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Health Monitoring Using Wireless Sensor: "A Matlab Approach"

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A wireless sensor network consists of locally distributed independent sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants. Wireless Body Area Network (WBANs) represents a promising trend in wearable health monitoring systems. WBANs promise to revolutionize health monitoring and offer continuous and omnipresent moving health monitoring at the least level of obtrusiveness, resulting in an increase in user's quality of life.

The main purpose of this study is to model a wireless sensor network with Simulink (a MATLAB based simulation program) in order to perform the simulations which correspond to the real world body area network. These sensors communicate over the same bands as WiFi channels using Bluetooth, data received from these sensors are used in health monitoring.

The architecture consists of multiple sensor nodes that monitor temperature, blood pressure, humidity, sugar level, and heart activity. These signs are transferred via ZigBee or Bluetooth to a personal server running on a PDA, and later sent to a remote database using WLAN or WWAN.

From the modelling result it is obvious that the behaviour of the system was successfully described using MATLAB Simulink, which provides the ability to change the different system parameters to create new environment, and flexible approach to study the effect of different physical parameters on the performance of WSNs.

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Keywords	WSN, Matlab Simulation, Bluetooth, PDA, ZigBee, WLAN

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Acronyms

WSN   Wireless Sensor Network

ADC   Analog to Digital Convertor

WBAN   Wireless Body Area Network

BLE   Bluetooth Low Energy

BCU   Body Control Unit

DAC   Digital to Analog Convertor

PDA   Personal Digital Assistant

WLAN   Wireless Local Area Network

WWAN   Wireless Wide Area Network

GPRS   General Packet Radio Service

MAC   Media Access Control

IoT   Internet of Things

MATLAB   Matrix Laboratory

ETX   Expected Transmission Count

ISM   Industrial, Scientific, and Medical

SNR   Signal to Noise Ratio

6LoWPAN   IPv6 Low Power Wireless Personal Area Network

PHY   Physical Layer

1 Introduction

A wireless sensor is a group of specialized transducers, with a communication infrastructure, intended to monitor and record conditions at diverse locations. The common parameters measured are: temperature, humidity, pressure, wind direction, speed, illumination, intensity, vibration intensity, sound intensity, chemical concentration, pollutants levels, and vital body signs. [1]

Wireless Sensor Networks originated as a result for use in the Military battlefield surveillance. WSN today has many applications ranging from industrial process monitoring, health monitoring, habitat and environment, home automation, and traffic control [1,2,3].

A wearable WSNs system has been very vital for continuous health monitoring enabling the transition to more proactive and economical healthcare [2] [3]. They provide feedback whenever there are changes in vital signs in order to maintain an optimal health status. When these sensors are integrated into a telemedical system, they alert medical personnel when life-threatening alterations occur. In addition, the wearable WSNs can be used for health monitoring of patients in nomadic settings [4,405-414]. Examples are the use in diagnostic measure, excellent maintenance of a chronic condition, a supervised recovery from an acute event or surgical operation, to monitor constancy to treatment guidelines (e.g., regular cardiovascular exercise), or to monitor effects of drug therapy.

A WBAN consists of multiple sensor nodes, a gateway and a remote database. The sensor nodes sample, process and communicate one or more vital signs (oxygen saturation, heart rate, blood pressure) or environmental parameters (temperature, light, humidity) to a remote database through a gateway (Base station). Typically, these sensors are placed at key places on the human body as microscopic patches or hidden in users' clothes and communicates using different wireless communication scheme (Zigbee, Bluetooth) allowing pervasive health monitoring in their endemic environment for lengthy periods of time. This gives the freedom of flexibility and enhances the patient's quality of life [5].

The structure of smart sensors work in one of three ways; by proximity to target (such as seismic sensors), by a line of sight to the target (such as visual sensors), and by propagation like a wave with possible bending (such as acoustic sensors) [4, 405-414,5]

Fundamental purposes of sensor networks are accuracy, flexibility, reliability, cost effectiveness and ease of deployment. Intrinsic characteristic and benefits of WSN are outlined below [5]:

1. **Area coverage**: This simply means that WSN can span a wide geographical area in a fast and efficient manner without adverse impact on the overall network cost.

2. **Operability in harsh environments**: WSN are designed in such a way that they can withstand harsh environment since the nodes consist of powerful sensor design, unified with high levels of fault tolerance.

3. **Sensing accuracy**: The usage of huge number and mixture of sensor nodes provides potential for greater accuracy in the information accrues as compared to that procured from a single sensor.

4. **Dynamic sensor scheduling**: This implies to some scheduling scheme, sensor network is proficient of setting preference for data transmission.

5. **Connectivity**: Sink nodes connect multiple sensor networks, along with existing wired networks (e.g. Internet). The clustering of networks enables each individual network to focus on specific areas or events and share only relevant information.

The main purpose of this thesis is to model a wireless sensor network with Simulink (a MATLAB based simulation program) in order to perform the simulations which correspond to the real world body area network. These sensors communicate over the same bands as WiFi channels using Bluetooth. Data received from these sensors are used in health monitoring.

This thesis organization is as follows: Chapter 2 details related work in the area of nomadic health monitoring. Description of the overall system and component architecture is illustrated in chapter 3. It begins by briefly describing the overall system architecture, topologies, data propagation and then WSN protocol and security requirements. Chapter 4 describes the WBAN communication scheme and how its design is well suited for ultra-low power sensors such as the nodes in our WBAN. Chapter 5 describes the modelling of the WSN in Matlab Simulink,the corresponding results with different received SNR and Interference, and conclusion .

2   Nomadic Health Monitoring

Several applications have employed Wearable WSN systems for health monitoring in recent time. [4, 405-414]. Possible systems range from those serving sport activities such as personal fitness and wellness management to those serving health monitoring to provide remote monitoring or diagnostic of cardiovascular problems. A number of research programs are pursuing development of health monitoring systems as well. This chapter provides a survey of both commercial systems.

2.1   Commercial Devices

There are many vendors producing sensor devices, but this section will consider a brief summary of popular vendors, their capabilities, and their applications. Most sensors communicating via the lowest two layers in the protocol stack (the MAC and PHY layer) available in the market uses the IEE802.15.4 standard. While at higher layers, hetero-geneity exist enabling different vendors to select different options such as 6LoWPAN, Zigbee, and WirelessHART. Some of these vendors have the ability to form mesh and multi-hop routing within a network.

Dust Networks: It is generally used in applications such as asset management, process control, environmental monitoring, and health safety monitoring. A typical example of the dust network is the SmartMesh products that operate using IEEE802.15.4 radio in the 2.4 GHz ISM bands. In rare cases some of the products operate in 900 MHz. The SmartMesh-IA products from Dust Network uses WirelessHART protocol for industrial automation. The WirelessHART protocol employ combination of mesh networking for redundancy, channel hopping to avoid interference time-synchronized messaging, and 128-bit encryption and authentication. It is reliable and secure.

Crossbow: One of the first vendors of mote-class sensor devices is used for applications such as industrial automation, environmental monitoring, asset tracking etc. Most crossbow products operate using IEEE802.15.4 radio in the 2.4 GHz ISM unlicensed bands, in some case there are other products that operate in the 888 or 916 MHz unlicensed bands. The Cricket Mote is a sensor with two different transceivers (RF transceiver and ultrasound transceiver). The ultrasound transceiver is used for obtaining information using time of flight of the ultrasound signal, the information obtained can be used to localize sensor nodes after deployment. The table 1 below shows list of some common vendor that produces sensor devices and their product features.

Table 1 List of Some Vendors of Sensor Devices and Features of Some Products

Company	Types of sensor device	Frequency bands	Standards supported	Applications supported
Crossbow	Evaluation kits, BSs, motes, data-acquisition boards	2.4 GHz, 868 MHz, 916 MHz	802.15.4, ZigBee	Asset monitoring, climate control, surveillance
Dust Networks	Evaluation kits, motes, managers	2.4 GHz, 902–928 MHz	802.15.4, WirelessHART	Process control, asset monitoring, health safety monitoring
Ember Corporation	ZigBee chips, software, development tools	2.4 GHz	802.15.4, ZigBee	Home and building automation, asset management, defense applications
Sensinode	Development kits, Nanoseries sensors and routers	2.4 GHz	802.15.4, 6LoWPAN	Hospital asset management

3 WBAN System Architecture

WBAN system architecture consists of several tiny sensor nodes which are placed in some important locations on the human body, resulting in a wireless sensor body area network that is capable of monitoring different vital signs. These vital signs are conveyed to a medical doctor or any end user. The architecture consists of three tiers as shown in the figure 1 below, multiple sensor nodes that monitor temperature, blood pressure, humidity, sugar level, and heart activity, these signs are transfered via zigbee or Bluetooth to a personal server running on a PDA, and later sent to a remote database using WLAN or WWAN
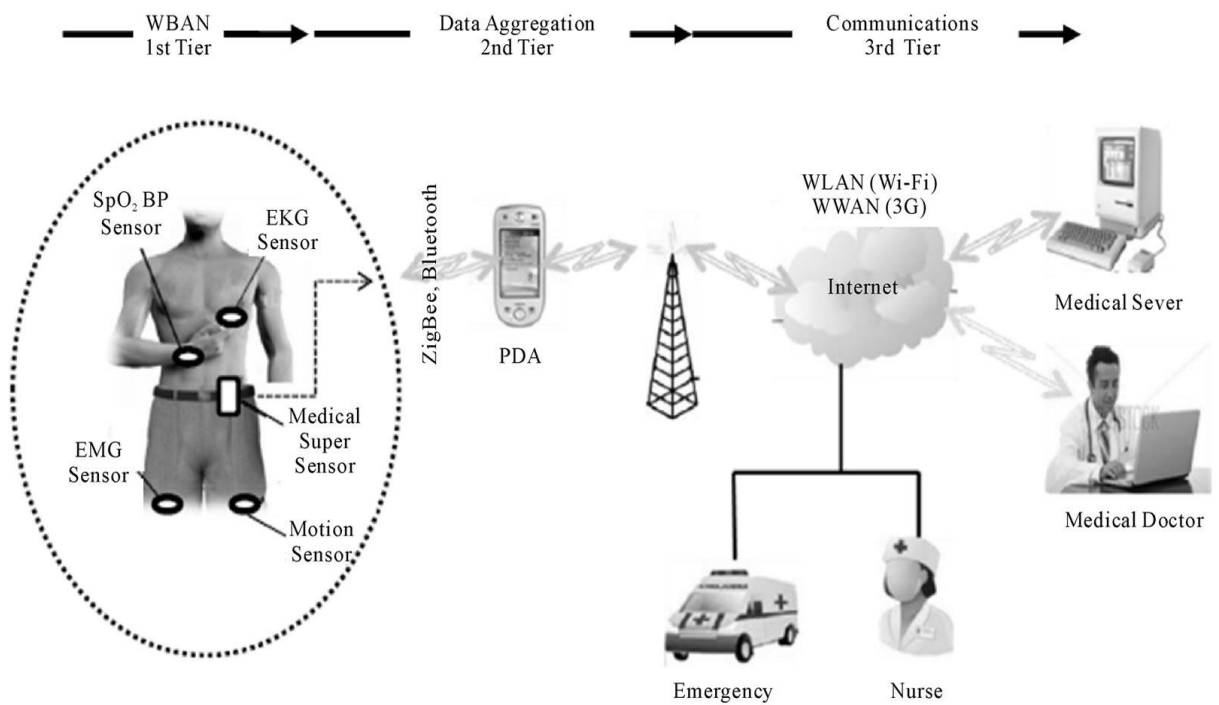

Figure 1 WBAN System Architecture, Reprinted from [6, 820-825]

3.1 System Overview

The proposed WSN for health monitoring consist of telemedicine system with different tier as shown in the figure 1 above. The telemedicine system stretches over network that encompasses individual health monitoring systems that connects a medical server via the internet. This system provides distributed data processing and analysis func-

tions other than a distributed data logger. The different tiers in the system architecture are intelligent and provide some forms of analysis, real time diagnosis are often possible in some rare cases. The medical server is developed to serve hundreds or more end users

The sensor nodes which are either implanted or worn on the body are designed to privately sample vital signs and transfer the sampled signs (data) through a wireless personal network implemented using Bluetooth (IEEE802.15.1) or ZigBee (IEEE802.15.4). The personal server running on a PDA is also called the gateway or Body Control Unit (BCU) or a sink; it collates all the information acquired by the sensor nodes and informs the users. [7]

3.1.1 Medical Server

This consist of database for data storage, processing and analysing software for delivering system intended service. It is the backbone of the architecture and receives data from the personal server, it is also responsible for user authentication. It is always at a remote location where medical services are provided; it is smart and capable of learning patient specific threshold and retrieving previous data of a patient. The real time state of a patient can be observed by the medical personnel.

The data measured by the sensors are sent through the internet/intranet to medical personnel who examine it and ensure the received data is within expected health metrics. Whenever there is deviation from the expected health metrics, the medical unit is notified and necessary actions will be taken. [7] Figure below shows a typical medical server with patient record.

Figure 2 Medical Database, Reprinted from [8]

3.1.2   Personal Server

The personal server (body gateway) running on a Personal Digital Assistant (PDA) connects the wireless nodes via a communication protocol using either Bluetooth or ZigBee. It is configured to a medical server using the server's IP address in order to interface the medical services. The vital signs generated from the sensor nodes are processed by the personal servers and in some cases when there are critical signs it prioritizes the transmission and send it to the medical server.

The PDA is intelligent device that performs the task of analysing the vital signs and make a comparative check with patient health status based on the data received by the medical server, thus providing a feedback through user-friendly graphical interface. Figure 3 shows a typical Blackberry PDA and figure 4 shows the flow chart for personal server working mode.

Connection between the personal server and the third tier is done using 3G communications but for long range communication protocols such as GPRS, WWAN are used. [7]
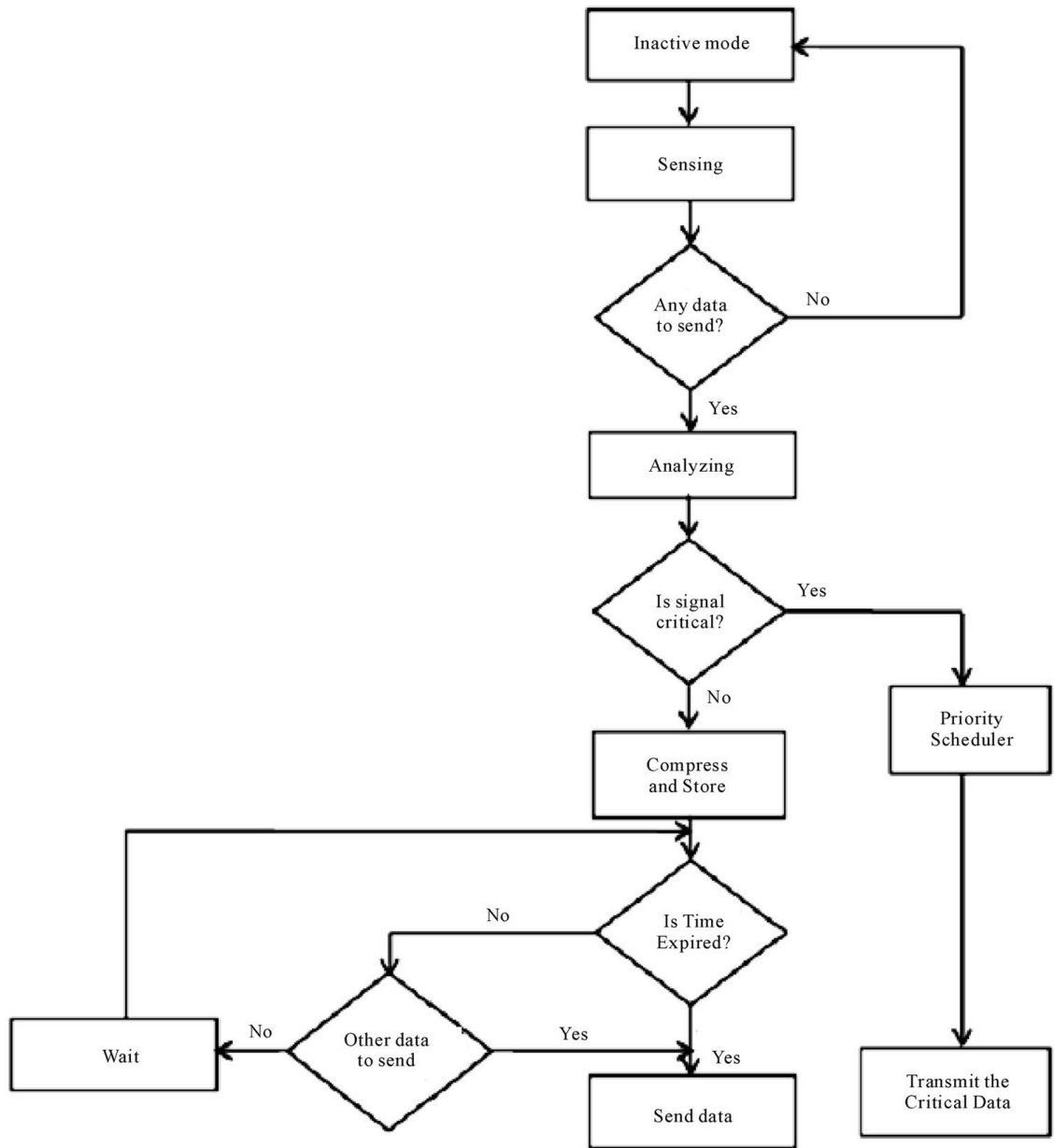

Figure 3 a PDA, Reprinted from [9]

Figure 4 Flow chart for personal server working mode, Reprinted from [10]

3.1.3   Sensor Nodes

These are devices that respond, gather data on physical stimuli. The data is processed and transferred wirelessly. The sensors are very sensitive and monitor any variation in the vital signs, also providing real time feedback to ensure optimal health maintenance. Figure 5 shows the basic architectural component of a smart sensor.

The sensor nodes basically have five main components, which are:

1. **Sensor**: It contains an embedded chip used in sensing vital signs from the patient's body.

2. **Microcontroller**: This is the brain of the sensor node, microcontroller controls how other components function and also performs local data processing such as data compression.

3.   **Memory**: It is usually very small in capacity, used to store data sensed by the sensor nodes temporally.

4. **Radio Transceiver**: Communication between nodes is achieved by the radio transceiver; it also allows physiological data to be send/received wirelessly.

5. **Power supply**: The sensor nodes are powered by batteries with a lifetime of several months.

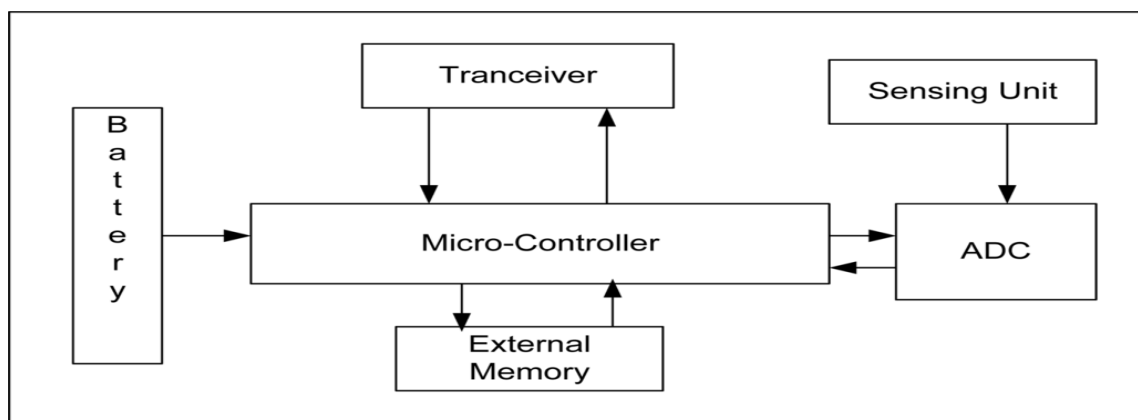6. **ADC**: This unit converts Analog signals into Digital signals. [11].

Figure 5.Basic architectural components of a smart sensor Reprinted from [13]

3.2 WSN Topologies and Data Propagation

WSN has many topologies and is not limited to one; the choice of topology is determined by the design task. The different topologies are stated below:

1. **Star Topologies**: This is the simplest of all types of WSN topology; the nodes in this type of topology are very small and close to the gateway around 30 meters, where nodes far away from the gateway will have poor quality connection. It is connected directly to the gateway. Thus, this kind of topology is more efficient when the number of nodes in the network is very small. The biggest limitation to star topology is the problem of scalability. [14]

2. **Mesh Topology**: When large coverage area is required, this type of topology is used; this is achieved by multi hopping, where a signal from one sensor goes to another until it finally reaches the gateway. Routing protocol is used to determine how signals are routed. [14]

3. **Tree Topology**: This is the most common topology for larger WSNs, the nodes are divided into regions, where nodes in each region send physiological data to local cluster head, and all the cluster heads in the different regions collectively send the received data to the gateway. It is also possible for the cluster head of one region to send data to another cluster head which then can send to a gateway, a phenomena called "interlacing". In order to increase the transmission speed and reliability of the network, the nodes are connected through a wire. One of the biggest merit of Tree topology is the division of nodes into smaller regions, where routing of signals are done locally. [14]. Figure 6 below shows the three common topologies used in WSNs.
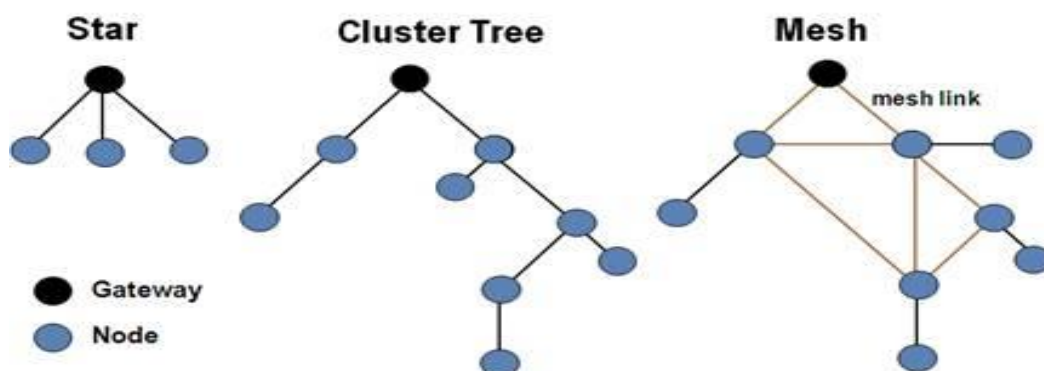

Figure 6.WSNs Topologies, Reprinted from [15]

3.2.1 WSN Data Propagation

A sensor start sensing once the need arises, as soon as a matching event is detected, data messages are sent to the relevant neighbours using the gradients established. A data cache is maintained at each sensor recording history. There are different data propagation protocols such as Directed Diffusion (DD), LEACH, Local Target Protocol (LTP), Probabilistic Forwarding Protocol (PFR), and Energy Balanced Protocol (EPB).

3.2.2 Parameters for Measuring the Effectiveness of a Topology

1. **Range and Coverage**: The physical layer quality and data transmission efficiency are crucial factors affecting a wireless network. The node to node range at a given antenna gain and data rate are obviously the important requirements for a Wireless Sensor Network (WSN). In order to have a better coverage area, dead spots are eliminated from the network.

2. **Scalability**: In recent years, demand for higher bandwidth and performance supercomputers, resulted into scalable networks. The ability to cope with network cells as small as few nodes to thousands of cells increasing the size of existing network by a magnitude without involving an expensive cellular communication is called Scalability. Many of the factors that are associated in scaling a network topology can only be improved at the expense of others leading to an optimal concession between many factors. These factors include but are not limited to bisection bandwidth, alteration in network throughput, cost and size of expansion, routing and flow control alterations, variation in communication latency, etc.

3. **Expected Transmission Count (ETX)**: Environmental hazards, data loss due to medium access contention, and number of transmissions used to successfully transmit a packet over a link are accounted for by ETX.

4. **Hop Count**: For wireless multi-hop network commonly used metric is the Hop Count. Paths with minimum number of links between a given source and sink are selected.

5. **Network Longevity**: Ability to extend network lifetime has been mentioned in different journals and publication regarding WSNs communication protocols.

The location of sensor nodes has significant effect on the network life time because closer nodes to the base station gets energy at a rate higher than other nodes far from the base station, improper location of the nodes can result into unbalanced and bottlenecks traffic. [14]

3.2.3 WSN Protocol Stack

Sensor nodes are typically more than a typical ad-hoc network, and they are generally prone to permanent failure. These sensors have limited memory and power, therefore using broadcasting instead of point-point communication used in ad-hoc nodes. A typical packet overhead may be too large for Sensor nodes; they therefore do not usually have a global ID.

Due to these reasons algorithms developed for wireless ad-hoc networks cannot be used for sensor networks. The protocol architecture for sensor networks shown in figure 7 below promotes cooperative efforts of sensor nodes, and integrates power and networking protocols via wireless medium.

The protocol stack consists of transport layer, application layer, physical layer, data-link layer, network layer; couple with task-management plane, power-management plane, and mobility-management plane.

1. **Physical Layer**: This layer is responsible for generation of carrier frequency, data encryption, robust modulation, selection of frequency, transmission of data, receiving data, signal deflection.

2. **Data Link Layer**: Since power is limited in sensor nodes, minimizing packet collision with neighbouring nodes is achieved by the media access control (MAC). It is also responsible for data frame detection, error detection, and multiplexing of data.

3. **Network Layer**: Routing of packets delivered by the transport layer, and address assigning are done within the network layer.

4. **Transport Layer**: This layer specifies how packets can be transported in a reliable manner.

5. **Application Layer**: This layer provides an interface for interaction between the end users and sensor nodes, it is also responsible for specifying how data are requested.

6. **Power Management Plane**: Accurate location of sensor nodes is required for sensing task and network routing techniques of the nodes, this plane is responsible for power management of sensor nodes.

7. **Mobility Management Plane**: A mobilizer is used to keep track of the closest neighbour and to move sensor nodes enabling them to carry out an assigned task and maintain return path to the user.

8. **Task Management Plane**: Series of energy-aware MAC, Clustering and routing protocols have been developed for WSNs for self-organization of sensor nodes. Most of the MAC protocols aim to either adjust the transmission power or keep transceiver off as long as possible. [14] [16]
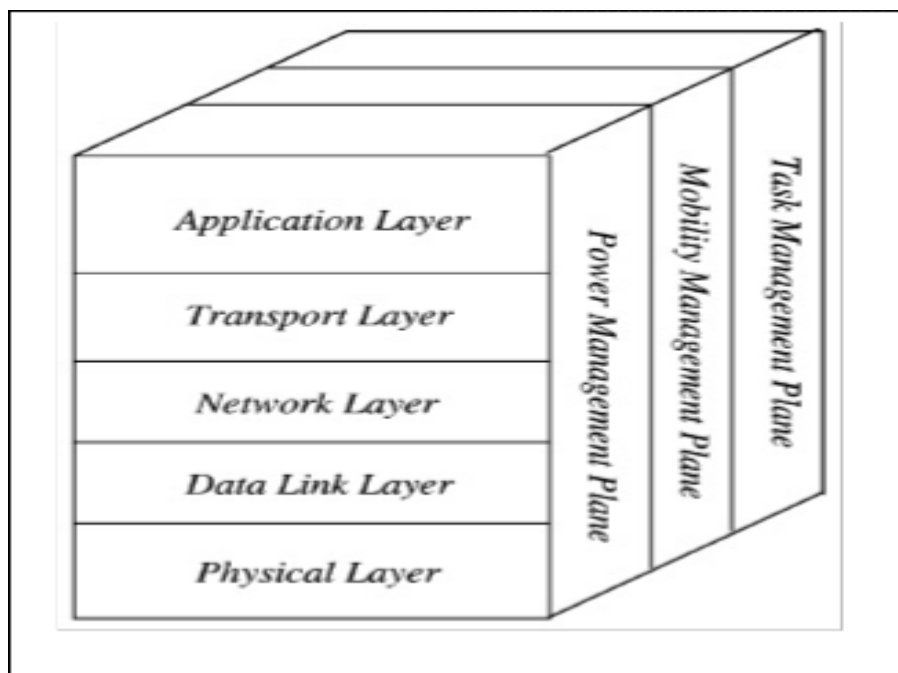

Figure 7 Protocol Stack Architecture for WSNs, Reprinted from [16]

3.2.4 WSNs Security Requirement

It is mandatory to protect the information sent by nodes in WSNs, so security is crucial in all sensor networks. The security requirements in WSNs include but not limited to:

1. **Authorization**: Sensor nodes that communicate within a network are those that have been authorized to do so, any without an authorization will not be able to communicate.

2. **Authentication**: In order to avoid malicious node from communicating as a trusted node, all nodes in the network need to be authenticated, thereby providing genuine communication.

3. **Integrity**: It is very important that information sent from nodes to nodes is not tampered with by any malicious node, so integrity is an important part of WSNs security requirement.

4. **Availability**: It is paramount that the desired service be available at any point in time irrespective of the presence attacks in the network.

5. **Confidentiality**: Information been transferred should be encrypted in a way that only the recipient can only decode it.

3.3 WSNs Communication Protocols

In WSNs nodes communicating with other nodes lead to transfer of sensed data to the sink. WSN requires basically two types of protocol (Medium Access Control and Routing protocols).

Routing protocols used for maintaining routes and reliable multi-hopping in the network; these protocols differ greatly from the conventional routing in wired networks. Wireless links are unreliable, leading to sensor nodes failing and routing protocol need to meet the strict energy saving requirements.

The MAC layers (a sub-layer in the data-link layer) ensure efficient use of the communication channel so that access to the channel by multiple nodes will be possible without collision; it also plays an important role in throughput, QoS, energy saving etc.

Contention-based and contention free are the two groups of MAC protocols. Protocols for contention based group allow one channel to be used by multiple nodes but each node needs to sense the medium before transferring data. Retransmission is required when collision occurs. Whereas channels used for contention-free protocols are divided into time slots, these time slots are allocated to different nodes to send data, no collision occur using contention-free protocol since different time slots are allocated to the nodes. [17]

3.3.1 Routing Protocols for WSNs

There are different categories of routing protocol for WSNs, table 2 below shows the representative protocols for different routing protocol, while figure 8 illustrates the routing protocols in WSNs.

Table 2 Routing Protocols for WSNs Reprinted from [17]

Category	Representative Protocols
Location-based Protocols	MECN, SMECN, GAF, GEAR, Span, TBF, BVGF, GeRaF
Data-centric Protocols	SPIN, Directed Diffusion, Rumor Routing, COUGAR, ACQUIRE, EAD, Information-Directed Routing, Gradient-Based Routing, Energy-aware Routing, Information-Directed Routing, Quorum-Based Information Dissemination, Home Agent Based Information Dissemination
Hierarchical Protocols	LEACH, PEGASIS, HEED, TEEN, APTEEN
Mobility-based Protocols	SEAD, TTDD, Joint Mobility and Routing, Data MULES, Dynamic Proxy Tree-Base Data Dissemination
Multipath-based Protocols	Sensor-Disjoint Multipath, Braided Multipath, N-to-1 Multipath Discovery
Heterogeneity-based Protocols	IDSQ, CADR, CHR
QoS-based protocols	SAR, SPEED, Energy-aware routing

3.4 Structure Based Routing Protocols

Routing protocol earlier discussed are grouped into structure-based, and are generally determined by the design constraints given for the network structure. They are classified as hierarchical, location-based, and flat routing. Table 3 shows the difference between hierarchical and flat routing. [18]

3.4.1   Hierarchical Routing

This type of routing employs clustering where all nodes in the network are grouped into cluster, where a cluster head performs the function of data aggregation and redundancy check before transferring the sensed data to a sink. This reduces communication and processing work resulting in energy saving. [18]

3.4.2   Location-Based Routing

All nodes in the network are addressed using their respective locations, the strength of the incoming signal is used to determine the nearest neighbouring node distance. The presence of obstacle in the network reduces the signal strength, which makes it difficult to locate the nearest neighbour. When there is no transmission going on, Location-based routing requires that nodes should switch their state from active to sleep mode, in order to save energy

GAF (Geographic Adaptive Fidelity) and GEAR (Geographic and Energy aware Routing) are two examples of location-based routing scheme. [18]

3.4.3   Flat Routing

This type of routing allows all nodes to equal roles, such as collecting data, and transmitting to the sink. Data collected from remote location can be the same or duplicated as all nodes in the network perform the same function. [18]

3.5 Protocol Operation Based Routing Protocols

Protocols are grouped into operation based function according to the network structure, or variation in network structure. The protocols are divided into query-based, quality-of-service (QoS) based, negotiation-based, coherent-based, and multi-path based.

3.5.1   Query-based

The sink sends queries to the network requesting for information, then nodes within the network read these queries. Once there is a match with a data requested in the query, it begins to transmit the data to the sink. This process is called Direct Diffusion. Thus, energy is saved and data aggregation is done. [19, 56-67]

3.5.2   Quality-of-service Based

This type of protocol ensures that both quality and energy are maintained within the network. When a sink requests for data from nodes in the network, the transmission must meet certain quality-of-service parameters like bounded latency and bandwidth

consumed. Bounded latency simply means that data has to be sent immediately when it is sensed without any delay. Sequential Assignment Routing (SAR) [20, 16-27] is one of the first protocols to use the notion of QoS in routing decision. In SAR routing decision depends on these factors: energy consumed by sink and nodes within the network, QoS of each transmission path in the network, and level of priority for sent packet. [21]

3.5.3 Negotiation Based

In this protocol high level descriptors are used to eliminate the redundant data transmissions. Data are separated using flooding because flooding data overlap and collision occurs during transmission. A lot of energy is used during this process as nodes receive duplicate copies of data during transmission. SPIN [22,319-349], a negotiation based protocol is used to suppress the duplicated data, preventing redundant data from been sent to the next nodes; or towards the base station by performing several negotiation messages on the real data that has to be transmitted. [22,319-349]

3.5.4 Coherent Based

Processing of the sensed data is the most crucial in WSNs. There are basically two kind of data-processing methods, which are coherent and non-coherent. In non-coherent processing each node in the network processed the received data, before sending it to an aggregator that further processed the data. While in coherent processing, functions like time stamping or suppression duplication are performed before the data is sent to the aggregator. Since all nodes process data independently, this type of technique is energy efficient and also reduces total time spent. [21]

3.5.5 Multi-path Based

In the case of handling multiple data paths, this kind of protocol is more efficient, since nodes send data through multiple paths instead on single path then reliability and fault tolerance increases using this type of protocol.
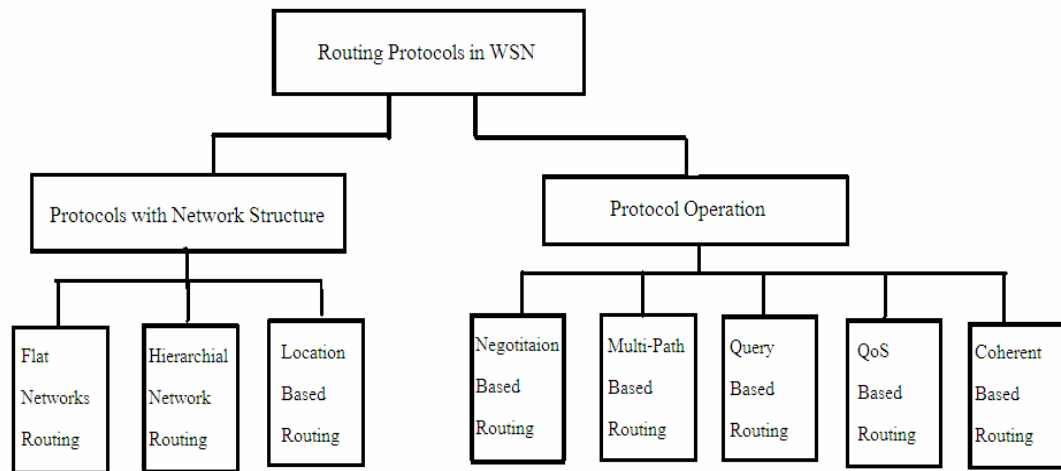
Figure 8 Routing Protocols in WSNs

Table 3 Hierarchical vs. flat topologies routing, Reprinted from (Jamal N. Al-Karaki et al.2004).

Hierarchical routing	Flat routing
Reservation-based scheduling	Contention-based scheduling
Collisions avoided	Collision overhead present
Reduced duty cycle due to periodic sleeping	Variable duty cycle by controlling sleep time of nodes
Data aggregation by clusterhead	Node on multihop path aggregates incoming data from neighbors
Simple but non-optimal routing	Routing can be made optimal but with an added complexity.
Requires global and local synchronization	Links formed on the fly without synchronization
Overhead of cluster formation throughout the network	Routes formed only in regions that have data for transmission
Lower latency as multiple hops network formed by cluster- heads always available	Latency in waking up intermediate nodes and setting up the multipath
Energy dissipation is uniform	Energy dissipation depends on traffic patterns
Energy dissipation cannot be controlled	Energy dissipation adapts to traffic pattern
Fair channel allocation	Fairness not guaranteed

4   MAC (Medium Access Control)

In wireless sensor networks, different nodes communicate with each other and also with the sink (gateway). During this communication process, data may be corrupted, and collision may also occur. When this happens, data is retransmitted resulting into more energy consumption. Energy efficiency is one of the major challenges in WSN, when MAC protocol are properly designed the nodes will be able to access the channel in a very efficient way saving energy and increasing quality of service.

A MAC protocol comprises one or several multiple access schemes like FDMA, TDMA, and CDMA. These schemes are briefly explained below.

4.1   Multiple Access Scheme

Three types of multiple access schemes used in WSNs will be briefly describe below.

4.2   TDMA

In Time Division Multiple Access, nodes are given time slot to transmit, so that different nodes can access the communication channel without collision. In a typical WSN, different node communicate with the base station, when a time slot is given to each nodes it allows a particular node to send data to the sink during the allocated time, during the inactive slots node sleep to conserve energy. Pictorial representation of TDMA is shown in figure 9 below.

Full bandwidth is occupied during the time slot, in order to avoid collision clock synchronization is required. The sink or base station broadcast the clock synchronization packet to all nodes. All nodes has to be in active mode to receive synchronization.
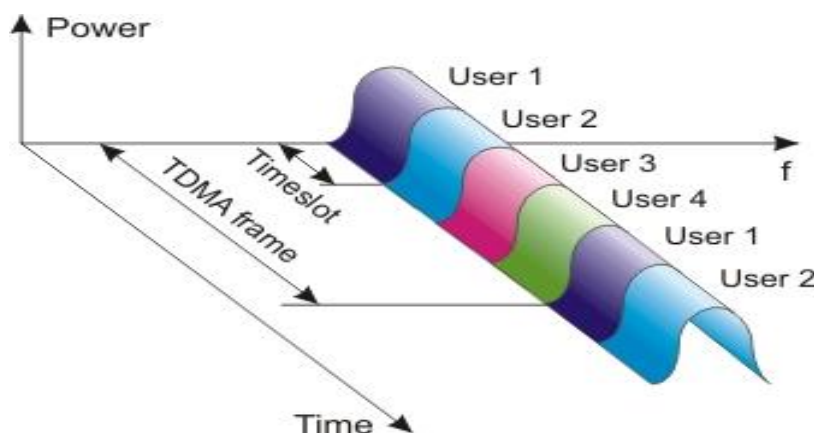

Figure 9 Time Division Multiple Access, Reprinted from [24]

4.2.1 Advantages of TDMA

1. TDMA has an ability to carry data rates within the range of 64kbps to 120kbps.

2. TDMA transmits only portion of the time allocated, providing users with an extended battery life.

3.   TDMA can transmit both data and voice easily.

4.   Since TDMA technology separates users according to time, it therefore avoid interference from simultaneous transmissions.

5.   When converting from analog to digital systems. TDMA is the most cost effective technology to be used.

4.2.2 Drawbacks of TDMA

1.   User has a predefined time slots, when a node moves from one cell to another when there are no available time slot In the new location, the node might be disconnected.

2.   TDMA is subjected to multipath distortion, system time limit can be used to overcome this distortion, once the time limit is expired the sign is ignored.

4.3   FDMA

Unlike TDMA, where each node has to be in active mode to receive synchronization packet, which may result into delay in communication, FDMA avoids this problem. Nodes are divided into different frequencies, so that multiple nodes can communicate via the gateway at the same time. Figure 10 shows a typical FDMA, in order to get synchronization in FDMA, nodes exchange their schedules.
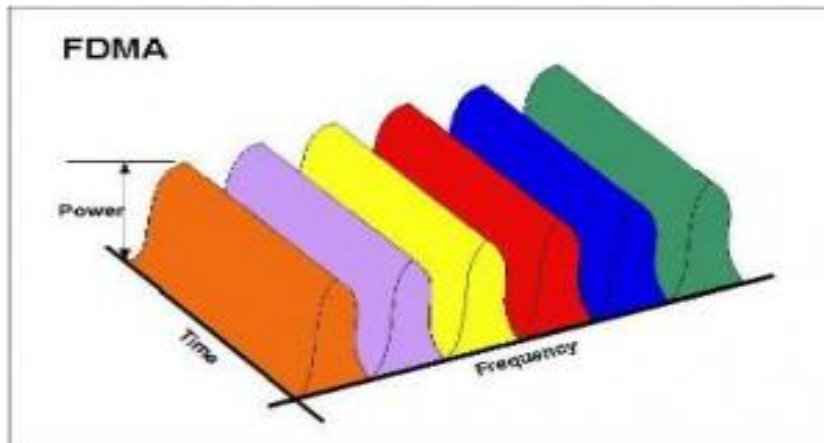

Figure 10 Frequency Division Multiple Access, Reprinted from [25]

4.3.1   Advantages of FDMA

All nodes can operate continuously without having to wait for their turn to come like in TDMA. The numbers of channels determine the transmitted power, SNR is improved due to the use of Frequency Modulation (FM). [25]

4.3.2   Drawbacks of FDMA

There are interference due to adjacent channel in spite of the guard bands provided, it requires large bandwidth since FM is been used, thus resulting into smaller number of channels. Lastly, due to the non-linearity of companders, the intermodulation products are generated. [25]

4.4 CDMA

Code Division Multiple Access is scheme where different nodes are assigned with different codes. It provides slight interference during simultaneous transmission. It overcomes the drawback of communication delay in TDMA and limited bandwidth in FDMA as it provides the full bandwidth to the nodes. Figure 11 below illustrates a typical CDMA.
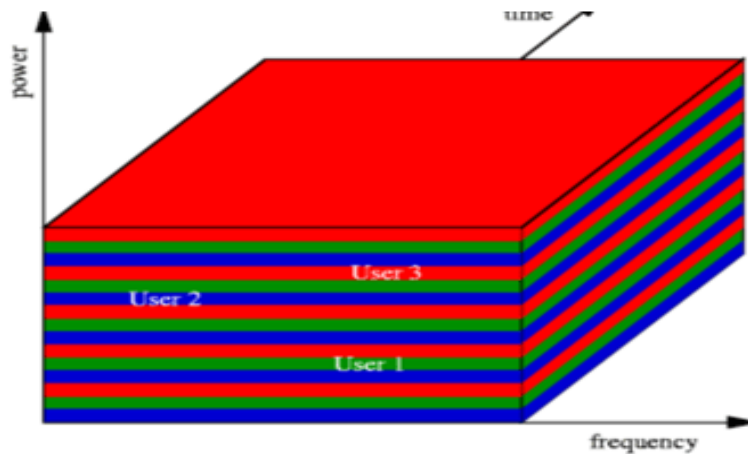
.

Figure 11 Code Division Multiple Access, Reprinted from [26]

4.4.1 Advantages of CDMA

1. Less multi-path interference: RAKE receivers are used in CDMA to resolve multi-path interference if signal arrive from more than one nodes. The figure 12 below shows the basic principle of RAKE receiver
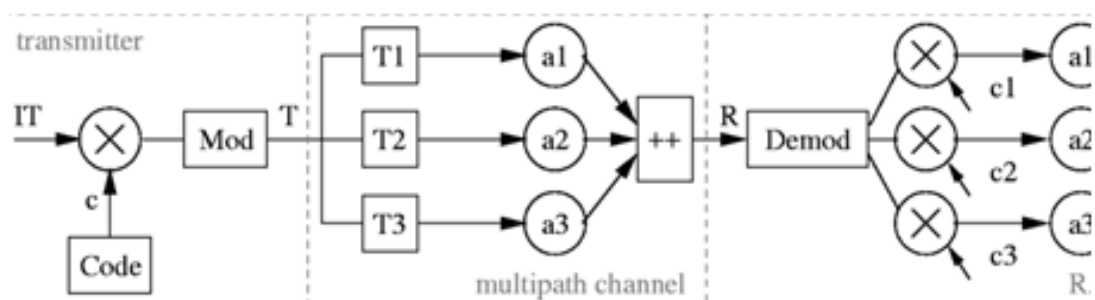

Figure 12 showing a RAKE receiver Reprinted from [26]

After spreading the modulated signal from the transmitter end, the signal suffers from multi-path channel. The signal from different propagation path is further demodulated and passed to the RAKE receiver.

The number receiver finger in the RAKE is limited by the receivers hardware complexity or cost. In each finger the signals are dispread and time aligned with one of the multi-path channels, then weighed and combined.

2. Power Control Mechanism: In a DS-CDMA all transmitters use the same bandwidth at the same time to send data to the receiver. In a case where a receiver receives multiple data from different transmitter at different locations, the signals are received with different power levels. Transmitter closer to the receiver have higher power levels than ones far away, this effect is called near-far effect. Changes in propagation also vary the signal strength.

Transmitter power control mechanisms are implemented to ensure that signals arrive at the receiver with the same power level.

3. Soft Handoff: Handoff is a process of moving from one cell to another without interrupting the connectivity. CDMA uses soft handoff rather than hard handoff used in GSM, soft handoff allows nodes to start communication with a new base station without interrupting previous communication with the old base station. Soft handoff provides site selection diversity; which is a process where information from multiple transmitter is combined to increase the effective SNR or received packets.

4.4.2 Limitations of CDMA

1. High Degree of Synchronization between the sender and the receiver: CDMA employ orthogonal codes and in the presence of slight mismatch between the transmitter and receiver can result to decoding the whole message in a wrong and produces lots of errors.

2. Power Variations When Load is Excess: High voice clarity and data efficiency is one of the merits of CDMA. When the number of users increases above the expected, then variable power losses exist as the coverage area shrinks, thus affecting the SNR and efficiency of the system. Power variation is also experienced when a node is far from the base station. Nodes closer to the base station receive more power than those in far locations. This situation is called Near-Far Problem in CDMA.

3. Less Popular than GSM: CDMA is still yet popular like GSM although it is more effi-
cient than GSM, it will take some time to gain popularity.

4. Practical Limitations: As the number of users increases in CDMA, there may be
problem of giving each user a unique spreading sequence. This can result into limita-
tion in performance and number of users.

5   Simulation and Result

This section explains the simulation methodology used; description of how the WSN
was simulated using Simulink MATLAB, and the result of the simulation. I will start with
the simulation methodology, thereafter the Simulink MATLAB simulation.

5.1   The Proposed WSN simulation methodology

I built the simulation in an environment called MATLAB. MATLAB stands for matrix
laboratory; it was developed by Mathworks Inc., a software package used for high per-
formance numerical computation and visualization. MATLAB became a premier soft-
ware package for scientific researchers since it combines flexibility, reliability, and
powerful graphics.

The most important feature of this software is its programming capability, which is very
easy to use and learn, enabling user-developed functions. The external interfaces allow
access to Fortran algorithms and C codes. There are several optional toolboxes written
for special applications such as control systems design, neural networks, signal pro-
cessing, system identification, fuzzy logic and others. MATLAB has been enhanced by
the very powerful Simulink program [27].

Simulink is a software package used for modelling, simulating, and analysing dynam-
ical systems. Linear and nonlinear systems, sampled time, modelled in continuous time
are all supported by Simulink. For modelling, Simulink provides a graphical user inter-
face (GUI) for building models as block diagrams, using click-and-drag mouse opera-
tions. The interface allows you to draw the models just as you would with pencil and
paper. Simulink comprises of comprehensive block library of sinks, source, connector,
linear and nonlinear components, one has the opportunity to create his own blocks
models hierarchical.
This approach gives an insight to how a model is organized and its parts interact. After
you defined a model, you can simulate it using a choice of integration methods, either

from the Simulink menus or by entering commands in MATLAB's command window. The simulation results can be put in the MATLAB workspace for post processing and visualization. Since MATLAB and Simulink are integrated, you can simulate, analyse, and revise your models in either environment at any point. [27].

5.2   Simulating a simple WSN in Simulink MATLAB

This network consists of three sensors sending their measured data samples to a master node. In this work, MATLAB Simulink communication block set was used to build a complete WSN system. The procedure includes building the hardware architecture of the transmitting nodes, modeling both the communication channel and the receiving master node architecture. The physical layer communication with respect to different channel parameters such as SNR, Attenuation, and Interference was achieved using Bluetooth. Appendix 1 shows the modelling of a simple WSN in a Simulink environment. The model was simulated and the corresponding result was recorded. A simple WSN model was built as shown in figure 13.
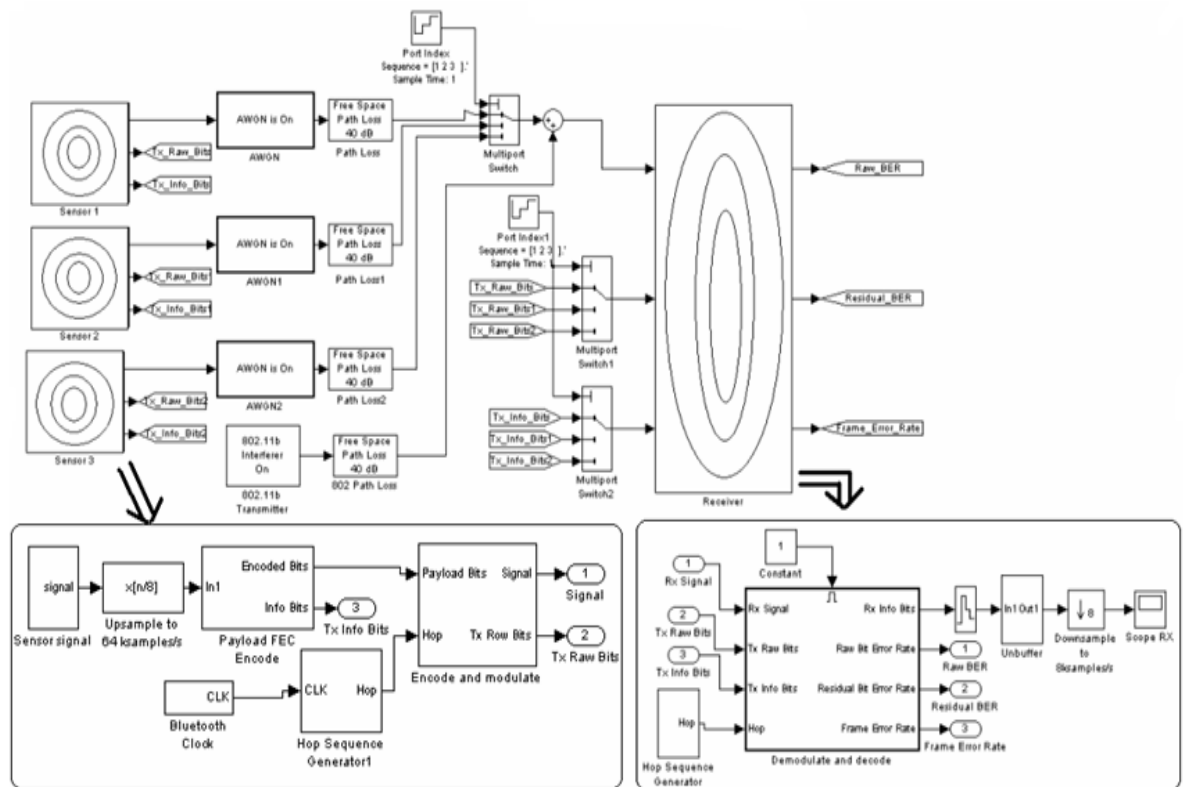

Figure 13 showing a simple WSN model, Reprinted from [28].

The architecture of the WSN could be explained as follows:

1. **The transmitter**

Bluetooth technology is used as the backbone of the transmission. Bluetooth operates in the 2.4GHz Industrial, Scientific, and Medical (ISM) band. The signal modulation for the system is done using Gaussian frequency shift keying (GFSK) over a radio channel with maximum capacity of 1Mbps. Appendix 2 and 3 shows the connected elements inside the transmitter and receiver respectively. The transmitter has the following blocks:

- Sensor signal stage: A sensor is used to sense the physical signals such as pressure, humidity, temperature etc., then a transducer is used to convert these signals to electrical signals. There is also an A/D converter that changes the signal from Analog form into a Digital one using 256 quantization level.

- Up-sampling to 64Ksample/s: The signals are up sampled to an higher rate by inserting zeros between samples.

- Payload FEC encode: An FEC encoder which includes a binary convolutional encoder followed by a puncturing device is used to encode the data for error correction.

- Bluetooth Clock: There is a free-running 28-bit Bluetooth clock in each Bluetooth device. The clock ticks once every 312.5 µsec, representing a clock rate of 3.2 KHz.

- Hop Sequence Generator: For effective communication between devices, they must transmit and receive at the same frequency and time. The hop sequence generator generates a sequence of hop frequencies in the range 0 to 78.

- Encoder and modulator: The 366 data bits are transmitted at 1 Mbps and modulated using GFSK.

2. **The medium which consists of the following blocks**

- AWGN Channel: The AWGN Channel block adds white Gaussian noise to a real or complex input signal. When the input signal is complex, the block adds complex Gaussian noise and produces a complex output signal. When the input signal is real, this block adds real Gaussian noise and produces a real output signal.

- Path Loss: This block reduces the amplitude of the input signal by an amount specified using "Decibels" mode, or indirectly using the "Distance and Frequency" mode.

- 802.11b interferer: This block adds signals of same frequency in order to ensure interference between the data signal and other signals.

- Multiport Switch: This block is use to simulate the multiple access and multiplexing functions of the channel. It chooses between a number of inputs. The first input is called the control input, while the rest input are called data input. The value of the control input determines which data input is passed through to the output port.

3. **The receiver consists of the following blocks:**

- Hop Sequence Generator: As discussed earlier.

- Demodulation and decoding: This block is used to get back the original signal from a modulated carrier wave, and recover the information content in it.

- Zero-Order Hold: This block samples and holds its input for the specified sample period. It accepts one input and generates one output, both of which can be scalar or vector. All elements are held for the same sample period, if the input is a vector.

- Un-buffer: This block un-buffer an M-by-N frame-based input into a 1-by-N sampled based output. That is, inputs are un-buffered row-wise so that each matrix row becomes an independent time-sample in the output. The rate at which the block produces output is generally higher than the rate it produces input.

- Down-sampling to 8Ksample/s: This block down-sample the input to a lower rate by deleting the repeating samples.

- Scope RX: It was used to display the received signal and compare it with the original signal to examine the system behaviour.

5.3   Result

From the below result presented in appendix 4, it is clearly shown that the behaviour of the model was successfully described using Simulink. Simulink MATLAB provides a flexible approach to study the effect of different physical layer parameters on the performance of WSNs, also provides ability to change the different system parameters to create new environment.

Summary of the different simulation methods of WSN including MATLAB SIMULINK is given in table 4 below.

Table 4. The features of the different simulation methods of WSN, Reprinted from [28]

Simulation Environment	Programming Language	WSN support
GloMoSim/ QualNe	C and Parsec	GloMoSim: basic mobility and radio propagation models; 802.11; QualNet: additionally battery and energy model; ZigBee → GloMoSim seems to be outdated; QualNet seems to be more up-to-date, but commercial
OPNET Mod-eler Wireless Suite	configuration by GUI; internals C++	Different propagation models; 802.11,ZigBee; some MANET protocols, but no special WSN sup-port → powerful tool with a nice GUI, but expensive
TOSSIM (part of TinyOS)	nesC	All TinyOS-based WSN protocols can be simulat-ed with TOSSIM without modifications → good ap-proach especially if im-plementation should also be used with TinyOS-based nodes
OMNeT++	basic modules C++; larger structures NED	Several frameworks that add WSN functionality to OMNet++ such as MiXiM, Castalia, etc. → active project with a huge user base; Eclipse-based IDE for development
NS-2	C++; configu-ration OTcl	Huge amount of protocols available contributed by NS-2 users →complex configuration; unclear situation due to large number of different user contributed implementa-tions
Avrora	AVR microcontroller binaries	Particularly for programs written for AVR micro-controller with support for support for Mica2 and Mi-caZ → very special appli-cation area; project seems to be still active –still changes in CVS

J-Sim	Java; configuration Tcl/Java	Includes sensor network package containing models such as propagation, battery, radio model and sensor protocol stack including AODV and 802.11 → project seems to be abandoned
ATEMU	AVR microcontroller Binaries	Complete emulation of the AVR instruction set with partial Mica2 support; TinyOS based code can be run → very special application area; slow simulation speed; project seems to be abandoned
EmStar	C	Provides network funtionality for wireless embedded systems; EmTOS can be used to run TinyOS applications as EmStar module → project seems be abandoned (download links broken)
Shawn	C++	Algorithmic approach that concentrates on lower layers, no special WSN protocols → very active project -lot of recent changes in SVN
MATLAB SIMULINK	C , Java	Detailed simulation of the end nodes and their architecture, Physical layer parameters, different modulation & encoding techniques, communication channel modeling(SNR, effect of different Noise schemes, Interference, distance,etc..), various methods to monitor and record results, making use of the rich library of Matlab/Simulink.

5.4   Conclusion

A new simulation methodology for wireless sensor networks was presented; MATLAB/Simulink was used to build the simulation environment. With this simulation tool it was easy to study the effect of different physical layer parameters (SNR, channel noise and interference, etc.) on the system behaviour. The simulation also provided flexibility in building the end nodes and sensors. This simulation methodology can be employed to build different WSN types and gives an opportunity to use MATLAB in this new field.

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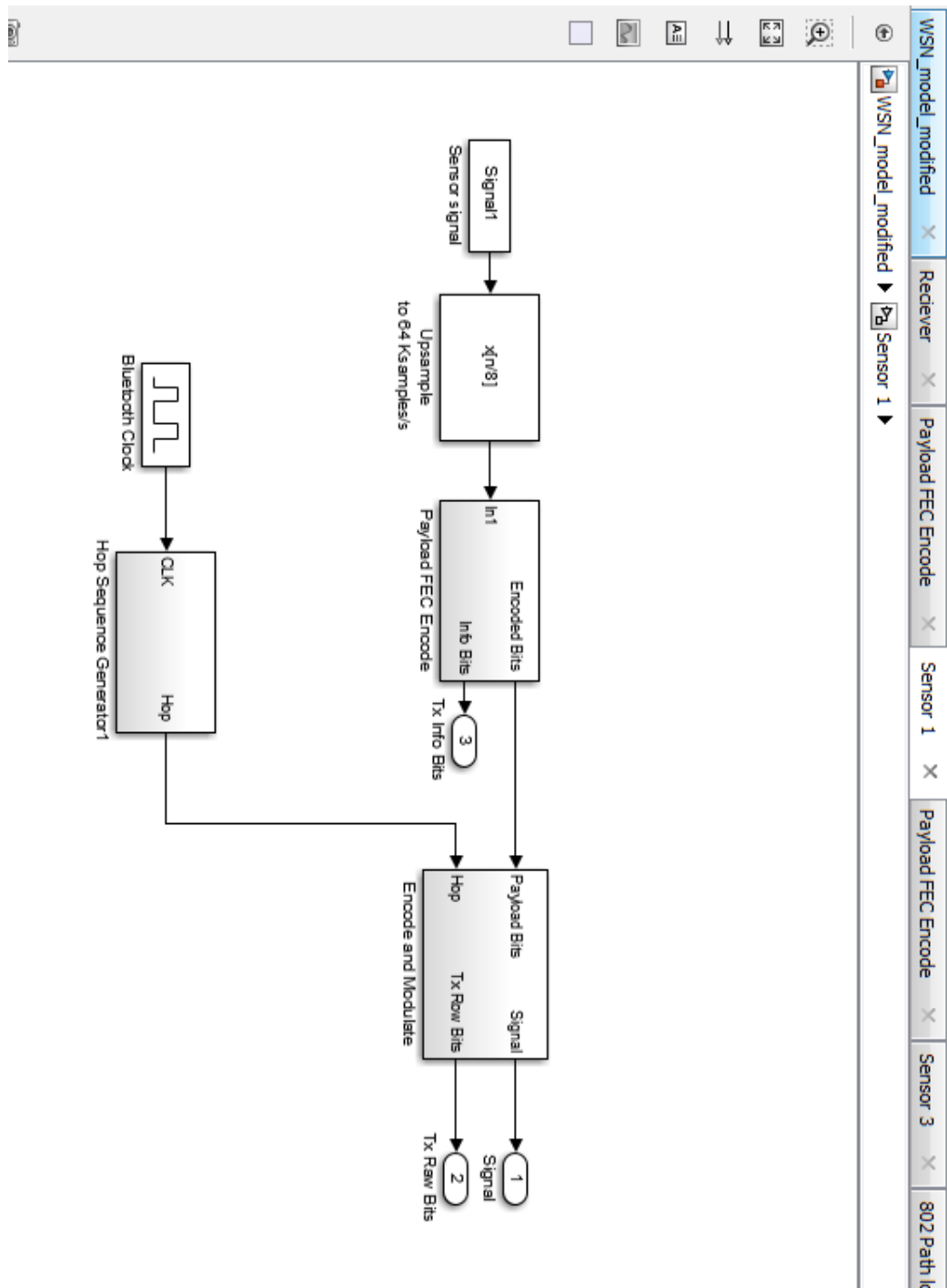
[28] Simulation Framework of Wireless Sensor Network (WSN) Using MATLAB/SIMULINK Software by Qutaiba I. Ali

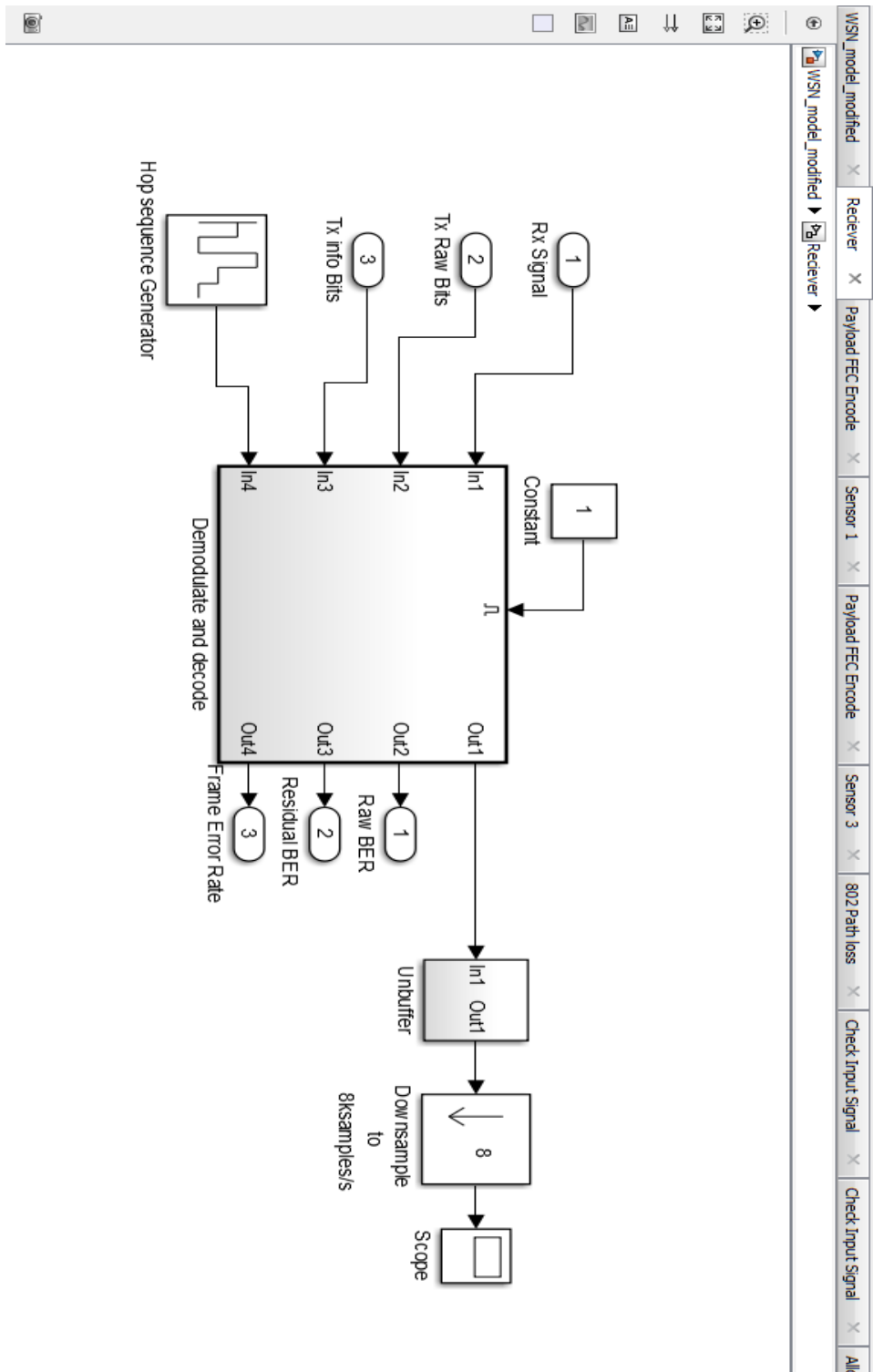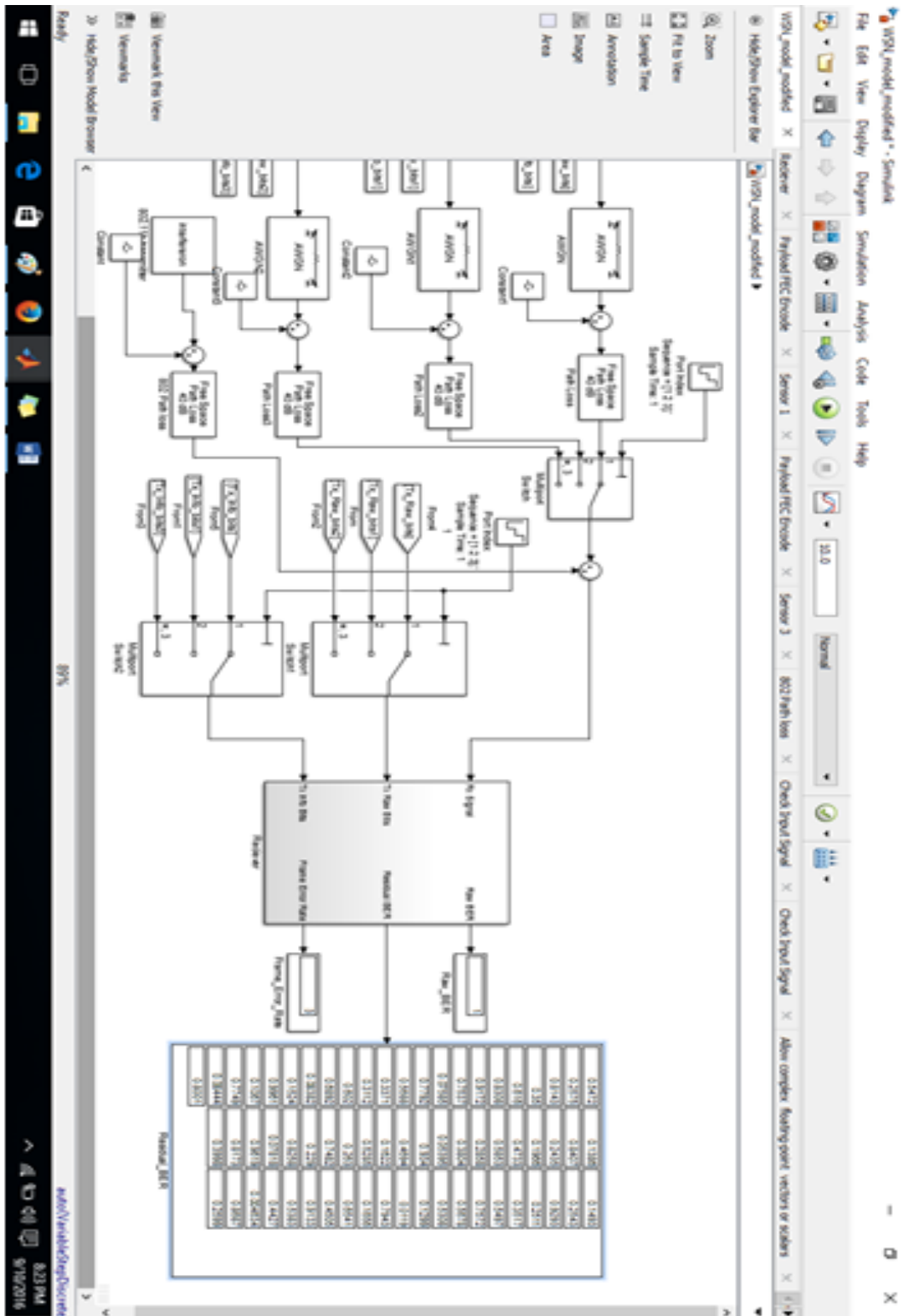**Modelling of a simple WSN in a Simulink environment.**
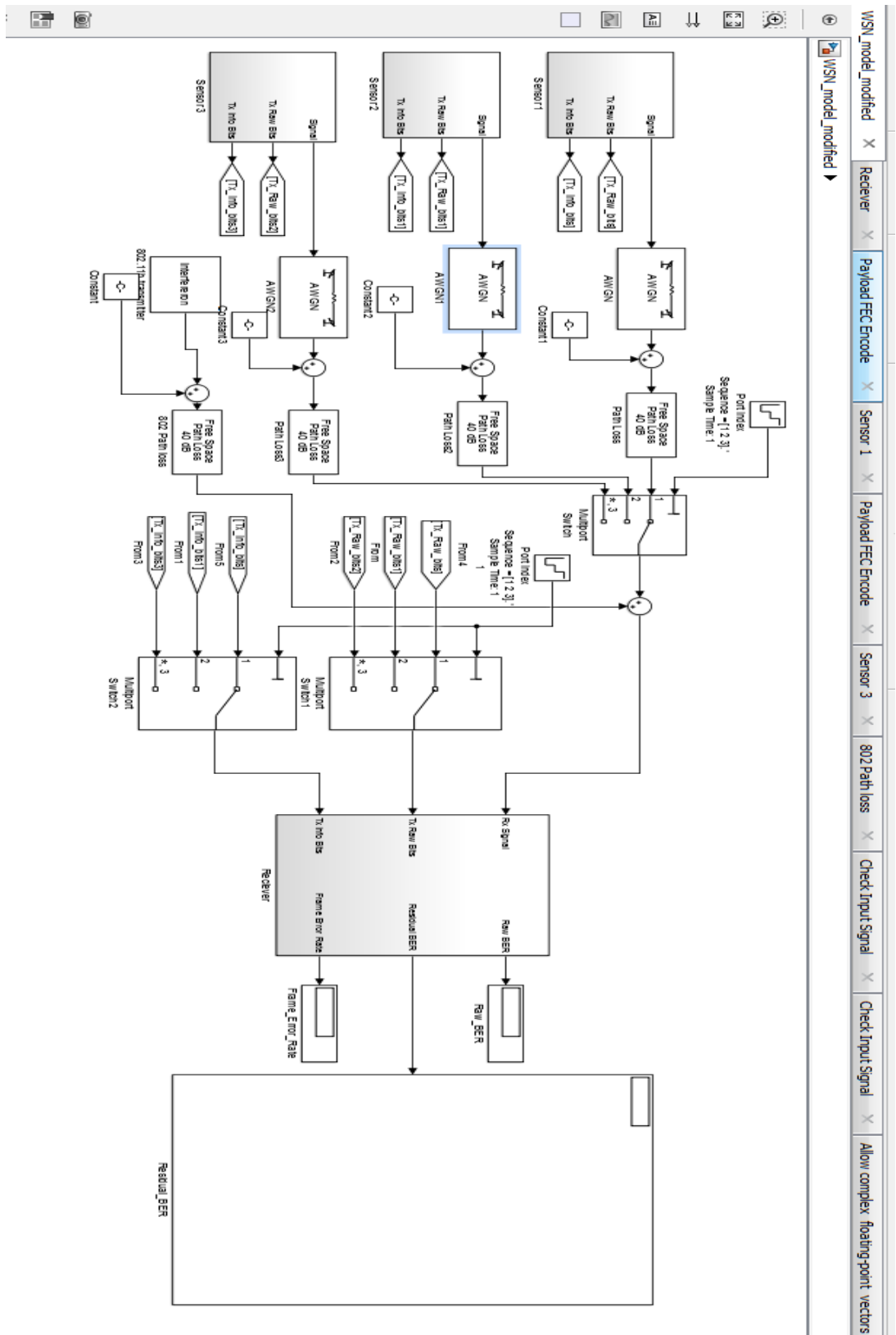
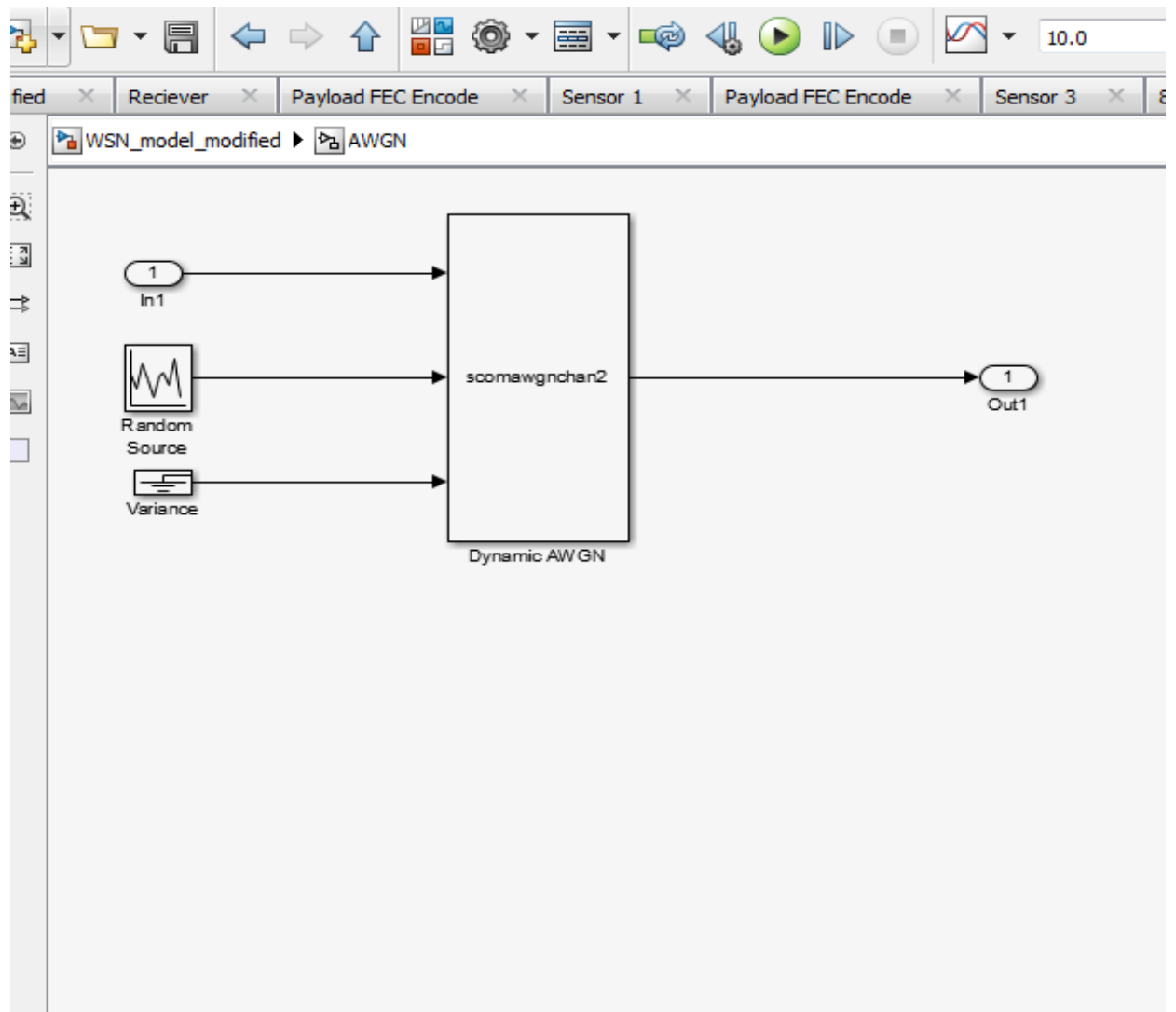**The connected elements inside the transmitter**

The connected elements inside the receiver
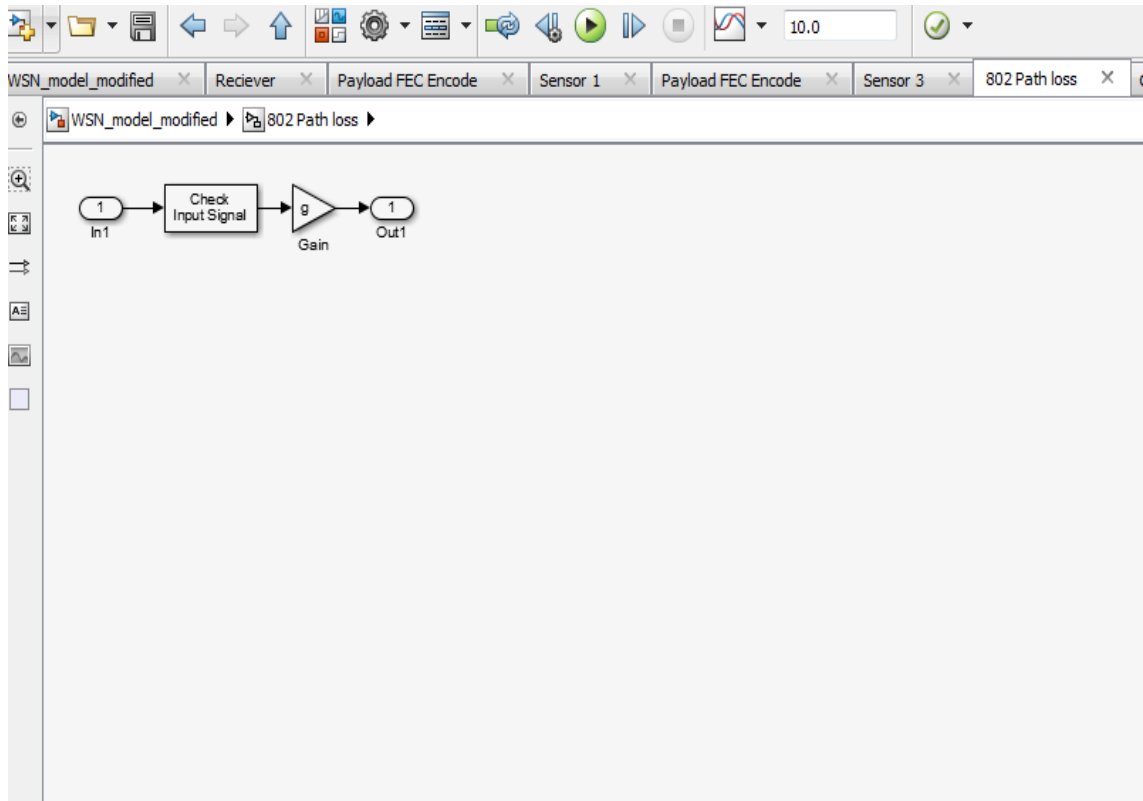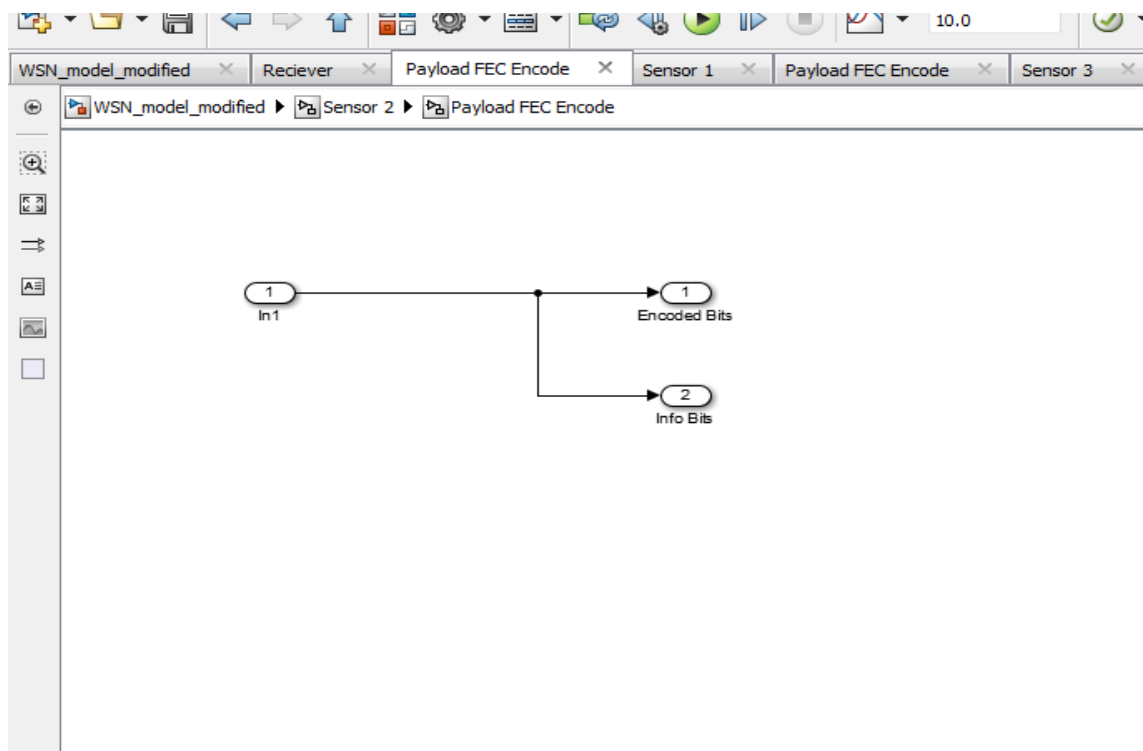
Result of the Simulation

The Connected Elements inside AWGN

The Connected Elements inside Path loss

The Connected Elements inside Payload FEC

The Connected Elements inside Input Check Signal