A Comprehensive Survey of Secure And Energy Efficient Routing Protocols And Data Collection Approaches In Wireless Sensor Networks

Ravi Kumar Sanapala[1], Sreenivasa Rao Duggirala[2]
[1, 2] Dept of Electronics and Communication Engineering
[1, 2] Jawaharlal Nehru Technological University Hyderabad

Abstract- *Wireless sensor networks (WSNs) consist of numerous, tiny, multifunctional sensor nodes for collection of data and information from various target areas or sensing fields. WSNs can be used for various applications such as health-care monitoring, military investigations, space exploration, environment monitoring, disaster management, etc. these are also useful for applications where traditional wireless and wired networks cannot be deployed. Data transmission in WSNs is not an easy task due to resource constrained nodes, limited battery time, low transmission power, etc. energy is the crucial parameter in WSNs for sensing and transmitting the sensed data to the sink. WSNs are deployed in hostile and remote locations making them vulnerable to various types of security attacks. Thus design of WSNs routing protocols must consider various routing challenges and design issues. The survey describes various data collection approaches and efficient routing protocols to reduce the networks energy consumption. The paper presents various routing challenges as well as the limitations of WSNs. It also provides a detailed explanation of four basic types of routing protocols namely location-based, info-centric, hierarchical and multi-path based routing. Some open research issues are also listed along with the conclusion.*

Keywords- Wireless sensor networks, routing protocols, base stations, remaining energy, clustering, routing.

I. INTRODUCTION

A wireless sensor network (WSN) is the rapidly growing research area in recent days in the information world [1]. WSNs consist of numerous small sensor nodes (SNs) with integrated capabilities such as data sensing, data gathering, data processing and limited storage space. WSNs provide the SNs with platform for monitoring and sensing the network area. These platforms are battery dependent. WSNs are used in sensitive applications such as hospitals, environment monitoring, homeland security and infrastructure systems. They are also used in space science, mechanical stress level, smart homes, habitat monitoring, and weather forecast. Due to such wide range of applications, WSNs have attracted several researchers and scientists all over the globe [2]. WSNs compromises of numerous inexpensive, battery constrained and small sized sensor nodes [3]. SNs are tiny sensing devices having data sensing capabilities within its own sensing range transmits them to data collection points. The basic components of a SN is sensing unit, power unit, processing unit and communication unit. These SNs have irreplaceable and non-chargeable battery thus have limited energy and power. This makes energy saving techniques, a big challenge in WSNs.

Majority of research in WSNs domain focuses on maximizing the networks lifetime and the overall working time of the sensor network. Various types of energy efficient routing schemes are proposed for improvement and maximization of networks lifetime. WSNs routing protocols design depends on wide range of factors such as data reporting method (event driven, time driven, query driven), node distribution strategy (non-deterministic and deterministic node distribution), nature of nodes (heterogeneous and homogeneous), network dynamics (stationary and mobile), connectivity, transmission media, coverage area, deployment environment (unattended and supervised), cost, data aggregation, etc. LEACH (Lower Energy Adaptive Cluster Hierarchy) is the most popular routing scheme used in WSNs. Recently, several scholars considered comprehensive sensing scheme [4], [5] for prolonging the networks lifetime. Few researchers proposed grid clustering schemes for WSNs routing protocols [6], [7]. Several researchers proposed tree based approaches. Several routing protocols are presented in this article.

The remainder of the paper is organized as follows. Section 2 describes the routing challenges in WSNs that includes node distribution, data reporting model, defect resistance, connectivity and extensibility, unattended locations and quality of service. Section 3 presents the limitations and challenging issues for WSNs including survivality issue, resource consumption issue, and critical use issues. Section 4 classifies the existing routing protocols. Survey of WSNs

routing protocols are presented in section 5. This section explores four basic types of routing protocols categories namely info-centric, hierarchical, location-based and disjoint path routing protocols. Also, comparison of various existing routing protocols on the basis of their classification, mobility, scalability, data aggregation, power consumption and query based are presented in this section. Section 6 details the open future research issues in WSNs and finally section 7 concludes this article.

II. LIMITATIONS OF WSNS

SNs in WSNs have limited energy, processing power, storage and communication bandwidth. The WSN faces several challenges and all such issues are detailed below.

- *Survivality issues*:

The ability of routing technique to achieve the desired result or target within its available limited power resources is termed as survivality. Distribution of storage load is major survivality issue. Sensor nodes also must be scalable enough to dynamically adapt to topology and node density changes. SNs in WSNs are mainly heterogeneous in nature and thus heterogeneity of devices is an important survivality issue.

- *Resource consumption issue*:

Bandwidth consumption is the major issue as the bandwidth may vary over the networks lifetime. Also the nodes are battery powered and thus energy consumption is another issue in WSNs. In order to balance energy consumption, several solutions were proposed such as deployment optimization [12], mobile relay nodes [13], topology control [14], and data aggregation [15]. Implementation cost is another issue as WSNs may require specialized hardware's or software's or some defined storage capacity.

- *Critical use issues:*

Timeliness and accuracy is the major critical use issues related to WSNs. Timeliness refers to the gathered data specifying the time period whereas accuracy refers to the collected data being secure and trustworthy.

III. ROUTING CHALLENGES IN WSNS

Due to various characteristics of WSNs, routing is a major challenge. The SNs have limited energy, storage space and communication bandwidth. Lifetime of the network is the major criteria for performance evaluation of any wireless sensor network. Several challenges faced by WSNs are detailed below.

- *Node distribution:*

The WSNs can be deterministic or non-deterministic based on node deployment strategy for varied applications. Data transmission is done through pre-computed path and the sensors are placed manually in deterministic deployment of WSNs whereas nodes are scattered randomly without involvement of any pre-computed paths in non-deterministic deployment of WSNs. The routing protocols designed must be able to perform optimal clustering and energy efficient operations for non-uniformly distributed networks [8].

- *Data reporting model:*

Data sensing and reporting in WSNs is based on the applications. There can be three basic types of data reporting model namely query driven, event driven and time driven. Data is monitored periodically and transmitted at regular intervals of time in case of time driven data reporting model. In case of query or event driven data reporting models, data reporting is done whenever an event or query is sent by the base station. The data reporting models affect the performance of the routing protocols in terms of route stability and energy consumption [9]. Some applications such as environment monitoring require uninterrupted data delivery to the sink.

- *Defect resistance*:

Sometimes nodes in WSNs may die because of insufficient power, environmental interferences or physical damage. The overall network functioning must not be interrupted due to such failed nodes. The employed routing protocols must be capable of establishing new routes to the base station [10].

- *Connectivity and extensibility*:

WSNs comprises of high density of connected SNs. If few SNs are subject to change, it may cause topology and network sizes to change. The routing protocols used in WSNs must be capable of adapting to such topological changes. Also, the routing protocols must be capable of dealing with multiple SNs that are scattered in the sensing environment. The routing protocols must be extensible enough to cover all the sensor nodes whenever the network size increases [11].

- *Unattended locations*:

SNs in majority of applications are initially distributed without any human control later. In case of any change in requirements, the SNs must be able to reconfigure themselves. Thus the routing protocols must allow self-configure SNs according to the requirements of the applications.

- *Quality of service*:

There is requirement of immediate delivery of sensed data for certain time critical applications. In such applications, networks lifetime is not that important, rather sent data quality is important. Thus the routing protocols used must fulfil such requirements of time critical applications.

- *Sensor positions and network dynamics*:

The major challenge in designing a routing protocol for WSNs is the nodes position management. In general, the routing protocols assume the SNs to have same location throughput. SNs in WSNs are mobile or stationary. Message routing is a challenge in case of mobile SNs due to issues related to route stability. The routing protocols designed must consider such issues for delivering of data to mobile SNs.

IV. CLASSIFICATION OF ROUTING PROTOCOLS

WSNs routing protocols differ from traditional stationary network routing protocols. These WSNs link have physical resource limitations, no infrastructure and are unreliable with chances of node failure. Routing protocols in WSNs can be classified into four basic categories as listed in the table below.

TABLE I
CATEGORIES OF ROUTING PROTOCOLS

Categories of WSNs routing protocols	
Location based protocols	SMECN, MECN, GEAR, GAF, BVGF, TBF and GERAF
Hierarchical routing protocols	LEACH, HEED, PEGASIS, TEEN, APTEEN
Info-centric protocols	SPIN, rumour routing, directed diffusion
Multi-based protocols	Disjoint path, braided paths, multipath discoverer

V. SURVEY OF WSNS ROUTING PROTOCOLS

Some of the most popular routing protocols in WSNs are explored in this section. The section focuses on working principle, advantages, disadvantages and design issue of every routing protocol [24], [25], [26]. The various categories of WSNs routing protocols are discussed below.

A. Location based routing

Packets or data routing is done based on the position information of the sensor node. SNs are accessed according to their position. Routing distance is calculated based on the incoming signal strength. Few location based routing protocols are discussed below.

- *Geographic adaptive fidelity:*

Remaining energy of every node is stored in GAF protocol. Every node monitors the energy dissipated in receiving and sending data. The WSN is organised into grids and every grid consists of sensors deployed on the basis of their geographic locations. All sensors in one single grid have similar capacity of data forwarding. A node can be in three possible states namely, active, discovery and sleeping states. Sleeping states conserves energy of the node by turning the radio off. Discovery messages are exchanged in the discovery state. Only one node in one grid can be in active state. This increases working time and saves energy of the network. Based on the remaining energy of the nodes, these nodes are assigned ranks.

- *Geographical energy aware routing:*

Unused energy and the location of SNs form the basis for GEAR. GEAR considers various energy saving technologies and performs two basic tasks. Firstly, it routes data to the target location and secondly, distributes the data within the target region. It uses repetitive geographic sending technique for distribution of data within the target region [16].

- *Geographic random forwarding:*

The best known forwarding protocol is GERAF. It employs a scheduling algorithm namely awake-sleep algorithm enabling only few nodes to be active at one particular time. The active node situated nearer to the sink sends the CTS message (clear to send) to the source. This process is repeated continuously by the source node until it discovers a relay sensor. Upon relay sensor discovery, the source node receives acknowledgement reply from the relay node [17].

B. Info-centric protocol

In these routing techniques, the data is treated as an attribute values. Data aggregation is performed between the source and the sink for facilitating energy conservation. Source generates queries in the target region and waits for a reply. Few of the most common info-centric routing protocols are detailed below.

- *Sensor protocol for information via negation*:

Facts inaccessible and blind forwarding problems are resolved by SPIN protocol. Thus it removes the disadvantages of the flooding protocols. The two major key feature of ths protocol is resource adoption and negotiation [18]. The two type of SPIN protocol is differentiated in the table below.

TABLE II
OSI LAYERS AND RELATED PROTOCOLS

SPIN1	SPIN2
• Three way handshaking involving REQ, ADV and DATA messages. • Process: data is advertised using ADV message broadcast. The interested node sends the REQ messages.	• Similar to SPIN1 in case if the nodes have enough communication energy. • In case of energy constraints, SPIN2 considers the notion of remaining energy for data dissemination process. • Nodes having lesser residual energy are not involved in data routing thereby increasing networks lifetime.

- *Direct diffusion*:

Data is accessed utilizing the attribute values in direct diffusion routing schemes. A direct diffusion scheme improves robustness, scalability and the energy efficiency of the sensor network. Incoming events in DD are provided with a smaller data rate and the original message is sent at a higher data rate by the sink [21], [22].

- *Rumour routing*:

It is more energy efficient protocol as compared to other protocols such as flooding or direct diffusion if the geographical information is unavailable. Rumour routing also handles the node failure issues in an efficient manner. Long lived packets, often called agents traverse the entire network and informs about the learned events to the nodes that are encountered in between. After a specified number of hops, the agents die. The events distance is described by each entry in terms of hop distance from the current node. Agents synchronize its evens list whenever a node is encountered throughout the network.

C. Hierarchical routing protocols

Sensor nodes in hierarchical routing protocols may be heterogeneous or homogeneous in nature. Few SNs in heterogeneous networks have special capabilities for performing high computing tasks. Such schemes deal with CH selection and routing techniques. Few of the hierarchical routing protocols are detailed below.

- *Low energy adaptive cluster hierarchy:*

An energy based approach for WSNs in LEACH in which randomly selected CH collects the data, adds its own data and sends them back directly to the sink. The major disadvantage of LEACH is that it suffers from the problem of energy dissipation and does not also possess any efficient CH selection approach. Object clusterhead routing (OCR) is energy efficient technique used by LEACH and SPSOC solves the problem of energy dissipation in LEACH protocol. OCR uses weight function for the decision making. Clusterhead in any cluster posses a highest value of weight function. OCR receives information from all other CHs and sends them to the sink. CH selection is also dependent on the fitness function to facilitate lesser energy consumption and increased networks lifetime. OCR also reduces the number of dying nodes thereby enhances the lifetime of the sensor network [20].

- *Energy efficient multi-hop hierarchical routing*:

It is a multi-hop transmission technique that depends on energy of nodes for prolonging the networks survival time. Energy consumption is the major criteria for prolonging the networks lifetime. The CHs selection in EMHR protocol is based on energy and the neighbour distance for data transmission to the sink. Nodes having maximum energy level are elected as cluster head and these serve their purposes until the remaining energy of the node is higher than any given threshold value. In case CHs energy value is lesser than the threshold value, CHs election process restarts until the next CH is found. A CH receives the sensed data from all nodes, adds its own data and then sends them to the sink node through multi-hop or single- hop depending on the distance of the CH from the sink. If the communication distance between the sink and the CH is small, the CH transmits data directly to the sink otherwise transmits via multi-hop that is sent to the nearest CH and the process continues until the data is received at the sink. EMHR is more efficient than LEACH in terms of energy consumption and networks lifetime [23].

- *Hybrid energy efficient distributed routing*:

It consists of heterogeneous nodes divided according to their energy levels. It may consist of three types of nodes namely super nodes, advanced nodes and normal nodes. The super nodes have the maximum energy and the normal nodes have least energy level. The advanced nodes have energy level intermediary between the normal nodes and the super nodes. Therefore the super nodes have longest life in the sensing

environment while the normal nodes die early. Also these routing protocols elect CH based on residual energy level of the nodes.

- *Weight energy efficient clustering*:

An extended version of LEACH protocol is WEEC. Energy consumption optimization is done by CH selection approaches for prolonging the networks lifetime. Every node in the network has equal probability of being elected as a cluster- head. Initially, the CHs are randomly selected and once the first round is completed, the CHs changes and the next CH selection depend on distance between the base station and the cluster-head. The nodes that are placed closer to the BS have higher probabilities to be elected as a CH than those nodes residing at farther distance. WEEC is also a single-hop routing approach and as compared to LEACH, it provides optimal number of CHs and clusters.

- *Power efficient gathering in sensor information systems:*

It is a hierarchical protocol and an enhancement of LEACH. PEGASIS is a chain-based protocol in which a chain is formed and every node in the chain communicates with only the neighbouring nodes. Cluster formation is not the property of PEGASIS. Thus there is only one that is sending and receiving data from the sink. In case of node failure due to energy loss, a new chain is formed excluding the failed nodes using greedy algorithm. Every round selects a random node for transmission of aggregated data.

- *Threshold energy efficient sensor network*:

A hierarchical routing protocol using a data centric technique is TEEN protocol. Clusters are formed from among the sensors and one node is chosen as CH node from each cluster. CH aggregates the data from all the normal nodes and sends it to the next CH and this process continues until the data reaches the BS. In case of sudden changes, TEEN reacts immediately thus is more useful for certain time critical applications. But, TEEN protocol is not suitable for sensing applications requiring periodic reports as data is not at all generated in case the threshold is not reached.

- *Data acquisition and compressive sensing*:

An energy efficient compressive sensing technique, DACS, numerically analyzes and evaluates the energy consumption. The communication among the compressive nodes as well as between sink and the compressive node uses a Mica platform. Energy dissipation consists of three basic components. Firstly, data acquisition energy, secondly, background energy dissipation and thirdly, processing energy dissipation. The DACS protocol uses graph based analysis technique. Sensor nodes are divided into several levels and the sensed data is sent to the sink based on the distance between nodes. The data is sent to the sink and then the sink acknowledges the transmitted packets. The energy consumption and signal processing task of nodes is reduced.

- *Compressive sensing based data gathering*:

Every node is compressive nature in CSDG and the number of transmissions is reduced. The CHs directly communicate with the sink and CHs selection is done randomly as in LEACH protocol in the initial round. In the next round, every node has similar probability to be elected as a CH in order to balance the entire networks energy.

D. Multipath based routing

It uses multiple paths for reliability and network attainment improvement. These multiple paths facilitates fault tolerant network. These multi-paths lead to more energy consumption and increased traffic as in case of path failure, alternate paths are selected. One of the most widely accepted multipath based routing is disjoint routing which is detailed below.

- *Disjoint routing*:

The best available data path routing is referred to as primary path. If there is node failure in the primary path, to continue data routing, alternative routing paths are discovered.

Comparisons of above detailed routing protocols is performed in the table below based on various parameter such as classification, position awareness, mobility, scalability, data aggregation, power consumption, query-based and multi-path routing[27],[28].

TABLE III
COMPARISON OF VARIOUS ROUTING PROTOCOLS AND APPROACHES

Protocol	Classification	Mobility	Scalability	Data aggregation	Power consumption	Query based
GAF	Location	Limited	High	No	Limited	No
GERAF	Location	Limited	Low	No	Limited	No
GEAR	Location	Limited	Low	No	Limited	No
SPIN	Data-centric	Very Limited	Low	Yes	Limited	Yes
DD	Data-centric	Limited	Low	Yes	Limited	Yes
LEACH	Hierarchical	Fixed base station	High	Yes	High	No
PEGASIS	Hierarchical	Fixed base station	High	No	High	No
APTEEN	Hierarchical	Fixed base station	High	Yes	High	No
TEEN	Hierarchical	Fixed base station	High	Yes	High	No
Disjoint paths	Multi-path	Fixed base station	Low	No	High	No

VI. OPEN RESEARCH ISSUES

Further considerations of WSNs are included in this section. WSNs performance and applicability can be enhanced by making research efforts on some of the below mentioned issues.

- In WSNs, sensor node covers large areas thus requiring communications among the SNs. This communication among nodes must be more energy efficient.
- In order to reduce the communication energy in WSNs, computations must be performed near the source. For this secure localization algorithm needs to be designed.
- Hierarchical WSNs increases the scalability and efficiency of the routing protocols. More research to prolong the networks lifetime needs to be done for these hierarchical routing.

Currently base stations and nodes in WSNs are stationary. In some situations, these components needs to be mobile and thus new routing algorithm must be designed for efficient data routing in mobile WSNs.

VII. CONCLUSION

In this paper, various energy efficient routing techniques available in the literature is listed and surveyed. Various routing challenges and the limitations of WSNs are also detailed in this article. Routing protocols described are categorized under four basic categories namely info-centric, hierarchical, location-based and disjoint-path routing techniques. Design issues, limitations and advantages of these routing protocols are described. Comparisons of various routing protocols are provided based on certain parameters such as classification, mobility, scalability, data aggregation, power consumption and query based. Among many developed routing protocols, none are perfect and some issues related to them needs to be resolved. The article thus presents some future issues in this regard.

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