IMPROVING ON THE NETWORK LIFETIME OF CLUSTERED-BASED WIRELESS SENSOR NETWORK USING MODIFIED LEACH ALGORITHM

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ABSTRACT

Wireless sensor networks (WSNs) composed from a large number of sensor node with the ability to sense and process data in the physical world in a timely manner. The sensor nodes contain a battery constraint which limit the network lifetime. Due to energy constraints, the deployment of WSNs will required advance techniques to maintain the network lifetime. A clustering based routing algorithm called Low-Energy Adaptive Clustering Hierarchy (LEACH) was proposed as a solution for low power consumption. This document is a study about LEACH algorithm where the implementation was done using OMNeT++ network simulator to study the performance of this algorithm in term of network lifetime. OMNeT++ was selected as a simulator because it provides some important features for this project like very good scalability unlike other simulators do. During this study, LEACH algorithm shows some drawbacks that need an improvements to overcome it as to improve the performance. Then, the modified LEACH algorithm was proposed where the improvement was done in cluster head selection based on LEACH. In cluster head selection, modified LEACH taking into account the residual energy of each node for calculation of the threshold value for next round. Meanwhile in LEACH, the cluster head selection was based on distributed algorithm. Both of these protocols was implemented in network simulator to compare the performance. This study shows that there were a better performance achieved by modified LEACH depends on the results obtained.

ABSTRAK

Rangkaian sensor tanpa wayar terdiri daripada sejumlah besar nod sensor dengan kebolehan untuk mengesan data dalam dunia fizikal tepat pada masanya. Nod sensor dikuasakan oleh bateri yang menyebabkan terdapat had untuk jangka hayat rangkaian. Disebabkan oleh masalah tenaga, penempatan rangkaian sensor tanpa wayar ini memerlukan teknik yang baik bagi mengekalkan jangka hayat rangkaian. Protokol yang berasaskan kepada algoritma kelompok yang dikenali sebagai Low-Energy Adaptive Clustering Hierarchy (LEACH) telah diperkenalkan sebagai penyelesaian untuk penggunaan tenaga yang rendah. Dokumen ini ialah kajian mengenai algoritma LEACH di mana perlaksanaannya di lakukan dengan menggunakan simulator rangkain OMNeT++ untuk mengkaji prestasi algoritma ini dalam bentuk jangka hayat rangkaian. OMNeT++ dipilih sebagai simulator kerana ia menyediakan ciri-ciri yang penting untuk projek ini seperti skalabiliti yang baik tidak seperti simulator yang lain. Dalam perlaksanaan kajian ini, algoritma LEACH menunjukkan beberapa kelemahan yang memerlukan penambahbaikan untuk mengatasinya serta meningkatkan prestasinya. Kemudian, LEACH yang diubahsuai telah diperkenalkan dimana penambahbaikan telah dilaksanakan dari segi pemilihan ketua kelompok yang berdasarkan kepada LEACH. Dalam pemilihan ketua kelompok, LEACH yang di ubahsuai mengambil kira baki tenaga setiap nod untuk pengiraan nilai ambang untuk kitaran berikutnya. Sementara dalam LEACH, pemilihan ketua berdasarkan kepada algoritma pembahagian. Kedua-dua protokol telah dilaksanakan dalam simulator rangkaian untuk membandingkan prestasinya. Kajian menunjukkan prestasi yang baik dicapai oleh LEACH yang di ubahsuai berdasarkan keputusan yang diperolehi.

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LIST OF SYMBOLS AND ABBREVIATIONS

WSNs	-	Wireless Sensor Networks
CHs	-	Cluster Heads
BS	-	Base Station
LEACH	-	Low-Energy Adaptive Clustering Hierarchy
TDMA	-	Time Division Multiple Access
CSMA	-	Carrier Sense Multiple Access
MAC	-	Medium Access Control
OSI	-	Open System Intercopnnection
TCP/IP	-	Transmission Control Protocol/ Internet Protocol
FND	-	First node dead
HND	-	Half node dead
p	-	Desired percentage of cluster head
r	-	Current round
k	-	Number of cluster
$T(n)$	-	Threshold value for cluster head selection
n	-	Number of nodes
G	-	Number of node that not yet become cluster head
$E_{residual}$	-	Node residual energy
E_{total}	-	Network total residual energy
E_{TXelec}	-	Transmit energy consumption
E_{RXelec}	-	Received energy consumption
E_{amp}	-	Amplifier energy consumption

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Wireless Sensor Networks (WSNs) are widely used to create a smart environment that relies on sensory data from real world. The application of wireless sensor networks provides an enormous wirelessly connected infrastucture facilitating the function of monitoring a physical and enviromental conditions, such as temperature, sound, vibration, pressure, humidity, acidity, motion and pollutants. The advent of smart environments relies heavily on sensor network for data acquisition and dissemination whether in building, shipboard, intelligent transportation system, habitat monitoring, healthcare monitoring, home automation, traffic control, or elsewhere (Lewis F. , 2004) (Ali, Abdulmaowjod, & Mohammed, 2011). A smart sensor used in WSNs is a combination of sensing, processing and communication technologies.

The basic architecture of smart sensor is shown in Figure 1.1 Sensing unit is used to detect the changes of parameters in the network, signal conditioning responsible for smoothing the analog electrical signal before it is converted to digital domain. The resultant digital signal is used as the input to the application algorithm or processing unit and then cached in the memory. The transceiver is used to communicate with other sensors or base station (BS) which may act as an internet gateway in WSN (Ali, Abdulmaowjod, & Mohammed, 2011).

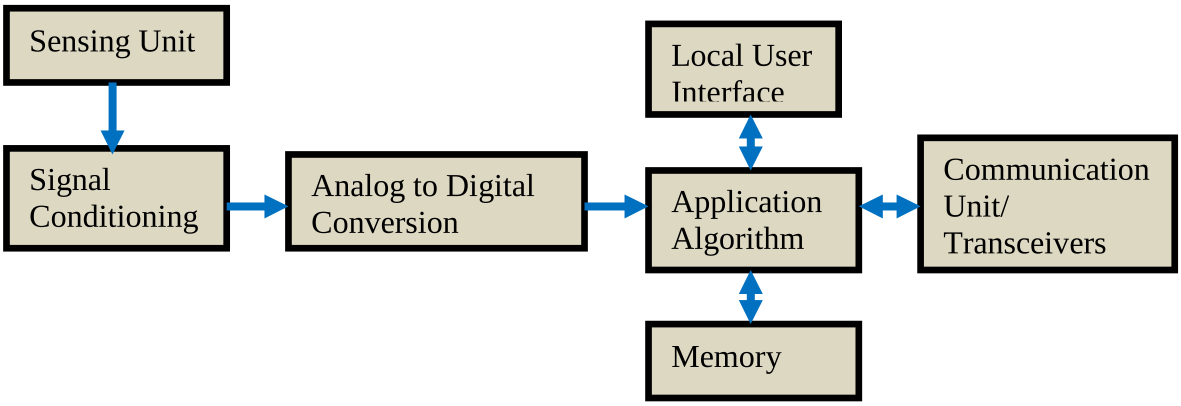


Figure 1.1: Smart sensor architecture

(Dietrich & Dressler, 2009) stated in their study stated that network lifetime is a key characteristic to evaluate a sensor network. The effectiveness of WSNs depends on the functionality of all sensors in the network. If the sensor node is active, it proceeds to perform a duty to sense, communicate and process information (temperature, humidity etc). There are two major factors that affect the network lifetime: how much energy it consumes over time and how much energy is available for the particular node. The proposed technique to deal with network lifetime called clustering, which is an important method. Additionally, a good performance WSNs is highly dependent on energy-efficient clustering routing algorithm (Liu, et al., 2010). The development involve a clustering-based hierarchy protocol that optimizes the energy-efficiency in WSNs is called Low-Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman, Chandrakasan, & Balakrishnan, 2000).

1.2 Description

The aim of this thesis is a research about the network lifetime of WSNs. Using an appropriate algorithm in routing protocol, power consumption can be achieved. The research presented in this thesis focussed on the implementation of Low-Energy Adaptive Clustering Hierarchy (LEACH) algorithm within the WSNs routing protocol, in which original work and was introduced by (Heinzelman, Chandrakasan,

& Balakrishnan, 2000). Although LEACH algorithm provides an improvement in the network lifetime for WSNs, there are still areas that need to be developed so that more energy can be conserved. There are many researches that were conducted based on LEACH algorithm for example Energy LEACH (E-LEACH) (Xiangning & Yulin, 2007), Two-Layer LEACH (TL-LEACH) (Loscri, Morabito, & Marano, 2005), Centralize LEACH (C-LEACH) (Heinzelman, Chandrakasan, & Balakrishnan, 2002) and V-LEACH (Yassein, Al-zou'bi, Khamayseh, & Mardini, 2009).

In this thesis, some modifications were introduced based on LEACH algorithm and various performance comparisons were made to illustrate the improvements of this algorithm. Common features were maintained in the simulated network which were already present in the majority of the up-to-date WSN implementations. Furthermore, advanced features and parameters will be analyzed in order to obtain an energy consumption improvement. Therefore, it is essential to analyze and study the original LEACH algorithm through reviewing the literatures, building the simulation test-bed and performing the simulation on the existing algorithms. After that, the modification of LEACH will be implemented in the simulation test-bed and the most used simulation environments will be evaluated and analyzed.

1.2.1 Wireless sensor networks

According to definition given in (Sohraby, Minollil, & Znati, 2007),“A wireless sensor networks (WSNs) consists of densely distributed nodes that support sensing, signal processing, embedded computing, and wireless connectivity; sensors are logically linked by self-organizing means. WSN typically transmit information to collecting (monitoring) stations that aggregate some or all of the information. WSN have unique characteristics, such as, but not limited to, power constraints and limited battery life for the WNs, redundant data acquisition, low duty cycle, and, many-to-one flows.” Although the development of this kind of networks was initially for military applications, but nowadays they are used in many different industrial and civilian application areas, including industrial process monitoring and control, healthcare applications or traffic control. WSNs are composed of a set of sensor nodes, typically equipped with some sensors, a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery. Therefore, these devices make up a network with sensing, data processing and routing capabilities.

1.2.2 Advantages of wireless sensor networks

Knowing about the advantages of WSNs, it is enough to be conscious of the wide variety of applications where WSNs are present. Typically, WSNs applications involved in some kind of monitoring, tracking, or controlling. Some of the numerous applications and the benefits that WSNs bring are:

i. **Environmental Monitoring:** watershed management, forest fire prediction or irrigation management. It helps to preserve and maintain the natural resources.

ii. **Structural Health and Industrial Monitoring:** machinery failure detection. It reduces the maintenance costs and prevents from catastrophic failures.

iii. **Civil Structure Monitoring:** health monitoring of large civil structures, like bridges or skyscrapers. It prevents from human catastrophes.

iv. **Medical Health-care:** telemedicine, remote health monitoring. Allows doctors in remote and rural areas to consult with specialists in urban areas, remote handling of medical equipment (tele-surgery), etc.

1.2.3 Drawbacks of wireless sensor networks

Although WSNs offer many advantages in a numerous application, there are several constraints which will affect directly the networks and devices’ design. Some of the most significant constraints are:

i. **Power consumption**: this constraint affects directly on the nodes' operating lifetime. With energy-aware and transmitting power adjusting capacity protocols, the energy consumption can be highly reduced, and thus increased the network lifetime.

ii. **Self-configuration capability and good scalability**: this issue can be solved by choosing and implementing the suitable network protocol.

iii. **Fault tolerance**: if all the devices process the same signal (temperature, humidity, etc.), the network will offer replication in a native manner. If the devices do not develop the same function, the device replication can solve the fault tolerance problem, and this solution shouldn't affect the scalability due to the nature of the network.

This thesis proposed a mechanism to will counter the first drawback of WSNs which is the power consumption by designing and implementing the appropriate algorithm in a routing protocol.

1.3 Objectives

The main objectives of this thesis are:

i. To implement and simulate a wireless sensor networks (WSNs) using OMNeT++ network simulator.

ii. To implement a modified LEACH algorithm that solves the energy consumption problem in wireless sensor networks.

iii. To compare and evaluate the performance of the LEACH and modified LEACH in term of network lifetime.

1.4 Thesis Outline

As an introduction (Chapter 1), the motivation of the research and general description on WSNs including the advantages and drawbacks are presented in this chapter. Objectives of the research are also included as a guideline to complete this research.

Chapter 2 desribed the previous works of other researchers. The work on WSNs including the MAC protocol and the classification of WSNs are discussed in this chapter. Additionally, a comparison between various routing protocol are elaborated and the rationale for implementing LEACH protocol also identified.

Chapter 3 compare a number of network simulator that available to implement the proposed algorithm. An explanation of OMNeT++ simulator step by step done starting form building a network until running the simulation.

Chapter 4 explains abaout the implementation of LEACH algorithm and modified LEACH algorithm in OMNeT++ network simulator. Besides, the details abaout the algorithm are also included.

Chapter 5 is about the analysis and evaluation of results from the simulation. In the first section, the parameters for the simulation is explains. Second section is about the analysis of first node dead and half node dead to determine the improvement of network lifetime.

Chapter 6 concluded the thesis and proposed some areas for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

WSNs are increasingly deployed in a variety of applications, initially for military application and currently used in monitoring of medical conditions inside human body, monitoring the climate change and also used in reporting the mechanical stresses in building and bridges. A standard WSNs consists of a set of sensors that communicates to the external world via BS or sink. The sensors are autonomous small devices with several constraints like the battery power, computation capacity, communication range and memory. They include transceivers to gather information from its environment and pass it on up to a certain base station, where the measured parameters can be stored and available for the end user. Sensor networks are also energy constrained since the individual sensors, which the network is formed with, are extremely energy-constrained as well. The communication devices on these sensors are small and have limited power and range.

2.2 A wireless sensor network model

WSNs consist of a set of many sensors with sensing, wireless communication and computation capabilities. These sensors are scattered in the preserved environment and located far from users. The architecture of WSNs includes three entities as in (Karl & Willig, 2005). There are:

- Sensors which make up the network: its function is based on taking local measures through a discrete system, creating a wireless network in an unattended environment, gathering data and sending them to the final user through the BS.
- Base station or gateway node: it is located near the sensor field. The data or information gathered by the sensor field is sent to the base station through a multihop infraestructureless architecture, which communicates with the user via Internet or satellite communication.
- User: it is the entity interested in obtaining the information about a specific phenomenon by means of measuring or monitoring the environment.

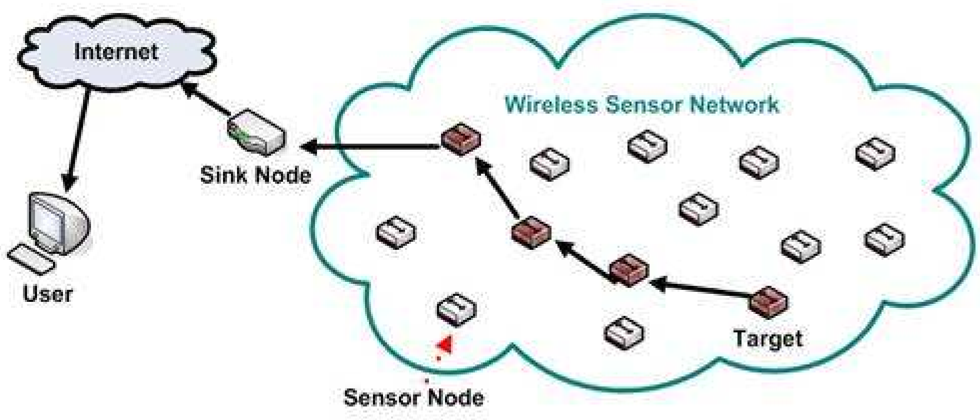


Figure 2.1: Wireless sensor network architecture

2.2.1 Protocol architecture

Protocol architecture is the layered structure of hardware and software that support the exchange of data between two systems. When communication is desired among computers from different vendors, the data must be transmit in the specific format because different vendors use different data format and data exchange protocols. The key fucntions normally performed by a protocol include encapsulation, segmentation and reassembly, connection control, ordered delivery, flow control, error control, addressing and multiplexing. There are two protocol architecture have served as the basis for the protocol standards which is TCP/IP and OSI model (Stalling, 2004). Figure 2.2 indicates the different between TCP/IP and OSI model.

<table>
<tr><th>TCP/IP</th><th>OSI</th></tr>
<tr><td rowspan="3">Application</td><td>Application</td></tr>
<tr><td>Presentation</td></tr>
<tr><td rowspan="2">Session</td></tr>
<tr><td rowspan="2">Transport (host-to-host)</td></tr>
<tr><td>Transport</td></tr>
<tr><td>Internet</td><td rowspan="2">Network</td></tr>
<tr><td rowspan="2">Network Access</td></tr>
<tr><td>Data Link</td></tr>
<tr><td>Physical</td><td>Physical</td></tr>
</table>

Figure 2.2: A comparison of the OSI and TCP/IP protocol architecture

2.2.1.1 OSI model

OSI model was developed by ISO which would allowed the exchange of data between various platform of different vendors. It has seven layers where each layer perform a certain internetworking function. The function of each layer described as follows:

i. **Physical Layer**: Transmits the bit stream over the physical medium.
ii. **Data Link Layer**: Provide reliable transfer of information.
iii. **Network Layer**: Provides transmission & switching technologies.
iv. **Transport Layer**: End-to-end error recovery and flow control.
v. **Session Layer**: Establishes, manages & terminates connections.
vi. **Presentation Layer**: Represent the data.
vii. **Application Layer**: Provides access to the OSI environment for users.

2.2.1.2 TCP/IP protocol architecture

The TCP/IP model organizes the communication task into five relatively independent layers:

i. **Physical Layer**: Physical interface between a data transmission device (e.g. computer) and a transmission medium or network. This layer concerned with the characteristics of transmission medium, signal level and data rates.
ii. **Network Access Layer**: Perform the data exchange between an end system. The destination address provision so thet the network can send the data to the appropriate destination.
iii. **Internet Layer**: Provides the routing function across multiple networks. This function uimplemented in the end system and routers.
iv. **Transport Layer**: This layer corcerned on end-to-end data transfer. The Transmission Control Protocol (TCP) is the most commonly used protocol to performed this functonality.
v. **Application Layer**: Support user application for example http, smtp and fttp.

2.2.2 MAC protocol

The MAC layer is a sublayer of the data link layer and it is used in networks where multiple machines need to communicate via a single communication channel. MAC layer must be energy-efficient to improve the network lifetime which become the main objectives of current research and study. In (Ye, Heidemann, & Estrin, 2001), there are several causes of energy waste corcerning MAC layer. There are are collisions, overhearing, control packet overhead, idle listening and overemitting.

Collisions consist on the reception of more than one packet at the same time which resulted in packets being dropped and retransmission was initiated. Overhearing occurs when a node receives packets destined to other nodes. The control packet overhead or the number of control packets should be minimized as far as possible in a data transmission. Idle listening is produced when a node listens to an idle channel to receive possible traffic. On the other hand, overemitting is caused by the transmission of a message when the destination node is not ready. A correctly-designed MAC protocol should avoid these facts in order to obtain the best performance and minimum energy consumption.

A survey done by (Demirkol, 2006) presented the advantages and disadvantages of several MAC protocols. These protocols are:

i. Sensor-MAC (S-MAC)

The basic idea of this MAC protocol consists on locally managed synchronizations and periodic sleep listen schedules based on these synchronizations. Nodes sleep and wake up periodically introducing the term of duty cycle. This MAC protocol shows a disadvantages when two neighbor nodes reside in two different virtual clusters which set up a common sleep schedule, they wake up at listen periods of both clusters.

Schedule exchanges are accomplished by periodical SYNC packet broadcasts to immediate neighbors. The period for each node to send a SYNC packet is called the synchronization period. A sample of sender-receiver communication is shown in Figure 2.3. Collision avoidance is achieved by a carrier sense, RTS/CTS packet exchanges prevent from the hidden node problem, and adaptative listening can be used in order to reduce the sleep relay and thus the overall latency.

The advantages of this MAC protocol, includes the implementation simplicity and its reduced energy consumption through sleep schedules. Besides, there are another disadvantages which are the increment of collision probability when broadcasting does not use RTS/CTS, the efficiency loss with its constant and predefined sleep and listen periods, overhearing and idle listening problems.

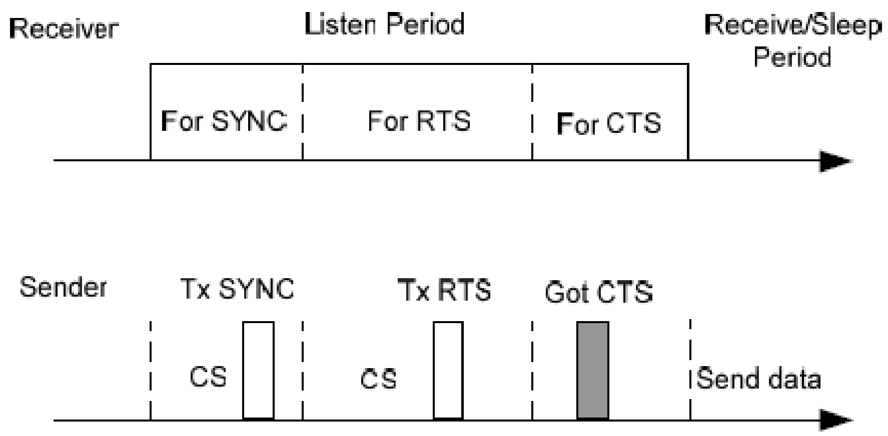


Figure 2.3: SMAC messaging scenario (Ye, Heidemann, & Estrin, 2001)

ii. Wireless sensor MAC (WiseMAC)

This protocol is spatial TDMA and CDMA with preamble sampling technique. Data channel is accessed with TDMA method, whereas the control channel is accessed with CSMA method. All network nodes sample with a common media period, but using independent relative schedule offsets. They initialize the preamble with the same sampling period's length. During the protocol's use, after waking and sampling the media when a node reaches an it's occupied, stays hearing until receives a packet or finds free the media. This protocol has overemitting problems when after the preamble due to reason like interference, the receiver is not available. WiseMAC offers a method to dynamically determine the length of the preamble to reduce the power consumption. That method uses the knowledge of the sleep schedules of the transmitter node's direct neighbors. The drawbacks of wiseMAC is the difficult of broadcast communication due to the decentralized duty cycle planning and the hidden terminal problem apparition are the main inconvenients. Figure 2.4 shows the wiseMAC concept.

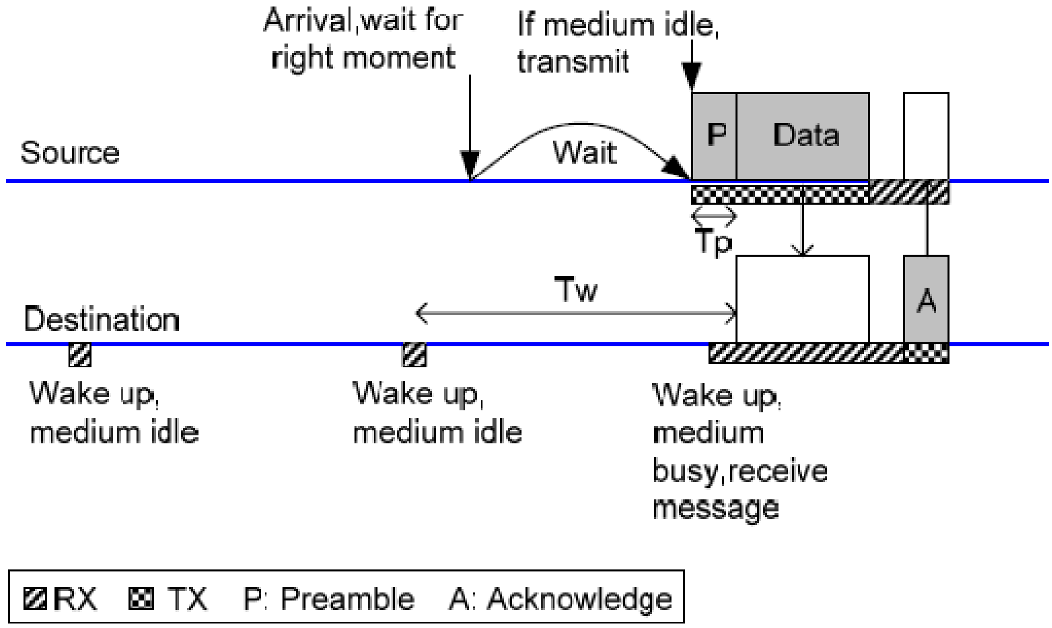


Figure 2.4: WiseMAC concept (Demirkol, 2006)

iii. Traffic-Adaptive MAC Protocol (TRAMA)

TRAMA is a TDMA-based algorithm and proposed to increase the utilization of classical TDMA in an energy-efficient manner (Demirkol, 2006). In TRAMA protocol, a distributed election algorithm is used in order to select a sender inside a two-hop neighborhood. By means of this mechanism, the hidden terminal problem is eliminated and nodes inside the onehop neighborhood guarantee no collision packets will be received. In this registry, time is divided in two different transmission periods which are random-access periods, where two-hop topology information through contention-based channel access, and scheduled-access. In these last ones, slots which will be used by nodes are announced by a schedule packet and the bitmap message scheduled receivers.

The advantages of TRAMA is higher percentage of sleep time and less collision probability is achieved compared to CSMA based protocols. Meanwhile a disadvantages is transmission slots are set to be seven times longer than the random access period. Even so, TRAMA duty cycle is at least of 12.5%, a considerable high value.

iv. SIFT

This protocol is proposed for event-driven sensor network environment (Demirkol, 2006). The main idea of this protocol is when an event is sensed, the first R of N potential reports is the most crucial part of messaging and has to be relayed with low latency. SIFT uses a non-uniform probability distribution function. This function helps to the slot acquisition within the slotted contention window: if nodes don't transmit on the first window slot, all nodes increment exponentially its transmission probability on the next slot considering limited the number of competitors.

One of advantages in this MAC protocol is very low latency is achieved with many traffic sources. This parameter can be set properly to the environment requirements. Thus, it could be possible to obtain a power consumption decrement losing some features as low latency when network life time is the main objective. One of the main drawbacks is increased idle listening caused by listening to all slots before sending as well as overhearing.

v. DMAC

The purpose of this protocol is to achieve very low latency, but still to be energy efficient. This protocol makes use of a convergecast communication pattern within sensor network where unidirectional paths from the possible sources to the BS can be represented with data gathering trees. The data gathering tree and implementation of DMAC is shown in Figure 2.5. During a node reception period, all its son nodes have also the same transmission period and they compete for the media. Thus, this protocol provides low latency by assigning contiguous slots to the consecutive nodes along the transmission path.

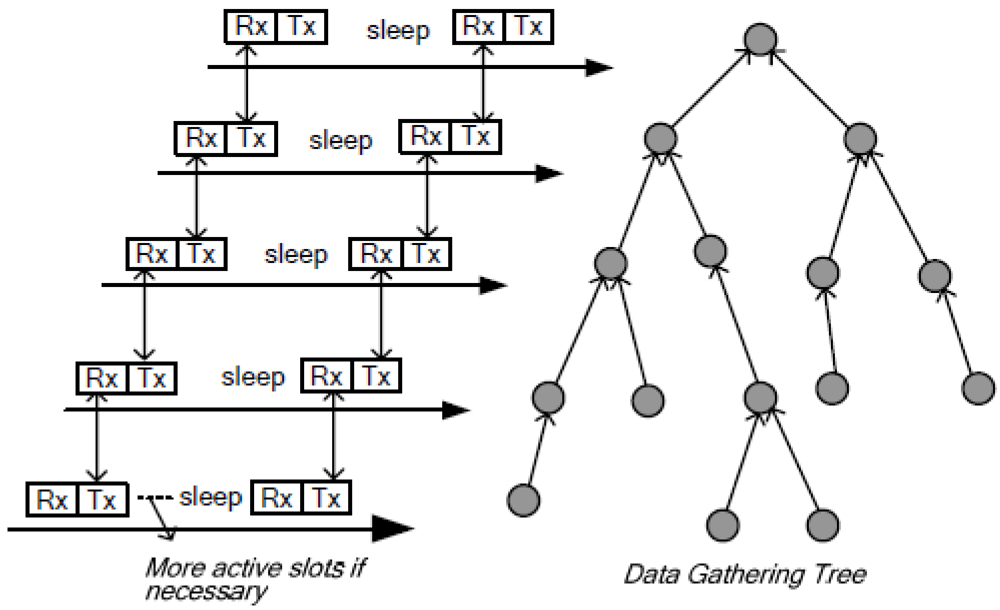


Figure 2.5: A data gathering tree and its DMAC implementation (Demirkol, 2006)

The advantage of DMAC is it achieves very good latency compared to other sleep/listen period assignment methods. Meanwhile, this protocol doesn't use collision avoidance. For this reason, when a considerable number of nodes on the same level try to send data to the same node, collisions will happen.

vi. DSMAC

Dynamic Sensor-MAC is an extention of SMAC which adds dynamic duty cycle and attempts to decrease the latency for delay-sensitive applications (Demirkol, 2006). In this protocol all nodes start with the same duty cycle, and when a node realizes that average one-hop latency is high, it decides to shorten its sleep time and announces it within SYNC period. As a consequence, after a sender node receives this signal, it checks its queue for packets destined to that receiver node and decides to double its duty cycle when its battery level is above a specified threshold. The duty cycle dubling is as shows in Figure 2.6.

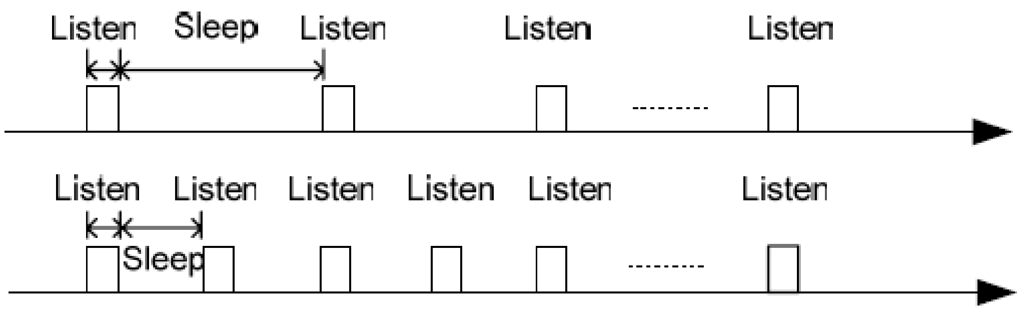


Figure 2.6: DSMAC duty cycle dubling (Demirkol, 2006)

i. CSMA

In Carrier Sense Multiple Access (CSMA), the nodes verify the absence of other traffic before transmitting on a shared transmission medium (Rom & Sidi, 1989). Two versions of CSMA exist which are non-persistent CSMA and p-persistent CSMA. In non-persistent CSMA, a backoff is performed before attempting to transmit if the sensed channel is busy, and the transmission is carried out immediately if the device senses no activity on the channel. In p-persistent CSMA, a node continues sensing the channel if it detects activity instead of delaying and checking again later. When the device senses no activity on the channel, it transmits a message with probability p and delays the transmission with probability $1 - p$.

The benefit of CSMA/CA techniques in sensor networks depends on the traffic conditions, wireless channel characteristics, and network topology, so in some cases it may prove beneficial and in others an unnecessary overhead.

2.3 Classification of wireless sensor networks

A Wireless Sensor Network can be classified based on their mode of functioning and the type of target application.

2.3.1 Proactive network

The nodes in this type of network periodically switch on their sensors and transmitters, sense the environment and transmit the data to the interest. This sort of network is suitable for application requiring periodic data monitoring. Some known instances of this kind are the LEACH protocol (Heinzelman, Chandrakasan, & Balakrishnan, 2000) and some improvement of LEACH protocol (Xiangning & Yulin, 2007) (Loscri, Morabito, & Marano, 2005) (Yassein, Al-zou'bi, Khamayseh, & Mardini, 2009).

2.3.2 Reactive network

The nodes of the networks according to this scheme react immediately to sudden and drastic changes in the value of a sensed attribute. They are well suited for time critical applications. Typical instances of this sort of networks are (Manjeshwar & Agrawal, 2001) and (Ping, Yu, & Hao, 2006).

2.3.3 Hybrid network

The nodes in such a network not only react to time-critical situations, but also give an overall picture of the network at periodic intervals in a very energy efficient manner. Such a network enables the user to request past, present and future data from the network in the form of historical, one-time and persistent queries respectively. Some instances of this kind of networks are (Manjeshwar & Agrawal, 2002) and (Younis & Fahmy, 2004).

2.4 Routing protocol

The objective of routing protocol is to render the network useful and efficient. In general, routing in WSNs can be divided into three groups depending on the network structure: *flat-based routing*, *hierarchical-based routing*, and *location-based routing depending*. In flat-based routing, all nodes are typically assigned equal roles or functionality. In hierarchical-based routing, however, nodes will play different roles in the network. In location-based routing, sensor nodes' positions are exploited to route data in the network. A routing protocol is considered adaptive if certain system parameters can be controlled in order to adapt to the current network conditions and available energy levels. Furthermore, these same protocols can be classified into *multipath-based*, *query-based*, *negotiation-based*, *QoS-based*, or *coherent-based* routing techniques depending on the protocol operation.

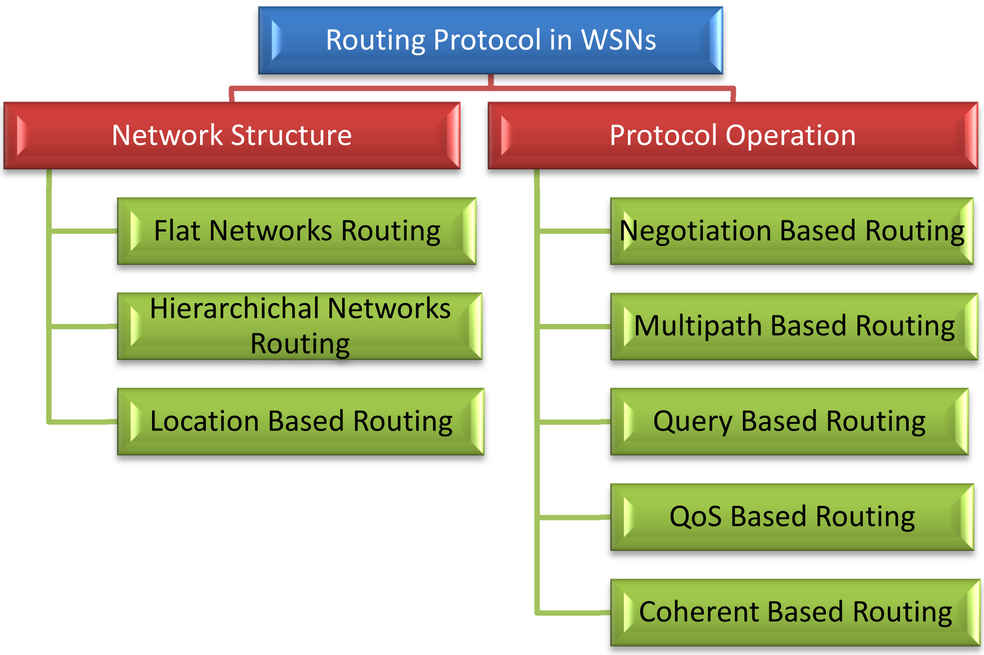


Figure 2.7 : Classification of routing protocols in WSNs

In the rest of this section, a detailed overview of the main routing paradigms in WSNs are presented.

2.4.1 Network structure based protocols

The underlying network structure may play an important role in the operation of routing protocols in WSNs. In this section, the most detailed research protocols that fall under this category are presented.

2.4.1.1 Flat routing

The first category of routing prorocols are multihop flat routing protocols. In flat networks, each node usually plays the same role and sensor nodes cooperate together to carry out sensing task. Due to large number of nodes, it is not entitled to set global identifier for each node. This consideration has led to focused data path, where the BS sends queries to certain areas and wait for data from sensor located in the selected area. Since data is being requested through queries, attribute-based name is necessary to specify the data attributes. In flat routing group, we can find a huge variety of protocols:

i. **Sensor Protocols for Information via Negotiation (SPIN)**

(Heinzelmen, Kulik, & Balakrishnan., 1999) and (Kulik, Heinzelmen, & Balakrishnan, 2002) proposed a family of adaptive protocols called Sensor Protocols for Information via Negotiation (SPIN), which disseminates all information at each node to every node in the network assumes that all nodes in the network base-station potential. This allows the user to query any node and get the required information immediately. This protocol makes use of the property that the nodes in close nearby has the same data, and therefore there is a need for other nodes only forward data do not have. SPIN family of protocols to use data negotiation and resource-adaptive algorithm. Nodes running SPIN assign a high-level name to completely describe their data collected (called meta-data) and perform the meta-data negotiations before any data is transmitted. This guarantees that there is no redundant data sent across the network. Semantic meta-data format is application-specific and not specified in SPIN. For example, the sensor may use a unique IDs to report meta-data if they cover a certain known region. In addition, SPIN has access to the current node energy level and adapt the protocol is running based on how much energy is remaining. This protocol works in time-driven fashion and distributes information across the network, even when the user does not request any data. This protocol is designed to address the deficiencies of classic flooding by negotiation and resource adaptation. The SPIN family of protocols is designed based on two basic ideas:

1. Sensor nodes operate more efficiently and conserve energy by sending data that describe the sensor data instead of sending all the data; for example, image and sensor nodes must monitor the changes in their energy resources.
2. Conventional protocols like *flooding* or *gossiping* based routing protocols (Hedetniemi, Hedetniemi, & Liestman, 1988) waste energy and bandwidth when sending extra and unnecessary copies of data by sensors covering the overlapping areas. The deficiencies of flooding include implosion, which is caused by duplicate messages sent to the same node, overlap when two nodes sensing the same region will send similar packets to the same neighbor and resource blindness by consume large amounts of energy without consider for an energy constraints. In Figure 2.8, node A starts by flooding its data to all of its neighbors. Two copies of data arrive at node D will cause the wastes of energy and bandwidth in a system for one necessary transmits and receives. Gossiping avoids the problem of implosion by just selecting a node randomly and sends the packet to rather than broadcasting the packet blindly. However, this causes delays in propagation of data through the nodes.

The SPIN family includes many protocols. The main two protocols are called SPIN-1 and SPIN-2, which incorporate negotiation before transmitting data in order to ensure that only useful information will be transferred. Also, each node has its own resource manager which keeps track of resource consumption, and is polled by the nodes before data transmission. The SPIN-1 protocol is a 3-stage protocol, as described above. An extension to SPIN-1 is SPIN-2, which incorporates threshold-based resource awareness mechanism in addition to negotiation. When energy in the nodes is overflow, SPIN-2 communicates using the 3-stage protocol of SPIN-1. However, when the energy in a node starts approaching a low energy threshold, it reduces its participation in the protocol, i.e., it participates only when it believes that it can complete all the other stages of the protocol without going below the low-energy threshold.

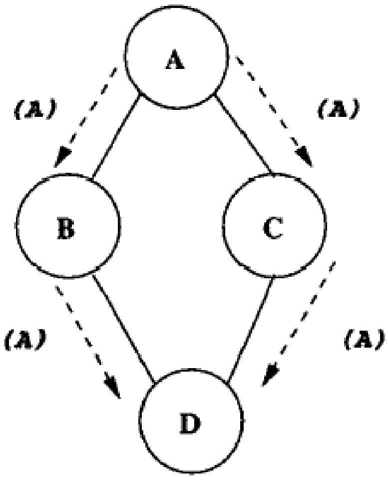


Figure 2.8: The implosion problem (Heinzelmen, Kulik, & Balakrishnan., 1999)

In conclusion, SPIN-l and SPIN-2 are simple protocols that efficiently disseminate data, while maintaining no per-neighbor state. These protocols are well-suited for an environment where the sensors are mobile because they base their forwarding decisions on local neighborhood information. Besides these two protocols, there are other protocols in SPIN family as described in (Heinzelmen, Kulik, & Balakrishnan., 1999) and (Kulik, Heinzelmen, & Balakrishnan, 2002).

i. SPIN-BC: This protocol is designed for broadcast channels.
ii. SPIN-PP: This protocol is use for a point to point communication, i.e., hop-by-hop routing. The example of SPIN-PP protocol is as shown in figure 2.9.
iii. SPIN-EC: This protocol works similar to SPIN-PP, but with an energy heuristic added to it.

iv. SPIN-RL: When a channel is lossy, a protocol called SPIN-RL is used where adjustments are added to the SPIN-PP protocol to account for the lossy channel.

One of the advantages available in SPIN is that topological changes are localized since each node needs to know only its single-hop neighbors. SPIN provides much energy savings than flooding and meta-data negotiation almost halves the redundant data. However, SPINs data advertisement mechanism cannot guarantee the delivery of data. To see this, consider the application intrusion detection where reliable data are reported more regular intervals and assume that the nodes that are interested in data that is located away from the source node and the node between the source and destination nodes are not interested in these data, the data did not will be sent to the destination at all.

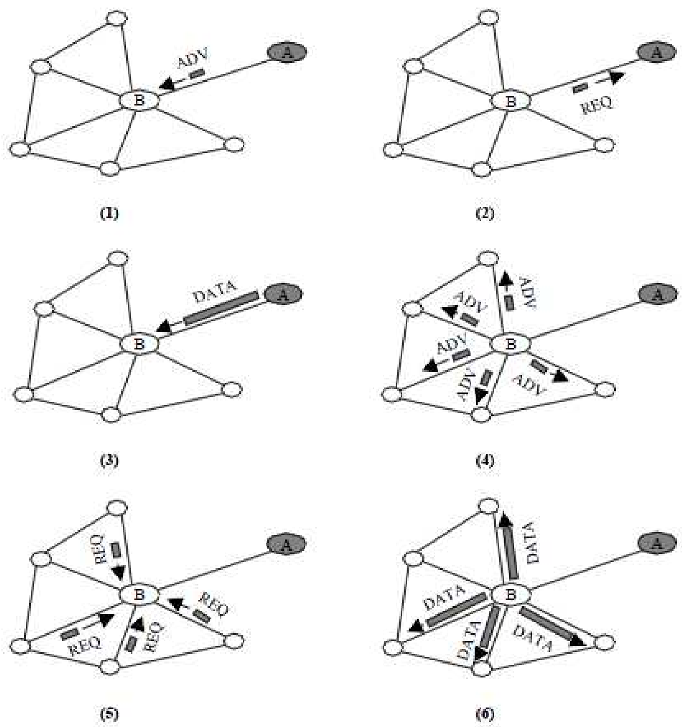
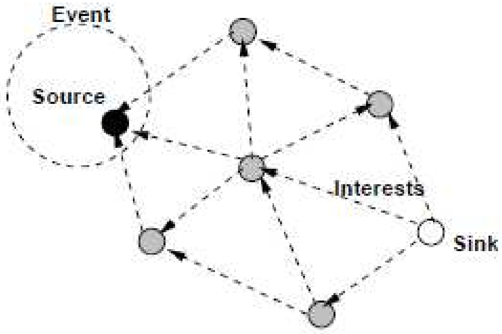


Figure 2.9: The SPIN-PP protocol. Node A starts by advertising its data to node B (1). Node B responds by sending a request to node A (2). After receiving the requested data (3), node B then sends out advertisements to its neighbors (4), who in turn send requests back to B (5,6). (Kulik, Heinzelmen, & Balakrishnan, 2002)

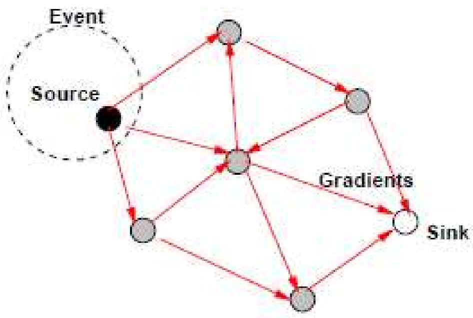
ii. Directed Diffusion

(Intanagonwiwat, Govindan, & Estrin, 2000) proposed a popular data aggregation paradigm for WSNs, called directed diffusion. Directed diffusion is a data-centric (DC) and application-aware paradigm in the sense that all data generated by sensor nodes is named by attribute-value pairs. The main idea of the DC paradigm is to combine the data coming from different sources enroute (in-network aggregation) by eliminating redundancy, minimizing the number of transmissions; thus saving network energy and prolonging its lifetime. Unlike traditional end-to-end routing, DC routing finds routes from multiple sources to a single destination that allows in-network consolidation of redundant data.

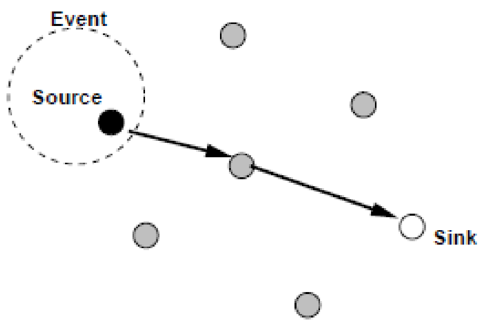
In directed diffusion, sensors measure events and create gradients of information in their respective neighborhoods. The base station requests data by broadcasting interests. Interest describes a task required to be done by the network. Interest diffuses through the network hop-by-hop, and is broadcast by each node to its neighbors. As the interest is propagated throughout the network, gradients are setup to draw data satisfying the query towards the requesting node, i.e., a BS may query for data by disseminating interests and intermediate nodes propagate these interests. Each sensor that receives the interest setup a gradient toward the sensor nodes from which it receives the interest. This process continues until gradients are setup from the sources back to the BS. More generally, a gradient specifies an attribute value and a direction. The strength of the gradient may be different towards different neighbors resulting in different amounts of information flow. At this stage, loops are not checked, but are removed at a later stage. Figure 2.10 shows an example of the working of directed diffusion. When interests fit gradients, paths of information flow are formed from multiple paths and then the best paths are reinforced so as to prevent further flooding according to a local rule. In order to reduce communication costs, data is aggregated on the way. The goal is to find a good aggregation tree which gets the data from source nodes to the BS. The BS periodically refreshes and re-sends the interest when it starts to receive data from the sources. This is necessary because interests are not reliably transmitted throughout the network.



(a) Interest propagation



(b) Initial gradients Set-up



(c) Send data and path reinforcement

Figure 2.10: A schematic for Directed Diffusion (Intanagonwiwat, Govindan, & Estrin, 2000)

All sensor nodes in a directed diffusion-based network are application-aware, which enables diffusion to achieve energy savings by selecting empirically good

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