LIFETIME MAXIMIZATION OF WIRELESS SENSOR NETWORK USING ENERGY AWARE TOPOLOGY CONTROL ALGORITHM

ALI ABDULJABBAR ALI

UNIVERSITI KEBANGSAAN MALAYSIA

LIFETIME MAXIMIZATION OF WIRELESS SENSOR NETWORK USING
ENERGY AWARE TOPOLOGY CONTROL ALGORITHM

ALI ABDULJABBAR ALI

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQAUIREMENT FOR THE DEGREE OF
MASTER OF COMPUTER SCIENCE

FACULTY OF INFORMATION SCIENCE AND TECHNOLOGY
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2017

PEMAKSIMUMAN JANGKA HAYAT RANGKAIAN PENDERIA WAYARLES MENGGUNAKAN ALGORITMA KAWALAN TOPOLOGI SEDAR TENAGA

ALI ABDUALJABBAR ALI

DESERTASI YANG DIKMUKAKAN UNTUK MEMENUHI SEBAHAGIAN DARIPADA SYARAT MEMPEROLEHI IJAZAH SARJANA SAINS KIMPUTER

FAKULTI TEKNOLOGI DAN SAINS MAKLUMAT
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2017

DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

14 November 2017

ALI ABDULJABBAR ALI
P75804

ACKNOWLEDGEMENT

First and foremost praise be to Almighty Allah for all his blessings for giving me patience and good health throughout the duration of this Master research.

I am very fortunate to have Dr. Khairul Azmi Abu Bakar as a research supervisor.

I would like to thank my parents, my brother, my sisters and all my friends.

ABSTRACT

Wireless sensor networks (WSN) have emerged as one of the most common and widely spread wireless networks which has been widely deployed in different fields and environments. To provide reliable functionalities in WSN, most WSN applications require essential network services which can manage data collection, synchronization and localization where WSN has limited resources and low energy in particular. Topology control algorithms aim to conserve energy and improve the network capacity by choosing the right transmission power and neighbours such that the network is connected and has desired properties. In WSN, topology far nodes send data of their messages over different paths, which require higher amounts of energy than nodes which are near sink nodes. On the other hand, if any parent node in the topology fails due to technical error or energy depletion, nodes that send data over these failed nodes consume more energy and experience high data loss due to selecting higher cost paths or failing to find an alternative one. In this thesis, energy aware and fault tolerance topology control has been proposed which mainly can build topology to minimize energy consumption and rebuild affected parts of the network topology in case of parent node failure. The proposed topology control mechanism has two main phases, the topology building phase and the fault tolerance phase. WSN topology is built to minimize the maximum relative load of each topology node which can minimize power consumption and maximize the network lifetime. On the other hand, in the fault tolerance phase, the proposed mechanism monitors WSN nodes and in case of node failure, the affected part of the network topology is re-built and the affected node can resume data collection immediately. The proposed topology control mechanism has been implemented and simulated using the NS2 simulator and compared against other latest proposed topology control mechanisms. Results show that the proposed mechanism reduces the maximum relative load up to 35% compared to when no topology network. However, the packet delivery ratio and network throughput has been increased up to 44% when failure tolerance topology control mechanism is used in case of node failure.

ABSTRAK

Rangkaian penderia wayarles (WSN) telah muncul sebagai salah satu rangkaian wayarles secara meluas digunakan di dalam bidang dan persekitaran yang berbeza. Untuk menyediakan kefungsian yang boleh dipercayai di dalam WSN, kebanyakan aplikasi WSN memerlukan perkhidmatan rangkaian yang boleh mengurus pengumpulan data, penyerentakkan dan penyetempatan di mana WSN mempunyai sumber yang terhad dan khususnya tenaga yang rendah. Algoritma kawalan topologi bertujuan untuk menjimatkan tenaga dan meningkatkan kapasiti rangkaian dengan memilih kuasa penghantaran dan jiran yang betul sehingga rangkaian itu disambungkan dan mempunyai ciri-ciri yang dikehendaki. Dalam WSN, nod pinggir topologi menghantar data mesej mereka melalui laluan yang berbeza, yang memerlukan jumlah tenaga yang lebih tinggi berbanding nod yang hampir dengan nod tenggelam. Sebaliknya, jika ada nod induk di dalam topologi tersebut gagal kerana kesilapan teknikal atau kesusutan tenaga, nod yang menghantar data melalui nod gagal ini menggunakan lebih banyak tenaga dan mengalami kehilangan data yang tinggi kerana memilih laluan kos lebih tinggi atau gagal untuk mencari suatu alternatif lain. Di dalam tesis ini, suatu kawalan topologi sedar tenaga dan bertoleransi kerosakan telah dicadangkan yang terutamanya boleh membina topologi rangkaian untuk meminimumkan penggunaan tenaga dan membina semula bahagian yang terjejas sekiranya berlaku kegagalan nod induk. Mekanisma kawalan topologi yang dicadangkan mempunyai dua fasa utama, fasa pembinaan topologi dan fasa toleransi kerosakan. Topologi WSN dibina untuk meminimumkan beban maksimum bagi setiap nod topologi yang boleh meminimumkan penggunaan kuasa dan memaksimumkan jangka hayat rangkaian. Sebaliknya, dalam fasa toleransi kerosakan, mekanisma yang dicadangkan memantau nod-nod WSN dan sekiranya berlaku kegagalan nod, bahagian rangkaian topologi yang terjejas dibina semula dan nod terjejas boleh meneruskan pengumpulan data serta merta. Mekanisma kawalan topologi yang dicadangkan itu telah dilaksanakan dan disimulasi menggunakan simulator NS2 dan dibandingkan dengan mekanisma kawalan topologi lain yang terkini. Keputusan menunjukkan bahawa mekanisma yang dicadangkan mengurangkan beban maksimum sehingga 35% berbanding dengan tiada rangkaian topologi. Walau bagaimanapun, nisbah penyampaian paket dan daya pemprosesan rangkaian telah meningkat sehingga 44% apabila mekanisma kawalan topology toleransi kegagalan digunakan sekiranya berlaku kegagalan nod.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ABBREVIATIONS

ADCs	Analog to Digital Converters
ADPV	Adaptive Disjoint Path Vector
AELB	Atomic Energy Licensing Board
ANs	Application Nodes
AODV	Ad Hoc On-Demand Distance Vector
ARM	Advanced RISC Machine
BAMP	Biconnectivity Augmentation with Min Max Power
BICONN	BICONNectivity
BSs	Base-Stations
CC	Chip Con
CMP	Connected Min Max Power
CONNECT	CONNECTivity
DC-DC	Direct Current to Direct Current
DPV	Disjoint Path Vector
EAFTC	Energy Aware and Fault tolerance Topology Control
EATC	Energy-efficient Topology Control algorithm
FTMRT	Fault Tolerance by constructing a Multi-Routing Tree
FTTC	Fault Tolerant Topology Control approach
HWSNs	Heterogeneous WSNs
GUI	Graphical User Interface
IP	Internet Protocol
ISM	Industrial Scientific Medical
IAEA	International Atomic Energy Agency
LINT	Local Information No Topology
LILT	Local Information Link State Topology
MCU	MicroController Unit
MHz	Mega Hertz

MEMS	Micro-Electro-Mechanical Systems
MTTF	Mean Time To Failure
NAP	Neighbor Addition Protocol
NS2	Network Simulator 2
ODI	Overseas Development Institute
PDR	Packet Delivery Ratio
RREP	Route REPly
RREQ	Route REQuest
PSU	Power Supply Unit
QoS	Quality of Service
SNR	Signal-to-Noise Ratio
TC	Topology Control
TTL	Time To Live
U.S. ARMY	UNITED STATES ARMY
UKM	Universiti Kebangsaan Malaysia
WSN	Wireless Sensor Network

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

Networks are considered as crucial factors for world communications. It is the most critical way to accelerate and enhance individuals and organizations access. Computer networks provide data transfer between two or more computers by interfacing them with each other. Computer networks are a combination of software and hardware modules.

Such type of networks can be divided into two main types: wired and wireless networks. Wired networks such as Ethernet networks which depend on Ethernet cables to connect computer devices with switches or routers using network interface cards. On the other hand, wireless networks mainly depend on radio waves to transfer data between wireless nodes, which provide higher mobility and extra flexibility. Wireless networks can be divided based on the topology of the network into two types: infrastructure wireless networks and ad-hoc wireless network. In infrastructure wireless networks, nodes are connected using a central access point or base station, while in the ad-hoc wireless network, nodes can communicate directly or peer to peer via communication (Bandeira & Poulsen 2004).

Wireless Sensor Networks (WSNs) is one of the most active and popular wireless networks which gathered worldwide attention recently. An enhancement in Micro-Electro-Mechanical Systems (MEMS) technology has utilized the development in smart and small sensors production, which accordingly made WSN more popular. Smart sensor nodes are low power devices equipped with one or more sensors, a processor, memory, a power supply and an actuator with appropriate network services and protocols. A WSN can collect the information from the monitored environment and deliver this information from sink node to interesting sensor node via multi-hop wireless communications. WSN technology connects the physical world to the digital world. It has attracted tremendous attentions from both academia and industry due to its great potential role in changing our ways to interact with the environment.

The standard architecture of WSNs is shown in Figure 1.1. WSN mainly consists of sensor nodes, sink node and a remote user. All the data collected by the sensor nodes are forwarded to a sink node. Therefore, the placement of the sink node has a great impact on the energy consumption and lifetime of WSNs where all collected data has to be forwarded to the sink node. Shorter distance with the sink node result in less power consumption to forward data.

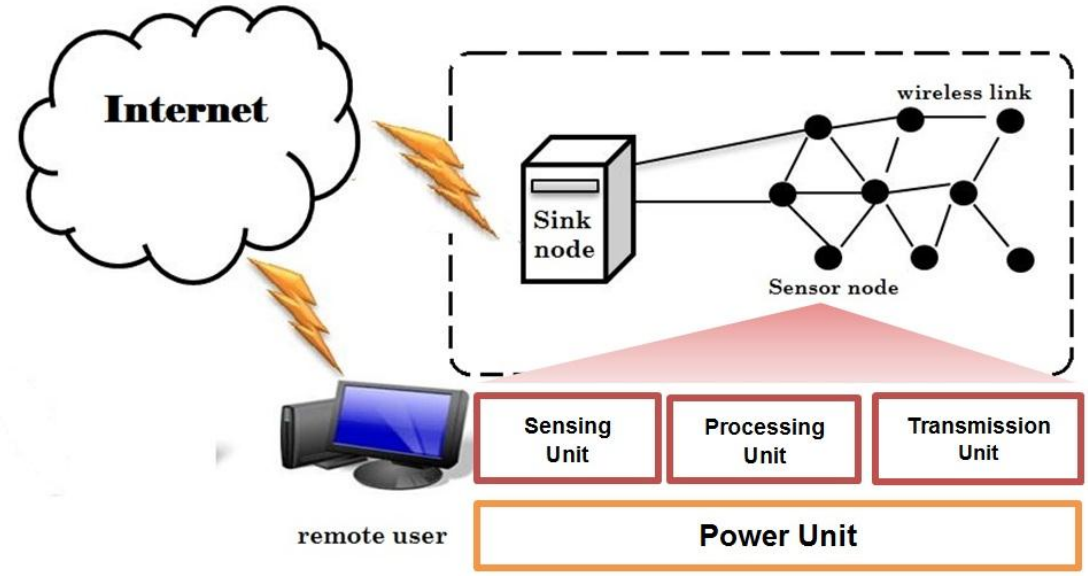

Figure 1.1 WSNs Architecture

Typically, a sensor node has four main components: sensing, processing, transmission, and power units. Sensing unit consists of a sensor and Analog to Digital Converters (ADCs) which converts analog signal produced by a sensor to a digital signal. The sensor converts physical phenomenon to the electrical signal. Processing unit constitutes of a microprocessor or microcontroller which control sensors, execution of communication protocols and signal processing algorithms on the collected sensor data. Transmission unit collects the information from the processing unit and then transmits it to sink node. In the power unit, the main source of energy is the battery power. So, power unit supplies the battery power to the sensor node.

WSNs can be deployed to various environments where the users are concerned. Sensor nodes can be either simply distributed randomly in the field, or their locations are carefully planned. Such flexibility extends the feasibility of WSN. For example, they can be deployed in the area where people are hard to reach. In a WSN, typically there are many sensor nodes and one or more sink nodes. The sensor nodes are responsible for collecting information from the environment. The sink nodes are responsible for storing and processing information collected by the sensor nodes and delivering the control messages to the sensor nodes. They also serve as the gateways between the users and the sensor network. A user can query the data generated by some sensor nodes via the sink nodes, or receive the reports of events detected by some sensor nodes via the sink nodes.

1.2 RESEARCH BACKGROUND

A WSN is a network consisting of sensor nodes capacitated with sensing, processing and communication capabilities. Sensor nodes can measure the surrounding environment, process raw sensory data and communicate with other sensor nodes via wireless communications (Yick et al. 2008). The number of connected sensors to a WSN depends on the area covered by sensor nodes. One of the most known types of data exchanging ways is Many-To-One communication scenario (all sensor nodes transfer messages and data to a single sink). In some WSN applications, distributed sensors can lose the connection to the sink node due to tough conditions of surrounding environment like forest fire detection, and battlefield surveillance where adding a new sensor node is cheaper than changing the defective battery of disconnected sensor node.

In WSN, sensors are distributed over different distances of the network. Each of them needs different energy to send required messages since theses nodes are located at different distances away from the sink node. While the sensor node can only be equipped with a limited energy supply, it many loses its energy during data communication. In some application scenarios, the replenishment of energy resources is costly since the sensor nodes are distributed in the remote environment. Hence, nodes located away from sink node require more energy to forward data so they lose their energy faster than nearer ones and become inactive sooner. The frequent topology changes due to the death of sensors make the network quite unstable.

One proposed solution for different required energies and distance is the pattern of sink node mobility, which has to specify the requirements to where and when to move the sink mode. Such movement pattern should confirm that energy is consumed efficiently and in a balanced manner. Mobile sink node will wait at specific locations called sink site or migration point to gather data from nodes. After then it will move to a new location to complete collecting data. Network parameters should be used to regulate the mobility scheme (Chatrchyan et al. 2012).

WSN sensor nodes have to deploy manually and topology is being constructed autonomously to the application region. Hence a topology control mechanism is required to construct and preserve the network topology. Additionally, several causes might do alteration in WSNs topology including communication link breakdowns, mobility and power drains of the nodes. To maintain the network connection as long as possible and improve the network lifetime, throughput and energy preservation, topology control techniques are vital for WSNs.

Topology control is clarified as adjusting the neighbor set of nodes in a WSN by modifying the transmission domain and/or transmit the messages by picking particular nodes (Y. Li et al. 2008). The efficient use of available energy conservation in a network is always one of the fundamental metrics, especially in a WSN. Since nodes have limited power, it is critical for nodes to save energy. Thus, in order to reduce energy consumption, a practical and efficient approach is to reduce the transmission power.

Considering the wireless channel and energy consumption models in WSN, one observation is that instead of using a long, energy-inefficient edge, nodes should choose a multi- hop path composed of short edges that connect the two endpoints of long edge to communicate (Santi 2005). This observation is a fundamental idea in topology control to reduce energy consumption. Therefore, topology control algorithms in battery-powered WSN aim to choose short links between nodes while preserving the network connectivity. However, energy consumption is not always the critical aspect when choosing links. Nodes need to manage energy smartly. Therefore, nodes should choose neighbors wisely in WSN node based on not only the energy consumption but also the residual energy of their neighbors.

1.3 PROBLEM STATEMENT

The WSN contains a huge number of connected nodes which achieves the data transmitting from the source nodes to the destination nodes. Most of the times those transmitting data will follow best paths (Tree, 2014). In other words, the message between source nodes will hop to many intermediate nodes in order to reach the destination nodes. Each of those nodes will be affected when data transmitting accrue in the manner of energy losing. Typically, the transmitting of data in wireless network required a power and the high routing will affect power consumption.

Network routing protocols are built to achieve best path in term of distance, cost, delay or any other cost between any node toward any destination. Energy is considered as a cost for routing protocols. However these routing protocols are deployed based on the defined topology (Pantazis, Nikolidakis, & Vergados, 2013).

In addition, some far nodes still have to send data of their messages using available and lower cost paths, which require higher amounts of energy than nodes which are closer to the sink node. Some of these nodes stop sending data in shorter periods of time because of energy depletion which decrease network lifetime. Furthermore, some nodes that will face technical issues (failed to receive or send data). So in both cases, it will stop working, thus, sending data over the stopped nodes will lead to consuming the network energy which will cause network failure.

1.4 RESEARCH OBJECTIVES

The main objective of this research is to maximizing energy lifetime of nodes in WSN that negatively influence their performance to reduce transmission powers by finding the shortest possible path in order to prevent nodes energy depletion in WSN. The sub-objectives of this proposal includes:

- To provide a topology structure with power aware to minimize power consumption and extend network lifetime.
- To minimize load on low power nodes to prevent network disconnectivity.
- To avoid energy depletion failure, and recover affected topology parts.

1.5 RESEARCH SCOPE

Computer networks require monitoring and traffic control. Network management tasks are responsible for such requirements where five functional domains are identified to cover it. These domains include configuration management, security management, fault management, accounting management and performance management (Potdar et al. 2009). On the other hand, WSN required an additional management domain which is topology management which is responsible for controlling the degree connectivity parameters of the network and nodes power and rules. The main goal of the network topology control is to maintain a sustainable coverage and conserve energy consumption.

Topology control mechanism works on monitoring the status of nodes communication links between network nodes, energy consumption is optimized by selecting specific forwarding data paths from the source towards their destination. WSNs Topology management can be done using deterministic node placement or performed autonomously after random deployment given the limited human intervention (Potdar et al. 2009).

In this thesis, network topology is designed to be built to minimize the maximum relative load of network nodes which can result in increasing the lifetime of WSN network. Fault tolerance mechanism is applied to overcome energy depletion node failure and continue data forwarding process through alternative paths.

1.6 SIGNIFICANCE OF RESEARCH

Proposed topology control mechanism can build WSN to maximize the network lifetime, minimize the average maximum relative load of all the network nodes, and optimize energy consumption by minimizing the energy cost of data forwarding. Node failure can result in high data dropping and catastrophic consequences at the level of network performance. Handling node failure can overcome performance issues, reduce data drops and maximize the network lifetime. Proposed topology control mechanism monitors the node energy level and when a predefined threshold is reached, affected part of the network topology is rebuilt to confirm data forwarding and high network performance.

1.7 ORGANIZATION OF THE THESIS

The thesis comprises of five chapters. Chapter I introduces the topic with a study of background information about WSNs. It also presents the problem statement, research objectives, significant of research study including the scope and methodology of this research.

Chapter II presents a comprehensive literature review. It begins with an introduces topology control in WSN and energy consumption in case fault tolerance, Hierarchical and Geographic Position; as well as works related to WSN lifetime.

Chapter III presents the used methodology to accomplish thesis objectives, in particular, a complete simulation methods description. Chapter III also provides a brief introduction to the selected network simulator software which is NS2, which is used to implement and investigate the performance Energy Aware and Fault Tolerance Topology Control (EAFTC) algorithm. At the end of the chapter, simulation descriptions of environments, setup, and configurations are provided.

A detailed explanation about the development and the evaluation of EAFTC algorithm is provided in Chapter IV to implement and maintain a reliable topology control which constructs network topology to minimize the maximum relative load and to tolerate faults. EAFTC is implemented to maximize the network lifetime of WSN. Simulation results are analyzed using different performance metrics; PDR, throughput, E2E delay, and maximum nodes relative load. The simulation results are obtained from various simulation runs. This chapter concludes with a discussion of the simulation results.

Chapter V summarizes the study results, draws conclusions from the results and provides suggestions for further research works which can improve the current research study.

1.8 CHAPTER SUMMARY

In this chapter, an introduction to WSN is presented to provide solid background about the research topic. In the second section, the problem statement is described and investigated where objectives are identified at the next section. The scope of the project is illustrated and the research significance is presented which include all contributed ideas and concepts. At the end of the chapter, the thesis organization is listed.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

In recent days, the world still looking for an efficient way to gathering data and information to make decision making. Collecting required data from some environments which are not easily accessible or that are dangerous to humans requires the right technology. One technology that fits the requirements fundamental for a flexible and low-cost mechanism to collect data from any location including urban environments, multiary fields, personal networks and environments in constrained communication access conditions. So, Wireless Sensor Networks (WSNs) infrastructures is a solution. As it is illustrated later in this chapter, theise types of networks devices have very limited resources, which results in making it essentials for them to work efficiently. So, network performance are mostly measured in terms of power consumption. Topology Control (TC) has been recently considered as one of the fundamentals ways in achieving energy-efficient consumption in WSN. This thesis is mainly focusing on it.

In this chapter, the main concept of WSNs and TC are formally introduced. Furthermore, it mainly explains the motivations behind the WSNs usage and how TC algorithms performance can be improved in detail. Subsequently, the problem statement will be introduced, accompanied by some discussion on the key study variables and procedures used in this work.

2.2 WIRELESS SENSOR NETWORK (WSN)

Proposed advances in wireless and sensor communication mechanisms and developments in microelectronics results in availablility of new approach of network communication with made battery-powered wireless devices integrated with sensing capabilities. WSNs, as they are defined and built, are infrastructure-less and self-configured wireless networks which include small devices that has a built-in wireless transceivers, specialized sensors, a small memory unit, a power source and a processing unit, power sources can be as small as a pair of “AA batteries.” A general structure of WSN diagram is shown in Figure 2.1 (Vision et al. 2002).

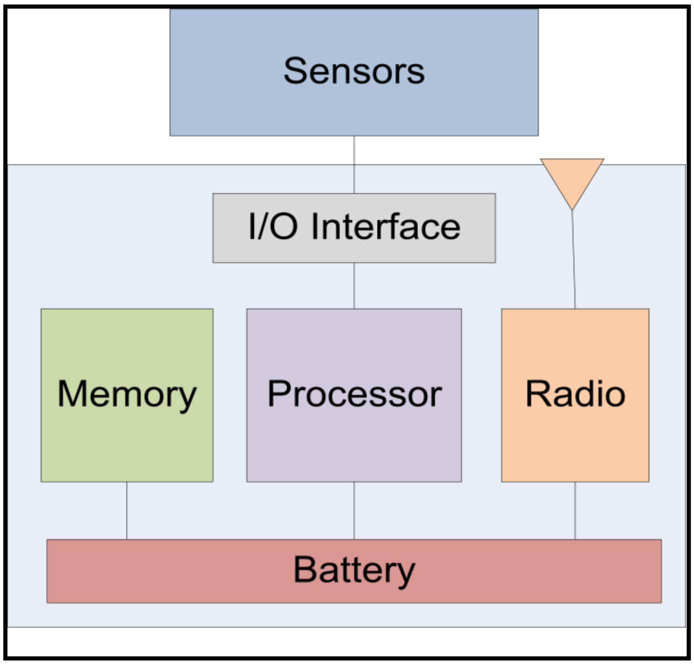

Figure 2.1 Diagram of components of a wireless sensor device

WSN has been built to collect required information from different environments and forward it to a reporting central location. In this location, high , high performance computers computers are located where collected information can be saved, managed and analyzed. Reporting central location also can be located at different nodes in Wireless sensor devices where it can get required respond to performe on demand sensing tasks or obtain specific data. Wireless sensor nodes can also include actuators which can be used to do specific actions based on specific conditions or statements. This types of wireless networks are referred as Wireless Sensor and Actuator Networks in more specific manner.

Some of the WSN applications, WSN has been used in observing and generate actions depending on events which can be dangerous or in inaccessible places for users.

For example, in chemical plants WSNs can be installed to observe the levels of water plants, rivers, poisonous gas, lakes and the like. It also can be used to investigate the water quality and level in places with endangered species, where water travel patterns and behaviors can be monitored; on the other hand, WSN can be used in buildings where air quality can be monitored and make them more efficient in power consumption. WSN in military field can be used in detecting intruders; monitoring enemy areas or in other similar purposes. An example of a complete solution of WSN is shown in Figure 2.2 which integrates WSNs with other recent technologies, including internet, cellular network, and other wireless ad hoc technologies (Vision et al. 2002).

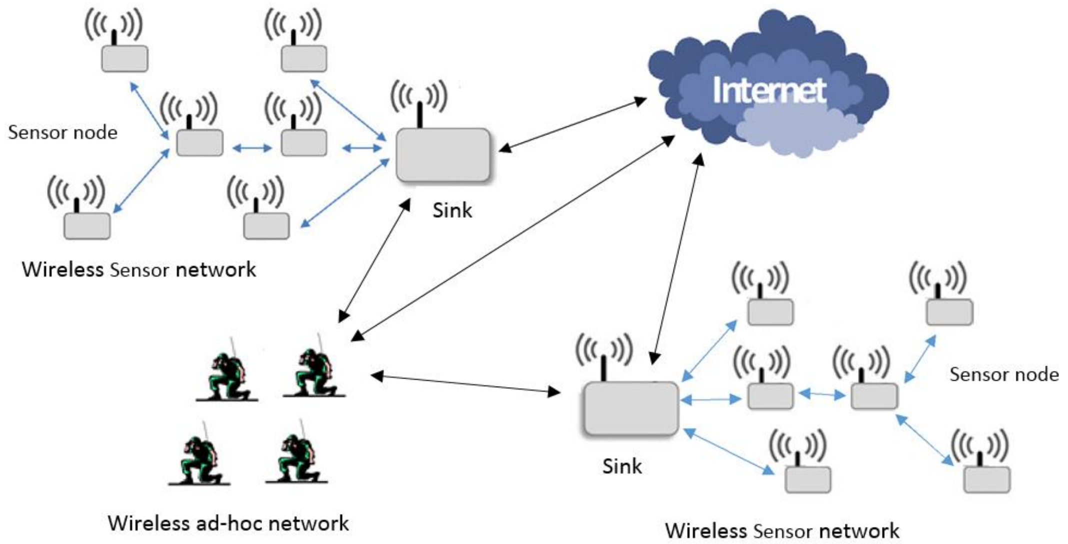

Figure 2.2 Example of a network architecture that includes a WSN

Source: (Vision et al. 2002)

A wireless sensor has the capabilities of sensing, processing, communicating and analyzing. Through these capabilities, a wireless sensor not only senses the physical data but also communicates with other sensors collectively in real time. Such a collective collaboration of wireless sensors deployed in a given area is called as WSNs. The block diagram of typical WSNs is shown in Figure 2.3 (Dargie & Poellabauer 2010). Multiple sensor nodes form WSNs to cooperatively monitor a given physical environment. They communicate with other sensors within their transmission range and transmit the collected data to the base station, which further sends the information to remote devices for analysis, storage, mining, and processing, WSNs have a wide range of applications across various fields from medical, engineering, and military.

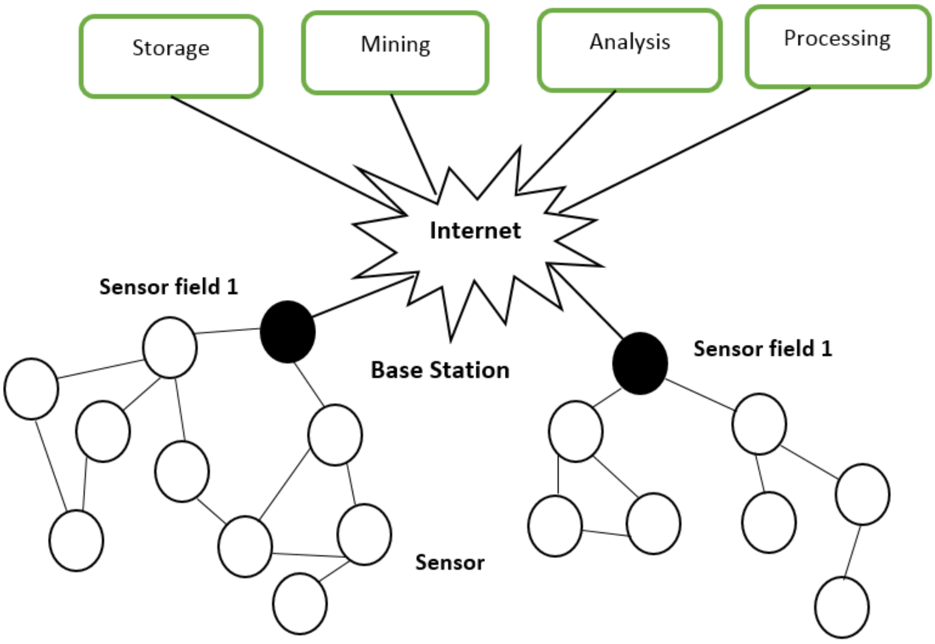

Figure 2.3 Typical wireless sensor node

Source: (Dargie & Poellabauer 2010)

Typical WSNs are constituted of sink nodes (master nodes) and regular nodes (ordinary nodes). A sink node can be defined as a master node that acts as a gateway between the base station and the regular nodes. It possesses a two-way communication capability between the base station and regular nodes and vice versa. They are equipped with the better configuration in terms of processing, computing, memory, and energy against regular network's devices. Regular nodes can fail, but sink nodes are not usually expected to fail. Regular nodes constitute the majority of the network. They are responsible for collecting real-time data and reporting it back to the sink. Regular nodes communicate with sink through a multi-hop network.

The sink nodes are performing as gateways for WSN where all collected data from the sensor network devices will be forwarded to the sink node which in turn transmit it to the control central location. Sink node use a secondary communication network interface to perform such task, like cellular, Ethernet, satellite or any other type of wireless network technology. On the other hand, external updates, command or queries can be delivered to WSN nodes using the sink nodes. However, in specific cases, network can be organized by the sink nodes by maintaining state track of the nodes and managing the address assignation process, or by acting as the maintenance procedures initiators.

The gross majority in the network nodes are considered regular nodes which are responsible for collecting all the data related to predefined variables that required to be observed before forwarding it to the sink node. However, regular network nodes cannot connect directly with the sink node in the case of large and widely spread network. So, these regular nodes have to communicate in a multi-hop manner to forward collected data toward sink node. By multi-hop communication approach even the farthest nodes has the ability to forward their collected data to the sink node. Because of the critical responsibilities assigned to the sink node, it is often have equipped with higher resources capabilities, when compared to the regular nodes, including processing unit, memory chips and, of course larger energy batteries or resources. So, if there is a probability that regular node fail, the sink nodes are not expected to.

The domain of WSNs application has been limited to reporting applications or simple data monitoring related, due to limited resources of current network nodes in WSN technology. New architectures for WSN with different and new advances in applications technology of WSNs has been considered which includes multiple advanced functions like multimedia data handling.

However, recently, among all the nodes constraints that are considered in majority available wireless sensor devices, power consumption is considered the most critical one. This importance can be due to the following two main reasons. The first reason is that each single wireless node has a limited power resource, which is designed to provide node with required power for several months. The second reason is related to the location of the network where it is deployed in an inaccessible environment which making the process of replacing depleted batteries is not feasible. So the wireless node has to consume limited amount of energy in efficient manner. These two reasons are the main motivation for this WSNs research which is concentrated on the design of reliable topology control mechnism and energy efficient protocols and algorithms. This increasing motivation for all WSN researchers can be measured in term of large number of techniques, protocols and algorithms which has been proposed to provide efficient power consumption in all of the processes related to WSN working mechanism which also can reuslt in maximizing network lifetime. Topology control has been considered as one of the most critical techniques which is utilized to reduce WSNs energy consumption. One of the key objective of recent research related to sensor networks is the protocols and algorithm development which is subject to optimize the set of the severe resource constraints. Power consumption is the main key constraint where the battery cannot be recharged or replaced in sensor devices which are deployed in a hostile area. Topology control, multi-hop communication, exploiting node redundancy, data aggregation, are all some of the standard energy conserving and inbuilt mechanisms which provides a trade-off between throughput and network used in sensor networks. Since the designing, implementing and deploying cost of sensor networks is continually reduces, these types of networks will transcend from research laboratories to everyday human life.

In recent years, the process of tiny and cheap sensors development with efficient processing capabilities and a wireless communication modules has encouraged the WSN technology. The main goal of WSN is to perform several critical tasks including monitoring and tracking by reading collected data sensed using separated sensors. Pre-installed infrastructure is not required for nodes in WSNs where they can be randomly deployed in heterogeneous geographical areas and autonomously run without human interaction.

WSN work based on data-centric behavior and are mainly managed lead by queries started generated by central control unit. The sensor devices that has the required data need to satisfy the pre-defined rules which reply to the generated query by sending back their collected data. Usually, the sensor device collected data is forwarded to a control station or a pre-determined sink node which perform as a super device or an actor. To minimize energy consumption during the data exchange, the sensor device in a sensor network mainly depends on a multi-hop communication behavior instead of direct nodes communication (Murthy & Manoj 2004).

WSNs design challenges and key features can be summarized as follows (Murthy & Manoj 2004):

- Sensor devices are mainly depends on batteries for power supplements so WSN applications has to implement efficient power consumption mechanisms to maximize the network lifetime.
- Node failure and energy depletion are very common in sensor devices, so WSN applications is designed to tolerate failure fault tolerant where it can continue operating whenever any network node is failed.
- WSNs algorithms should be scalable where WSN can include high number of sensor devices running on it.
- Retrieving global network topology information can have high cost in term of power consumption because of high number of sensors. So, WSN algorithms operates over sensor nodes should be able to operate with local data and should be distributed.
- Sensor nodes has to be self-organizing and autonomously operate in order to achieve their mission where WSNs are usually deployed on less geographical areas with no predefined infrastructure where manual human interaction is not possible.

Besides the previously iluustrated key features and challenges, there are also multiple requirements for various types of WSN applications which includes sensor nodes time synchronization, quality of service (QoS), secure communication, real-time communication, localization, data aggregation connectivity and coverage requirements, in-network query evaluation, special protocols for handling mobility and routing. Basically five various types of WSNs are found as shown in Figure 2.4 (Yick et al. 2008):

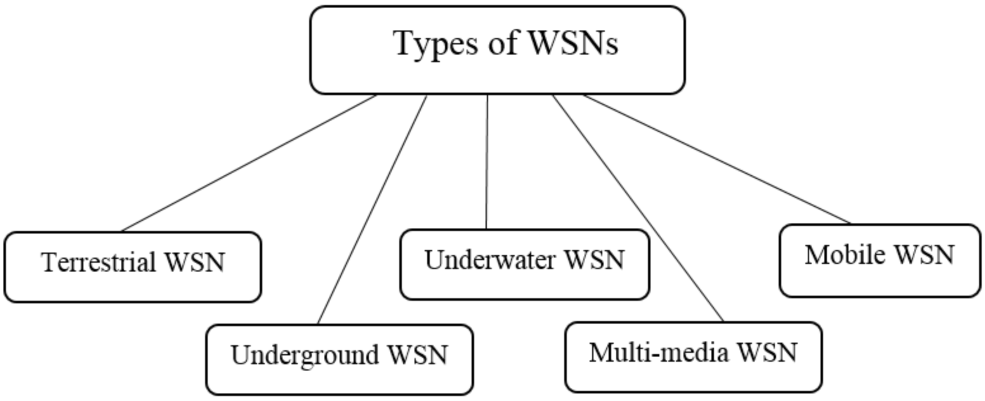

Figure 2.4 Types of WSNs

1. Terrestrial WSN: this type of WSN contains a high number low cost sensor devices. Communication between these high density deployed sensors should be reliable. This type of WSN can be deployed in either random manner or according to pre-defined deployment plan. In case of random deployment, sensors can throw using an airplane in a wide geographical environment.

2. Underground WSN: this type of WNS is used to obtain data from the underground conditions where sensor devices are located inside the soil or even distributed mines or caves. Nodes which are located above the ground main task is to collect data from the sensor devices and forward it toward the central control location. However, WSNs sensors used under the ground are more expensive than to terrestrial WSNs since they designed to tolerate harsh conditions of the underground environment. So specialized components is required to communicate under the circumstances of high signal loss and increased attenuation. On the other hand, these expensive sensors required a predefined planned deployment procedure of sensor devices where redeployment process is not allowed.

3. Underwater WSN: this types of sensros are located under water. However sensors number is much fewer than a terrestrial WSN sensors devices where acoustic waves is used for communication and make it more expensive and not effiecent for dense deployment purposes. Sensor devices data is retrieved by the autonomous underwater vehicles. Main challenging issues for this type of WSNs is high latency and low bandwidth.

4. Multimedia WSN: in this type of WSN, network nodes include microphone and camera. They deployment process is implemented based on a plan to ensure complete coverage of the required location. High energy consumption, high bandwidth, and quality of service are main requirements of multimedia WSNs.

5. Mobile WSN: in this type of networks, sensors devices are mobile where they are capable of moving and repositioning their location at the topology of network. Mobile sensors can change their location based on events area while they are still able to communicate with other network sensors which are location inside the range of communication coverage. In contrast to static sensor networks, mobile networks requires dynamic routing protocols. The main issues of mobile WSN includes navigation, localization connectivity and coverage controlling.

WSNs application areas and examples include the following:

- Military Applications: the purpose of this application varies among battlefield surveillance, border protection, tracking, soldier detection, soldier wearable sensors, anti-submarine, chemical/biological vapor detection and warfare (Bokareva et al. 2006; Đurišić & Tafa 2012; Lim et al. 2010; Ren et al. 2011; Z. Sun et al. 2011).
- Environment Monitoring: this applications perform tasks including animal tracking, volcano eruption monitoring, habitat monitoring, forest fire detection, and pollution detection. (Hefeeda & Bagheri 2007; Mainwaring et al. 2002; Yick et al. 2008).
- Medical Applications: various tasks can be included in this application including monitoring aged people, patient vital sign monitoring and in-field medical large-scale studies (Alemdar & Ersoy 2010; Ko et al. 2010; Milenković et al. 2006; Schwiebert et al. 2001).
- Industry Applications: in industrial fields applications can be built to automate building and factory It can also be used to monitor industrial equipment and factory process monitoring and control underground mine monitoring and offshore oil station monitoring also can be implemented (W. Y. Chang 2008; M. Li & Liu 2009; Paper et al. 2005; Yick et al. 2008).

- Traffic Monitoring: WSN application can be built to predict traffic load, track vehicle routing, and signal dynamic traffic. WSN applications are also the core of the intelligent transportation systems (W. Y. Chang 2008; Paper et al. 2005).
- Rescue and Disaster Relief: WSN application can be deployed to detect of earthquake survivors (S. M. George et al. 2010; Paper et al. 2005; Pogkas et al. 2005).
- Smart Homes: WSN application makes automated smart home and provides energy efficient buildings (Duan et al. 2011; Gomez et al. 2010).

2.2.1 Sensor Node in WSN

Generally, a sensor node is comprised of four components: i) a microcontroller unit (MCU) consisting of a microprocessor and memory or a microcontroller, ii) a radio communication unit, iii) a sensing unit consisting of one or more sensing devices, and iv) a power supply unit (PSU) including batteries and the DC-DC converter. The general architecture of a sensor node is shown in Figure 2.5. The Micro Controller Unit (MCU) controls the sensors, executes the signal processing algorithms on the gathered sensory data and the communication protocols. Intel's Strong ARM microprocessor and Atmel's microcontroller are two commonly used MCUs. Due to the low-cost requirement, the processing power of MCUs is often very low. For example, A Mica2 node uses Atmel AT mega 128L processor running at 4 MHz (Lin et al. 2010). The sensing unit is usually composed of sensors and Analog-to-Digital Converters (ADCs). The ADC is responsible for converting the analog signals generated by sensors to digital signals, which are forwarded to MCU for processing. There are many types of sensors that measure different environmental parameters such as temperature, humidity, and sound. The radio communication unit provides wireless communication capability to sensor nodes. Wireless communication allows sensor nodes to discover and communication with neighboring nodes, and hence form a self-conjurable and functional sensor network. The radio transceiver in the radio communication unit is often very simple. Besides, the maximum transmits power also low. Thus, the data rate of wireless communication is low. For example, the Chip Con CC1000.

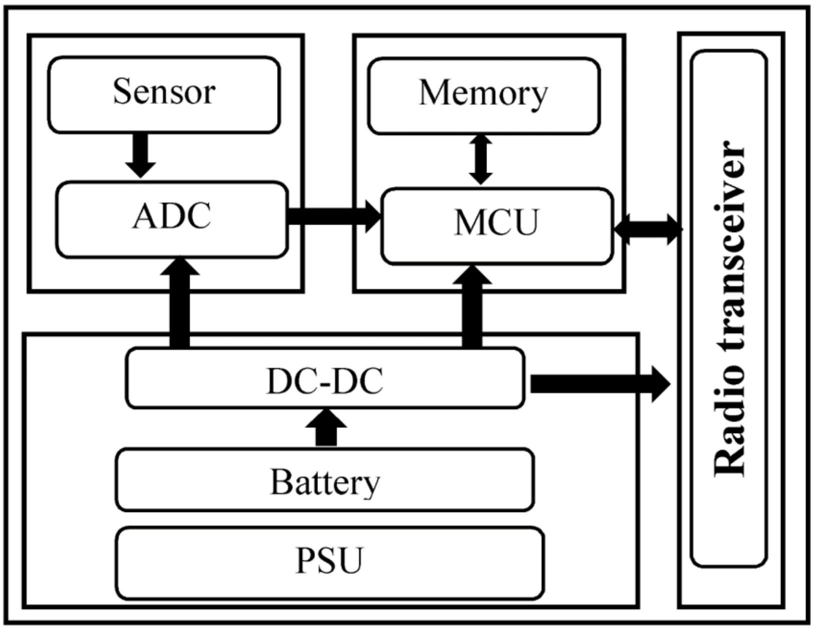

Figure 2.5 The general sensor node architecture

Radio transceiver used in a Mica2 node operates on 300-1000 MHz and has a data rate up to 38.4 kb/s (Erazo et al. 2006)(Erazo et al. 2006).

The Power Supply Unit (PSU) provides energy for the other units and hence is critical to the performance of WSNs. The PSU in most sensor nodes is composed of several batteries and the DC-DC converter. For example, the PSU of a Mica2 node has two AA batteries. In most WSNs, the cost to replace or recharge the batteries of sensor nodes is very high, or it is impossible to replace or recharge them. Thus, energy is a scarce resource in sensor nodes. To prolong the operational lifetime of sensor nodes, the power dissipation of other units should be minimized.

To design energy efficient operations for sensor nodes, the power consumption model of sensor nodes should be investigated (Shnayder et al. 2004). The MCU and the radio transceiver usually dominate the energy consumption of sensor nodes. Thus, energy efficiency should be achieved by designing efficient energy operations for the MCU and the radio transceiver. Both components have active and idle and sleep mode. In the active mode, both components perform certain operations and consume energy fast. A substantial amount of energy is still consumed by the MCU and the radio transceiver during the idle mode, and only in the sleep mode, little energy is consumed.

Therefore, to minimize energy consumption, sensor nodes should be put into sleep mode

To ensure the functionalities of WSN, it is necessary to adopt a set of essential network services in the sensor network. As the data collected by sensor nodes, which are often spatial-temporally related, localization and time synchronization services are required by most WSN applications. Localization determines the physical locations of sensor nodes, which can be used to label the generated data and facilitate the operation of other functions such as routing. Time synchronization synchronizes the clocks of sensor nodes and provides an accurate global clock for the sensor network. This ensures that data collected by sensor nodes have the correct time attribute (Rudafshani & Datta 2007). The most consuming energy for the wireless sensor node is a radio communication and is further aggravated by idle-listening and retransmission of packets for each neighboring node (Santi 2005). Sensor nodes are often densely deployed. Besides, they often collaborate with each other to perform certain tasks. Thus, TC is vital for WSN.

2.2.2 Node Architecture

A sensor node performs operations such as detecting data, storing data, analyzing data, processing data, and transmitting data. It communicates with its neighboring sensors and the base station. A typical sensor node is composed of five units as depicted in Figure 2.6, such as memory, communication device, controller, power supply, and sensors actuators. Sensors are used to detect the changes in the surroundings. Memory is used to store the data. Consequently, that is processed by a controller that works on the arbitrary code (Erazo et al. 2006).

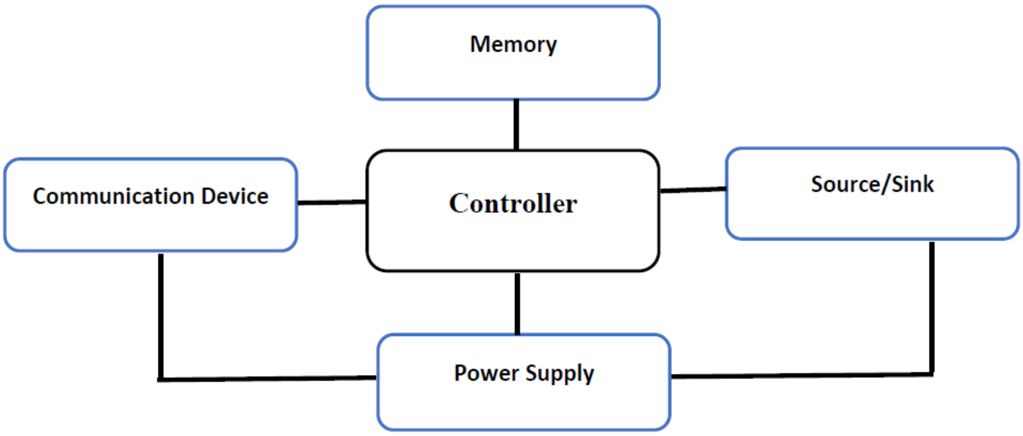

Figure 2.6 Sensor Node Architecture (Erazo et al. 2006)

Communicating device consists of a transceiver to send and receive data, and finally, a power supply consists of AA battery to provide external power to the node. All the above components need to work efficiently considering tradeoffs of each in order to consume minimal energy. The most commonly used microcontrollers are the Atmel processor and the Intel Armstrong processor. However recently Mica2 and Mica Z motes are used in WSNs as they are more appropriate for large scale deployment of WSNs and have a transmission range of 500 feet. In addition to this they have a battery lifetime of 7 years (Erazo et al. 2006).

For actual communication, a sensor node must consist of a transmitter and a receiver to send and receive data. This can be done by using a transceiver on the sensor node. Typically WSNs transceiver operates in 915MHz or 2.4GHz band i.e. Industrial Scientific Medical (ISM) band. A transceiver should have the capability to convert bit stream data (data in binary or frames) to radio waves. Hence the half duplex model is usually preferable for WSNs communication. Transceiver consists of circuitry for modulation, demodulation, filters, mixers and amplification.

2.3 TOPOLOGY CONTROL IN WSN

Topology control (TC) refers to the mechanism which specifies how network nodes are exchange data depending on the transmission range. TC can be used to reduce the consumption of node energy and increase network capacity (Shnayder et al. 2004). So, the main objectives of deploying TC are to:

- Increase the capacity of the network.

- Reduce energy consumption.

2.3.1 Definition TC in WSN

TC referred to as the reconfiguring process of the network topology using tunable parameters after deployment. Three main tunable parameters for TC in WSN can be configured: as follows

• The mobility of the Node: In mobile nodes WSNs, like robotics sensor networks, node mobility adapt both coverage and connectivity accordingly.

• Transmission power management: In static nodes WSNs, if the density of the nodes deployment is already sufficient to provide the required coverage level, adjusting the constituent nodes transmission power can be done by assigning network connectivity properties.

• Sleeping scheduling: In large scale networks, static WSNs nodes are deployed at a high density. In this situation, network life time extending and energy efficiency are the main requirements of the appropriate TC mechanism. Turning off redundant nodes is an example.

TC is considered as one of the main mechanism for handling wireless ad hoc and sensor networks to minimize energy consumption and radio interference which result in maximizing network lifetime and increase network traffic carrying capacity. TC is the process of configuring or reconfiguring a network's topology through tunable parameters after deployment. (Karl & Willig 2005) Let V referred to the group of wireless sensor nodes where G (V, E) is a subgraph on V that includes all network edges in the case of each network node transmits with the maximum available transmission power. The edge group E of G is built where a directed edge is exist from u to v in the case where only u can connect to v by utilizing its maximum available transmission power. Graph G assigned an upper limit on the maximum number of connections which a wireless network can include. The TC mechanism construct a topology T constructed from G, where T is a subgraph of G on V. (Karl & Willig 2005) A WSN have to meet the following connectivity requirement: if there is a path from u to v in G then there is also a path from u to v in T for any pair of nodes u and v. (Karl & Willig 2005) or can we Definition : TC, as defined in (Santi 2005), is the technique of coordinating nodes' decisions regarding their transmission power levels in order to generate a network backbone which aims to maintain a certain connectivity level k of the network while simultaneously reducing the overall network energy consumption. Simply put, given a maximum power communication graph G-max = (V, E max) (A communication graph or simply a graph G is an ordered pair of a set of vertices V and a set of edges E, i.e. G = (V, E). A graph is analogous to a network topology which consists of a set of nodes and the associated set of communication links between the nodes), in which the transmitting power of the nodes is set to the maximum allowable level, and whose network connectivity K (G max) ≥ k (a more formal definition of network connectivity is given in Section 4.2), the aim of TC is to generate a spanning subgraph, G = (V, E) of the maximum power communication graph, with nodes now transmitting at reduced power levels, such that E ⊆ and K(G) = k, i.e. G contains as few edges as possible while still ensuring the desired connectivity level k. In other words, G is a sparse representation of the maximum power communication graph that, at the same time, preserves the network connectivity.

A recent survey (Fitzpatrick et al. 2013) however, provides a broader definition of TC. It refers to TC as any technique that uses a controlled network parameter to reduce energy consumption and maintain the desired network properties. The controlled network parameters include the transmission power, the operating power mode of the sensor nodes (such as sleep, idle or active) and the node role (such as cluster head or sensing node in clustering based protocols).

The WSN topology defines the connectivity of nodes belong to a wireless network and deeply affect the network applied routing algorithms. Topology also impact other critical network features including nodes communication cost and resiliency. Efficient network energy utilization has been established in recent research as one of the major research issues in the field of WSNs. Network topology controlling has been emerged as an efficient solution to this problem. TC protocols, like all other research topics of WSNs, include designing and implementation mechanism which is subjected to a severe set of energy and computational constraints.

The sensor node radio used for data transmission consume the biggest part of power. All of radio four phases of states including transmission, reception listening, and idle states consumes power. However, WSNs should be primarily evaluated in terms of energy depletion of sensor nodes when it is compared to wireless ad-hoc networks and traditional wired.

Sensor nodes equipped with non-renewable and limited power sources. When these sources is deployed, battery of a sensor node is rarely recharged or replaced especially when it is located in a hostile area. These limitation result in considering energy conservation metric as primary objectives. One of most efficient ways for energy consumption optimizing in WSN is to select a reliable approach to selectively turn off the sensor nodes radio depending on the alternate routing paths availability. Turnning off the sensor nodes radio is only permitted when the network topology is configured in specific manner to prevent network partitioning due to inactive nodes. So, efficient topology controlling of the network has been presented as a reliable solution to the problem of WSNs radio energy dissipation.

TC algorithms are designed to utilize the network high sensors density to maximize the network lifetime and maintain connectivity. The following criteria have been proposed as the main designing TC protocols concepts for WSNs.

1- To accommodate frequent network changing, Sensor nodes must be self-configure in term of mobility, and the node energy.

2- Redundant nodes selection process mainly depends on distributed localized algorithms.

3- Minimum network connectivity must be ensured in TC protocols to prevent network partitioning.

4- In large-scale WSNs, TC protocols utilize the high node density to reduce the network energy dissipation.

The main objectives of TC is to update the maximum power topology when network is initialized and prevent the previously mentioned problems occurrence which has a critical impact on the power consumption by updating the networks topology. However, important networks characteristics including connectivity and coverage are kept.

TC is not critical in the case where network administrator wants to use predesign topology to guarantee network optimality. The optimal topology solution can be calculated off-line and replicated in reality. However, this kind of solution should consider the characteristics of the radio spectrum, the terrain and other variables which reflects on the actual communication among nodes when they are deployed. However, these information is difficult to obtain in some cases. The manual deployment, the permanent testing, and the large possible combinations number which required to generate a successful output may add extra time for the whole deployment process.

The deployments process is performed based on random topologies and the nodes location is fixed or not even defined. In such scenario, two variables are still can be used by the user for topology reorganizing: the nodes activity state of both active or inactive state and the transmission power of the node radio.

The activity node state is the first variable whether active or inactive to provide the user with the ability to minimize the active nodes number which can impact the networks density in specific areas, minimizing interference and the redundant data generation. To achieve very low energy consumption mode, inactive nodes switch off their radio transceivers. However, it can switch on it again to come back as an active part of network when it is required.

The second variable is the radio transmission power which impacts energy consumption directly in addition to the interference level. Radio transmission is the most expensive operation and mostly common for energy. So, required energy reduction for message transmitting represent a critical power savings.

The random topology advantage is that the nodes deployment process can be achieved relatively quickly, and immediately the network may become available. In addition, to take care of the characteristics of the deployment area, TC algorithm must be robust. On the other hand, the main disadvantage of random deployment is that excessive nodes number is required in order to maximize the probability of having nodes in most of the monitored area region, which impact directly the network cost.

In general, TC can be seen as an iterative process (Fitzpatrick et al. 2013). First, there is an initialization phase common to all WSN deployments. “TC is the reorganization and management from time to time of certain node parameters and modes of operation to modify the topology of the network, with the goal of extending its lifetime while also preserving important characteristics, such as network connectivity and sensing coverage.” (Fitzpatrick et al. 2013).

1- At initialization phase the nodes obtain their own status and exploit the maximum transmission power of radio to initialize the topology structure. In the second phase, which referred to as Topology Construction, a new reduced topology is built. This new reduced topology will run for a specific duration where the participating sensors over time will consume their stored energy. Therefore, Topology Maintenance phase has to start working immediately after the topology construction phase complete the phase of the reduced network building.

2-The during algorithm must be in place to monitor the status of the reduced topology and trigger a topology restoration process when appropriate. That may be a process entirely defined by the maintenance protocol itself, or that may include the invocation of the topology construction algorithm, over the lifetime of the network.

2.3.2 Taxonomy of Existing TC

In WSNs, in most cases, nodes deployment process is performed automatically without human interaction. It is not done manually, and so a predefined network topology is required. After the deployment to the application environment, the network topology is built autonomously by the network sensors interactions. Therefore, a reliable TC mechanism is required to construct and maintain the topology of the network. On the other hand, WSNs topology is vulnerable to dynamic change including communication link failure, nodes energy depletion, and nodes mobility due to various reasons. TC protocols are very vital for WSNs topology construction in order to maintain the network connected as far as possible and maximize both network throughput and network lifetime.

TC works on controlling the group of sensors neighbors in a WSN by choosing suitable nodes to forward the data to (Y. Li et al. 2008). TC mechanisms can be categorized into two main kinds, homogeneous and nonhomogeneous (Santi 2005). In the first kind, which is homogeneous approaches, all sensor transmission range are identical. However in the kind of nonhomogeneous approaches, sensors can work on various transmission ranges.

Proposed TC approaches can be distinguished depending on the network type which topology has been built to work with. Most TC mechanisms work on flat topologies whereas however fewer TC mechanisms work on heterogeneous topologies where different types of nodes are used to build the network.

There are many TC mechanisms in the literature, and used techniques can be categorized based on it . Many TC methods are (Blough et al. 2003; Mihaela Cardei et al. 2008; J. C. J. C. Hou et al. 2004; Kubisch et al. 2003; L. Li et al. 2001; L. E. Li et al. 2005; N. Li & Hou 2006; Ning Li et al. 2005; Ning Li & Hou 2004; Zhu et al. 2013)constructed on the adjustment technique of the transmitting power which depends on the self-transmit power controlling sensors. Some algorithms (Blough et al. 2003; Chen & Son 2005; Kumar et al. 2008; Hua & Yum 2007; Baryshnikov et al. 2008) utilize the concept of sleeping scheduling which focus on decreasing the consumption of energy for sensors which are in idle state. On the other hand other researchers use the geometrical structures including both direction and location information. Clustering approaches combined a set of the previously mentioned mechanism (Ning Li et al. 2005; B. R. Szewczyk et al. 2006; Xiang-Yang Li et al. 2004; Younis et al. 2004). (Santi 2005) says that approaches that do not update the nodes transmitting power cannot be categorized as TC mechanisms. They adopt a more inclusive TC definition given by (Y. Li et al. 2008) that is managing a group of neighbors by specifying transmission range and/or choosing specific devices to forward their data. Neighbor's selection mainly depends on the approach of TC that is defined to fit a certain scenario requirements.

Another mechanism of TC utilize clustering on organizing the wireless network into a connected hierarchy. The main purpose if this approach is to balance the load between the network nodes and maximize network lifetime (Younis et al. 2006). Hierarchical clustering techniques (Banerjee & Khuller 2001; Mamidisetty et al. 2012) choose the head of each cluster on the basis of different criteria and establishes a layered architecture.

However, these mechanism begin with a flat topology type and end up with a layered topology. On the other hand, at the beginning, researchers work on layered architecture, where the master nodes are already specified. Focusing on maintaining fault-tolerant connectivity between sensor nodes and master nodes instead of building clusters. A taxonomy of existing TC approaches is illustrated in Figure 2.7 (Santi 2005) groups the TC mechanisms as follows: