Improving QoS of Data Transmission over Wireless Sensor Networks

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صدق الله العظيم

الآية 114 من سورة طه
Declaration

I certify that this work has not been accepted in substance for any academic degree and is not being concurrently submitted in candidature for any other degree. Any portions of this thesis for which I am indebted to other sources are mentioned and explicit references are given.

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Signature:
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<td>Interface Queue</td>
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<td>Link Layer Object</td>
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<td>RREP</td>
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<td>SVM</td>
<td>Static Velocity Monotonic Scheduling</td>
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<td>TCL</td>
<td>Tool Command Language</td>
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<tr>
<td>TTL</td>
<td>Time to Live</td>
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<td>Wireless Sensor Network</td>
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Abstract

Wireless Sensor Networks (WSNs) consist of sensor nodes that are spatially distributed. These sensor nodes are connected to each other through wireless technology. They are an important emerging technology that will revolutionize sensing for a wide range of military, scientific, industrial and civilian applications. In many WSN applications, the sensor nodes are deployed in an ad hoc style without careful any preplanning and engineering. Once deployed, the sensor nodes must have the ability to autonomously organize themselves into a wireless communication network.

New packet scheduling schemes have been developed for real-time data communication. These schemes work on prioritizing packets according to their deadlines. Packet prioritizing cannot support real time applications or assure network lifetime. In extreme traffic environments, large queues may lead to packet delay and packet dropping. Packet dropping leads to energy loss, as a packet could have consumed high energy in order to be delivered to its destination.

The continuous decrease in the size and cost of sensors has motivated intensive research addressing the potential of collaboration among sensors in data. Current research on routing and scheduling in wireless sensor networks focused on energy aware protocols to maximize the lifetime of the network. These researches are scalable to accommodate a large number of sensor nodes. In addition, they are tolerant to sensor damage and battery exhaustion. Sensor networks are deployed to gather information for later analysis, monitoring or tracking of phenomena in real-time.

In WSNs, transmitted packets are queued at intermediate nodes. Each node schedules the queued packets by assigning priorities to each packet. Priorities are assigned to packets according to their deadlines. This method in packet
prioritization does not take into consideration either the network life time or energy consumption. Besides, it may lead to dropping high energy valuable packets. In many applications, WSN lifetime is considered a very critical issue, while setting up the network.

In this thesis, a new scheduling scheme, named Energy Based Scheduling scheme is introduced. In this scheme, packets are not only prioritized according to their deadlines but also according to some energy measures related to the network, that are obtained from the network nodes and are used in packet prioritization. The proposed scheme is integrated with the AODV routing protocol. The unused bits in the AODV packets are used by the proposed scheme in assigning sending priorities to each packet in the network. Through this thesis, the proposed scheduling scheme is compared with the Basic Priority Scheduling scheme, using NS-2. Comparisons are done according the network life time, energy consumption and the fairness index measure. The results prove that the Energy Based scheduling scheme increase the network life time and decrease the energy consumption for the goodput packets. On the other hand, the fairness index was affected.

Keywords: Wireless Sensor Networks, scheduling scheme, AODV, Basic Priority scheduling scheme, NS-2
Chapter 1

Introduction

Wireless networks, like wireless mobile ad-hoc networks and Wireless Sensor Networks (WSNs) have played a great important role in a wide range of applications. In the 21st century, they have been identified as one of the most important technologies. WSNs are a rapidly emerging technology which will have a strong impact on research and will become an integral part of life in the near future. The huge application space of WSNs covers health care, surveillance, military, environment monitoring and many more. Because of their great usage applications, they have attracted considerable research interest in recent years. WSNs support monitoring and controlling of physical environments from remote locations with better accuracy [1].

Sensor networks are dense wireless networks of small and low-cost sensors. They are composed of a large number of sensors deployed randomly in an ad-hoc manner in the area/target to be monitored. Sensors collect and disseminate environmental data. Each sensor has limited battery energy supply, transmission radius and sensing capability. The random deployments of sensors don’t require be engineering or predetermining. This allows fast random deployment in inaccessible terrains or disaster relief operations [2]. On the other hand, random deployment requires that sensor network protocols and algorithms must possess self-organizing capabilities. They support monitoring and controlling of physical environments from remote locations with better accuracy [3].

In wireless sensor networks, energy sources provided for sensors are usually battery power. It has not yet reached the stage for sensors to operate for a long time without recharging. The energy conservation is the most critical issue because of the weight and size limitations of sensor nodes [4].
Since sensors are often purposed to work in remote or hostile environment, such as a battlefield or desert, it is undesirable or impossible to recharge or replace the battery power of all the sensors.

WSNs can be deployed in the places where the wired sensor system cannot be deployed. These places are in the chemical environments that are inaccessible by humans. They are used in order to facilitate monitoring and controlling of physical environments from remote locations with better accuracy [5].

1.1 Problem Definition

Sensors are often purposed to work in remote or hostile environment, such as a battlefield or desert. So, it is unwanted or impossible to recharge or replace the battery power of all the sensors [6].

WSNs contain a lot of constrains, such as energy limitation, decentralized collaboration, and fault tolerance. These constraints cause many unresolved design and implementation problems, so measurements are virtually impossible. However, long system lifetime is expected by many monitoring applications. The system lifetime, that is measured by the time until all nodes have been drained out of their battery power or the network no longer provides an acceptable event detection ratio, directly affects network usefulness [4, 7].

The most energy consuming operation is data transmission and reception. Control messages and sensing and processing operations also contribute to the energy consumption [8]. In order to minimize the consumed energy, dropping packets should not be only according to the deadline but also according to the packet energy consumption. So, the scheduling needs to consider the queuing delay and packet energy consumption, in order to achieve better network QoS and improve the WSN lifetime [9, 10].
1.2 Research Objectives

The objective of this thesis is to introduce a new scheduling schema. Most of WSN energy consumption is due to the packet transmission. The new schema should have the ability to prioritize packets according to energy consumption and deadline, besides improving the network quality of service. In WSN, packets are buffer in each node on the path from source to destination. As each node has a finite buffer size, packets are dropped and transmitted in order to keep the queue ready for new packets. Dropping and transmitting packets is done according to many constraints.

The process of managing the packets in each node queue is called scheduling. Existing Scheduling algorithms are according to deadline or the technique of first come first served. Energy consumption by the packets during the transmission and reception process is not considered in any scheduling algorithm.

1.3 Contributions

In this thesis, we develop the Energy Based Scheduling schema for Wireless Sensor Networks. It offers a significant improvement in the network lifetime and QoS. It reduces the energy consumption and a packet delay for remote nodes from the destination. Both data and control packets are treated in the same manner, according to energy consumption and packet deadline.

1.4 Thesis Organization

The rest of the thesis is organized as follows:

Chapter 2 presents an introduction to wireless sensor networks, including network architecture, layers, Applications and challenges. This introduction includes the sensor hardware component and the types of WSN architectures. In addition, the main types of routing protocol are mentioned including Pro-
active (Table-Driven) routing and Reactive (On Demand) Routing Protocols. The main routing protocols for these types were briefly discussed.

In chapter 3, we present a brief review of Scheduling techniques in Wireless Sensor networks and the types of delay in WSN. This review includes the main types of the scheduling techniques which they depend on in packet scheduling.

Through chapter 4, the proposed energy based scheduling schema is introduced. The equations used in the proposed schema are discussed. Besides, the integration of the proposed schema with AODV routing protocol has been discussed.

The simulation and results when comparing the proposed energy schema, is introduced in chapter 5. In this chapter, a comparison is done between the proposed energy schema with AODV and the basic priority scheduling schema with AODV, DSR and DSDV.

Finally, chapter 6 concludes the thesis and presents a future work of it.
Chapter 2
Survey on Wireless Sensor Networks

Advancements in the area of wireless communication technologies are undergoing rapidly. The last years have experienced a huge growth in research in the area of wireless sensor networks (WSNs). In WSNs, communication is established with the help of distributed sensor nodes are used to sense specific information [12]. WSNs consist of individual nodes that are able to react with their environment by sensing, monitoring or controlling physical parameters. WSNs are powerful because of its ability to support a lot of different real-world applications. In a WSN, each sensor node has the ability to independently perform some processing and sensing tasks [1]. The position of sensor nodes doesn’t need to be engineered or pre-determined. This means that wireless sensor network protocols and algorithms must be able to possess self-organizing capabilities.

In this chapter, we will introduce wireless sensor network architecture, applications, protocols and challenges.

2.1 Wireless Sensor Network Architecture

A WSN is a network consisting of many sensor nodes with sensing, wireless communications and computing capabilities. These sensor nodes are dispersed in an unattended environment (i.e. sensing field) to sense the physical world. The sensed data can be gathered by a few sink nodes which have accesses to infrastructure networks like the Internet [13].

The hardware resources, which are available on micro-sensor nodes, are significantly more limited than other wireless devices such as PDAs or laptops. This limitation is driven by cost and size considerations. The challenge is how to make balance the application requirements and the limited available resources. Reducing the consumed energy is often the primary target; since the transmission is one of the most costly operations
(transmitting 1 byte 100 meters consumes similar energy as processing several thousand instructions) [10, 14].

The concept of wireless sensor networks is based on a simple equation [15]

Sensing + CPU + Radio = Thousands of potential applications

2.1.1 The Sensor node Architecture

A basic sensor node comprises five main components (Figure 2.1) [16]:

- **Controller:** A controller works on processing all the relevant data, capable of executing arbitrary code.
- **Memory:** It is used to store programs and intermediate data; usually, different types of memory are used for programs and data.
- **Sensors and actuators:** They are actual interface to the physical world: devices which can be able to observe or control physical parameters of the environment.
- **Communication:** In order to turn nodes into a network, a device requires sending and receiving information over a wireless channel.
- **Power supply:** As usually no tethered power supply is available. Some forms of batteries are necessary to provide energy. Sometimes, some form of recharging by obtaining energy from the environment is available as well (e.g. solar cells).

![Figure 2.1 Overview of main sensor node hardware component](image-url)
2.1.2 Wireless Sensor Networks Architectures

WSNs are considered application specific. A sensor network is usually deployed for a specific application. Therefore, it has some different characteristics. According to different criteria, WSNs are classified into different categories [17].

- **Static and Mobile Network.** According to the mobility of sensor nodes, a sensor network can be static or mobile. In a static sensor network, all sensor nodes are static without movement, which is the case for many applications. However, some sensor applications require mobile nodes to accomplish a sensing task [18, 19].

- **Deterministic and Nondeterministic Network.** According to the deployment of sensor nodes, a sensor network can be deterministic or nondeterministic. In a deterministic sensor network, the positions of sensor nodes are preplanned and are fixed once deployed. It is difficult to deploy sensor nodes in a preplanned manner because of the harsh or hostile environments. Instead, sensor nodes are randomly deployed without preplanning and engineering. Obviously, nondeterministic networks are more scalable and flexible, but require higher control complexity [20, 21].

- **Static - Sink and Mobile - Sink Network.** A data sink in a sensor network can be static or mobile node. In a static - sink network, the sinks are static with a fixed position located close to or inside a sensing region. All sensor nodes send their sensed data to the sink(s). In a mobile - sink network, the sink(s) move around in the sensing region to collect data from sensor nodes, which can balance the traffic load of sensor nodes and alleviate the hotspot effect in the network [22, 23].

- **Single - Sink and Multisink Network.** A sensor network can have a single sink or multiple sinks. In a single - sink network, there is only...
one sink located close to or inside the sensing region. All sensor nodes send their sensed data to this sink. In a multisink network, there may be several sinks located in different positions close to or inside the sensing region [24].

- **Single - Hop and Multihop Network.** According to the number of hops between a sensor node and the data sink, a sensor network can be classified into single - hop or multihop. In a single - hop network, all sensor nodes transmit their sensed data directly to the sink, which makes network control simpler to implement. Multihop networks have a wider range of applications at the cost of higher control complexity [25].

- **Self - Reconfigurable and Non - Self - Configurable Network.** According to the configurability of sensor nodes, a sensor network can be self - configurable or non - self - configurable. In a non - self - configurable network, sensor nodes have no ability to organize themselves into a network. Instead, they have to rely on a central controller to control each sensor node and collect information from them. A network with such self - configurability is suitable for large - scale networks to perform complicated sensing tasks [26].

- **Homogeneous and Heterogeneous Network.** According to whether sensor nodes have the same capabilities, a sensor network can be homogeneous or heterogeneous. In a homogeneous network, all sensor nodes have the same capabilities in terms of energy, computation, and storage. In contrast, a heterogeneous network has some sophisticated sensor nodes that are equipped with more processing and communicating capabilities than normal sensor nodes [27].

2.2 Wireless Sensor Networks Layers

The protocol layers for WSNs consists of five protocol layers, the physical layer, data link layer, network layer, transport layer, and
application layer, as shown in Figure 2.2. The protocol layers can be divided into a group of management planes across each layer. Each layer includes power, connection, and task management planes. The power management plane has the responsibility for managing the power level of a sensor node for, processing, sensing, transmission and reception, which can be implemented by employing efficient power management mechanisms at different protocol layers [28]. The connection management plane is responsible for the configuration and reconfiguration of sensor nodes to establish and maintain the connectivity of a network in the case of node deployment and topology change due to node addition, node failure, node movement. The task management plane is responsible for task distribution among sensor nodes in a sensing region in order to improve energy efficiency and prolong network lifetime [29].

![Figure 2.2 Protocol layers for sensor networks](image)

**2.2.1 Physical layer**

The responsibilities of the Physical Layer are carrier frequency generation, frequency selection, signal detection, modulation and
Its first priority is energy minimization and secondary concerns are the same as those of other wireless networks. This task is carried out by devices called transceivers. So, it should deal with various related issues, like transmission medium and frequency selection, carrier frequency generation, signal modulation and detection, and data encryption.

2.2.2 Data Link Layer

The data link layer has the responsibility of multiplexing of data frame detection, data streams, medium access and error control. It has the task of ensuring a reliable communications link between neighboring nodes, which in the case of WSNs means between nodes in radio range.

2.2.2.1 Medium Access Control (MAC) protocols

Medium Access Control (MAC) protocols are the first and most important protocol layer above the Physical Layer. Medium access was and still one of the most active research areas for WSNs. MAC is one of the critical issues in the design of wireless sensor networks (WSNs) The main functions of a MAC protocol for WSNs are the coordination and scheduling of transmissions between the competing nodes. The design of MAC protocols for WSNs must take in consideration the characteristics of these networks such as the node mobility, the lack of any central coordination, the unreliability of the wireless medium, the problems of hidden and exposed nodes and the energy constrained problem.

Modified versions of the IEEE 802.11 MAC layer protocol are often used by sensor network platforms. Since IEEE 802.11 is the most deployed wireless MAC protocol, it has been chosen as the main MAC protocol in our thesis.

The 802.11 MAC layer specifications specifies two kinds of access methodologies as follows.

1. Point Coordination Function (PCF): It is usually used for real time data transmission with priorities in infrastructure networks. This
is a contention free access protocol; PCF is not used in Ad hoc networks.

2. **Distributed Coordination Function (DCF):** Probably, all Ad hoc networks (including sensor networks) use DCF as the access methodology. This is a contention based access protocol. This section describes the features of DCF.

### 2.2.3 Network Layer

The network layer is surely the area with the most active research interest. Network layer mainly deal with determining the route from source to destination and manage traffic problems. Generally, network layer is responsible for end-to-end packet delivery, whereas the data link layer is responsible for node-to-node (hop-by-hop) packet delivery [21]. Routing protocols in WSN can be categorized as follows:

- **Data-Centric:** Data are spreaded between sensors without the need for global unique ID. It depends on the naming of desired data.
- **Hierarchical:** Sensors are controlled by a sensor (cluster-head) to aggregate data. Cluster-head is either a special (more powerful) node or an elected sensor among each cluster.
- **Location-based:** These protocols are location-aware; by utilizing a Global Positioning System (GPS). The ability to find the location makes it easier to route data to single and specific region instead of broadcasting traffic to all regions.
- **Quality of Service based:** Protocols which ensure some QoS requirements such as minimum cost path, minimizing energy consumption, low throughput and delay.

### 2.2.4 Transport Layer

It is responsible for packet transmission and reception. In other words, it is responsible for reliable end to end data delivery between sensor nodes and the sink(s). Routing protocols are handled in this layer. Normal transport protocols developed for wireless or wired communication does not address
WSN resource constrains [16]. Some consideration must be taken while developing transport protocols specific for WSN:-

- Reliability for both ways of communications; sink-to-sensors and sensor-to-sink.
- A good Congestion Control mechanisms increases network efficiency and save power.
- Self-configuration approaches to adapt to frequent changes in network topology.
- Should be energy-aware.
- Data-centric.

2.2.5 Application Layer

Many WSNs’ applications heavily rely on coordinated services such as localization, time synchronization, and in-network data processing to collaboratively process data. Normal transport protocols developed for wired or wireless communication does not address WSN resource constrains. Although many sensor network applications have been proposed, their corresponding application - layer protocols still need to be developed [28].

2.3 Sensor Networks Applications

WSNs find a diversity of applications in both the civilian population and the military a worldwide. They can be used in various applications such as intelligent agriculture, medical health care, environment monitoring and protection, and military battlefield surveillance. In many WSN applications, individual nodes in the network cannot easily be connected to a wired power supply, so they have to rely on onboard batteries [30]. This means that, energy efficiency of any proposed solution is a very important issue, if the power supply is an issue. WSNs can be divided into two types, homogeneous and heterogeneous [30]. In heterogeneous networks, there are different types of sensors. They perform multiple operations simultaneously. While in homogeneous, each node has an identical function and performs
the same task. In this section, some WSNs applications will be discussed [27].

2.3.1 Environment applications

Environmental monitoring can be used for animal tracking, forest surveillance, flood detection, and weather forecasting. It is one of the primary applications of wireless sensor networks. The advantages of WSNs are the long-term, unattended, wirefree operation of sensors close to the objects that have to be observed. WSNs can be used in gaining an understanding of the number of plant and animal species that live in a given habitat [31].

2.3.2 Military applications

The initial wireless sensor network is used in the military applications. Since sensor nodes are low-cost, destruction of some nodes by hostile actions in the battlefields may not affect a military operation. Military applications are very closely related to the concept of wireless sensor networks. WSNs are used in covering areas of interest extents from information collection to battlefield surveillance, enemy tracking or target classification [31].

- **Battlefield Monitoring**: Sensors are deployed in a battlefield to monitor the presence of forces and vehicles, and track their movements, enabling close surveillance of opposing forces.

- **Object Protection**: Sensor nodes are deployed around sensitive objects, for example, atomic plants, strategic bridges, oil and communication centers, gas pipelines, and military headquarters, for protection purpose.

- **Intelligent Guiding**: Sensors can be mounted on unmanned robotic vehicles, tanks, submarines, missiles, fighter planes, or torpedoes to guide them around obstacles to their targets and lead them to
coordinate with one another to accomplish more effective attacks or defenses.

- **Remote Sensing:** Sensors could be deployed for remote sensing of biological, nuclear and chemical weapons, detection of potential terrorist attacks, and reconnaissance.

### 2.3.3 Health Care Applications

WSNs can be used to monitor and track elders and patients for health care purposes, which can significantly relieve the severe shortage of health care personnel and reduce the health care expenditures in the current health care systems [32]

- **Behavior Monitoring:** Sensors can be deployed in a patient’s home to monitor the behaviors of the patient. For example, it can alert doctors when the patient falls and requires immediate medical attention. It can monitor what a patient is doing and provide reminders or instructions over a television or radio.

- **Medical Monitoring:** Sensors can be integrated into a wireless body area network to monitor vital signs, environmental parameters, and geographical locations. Besides, they allow long term, noninvasive, and ambulatory monitoring of patients or elderly people with instantaneous alerts to health care personal in case of emergency, immediate reports to users about their current health statuses, and real-time updates of users’ medical records.

### 2.3.4 Industrial Process Control

In industry, WSNs can be used to monitor manufacturing processes or the condition of manufacturing equipment. For example, wireless sensors can be instrumented to production and assembly lines. So, they can be able to monitor and control production processes. Chemical plants or oil refiners can use sensors to monitor the condition of their miles of pipelines. Tiny sensors can be embedded into the regions of a machine that are inaccessible
by humans to monitor the condition of the machine and alert for any failure [33].

2.3.5 Security and Surveillance

WSNs can be used in many security and surveillance applications. For example, acoustic, video and other kinds of sensors can be deployed in buildings, airports, subways and other critical infrastructure. Also, sensors can be used in nuclear power plants or communication centers to identify and track intruders, and provide timely alarms and protection from potential attacks [32].

2.3.6 Home Intelligence

WSNs can be used to provide more convenient and intelligent living environments for human beings [32].

- **Smart Home.** Wireless sensors can be embedded into a home and connected to form an autonomous home network. For example, a smart refrigerator connected to a smart stove or microwave oven can prepare a menu based on the inventory of the refrigerator. Then, it sends relevant cooking parameters to the smart stove or microwave oven, which will set the desired temperature and time for cooking. The contents and schedules of TV, VCR, DVD, or CD players can be monitored and controlled remotely to meet the different requirements of family members.

- **Remote Metering.** Wireless sensors can be used to remotely read utility meters in a home like water, gas, or electricity and then sends the readings to a remote center through wireless communication.

2.4 WSN Design Objectives

Sensor Networks characteristics and requirements for different applications have a decisive impact on the network design objectives in terms of network capabilities and network performance. WSN design should follow some aspects in order to achieve its goal. They are:
• **Small Node Size.** One of the primary design objectives of sensor networks is to reduce the node size. Sensor nodes are usually deployed in a harsh or hostile environment in huge numbers. Reducing node size can facilitate node deployment, and also reduce the cost and power consumption of sensor nodes.

• **Low Node Cost.** Node cost reduction is another primary design objective of sensor networks. Since sensor nodes are usually deployed in a harsh or hostile environment in large numbers and cannot be reused, it is important to reduce the cost of sensor nodes so that the cost of the whole network is reduced.

• **Low Power Consumption.** Reducing power consumption is the most important objective in the design of a sensor network. Since, the sensor nodes are powered by battery and it is often very difficult or even impossible to change or recharge their batteries. It is crucial to decrease the power consumption of sensor nodes in order to increase the lifetime of the sensor nodes, in addition to the whole network.

• **Self - Configurability.** In sensor networks, sensor nodes are usually deployed in a region of interest without careful planning and engineering. Once deployed, sensor nodes should be able to autonomously organize themselves into a communication network and reconfigure their connectivity in the event of topology changes and node failures.

• **Scalability.** In WSNs, the number of nodes may be on the order of tens, hundreds, or thousands. Thus, network protocols designed for sensor networks must be scalable to different network sizes.

• **Adaptability.** In sensor networks, any node may fail, join, or move, which would result in changes in node density and network topology. Thus, network protocols which are designed for sensor networks should be adaptive to such density and topology changes.
• **Reliability.** For many sensor network applications, it is required that data be reliably delivered over noisy, error-prone, and time-varying wireless channels. To meet this requirement, network protocols designed for sensor networks must have the ability to provide error control and correction mechanisms to ensure reliable data delivery.

• **Fault Tolerance.** Sensor nodes are apt to failures due to harsh deployment environments and unattended operations. So, sensor nodes must be able to be fault tolerant and have the abilities of self-testing, self-repairing, self-calibrating and self-recovering.

• **Security.** In many military applications, sensor nodes are deployed in a hostile environment and thus are vulnerable to adversaries. In such situations, a sensor network should introduce effective security mechanisms to prevent the data information in the network or a sensor node from unauthorized access or malicious attacks.

• **Channel Utilization.** Sensor networks have limited bandwidth resources. Thus, communication protocols designed for sensor networks should efficiently make use of the bandwidth to improve channel utilization.

• **QoS Support.** In sensor networks, different applications might have different QoS requirements in terms of delivery latency and packet loss. For example, some applications, for example, fire monitoring, are delay sensitive and thus require timely data delivery. Some applications, for example, data collection for scientific exploration, are delay tolerant but cannot stand packet loss. Thus, the design of network protocol should consider the QoS requirements of specific applications.
2.5 Challenges of WSN

Handling a wide range of application types would hardly be possible with any single realization of a WSN [34].

2.5.1 System Architecture

There is no unified system and networking architecture that is stable and mature enough to build different applications on top. Most of the applications and research prototypes are vertically integrated in order to maximize performance.

2.5.2 Wireless Connectivity

Wireless communication in indoor Environments is still quite unpredictable using low-power consumption RF transceivers, in particular in clutter environments common inside buildings, with many interfering electromagnetic fields, such as the one produced by elevators, machinery and computers, among others.

2.5.3 Programmability

Some form of network re-programmability is desirable; doing so in energy and communication conservative form remains a challenge. Nodes should be programmable, and their programming must be changeable during operation, when new tasks become important. This means that a fixed way of information processing is not sufficient.

2.5.4 Adaptation

The network operation should adapt itself to application requirement changes, time-varying wireless channels, and variations of the network topology. For instance, the group of application requirements may change dynamically and the communication protocol must adapt its parameters to satisfy the specific requests of the control actions.
2.5.5 Energy Consumption

Sensors nodes are battery powered nodes and thus have very limited energy capacity. Energy consumption is a central design consideration for wireless sensor networks whether they are powered using batteries or energy harvesters. The energy constraint will not be solved soon due to slow progress in developing battery capacity [30]. In many scenarios, nodes will have to rely on a limited supply of energy. Replacing the energy sources in the field is usually not practicable or a visible solution. Surveillance nature of many sensor network applications requires long lifetime. So, it must be a very important research topic to provide a form of energy-efficient surveillance service for a geographic area.

The energy consumed for transferring one bit of data to a receiver at 100 m away is equal to that needed to execute 3,000 instructions. The ratio of energy consumption for communicating 1 bit over the wireless medium to that for processing the same bit could be in the range of 1,000 – 10,000. Furthermore, the energy consumed for transmission dominates the total energy consumed for communication and the required transmission power grows exponentially with the increase of transmission distance. Therefore, it is desired to reduce the amount of traffic and transmission distance in order to increase energy savings and prolong network lifetime [30].

The precise definition of lifetime depends on the requirement of application at hand. The main limiting factor for the lifetime of a sensor network is the energy supply. Each sensor node should be designed to manage its local supply of energy in order to maximize total network lifetime. The node minimum lifetime is more important than the average node lifetime [35].

There direct trade-offs between the lifetime of a network and quality of service. As, investing more energy can increase quality but decrease lifetime. In a wireless sensor node the radio consumes a vast majority of the system energy. This power consumption can be reduced through decreasing the transmission output power or through decreasing the radio duty cycle. Both of these alternatives involve sacrificing other system metrics.
2.5.6 Quality of Service

Quality of service (QoS) is an important factor in networking, but it is also a significant challenge. The QoS is one of the most important challenges that face WSN. More energy is required to achieve better QoS. Therefore, WSN lifetime is affected. Providing QoS guarantees have become even more challenging when you add the complexities of wireless and mobile networks [17].

2.5.6.1 Definition of Quality of Service

QoS is the ability to provide different priorities to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow. QoS guarantees are important if the network capacity is a limited resource. Due to the limitation of network resources especially in wireless networks, real time traffic need to be given higher priority to ensure that arrival to the destination on time.

2.5.6.2 Quality of Service parameters

QoS parameters differ from application to application. In sensor networks, battery life and energy conservation would be the prime QoS parameters. The QoS parameter considered here is aimed to real time applications. However, maximizing QoS and minimizing energy consumption are in most cases conflicting requirements [17].

2.5.6.3 Quality of Service in different layers

- **Physical layer:** It means the quality in terms of transmission performance. Power control is used both to ensure the quality of reception and to optimize the capacity. It seeks to avoid the interference with other networks or natural sources of radiation.

- **Data Link layer:** The scheduling of medium access and the sequence of packets to be sent is changed to supply the QoS requirements. These changes may be achieved by packet reordering and by priority control and admission policies. It is possible to adjust
the amount of control packets sent to increase the QoS of a data packet. Current proposed MAC protocols in WSN concerns mainly about power conserving. They don’t support real QoS due to the tradeoffs between energy efficiency and QoS capability. QoS implemented in MAC layer is also important. It could provide high probability of access with low delay when stations with higher user priority want to access the wireless medium [36].

- **Network Layer**: It mainly deals with determining the route from source to destination and manages traffic problems. Some routing protocols in WSN are developed to ensure some QoS requirements such as minimum cost path; in term of energy for example, low throughput and delay. Similar to the link layer, it is possible to use packet prioritization.

- **Application Layer**: QoS may interpret in two different prospective. One prospective defines QoS as quality perceived by the user or application (subjective). The other is defining QoS in respect to network

### 2.5.6.4 Models of Quality of Service

QoS model are defined into two types. They are Integrated Service (IntServ) and Differentiated Services (DiffServ) [38].

- **IntServ**: provides QoS to individual applications or flows. Resource Reservation Protocol is used to provide a circuit switched service in packet switched network. IntServ decides if the desired service could be provided with the current available network resource. The scalability problem is the main drawback of IntServ. It caused by the need of storing every flow state in the routes.

- **DiffServ**: provides QoS to large classes of data or aggregated traffic. Routers are divided into two types: edge routers and core routers.
Edge routers are at the boundary of the networks. In edge routers, traffic will be classified, conditioned and assigned to different behavior aggregate when it traverse between different networks. Core routers forward packets based on this ToS field. In addition, core routes also need to follow the per-hop behavior which takes charge of scheduling of packets.

2.5.6.5 Challenge of QoS in WSN

WSNs differ from the traditional wired networks. Due to bandwidth, memory and processor limitations, QoS in WSN is a challenging task. WSNs have certain unique characteristics which cause difficulties for providing QoS in such networks [39]. These characteristics are:-

- **Dynamically varying network topology**
  In a WSN, mobility problem can also exist if the sensor nodes are mobile in the given application. When nodes are mobile, network topology is changing dynamically. The route which is already set up with required QoS could not satisfy QoS anymore if one of the nodes on this established route moves. A node could move to an area with more interference to it.

- **Limited resource availability**
  WSN life nature is limited because of the fact that most nodes operate on unchangeable power source like battery; another reason is the ease of node damage. The data rate is so limited for wireless links if we compared it with the data rate available in wired network. The basic characteristics of the wireless channel like fading, noise, and shared data rate between neighbor nodes will also degrade the wireless data rate. The actual radio data rate becomes much smaller. As a result, it is very hard for a wireless network to provide too high data rate which could be provided by the wired network. It also brings problem of cooperation between wireless network and wired network.
• **Lack of precise state information**
  Because of the dynamic characteristic, information of nodes transmitted to other nodes may change right after this information is transmitted to its neighbors.

• **Application diversity**
  WSN consider being application specific rather than general purpose. They carry only the software and hardware that is needed for the application. The vast number of applications in WSN offers different QoS requirements.

• **Data correlation**
  Data, which is collected by a sensor node, tends to be correlated to the data collected by its neighbors, thus it may be dropped or submitted to fusion or preprocessing in order to decrease bandwidth utilization.

### 2.6 Research Areas in Wireless Sensor Networks

Wireless sensor network faces a lot of problems. These problems appear from the nature of the WSN [39]. Through this section, we focus on the most important problems in wireless sensor networks.

#### 2.6.1 Localization in WSN

In wireless sensor networks, localization is identified as the process of determining the geographical positions of sensors. In other words, it is defined as an algorithm that finds the Euclidean position for some or all of the nodes in the network. Only some of the sensors in the networks have prior knowledge about their geographical positions. In many applications of wireless sensor networks, valuable location information of sensor nodes is critical to the success of the applications. Most of the collected data from
sensors are only meaningful when they are coupled with the location information of the corresponding sensors [40].

For example, consider an application of habitat monitoring. Thousands of sensors are dropped in the target region of a tropical rain-forest by an aeroplane. Sensing devices are attached with nodes to monitor the changes of temperature and humidity of the environment.

### 2.6.2 Routing in WSN

Sensor networks can be considered a special class of ad hoc networks. Routing for traditional ad hoc networks is considered a well-researched area and it is possible to adapt protocols developed there to sensor network operation. For some applications, messages should arrive at a destination by a deadline. Due to the high degree of uncertainty in WSN it is difficult to develop routing algorithms with any guarantees. However, several characteristics of sensor networks make such protocols poorly suited for them. These characteristics include [41]:

- Data dissemination model of the sensor networks is far from the view of the traditional wireless ad hoc networks where mostly the communication is from one source to one destination;
- Data-centric operation where communication is directed to sensors that satisfy a query attributes differs from the IP-centric view of ad hoc networks
- The emphasis of ad hoc networks is on mobility, many sensor networks are static.
- Sensor network nodes are more energy constrained than ad hoc nodes, and are not rechargeable. Because of these reasons, several new routing protocols have been proposed for sensor networks.

There are two types of routing protocols which are reactive and proactive. In reactive routing protocols, the routes are created only when source wants to send data to destination whereas proactive routing protocols are table driven. Reactive routing protocol uses traditional routing tables.
One entry per destination and sequence numbers are used to determine whether routing information is up-to-date and to prevent routing loops.

2.6.2.1 Pro-active (Table-Driven) routing

Proactive routing protocols preserve routes to all destinations, regardless of whether or not these routes are needed. In order to preserve correct route information, a node must periodically send control messages. Therefore, proactive routing protocols may waste bandwidth since control messages are sent out unnecessarily when there is no data traffic. The main advantage of this category of protocols is that nodes can quickly obtain route information and quickly establish a session [42].

2.6.2.2 Reactive (On Demand) Routing Protocols

Reactive routing protocols have the ability to dramatically reduce routing overhead because they do not need to search for and maintain the routes on which there is no data traffic. On demand routing protocols execute the path finding process and exchange routing information only when there is a requirement by the station when it want to initialize a transmission to some destination. By using the method of on demand routing, the routing load is decreased a lot. This property is very appealing in the resource-limited environment [43].

2.6.2.2 Hybrid Routing Protocols

The advantages of proactive and of reactive routing are combined in this type of routing protocols. The routing is initially established with some proactively prospected routes and then serves the demand from additionally activated nodes through reactive flooding.
2.6.3 MAC protocols in Wireless Sensor networks

As in all shared-medium networks, medium access control (MAC) is an important technique which enables the successful operation of the network. A MAC protocol specifies how nodes in a wireless sensor network coordinate their communication over a shared communication channel.

A significant amount of energy is consumed by the sensor node’s radio. Great research has been done on the design of low power electronic devices in order to reduce energy consumption of these sensor nodes. Due to the hardware limitations, energy efficiency can be achieved through the design of energy efficient communication protocols. MAC is an important technique which ensures the successful operation of the network. One fundamental task of the MAC protocol is to avoid collisions from interfering nodes.

MAC protocols for the WSN must achieve two objectives. The first objective is the creation of the sensor network. A large number of sensor nodes are deployed and the MAC scheme should be responsible for establishing the communication links between the sensor nodes. The second objective is to achieve better fairness index value. This could be done by sharing the communication medium fairly and efficiently.

The network topology changes over time as well due to many reasons. A good MAC protocol should be able to easily accommodate such network changes. Fairness, latency, throughput and bandwidth utilization are generally the primary concerns in traditional wireless voice and data networks.

2.6.4 Security in Wireless Sensor networks

WSN is an emerging technology that are used in applications, including wildlife and ocean monitoring, manufacturing machinery performance monitoring, building safety and earthquake monitoring, and many military applications. Because of the nature usage of the WSN, traditional security techniques used in traditional networks cannot be applied directly. Sensor nodes are often deployed in accessible areas, presenting the added risk of
physical attack. Besides, sensor networks interact closely with their physical environments and with people, posing new security problems. Therefore, existing security mechanisms are inadequate [32].

2.7 Routing protocols in Sensor networks

In the section, we make introduce different routing protocol for WSN. Besides, a detailed explanation of the AODV would be presented as it integrated with the proposed energy based scheduling schema.

2.7.1 Ad Hoc On-Demand Distance Vector Routing Protocol (AODV)

AODV routing protocol is another on demand routing protocol. Routes are established when they are required. Compared with DSR, AODV maintains the routing table in each node rather than in each data packet header.

2.7.1.1 Route Discovery

When the source node initiates a route discovery process to the destination, a RREQ packet will be broadcast to the network. When its neighbours receive this packet, they will check the source address and request id, which can uniquely identify this packet. If it is the first time they receive this packet and they do not have the routing information to the destination, they will rebroadcast it and the hop count of RREQ will be increased by one. Otherwise, they will discard it. In addition, they will set up a backward entry those points to the source in their routing table. Eventually, the destination or any intermediate node that has routing information to the destination receives this RREQs packet. Then a RREP packet will be sent back to the source [48].

Figure 2.3 illustrates the process of route discovery. The RREP packet will travel back to the source in the reverse direction. In addition, all intermediate nodes will set up a forward entry in their routing table to the
destination. When the RREPs packet arrives at the source, the route discovery process is completed.

![Figure 2.3 AODV route discovery](image)

The RREP packet will travel back to the source in the reverse direction. In addition, all intermediate nodes will set up a forward entry in their routing table to the destination. When the RREPs packet arrives at the source, the route discovery process is completed. When the route is set up successfully, the source can start sending data packets to the destination. Each routing entry has an expiration period. If this routing entry is idle for a while, this route will be considered broken and a RERR packet will be generated and sent back to the source indicating that the destination is unreachable.

Each node can get to know its one-hop neighborhood by using HELLO packets. The purpose of HELLO packets is to inform its neighborhood that is still alive. Hello packets will not be forwarded. When a node receives a HELLO packet, it updates the corresponding lifetime of the neighbor information in its routing table. This local connectivity management should be distinguished from general topology management to optimize response time to local changes in the network.
In addition, AODV uses sequence numbers to solve the loop problem. Each node maintains its own sequence number. When it sends a RREQ, its sequence number will be incremented. In addition, when it sends a RREP, its own sequence number will be the maximum of the current sequence number and the sequence number in the RREQ.

2.7.1.2 Route Maintenance

When a route which is active is down due to node failure, the neighborhood nodes are notified through a RERR message. When a node receives an RERR, it marks its route to the destination as invalid. When a source node receives an RRER, it can reinitiate the route discovery.

2.7.1.3 Control Messages

There are three kinds of control packets used in AODV. Control messages used for the discovery and breakage of route are as follows [47]:

- **Route Request Message (RREQ)**
  
  A route request packet is flooded through the network when a route is not available for the destination from source. This packet is used in a route discovery operation when the destination is not available. It includes the addresses of the source and the destination. In addition, it has request ID, hop count and the sequence number of the source and the destination. Figure 2.4 shows the fields contained in a RREQ packet.

<table>
<thead>
<tr>
<th>Source Address</th>
<th>Request ID</th>
<th>Source Sequence Number</th>
<th>Destination Address</th>
<th>Destination Sequence Number</th>
<th>Hop Count</th>
</tr>
</thead>
</table>

Figure 2.4 AODV RREQ packet
After receiving of request message, each node checks the request ID and source address pair. The new RREQ is discarded if there is already RREQ packet with same pair of parameters. A node that has no route entry for the destination, it rebroadcasts the RREQ with incremented hop count parameter. A route reply (RREP) message is generated and sent back to source if a node has route with sequence number greater than or equal to that of RREQ.

- **Route Reply Message (RREP)**

  If the intermediate node knows the route to the destination or the destination receives a RREQ packet, they will send a RREP packet back to the source. Figure 2.5 shows the fields contained in a RREP packet.

<table>
<thead>
<tr>
<th>Source Address</th>
<th>Destination Address</th>
<th>Destination Sequence Number</th>
<th>Hop Count</th>
<th>Life Time</th>
</tr>
</thead>
</table>

Figure 2.5 AODV RREP packet

- **Route Error Message (RERR)**

  The neighborhood nodes are monitored. When a route that is active is lost, the neighborhood nodes are notified by route error message (RERR) on both sides of link.

<table>
<thead>
<tr>
<th>Unreachable destination IP address</th>
<th>Unreachable destination sequence number</th>
<th>Additional unreachable destination IP Address</th>
<th>Additional unreachable destination sequence number</th>
</tr>
</thead>
</table>

Figure 2.6 AODV RERR packet

30
• HELLO Messages.
The HELLO messages are broadcasted in order to know neighborhood nodes. The neighborhood nodes are directly communicated. In AODV, HELLO messages are broadcasted in order to inform the neighbors about the activation of the link. These messages are not broadcasted because of short time to live (TTL) with a value equal to one.

<table>
<thead>
<tr>
<th>Destination IP address</th>
<th>destination sequence number</th>
<th>Originator IP Address</th>
<th>Originator sequence number</th>
</tr>
</thead>
</table>

Figure 2.7 AODV Hello packets

2.7.2 Dynamic Source Routing (DSR)
The Dynamic Source Routing (DSR) Protocol is a source-routing on-demand protocol. The difference in DSR and other routing protocols is that it uses source routing supplied by packet’s originator to determine packet’s path through the network instead of independent hop-by-hop routing decisions made by each node. The two major phases of the protocol are: route discovery and route maintenance. It is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes [45].

When the source node wants to send a packet to a destination, it looks up its route cache to determine if it already contains a route to the destination. Each node maintains route caches containing the source routes that it is aware of. The node updates entries in the route cache as and when it learns about new routes. If the node finds that an unexpired route to the destination exists, then it uses this route to send the packet. On the other hand, if the node does not have such a route, then it initiates the route discovery process by broadcasting a route request packet throughout the network [46].

The route request packet contains the address (usually the IP) of the source and the destination, and a unique identification number. Each
intermediate node checks whether it knows of a route to the destination. If it does not, it appends its address to the route record of the packet and forwards the packet to its neighbors. To limit the number of route requests propagated, a node processes the route request packet only if it has not already seen the packet and its address is not present in the route record of the packet [45, 46].

DSR uses Route Error packet to flag invalid links (links that are now unreachable due to mobility). When a node faces a fatal transmission problem at its data link layer (when the retransmit limit is reached), it generates a Route Error packet. When a node receives a route error packet informing it of a link that is now unusable, it removes the invalid link from its route cache. All routes that contain invalid link are truncated to that point.

In route discovery process, source node checks whether it has a route to this destination in the route cache then it sends packets to a destination. If the destination address is not in the table, the source node will initiate a route request (RREQ) packet for broadcast. Nodes receiving this RREQ will first see whether the destination is itself. If yes, it will reply with a route reply (RREP) packet unicast to the source node with the reverse path the RREQ traversed. Otherwise this node is an intermediate node. Intermediate nodes who receive this packet should first check the freshness of this RREQ. If the intermediate nodes have received this RREQ recently, it will ignore the packet; or else the intermediate node will rebroadcast this RREQ, another alternative is that the intermediate node replies the RREQ when it knows a route to the destination.

Source node should be notified using route error (RERR) packets when there is a break on any link on the route which is in use. Source node receiving the RERR will delete all the routes which contain the reported link. A new RREQ will be generated when the route is still needed.

The advantages of the DSR protocol include easily guaranteed loop-free routing, support for use in networks containing unidirectional links, use of only "soft state" in routing, and very rapid recovery when routes in the
network change. The DSR protocol is designed mainly for mobile ad hoc networks of up to about two hundred nodes. It is designed to work well with even very high rates of mobility [46].

2.8 Summary

In this chapter, we made an overview on the Wireless sensor networks. This overview took into account many topics regarding the WSN. These topics include architecture, design objectives, challenges and research areas. Then, we explain in details routing protocols which are related to our work.

In the next chapter, we will introduce scheduling techniques which are used in WSN.
Chapter 3
Scheduling Techniques in Wireless Sensor Networks

Scheduling is the primary mechanism available to intermediate nodes achieve their deadlines. The goal of real-time scheduling algorithms is to ensure that critical timeliness constraints, such as response time and deadlines, are met. When necessary, decisions are made that favor the most critical timing constraints, even at the cost of violating others [49].

This chapter is divided into four sections. The first section gives a brief overview on the scheduling in WSN. Then, the types of packet delays are mentioned. After that, the types of the scheduling schemas used in WSN, are introduced with a brief explanation for each one of them.

3.1 Scheduling in WSN

In the applications based on sensor networks, the scheduling algorithms have to work in a distributed manner. The scheduler residing on each node makes scheduling plans without any global knowledge [50].

Traditional real-time scheduling algorithms are designed for centralized systems such as a mainframe. Figure 3.1 shows a simple model of the function of a scheduler. For an input set of parameter values of a specified job, the scheduler outputs the priority of this job that is used for arbitrating scheduling on a critical resource.

![Scheduler function model](image)

Figure 3.1 Scheduler function model
The challenge here is how to schedule multiple data packets at each node independently so as to minimize the global data transmission miss ratio. Besides minimizing the global transmission ratio, minimizing energy consumption is another important challenge. Communication protocols for sensor networks must have the ability to provide real-time assurances, data transmission assurance and energy [26].

The nature of traffic in wireless sensor networks is bursty. It can cause the exceed of the network resources. In addition, the ad hoc nature of multi-hop sensor networks makes it difficult to schedule network traffic centrally as in traditional real-time applications. The scheduler residing on each node makes scheduling plans without any global knowledge. How to schedule multiple data packets at each node independently so as to minimize the global data transmission miss ratio is the challenge here [51, 52].

Existing real-time data communication work have developed packet scheduling schemes. These schemes work on prioritizing packets according to their deadlines. Packet prioritization cannot completely support real-time data communication requirements nor the energy consumptions constrains. Examples of the most used real-time sensor network protocols are the Basic Priority Scheduling, RAP, Just in Time Scheduling (JiTS). In our thesis, we will focus on the Basic Priority Scheduling in our simulations.

3.2 End-to-End Packet Delay in WSN

End-to-end delay refers to the time taken for a packet to be transmitted from source to destination across a network. For data communications across WSN, the problem is providing timeliness guarantees for multi-hop transmission under energy constraints. Any packet in the network, whether it is control or data packets, needs to traverse multiple hops from the source to the sink according to its deadline [53, 54].
3.2.1 End-to-End Packets Delay Components

The transport delay and the queuing delay are the main components of the end to end delay. They affect the packet end to end delay during transmission from source to destination.

3.2.1.1 Transport Delay

The transport time of packets from the source to sink are affected by the processing delay and the propagation delay. Minimizing the transport time of each packet is not close enough to minimize the end to end delay. The queuing delay at intermediate nodes is more important. As most of packets time, is consumed at intermediate nodes. The transport delay happens because of two delays:-

- **Processing Delay**
  
  While the transmission of control and data packets through intermediate nodes, specific processing might be necessary. Specific processing might be necessary, for some applications.

- **Transmission Delay** (or store-and-forward delay)
  
  The propagation delay of packets is determined by the bandwidth and the size of the message. In a network based on packet switching such as WSN, transmission delay is the amount of time required to push all of the packet's bits into the wire. In other words, this is the delay which is caused by the data-rate of the link.

3.2.1.2 Queuing delay

It is the time spent in the queues at each intermediate nodes on the path from the source to the sink. In other words, the time a job waits in a queue until it can be executed. It is a key component of network delay. As a packet is received at an intermediate node, it is placed in the MAC layer incoming queue. The queuing delay may be controllable by a scheduler, since a queue is used to store a data packet temporarily at any forwarding node. When the
network layer receives from the queue, it looks at the packet and decides where it needs to be forwarded next. The routing layer places the packet in a local queue while making routing decision. Consequently, the packet is placed in the MAC layer outgoing queue to be forwarded to the next hop. Since a queue is used to store a data packet temporarily at any forwarding node, the queuing delay may be controllable by a scheduler.

The queuing delay may grow to be the main part of the end-to-end packet transport time especially under high load. More specifically, under moderate to high data generation rates, congestion and other reasons, the queuing contribution to delay can far outgrow the physical transmission and processing contributions.

### 3.3 Main Scheduling Concepts in Wireless Sensor Networks

In WSN, there are different ways in packet scheduling. Scheduling could be done according to deadline, where packet deadline is the main constraint that affects the packet sending decision. Other technique depends on the available time that a packet may have through its journey to the destination [50]. Figure 4.2 shows the types of packet scheduling.

#### 3.3.1 Deadline-based Scheduling

In a wireless sensor network, the scheduling decision is made at each node independently. The deadline-based scheduling procedure schedules all incoming data packets based on their deadlines. If a data packet has an earlier deadline, it receives a higher priority than another with later deadline. These scheduling algorithms do not differentiate the up-to-date real-time status of each packet through its forwarding path and therefore may hurt the overall performance of the real-time scheduling system.
3.3.1.1 Rate Monotonic Scheduling

Rate monotonic scheduling is a kind of fixed-priority scheduling strategy, it is a deadline-based scheduling algorithm. The scheduling decision has to be made distributedly. Once the priority of one task is identified according to its periodicity, it will not change with time. A task in smaller periodicity has higher priority. RM can schedule a group of tasks while other fixed priority strategies can. Fixed-priority strategy is more suitable for wireless sensor network operating system, because it needs to be scheduled one time before running. Fixed-priority will be able to ensure the cyclical behavior, and the tasks are scheduled only in one queue. RM's shortcoming is the lack of flexibility due to its unchanged in running time. Therefore, it is not suitable for working during running [51].

RMS is the optimal static-priority algorithm. If a set of tasks cannot be scheduled using the RMS algorithm, it cannot be scheduled using any static-priority algorithm. A major limitation of fixed-priority scheduling is that it is not always possible to fully utilize the CPU [55]. Even though RMS is the optimal fixed-priority scheme, it has a worst-case schedule bound of:
\[ W_n = n \times \left(2^n - 1\right) \quad (3.1) \]

Where:-
- \( n \) is the number of tasks in a system.
- \( W_n \) is the worst-case schedule bound

The worst-case schedulable bound for one task is 100%. However, as the number of tasks increases, the schedulable bound decreases, eventually approaching its limit of about 69.3% (\( \ln(2) \), to be precise). It is theoretically possible for a set of tasks to require just 70% CPU utilization in sum and still not meet all their deadlines.

### 3.3.1.2 Earliest deadline first

Earliest deadline first (EDF) or least time to go is a scheduling algorithm used in packet scheduling. It places packets in a priority queue. Each packet is assigned a sending priority according to its deadline. The closer the deadline of a packet, the higher is its sending probability.

### 3.3.2 Real-Time Architecture for Sensor Networks

The key role of a scheduling algorithm in real-time communication architecture is to schedule the incoming packets for forwarding. Traditional first come first served scheduling may not work well in real-time applications. As, packets have different remaining times to their deadlines, besides the difference in the distances to reach their destination. Most of the scheduling schemas take neither the energy consumption nor the wireless sensor network lifetime in the calculations of the priorities. In the following sections, we present some scheduling schemas.
3.3.2.1 Basic Priority Scheduling

It is a technique for scheduling, which is the default scheduling schema in the NS-2. It depends on prioritizing the packets according to their usage. Priority values are assigned to every packet in the network regardless its energy consumption. High priority values are usually given to control packets, while medium or low priority values are given to data packets. Data Packs of same type are served in FIFO order [56].

3.3.2.2 Lagging Flow First Algorithm

Lagging Flow First (LFF) is a location-free algorithm proposed in [57]. This technique considers not only how to deliver the packets to arrive at their destinations within their deadlines but also how to minimize the maximum degradation. The degradation value is defined as $\epsilon$:

$$\epsilon = 1 - \frac{M_i^a}{M_i} - e_i$$  \hspace{1cm} (3.2)

Where:-
- $M_i^a$ is the number of packets that flow $i$ actually successfully delivered
- $M_i$ is the number of packets that flow $i$ was supposed to deliver
- $e_i$ is acceptable packet loss rate.

This technique maintains two queues, one is a reservation list to hold the packets that will be delivered, and the other is a buffer to hold packets that do not have spots in the reservation list. This technique is composed of two phases. In first phase, whenever a packet is available to be scheduled, a time slot could be reserved based on its deadline. Then this packet could be inserted into a reservation list if it is possible. Otherwise, this packet will be inserted into the second queue. In the second phase, a packet is scheduled in the
reservation list. Therefore, we can observe that the packets in the reservation list have higher priorities. This algorithm takes into consideration both the deadline and the degradation of the traffic flow.

### 3.3.2.3 Velocity Monotonic Scheduling Algorithm

Velocity Monotonic Scheduling Algorithm is a location-based algorithm proposed by [57]. The basic idea of this algorithm is to prioritize packets based on their velocities. The definition of packet's velocity is the ratio of the distance that it needs to travel to the time before its deadline. There are two versions of velocity monotonic scheduling: static VMS (SVM) and dynamic VMS (DVM).

VMS improves the number of packets that meet their deadlines because it assigns the “right” priorities to packets based on their different urgencies on the current hop. VMS also solves the fairness problem in sensor networks because packets that are far away from the base station will tend to have higher priorities when it competes against other packets that are closer to the destination.

VMS calculates the required packet “velocity”, which is used as its priority, from the deadline and distance between source and sink. In Static VMS, the velocity is computed once at the source. In Dynamic VMS velocity is recomputed at intermediate nodes. It also modifies the MAC layer back-off scheme to schedule packets according to priority. In the following section, we explain in details the static and dynamic versions of VMS [58].

#### A. Static Velocity Monotonic Scheduling

In Static VMS (SVM), packets are prioritized based on a fixed requested velocity. Velocity is computed at packet generation time. The values of parameters used by prioritizing at any intermediate node are that of the data source, not the forwarding node. All intermediate nodes have a separate queue for each priority level and packets of higher priority are always forwarded
before packets of lower priority. Since the priority is fixed at the beginning, an intermediate node cannot change it even if any unpredictable delay occurs. So the velocity is fixed or static and defined as follows:

\[
Velocity = \frac{\text{Distance between source and destination}}{\text{E2E Deadline}}
\]  

(3.3)

For routing protocols with different policies, the distance between source and destination is measured in different ways. The distance is measured in number of hops, when using shortest path routing. For geometric routing, it would be measured in Euclidean distance. The shortcoming of SVM is that since the delay times of packets at intermediate nodes are unpredictable, it is unable to increase the priority of a packet that is unexpectedly delayed, or reduce the velocity of a packet that is lucky enough to make quick progress initially towards the destination.

**B. Dynamic Velocity Monotonic Scheduling (DVM)**

Dynamic VMS recalculates the velocity and resulting priority at each intermediate node. The value of velocity is decided by function:

\[
Velocity = \frac{\text{Distance between Current node and destination}}{\text{E2E Deadline}}
\]  

(3.4)

The advantage of dynamic VMS is that an intermediate node has an ability to adjust the priority based on the specific situation. Table 3.1 shows how DVM and SVM are calculated for a packet between node a and node b.
Table 3.1: Packet priorities when different VMS policies are used

<table>
<thead>
<tr>
<th>VMS policy</th>
<th>At node a</th>
<th>At node b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static VMS</td>
<td>(\text{distance(a, sink)}) / E2E Deadline</td>
<td>(\text{distance(a, sink)}) / E2E Deadline</td>
</tr>
<tr>
<td>Dynamic VMS</td>
<td>(\text{distance(a, sink)}) / E2E Deadline</td>
<td>(\text{distance(b, sink)}) / E2E Deadline  — Elapsed Time</td>
</tr>
</tbody>
</table>

3.3.2.4 Just in Time Scheduling (JiTS)

The Just in time scheduling is a scheduling scheme that is used for real-time data communication in sensor networks [59]. This approach overcomes the shortcoming of other real-time approaches by setting target transmission times for the packets according to their deadline and the remaining distance along the path to achieve more effective communication by allocating the slack time (time until the deadline) among the intermediate hops. JiTS delays data packet transmission during forwarding for a duration that correlates with their remaining deadline and distance to the destination. Intuitively, this helps in heavy-traffic communication environment by making sure that priority inversion does not occur due to a node with low priority packets sending. Also, it helps in preventing a node with high priority packets from doing so. The Estimation of Transmission Delay (ETD) is used to approximate the MAC layer transmission delay. Since this time is spent below the network layer, the scheduling cannot directly affect it.

Before a data packet reaches the sink, the end-to-end transmission and processing delay cannot be obtained. Therefore, previous measurements of delay were used to estimate the overall delay: it is called this estimate the end-
to-end Estimate of Transmission Delay (EETD). Summing the ETD’s of a data packet hop by hop during its forwarding can lead to inaccurate estimates since one hop ETD can fluctuate significantly. Therefore, we use the following function to decide the EETD:

\[ \text{EETD} = \text{ETD} \cdot \frac{\text{E2E distance}}{\text{One hop distance}} \]  

(3.5)

Where:-

- The distance can be measured in different ways.

Different JiTS scheduling policies can be developed based on the allocation of the available slack time among the different hops. The target transmission times are either set by the source or computed at intermediate hops based on a known algorithm. In the base JiTS algorithm, the target transmission time is set to be equal at all hops and is determined as follows:

\[ \text{Target Delay} = \frac{\text{deadline} - \text{EETD}}{\text{distance}(X, \text{sink})} \cdot \alpha \]  

(3.6)

Where:-

- \( \alpha \) is a constant safety factor for insurance that the real-time deadline would be met.

Packet priority is determined by the Target Delay. The time a packet is delayed in the queue can be used as the key to a priority queue that holds the packets to be transmitted. The end-to-end transmission and processing delay is considered along with the queuing delay, by considering the end-to-end deadline, distance and EETD.
A. Static Just-in-Time Scheduling

In static JiTS, the target delay is set with the values of parameters at the data source. In equation 3.6, the end-to-end deadline is fixed at the data source; the EETD is measured with the ETD of forwarding node and the distance from source to sink (X is the data source). So even we call it static, the different ETD’s of forwarding nodes would make the target delay at each node different.

B. Dynamic Just-in-Time Scheduling

In dynamic JiTS, the target delay is re-set at each forwarding node with the local value of parameters. In Equation 3.4, the end-to-end deadline of a packet at some forwarding node is the remaining slack time, measured by E2E Deadline − Elapsed Time. The EETD is decided by the one-hop ETD of the forwarding node and the distance from it to the sink. It is not the distance from source to sink. So, the dynamic JiTS is able to continuously refine the priority of the packet.

C. Non-linear Just-in-Time Scheduling

It is possible to allocate the available slack time non-uniformly among the intermediate hops along the path to the sink. For example, it is desired to provide the packets with extra time as it gets closer to the sink. The anticipation is that in a gathering application, the contention is higher as the packet moves much closer to the sink. Different policies can be developed to break down the available time. We explore the following policy:

\[
\text{Target Delay} = \frac{\text{E2E Deadline} - \text{EETD}}{2 \cdot \text{One hop Distance}} \cdot \alpha \quad (3.7)
\]
3.3.2.5 RAP: a Real-time Architecture for Sensor Networks

RAP is a real-time framework developed at the University of Virginia [58]. RAP uses Velocity Monotonic Scheduling (VMS) to prioritize the data packets. RAP does not consider the queuing delays of data packets; once the packet is assigned a priority it remains at that priority regardless of queuing delay. RAP also modifies the MAC layer back-off schemes to schedule packet transmission. The main design goal of RAP is to develop a fair scheduling algorithm for data dissemination in a distributed wireless sensor network, so as to minimize the miss ratio of real-time data traffic. RAP requires support from several layers in the network, which represents a significant deployment barrier, especially for heterogeneous networks. In RAP, each incoming data packet is assigned a priority by VMS scheduler based on its requested velocity, and then queued into the priority queues before it is forwarded.

3.4 Summary

In this chapter, we make a brief introduction of scheduling schemas in WSN. This introduction includes the definitions of the scheduling process in WSN. Then, we explored the types of end to end delays in WSN. Finally, we introduced the some scheduling schema and algorithms used in WSN, classified according to their packet priority assignment process.

In the next chapter, we will introduce in details our proposed energy based scheduling schema.
Chapter 4

Proposed Energy Based Scheduling Scheme

The key role of a scheduling algorithm in real-time communication architecture is to schedule the incoming packets for forwarding. Traditional FCFS scheduling does not work well in real-time applications because packets have different remaining times to their deadlines, but also different distances to reach their destination. In the context of sensor networks, packet scheduling should be both deadline-aware and distance aware. Deadline-aware means that a packet’s priority should relate to its deadline, the shorter the deadline, the higher the packet priority. Distance aware means that a packet’s priority should relate to its distance from the destination, the longer the distance, the higher the packet priority.

The primary challenges here are how to prioritize and schedule packets. Other challenge in real-time sensor network applications is how to carry out sensor data dissemination given source-to-sink end-to-end deadlines when the communication resources are scarce. In a sensor node, energy is consumed by sensing, communication and data processing. More energy is required for data communication than for sensing and data processing.

In this chapter, a new scheduling scheme that will not only prioritize packets according to their deadlines but also according to their sizes, energy consumption during transmission and energy path level. The new scheme efficiently manages packet dropping at each node in order to avoid dropping packets, which consumed high energy during transmission. Moreover, it does not require any support from or changes to the lower layer protocols. In addition, the new scheme can work with Ad hoc On Demand Distance Vector (AODV) Routing Protocol.
4.1 Main Idea of the Proposed Scheme

Energy usage in packet transmission is much greater than its usage in data processing and sensing. Efficient usage of sensor's energy resources and maximizing the network lifetime are the main design considerations for the most proposed protocols and algorithms. However, depending on the type of application, the generated data packets may differ in their energy consumptions. This section, will introduce a new scheduling scheme called Energy Based Scheduling Scheme

A. Energy Based Scheduling Scheme

The primary challenges of packet prioritizing according to deadline or available time slack, is that it may lead to dropping high energy valuable packets. Packets arriving from far sources may consume much energy. Dropping these valuable energy packets may lead to shorten the network lifetime. In addition, packet transmission path is a major issue that should be considered in packet scheduling. Packet transmission decision should not only be affected by the packet deadline, but also by packet energy consumption and packet transmission path. Routing protocols are responsible for the path selection. According to the selected path, packets are sent from source to destination. During packet transmission, each node queues the packets to its buffer. Energy Based Scheduling Scheme schedules the buffered packets at each node, according to specific parameters. This Scheme is the primary contribution of this thesis.

4.2 Scheme Parameters

The proposed scheme depends on the fact, that energy usage in packet transmission is so greater than its usage in data processing and sensing. Scheduling schemes have the responsibility of whether to drop, delay or send the packet according to some measures, form node queues. The problem is how
to prioritize packets according to four constraints packet deadline, packet size, packet energy consumption during transmission and packet energy path level. According to this measure, we can find the path stability and strength that a packet uses through its transmission from source to sink. The following information is needed to schedule packets in the proposed scheme.

4.2.1 Packet Deadline

This information is provided by the application in the data packet. It is required by any real-time data communication application. According to this information, each node might drop or delay the packet for a particular time. When any packet reaches its deadline, the corresponding node, which is holding that packet in its queue, must drop it.

4.2.2 Packet Size

In WSN, there are two types of packets. They are control packets and data packets. Control packets are used by the routing protocol for handling data delivery. Data packets are the packets that are responsible for carrying the required sensed data from a particular node to the destination. Control and data packets contain reserved bits that will be used by our scheme. In the proposed scheme, packet size might be used in prioritizing packets.

4.2.3 Packet Energy Path Level

It is a new measure that is required by the proposed scheme. This energy measure reflects the value of the energy nodes across a specific path. According to this measure, we can find the path stability and strength that a packet uses through its transmission from source to sink. This measure is calculated at each node which a packet uses during transmission.
4.2.4 Packet Energy Consumption during Transmission

During packet journey from source to destination, each node receives the packet, buffers it and retransmits it to the destination or the next node close to the destination. In the proposed scheme, Packet Energy Consumption during Transmission is an important factor in prioritizing packets, as energy consumption in packet transmission is so greater than its usage in data processing and sensing.

4.3 Scheme Equations

Buffered packets at each are assigned sending priorities in a priority queue. The priority queue holds the packets to be transmitted. In the proposed scheme, each assigned priority is according to packet deadline, packet size, and packet energy path level and packet energy consumption during transmission. These four parameters have major effect on the network energy measures. These measures might be the network life time or the energy consumption for the goodput. Some other network measures might be affected when applying the scheme. Through the next chapters, these measures are used in comparing the proposed scheme against.

The following notations are used in the discussion.

- PD: packet deadline
- PS: packet size
- PEP: packet energy path level
- PEC: packet energy consumption during transmission

Subscript ‘i’ is often used with these parameters to indicate that they are for a node i, while subscript ‘x’ is used to indicate that they are for a packet x.

For packet x, $PEP_x$ at node d, is calculated through the following equation:
\[ PEP_x(d) = \sum_{i \in R_x} \frac{E(i)}{IE_i} \] (4.1)

where:-
- \( PEP_x(d) \) is packet energy path level at node \( d \) for packet \( x \)
- \( E(i) \) is the current energy for node \( i \) while receiving packet \( x \)
- \( IE_i \) is the initial energy for node \( i \).
- \( R \) denotes the set of nodes that packet \( x \) uses through transmission from its source to node \( d \). It shows the path strength and stability according to the energy of each node.

To calculate the \( PEC_x \) for packet \( x \) at node \( d \), we use the following equation:

\[ PEC_x(d) = \sum_{i \in RT_x} \frac{ET_x}{E(i)} + \sum_{i \in RR_x} \frac{ER_x}{E(i)} \] (4.2)

where:-
- \( PEC_x(d) \) is the packet energy consumption during transmission of packet \( x \) at node \( d \)
- \( ET_x \) is the energy transmission cost for packet \( x \)
- \( ER_x \) is the energy cost for packet \( x \) reception.
- \( RT_x \) and \( RR_x \) are set of nodes used for transmission and reception respectively.

So, the problem is simplified to find a suitable priority for each packet during its transmission. This priority should consider packet deadline, packet size, and packet energy path level and packet energy consumption during transmission. According to this priority, any packet buffered in a queue, could be sent or delayed. Therefore, the equation used for packet priority calculation in our scheme should reflect the effect of its related parameters. In order to apply the proposed scheme, the maximum packet size and deadline values,
used by the network, are required. These values are used to normalize the packet size and deadline.

The following equation is used to calculate the packet sending priorities (PSP) for each packet \( x \) at each node \( d \) in:

\[
PSP_x(d) = \frac{PSN_x \times \frac{PEC_x(d)}{N_x} \times \alpha}{\frac{PEP_x(d)}{N_x} \times PDN_x}
\]

(4.3)

Where:-

- \( PSP_x(d) \) is the packet sending priorities of packet \( x \) at node \( d \)
- \( PEC_x(d) \) is the packet energy consumption during transmission of packet \( x \) at node \( d \)
- \( PEP_x(d) \) is packet energy path level at node \( d \) for packet \( x \)
- \( \alpha \) is a constant factor for insurance that the packet deadline would be met
- \( N_x \) represents the number of nodes, which packet \( x \) used
- \( PSN \) and \( PDN \) are the normalized values for packet size and deadline.

According to PSP value, each node would decide whether to send the packet at once or delay it. This scheme would help in increasing the network lifetime for the remote node of the networks. Packets from remote nodes would have increasing sending priorities through their path to the destination. We use PEP in order to overcome the problem of higher sending priorities for packets from remote nodes.

During the packet trip from its source to destination, it is buffered in every node queue across its path. Each node carries the responsibility of calculating the \( PSP \) for each packet in its buffer. In order to get the value of \( PSP \) for each packet, we modify the packet header by adding new header parameters to it. These parameters will be the values of \( PEP, PEC \) and the number of visited
nodes without the current node. Using these parameters, each node will be able to calculate $PSP$ for each packet in its queue. Before packet transmission, the node transmitting the packet must update the new added parameters in the packet header.

### 4.4 Priority Queue

Managing limited resources such as bandwidth on a transmission line can be done through Priority queuing. The output of energy based scheduling scheme is the queuing of packets, which is assigned sending priorities. This queue is used by the routing protocol to decide which packet to retransmit according to the assigned priority (by passing it to the MAC layer). A single priority queue for packet forwarding based on the computed target transmission time is used by the energy based scheduling scheme. When the queue is full, the scheme selects the packet at the head of the queue to immediately forward it instead of dropping any packet in the queue.

If there was no heavy traffic through the current node and priority queue is not almost full, the energy based scheduling scheme is not needed. The proposed scheme can be disabled and packets are forwarded normally.

A single priority queue is used in the routing layer for forwarding packets. It can better track the priority of data packets than the approach of several FIFO queues with different priority levels.

### 4.5 Integration with routing protocols

In this section, we will show how to integrate the proposed scheme with the Ad hoc On Demand Distance Vector routing algorithm. AODV don’t have any effect on the sending priorities, as they are assigned by the proposed scheme.
4.5.1 Energy Based Scheduling Scheme for AODV

The Ad hoc On Demand Distance Vector (AODV) routing algorithm is a routing protocol designed for wireless mobile networks. It is selected as the baseline routing protocol because it is an on-demand protocol without global periodic routing advertisement. Besides, it consumes less overall network bandwidth as the network is silent until a connection is needed. It creates no extra traffic for communication along existing links [47]. AODV achieves comparable results when it is used in wireless sensor networks and compared with the common WSN routing protocols [60,61]. In [62 - 64] several updates are applied to the AODV in order to make it applicable to be used in WSN.

4.5.1.1 Ad hoc On Demand Distance Vector (AODV) Routing Protocol

The AODV was mentioned in chapter 2. Being a reactive routing algorithm, AODV only maintains the routing paths which are used in packet transit. It is considered a destination based reactive protocol, which avoids routing loops by using of sequence numbers. In this protocol, the nodes use the sequence numbers to avoid loops and take the path information as updated as possible. When a source node wants to transmit information to a destination node, a short route request (RREQ) message will be initiated and broadcast by the source, with an estimated and pre-defined lifetime (TTL). RREQ is rebroadcast until the TTL reaches zero or a valid route is detected. Each node, receiving the RREQ will add a valid route entry in its routing table to reach the RREQ source, called reverse route formation. When the RREQ reaches the destination or a node that has a valid route to the destination, a route reply (RREP) message is uni-cast by this node to the source. The RREP message will go to the source, following the reverse route formed by the RREQ [47].
4.5.1.2 Scheme Implementation for AODV

In order to apply our scheme on AODV, the energy for each node in transmission path and the energy consumption during transmission should be assigned to packet, which used that path. For AODV, there are four types of packets, which are used for routing and path discovery. They are Route Request (RREQ), Route Reply (RREP), Route Error (RERR) and Route Reply Acknowledgment (RREP-ACK). According to [11], each packet has a number of unused bits, called reserved bits. The number of unused bits in each packet is shown in Table 4.1. Our proposed scheme works on making use of these unused bits to store the PEP and PEC for each packet, in order to use them in calculations. Figure 4.1 shows how the proposed scheduling scheme reacts with the different components of the WSN.

<table>
<thead>
<tr>
<th>AODV packet type</th>
<th>Number of unused bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>RREQ</td>
<td>11</td>
</tr>
<tr>
<td>RREP</td>
<td>9</td>
</tr>
<tr>
<td>RERR</td>
<td>15</td>
</tr>
<tr>
<td>RREP-ACK</td>
<td>8</td>
</tr>
</tbody>
</table>

4.6 WSN Application adaptation

As we mention in section 2.3, WSN applications differs in its requirements from one application to another. These differences are according to application nature or usage. Some WSN applications, which are used in Battlefield Monitoring in military applications, might need to have a better network life time. In addition, deploying sensors in a battlefield to monitor the presence of forces and vehicles, and track their movements, enabling close surveillance of opposing forces, would make replacing low battery nodes, so hard and
dangerous. So, the calculated packet sending priorities (PSP) could be compared to a threshold. According to this threshold, each node can take the decision of whether buffering the packet for a period of time or immediately forward it, regarding the energy packet consumption.

![Figure 4.1 Scheduling Scheme in WSN architecture](image)

According to Figure 4.2, we could find that low threshold packets with low energy consumption have the same chance as packets with high energy consumption and high threshold. However, high threshold value would give packets with high energy consumption much better chance in retransmission than other packets. The proposed scheme by default could assign sending probability to packets depending on the consumed energy for each packet. Sometimes, WSN application might require high threshold value in order allow
packets of high energy consumption to have much better sending probability. The use of the threshold value and its effect on network lifetime and packet delivery ratio would be disused in the next chapter.

![Packet Energy consumption vs. the threshold](image)

Figure 4.2: Packet Energy consumption vs. the threshold

### 4.7 Properties of proposed Energy Based Scheduling Scheme

The proposed scheme has some important features and properties that differs it from other scheduling algorithms. These features and properties give our scheme advantages in the energy and lifetime fields. In this section, we will show the features of our scheme.

#### 4.7.1 Routing protocol independent

The main advantage of the Energy Based scheduling scheme is the routing protocol independency. The scheme can work with any routing protocol. The required parameters for the scheduling scheme can be calculated easily at any node, without any support from the routing protocol or the MAC layer. However, a trade off might appear if the used routing protocol does not have
reserved bits in the used packets. Moreover, additional bits to any packet format might lead to an increase in the networks energy.

4.7.2 MAC layer protocol independent

Unlike the JiTS, the Energy based scheduling scheme does not require MAC layer support for prioritized scheduling. This makes Energy based scheduling scheme readily deployable on existing infrastructure. The Energy based scheduling does not require MAC layer support for prioritized scheduling or for tracking delay.

4.7.3 Energy aware

The important feature of the proposed scheme is its energy awareness. Any priority assigned or packet dropped or retransmitted, is done according to some energy measures. This way in taking decisions helps in increasing the network lifetime and decreasing the energy consumption for the goodput.

4.7.4 QoS aware

Minimizing the packet loss ratio is an important factor in the proposed scheme. Moreover, decreasing the packet loss should be achieved with an increase in the network lifetime and the energy consumption for the goodput.

4.8 Overall Proposed Scheme

In this section, we will show in steps how the proposed energy based scheme works when a packet is queued in the queue of a node in WSN. When a packet is buffered in the nodes the following should be done by the proposed scheme:

- If the packet is buffered in its source node
  1. The current node energy is normalized according to the node initial energy and stored in the node header.
2. The amount energy consumed by node for send a packet is normalized according to current nodes energy and stored in the packet header.

- If the packet is buffered in an intermediate node
  1. The current node extracts the values of the previous node(s) energy and the amount of energy consumed by the node during it journey.
  2. The node adds the value of the current node energy after normalization to the extracted energy value.
  3. The PEP is calculated for this packet according to equation (4.1)
  4. The node adds the value of the amount energy consumption after normalization to other extracted energy values
  5. The PEC is calculated for this packet according to equation (4.2).
  6. The PSP is calculated according to equation (4.3)
  7. According to the value of PSP, the decision of whether to send or delay a packet in the queue is taken.

4.9 Summary

In this chapter, we have presented the proposed energy based scheduling scheme and its integration with the AODV.

The chapter starts with brief introduction of the effect of the energy on WSN which followed by introducing the proposed scheduling energy based scheme. Then, we present equations used in our scheme in order to calculate the packet sending probability for every packet.

Next, we show how to integrate the proposed energy based scheme with AODV routing protocol. Then, we present the steps used in calculating packet send probability.

The next chapter will show how our scheduling scheme integrated with AODV, works in WSN. Also, we will compare it with other routing protocols
Chapter 5
Simulation of the Scheme and Results

The primary goal of the research is to develop a scheduling scheme, which fulfills the demands for minimizing the energy consumption and maximizing the WSN life time. A great attention should be paid for the QoS and fairness while achieving these demands. The previous chapter presented the proposed energy based scheduling scheme in wireless sensor networks. It shows the mathematical equations, which are used in the proposed scheme in assigning send priorities to data and control packets. In this chapter, a comparison is done between the proposed scheme and the Basic priority scheme.

Simulation is the most deployed method to evaluate algorithms and protocols for WSNs. It enables the researcher to deal with complex topologies, network scalability, and repeating of experiments. Simulations are also carried out at low cost, for these reasons simulation gains a lot of popularity as evaluation method. In the simulation, NS2 was used as the network simulator. The proposed scheme would be compared according to some network metrics.

This chapter introduces the evaluation and comparison of the proposed energy scheme against the Basic priority scheme using simulations. The comparison is done against the normal AODV, DSR and DSDV.

5.1 The Network Simulator (NS-2)

The Network Simulator (NS-2) was used as simulation software to accomplish the performance evaluation in this thesis. NS-2 is a discrete-event simulator, which can be obtained as public domain software. Currently, it is widely used in all kinds of network research areas such as, LAN, Internet and wireless sensor network. It is free and open source software that makes NS very popular and is used in several research projects [67].
NS-2 is an object oriented simulator developed as part of the VINT project at the University of California in Berkeley. The project is funded by DARPA in collaboration with XEROX Palo Alto Research Center (PARC) and Lawrence Berkeley National Laboratory (LBNL). Ns-2 is extensively used by the networking research community. It provides substantial support for simulation of TCP, routing, multicast protocols over wired and wireless (local and satellite) networks, etc.

5.1.1 Why Network Simulator (NS-2)?

Several extensions for NS-2 can be obtained from researchers worldwide. It provides many useful tools such as NAM, trace file and TCL. In addition, many protocols have already been implemented in this simulator for example, TCP, UDP, many routing algorithms, multicast protocols and IEEE 802.1 1 DCF. Therefore, it can concentrate on implementing and studying our scheduling scheme.

NS-2 is written in both C++ and OTcl programming languages. The Code in C++ is used for data path and in OTcl for control path. OTcl is an object oriented language, which is an extension to the scripting language Tcl. OTcl is an easy to use language that can be used to have rapid application development. The OTcl linkage matches an OTcl object for one of the C++ objects to enable the control of C++ objects to C++. NS-2 has also C++ objects, which operate without the need of OTcl control. The simulator has modules that are completely implemented in OTcl and are not in C++. NS-2 is controlled by utilizing of user simulation scripts, which are written in OTcl [68].

The OTcl script maintains the main characteristics of the case study to be simulated. An OTcl interpreter is used to set up the simulation configurations and controls of C++ data path. NS-2 was firstly focused on wired networks and later was extended to wireless and mobile hosts. Also, users can use NAM which is a Tcl/TK based animation tool to observe network simulation. It
provides network topology layout, packet transmission animation, and various data inspection tools [68].

The simulation process of a protocol is achieved through the simulation scripts in OTcl. Otherwise, the user needs to implement the protocol firstly in C++. User can then simulate the protocol using simulation scripts written in OTcl. The OTcl script maintains the main characteristics of the case study to be simulated. An OTcl interpreter is used to set up the simulation configuration and controls of C++ data path. As mentioned before, NS-2 was firstly focused on wired networks and later was extended to wireless and mobile hosts.

5.1.2 Node Architecture in Network Simulator-2

In NS-2, network physical activities are translated to events. Events are queued and processed in the order of their scheduled occurrences. And the simulation time progresses with the events processed. And also the simulation “time” may not be the real lifetime as we “inputted”. It can configure transport layer protocols, routing protocols, interface queues, and also link layer mechanisms. We can easily see that this software tool in fact could provide us a whole view of the network construction, meanwhile, it also maintain the flexibility for us to decide. Thus, just this one software can help in simulating nearly all parts of the network. This definitely will save us great amount of cost invested on network constructing.

This thesis focuses on the implementation of IFq module and prioritized MAC module. In this section, we mainly discuss the implementation of IFq module. It is known that IFq module provides a buffer and a scheduling algorithm. Therefore, one of our main tasks is to implement our proposed algorithms to replace the original IFq algorithm. The architecture of the NS-2 MAC layer has been changed as shown in Figure 5.1. In this chart, the energy based scheduling scheme is between the LL module and the MAC module. It accepts packets from the LL module and selects a packet in terms of its
scheduling algorithm. Then it transmits packets to the MAC module. The real-time scheduling module contains the implementation.

![Architecture of the WSN node in NS-2](image)

Figure 5.1: architecture of the WSN node in NS-2

### 5.1.3 Simulation Process Steps

In order to evaluate, compare and study the effect and behavior of our scheme, simulation is done against the Basic priority Scheme. Each time a simulation is run the following steps are done.

1. Traffic pattern is generated by Matlab. These patterns connectivity of sources in the OTcl script.
2. The user programs scenario to be simulated with OTcl. This includes event scheduler initiation, set up of network topology, starting and ending of packet transmitting, setting values of corresponding data, event log and visualization set up.
3. The Network Simulator executes the OTcl script.
4. After executing of the OTcl script, the results are taken in form of trace files. Each line in a trace file contains a packet event. It is very helpful that tracing in NS-2 can be done at MAC level and at routing level. The network simulator supports two trace formats that are called old and new trace format. The new trace format is designed for the wireless traces. The generated trace files are then analyzed by utilizing of scripts written in a scripting language as AWK. NS-2 includes the NAM tool, which enables the visualization of packets exchange.

5.1.4 The Simulation Scripts

Simulation scripts are the input to the network simulator, which include all the information related to the simulation case study. The script begins usually with the configuration of the simulation components of the network such as the topography, the queues, the MAC protocol, the routing protocol and the wireless channel.

The instructions to create the trace files are included in the simulation script. The configuration of the mobile nodes is done and that is followed by the creation of the nodes. The next part in the simulation script is to define the initial positions of the nodes followed by definition of the mobility pattern of the node.

5.2 The Hardware used in the Simulation

All simulation and programming works in this thesis were performed in Window Server 2003 Enterprise Edition service pack 2 using the compiler gcc 2.9.6. All experiments were running on Dell PowerEdge 2800 tower server with Intel Xeon CPU 3.40 GHz and 4 GB of RAM.

The simulation of wireless communication using NS-2 is a very time consuming process. The execution of one simulation may take more than 10 hours. This simulation duration is increased by the increasing the traffic and network simulation time. The NS-2 output trace files which requires a big
memory space for storage. Some of the trace files have sizes of several giga bytes. Appendix B will show the format of the trace files and the code required for analyzing and processing the large size trace files.

5.3 Simulations Parameters and environment

In our simulation, some parameters will be constant across all the simulation, in order to have a clear view of the effect of the proposed scheme. These parameters are shown in table 5.1. 100 sensor nodes are randomly deployed in a square area in different scenarios to simulate our scheme [69]. The source and destination of traffic flows (CBR) are randomly selected as well. All traffics are periodic of CBR type, with a constant packet size of 32 Byte. The physical and MAC layer parameters were set as in table 5.1 [69].

Table 5.1: Simulation Parameters

<table>
<thead>
<tr>
<th>Mac layer Protocol</th>
<th>IEEE 802.11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission Radio Range</td>
<td>250 Meter</td>
</tr>
<tr>
<td>Data Packet Size</td>
<td>32 Byte</td>
</tr>
<tr>
<td>Data Rate</td>
<td>2 packet/sec</td>
</tr>
<tr>
<td>Simulation Area</td>
<td>1000 Meter X 1000 Meter</td>
</tr>
<tr>
<td>Number of Sensor nodes</td>
<td>100</td>
</tr>
<tr>
<td>Node Initial Energy</td>
<td>100 Joule</td>
</tr>
<tr>
<td>Transmission Power</td>
<td>0.024 Joule</td>
</tr>
<tr>
<td>Reception Power</td>
<td>0.0135 Joule</td>
</tr>
</tbody>
</table>

Figure 5.2 shows the network structure used in our simulations. The sink node is placed roughly at the center of the network. Nodes publish data at the
rate of 2 packets per second in order to simulate a fairly high load traffic scenario. In this thesis, the proposed scheme is compared with the basic priority scheduling. All nodes in the WSN have a queue size of 50. Figure 5.2 shows three random deployments of 100 sensor nodes in a 1000 × 1000 m² areas.

Figure 5.2a The position of the sink node in the simulated WSN
5.4 The Simulations Metrics

The metrics measured in simulations, in order to compare the proposed scheme against the Basic priority scheme. They are average end to end delay, drop ratio, fairness index, average network lifetime and average energy consumption fair received packets.

5.4.1 Average End to End Delay

Average end to end delay is defined as the delay of the successfully transmitted packet from the source to the destination. This metric includes queuing delay, retransmissions delays at MAC layer, propagation delay and packet transfers times. It is an important factor to judge the effectiveness of a network protocol. Equation 5.1 is calculated as follows.

\[
\text{Average End to End delay} = \frac{\sum_{\text{delivered packets}}(\text{Arrival time} - \text{departure time})}{\text{All received packets}} \quad (5.1)
\]
5.4.2 Drop Ratio
The Drop ratio metric is defined as the number of unsuccessful received packets during a specific time. It is another metric of throughput effectiveness of a protocol. Equation 5.2 is used to calculate the drop ratio.

\[
Drop\ Ratio = \frac{Number\ of\ Dropped\ Packets}{All\ transmitted\ packets} \quad (5.2)
\]

5.4.3 Fairness Index
The fairness index is a measure used in network engineering in order to determine whether users or applications are receiving a fair share of system resources. Equation (5.3) is used to calculate the fairness index [70].

\[
Fairness\ Index = \frac{\sum_{i=1}^{n} x_i}{n \left[ \sum_{i=1}^{n} x_i^2 \right]} \quad (5.3)
\]

Where:-
- \( n \) represents the total number of sending nodes
- \( x \) represent the throughput of every node.

5.4.4 Average Network lifetime
Wireless sensor network lifetime is one of the most important constraints for the network. Most, of routing, scheduling and MAC protocols focus on the constraint. It is measured as the amount of time network spends until most of its nodes are down.

5.4.5 Average Energy consumption for received packets
Energy consumption is another important constraint WSN. It is defined as the average energy consumed by the whole network in order to deliver control and data packets to the destination.
Average energy consumption for received packets = \[
\frac{\text{Total Energy consumption by whole network}}{\text{Number of successfully received packets}}
\] (5.4)

5.5 Simulation Results

In order to find the efficiency of our scheme, we compare it with the Basic Priority Scheduling. This comparison is done against the AODV, DSR and DSDV. Comparisons will be according to the previous mentioned simulation metrics. After that, we show the effect of applying the threshold value on the proposed and scheme and compare it to the Basic Priority Scheduling Scheme. In all simulation, the energy based scheduling scheme is integrated with the AODV (EB-AODV), as mentioned in the previous chapter. The sections show the comparison of the EB-AODV against the AODV, DSR and DSDV.

5.5.1 Proposed scheme against AODV

In the following section, we will compare the proposed energy based scheme with the AODV against the basic priority with AODV.

5.5.1.1 Network lifetime

The WSN lifetime has increased because our scheme works on avoiding dropping packets with high energy usage. This means that, remote nodes from the sink will not have to retransmit the dropped packets. Because our scheme avoids dropping packets with high energy consumption during transmission, network lifetime has increased. Figure 5.3 shows how our proposed scheme extends the network lifetime. Network lifetime was extended by 3%. As packet size affects the sending priority, dropping small packets which consumes low amount of energy, helps in saving network energy.
5.5.1.2 Energy consumption and delivery ratio

From Figure 5.4, it is found that the Energy Based Scheme achieves a better packet delivery ratio value than the Basic Priority Scheduling. Through the WSN energy consumption, the Energy Based Scheme makes an efficient usage of the batteries attached to each node in the WSN. It increases the packet delivery ratio by giving the packets, which consumes more energy, higher sending priorities. Packets whose energy transmission path level (PEP) is low, are prioritized with high sending priority. As shown in Figure 5.4, the Basic Priority Scheduling achieves better delivery ratio at network energy level of 60%. This happens, because of the greedy nature of the proposed scheme. Sometimes, remote data packets might take the higher priority through its journey to the destination. This might affect data packets from sink closed
nodes. The Energy Based Scheme works on achieving better packet delivery ratio than the Basic Priority Scheduling. In the Energy Based Scheme, both control and data packets have the treatment. They get their sending priorities according to the energy consumption of each one of them.

![Figure 5.4 Network Energy consumption vs. Packet Delivery Ratio](image)

The greedy nature of the Energy Based Scheme is considered a normal behavior. Most of the packets, which consume more energy in transmission, are remote source packets. This means, that remote data packets have a great chance to get high sending priority than the other packets. In order to know how this greedy nature affects the WSN, we measure the fairness of the Energy Based Scheme and compare it to the fairness of the Basic Priority Scheduling.
5.5.1.3 Fairness Index

Figure 5.5, shows how the Basic Priority Scheduling with AODV overcomes the proposed scheduling scheme in the fairness. In the Basic Priority scheme, packets are assigned sending priorities only according to their type. Assigning priorities to packets according to their types, helps in achieving better fairness among all the WSN nodes. Sending priorities assigned to packets from remote nodes are affected by the energy used to deliver the packets, the energy path level and packet size. Although, these parameters are considered in priority calculations for each packet, the fairness is affected. The fairness of the Energy Based Scheme is affected because remote nodes have better chance to deliver their packets. Besides, there are no weights in calculating the sending priorities.

5.5.2 Proposed scheme against DSDV

Energy and power management are the main constraints that affects wireless sensor networks lifetime. These constraints have this sort of importance due to the nature and effect of WSN. Mainly, most of energy consumption is due to the packet transmission and reception. In this section, we compare the energy based scheduling scheme with AODV against the DSDV routing protocol. As, DSDV is a proactive table driven routing protocol, routing information must be updated periodically. This leads to overuse of the network energy and a decrease in its lifetime.
5.5.2.1 Network lifetime

Figure 5.6 shows how the energy based scheduling scheme increases the WSN lifetime. It achieves better network lifetime than the DSDV. As, AODV is a reactive routing protocol (it establishes a route to a destination only on demand), the energy consumption for transmission and reception is quite less than in DSDV. Network lifetime was extended by 8%. In addition to that, the energy based scheduling scheme maintains each operation done for transmission or reception according to the energy consumption, Packet Energy Path Level, packet size and deadline.
Figure 5.6 Network average Energy Level across Network lifetime

5.5.2.2 Energy consumption and delivery ratio

In Figure 5.7, we find that the energy based scheduling scheme achieves a better ratio delivery ratio. Besides, the proposed scheme consumes less energy during the network lifetime in order to achieve better throughput. Although the proposed scheme suffers from its greedy nature, which may affect the delivery ratio, the proactivity nature of the DSDV plays an effective role in the energy consumption for the goodput packets. The overall packet delivery ratio of our proposed scheme under the AODV is better than the Basic Priority Scheme under the DSDV routing protocol.
5.5.2.3 Fairness Index

As it is mentioned before, the fairness index is an important factor in evaluation of any scheduling or routing protocol. In the study, this measure is used to know the nature of the energy based scheduling scheme against the DSDV routing protocol. Figure 5.8 shows how the DSDV achieves better and greater fairness index value than in the proposed scheme. DSDV achieves better fairness index during the network lifetime, while the energy based scheduling scheme suffers the fairness problem. This problem is due to the greedy nature of the proposed scheme. In DSDV, packets of the same type and nodes, regardless their position or distance from the sink node, are treated by equally. While in the proposed scheme, there is no equality in packet treatment.
5.5.3 Proposed scheme against DSR

DSR routing protocol is another protocol which is compared with the proposed scheme with. In practical, the DSR is so closed to the AODV in the way that forms a route on-demand when a transmitting computer requests one. However, it uses source routing instead of relying on the routing table at each intermediate device.

5.5.3.1 Network lifetime

In Figure 5.9, it is found how the proposed scheme still archives better overall network lifetime. Network lifetime was extended by 3%. The basic priority scheduling with the DSR works on assigning equally sending priorities to control packets then data packets, regardless how much energy is consumed.
by each of them. This way in treatment may lead to dropping high energy consumption packets or packets from low energy path level.

![Network average Energy Level across Network lifetime](image)

**Figure 5.9: Network average Energy Level across Network lifetime**

### 5.5.3.2 Energy consumption and delivery ratio

As, DSR is an on demand routing protocol, the average energy consumption for the goodput has lower value than in DSDV. However, the average energy consumptions for the proposed scheduling scheme is still better than in DSR. They happen due to the action of the Basic priority scheduling Scheme in DSR. Packets may face the chance of being dropping, whatever how much energy they have consumed, or how energy strength is the path that any packet has used in its journey to the destination. This way in packet treatment leads to an increase in the average energy consumption for the throughput. Figure 5.10
shows how the energy based scheduling scheme with AODV still overcomes the Basic priority scheme with DSR. The proposed scheme still achieves better overall packet delivery ratio than in DSR. In the Basic priority scheme with DSR, packets treatment is according to the type only. Control packets might have better sending position in the buffering queue at each node than the data packets. While in the energy based scheduling scheme with AODV, packets whose energy transmission path level (PEP) is low, are prioritized with high sending priority.

![Diagram showing energy consumption vs. delivery ratio in DSR](image)

Figure 5.10 Average Network Energy consumption vs. Packet Delivery Ratio in DSR

### 5.5.3.3 Fairness Index

Figure 5.11 shows how the Basic scheduling scheme with DSR overcomes the proposed energy based scheduling scheme integrated with AODV in
fairness. Sending nodes, when applying the Basic Priority scheme DSR have a fair treatment of their packets. However, this fairness in the treatment of packets, in most cases, may lead to an excessive decrease in the fairness in index. Some sending nodes might be far from the sink node. Moreover, the packet energy path level and packet energy consumption during transmission plays an important role in assigning sending probabilities to each packet in the queue.

![Graph showing Fairness Index of DSDV vs. the AODV with proposed scheme](image)

**Fig. 5.11** Fairness Index of DSDV vs. the AODV with proposed scheme

### 5.6 Energy Based Scheduling Scheme with Threshold

Fairness is an important factor when applying and comparing any scheme. Although, the fairness index values does not reflect the level of QoS, which achieved in the network. However, some WSNs applications might require a
high value in fairness index. As, the energy based scheduling scheme suffers a massive decrease in the fairness when comparing with the Basic Priority scheduling scheme, a new method in calculating the sending priority for each packets is used. This way is to use a threshold value.

The threshold is a value used by the Energy Based Scheduling Scheme in order to increase the fairness index value. Each packet sending priority is compared to this value. When the PSP exceeds the threshold value, it becomes equal to 1. Otherwise, the PSP values do not change. Applying this threshold would help in maximizing the fairness index of the proposed scheme. As, packets from remote nodes would have the same sending probability like packets from close nodes.

Figure 5.13 shows how the effect of the distance on the packets dropping probability. Transmitted packets from remote nodes have lower dropping probability than other packets from close to sink nodes. Therefore, the proposed scheduling scheme decreases the fairness index of the entire network. In order to apply fair treatment to any packets, regardless the location or nearness of its source, the threshold value should be carefully chosen. The value of the threshold and how it would be applicable to the used application could be a future work for the thesis.
Fig. 5.12 Fairness Index the Energy Based Scheduling Scheme before and after applying the threshold

Fig. 5.13 Dropping Probability vs. the distance from the sink node
5.7 Summary

This chapter have presented comparisons between the proposed scheduling energy based schemes integrated with AODV against other the Basic priority scheduling scheme with DSR and DSDV. These comparisons were according to network lifetime, amount of energy consumption for the throughput and the fairness index.

Next, it was shown how to overcome the problem of the fairness. This is done applying a threshold value to proposed scheduling scheme.

The next chapter will be the conclusion and future works of this research.
Chapter 6

Conclusion and Future Work

The aim of this research and thesis is to develop a new scheduling scheme for wireless sensor networks. Through this thesis, we have a brief overview on the wireless sensor networks architecture, applications, protocols layers and challenges. After that we discuss the previous scheduling scheme and show how they work. Then, we introduce our proposed energy based scheduling scheme and show how its integration with the AODV routing protocol. This scheme has the ability to schedule packets according to their deadlines and energy consumption. The proposed scheme takes into account the packet deadlines, size, energy path level and the energy consumption for each packet during its journey from the source to the sink. After that, a comparison was done between the proposed energy based scheduling scheme against the basic priority scheduling scheme.

6.1 Conclusion

Many researches have proposed different solutions. These solutions deal with routing protocols, data packet prioritization, and real-time scheduling. Most of these solutions prioritize packets at the MAC layer according to their deadlines and distances to the sink. Packet prioritization by itself cannot completely support real-time data communication requirements. The scheme was implemented in NS-2, which is widely used open source software.

In this work, Energy Based Scheduling Scheme with AODV routing protocol was developed. In this scheme, packets are not only scheduled according to their deadlines or first in first out. The experimental and simulation results showed how the proposed scheduling scheme can increase
the overall network lifetime. Moreover, it can decrease the average energy consumption for each transmitted packets. Dropping a packet which consumed high energy during its transmission or a packet arrived from a low energy path level would lead to a great loss in the overall energy of the network. So, the proposed scheme works on preventing this behavior by considering the energy consumption and energy path level in assigning sending probabilities. However, the fairness index problem rises as a problem for the proposed scheme. Packets from nodes near to the sink may face the probability of assigning low sending priorities to them. In order to overcome this problem, we introduce a threshold idea to be integrated with the proposed scheme. The threshold works on increasing the fairness index.

The energy based scheduling scheme is integrated with the AODV routing protocol. It works on the unused bits in the packet headers. Moreover, the proposed energy based scheduling scheme does not require any support from the MAC layer.

6.2 Future Works

Many challenges still remain in wireless sensor networks. A lot of research is ongoing in the field of routing and scheduling. The following could be considered as future work for this thesis:-

1. Adapting the energy based scheduling scheme to work in WSN with mobile nodes will be the next step in this research.
2. It would be also an interesting idea if the proposed scheme is integrated with the other routing protocol such as, Low-energy adaptive clustering hierarchy.
3. The threshold value and its suitable value for WSN application could be an interest future work.
4. An idle detection mechanism may be employed such that if an idle period passes without packet transmission, the head of the queue is sent immediately.
5. The proposed scheme could be integrated with the other routing protocols like Dynamic Source Routing or Destination-Sequenced Distance Vector routing.

6. An update would be applied on the proposed scheme in order to overcome the fairness problem.
Outcome From the thesis


References


Federal de Minas Gerais, April 2005.


2212-2216, 2012.


Appendix A - Trace File Field Types

The trace format is shown below.
S – t 0.267662078 - Hs 0 - Hd -1 - Ni 0 - Nx 5.00 - Ny 2.00 - Nz 0.00 – Ne -1.000000 - N1
RTR - Nw --- - Ma 0 - Md 0 - Ms 0 - Mt 0 - Is 0.255 - Id -1.255 – It message - Il 32 - If 0 - li 0 - Iv 32

r – t 100.004776054 - Hs 0 - Hd -1 - Ni 1 - Nx 25.05 - Ny 20.05 - Nz 0.00 – Ne -1.000000 - N1 AGT - Nw --- - Ma a2 - Md 1 - Ms 0 - Mt 800 - Is 0.0 - Id -1.0 – It tcp - Il 1020 - If 2 - li 21 - Iv 32 - Pn tcp - Ps 0 - Pa 0 - Pf 1 - Po 0

Field 0: event type
- s: send
- r: receive
- d: drop
- f: forward

Field 1: General tag
- t: time

Field 2: Next hop info
- - Hs: id for this node
- - Hd: id for next hop towards the destination

Field 3: Node property type tag
- - Ni: node id
- - Nx – Ny - Nz: node’s x/y/z coordinate
- - Ne: node energy level
- - Nl: trace level, such as AGT, RTR, MAC
-Nw: reason for the event

Field 4: packet info at MAC level
- Ma: duration
- Md: dest’s ethernet address
- Ms: src’s ethernet address
- Mt: ethernet type

Field 5: Packet information at IP level
- Is: source address. Source port number
- Id: dest address.dest port number
- It: packet type
- Il: packet size
- If: flow id
- Ii: unique id
- Iv: ttl value

Field 6: Packet info at “Application level”
which consists of the type of application like ARP, TCP, CBR, the type of ad-hoc
routing protocol like DSDV, DSR, AODV etc. The field consists of a leading –P and the
list of tags for different applications. For values of the fields for AODV and CBR are
described below;

For AODV :
- Pt : Control message type,
- Ph: Hop-count,
- Pb: Broadcast-id,
- Pd: Destination,
- Pds: Dest Seqno,
- Ps: Source,
- Pss: Source Seqno
• -Pl: Lifetime.
• -Pc: Pkt Type, REPLY/ERROR

For CBR:
• -Pn: This denotes the application of “CBR”
• -Pi: sequence number
• -Pf: how many times this pkt was forwarded
• -Po: optimal number of forwards
# Lim Kwang Yong

# Usage: awk -f <awk_script.awk> <trace_file.tr>

# Parse a ns2 wireless trace file and generate performance metrics

BEGIN {
    droppedRTGpackets=0;
droppedbRTGbytes=0;
droppedMACbytes=0;
droppedMACpackets=0;
droppedbDATAbytes=0;
droppedbDATApackets=0;
droppedIFQpackets=0;
droppedLQIbytes=0;
droppedLQIpackets=0;
droppedIFQbytes=0;
totalDROPPEDpackets=0;
totalDROPPEDbytes=0;
dataSent=0;
dataRecd=0;
sentData=0;
sentDataBytes=0;
TotalsentData=0;
TotalsentDataBytes=0;
recdData=0;
recdDataBytes=0;
sends=0;
recvs=0;
RTGbytes=0;
fwdData=0;
fwdDataBytes=0;
fwdRtg=0;
fwdRtgBytes=0;
fwdMac=0;
fwdMacBytes=0;
highest_packet_id=0; #used to compare with the packet id
highest_time=0
sum=0;
RTG=0;
MACDATA=0;
MACRTG=0;

{
#=======================================
# Check for the highest packet ID & time
#=======================================

action = $1;
time = $2;
node_id = $3
if ($7 =="cbr") {packet_id = $6;};
if ( packet_id > highest_packet_id ) {highest_packet_id = packet_id;};
if ( time > highest_time ) {highest_time = time}
#===============
# Calculate delay
#===============

if ( start_time[packet_id] == 0 ) {start_time[packet_id] = time;};
if ( action != "D" ) {
if ( action == "r" ) {end_time[packet_id] = time;};
}
else {end_time[packet_id] = -1;};
# Calculate PDF

if (($1 == "s") && ($7 == "cbr") && ($4 == "AGT")) {
    sends++;
dataSent=dataSent+$8;
}
if ( ($1 == "r") && ($7 == "cbr") && ($4 == "AGT") ) {
    recvs++;
dataRecd=dataRecd+$8;
}

# Calculate RTG load

if ((( $1 == "s") || ($1=="f") ) && ($7 == "cbr") && ($4 == "RTR")) {
    sentData++;
sentDataBytes=sentDataBytes+$8;
}
if ( ($1 == "r") && ($7 == "cbr") && ($4 == "RTR") ) {
    recdData++;
    recdDataBytes=recdDataBytes+$8;
}

# RTG protocol pkts

if ( ($(1=="f") || $(1=="s") ) && ($4 == "RTR") && ($7 == "AODV") ) {
    RTG++;
    RTGbytes=RTGbytes+$8;
}

# MAC data pkts
#=============
if ( (($1=="f") || ($1=="s") ) && ($4 == "MAC") && ($7 =="cbr"))
{ MACDATA++;
}
#=============
# MAC RTG pkts
#===============
if ( (($1=="f") || ($1=="s") ) && ($4 == "MAC") && ($7 =="AODV"))
{ MACRTG++;
}
#===============
# Dropped data pkts
#===============
if ( ($1 == "D") && ($7 =="cbr") && ($4 == "RTR"))
{ droppedDATAbytes=droppedDATAbytes+$8;
droppedDATApackets=droppedDATApackets+1;
}
#===============
# Dropped MAC pkts
#===============
if ( ($1 == "D") && ($4 == "MAC"))
{ droppedMACbytes=droppedMACbytes+$8;
droppedMACpackets=droppedMACpackets+1;
}
#===============
# Dropped RTG pkts
#===============
if ( ($1 == "D") && ($4 == "RTR") && ($8 == "AODV"))
{ droppedRTGbytes=droppedRTGbytes+$8;
droppedRTGpackets=droppedRTGpackets+1;
}
# Dropped IFQ pkts

if (($1 == "D") && ($4 == "IFQ")) {
    droppedIFQbytes=droppedIFQbytes+$8 ;
    droppedIFQpackets=droppedIFQpackets+1;
}

# Dropped LQI pkts

if (($1 == "D") && ($4 == "IFQ")) {
    droppedLQIbytes=droppedLQIbytes+$8 ;
    droppedLQIpackets=droppedLQIpackets+1;
}

# Total dropped pkts

if ($1 == "D") {
    totalDROPPEDpackets++;
    totalDROPPEDbytes=totalDROPPEDbytes+$8
}

# Forward data pkts

if ( ($1 == "f") && ($7 == "cbr") && ($4 == "RTR") ) {
    fwdData++;
    fwdDataBytes=fwdDataBytes+$8;
}

# Forward RTG pkts

if ( ($1 == "f") & ( $7 == "AODV") & ( $4 == "RTR") ) {
    fwdRtg++;
    fwdRtgBytes=fwdRtgBytes+$8;
}
#===============
# Forward MAC pkts
#===============
if ( ( $1 == "f") & ( $4 == "MAC") ) {
    fwdMac++;
    fwdMacBytes=fwdMacBytes+$8;
}
#==============
# Total forward pkts
#==============
if ( $1 == "f") {
    fwdpackets++;
    fwdBytes=fwdBytes+$8;
}
if ($1 == "D") {
    droppingnodes= $3;
}
}
END {
    for ( packet_id = 0; packet_id <= highest_packet_id; packet_id++ ) {
        start = start_time[packet_id];
        end = end_time[packet_id];
        packet_duration = end - start;
        if (start < end) sum= packet_duration+sum;
    }
    #==============
    # Show results
printf("\n .......Data parsed from trace file with 25
NODES.............\n\n") >> "performance.txt";
printf(" 1. No. of CBR Packets sent = %d PACKETS \n", sends) >>
"performance.txt";
printf(" 2. No. of CBR Bytes sent = %d BYTES \n", dataSent) >>
"performance.txt";
printf(" 3. No. of CBR Packets received = %d PACKETS \n", recvs) >>
"performance.txt";
printf(" 4. No. of CBR Bytes received = %d BYTES \n", dataRecd) >>
"performance.txt";
printf(" \n .......Routing details.............\n\n") >>
"performance.txt";
printf(" 5. No. of routing packets = %d PACKETS \n", RTG) >>
"performance.txt";
printf(" 6. No. of routing bytes = %d BYTES \n", RTGbytes) >>
"performance.txt";
printf(" \n .......MAC details.............\n\n") >> "performance.txt";
printf(" 7. No. of MAC packets for data sent = %d PACKETS \n", MACDATA) >>
"performance.txt";
printf(" 8. No. of MAC packets for Rtg sent = %d PACKETS \n", MACRTG) >>
"performance.txt";
printf(" \n .......Forwarding details............\n\n") >>
"performance.txt";
printf(" 10. No. of DATA Packets Fwd = %d PACKETS \n", fwdData) >>
"performance.txt";
printf(" 11. No. of DATA Bytes Fwd = %d BYTES \n", fwddataBytes) >>
"performance.txt";
printf(" 12. No. of RTG Packets Fwd = %d PACKETS \n", fwdRtg) >>
13. No. of RTG Bytes Fwd = %d BYTES
14. No. of MAC Packets Fwd = %d PACKETS
15. No. of MAC Bytes Fwd = %d BYTES
16. Total No. of Fwd packets = %d PACKETS
17. Total No. of Fwd Bytes = %d BYTES

18. Dropping nodes are %d nodes
19. No. of dropped data (packets) = %d PACKETS
20. No. of dropped data (bytes) = %d BYTES
21. No. of dropped MAC (packets) = %d PACKETS
22. No. of dropped MAC (bytes) = %d BYTES
23. No. of dropped RTG (packets) = %d PACKETS
24. No. of dropped RTG (bytes) = %d BYTES
25. No. of dropped IFQ (Packets) = %d PACKETS
26. No. of dropped IFQ (bytes) = %d BYTES

.......Dropping details............
printf(" 27. No. of dropped LQI (Packets) = %d PACKETS \n",droppedLQIpackets) >> "performance.txt";
printf(" 28. No. of dropped LQI (bytes) = %d BYTES \n",droppedIFQbytes) >> "performance.txt";
printf(" 29. Total No. of Dropped (packets) = %d PACKETS \n\n",totalDROPPEDpackets) >> "performance.txt";
printf(" 30. Total No. of Dropped (Bytes)) = %d BYTES \n\n",totalDROPPEDbytes) >> "performance.txt";
printf("\n .............PERFORMANCE METRICES ....................\n\n") >> "performance.txt";
printf(" 1. Packet Delivery Ratio (PDR %) = %f %\n", (recvs/sends)*100) >> "performance.txt";
printf(" 2. Average Network delay = %f \n", sum/highest_packet_id) >> "performance.txt";
printf(" 3. Network Throughput = %f \n", (dataRecd/highest_time)/25) >> "performance.txt";
printf(" 4. Normalised routing load (Packets %) = %f %\n", (RTG/sentData)*100) >> "performance.txt";
printf(" 5. Normalised routing load (Bytes %) = %f %\n", (RTGbytes/sentDataBytes)*100) >> "performance.txt";
printf(" 6. Routing OVERHEAD (Packets %) = %f %\n", (MACRTG/MACDATA)*100) >> "performance.txt";
printf(" 7. Optimal Hop Count = %f \n\n", MACDATA/sends) >> "performance.txt";
الملخص

تتكون شبكات الاستشعار اللاسلكية (WSNs) من نقاط الاستشعار التي يتم توزيعها مكانياً. وتتمثل هذه النقاط الاستشعارية ببعضها البعض من خلال الاتصالات اللاسلكية. وتعتبر هذه التكنولوجيا مهمة لأنه سوف تحدث ثورة واسعة في المجالات العسكرية والعلمية والصناعية والمدنية. في العديد من التطبيقات يتم نشر النقاط الاستشعارية دون الحاجة إلى تخطيط مسبق. حيث أنه فور نشر هذه النقاط فإنه يجب أن يتمتع بالقدرة على تنظيم نفسها بشكل مستقل في شبكة الاتصالات اللاسلكية.

لقد وضعت مخططات جديدة الجدولة حزم نقل البيانات في الوقت الحقيقي. حيث تعمل هذه المخططات على تحديد ألوان حزم وفقا ل مواعديها نهائية. إن إعطاء الأولوية للحزم لا يمكن أن تدعم تطبيقات الزمن الحقيقي أو يحافظ على عمر الشبكة. في ظروف الضغط على الشبكة، قد يؤدي انتظار الحزم في صفوف طويلة تأخير الحزم أو إزالتها. إن إسفاق الحزمة يؤدي إلى فقدان الطاقة، حيث أننا من الممكن أن تكون الحزمة قد استهلكت طاقة عالية من أجل تسليمها إلى وجهتها.

ان التطوير المستمر من أجل التقليل في حجم وتكلفة النقطة الاستشعارية قد ساعد في زيادة الإبحاث في هذا المجال. تركز الأبحاث الحالية في مجالات التوجيه وتخطيط على الحفاظ على الطاقة وزيادة عمر الشبكة. وتعمل هذه الأبحاث على إعطاء قابلية لاستيعاب عدد كبير من النقاط الاستشعار.

وبالإضافة إلى ذلك فإن هذه البحوث يجب تعطى الشبكة القدرة على مواجهة مشكلة الطاقة أو تلف أحد النقاط الاستشعارية. حتى يتم نشر شبكات استشعار لجميع المعلومات لتحقيقها لاحقاً، ورصد أو تتبع الظواهر في الوقت الحقيقي.

في شبكات الاستشعار اللاسلكية فإن الحزمة المرسلة يتم وضعها في قائمة الانتظار في النقطة الوسيطة. حيث تعمل كل نقطة على تعبين الأولويات إلى كل حزمة. يتم تعيين الأولويات إلى الحزم وفقا ل مواعديها نهائية. هذا الأسلوب في تحديد الأولويات الحزمة لا يأخذ في الاعتبار سواء في عمر الشبكة أو استهلاك الطاقة. إلى جانب ذلك، فإنه قد يؤدي إلى إسفاق الحزمة عالية الاستخدام للطاقة. في العديد من التطبيقات، ويعتبر العمر الافتراضي للشبكات الاستشعار اللاسلكية قضية حرجة للغاية، أثناء إعداد الشبكة.

في هذا البحث يتم تقديم مقتراح مخطط للجدولة يسمى مخطط الطاقة المجدولة. في هذا المخطط يتم تحديد الأولوية للحزم ليس فقط وفقا للمواعدينهائية ولكن أيضاً وفقاً لبعض قيادات الطاقة الخاصة بالشبكة. وقد تم دمج هذا المخطط مع بروتوكول التوجيه AODV. حيث يقوم المخطط المقترح على استخدام الخانات غير المستخدمة في الحزمة. من خلال هذا البحث، يتم مقارنة مخطط الجدولة المقترحة مع مخطط الجدولة الأساسية ذات الأولوية وذلك باستخدام NS-2. وتم المقارنات وفقا لعمر
الشيكة، واستهلاك الطاقة والمؤشر النزاهة. إن النتائج تثبت أن مخطط الطاقة الجدولية القائمة يعمل على زيادة حياة الشبكة وتقليل استهلاك الطاقة للجزم. من ناحية أخرى، فإن مؤشر العدالة يتغير سلباً.

و تتضمن الرسالة ستة اجواق وعدد 2 ملحق وملحق بالبرامج والقائمة بالمراجع تتضمن 69 مرجع ونورد فيما يلي ملخص لهذه الأبواب:

الباب الأول: مقدمة

ويتضمن هذا الباب شرح المشكلة وعرض ملخص الأبواب التالية في الرسالة

الباب الثاني: شبكات الاستشعار اللاسلكية

ويتضمن هذا الباب شرح تفصيلي لشبكات الاستشعار اللاسلكية وما يتعلق بها من هياكل وتطبيقات وتحديات. كما تحتوي على شرح لروتينات التوجيه.

الباب الثالث: ميكانيزمات الجدولة في شبكات الاستشعار اللاسلكية

ويتضمن هذا الباب شرحًا تفصيلي لمخططات الجدولة في شبكات الاستشعار اللاسلكية.

الباب الرابع: مخطط مقترح للجدولة يعتمد على الطاقة

ويتضمن هذا الباب عرضاً وشرحًا تفصيلياً لمخطط الجدولة المقترح.

الباب الخامس: المحاكاة و النتائج

ويتضمن هذا الباب عرضاً وشرحًا تفصيلياً للنتائج.

الباب السادس: الخلاصة والعمل المستقبل

ويتضمن هذا الباب عرضاً تفصيلياً للخلاصة والعمل المستقبل للرسالة.
تحسين البيانات اللاسلكية

الدين طه

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