# Energy Aware Classification for Wireless Sensor Networks Routing

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*Abstract*— **Wireless sensor network (WSN) is an application of wireless ad-hoc networks that is taking an increasing role in everyday lives. Because the energy efficiency of routing protocols is one of the major challenges facing WSN this paper aims to provide a survey on WSN that focuses on their ability to save power and contributes to prolonging the lifetime of WSN. The survey displays the traditional classification of WSN routing techniques running in the network layer, which classifies it into 3 categories: flat, hierarchal and location based. It is then further classified according to the protocol operation. This paper adds a new branch to the traditional classification that includes the Data reporting method, which was previously just a constraint for WSN routing, but now shall be considered a category since if highly influences the routing protocol in term of energy consumption. As the more frequent the data reporting occur the more transmissions take place consuming more of the battery capacity. To better categorize WSN routing protocols with respect to energy saving this paper introduces a new classification that is primarily focused on the energy awareness of different protocols. The paper shows that WSN save power by using traffic engineering based approaches, topology control based approaches or reserved based approaches and that all energy saving approaches can be classified under these three main categories. Using these three categories or combinations of them is a key to investigating routing design issue that needs to be enhanced in order to improve the life span of a wireless network. The paper applies the new introduced classification to a number of key routing protocols to show that it provides a distinction in their approaches towards saving power and that it is capable of highlighting the key features related to energy saving in each of these routing.**

***Keywords***— **WSN, Routing Protocols, Energy Aware**

## I. Introduction

WSN are specially motivated by military applications as well as many industrial and consumer applications such as industrial process, monitoring and control, machine health monitoring and in a home or large building for security. In a sensor field, each node senses surrounding conditions (data) may perform some data fusion and route the data back to the sink; which might be one or multiple nodes, to reveal some characteristics around the phenomena located in the area around the sensor. The route choice takes place in a multi-hop infrastructure-less architecture fashion [1]. The sink(s) communicates to the user, who acts as a task manager node through the Internet and/or satellite. Sensors are deployed manually or in a random fashion in the sensor field. They are made up of 4 basic components: a sensing unit, a processing unit, a transceiver unit, a location finding system, a mobilizer and a power unit (some of these units are optional, like the mobilizer and power generator). Sensing units usually consist of a sensor and Analog-to-Digital Converter (ADC). The signals sensed by the sensor from the sensor field are converted to digital signals by ADC and passed into the processing unit. The processing unit, which in general is associated with a storage unit, computes the tasks intended to be done with the other sensor nodes. Transceivers regulate communication across the network. One of the important components of a sensor node is the power unit, which commonly is just limited power resourced. Some units are application dependent like a mobilizer which is used when a sensor is mobile. However, most of the sensing routing techniques and tasks require accurate knowledge of the sensed data thus the location finding system is a common component in the sensor nodes. Usually they work in an unattended environment like in surveillance, environmental monitoring and telemedicine. This architecture is subject to many constraints, like the hardware constraints mentioned above, in addition to several restrictions on the design of these networks which act as a key design in planning such a network. The vital constraints are Fault Tolerance, Scalability & Production, Network Dynamics, Transmission Media, Coverage, Connectivity, Security, Self-Configuration, Quality of Service and most importantly Power Consumption. Being a micro-electronic device, wireless sensor node can only be equipped with a limited power source ($< 1.2$V) [2]. Sensor nodes can use up their limited supply of energy performing, computations and transmitting information in a wireless environment, even more the replacement of power resources might be impossible. The lifetime of a sensor node is highly coupled with the lifetime of a node battery. The sensor nodes act both as data sender and data router. The power failure cause malfunctioning of some sensor and can cause significant topological changes and may require rerouting of packets and reorganization of network structure. The network consists of small battery powered devices with limited energy resources. Once deployed, the small sensors are usually inaccessible to the user, and thus replacement of the energy source is not feasible. Hence, energy efficiency is a key design issue that needs to be enhanced in order to improve the life span of a network. Typically, Sensor nodes avoid direct communication with a distant destination since a high destination power is needed to achieve a reliable transmission. Instead, sensor networks communicate by forming a multi-hop network to forward messages to the collector node which is also called the sink node. In this regard, routing in such multi-hop networks becomes crucial in achieving energy efficiency. It is critically important to minimize the power consumption of the entire network (each sensor node) and thus maximize the lifetime of the entire network in order to prolong the sensing activity of the network and consequently enhance its efficiency. According to the multi-hop network structure and the organization of the sensor components itself, it can be shown that the power required by each host is split into 2 chunks: communication related power and non-Communication related power. The earlier chunk is further classified into processing power; where each node spends some power to execute network algorithms and run applications and transceiver power; which is the power consumed by radio transceiver to communicate with other nodes. The communication related power is the chunk in concern where it is worth mentioning that the processing power consumed is slight relative to the transceiver power consumed.

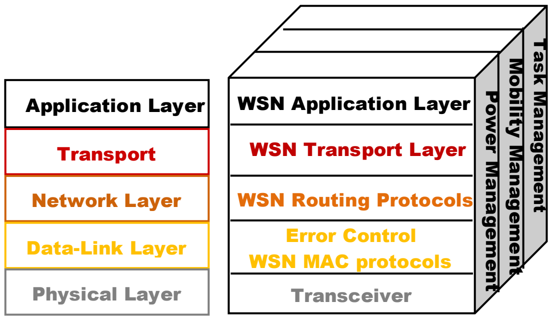


**Figure 1.** Sensor node protocol stack

The protocol stack for the sink and sensor node needs five layers of the OSI model, as shown in Figure1 , added to those are three cross layer planes . These vertical planes that cover all of the basic horizontal basic layers of the node which are power, mobility and task management planes monitor the power, movement and task distribution among sensor nodes by coordinating the sensing tasks while minimizing overall power consumption. As a result some of the sensor nodes perform their sensing tasks less than others due to their power level. [3] explores the WSN architecture according to the OSI model with some protocols in order to achieve good background on the WSN. In conclusion; it is worth mentioning that each protocol layer is closely coupled with its above and below layer (for example, if a routing protocol requires frequent updates, it will be hard to implement sleep modes in data link layer). In the near future, the wide range of applications area will make sensor networks an integral part of our lives. Among all layers, the network layer plays an important role in WSN due to the continuous changes in network topology; either because of delivered loads, node failures due to battery depletion and re-routing using different paths.

## II. Existing Taxonomy of Wireless Sensor Routing Techniques

The underlying network structure has a vital role in deciding the organization and operation of sensor node, traditionally it is classified into 3 categories: flat, hierarchal and location based. Furthermore, these protocols can be classified according to the protocol operation [1] as shown Figure (a).

After surveying the constraints of WSNs it was found that a new category can be added to this traditional classification of WSN protocols as shown in Figure (b); "Data Reporting Method": This category is totally application-dependent and highly coupled with the network dynamic challenge and also depends on the criticality of the data. It can be categorized as:

- Time-driven; which is suitable for applications that require periodic data monitoring where sensor nodes periodically switch on sensors and transmitters, sense the environment and send the data of interest at constant periodic time.
- Event-driven; where sensor nodes respond immediately to drastic and sudden changes in the value of the sense attribute due to a certain event and it is well suited for time- critical applications.
- Query-driven; in which sensor nodes respond due to a query generated by the BS and/or any other node in the network or simply a hybrid of both.

Data reporting method highly influences the routing protocol used in term of energy consumption and route calculations since the more frequent the data reporting occur, the more transmissions take place consuming more of the battery capacity.

## III. Energy Aware Classification of Wireless Sensor Network Routing Techniques

The in-text of this paper is trying to survey different protocols to minimize power consumption and takes it as the first constraint of a routing problem in WSN. This led to the urge of classifying the different techniques in the network layer primarily from the point of view of power awareness, categorizing the routing protocols according to the methodology of battery power conservation. This is done either by conserving energy in each node independently and thus preventing the rapid failure of nodes which might cause network dis-connection or by trying to even out the depletion of battery power of all nodes to prolong the lifetime of a WSN. The new discussed classification of routing techniques classifies all routing techniques in three main general categories. Under each chief category, WSN routing protocols are sub-categorized in groups according to the procedure of reducing energy consumption in a node power capacity and/or the overall energy conservation in a network. This scheme categorizes all current available approaches to preserve battery capacity, accommodates the developing of new categories of power conservation methodologies consequently making it drop definitely under the new introduced classification and

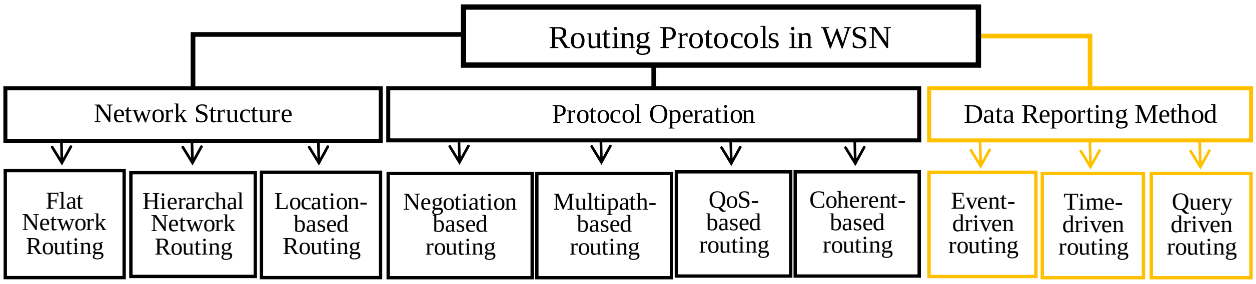


**Figure 2.** (a) Traditional classification of WSN routing protocols (b) Added category

further allows the extension of this classification with the rapid advancement of routing techniques in WSN. A routing protocol may be able to perform multiple techniques to conserve energy and can thus lay under multiple sub-categories as will be shown. Figure  shows the introduced classification. WSN routing protocols, from the power awareness point of view, can be classified as: Traffic based, Topology based and Reserved based routing protocols

### A. *Traffic Engineering Based Protocols*

Saving energy in these approaches is by controlling how the traffic flows through the wireless sensor network. This can be classified to two more sub-categories

***1) Energy Saving with Data Aggregation*****:** combining the data coming from different sources en route (in-network aggregation). Although this increases the transmission time of the transmitting node which is performing the aggregation; since it adds overhead cost and thus consumes more energy from this node, yet this minimizes the number of transmissions and avoids sending duplicates of the same data since the data processing consumes less power than data transmission,. Thus preserves the overall network energy and prolongs its lifetime.

***2) Load Balancing on Multiple Paths:*** by constructing by constructing more than one separate or braided paths and spread the data collected in the sources, properly between the paths. Hence, the energy of any single paths will not deplete quickly as energy is dissipated evenly among all nodes.

### B. *Topology Engineering Based Protocols*

In this approach energy saving is done by controlling the network architecture.

1) ***Topology Pre-Planning:*** When the WSN arrangement is predictable and so its structure would be better fixed and planned prior to network setup, thus allowing eliminating the complex overhead and high cost of outlining the structure of the network at network start-up. This is a common case in large stationary or quasi-stationary sensor networks where the deployment of sensor nodes is done manually or according to a planned structure.

2) ***Topology Control (TC):*** This approach puts the problem in parts and places a new layer that is partially in routing layer and another in MAC layer [4]. Routing techniques in the first mentioned layer are provided with the list of neighbour nodes and making decisions about the ranges of transmission power utilized in each transmission while power save protocols in the former layer are responsible to put the radio transceiver in sleep modes to save energy. It assumes that nodes have impact on the power used to transmit a message. According to [5] these algorithms are classified according to the energy conservation approach they adopt: power adjustment, power mode, clustering and hybrid.

- Power adjustment: deals with a technique that reduces energy consumption over the WSN by varying the transmission power of nodes, interested on achieving the energy efficiency of the whole network using one of the techniques presented in the rest of this classification. Some selected protocols: MECN [6], SMECN [7], COMPOW [8]
- Power mode: saves energy by switching-off the radios of idle nodes and placing the nodes into a sleep mode. Some mentioned protocols: GAF [9], STEM [10], ASCENT [11]
- Clustering approach: conserves energy by critically selecting a set of neighbor nodes to construct an energy efficient backbone in the network.
- Hybrid approaches: further improve the energy saving by integrating the clustering approach with either power mode or power adjustment approaches. Selected protocols: SPAN [12], LEACH [3], CLUSTERPOW [13].

It is worth mentioning here that all hierarchal network routing protocols under network structure class in the former traditional classification, can as well be placed under topology control-clustering and/or hybrid based routing in this classification. Hierarchical or cluster-based routing methods are well-known techniques with special advantages related to scalability and efficient communication. As such, the concept of hierarchical routing is also utilized to perform energy-efficient routing in WSNs [14]. In a hierarchical architecture, higher-energy nodes can be used to process and send the information, while low-energy nodes can be used to perform the sensing. The creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster, performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink node. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other for routing. However, most techniques in this category are not about routing, but rather "who and when to send or process/ aggregate" the information, channel allocation, and so on, which can be orthogonal to the multi-hop routing function. This make hierarchal routing protocols fall under clustering and/or hybrid –topology control based protocol class in this classification and probably under another class as well according to the technique used.

### C. *Reserved Based Protocols*

These approaches save power by trying to truncate actual data transmission to a minimum. This minimizes the amount of energy that will be consumed through the network as much as possible since only descriptors of smaller size will traverse the network or a predictive calculation/processing will be done, to preserve the battery capacity in each node and thus keep the whole network from partitioning. These actual data truncating can be either through:

***1) Negotiation approach:*** where the protocol will only communicate at start up with only descriptors of sensed data before actual transmission, discovering their paths to their destination in a resource adaptive fashion.

***2) Local predictive***; where the node requires only communication with nearest neighbors and/or assigning some local attributes in the node itself to take some decisions in order to be resource adaptive. This local predictive approach can be further classified to:

- A threshold based resource awareness mechanisms; where each node initially has a certain energy threshold. When the node approaches the threshold each protocol acts to divert paths away from the node to avoid depleting its energy

- Finding a relay region: in which minimum energy path is guaranteed to exist within its neighbors without going through the hassle of finding the exact path itself, which make it a local algorithm.

## IV. APPLICATIONS OF THE ENERGY-AWARE CLASSIFICATION TO EXAMPLE ROUTING TECHNIQUES

To better understand the new introduced classification, some of the popular WSN routing techniques will be briefly well explained highlighting how they fit under the new categorization. The following will reveal how these protocols use methods trying to conserve the consumption of battery capacity. Moreover to have a more reflective survey, the following and more routing protocols are referenced in Figure 3; each under their perspective methodology to conserve energy.

**Directed Diffusion**: A data aggregation –traffic based paradigm. It is data centric and application aware in the sense that all data aggregated by sensor nodes is named by attribute-value pairs [15]. The base station (BS) requests data by broadcasting interests which describe a certain task/event. An interest diffuses the network and each node broadcasts it to its neighbours while specifying the gradient which is assigning an attribute value and a direction. Nodes cache interests and when receiving a new one, it checks in its cache if it has recently re-sent a matching interest. If so, it suppresses the receiving interest avoiding more flooding. This process continues until gradient are set up from source to BS. When interest fit gradients, the best path is reinforced out of the multiple paths formed in order to prevent duplicates. The goal is to find a good aggregation tree according to the gradients. Again caching of sent data takes place to be compared with sensed data or nearly re-sent ones and silently dropping any packets that match a recently sent one to prevent more flooding and save energy. It is used in applications that have persistent queries to accommodate the cost of setting up gradients. The key idea of data aggregation here is by caching and processing data in the network by suppressing redundant data whenever matched with recently sent information in a node's cache in order to decrease the amount of end-to-end traffic, and result in higher energy savings. Note that, a slight modification in directed diffusion, making use of the multiple

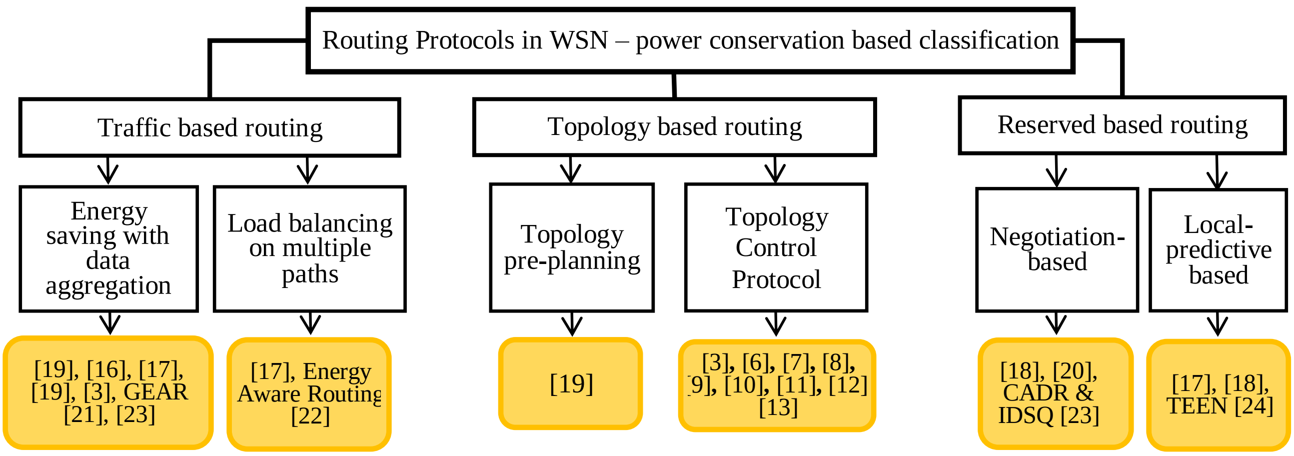


**Figure 3.** WSN routing techniques: Power aware Taxonomy

paths discovered while setting up the gradients, where data can be routed through multiple paths at low rates, can place it under load balancing on multiple paths- traffic based paradigm.

**Rumour Routing**: A data aggregation- traffic based paradigm. In variation of directed diffusion, where flooding is used to inject the query to the entire network, rumour routing routes the queries to the nodes that have observed a particular event and thus maintains only one paths from source to destination [16]. When a node detects an event, it adds the event to its local table, called an events table. Then it generates a long lived packet, called an agent. Agents travel the network in order to propagate information about local events to distant nodes. On its way, it combines its own event table with event tables of visited nodes. Whenever an agent crosses a path leading to another event, it starts to create an aggregate path to both (or multiple) events. Also when the agent finds a node with longer path than its own to the same event, it updates the routing table with the shorter paths. When a node generates a query for an event, the nodes that know the route may respond to the query by inspecting its event table; it is used applications that have small number of events to accommodate the cost of maintaining agents and event tables. The key idea of data aggregation here is synchronizing the event table of the agent with every visited node trying to discover shorter paths to the events or aggregating paths to multiple events in order to reduce the communication cost.

**Gradient Based Routing (GBR):** This protocol is classified as data aggregation and load balancing - traffic paradigm, as well as, reserved - local predictive paradigm. Each node calculates a parameter called the height of the node, which is the minimum number of hops to reach the BS. The difference between the node height and its neighbour is considered the links' gradient. Data aggregation is done when multiple paths pass through a relay node. Relay node combines data by establishing a data centric entity (DCE) [17]. The DCE compacts observations from different nodes, since sensor nodes that are triggered by the same event, are typically located in the same vicinity.

Load balancing is performed according to a stream based scheme, where new streams are not routed through nodes that are engaged in other streams in order to uniformly spread the traffic over the network. Another stochastic based scheme is used, where each node at each time transmitting picks at random a next hop when there are multiple hops of the same gradient.

It is a reserved local protocol since it assigns a local threshold value in each n ode. When a node detects that its energy resource has dropped below this threshold, it increases its height so that sensors are discouraged from sending data to it. Although this introduces an effect on delay, yet it noticeably conserves total communication energy by obtaining balanced distribution of network traffic.

**Sensor Protocols for Information via Negotiation (SPIN):** A Reserved – negotiation based family of protocols [18]. (SPIN-PP) It uses a three way handshake to transmit sensed data. Nodes having new sensed data, advertise it using (ADV) message to its neighbours; which is a high level name to completely describe their collected data (meta-data). The semantics of meta-data is application specific, only dictating that the size of the meta-data of a sensed phenomenon is smaller than the sensed data itself. Upon receiving an (ADV) message, node checks weather it has already received this meta-data before. If not, it responds with a request for data (REQ) message. Finally, sender node transmits the actual data only to the node(s) of interest. With a slight modification, it could also be considered a data aggregation- traffic based paradigm, where data received from a sender node might be combined and aggregated with a node owns data and further advertised to the formers' node neighbours.

SPIN-EC: a variant of SPIN-PP that is reserved –local predictive threshold based paradigm as well. Each node uses a resource manager to keep track of actual resource consumption. When energy in the node is abundant it communicates using its ordinary protocol, but it becomes more selective in participation of the protocol when its energy starts dropping below this threshold. The node doesn't participate in the three way handshake if it predicts that its energy level will drop below this threshold on completion of all protocol stages. SPIN-BC and SPIN-RL: variants of SPIN-PP optimized for networks used in broadcast transmission media and for lossy networks. They add more details to the routing paradigm, like timers, to lessen the number of data transmissions.

**Virtual Grid Architecture Routing:** A pre-planning topology based protocol [19]. It is used in WSN applications of stationary nodes and extremely low mobility. Thus arranging nodes in a fixed topology, building clusters that are fixed, equal, adjacent and non-overlapping with symmetric shapes, prior to network start up, totally deducts the cost and energy consumed due to assigning the roles of nodes and cluster creation. It is also a data aggregation – traffic based paradigm done on two levels; Cluster heads are used to perform local in-cluster aggregation then a set of these cluster heads are used to perform global aggregation and fusion delivering the data to the BS. Performing aggregation on two levels further deducts the redundant data propagating the network. This technique is fast and scalable to large stationary sensor networks.

**Low Energy Adaptive Clustering (LEACH):** It is a hybrid topology control - based protocol [3]; which includes distributed cluster formation combined with MAC layer techniques. The operation is separated into two phases: The set-up phase; LEACH randomly selects a few sensor nodes according to a certain function as cluster heads (CHs) and rotate this role to evenly distribute the energy load among the sensors in the network. LEACH-C is an extension to LEACH that relies on the BS to determine the CHs. All nodes send their location and energy levels to the BS and the BS elects the CH. When a node is selected as CH, it advertises its status to all its neighbours. When a non- CH receive multiple CH advertisements, it decides which one it will belong to according to it signal strength and inform the CH. After receiving all messages from members in the cluster, a CH creates and broadcasts to all cluster nodes a TDMA schedule; assigning each node a time slot when it can transmit.

It is a data aggregation – traffic paradigm. Sensor nodes begin sensing and transmitting data to the CHs. The CHs, after receiving all data, removes all redundant information before passing it to the BS. Each cluster communicates using different CDMA codes to reduce interference from nodes belonging to other clusters. Also a certain code is reserved for communication between CHs and BS. LEACH assumes that all nodes can transmit with enough power to reach the BS and each node has computational power to support different MAC protocols. Therefore, it is not applicable in large region networks. It performs periodic and centralized data collection and thus used in applications when there is a need for constant monitoring by the sensor network. An extension was proposed in [20] which makes LEACH a Reserved – negotiation based algorithm as well. The main theme is to precede data transfers with high level negotiation using meta-data descriptors as in SPIN discussed earlier. This ensures that only data that provide new information is transmitted to the CHs.

## V. Conclusion

This paper introduced a new classification of WSN routing techniques from an energy-aware point of view. The paper showed how the new classification is applied to popular WSN protocols to emphasize how they relate to their perspective new categorization. The new classification orders all routing techniques in three main general categories: Traffic based, Topology based and Reserved based. Under each main category, WSN routing protocols are sub-categorized in groups according to the procedure of reducing energy consumption in a node power capacity and/or the overall energy conservation in a network. This scheme categorizes all current available approaches to preserve battery capacity, accommodates the developing of new categories of power conservation methodologies consequently making it drop definitely under the new introduced classification. This shows that any WSN routing technique can appropriately fit under the new taxonomy. Moreover, the new classification can accommodate new power enhancement methodologies to expand under the mentioned classification. This makes it easier for future research and science development when triggering new research trying to minimize power consumption allowing the extension of this classification with the rapid advancement of routing techniques in WSN.

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