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# Energy-Efficient Networking Solutions for Wireless Sensor Networks: A Systematic Literature Review

**Jayson E. Tamayo**
**College of Computing Sciences**
**Pangasinan State University**
*jayson.tamayo2@gmail.com*

**Abstract -** *The Internet of Things (IoT) has become a disruptive force for businesses. Smart grids and homes are just few examples of real world infrastructures made possible by IoT. These infrastructures are composed of networked sensors that collectively create a Wireless Sensor Network. In Wireless Sensor Networks, energy efficiency is a major concern. Sensor nodes are often deployed to a very hostile environment where harvesting energy is nearly impossible. However, each sensor node in WSN is required to have a lifetime that is long enough to fulfill its application requirements. In this paper, several energy-efficient networking solutions are reviewed. A systematic literature review method is used to select the primary studies to be evaluated. Primary studies showed three energy conservation practices or classifications - duty-cycling, data-driven approach, and mobility-based schemes.*

**Keywords:** *wireless sensor networks, energy-efficiency, energy conservation*

## 1 INTRODUCTION

The drive to digitize business made the Internet of Things (IoT) a disruptive force. In Gartner's 2016 Internet of Things Backbone Survey, which was conducted across China, Japan, Germany, India, UK and in the US, found that IoT initiatives are done to "address operational optimizations, such as workflow management, supply chain and inventory management" [1]. While IoT's impact on businesses is still not prevalent, the external and internal benefits are becoming clearer. In Gartner's Top 2017 Strategic Planning Assumptions, the analysts predicted that by 2022, IoT will save businesses $1 trillion a year in maintenance and service costs [2]. When robustly implemented, IoT can has an immense effect on maintenance cost reduction. For example, sensors can be deployed to report an object's characteristics to analytical servers. The analytics will then be used to identify patterns of when to do maintenance based on reported usage and conditions. This allows the technician to perform maintenance when needed and not on a fixed schedule [2].

Internet of Things (IoT) has been simplistically defined as a concept of connecting any real world objects to the Internet, or to each other. These real world objects can be everything from coffee makers, lamps, lights, washing machines and many more [3]. If this object has an on and off switch, most likely it can be part of IoT. Gartner says that by 2020 there will be over 26 billion devices interconnected [3]. Smart grids [4] and smart homes are just few of the infrastructure systems made possible by IoT. Through the use of wirelessly networked sensors and devices, coupled with other technologies, intelligent monitoring and management can be achieved.

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A Wireless Sensor Network (WSN) is a network made by a large number of sensor nodes where every node can detect physical occurrences such as heat, light, pressure, proximity and others [5]. WSNs have a wide variety of applications such as environmental monitoring [6], emergency detection [7], medical care [8], agricultural farming [9], education [10] and others. Every sensor node is a tiny device that includes three basic components: (1) sensing subsystem – responsible for collecting data in the physical environment, (2) processing subsystem – responsible for data processing and storage and (3) wireless communication subsystem – responsible for data transmission [11].

For every node to work, a power supply is needed. The power source often includes a battery with a limited energy life. Every node is often deployed to a very hostile environment where recharging its power source is nearly impossible. The required lifetime for a sensor should be long enough to fulfill its application requirements, several months or even years may be required. Sometimes, when sensors are deployed in the external environment it can scavenge energy from other sources (e.g. usage of solar cells) [12]. But one disadvantage of external energy sources is that it exhibits non-continuous behavior. Prolonged non-exposure to the energy sources can deplete the battery.

Among other number of related studies [47][48][49][50] discussing Wireless Sensor Networks, power efficiency is still a major concern. In the past few years, the growing interest on energy-efficient solutions for WSNs is remarkable. Figure 1 shows an overview for the increased writings on the energy-efficiency of WSNs.

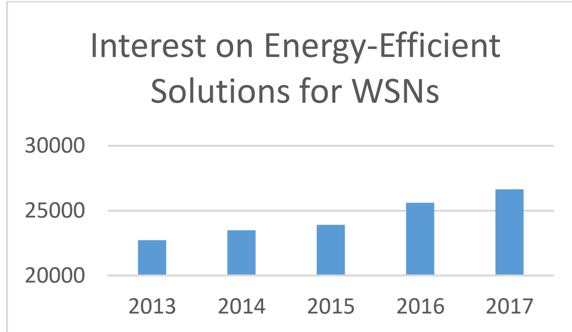


**Figure 1**: **Number of writings/results for "wireless sensor network energy-efficiency"**

In this paper, existing networking solutions for wireless sensor networks that aim to increase the energy efficiency of its components were reviewed.

Unlike other reviews in this research area, this paper uses a systematic approach. It uses the Systematic Literature Review (SLR) research method of Kitchenham [13]. This research method will be used to formulate research questions, define the search strategy or process, and to create inclusion and exclusion criteria.

The next section discusses the process on selecting the primary peer-reviewed studies to be used in this paper. It is then classified according to its content. The Section 3 focuses on the findings of the primary studies selected. The existing energy-efficient networking technologies are further discussed. The last section contains the conclusion.

## 2 METHODOLOGY

This paper uses the SLR method in undertaking a systematic literature review. By complying to the systematic procedure defined by the said research method, this paper can provide a more objective process in selecting relevant and note-worthy studies. The major steps in SLR include the following: (1) defining a research question, (2) search strategy for selecting studies and (3) management of studies.

Using the SLR methodology, the author should be able to define a research question that is anchored to purpose of the literature review. The author should also be able to plan for the search strategy and specify the steps needed. Lastly, the author should be able to manage the studies, filtering the irrelevant studies and selecting the pilot studies to be evaluated.

### 2.1 Defining a research question

This paper aims to identify energy-efficient networking solutions for wireless sensor networks and defining a research question is the initial step. The research question will be the basis for the search strategy and the selection of the pilot studies to be evaluated.

### 2.2 Planning a search strategy

The initial step in planning a search strategy is selecting the input data source. In this paper, ACM Digital Library will be used as a source for the relevant studies. ACM Digital Library has been chosen as the source because it is the most comprehensive database of full-text articles covering computing and information technology. The second step in our search strategy is to construct a query based on the research question. Keywords should be chosen carefully to maintain the proper balance between specificity and generality.

### 2.3 Managing the studies

After running the query in the ACM Digital Library, studies will be obtained. But there is a need for each of the study to be assessed for its actual relevance through inclusion criteria. Table 1 shows the inclusion criteria.

**Table 1: Inclusion Criteria**

| No. | Criterion | Description |
|---|---|---|
| 1 | It should be written in English. | There are some studies that are written in other language. They have provided English title and abstract so these papers will show up in the search results. Only studies written in English will be included. |
| 2 | It should be peer-reviewed. | To ensure the quality of this systematic literature review, only peer-reviewed studies will be included. |
| 3 | The publication date must not be earlier than 2013. | To ensure that only up-to-date energy-efficiency solutions are included, only studies that were published in the year 2013 onwards are selected. |

To furtherly filter the researches and articles, abstract and conclusion of each study are carefully examined. After selecting the pilot studies to be evaluated, the studies will be ordered and arranged according to these three general main-enabling techniques in energy conservation in wireless sensor networks [11].

#### 2.3.1 Duty Cycling

Duty cycling is the ratio of time during which a component, device or system is operated. Duty cycling, in wireless sensor networks, is mainly focused on the networking subsystem [11]. Duty cycling enables the nodes that are not currently needed can go to sleep and save energy. This includes topology control which guarantees that the optimal subset of nodes to be connected.

Researches and studies that mainly focus on sleep/wake-up scheduling algorithms and topology controls/structures will fall to this group.

#### 2.3.2 Data-driven approach

Data-driven approach is mainly focused on reducing power consumption spent for communication. Energy can be saved when unneeded data samples are reduced. Reducing the amount of data to be delivered to the sink node can also reduce power consumption [11].

Researches and studies that mainly focus on routing protocols in WSNs and data compression will fall to this group.

#### 2.3.3 Mobility-based schemes

Mobility-based schemes in energy conservation can be classified as mobile-sink and mobile-relay schemes and physical mobility features [11].

Researches and studies that mainly focus on physical mobility features, mobile-sink and mobile-relay algorithms and designs will fall to this group.

## 3 RESULTS AND DISCUSSION

This section will discuss the results of each step in the SLR methodology and later part will discuss the selected pilot studies according to the three main enabling techniques in energy conservation in wireless sensor networks.

### 3.1 Research question defined

This paper aims to answer the following question: What are the energy-efficient networking solutions for wireless sensor networks?

### 3.2 Results of the search strategy

Keywords were constructed from the research question. These keywords will be used in the search query in ACM Digital Library. The following search queries will be used: "*energy-efficient solution for wireless sensor networks*", "*energy-efficient solutions for wsn*" and "*power-efficient technologies for wireless sensor networks*". Synonyms, singular/plural forms and variation in the abbreviation are also taken in to consideration. Table 2 shows the number of search results per set of keywords:

**Table 2: Number of search results per query**

| Search query | Number of results |
|---|---|
| energy-efficient solution for wireless sensor networks | 398,395 |
| energy-efficient solutions for wsn | 388,511 |
| power-efficient technologies for wireless sensor networks | 413,192 |

### 3.3 Managing the studies

The first set of search results per search query has been analyzed. The results from the first search query, "energy-efficient solution for wireless sensor networks", returned the most relevant studies to be used in answering the research question. Therefore, the first query will be used as a source for the relevant studies.

The search result for the first query has been furtherly refined by publication year (>= 2013).

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Table 3 shows the number of search results for the given query.

**Table 3: Search result for the final query**

| Search query | Number of results |
|---|---|
| energy-efficient solution for wireless sensor networks | 119,429 |

To furtherly filter the results, advanced search feature has been used. Using the advanced search feature of the ACM Digital Library, items from the ACM Full-text Collection and ACM Guide to Computing Literature are selected. The first where clause will be on the Title field that matches all (compared to matches any) of the following words or phrases: "energy efficient wireless sensor networks". The next where clause will on the field of Publication Year, this is set to on or after (>=) 2013. The full query syntax is as follows:

*"query": { acmdlTitle:(+energy+efficient +wireless +sensor +networks) }*

*"filter": {"publicationYear":{ "gte":2013 }}, {owners.owner=HOSTED}*

The above query resulted to fewer matches. From a total of 483,622 ACM Full-text Collection records, there were only 40 results found.

To furtherly filter the results and finally select the pilot studies, abstract and conclusion were read to verify and assess the paper's relevance to the research question. Table 4 shows the final list of pilot studies to be evaluated.

**Table 4: Final list of researches with publication year**

| No. | Research Title | Publication Year |
|---|---|---|
| 1 | Network Coding-Aware Compressive Data Gathering for Energy-Efficient Wireless Sensor Networks [24] | 2015 |
| 2 | Adaptive Energy-efficient Scheduling for Hierarchical Wireless Sensor Networks [25] | 2013 |
| 3 | Energy-efficient Data Dissemination Using Beamforming in Wireless Sensor Networks [26] | 2013 |
| 4 | Energy-efficient Low Power Listening for Wireless Sensor Networks in Noisy Environments [27] | 2013 |
| 5 | Energy-Efficient Collection of Sparse Data in Wireless Sensor Networks Using Sparse Random Matrices [28] | 2017 |
| 6 | Energy Efficiency in Wireless Sensor Networks: A Game-theoretic Approach Based on Coalition Formation [29] | 2013 |
| 7 | Efficient and Balanced Routing in Energy-Constrained Wireless Sensor Networks for Data Collection [30] | 2016 |
| 8 | EDAL: An Energy-efficient, Delay-aware, and Lifetime-balancing Data Collection Protocol for Heterogeneous Wireless Sensor Networks [31] | 2015 |
| 9 | Virtually Moving Base Stations for Energy Efficiency in Wireless Sensor Networks [32] | 2015 |

| | | |
|---|---|---|
| 10 | Energy-efficient Reliable Data Dissemination in Duty-cycled Wireless Sensor Networks [33] | 2013 |
| 11 | Energy-efficient Randomized Switching for Maximizing Lifetime in Tree-based Wireless Sensor Networks [34] | 2015 |
| 12 | Paint It Black: Increase WSN Energy Efficiency with the Right Housing [35] | 2015 |
| 13 | Energy Level-based Efficient Wireless Power and Information Transfer in Sensor Networks [36] | 2017 |
| 14 | 3D-kCov-ComFor: An Energy-Efficient Framework for Composite Forwarding in Three-Dimensional Duty-Cycled k-Covered Wireless Sensor Networks [37] | 2016 |
| 15 | Heuristic and Meta-Heuristic Approaches for Energy-Efficient Coverage-Preserving Protocols in Wireless Sensor Networks [38] | 2017 |
| 16 | TR-MAC: An Energy-efficient MAC Protocol Exploiting Transmitted Reference Modulation for Wireless Sensor Networks [39] | 2014 |
| 17 | Energy Efficient Approach with Integrated Key Management Scheme for Wireless Sensor Networks: C.2.2 [Network Protocols [40] | 2013 |
| 18 | Wake-up Radio As an Energy-efficient Alternative to Conventional Wireless Sensor Networks MAC Protocols [41] | 2013 |
| 19 | TERP: A Trusted and Energy Efficient Routing Protocol for Wireless Sensor Networks (WSNs) [42] | 2013 |
| 20 | A Novel Cluster Head Selection Method Based on HAC Algorithm for Energy Efficient Wireless Sensor Network [43] | 2015 |
| 21 | Restructuring Binomial Trees for Delay-aware and Energy-efficient Data Aggregation in Wireless Sensor Networks [44] | 2015 |
| 22 | LS-LEACH: A New Secure and Energy Efficient Routing Protocol for Wireless Sensor Networks [45] | 2013 |
| 23 | On the Energy Efficiency and Performance of Neighbor Discovery Schemes for Low Duty Cycle IoT Devices [46] | 2017 |
| 24 | An image processing inspired mobile sink solution for energy efficient data gathering in wireless sensor networks. [14] | 2015 |
| 25 | Energy-efficient multi-level and distance-aware clustering mechanism for WSNs. [15] | 2015 |
| 26 | DARC: A Distributed and Adaptive Routing Protocol in Cluster-Based Wireless Sensor Networks. [16] | 2015 |
| 27 | An energy efficient joint localization and synchronization solution for wireless sensor networks using unmanned aerial vehicle. [18] | 2016 |
| 28 | A Clustering Solution for Wireless Sensor Networks Based on Energy | 2013 |

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| | | |
|---|---|---|
| | Distribution & Genetic Algorithm [22] | |

Additionally, the studies were categorized according to the main enabling techniques in power conservation in WSNs. Table 5 shows the categorized studies:

**Table 5: Categorized researches**

| General main-enabling technique | Studies |
|---|---|
| Duty-cycling | [25] [27] [29] [37] [43] [44] [46] [15] [22] [38] [40] [34] |
| Data-driven approach | [24] [26] [28] [30] [31] [36] [39] [41] [42] [45] [16] |
| Mobility-based scheme | [32] [35] [14] [18] |

The next sections will discuss the existing energy-efficient solutions available for the wireless sensor networks categorized by: duty-cycling, data-driven approach and mobility-based schemes.

### 3.3.1 Duty-cycling

One of the critical issues of WSNs is the collaborative processing. Collaborative processing includes how to schedule tasks in a systematic way, delegating tasks to sensor nodes, and to determine their communication schedules. [25] proposed a heuristic-based three-phase algorithm to allocate tasks and to find a communication scheduling scheme that minimizes the power impact.

[27][38] implemented a duty-cycle scheme of Low Power Listening (LPL) where certain nodes periodically wakeup to sample the wireless channel to detect activity

[29] introduced another method of deploying representatives (collection of small number of nodes) with increased processing power and lifetime where some nodes form coalition with in order to increase energy efficiency.

Energy consumption can also vary according to the type of topology used. [34][37][44][46] introduced a tree structure that takes the availability of resources into consideration. [43][15][22][40] also proposed subdividing the entire wireless network into clusters and selecting a cluster head based on HAC algorithm [43].

The table below shows the specific issues addressed per research article.

**Table 6: Duty-cycling issues addressed per research article**

| Issue | [25] | [27] | [29] | [37] | [43] | [40] |
|---|---|---|---|---|---|---|
| task scheduling | √ | | | | | |
| sleep/wakeup scheduling | | √ | | √ | | |
| clustering scheme | | | √ | √ | √ | √ |
| Issue | [44] | [46] | [15] | [22] | [38] | [34] |
| task scheduling | | | | | | |
| sleep/wakeup scheduling | | | | | √ | |
| clustering scheme | √ | √ | √ | √ | | √ |

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### 3.3.1 Data-driven approach

[24][28] proposed an algorithm for compressing dataset. Each compressed dataset refers to a weighted aggregation of data at one projection node. After the sink received the data, it will be decompressed to read the original measurements sent. [24] also presented a mathematical model to optimally construct forwarding trees to reduce the power consumption.

However, [26] introduced a new way for data dissemination. Instead of forwarding trees, collaborative beamforming is used. Collaborative beamforming uses multiple transmitters that send electromagnetic waves.

[16][30][39][41][42][45] provide another approach in energy-saving for WSNs. They proposed a distance-adaptive robust communication (DARC) [16] and MAC [39] protocol which is based on IEEE 802.15.4 but without the additional control frame overlay. It provides a dynamic tuning and opportunity of retransmission of frames according to the hop distance to the sink node. [30], on the other hand, introduced a new routing strategy for energy and balanced data collection in WSNs. As an alternative to a MAC protocol [39], [41] introduced wake-up radio. This is to address the overhearing and idle listening of the MAC protocol.

Aside from routing protocols and strategies, [31][28] introduced an energy-efficient data collection protocol for WSNs called EDAL. [36] proposed harvest-and-transfer protocol for wireless power and data transfer in a WSN.

The table below shows the specific issues addressed per research article.

**Table 7: Data-driven issues addressed per research article**

| Issue | [24] | [26] | [28] | [30] | [31] | [36] | [39] | [41] | [42] | [45] | [16] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| data compression | √ | | √ | | | | | | | | |
| data transmission | | √ | | | | | | | | | |
| data gathering | | | √ | | √ | √ | | | | | |
| routing protocol | | | | √ | | | √ | √ | √ | √ | √ |

### 3.3.1 Mobility-based schemes

[14] provide an energy efficient solution by implementing a multi-hop clustering protocol combined with a mobile sink. The clustering algorithm that was used is from an image processing field, waterwashed form, which is primarily used for image segmentation. The proposed clustering includes a cluster head (CH) for each cluster as well as cluster members. CH and other members near it have high energy reserves. A mobile sink then periodically visits each CH and collects data from them. [14], however, proposes energy-efficient multi-level

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and distance-aware clustering (EEMDC) mechanism for WSNs. In this mechanism, the area of WSN is divided into three logical layers which is based on hop-count distance from the base station.

Sensor nodes need to maintain its own geolocation data (its position) and the global time to relate a given event detection to a specific location and time. But GPS device consumes battery on a sensor node. [18] proposes an unmanned aerial vehicle (UAV) that is equipped with GPS that flies over the sensor field broadcasting the geographical location and time. The result of implementation shows reduced energy consumption.

Additionally, [32] proposed a virtually moving Base Stations (BSs) for the wireless sensor networks. Physically moving BS can improve energy efficiency of WSNs as this scheme evenly distributes the communication load in the network and not on a single node. But these physically moving BSs are complicated and costly. [32] proposed a virtually moving BS that adaptively re-select a subset of active BS to emulate a physical movement.

[35] showed that temperature has a significant effect in the energy efficiency of wireless sensor nodes' processing units. It shows that correct selection of housing for the sensors can increase its efficiency by up to 40.5%.

The table below shows the specific issues addressed per research article.

**Table 8: Mobility-based scheme issues addressed per research article**

| Issue | [32] | [35] | [14] | [18] |
|---|---|---|---|---|
| base stations/mobile sinks | √ | | √ | √ |
| housings | | √ | | |

## 4 CONCLUSION

This literature review outlines the most recent development in reducing power consumption on nodes inside a wireless sensor network. The SLR method has been followed in identifying the research question, formulating the keywords used in the search queries, filtering the results and providing some inclusion criteria.

Special attention has been also devoted in comprehensive classification of the pilot studies according to the three main areas for energy conservation [11]: duty-cycling, data-driven approach and mobility-based schemes. All of the primary studies that were analyzed clearly demonstrate a growing attention to the problem of energy-efficiency in wireless sensor networks. The findings show that the areas in Duty-cycling and data-driven approach is the most frequently investigated solution type to accomplish the energy efficiency goal.

It is worth noting that none of the studies fall in the same category. The considered approaches should not be treated as a single alternative but rather should be exploited and implemented together.

Another interesting point is that there are few studies intended for the mobility-schemes. It is not fully explored so there is room for developing and researching other techniques to reduce the energy consumption on the said area.

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