive research on WSN, those specific to EH-WSNs are still emerging. The main goals of EH-WSNs are to maximize throughput and minimize delay. Minimization of energy consumption and energy harvesting technology are thus key thoughts for maximization of the network lifetime [16, 18].

VII. CONCLUSION

In this paper we surveyed about wireless sensor networks, routing techniques, the hierarchical architecture in wireless sensor networks and provides a brief introduction on harvesting ambient energy from the environment to power WSNs. WSNs are designed for specific applications. Since radio transmission and reception consumes large amount of energy, power is an important factor to be investigated upon. The limited energy resources of sensors makes energy efficiency one of the major challenges in the design of WSNs. Protocols designed should aim in keeping sensors alive for long period so as to fulfill the application requirements.

Hierarchical architecture approach is the best to provide scalability along with an extended network lifetime. Sensors without energy can no longer accomplish its role unless source of energy is replenished. Wireless sensors that are powered by ambient energy harvesting is a promising technology for many sensing applications.

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