A SURVEY ON ENERGY CONSERVATION TECHNIQUES IN WIRELESS SENSOR NETWORKS

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Abstract - Wireless Sensor Networks have been a growing domain of research for the past few decades. The tasks performed by this network is basically sensing of required data as per the application by the deployed sensor nodes, collecting and processing the required data and forwarding the data of interest to the sink. These operations require energy to accomplish these tasks, which is provided by battery present in the nodes. Due to a limited source of energy, the sensor nodes are always prone to failure. This survey paper discusses about the basic issue of energy in WSN, distinct sources affecting energy, and the recent techniques to conserve energy.

I. INTRODUCTION

Wireless Sensor Network (WSN) has been an emerging area for the past few decades. Recent advances in the area of micro-electromechanical systems have boosted to the advantage of growth of this area. Generally, a wireless sensor network comprises of an area with tiny, low power, low-cost, multifunctional sensor nodes deployed either uniformly or randomly based on the need of the application with a sink. In order to measure different types of phenomena using threshold value, corresponding types of sensor nodes like thermal, seismic, magnetic, thermal, visual, acoustic, etc., can be utilized. Sensor nodes are deployed usually in a large quantity in either amicable or hostile environments. The sensor nodes generally have to be self-organized as they do not have any global identification. The sink is basically supplied with a large energy reserve and acts as repository of the data collected by the sensor nodes. WSN can be deployed for umpteen amount of applications like surveillance, environmental monitoring, health monitoring, & even military and commercial applications [1][2].

Sensor nodes are prone to failure due to various factors, & affect the basic mission for which it is deployed adversely. Generally, sensor nodes are powered by battery cells for their functionalities, there may be limited or no chance of replenishment of power supply when deployed in hostile environment. The basic issues faced by WSN are Hardware Constraints, Topology, Connectivity, Network Lifetime, Coverage, Energy, Congestion, Bandwidth Demand, Deployment etc. Among the discussed issues, the issue which is focused upon in this paper is the issue of energy in WSN, and presented a survey of the recent protocols and algorithms on energy conservation for WSN.

The rest of this paper is as follows: In Section 2, a brief discussion has been done on different factors affecting lifetime. It includes the classification of energy conservation techniques- System-Based Techniques and Network Based Techniques. The System-Based Techniques in Section 3 have been elaborately explained and classified. Finally, Section 4 concludes the survey of the lifetime reinforcing techniques made in this paper.

II. SENSOR OPERATIONS AFFECTING ENERGY

The basic task of sensing the required data is done by the sensing unit, followed by processing & forwarding of the collected data by the processing and communication unit. But, accomplishment of these tasks pressurizes the limited energy source, i.e., the power unit. The sensor node operations which are responsible for energy depletion are sensing, in-network processing/logging, receiving data from source/relay (along with overhearing), transmitting sensed/relayed data (including over-emitting, collision, channel polling and control packet overhead), startup transient energy (may increase due to frequent switching), idle state (including idle-listening) and sleep state.

The maximum energy is spent in the communication process (transmit (14.88mW) & receive mode (12.50mW)), then, next to it is the energy spent in idle mode (12.36mW) [3]. Although, a minimum amount of energy is spent in sensing, sleeping & processing mode, still they consume some energy. These processes need to be enhanced so, that they prove to be energy-efficient.

III. ENERGY CONSERVATION TECHNIQUES

The energy conservation techniques generally aim to prolong the network lifetime by the optimum use of limited available power source. So, as, the available energy is scarce, the restricted use of the power source can also be helpful for extending the lifetime. It is broadly classified into two categories- System-Based Techniques and Network-Based Techniques.

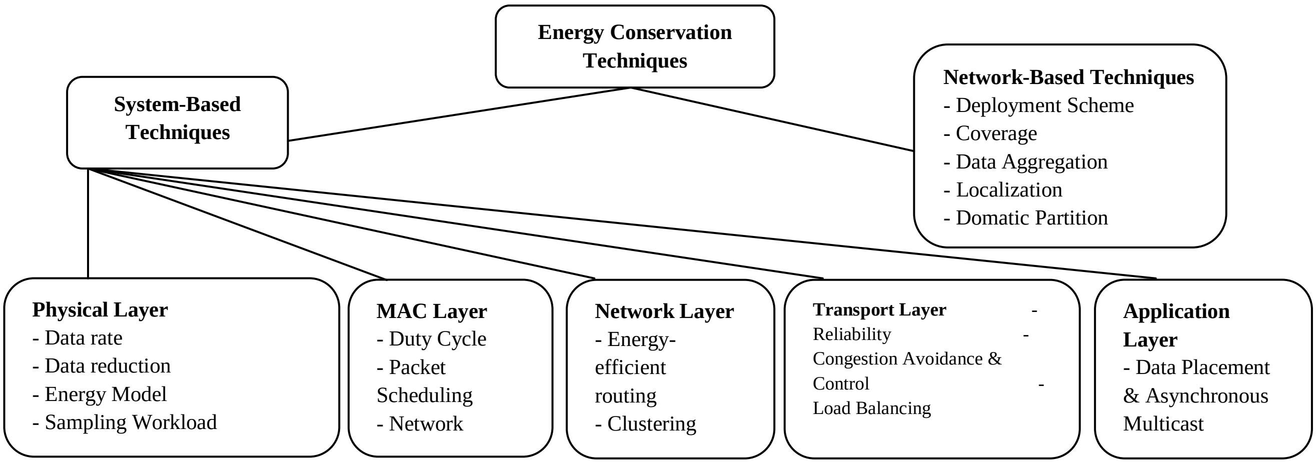

Fig.2. Classification of Lifetime Reinforcement Techniques

3.1. System-Based Classification

In this section, we now present a layer-wise study of the existing energy conservation techniques, for the extension of network lifetime. The detailed study of all the layer-based classification of energy conservation techniques has been summarized in Table 1.

a. Physical Layer

The physical layer is concerned with physical medium, communication channel, sensing, actuation, and signal processing. It also helps in addressing different techniques like modulation, transmission & receiving techniques. The following are the techniques concerned with the energy conservation techniques- Data Rate, Data reduction, Energy Model & Sampling Workload Allocation. Data rate control also known as flow control is responsible for preventing network congestion, variable data rate can help in reducing network latency and energy consumption. Data reduction technique reduces the amount of data sent by each node, it generates a subset of all the data produced and delivered at sink, from which original data can be reconstructed. As, the lifetime of the network mainly depends on the individual sensor node life, so, the battery lifetime of the nodes is crucial. Therefore, in order to address this, we are considering the type of energy model as a factor. Sampling workload allocation technique can also be helpful for balancing energy consumption among nodes.

b. MAC layer

As, energy is a crucial factor for the network lifetime, the MAC layer for WSN has to be energy-aware. The MAC layer has to be responsible for reliability, energy efficiency, high throughput & low access delay to optimally utilize the energy-limited resources of sensor nodes. The techniques used in MAC layer are- Duty Cycling (Topology Control & Duty cycling on active nodes), Packet Scheduling. Duty Cycle is the ratio of listening time for a sensor node to the total length of the frame. So, the adjusting of the sleep time, when the radio is turned off, for energy efficiency is done. In addition to the classification of duty cycle in [4], several new protocols have been added in this survey. Topology Control can be defined as the task of finding the optimum number of nodes in the process of duty-cycling (wakeup/sleep scheduling) which can remain active in order to ensure connectivity in the network & enhancing energy efficiency. Duty Cycling on active nodes is concerned with active nodes required for ensuring connectivity which need not remain active all the time, so, can follow wakeup/sleep schedule for energy conservation. Again, Packet scheduling is the effective scheduling of packets for transmission, for minimized energy consumption & avoiding phenomenon like collision, congestion, etc. Network coding refers to encoding the data at the intermediate nodes lying between the sink & source when multicasting of the information is required. It thereby reduces the number of data transmissions and effectively results in energy savings.

c. Network layer

Network Layer has the primary function of routing data, but, faces different issues like energy saving, limited memory and buffer, & unavailability of node identification. As, energy saving is considered as issue in routing, the techniques considered are- Energy-Efficient Routing Techniques, Clustering Techniques & Load Balancing. The energy-efficient routing technique improvises the general routing mechanism to be energy-aware. The clustering techniques clusters or form group of sensors based on certain parameters like distance, residual energy, etc. Among the group, one node is selected on basis of selection metrics as the cluster-head which coordinates the function in the cluster. This role of cluster-head is circulated between the selected nodes to retain energy among nodes equally in a cluster. The load on WSN can be defined as amount of frames created by the sensor itself &frames that the other sensors relay over it with the aim of delivery to the sink. Since, sensing range of nodes often overlaps, the same event is usually detected by multiple sensors, & its transmission wastes energy. Therefore, load balancing needs to be achieved while routing.

d. Transport Layer

The transport layer also contributes to the energy issue in WSN. Its basic function is to provide reliability and congestion avoidance, for achieving energy efficiency against data loss & retransmission. The transport layer functionalities are reliability, Congestion Control and avoidance and Load Balancing. Reliability is considered in terms of efficient data delivery from the source to the sink. However, this feature should be efficient in terms of energy. Congestion generally occurs in WSN, when the wireless link is overloaded with more data than it can transmit. It generally causes packet loss, queuing delay and retransmissions causing more congestion. So, for the proper functioning of the network, efficient congestion avoidance and control should be employed. Load Balancing can be considered as a means to avoid and control congestion at the transport layer.

e. Application Layer

The application layer generally sends queries to obtain certain information of interest and is responsible for traffic management. Application Layer Service for data placement and asynchronous multicast technique aims for energy conservation, by caching mutable data obtained from data-retrieval at locations & asynchronously multicasts updates from sensors to observers, reducing total no. of packet transmissions in the network.

Table-1 – Layer –Wise Classification of Techniques for Energy Conservation

Layers	Techniques of Energy Conservation	Energy-Efficient Protocols, Algorithms & Approaches		Contributions and Findings
Physical Layer	Data Rate Control	Dynamic Rate Adaptation & Control for Energy Reduction (DRACER) Protocol [5]		It uses a dynamic rate adaptation and control mechanism for energy reduction for the IEEE 802.15.4 specification
		Distributed utility fair rate & max–min fair rate control algorithm (Single path & Multipath networks)[6]		This paper proposes utility fair rate control algorithms for single-path & multipath routing, where application performance is modeled as utility function & utility framework of rate control has been developed
		Authentication Scheme for Collaborative Rateless Broadcast (CRBcast) Protocol [7]		This scheme describes a node collaboration approach to provide data authenticity & rateless information delivery mechanism to provide data availability.
	Data Reduction	Data prediction by LMS adaptive algorithm [8]		This scheme predicts data measured values both at source & sink, using Least-Mean-Square (LMS) adaptive algorithm, & doesn't use global model parameters.
	Energy Model	Peukert's Law and Kinetic Battery Model (KiBaM) [9][10]		This law defines non-linear relationship between battery lifetime & rate of discharge, without modeling the recovery effect. KiBaM is an intuitive battery model & called kinetic because it uses a chemical kinetics process as its basis.
		FSM-based Energy Model [11]		This paper proposes an energy model based on Finite State Machines (FSMs), and a special monitoring device, SNMD, to measure energy consumption of sensor node.
		Supercapacitor-based Empirical Energy Model [12]		In this case, the energy model proposed uses super-capacitors as power source rather than batteries, due to ease of charging & insensitivity to charge/discharge cycling.
		CMOS-based Processor Energy Model [13]		This energy model uses switching energy which is multiple of total capacitance switched and square of supply voltage.
	Sampling Workload Allocation	Balanced Energy CONsumption (BECON) Protocol [14]		This paper proposes a distributed algorithm and models sampling workload allocation as an optimization problem and proves it to be NP-Hard.
MAC Layer	Duty Cycle	Topology Control	Reliable Energy-Efficient Topology Control Algorithm [15]	This protocol increases network reachable probability by topology construction mechanism and balances energy consumption by topology maintenance mechanism.
			Distributed Topology Control Method [16]	It builds a virtual backbone considering energy reserves of individual nodes in a distributed manner by considering localized information.
		Duty Cycling on Active Nodes	Sensor-MAC (S-MAC) & Sensor-Mac GlobaL (S-MACL) [17][22]	It partitions the duty cycle into equal wakeup and sleep intervals for energy saving, the second approach improves the technique used in the first approach.
			Timeout-MAC (T-MAC)[18]	Here, the duty cycle has been made adaptive for individual sensor nodes rather than dividing into equal intervals.
			Data Gathering (D-MAC) [19]	It implements a staggered wakeup schedule for a fixed duty cycle.
			Berkeley-MAC (B-MAC) [20]	It uses adaptive preamble sampling to reduce duty cycle & minimize idle listening.
			Low-Energy Adaptive Clustering Hierarchy (LEACH), LEACH-CS & SecLEACH [21][23][24]	It follows a hierarchical clustering method by alternating the role of cluster-heads among the sensor nodes, the second protocol applies the concept of centralized sleeping to the above protocol, whereas the adds security concern.
			Queen-MAC Protocol [25]	It proposes a new quorum system is with low duty cycle for adjusting wake-up times of sensor nodes suitable for data

				collection applications
			Sleeping Scheme for Delaying Alarm Broadcasting [26]	Here, a sleep scheduling method has been proposed so that from any sensor node the delay of alarm broadcasting can be reduced, applicable for critical event monitoring.
			Adaptive CSMA/TDMA Hybrid MAC [27]	This protocol is proposed to decrease the energy consumption in beacon-enabled mode of 802.15.4 using slotted CSMA/CA method.
	Packet Scheduling	Inverse-Log Scheduling (ILS) Algorithm [28]		It proposes a low-complexity inverse-log packet scheduling mechanism, used to minimize energy consumed by fusion of data with varying transmission times of different sensor nodes.
		L-CSMA Protocol [29]		A lazy scheduling of packets or transmission at a lower bit rate and transmission power is given for energy savings by reducing the amount of data to be transmitted for traditional CSMA/CA protocol.
	Network Coding	Linear XOR Network Coding Technique for Multicasting [30]		Here, a linear encoding technique is used which considers a block of data as a vector over a certain base field and a linear transformation to a vector is applied by the intermediate nodes before passing it on to the next node while multicasting data bits.
		Network Coding Along with Duty-Cycling [31]		Here, the network coding concept is hybridized with duty cycling considering bottleneck zone to increase the lifetime & bounds for lifetime has also been derived
Network Layer	Energy-Efficient Routing Techniques	Directed Diffusion Protocol [32]		It is a data centric routing protocol with flat architecture for information gathering and dissemination for substantial energy savings [2].
		Power Efficient in Sensor Information System (PEGASIS) & Hierarchical-PEGASIS [33][34]		The first protocol is a proactive method which has a flat architecture aiming to extend lifetime by uniform energy consumption by all nodes, and reduce delay. The second protocol is an extension of first with a hierarchical architecture.
		Energy Aware Routing (EAR) Protocol [35]		It achieves reliable performance with high energy efficiency & its design is based on four parameters - expected path length, weighted combination of distance traversed, energy levels & link transmission success history to find best routes.
		BeeSensor protocol [36]		It is a bee-inspired distributed, routing protocol that is energy-aware, scalable & efficient.
		Termite-Hill Routing Algorithm [37]		A swarm intelligence routing protocol has been proposed in this work, to efficiently relay all the traffic destined for the sink, and also to balance the network energy.
		Network Coding-based Probabilistic Routing (NCPR) Protocol [38]		It proposes scheme, which is energy-efficient, reliable & alleviates the broadcast storm problem in a clustered WSN.
		Cost Function based Route (ESCFR) Protocol and Double Cost Function based Route (DCFR) Protocol [39]		In this paper, two cost function- based routing scheme have been proposed, where, first scheme maps small changes in nodal remaining energy to large changes in the function value, & second maps end-to-end energy consumption & remaining energy.
		Dynamic local stitching (DLS) Algorithm [40]		It proposes a routing algorithm for rectifying broken paths by stitching broken fragments of the original path spending minimum amount of energy & recovery time.
		Secure and energy-efficient multipath routing (SEEM) Protocol [41]		Here, a secured multipath routing protocol has been proposed which uses multipath alternately as the path for communicating between two nodes.
	Clustering Techniques	Hybrid Energy-Efficient Distributed Clustering (HEED) Protocol [42]		This clustering approach helps in topology control, improves network scalability and lifetime, by periodically selecting cluster heads by a hybrid of the node residual energy & a secondary parameter, node proximity to its neighbours or node degree
		Equalized Cluster Head Election Routing (ECHERP) Protocol [43]		It models the network as a linear system, uses Gaussian elimination algorithm & calculates the combinations of nodes to be chosen as cluster heads.
		Coverage-Aware Clustering (CACP) Protocol [44]		In this paper, a computation method for optimal cluster size to minimize the average energy consumption rate per unit area is proposed. It defines a cost metric favouring the nodes which are more energy-redundantly covered as better candidates for cluster heads and select active nodes for effective coverage.
		Hexagonal Clustering Approach [45]		This approach adopts hexagonal clustering instead of circular clustering.
		Energy-Balanced Lifetime Enhancing Clustering (EBLEC) Algorithm [46]		Here, cluster heads are selected based on residual energy of the nodes & their relative positions in the cluster for extending lifetime by balanced energy consumption.
		Virtual Infrastructure-Based Energy-efficient (VIBE) Protocol [47]		In this protocol, the information is routed in a multi-hop, cluster level fashion by enabling each sensor to make individual decisions regarding its mode of operation. So, it minimizes the average energy spent for each communication.
		Energy Constrained minimum Dominating Set (ECDS) Algorithm [48]		It models the problem of optimally choosing cluster heads with energy constraints by employing dominating set based

			clustering.
	Load Balancing	Load Balanced Reliable Forwarding (LBRF), Directional Load Balanced Spreading (DLBS) Algorithm & Multi-Sink Load Balanced Reliable Forwarding (MLBRF) [49] [50]	The first two cross layer protocols (MAC & Routing) address congestion with load balancing by considering balance of buffer occupancy levels at delivery to sink. The third scheme is an extension of LBRF with multiple sinks and uses Fuzzy Inference Engine for sink-selection mechanism.
Transport Layer	Reliability and Energy-Efficiency	Pump-Slowly, Fetch-Quickly (PSFQ) Protocol [51]	This protocol has the concept of data distribution from source at a slow pace, but, the other nodes having data loss collect data from neighbors quickly.
		Push Aggressively with Lazy Error Recovery (PALER) Protocol [52]	This protocol enhances the mechanism used in PSFQ, which employs an aggressive pushing mechanism and reduces the recovery mechanism to a single inclusive NACK.
	Congestion Avoidance & Control	Congestion Detection and Avoidance (CODA) Protocol [53]	It is an energy-efficient congestion control scheme comprising of three mechanisms - receiver-based congestion detection, open-loop hop-by-hop backpressure and closed-loop multi-source regulation.
		Event-to-Sink Reliable Transport (ESRT) Protocol [54]	It is a congestion controlling transport protocol for achieving reliable event detection with minimum energy expenditure.
		Rate Control-based Congestion Avoidance (RCCAP) protocol [55]	It has an adaptive rate control algorithm based on the combination of discrete proportional-integral-derivative (PID) control method and single neuron.
		Fusion Protocol [56]	It is a hybrid congestion control technique which combines rate limiting, hop-by-hop flow control, and a prioritized MAC.
	Load Balancing	Jointly Optimal Congestion-Control and Power-Control (JOCP) Algorithm [57]	It is a distributed power control algorithm coupling with existing transmission control protocols to increase end-to-end throughput, reduce congestion and utilizes power control balance of physical layer to achieve energy efficiency of the network.
		XLP: A Cross-Layer Protocol for Efficient Communication in WSN [58]	It is a cross layer protocol (physical, MAC, routing and transport layer) designed for congestion control, routing, & medium access control (dist. duty cycle operation).
Application Layer	Data Placement & multicast	Application Layer Service for data placement and asynchronous multicast [59]	This service aims at energy conservation, by caching mutable data obtained from data-retrieval at locations that minimize the sum of request and update traffic, & asynchronously multicasting updates from sensors to observers reduces the total number of packet transmissions in the network.

3.2. Network-Based Classification

In addition to the above techniques, other techniques which are not restricted to a particular layer have been discussed in the following section-

a. Deployment Scheme

The optimal deployment of nodes also adds to the lifetime of the network, along with determination of deployment cost, coverage, connectivity, etc. The deployment technique employed in [60], uses linear array, extended to two-dimensional array of sensor nodes, ensuring equal energy dissipation for all nodes through a efficient duty cycling for each data gathering cycle. It also ensures coverage & connectivity. In [61] & [62], optimal deployment of relay nodes & base station has been considered & [63] considers ant colony optimization for deployment. Finally, in [64], network lifetime & cost models have been used for evaluating different deployment strategies. The deployment scheme can also include deployment of heterogeneous nodes for efficient energy utilization like in [65].

b. Coverage Scheme

The issue of coverage in WSN addresses that how well the network is being monitored by the nodes. Generally, sensor nodes are deployed in large numbers to address the problem, but, optimum no. of nodes should be employed. In [66], coverage intensity is considered and the effect of duty cycle on network topology is discussed. As, already discussed in [44], clustering also has effect on coverage and [67], provides a survey on metrics of coverage, and provides its relationship with connectivity.

c. Data Aggregation

Data Aggregation is basically a technique of in-network data processing. It can be of various types (centralized, in-network, multi-path based, tree-based and cluster-based) [68] [69]. Here, [70] discusses about data aggregation in WSN, whereas [71] provides a review of different data aggregation techniques. In [72], a security aspect related to data aggregation is shown, where a watermarking-based authentication scheme is applied.

d. Localization

The deployment of nodes can either be in a planned manner or in a random manner. In case of planned manner, the node positions are known a prior, but, in latter, no prior knowledge of node's position is there, thereby giving rise to the problem of localization. It is crucial in the location-aware applications of wireless sensor network & can be tackled by using sampling techniques like in [73], where Monte-Carlo sampling technique is applied, or by using mobile acoustic beacons, where nodes estimate their distance from unknown beacon transmission locations [74].

e. Domatic Partition

Domatic partition is a technique of partitioning the whole WSN into distinct domatic sets, in which a node either belongs to one of the sets or has a neighbor belonging to the set for balancing energy consumption and maximizing lifetime. In [75], sleep coordination is done by domatic partition and isotonic regression, whereas in [76], approximation algorithms for domatic partition is provided for energy saving. In [77], dominating sets in domatic partition done for energy efficiency is discussed.

IV. CONCLUSION

In this paper, we have surveyed numerous techniques for handling the issue of energy conservation in WSN. The techniques present have been viewed from both sides of effective utilization, by a system-based approach and network-based approach. The system based classification provides a detailed layer-wise understanding of distinct energy-efficient approaches being used, whereas, network based classification intends to classify the techniques at a network level. Among the various techniques discussed, the hybridization of the techniques has been used to some extent, which proves to be more efficient than traditional techniques. There still remains the scope for the development of new protocols as well hybridized protocols.

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