MULTI-HOP SELECTIVE CONSTRUCTIVE INTERFERENCE FLOODING PROTOCOL FOR WIRELESS SENSOR NETWORKS

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by

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LIST OF ABBREVIATIONS

ACK	Acknowledgment
AD	Active Dominant
AG	Active Gateway
ACA	Adaptive Clustering Algorithm
ANS	Active Node Selection
CLS	Chip Level Synchronization
CID	Cluster Identification
CSMA	Carrier Sense Multiple Access
CI	Constructive Interference
CXFS	Concurrent Transmission Forwarder Selection
DESA	Distance-Energy Selection Algorithm
CIRF	Constructive Interference-based Reliable Flooding
CI-Flooding	Constructive Interference-Based Flooding
CDS	Connected Dominating Set
DSSS	Direct Sequence Spread Spectrum
DCWCH	Distributed Clustering Without Clusterhead
EACIF	Energy Adaptive Constructive Interference Flooding
IPI	Inter Packet Interval
IOT	Internet of Things
ID	Identification Number
I-phase	IN Phase

LEACH	Low Energy Adaptive Clustering Hierarchy
FLOC	Fast Local Clustering
PEACH	Power- Efficient and Adaptive Clustering Hierarchy
e3hBAC	Three-Hop Between Adjacent Clusterheads
LWB	Low-Power Wireless Bus
LEACH	Low Energy Adaptive Clustering Hierarchy
LSA	Link Selection and Alignment
MCU	Microcontroller
MAC	Medium Access Control
MLE	Maximum Likelihood Estimation
MDS	Minimum Dominating Set
MSCIF	Multi-hop Selective Constructive Interference Flooding
O-QPSK	Offset-Quadrature Phase Shift Keying
PN	Pseudo-Random Noise
PIP	Packets In Pipeline
PRR	Packet Reception Ratio
PEASST	Point-to-Point Packet Exchange with Asynchronized Sleep and Synchronized Transmission
PMF	Probability Mass Function
Q-phase	Quadrature Phase
RE	Residual Energy
RSSI	Received Signal Strength Indicator
SINR	Signal to Interference and Noise Ratio

TDMA	Time-Division Multiple Access
WSNs	Wireless Sensor Networks

PROTOKOL PEMBANJIRAN INTERFERENS MEMBINA TERPILIH BERBILANG LOMPATAN UNTUK RANGKAIAN SENSOR WAYARLES

ABSTRAK

Penyambungan merupakan isu kritikal dalam WSN kerana data yang dikumpulkan perlu dihantar ke stesen utama atau pusat pemprosesan. Penyambungan yang rendah disebabkan oleh julat radio nod sensor yang terhad dan pengagihan rawak menjadikan rangkaian dibahagikan berpetak-petak kepada kumpulan-kumpulan yang terputus sambungan yang mengganggu atau langsung menghalang komunikasi antara nod. Bagi mencapai komunikasi yang berkesan, setiap nod diletakkan cukup hampir antara satu sama lain. Kedudukan nod yang tidak sesuai menyebabkan kegagalan menghantar atau menerima isyarat radio dan menghasilkan rangkaian yang bersegmen atau tidak lengkap. Protokol Pembanjiran Interferens Membina Terpilih Berbilang Lompatan (MSCIF) dicadangkan untuk menangani masalah penyambungan rendah dalam WSN yang mempunyai agihan jarang dan mempertingkatkan jangka hayat rangkaian. MSCIF menggabungkan tiga algoritma utama: algoritma penggugusan, algoritma pemilihan, dan pembanjiran bersepadu. Langkah pertama protokol yang dicadangkan melibatkan pembangunan algoritma penggugusan yang cekap tenaga yang sesuai untuk WSN dengan topologi kepadatan jarang. Penggugusan adalah perlu dalam protokol yang dicadangkan kerana ia membantu mengeluarkan nod yang berada jauh daripada nod lain, yang akan menghabiskan tenaga yang banyak. Peringkat penggugusan ialah: pengawalan, penjadualan, dan penggugusan. Langkah kedua dalam protokol MSCIF melibatkan mereka bentuk algoritma pemilihan untuk memilih nod dominan minimum yang bersambung. Langkah ini dilakukan untuk mempertingkatkan keutuhan rangkaian dan mengawal penggunaan tenaga dengan

mengurangkan bilangan nod yang bekerjasama. Langkah ketiga menggunakan algoritma pembanjiran bersepadu pantas untuk mencapai interferens membina pada penerima bagi mempertingkatkan kekuatan isyarat yang diterima dan mempertingkatkan penyambungan. Keberkesanan algoritma yang dicadangkan dikaji menggunakan MATLAB. Penyambungan rangkaian dan jangka hayat dalam persekitaran ruang kosong dipertingkatkan sebanyak masing-masing 23% dan 18% berbanding dengan protokol lain. MSCIF merupakan protokol terpilih yang bilangan nod aktif dalam rangkaian adalah sekitar 70% berbanding bilangan nod aktif yang diperlukan apabila menggunakan protokol lain, menjimatkan tenaga dan mempertingkatkan prestasi rangkaian. MSCIF mencapai keutuhan rangkaian yang tinggi (hampir 100%). Ia sesuai untuk aplikasi yang perlu melakukan kebanjiran peket yang panjang kerana ia mencapai tempoh tangguh yang rendah (7.7ms) apabila peket mempunyai panjang maksimum (128-bait).

MULTI-HOP SELECTIVE CONSTRUCTIVE INTERFERENCE FLOODING PROTOCOL FOR WIRELESS SENSOR NETWORKS

ABSTRACT

Connectivity is a critical issue in WSNs, as the data collected needs to be sent to the base station or the processing centers. Low connectivity due to the limited radio range of sensor nodes and random distribution leads the network to be partitioned into disconnected groups, which can interrupt or completely prevent communication between nodes. For effective communication, each node must be located close enough to each other. Improper positioning of the nodes can cause a failure in sending or receiving radio signals, resulting in a segmented or incomplete network. A Multi-Hop Selective Constructive Interference Flooding (MSCIF) protocol is proposed to address the problem of low connectivity in WSNs with a sparse distribution and improve the network's lifetime. MSCIF integrates three main algorithms: clustering algorithm, selection algorithm, and a synchronized flooding. The first step of the proposed protocol involves the development of an energy efficient clustering algorithm which is appropriate for WSN with a sparse density topology. Clustering is necessary in the proposed protocol as it helps to exclude nodes that are far away from other nodes, which consume a lot of energy. The stages of clustering are: initialization, scheduling, and clustering. The second step in MSCIF protocol involves designing a selection algorithm to select the minimum connected dominating nodes. This is to improve the network reliability and control the energy consumption by reducing the number of cooperating nodes. The third step is applying a fast-synchronized flooding to achieve a constructive interference at the receiver to improve the received signal strength and improve connectivity. The effectiveness of the proposed algorithms is investigated

using MATLAB. Network connectivity and lifetime in free space environment are improve by 23% and 18%, respectively, compared to other protocols. MSCIF is a selective protocol, where the total number of active nodes in the network is around 70% of the number of active nodes needed using other protocols, saves energy and enhances the network performance. It achieves high network reliability (almost 100%). MSCIF is suitable for applications that need to flood long packets, since it achieves very low latency (7.7 ms) when the packet length has a maximum value (128-byte).

CHAPTER ONE

INTRODUCTION

1.1 Background

Rapid developments in wireless communications and embedded microprocessors have paved the way for a fast growth in WSNs. WSNs become a hot topic in the research and development field and the main driver for the development of Internet of Things (IoT) applications (Zhao & Guibas, 2004; Culler et al., 2004; Stanković et al., 2018). WSNs are composed of spatially distributed devices positioned in various locations to monitor the existing physical environments. Sensor networks have different applications, including security surveillance, terror-alert systems, target tracking (Tubaishat & Madria, 2003), habitat monitoring (Mainwaring et al., 2002), relief operations, and disaster and hazard monitoring. They are also utilized in the health industry and in domestic applications (e.g., smart environments) (Schwiebert et al., 2001; Rehman et al., 2017).

A sensor is a device that detects physical or electrical changes and produces an output as an acknowledgement (ACK). Generally, this output will be in the form of electrical or optical signal. The most frequently used sensors are classified by the quantities that they monitor such as radio sensors, electric current sensors, potential sensors, magnetic sensors or humidity sensors. Figure 1.1 shows different WSNs applications.

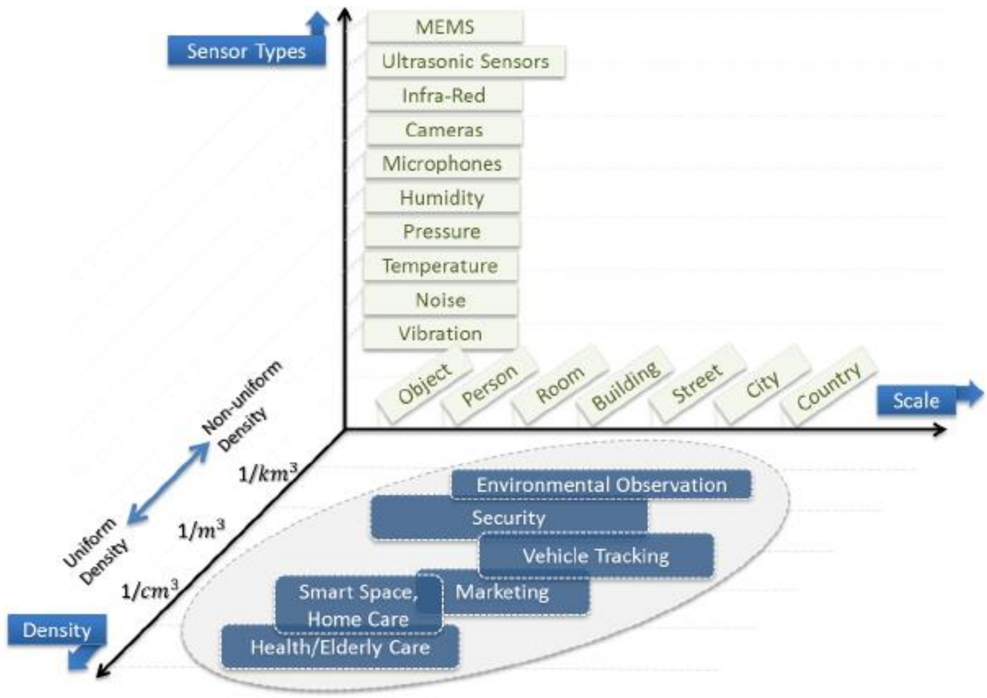

Figure 1.1: WSN Applications (Schwiebert et al., 2001)

1.2 Research Motivation

In establishing a WSN, hundreds or thousands of sensor nodes are spread in a determined area, and one or more sinks (base stations) are required as shown in Figure 1.2. Following the command of a process or application, the main task of the sensor nodes is to collect data from the environment (Akyildiz et al., 2002; Karthikeyan & Kavitha, 2013). Variables such as temperature, noise, vibration, radiation, and light are measured by the sensor nodes (Yick et al., 2008). Using multi-hop routing, the sensor nodes transmit the sensed data to the sinks for processing (Hsieh et al., 2010). Several approaches and strategies have been developed for improving the process of data routing in WSNs (Sohraby et al., 2007).

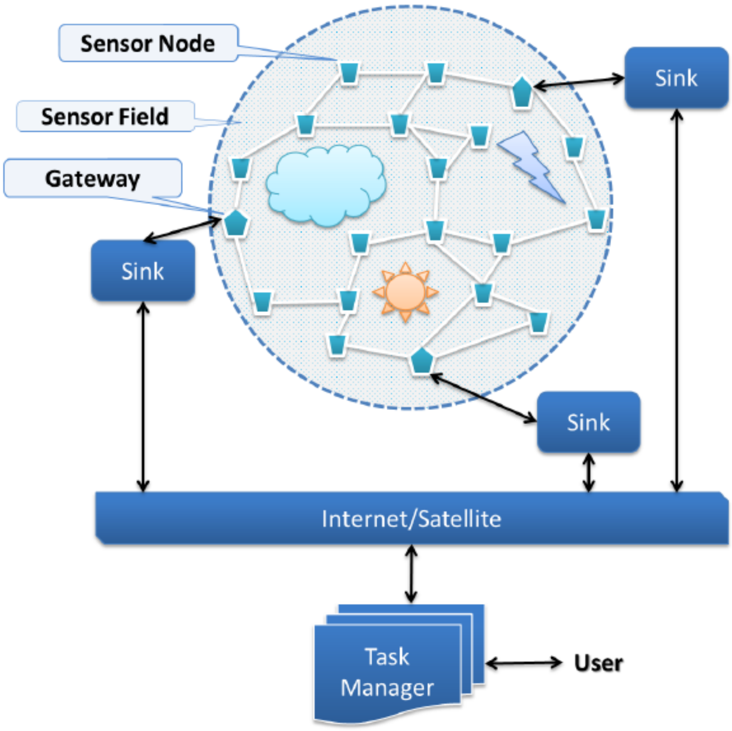

Figure 1.2: A Typical Sensor Network (Hsieh et al., 2010)

The data gathered from the sensor nodes are transmitted through a multi-hop network. At least, one route between source and destination should be recognized in this process to ensure the data transfer as shown in Figure 1.3. For effective communication, each node must be located close enough to each other. Improper positioning of these nodes can cause failure in sending or receiving radio signals, resulting in a segmented or incomplete network. Many factors such as incorrect sensor network configuration, node failure, and the increased noise might cause communication failure.

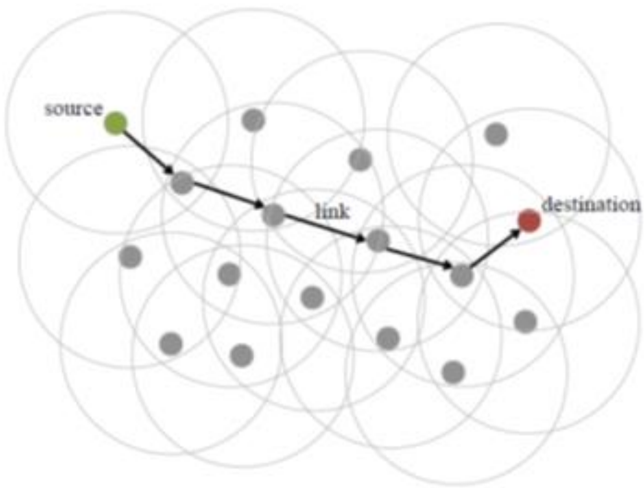

Figure 1.3: Example of Multi-Hop Single Path Routing (Akyildiz et al., 2002)

1.3 Research Background

Recently, the problem of low network connectivity has gained research attention (Akyildiz et al., 2002; Karl & Willig, 2005; Laneman et al., 2004; Kawadia & Kumar, 2005). Connectivity is a critical issue in WSNs. It is the ability of a single node to connect with other nodes in a network either through direct communication or multi-hop relays. Network performance is highly affected by the degree of connectivity, in terms of the capability of self-organization, network capacity, network lifetime, and energy consumption (Shankar, 2009).

1.3.1 Network Connectivity

To study connectivity, a common model based on transmission range is as follows: A node with radius, r can connect directly with any other node within its transmission range. If the distance between two nodes is larger than the transmission range of each node, then these two nodes cannot connect directly with each other. In other word, two nodes are connected if there is a multi-hop of relay nodes between them and the distance at each hop in the route is not larger than r. The range of transmission is affected by the environment between transmitter and receiver (Shankar, 2009).

Low connectivity can be a result of a network being broken up into disconnected groups of nodes. However, nodes can still be sparsely distributed whether they are installed manually or scattered from the air, as shown in Figure 1.4.

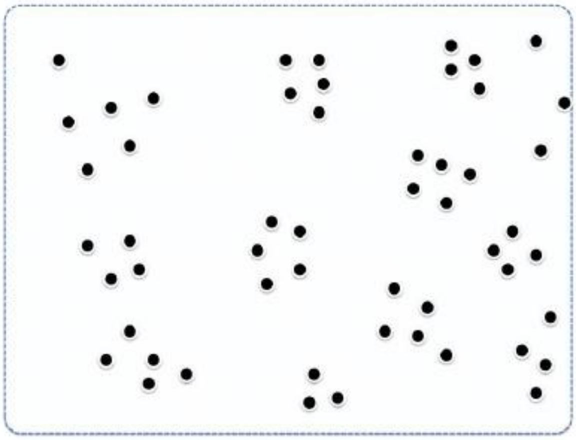

Figure 1.4: Sparse Density Topology (Shankar, 2009)

1.3.2 Network Lifetime

WSNs have limited energy that depletes rapidly. In this research, the network lifetime is represented by the cumulative active time of the network until the last sensor is out of power (Wang et al., 2006). Practically, when the network is on use, replacing the energy resources is impossible since the micro-sensor node lifetime depends heavily on the battery lifetime and the overall lifetime of a network is affected by its failure. Thus, the lifetime of a WSN is a priority.

Energy efficiency and lifetime of the network are closely related (Anand et al., 2012). When the network lifetime increases, the percentage of energy consumption decreases with increase in the number of hops possible and reaches a minimum at a critical number of hops. After critical hops, the energy consumption gradually increases due to increase in cumulative energy consumption of the intermediate nodes (Lambor & Joshi, 2011). Radio transmission power also relies on the remaining resources of the battery. Low battery level reduces transmission range and leads to a bad connectivity. Therefore, when developing approaches to improve the connectivity in a network, it is necessary to control the energy consumption. Maximizing the system lifetime and minimizing energy consumption are the major goals for connectivity maintenance in WSNs (He & Zeng, 2006). One important way to minimize energy consumption of the nodes is by reducing the communication cost in the network to prolong the lifetime of a sensor network.

1.4 Research Problem

Connectivity is critical for WSNs, as information collected needs to be sent for data collection or to the processing centers. A disruption to the network operation can be caused by a sudden failure of a node due to an external damage imposed by the unfriendly surroundings or due to hardware breakdown. A break in the communication paths of a network and unreachable nodes can be caused by a loss of a node. The limited radio range of the nodes can also lead to breaking up the network into disjoint groups which interrupt or completely prevent the connection.

For one or more deployed nodes, non-zero probability of isolation exists when the sensor network nodes are randomly distributed in the target area (sensor field). One often-cited example is the sensor nodes scattered from a helicopter or an airplane that may cause a random spatial distribution of nodes with different densities in each area (Akyildiz et al., 2002), i.e. sparse density distribution (Figure 1.4). In this example, some nodes will not have other nodes in their transmission range or no neighbors available for a certain node. The limited transmission range of isolated sensor nodes results in a low end-to-end connectivity in a sparse density topology of WSNs (Laneman et al., 2004; Kawadia & Kumar, 2005).

Furthermore, many WSNs that are deployed in a harsh environment might suffer from a large-scale damage which breaks up the network into disjoint groups. For instance, in a battlefield, parts of the distribution area can be attacked by explosives and a set of sensor nodes may be destroyed. Thus, the surviving nodes will be partitioned into disconnected segments. In those cases, restoring the connectivity is so important so that the network can operate again.

Recently, several approaches were proposed to solve this problem as many researchers proposed using cooperative transmissions to improve the connectivity (Hedaya et al., 2004; Saedy & Kelley, 2011; Wang & Giannakis, 2008; Chang & Lin, 2012; Shanoon, 2013). However, it is not enough for this critical problem, more algorithms should be applied to improve the network performance.

1.5 Research Questions

This research focuses on the problem of low connectivity and lifetime in WSNs with non-uniform spatial distributions of nodes as discussed in Section 1.2. The main research question is ―How can one improve connectivity and enhance the network lifetime in a WSN with non-uniform spatial distribution of node densities?

The sub questions include:

- How can one increase the transmission range of sensor nodes while maximizing the network lifetime?
- How can one select the most appropriate nodes to perform a synchronized transmission?
- How can one reduce energy consumption with high network reliability?

1.6 Research Objectives

The main goal of this research is to find a solution for the low connectivity problem in a WSN with a sparse distribution and improve the network's lifetime. The objectives of this research are as follows:

1) To analyze the behavior of WSN mathematically, in terms of communication link metrics and their impact on network connectivity, reliability, and energy consumption.
2) To propose an enhanced communication protocol that improves the end to end network connectivity and lifetime of sensor nodes for sparse density topologies;
3) To verify and validate the performance and efficiency of the proposed algorithms in terms of network connectivity, lifetime, reliability, and latency.

1.7 Research Scope

This research studies the issue of low connectivity in a WSN with sparse density topology. Randomly distributed identical nodes are assumed in a non-uniform network density in one plane or a flat area. All sensor parameters are constant. The sensed data is obtained by the nodes are gathered in the network. The BS is the sole point in which the data are being collected and processed within the sensor network.

Since the power level of each node cannot be changed, the transmission range of each node is constant. Channels can be located between a node and a BS through a multi-hop network with an omnidirectional antenna. A fixed radius, R is assigned for each node, which organizes the nodes' communication. The fixed radius guarantees good communication between nodes, or else, the connection will fail. For a systematic power addition, the network is divided into clusters (Younis et al., 2006).

Communication is done through multi-hop transmissions to a single sink node. This research focuses on the cooperative transmissions, synchronized flooding, clustering and selection approaches in WSNs. The evaluation is based on simulation. Figure 1.5 shows the research scope.

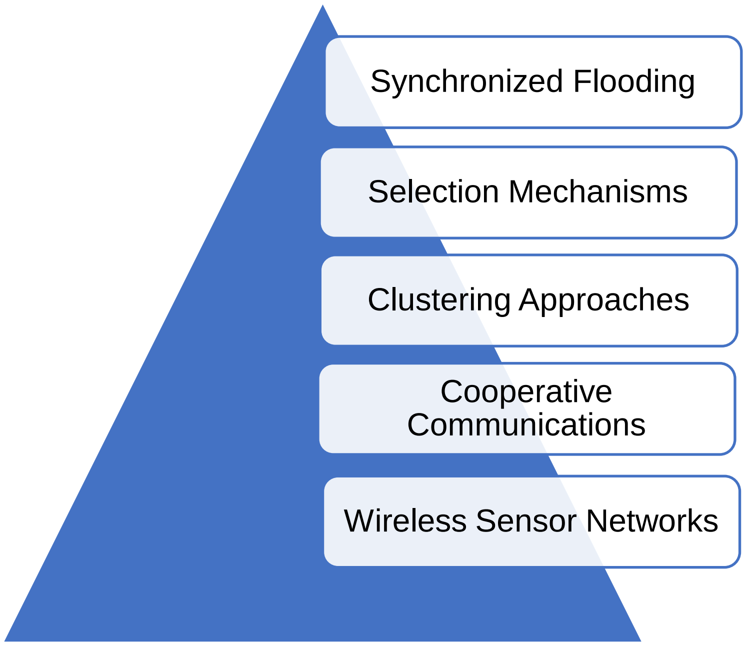

Figure 1.5: Research Scope

1.8 Research Framework

Figure 1.6 shows the research framework of this dissertation, which composes of four phases. Literature review is the first phase, consists of research background and study of previous and related works. The second phase is literature analysis, which discusses the drawbacks of related works and outlines the proposed solution. The third phase is designing and modeling the proposed solution. Investigation on the proposed protocol is discussed in the last phase.

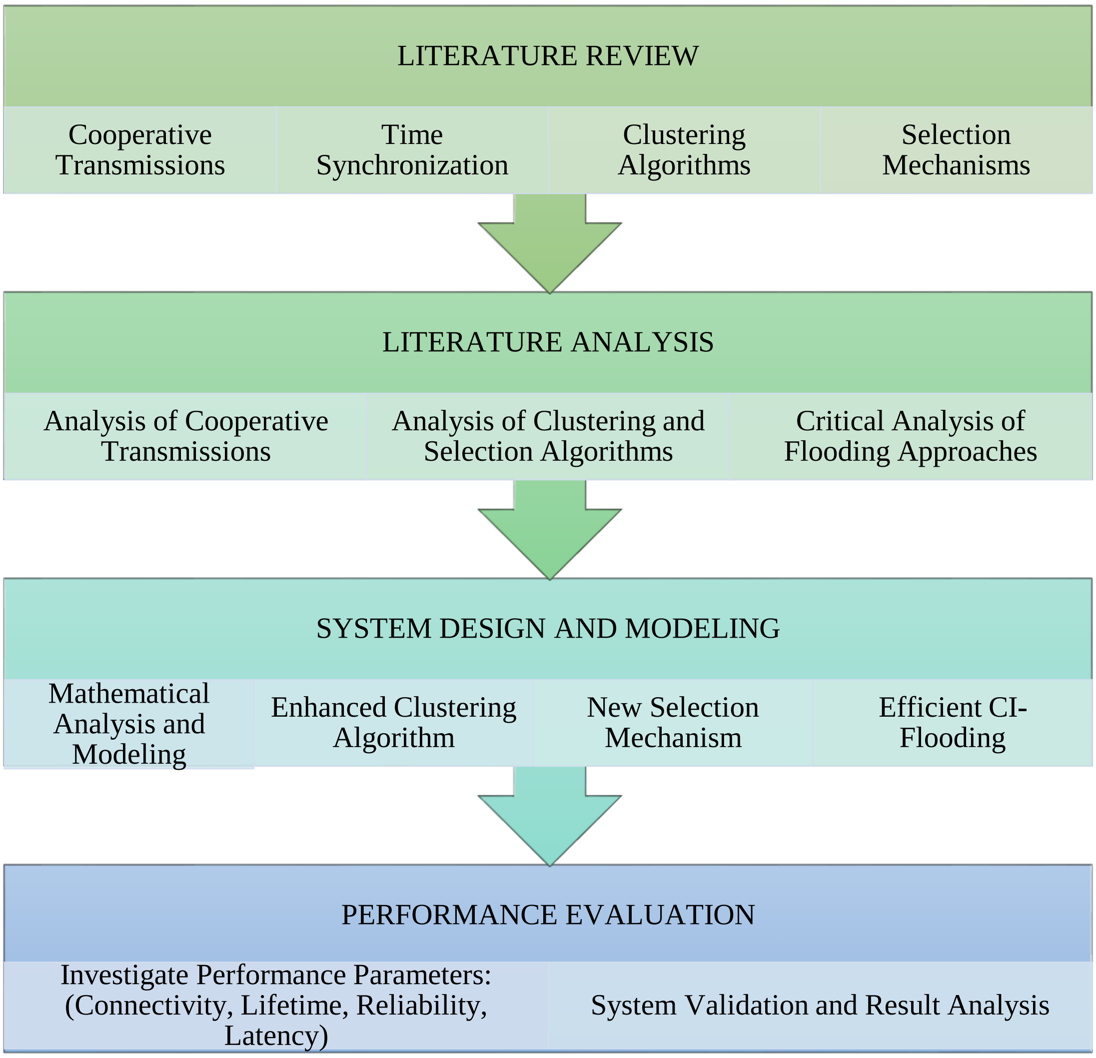

Figure 1.6: Research Framework

1.9 Overview of Dissertation

This dissertation is organized into six chapters as follows:

Chapter 2 covers the literature survey, presents the background on WSNs strategies to solve low connectivity problem, and discusses the most current related works in this regard.

Chapter 3 presents the proposed framework and mathematical analysis on how the proposed protocol can be sufficient to solve the discussed problems. MSCIF protocol for WSNs with a sparse density is introduced in this chapter. A clustering algorithm is developed to divide the network into clusters and each has its own cluster ID. A new selection mechanism is presented to elect the most appropriate nodes for transmission and to build a virtual backbone between the source and the destination. A very fast and well synchronized flooding is applied over the selected backbone to ensure the occurrence of constructive interference at the sink.

Chapter 4 introduces the simulation environment for the proposed protocol and it also presents the simulation parameters.

Chapter 5 presents the simulation results of the proposed methods and compares them with an existing approach.

Chapter 6 concludes the research findings and provides suggestions for potential future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the fundamentals of WSNs, their architectures, challenges, and study of previous works. Section 2.2 presents the structure of WSNs and their characteristics. The main challenges to WSNs especially the connectivity and lifetime problem in sparse networks are discussed in Section 2.3. Overview of network connectivity and lifetime is presented in Section 2.4. The strategies on low connectivity problem are surveyed and the cooperative communications and their classifications are introduced in section 2.5. In addition, a comprehensive analysis of Constructive Interference based on flooding and existing approaches in exploiting it are presented in section 2.6. Figure 2.1 illustrates the interest and boundary of this dissertation.

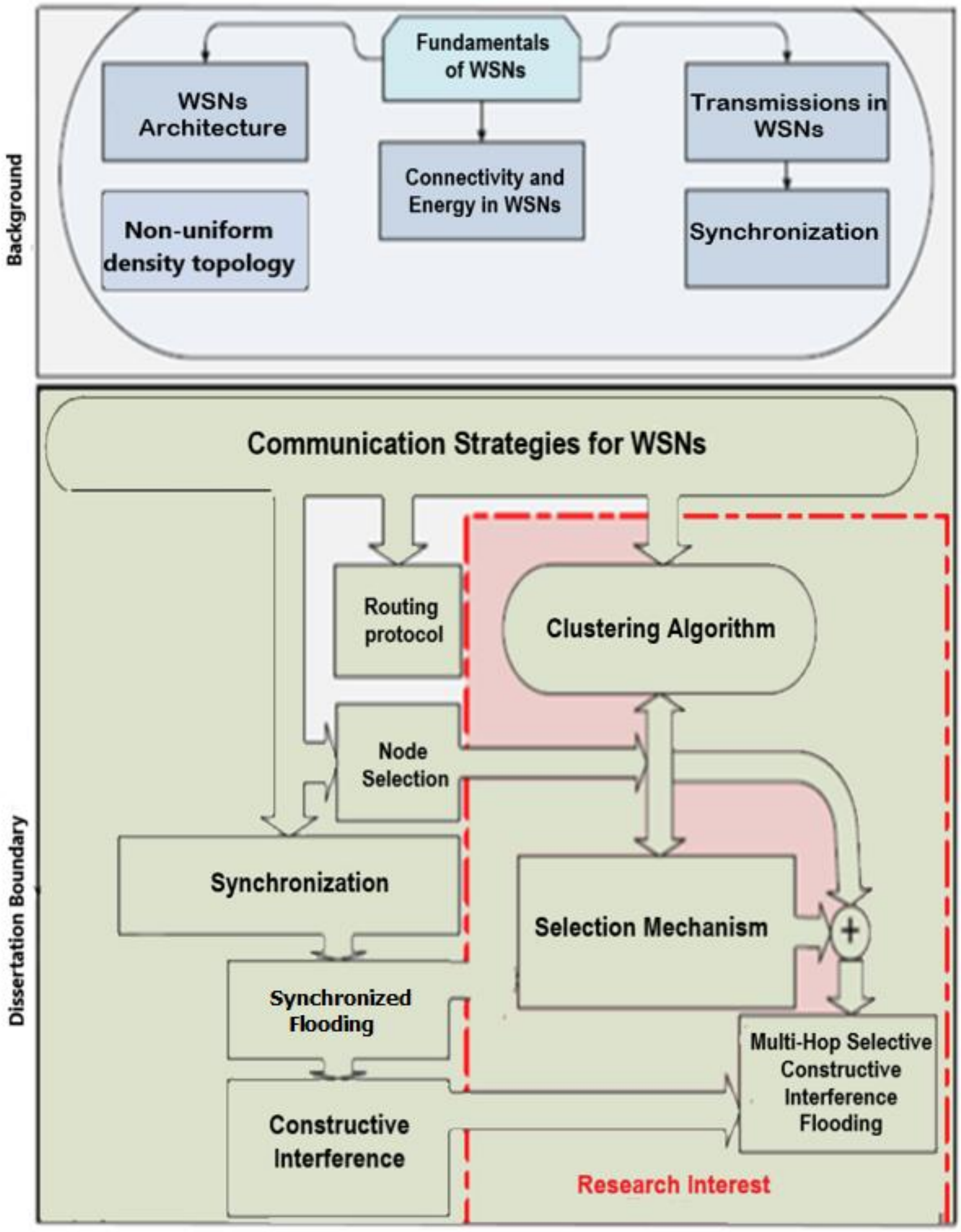

Figure 2.1: Dissertation Interest and Boundary

2.2 Fundamentals of WSNs

A huge increase in the use of WSNs has been reported recently, as they are able to track and control physical environments from remote locations and enhance the accuracy of information attained through cooperation between sensor nodes and the online processing of data (Karthikeyan & Kavitha, 2013).

A WSN consists of sensor nodes that are very small and lightweight devices, employed to monitor large physical environments (Rahman, 2010). Sensors measure the physical parameters (pressure, temperature, sound humidity, pollutants, and vibration) and send the collected data to the sink node. Nodes need to communicate with each other and with a base station (BS) through their wireless radio. This enables them to send the sensed data for further processing, analysis, storage systems, and visualization (Sharma et al., 2014).

2.2.1 WSN Architecture

Hundreds or thousands of nodes are densely deployed to build a WSN in monitoring a specific area and to sense some physical parameters (Akyildiz et al., 2002). The obtained information by a collector node is transmitted through multi-hop communications between sensor nodes until the data arrives at the sink or BS. This task can be performed using single multi-hop route or through cluster-based communication. Clustering applies a selection of strategies to select the most powerful nodes to form many clusters to do the same task of transmitting the collected data. Figure 2.2 shows how a WSN works.

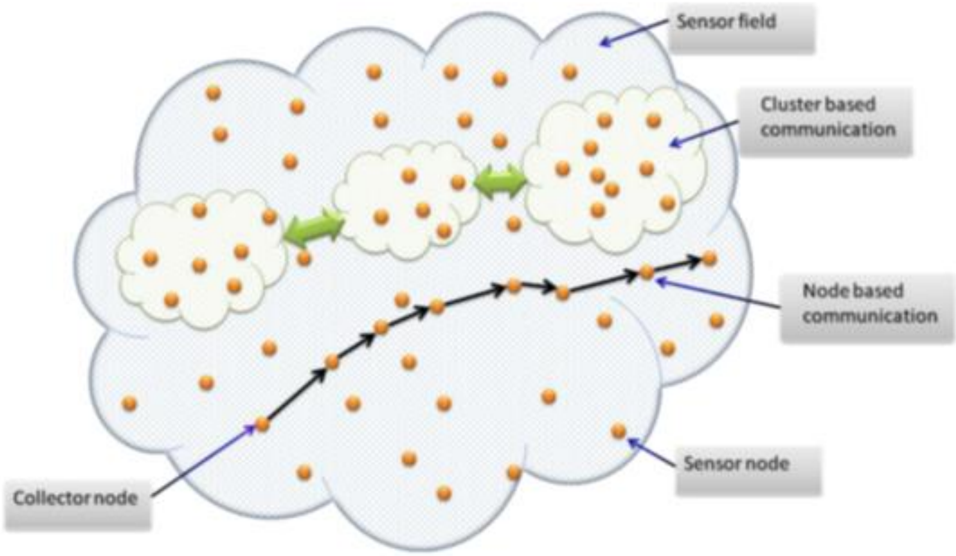

Figure 2.2: A WSN Architecture (Akyildiz et al., 2002)

2.3 Network Connectivity and Lifetime

In WSNs, connectivity is a serious issue as the data sensed needs to be delivered to BS for further processing. Good network connectivity is required for this transmission. The connectivity can be defined by a graph related to WSNs. A WSN can be described as a graph, in which the sensor nodes are represented as vertices in the graph. The direct connection of two nodes is indicated by undirected edge between two vertices. If the graph is connected, the WSN will be connected. A graph **G** is connected if there is a path between every two vertices (Diestel, 2005). Similarly, the network is connected if every node can connect to other nodes in the network either by direct connection or through relay nodes via multiple hops.

There are more definitions for connectivity such as 2-connectivity and 3-connectivity. However, they use the same graph theory. If there are two separate paths between two nodes in the network, it is called 2-connectivity, while if there are three paths between two nodes, it is known as 3-connectivity.

The network connectivity is affected by the positions of nodes, which are related to the sensor deployment. The two main approaches to deploy sensors in a WSN are random deployment where nodes are distributed randomly, and deterministic deployment, in which there are pre-engineered positions where the nodes are carefully placed on, and in the desired positions. Therefore, network connectivity can be easily achieved in the deterministic deployment if the nodes' specifications are known. Although the deterministic deployment seems to be perfect, it cannot be applied with all WSNs due to the very high costs in installing a large number of sensors using this deployment and, in many cases, the environmental conditions do not allow such deployment.

Therefore, there are requirements in using random deployment to install the sensor network with a very large number of nodes. Nodes may be spread by an artillery shell or a moving vehicle (Akyildiz et al., 2002). Therefore, the analysis of connectivity for WSNs should include a suitable modeling of random networks.

Sensor nodes can be launched via artillery in battlefields or air-dropped in the unfriendly environments, which leads to random spatial distributions of node densities in each area i.e. sparse distribution. In this case, a stationary two-dimensional Poisson point process can be used to model the location of the sensors (Daley & Vere-Jones, 2007).

2.3.1 Network Lifetime Based on Connectivity

Evaluation of sensor networks is not enough without evaluating the network lifetime. Network lifetime can be determined by the availability of nodes, sensor coverage, and connectivity that can be used to define the network lifetime (Dietrich & Dressler, 2009).

As it is difficult to measure the sensor coverage in wireless networks, connectivity can be used as a metric for network lifetime since the ability to successfully deliver data from the sensed node to the destination (high connectivity) is crucial for a WSN.

Blough and Santi (2002) defined network lifetime as the minimum time when either the size of the largest connected nodes of the network or the alive nodes percentage below a specified threshold.

Yu et al. (2001) and Baydere et al. (2005) defined network lifetime as the total number of packets that can be delivered to the sink. Although this number can be introduced as a pointer for the network persistent, it depends on the specific algorithms used in the network. For example, if algorithms of data aggregation are used, the number of transmitted packets is reduced. Therefore, this metric is not sufficient in comparing the network lifetime for different setups. This metric becomes ineffective particularly when algorithms of data aggregation are employed. Another limitation is the number of transmitted messages do not indicate how long the network could measure its environment. Similar considerations hold for in-network data processing (Dressler et al., 2007).

A third direction uses network connectivity to define the network lifetime in terms of the number of successful data gathering cycles (Olariu & Stojmenovic, 2006). Giridhar and Kumar (2005) limited lifetime to the number of cycles possible before any node dies. The difference from other definitions is lifetime not being measured in terms of time but as the number of network cycles.

2.4 Cooperative Communication Strategies

One of the most important network connectivity–energy management strategies is cooperative communication. Cooperative communication is a process of sharing and coordinating resources to improve transmission quality (Scaglione & Hong, 2003; Laneman et al., 2004; Sendonaris et al., 2003; Janani et al., 2004; Saedy & Kelley, 2011; Wang & Giannakis, 2008). Cooperative communication strategy reduces energy consumption of transmission and increases channel capacity (Yuan et al., 2006a). Recently, many researches merge cooperative communication with WSNs. However, sensor networks do not have multi-antenna devices because the sensor node can only support a single antenna (Cui et al., 2004). Therefore, cooperative communications will be between individual single antennas to transmit and receive data. In a cooperative network, nodes collect the received signals in physical layer and forward each other’s packets to provide spatial diversity (Baccarelli et al., 2005). There are three main approaches to perform cooperative diversity in WSNs: multi-hop, data flooding, and cluster-based approach.

2.4.1 Multi-Hop Relaying

Multi-hop relaying depends heavily on the physical channel (Kramer et al., 2005). This approach allocates network resources based on information theoretic metrics (Buratti & Zanella, 2011; Del Coso et al., 2007). Nevertheless, this approach is unsuitable for large networks because the number of transmitted bits per square meter gradually decreases with the increase in the network size (Gupta & Kumar, 2000; Scaglione & Hong, 2005). Figure 2.3 shows the multi-hop relaying process.

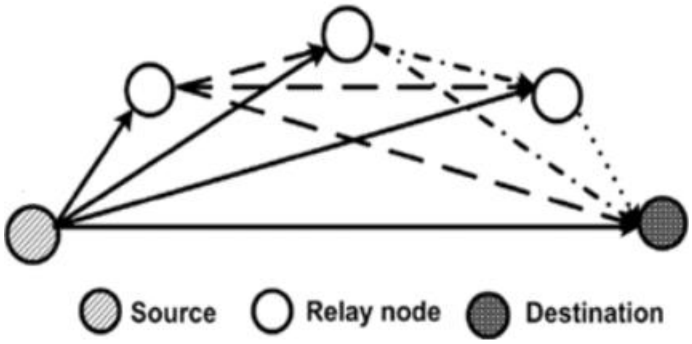

Figure 2.3: A Multi-Hop Relaying (Kaur & Malhotra, 2015)

2.4.2 Cluster-Based Approach

The objective of this approach is to divide the network into clusters of nodes that cooperatively transmit information (Culler et al., 2004). Coso et al. (2006) employed a clustering approach that performs cooperation in WSNs. Firstly, as clusters are formed, the multi-hop transmission is then applied from each cluster nodes. All cluster nodes can simultaneously transmit information via virtual multi-input and multi-output channels. There is no necessity for direct transmission to the destination since the source uses less power to transmit the message via clusters. Yet, managing the clusters is important for this approach. Vidhya (2010) studied the multi-input and multi-output cooperative transmission technique. This approach reduces energy consumption and increases the network lifetime at uniform density. Nevertheless, network capacity is considered low in this topology compared to the previous approaches (Gastpar & Vetterli, 2002; Gupta & Kumar, 2000). Figure 2.4 illustrates the cluster-based approach.

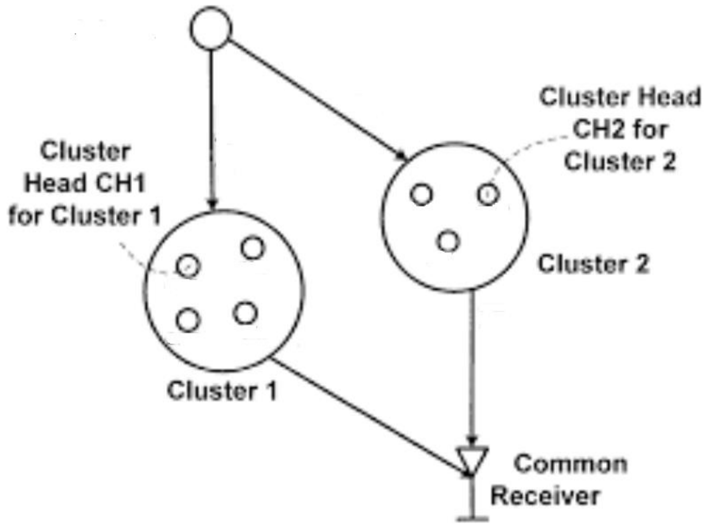

Figure 2.4: A Cluster-Based Cooperative Transmission (Coso et al., 2006)

2.4.2.1 Clustering Algorithms

Clustering algorithms are widely introduced in research to support WSNs' scalability. Clustering has been proposed in ad-hoc network studies (Amis et al., 2000; Chatterjee et al., 2002; Kawadia & Kumar, 2003; Layuan & Chunlin, 2007; Tuli & Kumar, 2011; Chiang et al., 2012). These previous studies aimed primarily to achieve stability in mobile node environments. Most of the proposed methods focused on the route stability and reachability of the node than the design of the WSN as network longevity and coverage. Many clustering algorithms have been developed (Bandyopadhyay & Coyle, 2003; Younis & Fahmy, 2004; Gupta & Younis, 2003; Farach-Colton et al., 2009; Mathew et al., 2005; Oldewurtel & Mähönen, 2012). Each clustering algorithm differs from others based on the network operation model, node deployment and bootstrapping schemes, the network architecture, and the clusterhead features.

A network is divided into clusters; each cluster has a leader called a clusterhead which may be allocated by sensors in the cluster or pre-assigned by the network designer. Most of the clustering algorithms use clusterheads as the sensors with larger number of resources. In addition to enhance the network scalability, clustering offers many advantages. Li et al. (2011) observed that clustering limits the routes established between nodes and reduces the stored routing table size in each node. Furthermore, it saves the communication bandwidth by reducing redundant message exchange between sensor nodes (Younis et al., 2003). Moreover, it lessens the overhead of network maintenance as the topology of the network is stabilized at the sensor level. Hou et al. (2005) and Yin et al. (2011) proved that sensors only focus on communications between clusterheads and are unaffected by the changes of inter-clusterhead.

Cluster architectures can be classified into two types based on the diameter of the cluster: one-hop clustering and multi-hop (*k-hop*) clustering. In one-hop clustering, each node in the cluster is located at most one hop from the clusterhead, which is considered as the central point. Consequently, all cluster nodes will be at most two-hop away from each other inside a cluster. Nodes that exist in other nodes' transmission range and can connect directly with each other are called as neighbors. In multi-hop clustering, constraint of a direct neighborhood from the clusterhead does not exist since the nodes can be at *k-hop* away from each other in establishing a cluster (Lin & Gerla, 1995; Lin & Gerla, 1997; Ohta et al., 2003). Figure 2.5 shows the classification of WSN clustering algorithms based on the overlapping features and number of hops. This thesis focuses on the one-hop WSN clustering algorithms. In this section, the most popular one-hop clustering algorithms are presented.

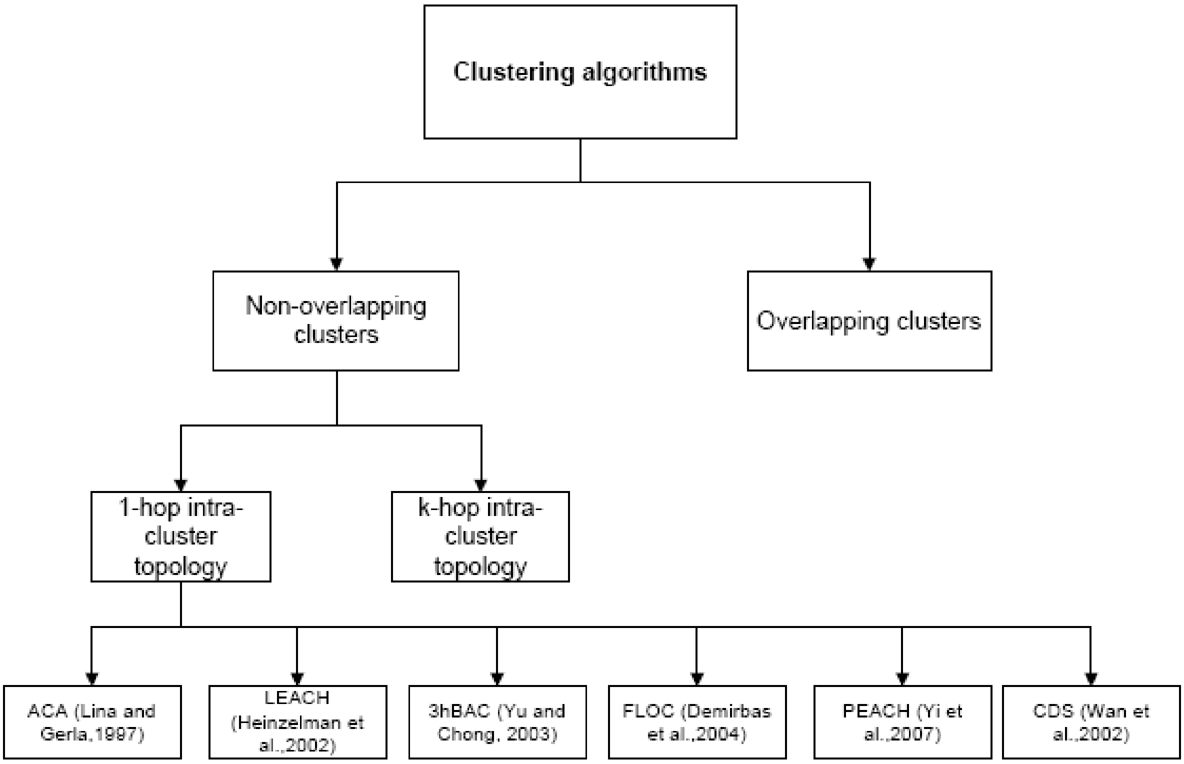

Figure 2.5: Classification of WSNs Clustering (Heinzelman et al., 2002)

(1) Low Energy Adaptive Clustering Hierarchy (LEACH)

LEACH is the most widespread WSN clustering algorithms (Heinzelman et al., 2002). It is an independent, application-specific, and distributed clustering algorithm that can considerably improve the network lifetime. LEACH assumes that all nodes have the same load distribution and each node can be reached within one hop of distance. Firstly, a node chooses itself to be a clusterhead with *p* probability and broadcasts its decision. Then, each unclustered nodes look for a cluster that can be reached using a minimum amount of energy and join it. Therefore, LEACH clustering depends heavily on the received signal strength. Clusterheads work as routers to the base stations. Data fusion and aggregation are performed locally at the clusterheads. The probability of becoming a clusterhead in LEACH is fixed and equal for all network nodes to lessen the unbalanced loads of the cluster nodes. Nevertheless, clusterheads can transmit data directly to the base station and thus, they are expected to have longer communication range than other nodes in the cluster. This result denies the assumption that all sensors in one cluster are equal in real environments. Additionally, the signal propagation problems and the presence of obstacles can delay the direct transmission from many nodes within the network. Therefore, the clusterhead nodes are not able to work efficiently in a WSN that is deployed in large areas.

Other limitation to LEACH algorithm is that it assumes energy consumption is the same among each node. However, this assumption is not feasible for heterogeneous networks with different energy distributions. These limitations lead to many algorithms developed to improve LEACH, for example, APTEEN (Manjeshwar & Agrawal, 2002), PEGASIS (Lindsey & Raghavendra, 2002), and TEEN (Manjeshwar & Agrawal, 2001).

(2) Adaptive Clustering Algorithm (ACA)

Lin and Gerla (1997) developed an adaptive clustering scheme to build clusters of non-overlapping architecture. In ACA, each node keeps its ID and the ID of its neighbors in a set. The clusterheads are defined as the nodes with the lowest number of neighbor IDs. The clusterhead sets the cluster ID (CID) as its own ID. The clusterhead is known to broadcast the CID information including its node ID and the CID whereby if its ID is the same as the CID so it's a clusterhead. Otherwise, it is an ordinary node. Only the clusterhead can broadcast its cluster information. If a node receives CID information from a neighbor, it will be removed from the set. The main advantage of this technique is the low communication overhead for constructing clusters, since only one CID message from each node is required to build a cluster. When the cluster construction completes, clusterheads will not be used in the following cluster maintenance. Nodes in one cluster must be equally accessible with at most two-hop distance. A cluster maintenance method is required by a node if the distance between this node and any node within one cluster becomes three hops. In this case, a node stays in the cluster and removes another node which is at three-hop away if there is other direct neighbor for the node with higher intra-cluster connectivity. Otherwise, it joins a neighboring cluster. In case if there is no proper cluster nearby, the node forms a new cluster to cover itself. This maintenance method builds new clusters without eliminating or merging the available clusters. However, the number of clusters increases with time and the cluster size is reduced. Since every node can construct a single-node cluster, this results in increasing the probability of cluster structure disappearance (Hou & Tsai, 2001).

More well-designed clustering algorithms include Fast Local Clustering (FLOC) (Demirbas et al., 2004), Power-Efficient and Adaptive Clustering Hierarchy (PEACH) (Yi et al., 2007), Three-hop Between Adjacent Clusterheads (3hBAC) (Yu & Chong, 2003), and Connected Dominating Set Algorithm (CDS) (Wan et al., 2002). Clustering achieves high scalability, reduces energy consumption, and extends the lifetime in large-scale WSNs. Nevertheless, clustering has several drawbacks because of the additional overhead of cluster construction and maintenance (Shanoon, 2013).

2.4.3 Data Flooding

Flooding is an old approach to spread data into a network or to reach a node which its location is unknown by flooding data into the whole network (Chong & Kumar, 2003; Perrig et al., 2002). It is a simple routing algorithm as each incoming packet is transmitted from each outgoing link. At the beginning, a node broadcasts packets to its direct neighbors. These neighbors will then rebroadcast the packets to their own direct neighbors until the packets are delivered to all nodes in the network.

Flooding guarantees that the data will reach the destination, if there is any path to it. Simplicity is the main advantage of flooding, while its key limitation is that it leads to heavy traffic. Thus, several techniques must be applied to ensure that the packets do not go indefinitely throughout the network. For instance, the maximum-hop counts method can be utilized, to lessen the number of times a packet is relayed. The maximum-hop counts supposed to be large enough to reach every intended receiver, but also small enough so that the packets are not being forwarded for a long period in the network. Another efficient technique is using sequence numbers in packets to recognize the packets so that the node can discard a packet that is received multiple times.

The opportunistic large array approach (Simeone & Spagnolini, 2006; Mitran et al., 2005) have been proposed for a flooded network with messages need to be transmitted. A received signal can be relayed at various times via neighboring nodes using this approach, which operates as forwarders. When the nodes flooded the network with the needed signal, a CI is created. Krohn (2006) and Tu and Pottie (2002) also developed an approach in which the white noise overlays the signal, thus increasing the possibility of having CI. Using a wave-front method, a message can flood into the network (Krohn, 2006). The accumulating cooperative transmission