# PERFORMANCE EVALUATION OF IEEE 802.15 WIRELESS BODY AREA NETWORK IN OMNET++

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**PERFORMANCE EVALUATION OF IEEE 802.15 WIRELESS BODY AREA NETWORK IN OMNET++**

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**BY**

**HATEM A. M. MUSA**

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I certify that in my opinion the thesis submitted by Hatem A. M. Musa titled "PERFORMANCE EVALUATION OF IEEE 802.15 WIRELESS BODY AREA NETWORK IN OMNET++" is entirely adequate in scope and quality as a thesis for the degree of Master of Science.

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The degree of Master of Science by the thesis submitted is approved by the Administrative Board of the Graduate School of Natural and Applied Sciences, Karabük University.

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Hatem A. M. Musa

# ABSTRACT

**M. Sc. Thesis**

**PERFORMANCE EVALUATION OF IEEE 802.15 WIRELESS BODY AREA NETWORK IN OMNET++**

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**Graduate School of Natural and Applied Sciences**
**Department of Computer Engineering**

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In present days, wireless sensor networks (WSN) have involved considerable attention of both academy and industry because of the varied range of contexts in which they could be used. The IEEE 802.15.6 has become the most important standard for body area network, and several software and hardware platforms are built on it. The implementation and performance analysis of this standard is essential to understand the important limits of it. The simulation is one the greatest valuable tools in protocol evaluation and prototyping design. Furthermore, network simulators play an important part to test new algorithms and other protocols built on this specification. In this thesis, performance of the IEEE 802.15.6 MAC standard protocols has been tested. The performance of the protocols regarding power consumption, throughput, delay, and congestion is compared using Castalia simulator.

**Key Words :** IEEE 802.15.6, wireless sensor network, wireless body area, network.

**Science Code :** 902.1.063

# ÖZET

**Yüksek Lisans Tezi**

**IEEE 802.15 KABLOSUZ GÖVDE ALANI AĞININ OMNET++ SİMÜLATÖÜNDE BAŞARI ANALİZİ**

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Kablosuz Sensor Ağları (WSN), günümüzde birbirinden çok farklı işlevlere sahip olması sebebiyle, hem akademik ve endüstri çevresinin ilgisini çekmektedir. IEEE 802.15.6 Vucut Alan Ağı çok önemli kullanım alanına sahip olup bu konuda birçok yazılım ve donanımlar geliştirilmektedir. Geliştirilen protokollerin test edilmesi ve mevcut protokollerle performanslarının karşılaştırılması için simülasyon araçları önemli bir yere sahiptir. Kablosuz ağlar geliştirilmiş bir çok simulatör olmasına karşın literatürdeki protokollerin bir çoğunu içinde barındıran simülatörler sayısı azdır. Bu tezde, IEEE 802.15.6 MAC standart protokolleri enerji tüketim, ağ çıkışı, gecikme ve sıkışıklık ölçütleri üzerinden Castalia simülatörü üzerinde geliştirilmiş simülasyon senaryoları kullanılarak sonuçlar elde edilip protokollerin performans karşılaştırmaları yapılmış ve sonuçlar değerlendirilmiştir.

**Anahtar Kelimeler :** IEEE 802.15.6, kablosuz sensör ağı, kablosuz vucut alanı ağı.
**Bilim Kodu** **:** 902.1.063

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08 June 2017 Hatem A. M. Musa

## CONTENTS

**Page**

**Page**

**Page**

**Page**

## LIST OF FIGURES

**Page**

# LIST OF TABLES

**Page**

## SYMBOLS AND ABBREVIATIONS INDEX

### ABBREVIATIONS

ADC : Analog to Digital Converter
BAN : Body Area Network
BCC : Body Coupled Communication
BSN : Body Sensor Network
CBM : Condition-Based Maintenance
CSMA/CA : Carrier-Sense Multiple Access with Collision Avoidance
DoS : Denial of Service
GTS : Guaranteed Time Slot
GUI : Graphical User Interface
ID : Identification
LAN : Local Area Network
MAC : Medium Access Control
QoS : Quality of Service
TDMA : Time-Division Multiple Access
UWB : Ultra Wide Band
WAN : Wide Area Network
WPAN : Wireless Personal Area Network
WSN : Wireless Sensor Network

# CHAPTER 1

# INTRODUCTION

The wireless connection is used to connect different devices without any physical connection like cables. The wireless type of connection reduces the cost and difficulties of using the traditional wired network. In wireless networks, the connected devices use the radio frequencies to send data between source and destination. The physical layer in the wireless network devices is responsible for getting connected to each other.

We can divide the wireless networks into two modes depending on the topology of the connection: infrastructure mode and ad hoc mode. In the infrastructure mode, there is a base station, and all the wireless devices communicate through this base. While in the other mode, the devices communicate with each other without any centralized station. This mode is a self-organized network, and the topology may change regularly because of the movement of the devices. The routing in such mode of networks may be difficult to manage due to the dynamic variations in the construction of the wireless network. Normally, the ad hoc network devices have limited source of energy and limited wireless connection bandwidth. Also, network protocols in this mode use many control packets to maintain an updated route of the network due to the frequently changes in network topology which consumed network devices resources. Thus, it is not an easy to find and keep the best route in an ad hoc wireless network. On the other hand, the infrastructure wireless network offers many significant advantages over the ad hoc wireless network such that higher level of security, much higher data transfer, and compatibility with the wired network [1].

The Institute of Electrical and Electronic Engineers (IEEE) confirmed the structure of a working collection for IEEE 802.15.4 (IEEE 2003) to outline a foundation to Body Area Network. The 802.15.4 defines both the physical & media access control layer. The physical layer can work in different bandwidths, the first one is the frequency band 2.4 to 2.4835 GHz using 16 different channels, the second one is the frequency band from 902 to 928 MHz using ten different channels, and the third one is one channel in the frequency band 868.0 MHz to 868.6 MHz. There are different features of the media access control layer managing. They are beacons, channel contact, managing of GTS, proof of the frames, and others. There are two methods of process of the media access control layer contingent on the topology that used and the need for certain bandwidth; they are: beaconless approach and beacon approach. In the beaconless approach, the manager sink node is the only state waiting for information. The expedient that wants to send info, it will first check if the channel is empty. If it is empty, then it will send the info. If it is not empty, it will wait for an arbitrary time that defined in the ordinary. If the manager sink node has info that must be sent to an expedient, it will wait till the nodes demand for the information. After that, the manager sink node must send the acknowledgment to reaction of the demand. The manager sink node will transmit the info if they are pending, by the use of the exact procedure of CSMA/CA. In the case of no info that waits, the manager sink node sends an empty info frame. The beaconless approach is naturally used in the nodes that sleep for a long time (99%). When an incident occurs, the nodes will wake-up and immediately will direct a frame of aware. In this kind of work, the manager sink node will not supply any synchronization for the nodes, no Guaranteed Time Slot (GTS) will be coming, and only arbitrary access is taken over for medium spreading on account of no superframe and the space of synchronization.

Recently, many articles have reviwed and detailed the aspects of wireless sensor network. Reference [2] reviews new routing protocols for sensor wireless networks and grants a cataloging for the several methods pursued. The Datacentric, the hierarchical and position-based are three important classifications that are inspected in this paper. The network flow and the quality of service modeling are discussed also.

Reference [3] reviews the synchronization of the time issue and the requirement for synchronization of the time in sensor networks, after that presents in detail, the synchronization of the time in the basic form approaches clearly designed and proposed for sensor networks.

Reference [4] suggests the unwanted EA's performance when dealing with grouped routing problem in WSN by framing a new fitness role that incorporates two clustering parts, viz. cohesion and separation error.

Reference [5] offers sensor-MAC (S-MAC), a new medium access control protocol clearly planned for the networks of the wireless sensors. While dropping power, feeding is the primary goal in the plan; the protocol has decent ability of changing the size and capable of escaping from collision. It achieves these by using a collection of scheduling and contention scheme.

In reference [6], the availability of WSN nodes are considered that can be addressed by indulging the distant testing and fixing the substructure for separate sensor nodes using COTs components, they built and evaluated the system level examination interface for distant testing repair and software update. This also covers contents regarding the plan methods which were carried to explore the difficulty using the projected infrastructure. The wireless broadcast can be used in easy way in various testing with optimum cost.

In reference [7], the modified superframe structure of IEEE 802.15.4 based MAC protocol is proposed which addresses the problems and improves the energy consumption efficiency. Moreover, priority guaranteed CSMA/CA mechanism is used where different priorities are assigned to body nodes by adjusting the data type and size.

Reference [8], presents an energy-efficient cooperative MAC (EECO-MAC) protocol using power control in mobile ad hoc networks. Cooperative communications improve network performance by taking full advantage of the broadcast nature of wireless channels.

In this thesis, we studied five different MAC layer protocols which are used broadly in wireless body area networks. Two different scenarios were created using Castalia simulator under the OMNET++ platform. We calculate throughput, delay, power consumption, and packets congestion with the using of two different sensor output power. A performance evaluation of each criteria was given for the five MAC layer protocols.

This thesis consists of six parts. In part one we gave an introduction about the different types of wireless networks. In part two, a detailed information has been given about the wireless sensor networks. In part three, we detailed the MAC layer different protocols. In part four, we discussed the network simulation tools and gave brief information about four different simulation tools available for researchers and developers. In part five, we discussed our simulation scenarios and presented the results of the calculated throughput, average delay, energy consumption, and packets congestion. In the last part, we gave the conclusion and recommendations for future work.

# CHAPTER 2

# WIRELESS SENSOR NETWORK

## 2.1. INTRODUCTION

Current developments in micro-electro-mechanical systems (MEMS) technology, wireless communications, and digital electronics have allowed the progress of low-cost, low-energy, multiuse sensors that are minor and connect free in small areas. These little sensors, that contain sensing, data processing, and communicating gears, force the knowledge of sensor networks grounded on cooperative energy of several nodes. Sensor networks signify a major upgrading over old-style sensors, these are organized in the next two methods [9]:

- Sensors could be located far away from the real action, i.e., somewhat identified by sense awareness. In that method, big sensors which use some compound methods to separate the goals from the around noise are essential.
- Numerous sensors which achieve only sensing could be organized. The sensor positions and infrastructure topology are wisely plotted. They spread time series of the sensed action to the main sensors where calculations are done, and information are bonded.

A sensor network is collected of sensor nodes with a high number, that are closely positioned in middle of the action or in very near position. The sensor network has the effort of cooparation between sensors. Sensors are trimmed using their CPUs.
We need the techniques of adhoc networking to get better understanding of the applications of sensor networks. While numerous protocols have been projected for traditional wireless ad hoc networks, they are not well matched for the sole topographies and application needs of sensor networks. To show that idea, the variances between adhoc and sensor networks are outlined below [10]:

- Sensor nodes may be much crowded than nodes in adhoc networks,
- Sensor nodes are placed close to each other,
- Sensor nodes are face failures more than in adhoc networks,
- The topology of the sensor networks might change faster than adhoc network,
- In sensor network, the nodes usually use broadcast connection method where in adhoc network, they use direct connection between each other,
- The sensor has restricted energy, memory, and pross abilities and
- The sensors might not have universal identification.

## 2.2. WIRELESS SENSOR NETWORK APPLICATIONS

There are many kinds of sensors used in sensor networks: low sampling rate magnetic, thermal, seismic, visual, infrared, acoustic and radar, which can sense different environment circumstances [11]:

- humidity,
- temperature,
- lightning condition,
- vehicular movement,
- noise levels,
- pressure,
- soil makeup and
- the current features like speed, course, and size of an item.

Sensor nodes could be beneficial for place sensing, continuous sensing, control of actuators, and event recognition. The idea of wireless connection and micro-sensing of these nodes open the door for many different application zones.

### 2.2.1. Military Applications

Sensor networks might act a major role of military order, control, communications, surveillance, computing, intelligence, reconnaissance and pointing systems. The selforganization, rapid deployment, and fault tolerance features of sensor networks put them as an accomplished sensing technique [12].

### 2.2.2. Area Monitoring

It is a normal utilization of WSN. In this monitoring, the WSN is installed in a district that an action is to be observed. An instance in the military application is the use of WSN to sense the enemy intrusion; a nonmilitary instance is the geo-fencing of gas or oil tubes [13].

### 2.2.3. Health Applications

Fragment of the health application for WSNs is patient monitoring; telemonitoring of man physical info; affording interfaces for the disabled; diagnostics; drug management in hospitals; monitoring the travels and internal processes of bugs or other small animals; and tracking and monitoring doctors and patients in a hospital [14].

### 2.2.4. Environmental and Earth Sensing

WSNs have been installed in some towns (London, Brisbane, and Stockholm,) to display the attentiveness of hazardous gasses for people. These could get benefit of the adhoc wireless connections instead of wired connections, that similarly let them to be more moveable for checking readings in changed areas [15].

A landslide discovery system lets the use of a WSN to sense the small actions of earth and variations in various constraints that might occur earlier or through a landslide. It might be probable to see the existence of landslides long before it happens through the gathered data [15].

### 2.2.5. Industrial Monitoring

WSN has been advanced to machinery condition-based maintenance (CBM) since they propose important charge savings and allow new ability. WSNs could be in positions hard or incredible to get with a corded system, like spinning equipment and released automobiles.

Because of the great mass of servers' racks in a data center, frequently wiring and IP addresses are a problem. To solve this issue increasingly racks are formfitting out with wireless heat nodes to check the input and output heat of racks. As much as 6 heat nodes for each rack, enmeshed wireless heat skill bounces a benefit associated to old corded nodes.

WSNs could be utilized to screen the illness of public substructure and correlated geophysical procedures near to actual time using suitably interfaced nodes [16].

### 2.2.6. Home Applications

While technology develops, intelligent sensors could be suppressed in appliances, like microwave ovens, vacuum cleaners, VCRs, and refrigerators. Those sensors which are inside the local machines could cooperate with each other and with the outside network using the Internet. They let users to admin the devices nearby and far away more simply.

The plan of the clever environment could have more than one distinct perspectives, i.e., technology-centered and human-centered. For the technology-centered, the new networking solutions, hardware technologies, and the middleware services should develop. For human-centered, a smart environment should adjust to the wants of the user regarding inputs and outputs abilities.

## 2.3. WIRELESS SENSOR NETWORK DESIGN

A WSN plan is prejudiced by different aspects, that contain faults tolerance; productions cost; scalability; sensor network topology; operating environment; communication media; hardware constraints; and energy feeding. Those aspects are significant since they aid as a recommendation to plan an algorithm or a protocol for WSNs. Furthermore, these swaying features could be utilized to compare distinct schemes [17].

### 2.3.1. Fault Tolerance

Few sensors might stop or be congested because of lack of energy, get physical break or environmental nosiness. The sensor nodes failure must not disturb the complete job of the WSN. This is the fault tolerance or reliability matter. Fault tolerance is a capability to keep up WSN functionality deprived of each break because of sensor failures.

### 2.3.2. Scalability

The sum of sensors positioned in reviewing a phenomenon might be hundreds or even thousands. This is depending on the application; the sum might range an exciting rate of millions. A new system should be up to function with that sum of sensors. They should moreover use the high-density fact of a WSNs. The density could vary from tens sensors to one hundred sensors in an area, that could be fewer than ten meter in diameter [18].

### 2.3.3. Productions Cost

While the WSNs contain many sensors, the price of one sensor is actual significant to defend the total price of the WSNs. In case the price of the network is higher than installing traditional nodes, then a WSNs is not gainful. Consequently, the price of each sensor must be reserved little. The state-of-the-art knowledge allows a Bluetooth wireless system to be fewer than some dollars. Likewise, the cost of a

PicoNode is meant to be fewer than a dollar. The price of a sensor must be more less than one dollar to the WSNs to be possible. The price of a Bluetooth wireless, that is recognized to be a low-price device, is even times higher price than the goal price for a sensor. Note that sensors also have some extra parts like processing and sensing.

### 2.3.4. Hardware Constraints

The sensor is consisted of 4 simple parts as showing in Figure 2.1: a processing part, a power part, sensing part, and a transceiver part. They might similarly have extra parts depending on application like a position detecting system, a mobilizer, and an energy generator. Sensing parts are normally containing two subparts: ADC (AnalogToDigital converter) and sensors. An analog signal generated using the nodes depending on the detected action are transformed to digital signals using the ADC, and after that passed into the processing part. The processing part, that is usually related with a minor saving part, directs the actions which let the node cooperate with the additional sensors to achieve the proposed detecting jobs. The transceiver part attaches the sensor to the network. A most significant part of a sensor is a power. Power parts might be reinforced using a power scavenging unit like solar cells. Also, there are two additional subparts, that are application dependent. Almost all of the sensing jobs and WSN routing techniques need the information of position with great accuracy. So, it is normal that the node has a position tracking system. The mobilizer might occasionally be wanted to transfer sensors when it is wanted to do the proposed jobs [19].

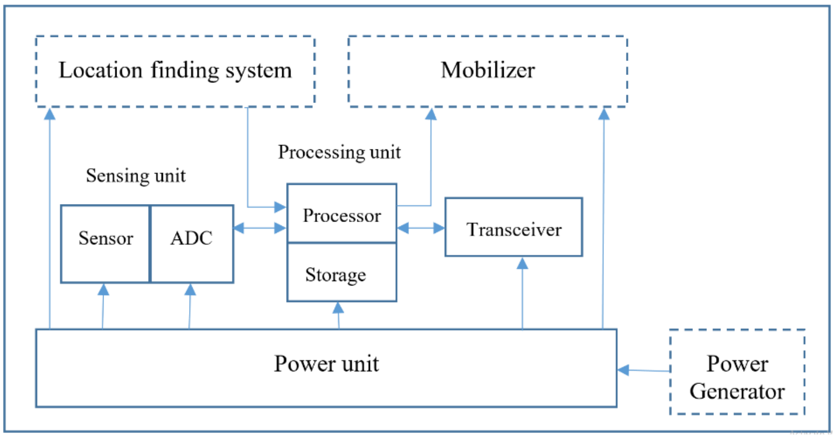


Figure 2.1. The sensor node components [19].

### 2.3.5. Topology of Sensor Network

Total numbers of unattended and inaccessible sensors, that are disposed to regular failures, let topology keep a difficult job. Hundreds or even thousands of sensors are installed through the node area. They are installed in some tens of meters between each other. A sensor density might be at most 20 nodes/m3. Positioning large amount of sensor closely needs cautious management of topology keep [20].

### 2.3.6. Environment

Sensors are densely installed either directly inside or very near to the phenomenon to be detected. Thus, they regularly function unattended in remote environmental zones. They might be working in:

- inside a huge machinery,
- in busy intersections,
- on the sea during the tornado,
- inside the twister,
- at the lowest point of a sea,
- in a battlefield behind the enemy,
- in a biologically or chemically polluted zones,
- in the home or the big building,
- attached to creatures,
- in the big silo,
- devoted to very speedy transferring automobiles and
- in the river or drain transferring with the current.

That list will give us a knowledge around in what circumstances sensors are probable to function. They function under great pressure in the lowermost of a sea, in hard environments like a battlefield or a debris, under extreme cold and heat such as in freezing regions or in the nozzle of a jet engine, and in an extremely loud environment like under intentional congestion [21].

### 2.3.7. Transmission Media

By using a multi-hop sensor network, interactive sensors are connected by a wireless connection. Those connections could be shaped by infrared, radio, or optical media. To allow worldwide action of those networks, the selected communication medium should be accessible universal [22].

### 2.3.8. Energy Consumption

The wireless sensor, could only be prepared with a partial energy foundation (less than 0.5 Ah, and 1.2 Volt). In few application, changing of energy incomes may be intolerable. Sensor node time, consequently, displays a robust necessity on the time of the battery. In a multihop adhoc wireless sensor network, every sensor acts the double part of information router and information creator. The dysfunction of limited nodes could reason important topological variations and may need re-arrange of the network and re-routing of packets. Therefore, energy administration and energy conservation take on extra position. It is for those causes which scientists are presently constraint on the plan of energy-aware algorithms and protocols for sensor networks [23].

Else moveable and ad-hoc networks, energy feeding has a significant plan aspect, but not the main attention, basically since energy funds could be altered by the operator. The importance is added on QoS provisioning than the energy productivity. By using sensor networks, however, productivity of energy is a significant act metric, straight persuading the network time. Application-specific protocols could be planned using suitably exchange off other act metrics like throughput and delay with energy productivity [24].

## 2.4. CHARACTERISTICS OF WSN

WSN platform normally has limited memory and processing capability. The plan of WSN devices typically favoritisms reduced charge over bigger abilities, therefore we cannot guess Moore's rule to prime to improved act. The elementary features of WNS brand them susceptible to DoS bouts.

The key features of a WSN contain [25]:

- Energy observing constraints for sensors using energy harvesting or batteries,
- Capability to handle the sensor failures (resilience),
- Some movement of sensors,
- Heterogeneity of sensors,
- Capability to withstand hard environmental circumstances,
- Scalability to huge deployment scale,
- Cross-layer design and
- Ease to use.

Cross-layer is flattering a chief learning zone for wireless connections. Furthermore, the normal layered method gives three important issues [26]:

- Due to the interference among various users, fading, admission struggles, and the modification of location in the WSNs, normal layered method to wired networks isn’t appropriate to wireless networks.
- Normal layered method cannot spread different info between various layers, that goes to all layers not taking whole data. The normal layered method cannot assure the idealization of the whole network.
- The normal layered method does not able to familiarize to the ecological modification.

Thus, the cross-layer could be utilized to brand the perfect inflection to advance the communication act, like information rate, power productivity, QoS, etc. Sensors could be abstract as minor PCs that are very elementary in components and their links. They regularly be made of a CPU with partial calculation power and partial ram, sensors or MEMS (with exact training motherboard), a connecting device, and an energy source regularly in the shape of a battery. Additional probable presences are power gathering units, and probably subordinate connection interface [27].

## 2.5. PLATFORMS OF WSN

### 2.5.1. Hardware

One of the key test in a WSNs is to generate little price and small sensor nodes. There are a rising amount of simple corporations creating WSN hardware and the treading state could be likened to PCs in the 1970s. A lot of the sensors are still in the study and improvement phase, mainly their software. Likewise, characteristic to WSN adoption is the utilize of actual little energy ways for information acquisition.

### 2.5.2. Software

Energy has been the rarest supply of WSN sensors and it controls the time of the network. WSN might be installed in big numbers in several locations such that in most situations adhoc communication is compulsory. So, protocols and algorithms must report issues such lifetime expansion where the energy feeding of the sensing node must be reduced and the sensor node must be power resourceful because of its partial power supply controls its time. To preserve energy the nodes usually turn off the wireless transceiver when not in use.

MAC is one of the serious issues in the plan of WSN. Like in most wireless network, congestion, that is produced using two nodes, transfer information at the similar period on the same shared medium is an excessive worry in WSN. To report that issue, a WSN should service MAC protocols to judge contact to the common medium to prevent information crash from dissimilar nodes at the similar time to resourcefully and fairly part the bandwidth between many nodes [28].

Operating systems of the sensors in WSN are obviously less compound than general use operating systems together since of the singular needs of WSN applications and since of the supply limitations in WSN hardware stages. For instance, sensor network applications are regularly not interactive in the exact method as applications for PCs. Because of this, the operating system has not to contain support for user interfaces. Additionally, the resource restrictions in terms of RAM and memory mapping hardware support make devices such as virtual ram either needless or impossible to apply. TinyOS is maybe the early operating system explicitly planned for WSNs. Different from all other operating systems, TinyOS is grounded on an event-driven programming model rather than multithreading. TinyOS applications are separated in to tasks and event handlers with run to completion semantics [29].

## 2.6. BODY AREA NETWORK

In current times, there has been growing awareness from researchers, application developers and system designers, on a novel kind of network construction commonly known as body area networks (BANs) or body sensor networks (BSNs), made possible by new developments on frivolous, ultra-low-power, small-size, and smart monitoring wearable sensors. In BANs, sensors constantly watch human's physical actions and activities, like motion pattern and fitness situation [30].

### 2.6.1. Body Area Network and Wireless Sensor Network

Even though many algorithms and protocols that projected for traditional WSNs, they are not fine matched to the sole structures and application needs of BAN. To demonstrate that fact, a comparison between BAN and WSN are below [31]:

- Density and Deployment

The quantity of sensors installed by the operator rest on on different aspects. Noticeably, BAN nodes are located intentionally on the user body, or are unseen under dress. Furthermore, BANs don't hire useless nodes to manage with various kinds of breakdowns else mutual plan delivery in conservative WSNs. Therefore, BANs aren't node thick. WSNs though, are regularly connected to positions which might not be easy to access by workers, that needs more sensors be put to compensate for sensor breakdown.

- Data Rate

A lot of wireless sensor networks are working for event-based sensing, that actions could occur at unequal interruption. By contrast, BANs are working for recording user's physical actions and movements, that might happen in an extra episodic way, and might outcome in the applications' information streams showing comparatively steady average.

- Latency

The latency is verbalized by the applications, and might be operated for better dependability and power feeding. Though, though power maintain is helpful, changing of batteries in body area network sensors is simpler done comparing in WSN, that sensors could be inaccessible after placement. Consequently, it might be needed to exploit battery lifetime in a wireless sensor network at the expenditure of larger latency.

- Mobility

Body area network users might move around. Consequently, BAN sensors have the same mobility design, different from WSN sensors that are regularly considered stationary.

### 2.6.2. BAN Advantages

There are several benefits presented by using wireless body area networks that contain:

- Flexibility

Non-invasive nodes could be utilized to robotically sensing physiological readings, that could be sent to close devices, like a wristwatch, a mobile phone, a laptop, a PDA, or a automaton, depending on the application necessities.

- Efficiency and Effectiveness

The signs which body sensors deliver could be efficiently treated to get consistent and precise physical approximations. Furthermore, it's very little energy consuming lets its batteries permanent for long time because of their very low energy consumption [32].

- Cost Effective

With the growing request of BAN in the customer electronics marketplace, additional sensors will be whole production at a comparatively little price, particularly in medical and gaming surroundings.

### 2.6.3. Communication Architecture of BAN

Comparing with current knowledges like WLANs, BANs allow wireless connection in or about a person body by uses classy universal wireless calculating devices.

Figure 2.2 demonstrates a overall construction of a BAN-based healthiness observation system. EEG (electromyography) ECG (electroencephalography) EMG blood pressure nodes, and motion nodes direct information to close individual server devices. After that, over a WLAN or Bluetooth linking, this information is forward remotely to a health doctor's location on the internet for live analysis, to a database of health for keeping file, or to the equivalent gear that subjects an emergency vigilant. The BAN connection architecture divided into three different components: Tier-1-intra-BAN connections, Tier-2- inter-BAN connection, and Tier-3-beyond-BAN connection, as in Figure 2.2 [33].

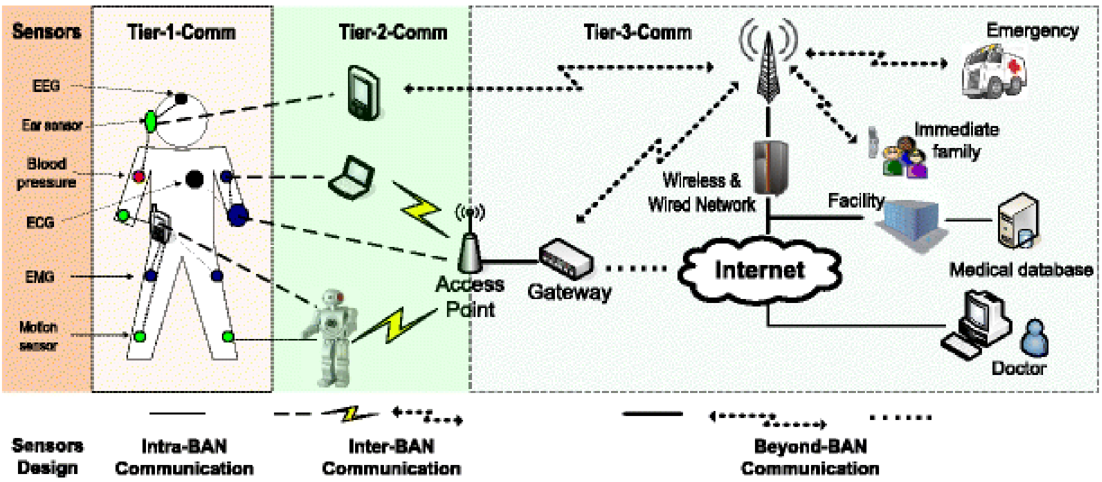


Figure 2.2. A three-tier architecture based on a BAN communications system [33].

### 2.6.4. Physical Layer

The features of physical layer are unlike a WBAN associated to a normal sensor network or an adhoc network because of the closeness of the human body. Examinations with TelosB specks presented lack of connections between sensors placed on the backbone of the patient and sensors placed on the chest [6]. That was highlighted after the sending energy was put to a low level for power reserves motives. Like deductions were figured with a CC2420 transceiver in [7]: once a man was sitting on a couch, no connection was able among the ankle and the chest. More good marks were gotten after the antenna was located one cm over the man's body.

#### 2.6.4.1. RF Communication

Numerous academics have been exploring the track cost along and in the man body either by means of Ultra Wide Band (UWB) or narrowband radio signals. Altogether of them decided that the radio signs involvement huge wounded.

#### 2.6.4.2. Body Movement

Changing position of the body plays a significant part in the conventional sign strength. In paper [34] it is exposed that arm moving to the side and front of the body could have a minor effect on the conventional energy. Additional important differences are originated once the arms are motivated so that they chunk the sightline between the two antennas. In paper [35] an initial system model for walk examination has been projected. It is determined that important weakening could happen (up to 20 dB) once a body limb is moved in between the Rx and Tx antenna.

#### 2.6.4.3. Non-RF Communication

Nearly to the spread of radio waves, numerous academics have inspected the opportunity to send electronic info by capacitive and galvanic coupling, also called body coupled communication (BCC). This radio act at little frequencies from.

Zimmerman [36] first presented the possible of very low energy info connection over the human body without interference.

# CHAPTER 3

# MAC LAYER PROTOCOLS

## 3.1. INTRODUCTION

At the MAC layer, there is an interchange among latency, reliability, and energy feeding that must be fixed. Clearly, the QoS needs, i.e., latency and reliability, create from applications, and power feeding mirrors the overall protocol complexity and appropriate duty cycle. Comparing to wireless networks for more wide areas, BANs experience much fewer power consuming which explains into more long times by getting an actual little duty cycle and a basic protocol jobs. Regularly, body sensor has a partial battery volume, particularly for these sensors that are located in the body. For raise the lifetime of those sensors, power effective MAC protocols will be a significant part. In contrast, some BAN grounded applications require very dependable connection, little delays, and little energy feeding [37].

Like the strategy goal lines of providing distinguished facilities per the traffic kind, though seeing the idealization of reliability, latency, transmission power, and remaining energy, the QoS methods used in WSNs could be powered once planning QoS protocols for BAN. Though, QoS techniques in BANs have sole necessities. For instance, in numerous scenarios, BANs should grip real-time connection. With the comparatively large sample amount from around sensors like ECG, it is significant that info is directed out before being released because of the buffer being overflow, seeing the small buffer scope of greatest nodes [38].

To report the serious problem of spreading sensor time, many low energy MAC protocols have been projected for general WSNs. In those protocols, the radio is switched on and off occasionally to maintain power. S-MAC [39], T-MAC [40], and TRAMA [41] suggest to synchronize its sending timetable and hearing times to enlarge productivity, although dipping power by switching off radios through more longer snoozing phases. Alternatively, little energy hearing methods like WiseMAC [42] and B-MAC [43] use channel polling to checked if a sensor should get up for information communicating, therefore dropping the need of idle hearing. SCP-MAC [44] uses a programmed channel polling for synchronize polling periods of all close nodes and removes extended preambles in low power listening to every transmission, thus allowing very low duty cycles. Though, all those protocols illustrate insufficient network productivity and delay act on changing traffic. RIX-MAC [45] projected a new receiver initiated MAC protocol, grounded on the X-MAX protocol with asynchronous duty cycles.

Body sensor network MAC (BSN-MAC [46]) is a devoted very-low-energy MAC protocol planned for star topology BANs. The BSN-MAC is well-matched with IEEE 802.15.4, and houses sole needs of the biosensors in body area networks. By abusing reaction data from spread nodes in the networks, BSN-MAC regulates protocol strictures animatedly to reach greatest power conservation on power serious sensors.

**3.2. S-MAC PROTOCOL**

Wireless sensor networks use battery functioned calculating and sensing gears. A network of those gears will cooperate for a shared application like ecological observing. We guess sensor networks to be positioned in an ad hoc style, with separate nodes residual mainly sedentary for extended phases of time, but then flattering unexpectedly active once something is noticed. Those features of sensor networks and applications inspire a MAC which is unlike old-style wireless MACs like IEEE 802.11 in nearly each means: power preservation and self-formation are main aims, though per-node equality and dormancy are fewer significant. S-MAC usages three new methods to decrease power feeding and provision self formation. To decrease power feeding in hearing to a silent network, nodes occasionally snooze. Adjacent nodes procedure practical groups to auto match on snooze timetables. Enthused by PAMAS, S-MAC likewise puts the radio to snooze through communications of further nodes. Different from PAMAS, it solitary utilizes in-network signing. Lastly, S-MAC puts on note transitory to decrease argument dormancy for sensor-network applications which need keep and advance dispensation as information transfer over the network [39].

The key aim in S-MAC protocol plan is to decrease power feeding, though supporting decent increase in size and impact escaping. That protocol attempts to decrease power feeding from all the foundations which have been recognized to be reason of power leftover, i.e., silent hearing, impact, overhearing and control overhead. To reach the plan aim, the S-MAC have been advanced which contains of three main parts: episodic hear and snooze, impact and overhearing escaping, and note transitory.

In numerous sensor network applications, nodes are in silent for an extensive period if no detecting occasion occurs. Assumed the statistic that the information amount through that time is actually little, it is not needed to maintain nodes hearing all the periods. S-MAC protocol decreases the hearing periods by allowing node go to episodic snooze approach. For instance, if in every second a node snoozes for half second and hears for the further half, its responsibility sequence is decreased to 50%. So, S-MAC could reach near to 50% power reserves [39].

The elementary arrangement is shown in Figure 3.1 every node goes to snooze for little period, and after that awakens and hears to realize if somewhat further node needs to communicate to it. Through snooze, the node switches off its wireless, and puts a clock to wake up itself far ahead.

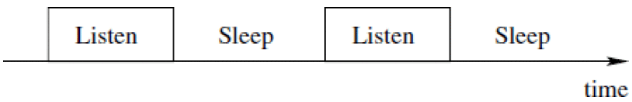


Figure 3.1. Episodic hear and snooze [39].

S-MAC protocol call a whole sequence of the hear and snooze a frame. Accept a packet reaches at the transmitter with identical possibility in period inside a frame. So, the average snooze delay on the transmitter is

$$D_s = T_{frame}/2 \tag{3.1}$$

where

$$T_{frame} = T_{listen} + T_{sleep} \tag{3.2}$$

## 3.3. T-MAC PROTOCOL

T-MAC protocol is a medium access control protocol planned particularly for wireless sensor networks. T-MAC allows wireless sensor node switch on its wireless at harmonized periods, and switch it off later of a firm time-out— once no message happens through some period. Messages are spread in bursts. This arrangement lets active alteration of the wireless-on period to altering message rates. T-MAC protocol keeps additional power comparing to its predecessor S-MAC in a network which message rates change. S-MAC protocol allow node switch the wireless on for a static period. S-MAC needs change to the message rate, while T-MAC does not [40].

T-MAC protocol has an issue with unequal message designs, whereas node might go to snooze though its neighborhood maintain has communications for it. That primary snoozing issue decreases the determined productivity intensely. Two projected resolutions for that issue composed dual the productivity, nevertheless it is maintaining fewer than 70% of the determined productivity of else protocols. That is a back-off to the adaption of the protocol.

Simulation tests have made known that the T-MAC protocol decreases the power utilized by the wireless with as high as 80%, in an ideal situation and likened to traditional protocols like CSMA. The S-MAC protocol keeps only 30% in that situation, after best alteration.

Application of the T-MAC protocol on physical wireless sensor network has made known that, in an idle state, the wireless could be switched off for as high as 97.5% of the periods, decreasing the overall power utilized with further than 96%. In a state with large communication rates, the T-MAC protocol does not rise the dormancy, because the nodes do not snooze in this situation. The T-MAC protocol application is basic and utilize only 42 bytes of state [40].

Figure 3.2 demonstrates the basic arrangement of the T-MAC protocol. Each node occasionally awakens up to connect with its neighbors, and after that time goes to snooze over till the following frame. In the meantime, new communications are lineup. Nodes connect with each other utilizing a Request-To-Send (RTS), Clear-To-Send (CTS), Information, Acknowledgement (ACK) arrangement, that delivers together impact escaping and dependable communication.

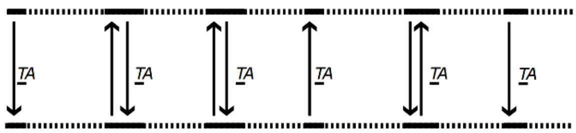


Figure 3.2. The basic T-MAC protocol arrangement, with adaptive active periods [40].

Nodes must not go to snooze whereas its neighbors are keep connecting, because it might be the acceptance of a following communication. Getting the begging of the RTS or CTS packet from an adjacent node is sufficient to activate a changed intermission in Time Active (TA).

Because of nodes might not listen, since it is not close, the RTS which starts a connection with its adjacent, the intermission TA should be extended sufficient to obtain in any case the start of the CTS packet. This thought deliver us a lesser boundary on the distance of the intermission TA:

$$TA > C + R + T \tag{3.3}$$

where C is the distance of the RTS argument intermission, R is the distance of an RTS packet, and T is the switch-around period (the small period among the finish of the RTS packet and the start of the CTS packet) [40].

### 3.4. B-MAC PROTOCOL

B-MAC is a carrier sense media access (CSMA) protocol for wireless sensor networks. Driven by ecological monitoring applications, B-MAC structures extreme low energy work, actual impact escaping, minor code scope, and expectable implementation. To reach little energy work, BMAC hires an adaptive little energy wireless selection arrangement to decrease working sequence, minimalize idle hearing, and remove the overhead of harmonization. B-MAC lets facilities to rearrange the MAC protocol for best act, whether it be for productivity, dormancy, or energy preservation [43].

B-MAC was planned with a simple method. B-MAC has a minor central of media admission functionality and issues out around reason and state upkeep to facilities utilizing the protocol. With that plan practice, facilities utilizing B-MAC could achieve advanced layer protocols deprived of touching extra node facilities. Because of that B-MAC does not have the RTS-CTS machinery or harmonization needs of further MAC protocols like S-MAC and T-MAC, the application is together humbler and slighter.

B-MAC achieves work cycling over episodic network sample which it calls Low Power Listening (LPL). Its method is similar to the one utilized by Aloha. Each time the node awakens, it switches on the wireless and forms for action. If power is noticed, the node wake up and remain awake for the period needed to obtain the inward packet. Afterward of coming, the node switches to snooze. If no packet is come (a incorrect positive), a break forces the node back to snooze.

The node’s time is strongminded by its complete power feeding. If the power feeding is reduced, formerly the time should be increased. All the powers, E, are clear in components of milliwatts. Computing the whole power utilize could be completed by multiplying E by the node time. Intended for B-MAC, the power utilized via a node contains of the power consumed from getting, sending, occasionally sample the wireless network with LPL, and snoozing [43].

$$E = E_{rx} + E_{tx} + E_{Hear} + E_{Snoze} \quad (3.4)$$

## 3.5. BANMAC PROTOCOL

Little-energy and small-weight sensor node would be positioned for e-health facilities in wireless body area networks (WBANs). Newly, the Institute of Electrical and Electronic Engineering (IEEE) presented an innovative standard, IEEE 802.15.6 for wireless body area transportations. The aim of that standard is to stipulate numerous physical layers (PHY) and medium access control (MAC) layer protocols for diversity of requests with numerous QoS needs [47].

The IEEE 802.15.6 standard stipulates a connection standard at PHY and MAC layers which must provision a diversity of medicinal, consumer electronics (CE) and entertaining requests. The primary current of the IEEE 802.15.6 standard was delivered in May 2010. It describes a MAC layer in provision of three dissimilar PHY layers. Those contain Narrowband (NB), Ultra-Wideband (UWB), and Human Body Communications (HBC) layers (Figure 3.3). On the MAC sub-layer, IEEE 802.15.6 provisions two dissimilar kinds of admission apparatuses which are: argument access and argument free access. The argument access stage provisions either a positioned ALOHA grounded admission apparatus or CSMA/CA grounded admission apparatuses. The argument free admission stage provisions a arranged up-link down-link admission arrangement in addition to an unpremeditated polling placement grounded admission arrangement. In this thesis, we emphasis on the act study of HBC PHY layer with CSMA/CA grounded MAC layer protocol.

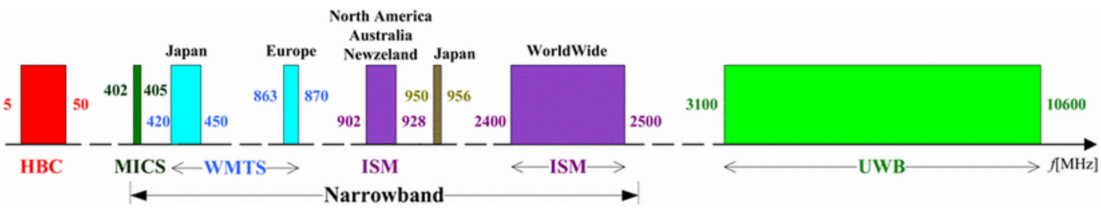


Figure 3.3. Different frequency bands of IEEE 802.15.6 PHY [48].

In IEEE 802.1.5.6 standard in a beacon manner with superframe limitations, a hub divisions the period to numerous super frames. Individually superframe building is sub divisions to numerous admission stages. Those admission stages are essentially categorized to argument grounded admission, connectionless argument free admission, and connection oriented argument free admission. Argument grounded admission is grounded on either CSMA/CA or positioned Aloha. In CSMA/CA, to get a new struggled distribution, the node makes its backoff counter to an arbitrary integer amount. The backoff counter amount for a node is protected if anybody of those circumstances is true: 1) the network is busy, 2) the present period is exterior the admission stages whereas the node could send, 3) the present period is at the begining of a CSMA slot inside an exclusive access phase (EAP), random access phase (RAP), or contention access phase (CAP), nonetheless the period among the finish of the slot and the finish of the EAP, RAP, or CAP is not extended sufficient for finishing a frame sending. Furthermore, the backoff counter is rearrange upon decrementing to 0. Figure 3.4 demonstrates a sample of a CSMA/CA mechanism of IEEE 802.15.6 MAC.

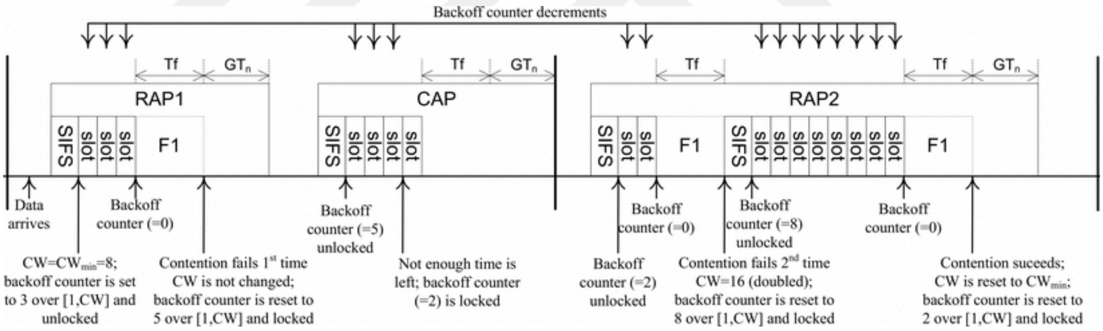


Figure 3.4. Sample of a CSMA/CA mechanism of IEEE 802.15.6 MAC [48].

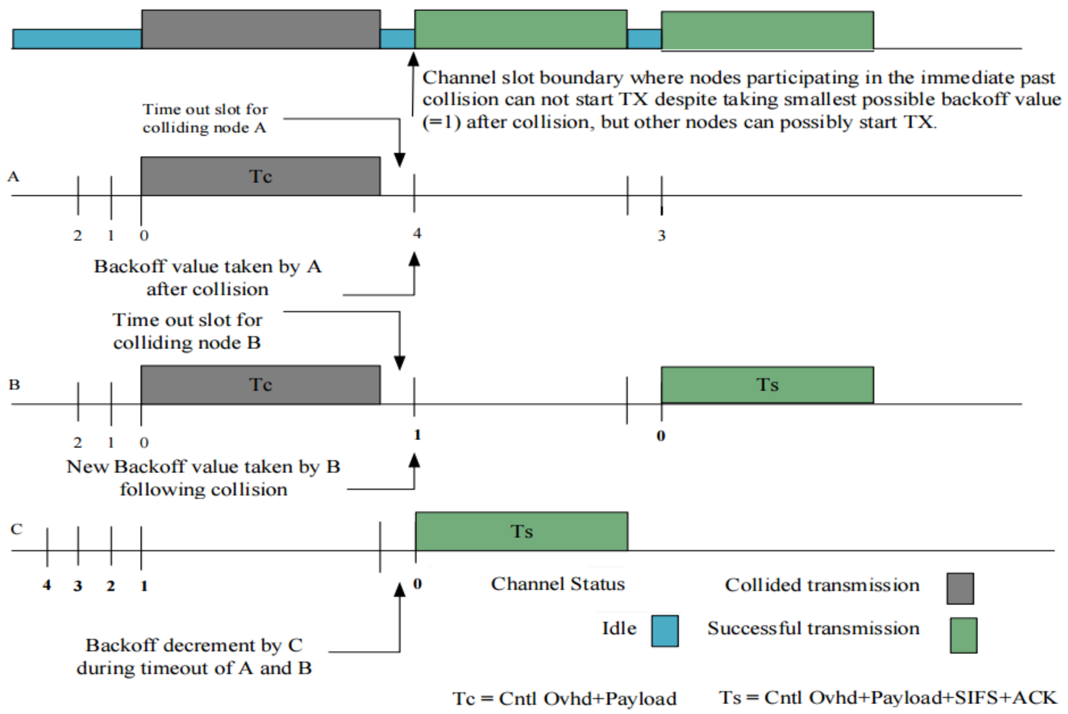


Figure 3.5. IEEE 802.15.6 CSMA channel access diagram [49].

The backoff counter amount is unprotected if: 1) the network has been free. 2) The period length among the present period plus a CSMA slot and the finish of the EAP, RAP, or CAP is extended sufficient for finishing a frame sending [47]. Figure 3.5 demonstrates IEEE 802.15.6 CSMA channel access diagram.

## 3.6. ZIGBEEMAC PROTOCOL

Presently, small-range, little-price, little energy ZigBee knowledge of wireless sensor network is the chosen expertise for wireless connection submissions. In current ages, wireless sensor network utilizing ZigBee connection knowledges has been extensively considered. IEEE 802.15.4 standard stipulates that MAC layer is largely accountable for retrieving of the physical layer wireless channel, that is to reach networks active admission grounded on the physical layer interface purposes [50].

There are mostly two types of information sending style in ZigBee networks: with-beacon connection and without-beacon connection. In with-beacon networks, the network director occasionally transmits beacon frames, gear in PAN network is harmonized per the beacon frames from director. Figure 3.6 directs the with-beacon information sending.

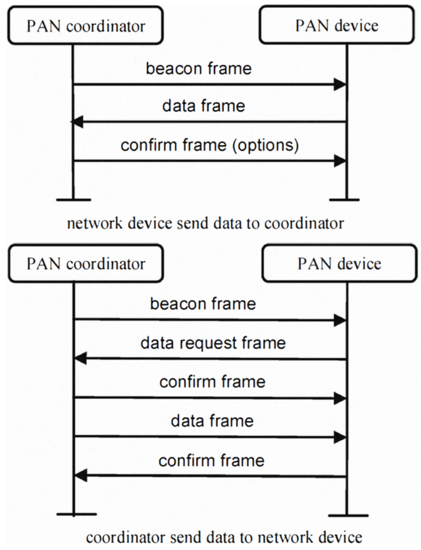


Figure 3.6. Information sending typical of with-beacon [50].

For without-beacon networks, the network director arbitrarily broadcast beacon frames from period to period. When the node is around to transmit info, initially, it must pause for an arbitrary distance of time, and after that start to sense the network situation, if free, the node begins to transmit info; if not free, the node must pause for additional time, and re-sensing network till the network is free to transmit info. To shorten the understanding of the protocol, the plan utilizes without-beacon info sending model. Figure 3.7 is without-beacon info sending model [50].

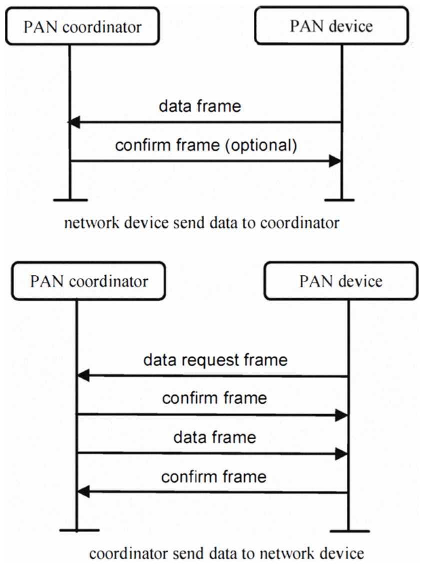


Figure 3.7. Info sending model of without-beacon [50]

# CHAPTER 4

# WBAN NETWORK SIMULATION TOOLS

## 4.1. INTRODUCTION

In communication and computer network study, network simulation is a system that a program models the performance of a network either by computing the communication among the changed networks objects (hosts/packets, etc.) using scientific formulas, or catching and playing back remarks from a construction network. The performance of the network and the various applications and services it supports can then be detected in a test lab; various characteristics of the environment could also be altered in a measured way to measure how the network will act below unlike circumstances.

Network simulators help a different of needs. Compared to the time and cost concerned in setting up a whole test bed covering multiple networked computers, data links, and routers, network simulators are comparatively inexpensive and fast. They let engineers, academics to exam scenarios that may be particularly expensive or difficult to emulate using actual hardware - for example, simulating a scenario with numerous nodes or testing a new protocol in the network. Network simulators are mainly useful in letting academics to exam new networking protocols or make deviations to current protocols in a reproducible and controlled environment [51].

There are numerous varied applications for network simulation. They are founded on either one of the next two ideas. The initial one is the clean simulation. This income all modules and all aspects of the network are simulated and the messages or packets, which are formed inside the simulation, are neither moved to an actual network, nor processed as actual network traffic exterior of the simulation. One sample for such a simulation is the application and integration of a trial network protocol in a network simulation. Hereby dissimilar features of such a protocol could be examined. One of those features could be the creation of irregularities concerning the behavior of the protocol to determine the reason of the irregularity. The simulation planer could makes also conditions for its technology which may not be applicable on the real-world testbed. The Figure 4.1 pictures the idea of how to utilize network simulation to assist guard in contradiction of a Denial of Service attack. [52].

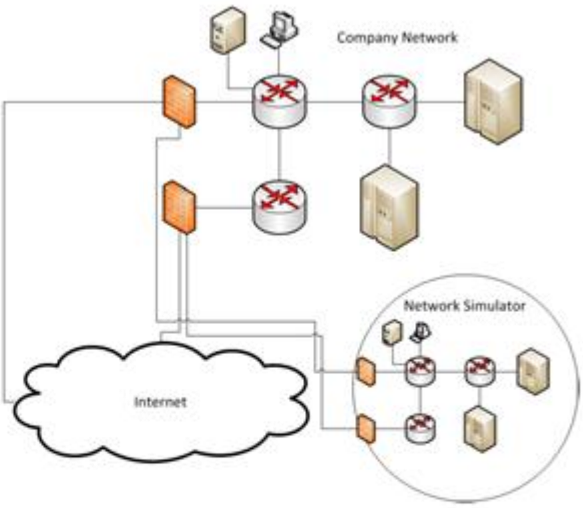


Figure 4.1. An example for network simulation [52].

The progress of a knowledge or a product with the aid of network simulation is an iterative procedure. As shown in Figure 4.2 a simulation is modeled on the thoughts and ideas of the simulation planer. The outcomes and dimensions of the simulation are handled to change it, to make unlike simulation behavior and outcomes, till the wanted results can be proficient. [53].

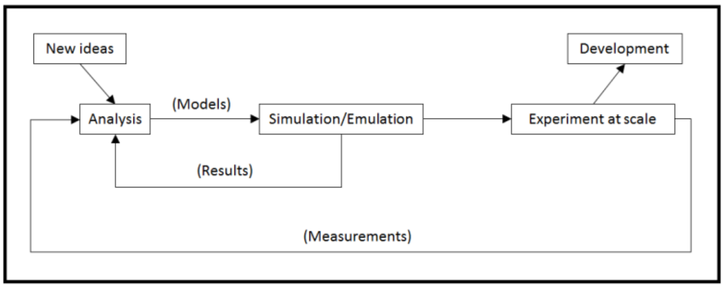


Figure 4.2. The cycle of network simulation [53].

## 4.2. NETWORK SIMULATORS

Normally talking, network simulators attempt to model the actual networks. The main knowledge is that if a system could be modeled, at that time structures of the model could be altered and the conforming outcomes could be examined. As the procedure of model adjustment is inexpensive comparing the whole actual operation, an extensive variation of scenarios could be examined at small charge [54] [55].

Presently there are a lot of network simulators which have various structures in dissimilar features. A small list of the present network simulators contains OPNET, NS-2, NS-3, REAL, OMNeT++, J-Sim, SSFNet, and QualNet. Though, in this chapter, we do not aim to shelter all the presented network simulators. We only choice some characteristic ones and do some study and compare some from the others a little to grow a good opinion of the key structures of a specific network simulator.

The network simulators that we will review are NS2, NS3, OPNET, and OMNeT++. NS3 redesigns many mechanisms built on the effective and the ineffective skills of NS2. OMNeT++ is also significant network simulator that has a influential modular core design and graphical interface.

### 4.2.1. Network Simulator-2

Network Simulator-2 (ns-2) is an open source, distinct occurrence network simulator. It is utilized for the simulation of network protocols with dissimilar network arrangement. It is able of pretending wired in addition to wireless networks. NS-2 was constructed in C++ and delivers the simulation boundary through OTcl, an object-oriented vernacular of Tcl. The end-user labels a network arrangement by script OTcl scripts, and after that the chief NS program pretends that arrangement with definite constraints. In ns-2, network animation (NAM) is utilized for the graphical display of the network. ns-2 is the greatest public and broadly utilized network simulator for investigation purpose. NAM interface covers switch structures which let end-users to send, silence, break and play the simulation. The interface of ns-2 is shown in Figure 4.3.

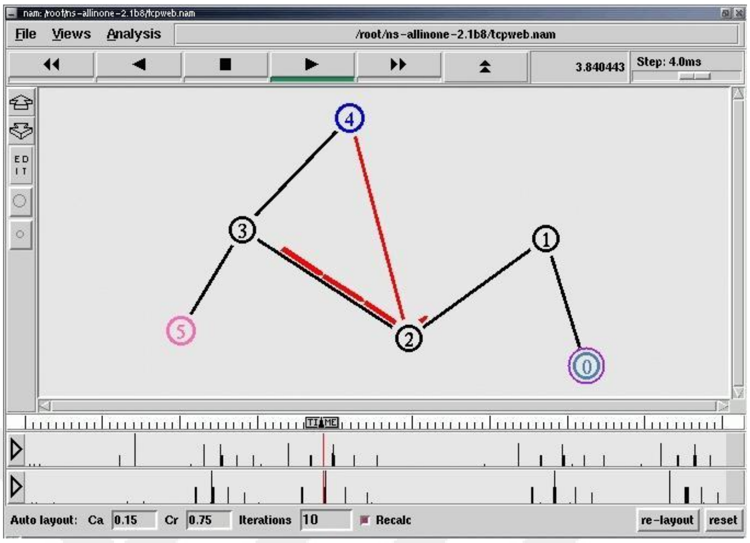


Figure 4.3. Ns-2 Simulator interface.

In ns-2, random network arrangements could be distinct which are collected of routers, links and common media. The physical actions of the network are treated and line up in shape of actions, in an arranged direction. Those actions are then treated as per arranged period which rises lengthways with the dispensation of actions. Though, the simulation is not actual period; it is measured virtual.

### 4.2.2. Network Simulator-3

The NS3 simulator is an open sourced discrete-event that goals mainly for informative and investigation usage. NS3 is licensed below (GNU GPLv2). It is existing for development and research [56].

The NS3 simulator is planned to substitute the NS2. Though, NS3 isn't an updated simulator of NS2 because NS3 is a new simulator and it isn't companionable with NS2.

The NS3 elementary knowledge comes from some dissimilar network simulators like NS2, GTNetS, and YANS. The fundamental of NS3 is programed in C++ and using

Python scripting interface where NS2 was with the OTcl. Numerous progressive C++ plan patterns are used also. NS3 support a combination of additional open-source network software and decrease the necessity to reprogram models for simulation. In NS3, lightweight virtual machine is used. Figure 4.4 shows an instance of virtualization testbed in NS3.

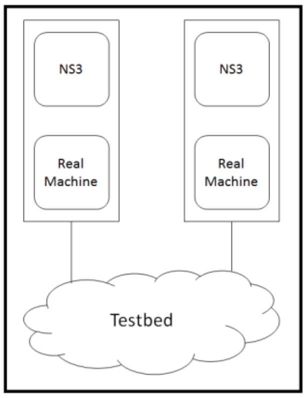


Figure 4.4. Testbeds interconnect ns3 stacks [56].

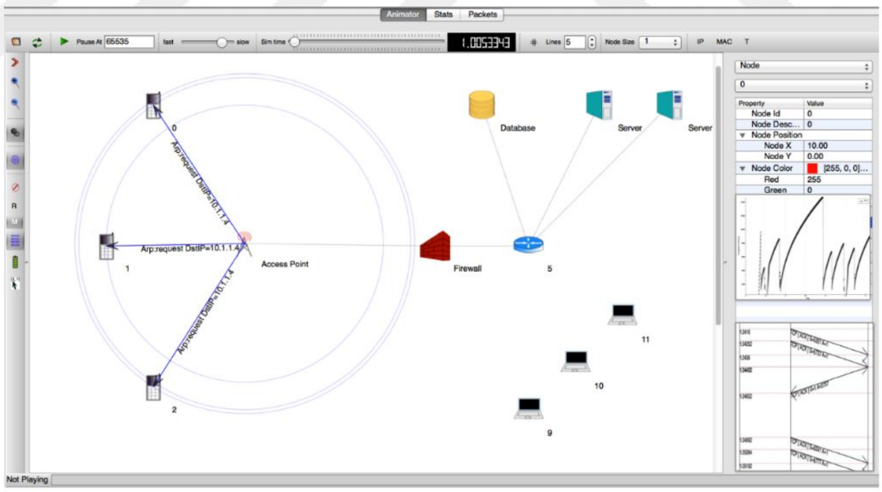


Figure 4.5. Netanim GUI.

Over the comparison between NS3 and NS2, we could short the NS3's features as listed:

- Modular,
- C++ plans and Python scripting
- Arrangement with physical systems

- Software addition
- Virtualization and testbed addition
- Quality system
- Updated models

NetAnim is a software that process the xml files for graphical output which are generated through NS3. The main graphic user interface is shown in Figure 4.5.

### 4.2.3. OPNET

OPNET (Optimized Network Engineering Tool) delivers a complete advance setting for the requirement, simulation and act study of connection networks. A big variety of connection systems from a sole LAN to worldwide satellite networks could be maintained. Separate occasion simulations are utilized as the resources of examining system act and their performance. Figure 4.6 demonstrats OPNET simulator interface [57].

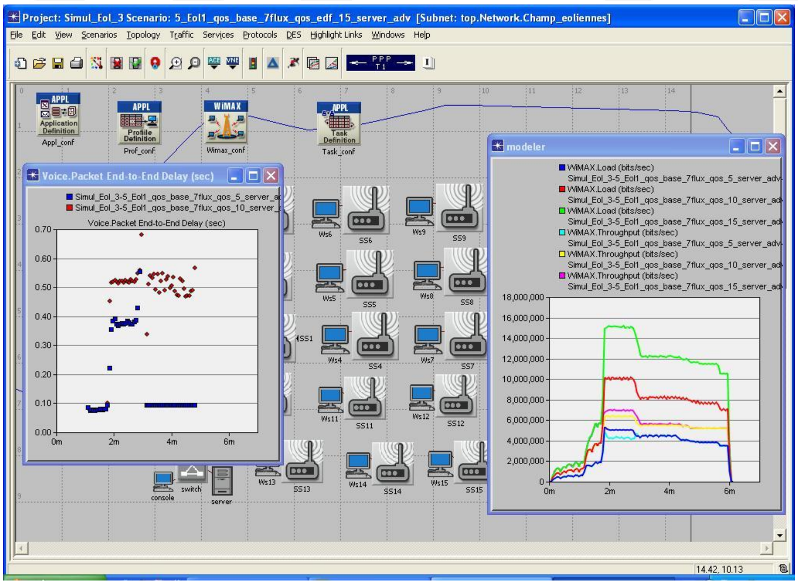


Figure 4.6. Opnet simulator interface.

The important structures of OPNET are brief here as:

- Demonstrating and Simulation Sequence: OPNET delivers influential gears to contribute end-user to go over three out of the five stages in a plan loop (i.e. the structure of replicas, the implementation of a simulation and the examination of the production info).

- Ranked Demonstrating: OPNET employments a ranked construction to demonstrating. every stage of the ranked labels dissimilar features of the whole prototypical being simulated.
- Particular in connection networks: Full collection replicas deliver provision for current protocols and let investigators and designers to either adjust those current replicas or advance new replicas of their individual.
- Involuntary simulation group: OPNET models could be collected into executable script. An executable distinct occasion simulation could be corrected or just implemented, resultant in out info.

### 4.2.4. OMNET++

Like with NS3, OMNeT++ is also an open-source, component-based network simulator with graphical user interface sustenance. Its core application zone is connection networks. OMNeT++ has flexible and generic building that styles it effective also in extra parts such as the IT systems, in the hardware buildings, in the queuing networks, or even in business processes also [58].

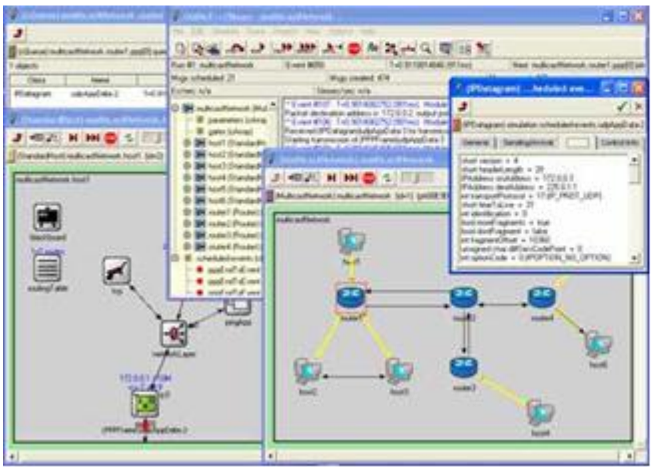

Figure 4.7. Omnet++ GUI.

Like NS3, OMNeT++ is a discrete occasion simulator also. It is a component-based building. Components are also named modules and are planned in C++ programming language. The components, after that, are collected into greater components and models by using a high-level programming language. Its purpose is like that of OTcl in the NS2 and Python in the NS3 simulators. Figure 4.7 is OMNeT++ screenshot.

Since OMNeT++ is planned to deliver a component-based construction, the models or modules of OMNeT++ are collected from recyclable components. An OMNeT++ components include [58]:

- Simulation kernel library
- Utilities (arbitrary number seed creation tool, make file formation means, etc.)
- Graphical production scalars visualization means
- Compiler for the NED topology description language
- Graphical output vector plotting tool
- Graphical user interface for simulation execution, relations into simulation executable
- Model documentation tool (opp_neddoc)
- Command-line user interface for simulation implementation
- Graphical network editor for NED files
- Papers, sample simulations, etc.

As the main feature of OMNeT++, the simulation kernel of C++ class library contains the utility classes and simulation kernel that would be used to make simulation components. The library includes also the substructure to collect simulations from dissimilar components. OMNeT++ could run on Windows, Linux, and other Unix-like systems.

OMNeT++ signifies a framework method. It delivers the substructure for script different simulations. Some application areas' necessities are met using various simulation frameworks and models, greatest of them are open sourced.

- Castalia

Castalia is a simulator utilized for Wireless Sensor Networks (WSN), Body Area Networks and generally networks of small power and engrained nodes. This simulator is grounded on the OMNeT++ platform and utilized by researchers and creators to test their dispersed protocols in an accurate wireless network and wireless model, with an precise node act specially concerning to contact of the wireless. Castalia can also be utilized to estimate dissimilar platform features for exact requests, meanwhile it is extremely parametric, and could pretend a varied choice of platforms [59].

The main structures of Castalia are:

- Progressive network prototypical grounded on empirically measured info.
  - Prototypical describes a chart of track cost, not just contacts among sensors
  - Compound prototypical for progressive difference of track cost
  - Completely provisions movement of the sensors
  - Interference is fingered as delivered sign strength, not as distinct property
- Progressive wireless prototypical grounded on actual wirelesses for little-energy connection.
  - Chance of response grounded on SINR, packet scope, inflection type. PSK FSK reinforced, convention inflection allowable by essential SNR-BER curve.
  - Many TX energy stages with separate node differences allowable
  - Conditions with dissimilar energy feeding and interruptions swapping among them
  - Accurate demonstrating of RSSI and carrier sensing
- Lengthy recognizing demonstrating provisions
  - Extremely stretchy physical procedure prototypical.
  - Sensing gear noise, bias, and energy feeding.
- Node timer drift
- MAC and routing protocols offered.
- Planned for edition and growth.

Castalia command user interface is shown in Figure 4.8.

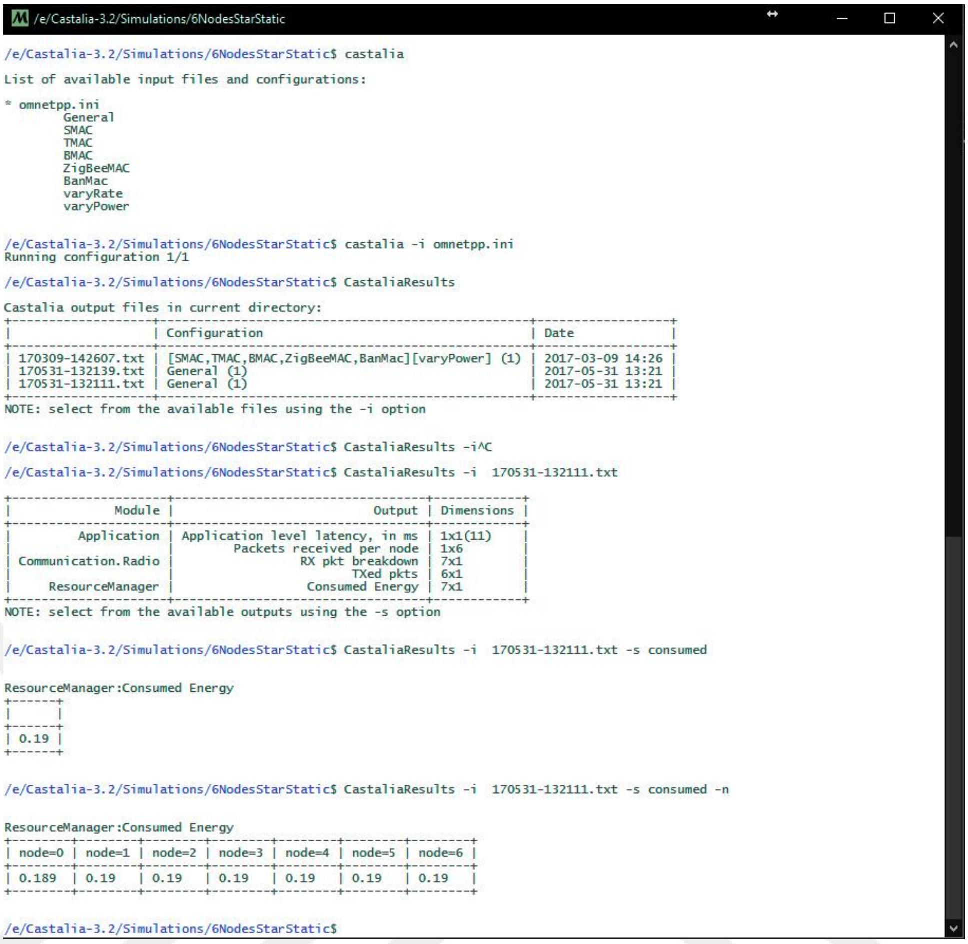


Figure 4.8. Castalia command user interface.

## 4.3. COMPARISON OF NETWORK SIMULATORS

The network simulators are of dissimilar kinds that could be likened grounded on:

- Range (from the actual basic to the actual compound),
- Agreeing the nodes and connections among these nodes and traffic among the nodes,
- Graphical requests (let end-users to simply picture the mechanisms of their simulated setting.),
- Text-based requests (license additional progressive forms of customization) and
- Programming oriented gears.

Table 4.1 shows comparison of network simulators.

Table 4.1. Comparison of network simulators.

| Simulator | Language | Platforms | Cost and Licenses | Network support type |
|---|---|---|---|---|
| Ns2 | C++ and OTCl | Windows, Linux | Free, Open Source | Wired Network, Wireless Ad-Hoc mode, Wireless Managed mode, Wired cum Wireless, Cannot simulate problems of the bandwidth or the power consumption in Wireless Sensor Network |
| Ns3 | C++, python | Windows, Linux, Mac OS | Free, GNU General Public License | Wired Network, Wireless Network, Wireless Sensor Network |
| *OMNeT++ | C++ | Windows, Unix-based, Mac OS X 10.6 and 10.7 | Free, Noncommercial license, commercial license | Wired Network, Wireless Managed mode, |
| OPNET | C (C++) | Hewlett-Packard, Sun-4 SPARC Various, Solaris 2.6, Windows NT / Windows 2000 | Commercial network simulator | simulate entire heterogeneous networks with various protocols |

# CHAPTER 5

# SIMULATION FRAMEWORK

## 5.1. INTRODUCTION

In this chapter, we debate the results achieved from simulations of the different sensor networks. We take four different considerations to compare among; throughput, delay, power consumed, and collision. To evaluate the performance of the wireless sensor network; we created a simulation scenarios using Castalia simulator based on OMNeT++ platform.

## 5.2. SIMULATION PARAMETERS

We created two different scenarios in Castalia simulator, first scenario with six sensors and one sink node and the second scenario with 24 sensors and one sink node. The simulation parameters that we used are shown in Table 5.1

In 6 sensors scenario, we assumed that all the 6 sensors are attached to one person only plus the sink node. as shown in Figure 5.1. For the 24 sensors scenario, we assumed that there are 4 persons in one room and every person have 6 sensors plus sink node attached for each one.

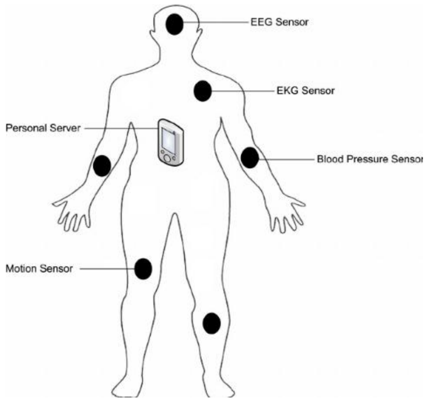


Figure 5.1. Distribution of the sensors.

We applied five different MAC layer protocols; TMAC, SMAC, BMAC, BANMAC (802.15.6), and ZigBeeMAC (802.15.4).

Table 5.1. Simulation parameters.

| **Parameters** | **Scenario 1** | **Scenario 2** |
|---|---|---|
| Topology | Star | |
| Number of Nudes | 6 + 1 | 24 + 1 |
| Field Area | 2 x 2 meter | 6 x 4 meter |
| Mobility | Static Nodes | |
| Simulation Time | 60 s | |
| Startup Delay Time | 1 s | |
| Application Packets Rate | 10 packets per second | |
| Application Packets Size | 105 Byte | |
| Node TX Power | -20 dBm, -10 dBm | |
| MAC Protocols | TMAC, SMAC, BMAC, BANMAC, and ZigBeeMAC | |
| Max Packet Size for MAC | No Limit | |
| Buffer Size for MAC | 32 Packets | |
| Packet Overhead for MAC | 11 Byte | |

## 5.3. SIMULATION FRAMEWORK

In both scenarios, the application in each node generate 10 packets per second, and each packet size is 105 Byte as listed in Table 5.1. To calculate the throughput, we compute the total number of packets received at the sink node from each sensor node during the simulation time which is one minute. Then, multiply the total number by the size of each packet which is 105 Bytes, and divided it by the simulation time which is 60 seconds to get the throughput in Bytes per second and multiply it by 8 to get the throughput in bits per second. By dividing the last result by 1000 we get the throughput in kilobit per second.

$$Throughput\ (kbps) = \frac{Total\ data\ delivered}{total\ time\ elapsed} = \frac{totla\ number\ of\ packets \times 105 \times 8}{60 \times 1000} \qquad (5.1)$$

We calculated the average delay from the delay histogram by take the average time for each interval in the histogram and multiply it by the number of packets received during this interval, then we take the summation of them and divided it by the total number of the received packets.

We calculated the power consumption for the nodes by assuming that each node will consume 3.0 mW per second during the transmission and receiving with -10dBm sensor power and 2.9 mW per second during the transmission and receiving with -20dBm sensor power. Then calculate the time the consumed to transmit and receive all the packets in each node and multiply it by the power rate for each sensor power that assumed above.

We calculated the packets congestion by computing the number of packet that failed to reached the sink node from each sensor due to the interference.

## 5.4. SIMULATION RESULTS

### 5.4.1. Average Throughput

We calculate network throughput with the five different MAC layer protocols.

#### 5.4.1.1. Average Throughput for 6 Nodes and -10 dBm Power

The throughput for six nodes and -10 dBm power is shown in Figure 5.2. In the output graph of the throughput using -10 dBm sensor power in six sensors, using ZigBeeMac protocol lets throughput of the six sensors to be almost one thousand packets per node. This is because ZigBeeMAC is beacon-enabled network, the network coordinator periodically broadcasts beacon frames, equipment in BAN network is synchronized per the beacon frames from coordinator.

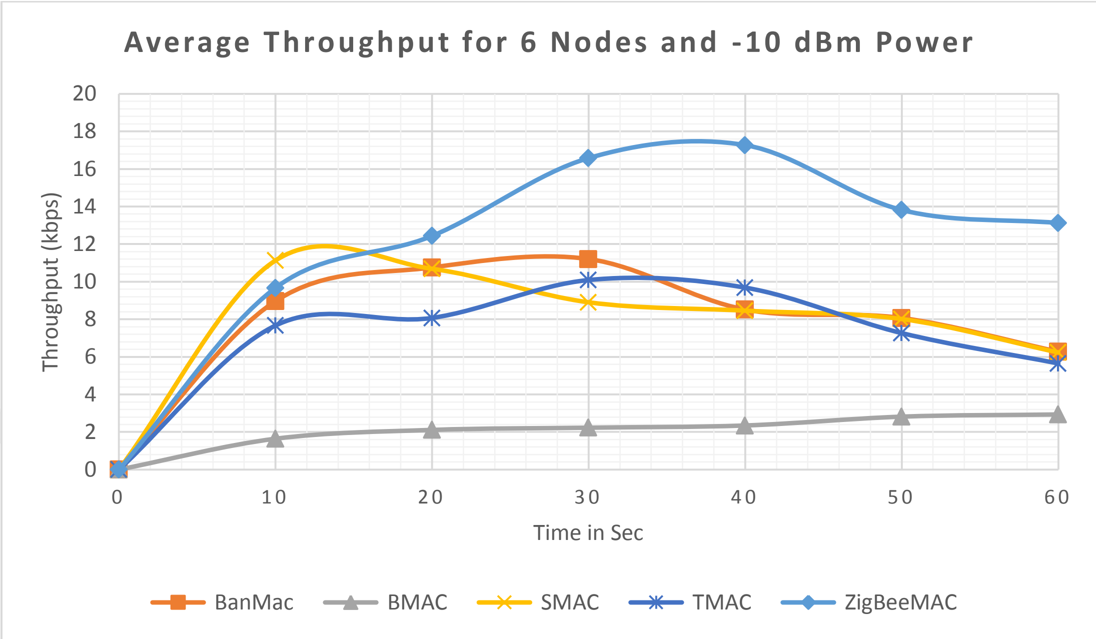


Figure 5.2. Average throughput for 6 nodes and -10 dbm power.

Using TMAC, SMAC, and BanMac protocols lets the throughput of the six sensors to be around six hundred packets per node. Using BMAC protocol, the throughput of sensor of index one reached almost one thousand packets but the rest five sensors throughput range from 11 to 24 packets per node. Since BMAC does not have the RTS-CTS mechanism or synchronization requirements of other MAC protocols like SMAC and TMAC.

#### 5.4.1.2. Average Throughput for 6 Nodes and -20 dBm Power

The throughput for six nodes and -20 dBm power is shown in Figure 5.3. In the output graph of the throughput using -20 dBm power in six sensors, using ZigBeeMac protocol lets throughput of the six sensors to be almost one thousand packets per node. This is because ZigBeeMAC is beacon-enabled network, the network coordinator periodically broadcasts beacon frames, equipment in BAN network is synchronized per the beacon frames from coordinator.

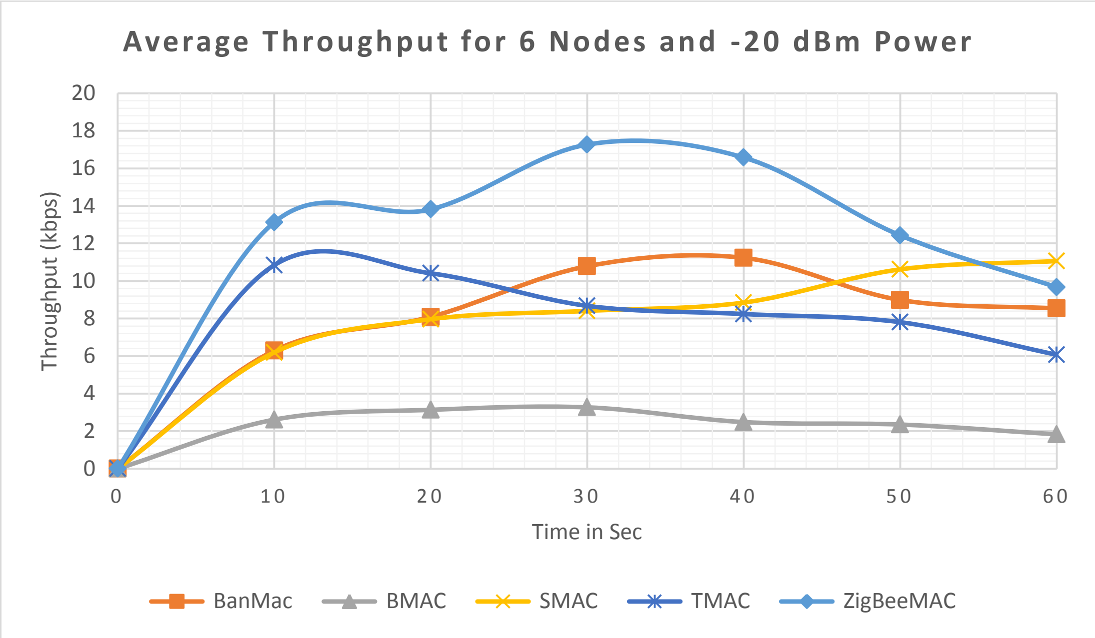


Figure 5.3. Average throughput for 6 nodes and -20 dbm power.

Using SMAC and BanMac protocols lets the throughput of the six sensors to be around six hundred packets per node. Using TMAC protocol, the throughput of the sensor of index two reached 752 packets and the sensor of index six reached as low as 466 packets. The other sensors throughput range from 540 to 703 packets per node. Using BMAC protocol, the throughput of the sensor of index two reached as low as 33 packets but the rest five sensors throughput range from 206 to 225 packets per node. Since BMAC does not have the RTS-CTS mechanism or synchronization requirements of other MAC protocols like SMAC and TMAC.

### 5.4.1.3. Average Throughput for 24 Nodes and -10 dBm Power

The throughput for 24 nodes and -10 dBm power is shown in Figure 5.4. In the output graph of the throughput using -10 dBm power in 24 sensors, using ZigBeeMac protocol lets throughput of the 24 sensors to be between 534 and 727 packets per node. This is because ZigBeeMAC is beacon-enabled network, the network coordinator periodically broadcasts beacon frames, equipment in BAN network is synchronized per the beacon frames from coordinator. Using BanMac protocol, the throughput of the sensor of index 16 reaches 687 packets, and the sensor of index 22 reaches 584 packets.

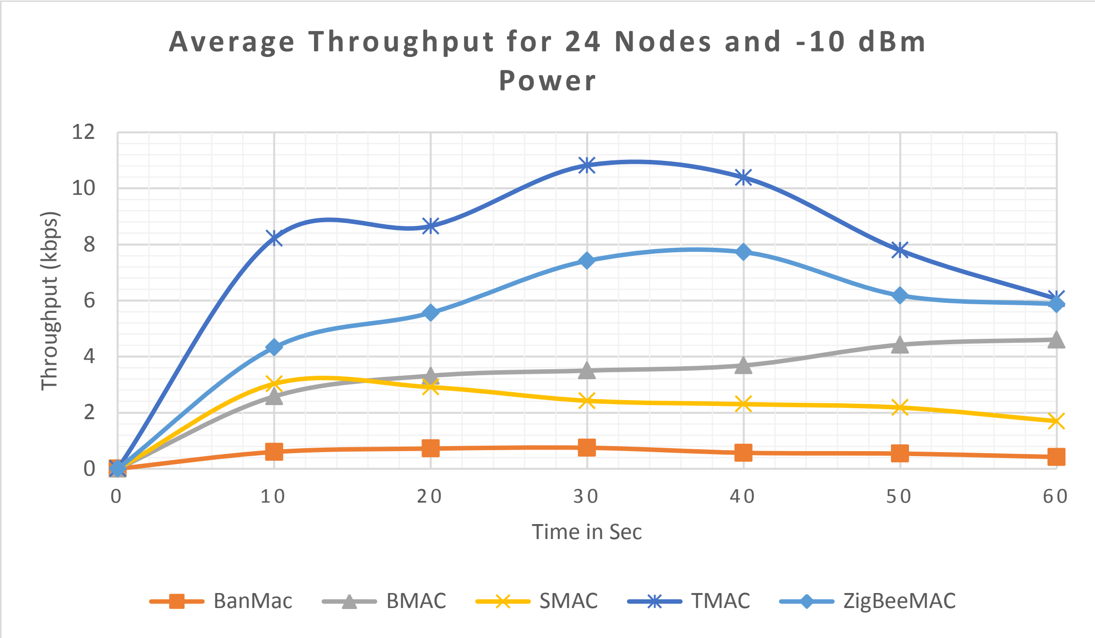


Figure 5.4. Average throughput for 24 nodes and -10 dbm power.

Though, the throughput of the sensor of index 24 gives only 323 packets. The rest of sensors throughput range from 339 to 523 packets per node. Using SMAC protocol lets the throughput of the 24 sensors to be range from 237 to 301 packets per node. Using TMAC protocol, the throughput of the sensor of index 15 reached as high as 768 packets but the sensors of indices 6, 8, and 16 throughputs range between 0 and 1 packet per node. The rest of sensors throughput range from 33 to 307 packets per node. Using BMAC protocol, the throughput of the 24 sensors range from 26 to 87 packets per node. Since BMAC does not have the RTS-CTS mechanism or synchronization requirements of other MAC protocols like SMAC and TMAC.

#### 5.4.1.4. Average Throughput for 24 Nodes and -20 dBm Power

The throughput for 24 nodes and -20 dBm power is shown in Figure 5.5. In the output graph of the throughput using -20 dBm power in 24 sensors, the throughputs of sensors with indices of 2, 19, and 20 is zero with using any protocol. The throughputs of the sensors using ZigBeeMac and BanMac protocols are quite similar; ranging from 301 to 740 packets per node excluding the zero throughput sensors. This is because ZigBeeMAC is beacon-enabled network, the network coordinator periodically broadcasts beacon frames, equipment in BAN network is synchronized per the beacon frames from coordinator.

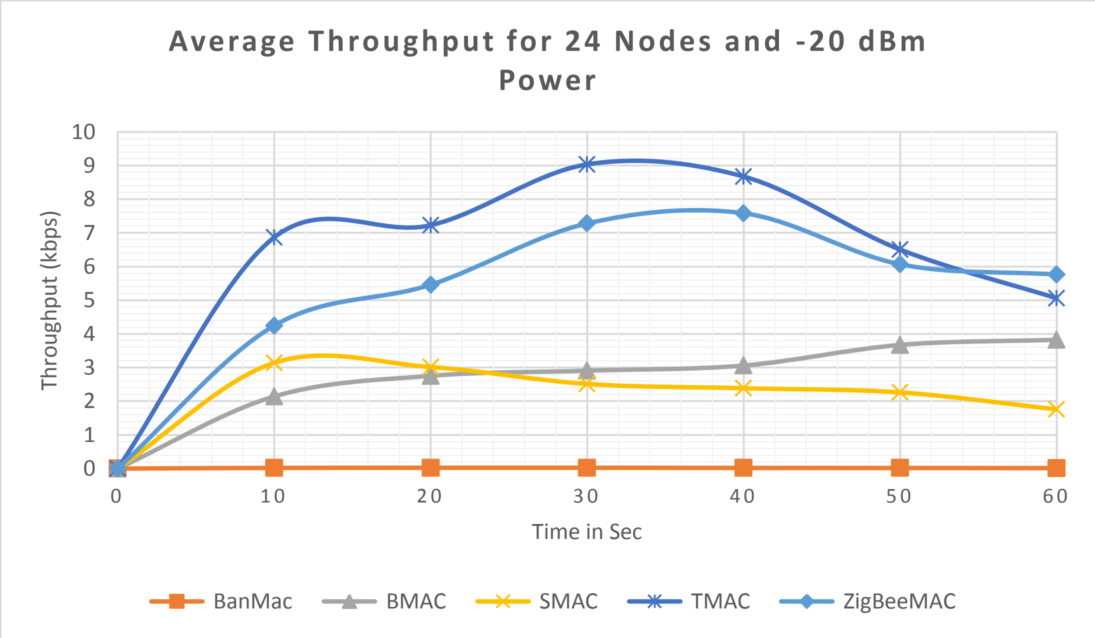


Figure 5.5. Average throughput for 24 nodes and -20 dbm power.

Using SMAC protocol lets the throughput of the sensors to be range from 182 to 296 packets per node excluding the zero throughput sensors. Using TMAC protocol, the throughput of the sensor of index 12 reached 615 packets. The other sensors throughput range from 0 to 401 packets per node. Using BMAC protocol, the throughput of the sensor of index 21 reached as high as 12 packets per second and the rest 23 sensors throughput range from 0 to 4 packets per node. Since BMAC does not have the RTS-CTS mechanism or synchronization requirements of other MAC protocols like SMAC and TMAC.

### 5.4.2. Average Delay

We calculate network average delay with the five different MAC layer protocols and two different power.

#### 5.4.2.1. Average Delay for 6 Nodes and -10 dBm Power

The average delay for six sensors and -10 dBm power is shown as a histogram in Figure 5.6. In the average delay chart for -10 dBm power in six sensors, all the packets are delivered within 0.5 sec by using BanMac and ZigBeeMac protocols.

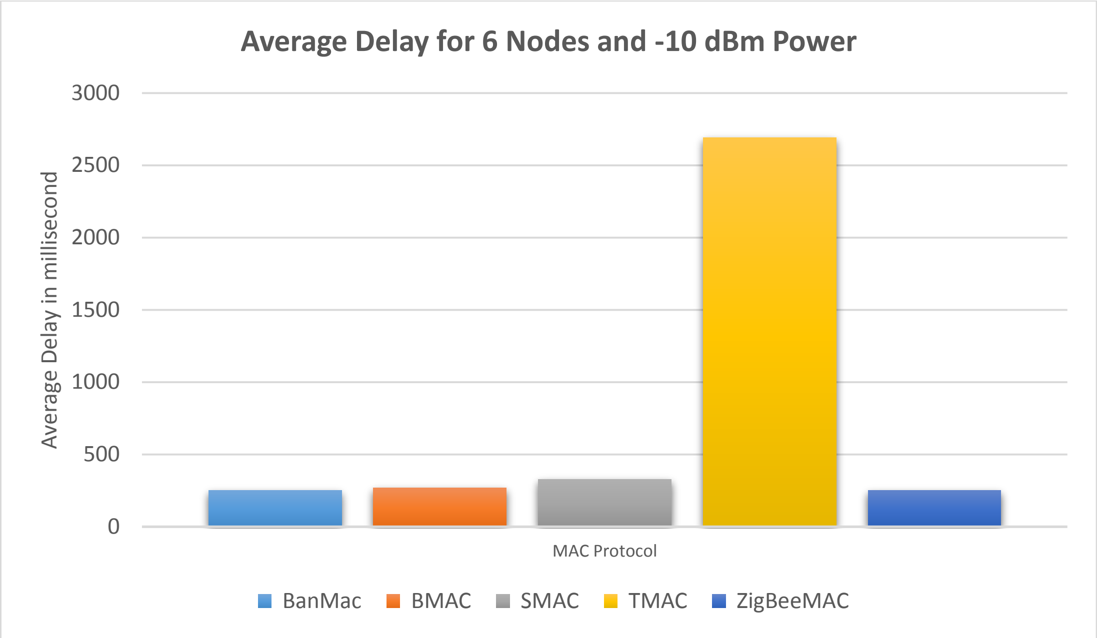


Figure 5.6. Average delay for 6 nodes and -10 dbm power.

Using SMAC, the packets are delivered almost within 1.5 sec. Using BMAC, the packets are delivered almost within 2 sec. Using TMAC protocol, 2580 packets are delivered within 5 sec. the rest of packets take longer time to be delivered. T-MAC protocol has a problem with asymmetric communication patterns, where nodes may go to sleep while their neighbors still have messages for them. This early sleeping problem increase average delay time.

#### 5.4.2.2. Average Delay for 6 Nodes and -20 dBm Power

The average delay for six sensors and -20 dBm power is shown as a histogram in Figure 5.7. In the average delay chart for -20 dBm power in six sensors, all the packets are delivered within 0.5 sec by using BanMac and ZigBeeMac protocols. Using SMAC, the packets are delivered almost within 1.5 sec. Using BMAC, the packets are delivered almost within 3.5 sec except one packet which takes more than 5 sec to be delivered.

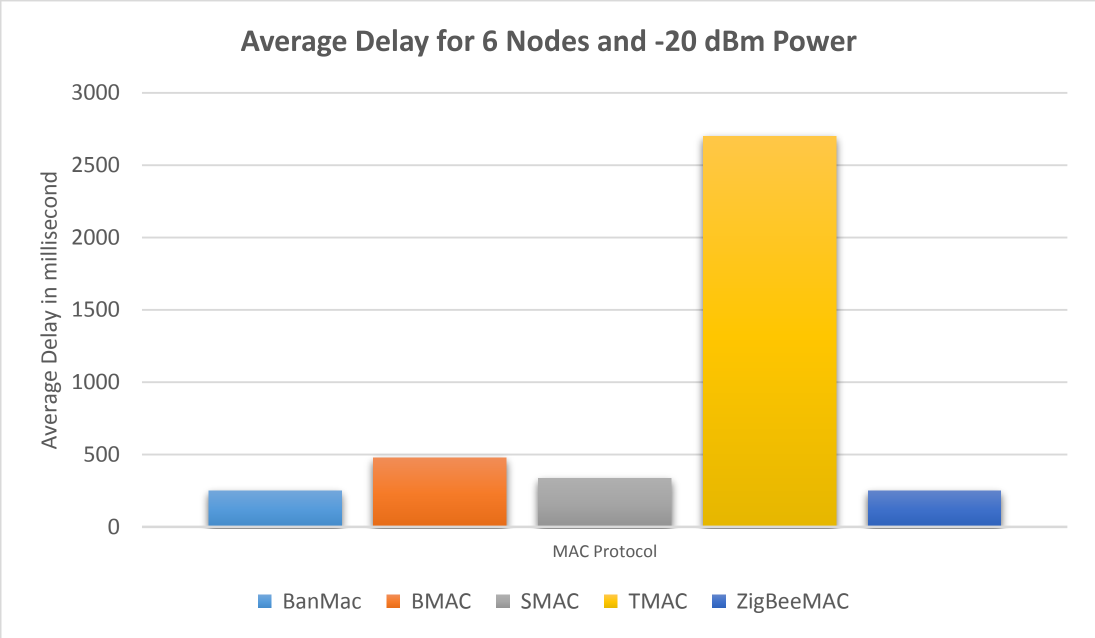


Figure 5.7. Average delay for 6 nodes and -20 dbm power.

Using TMAC protocol, 77% of the packets are delivered within 5 sec. the rest of packets take longer time to be delivered. T-MAC protocol has a problem with asymmetric communication patterns, where nodes may go to sleep while their neighbors still have messages for them. This early sleeping problem increase average delay time.

#### 5.4.2.3. Average Delay for 24 Nodes and -10 dBm Power

The average delay for 24 sensors and -10 dBm power is shown as a histogram in Figure 5.8. In the average delay chart for -10 dBm power in 24 sensors, all the packets are delivered within 5 secs by using SMAC and ZigBeeMac protocols. Using BanMAC, almost 98% of the packets are delivered within 5 sec. the rest of packets take longer time to be delivered. Using BMAC, almost 90% of the packets are delivered within 5 sec. the rest of packets take longer time to be delivered. Using TMAC, almost 46% of the packets are delivered within 5 sec. the rest of packets take longer time to be delivered.

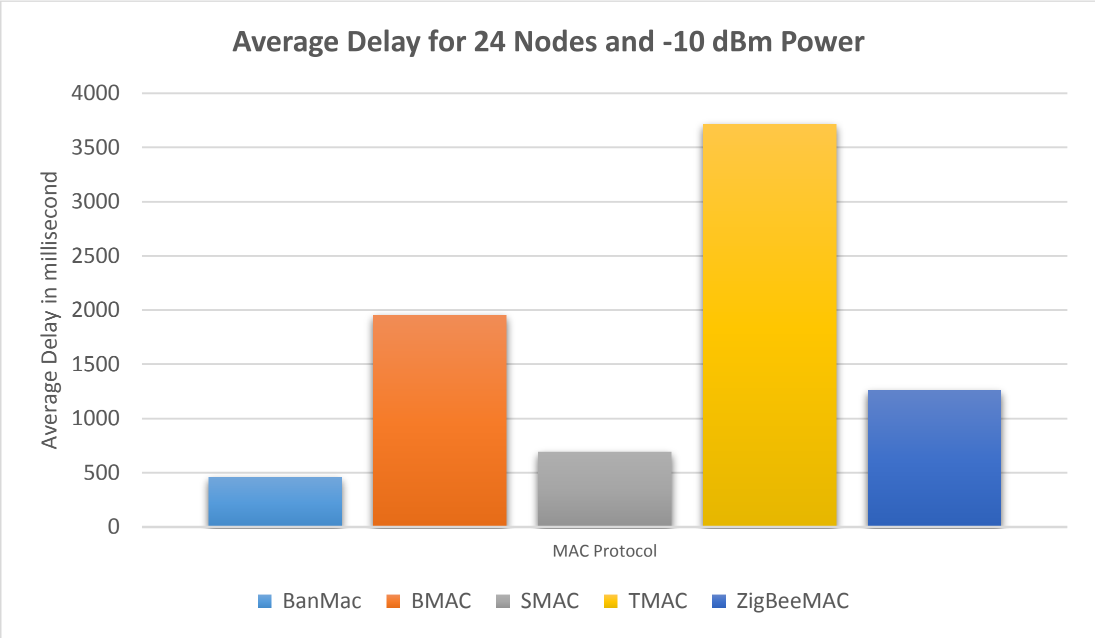


Figure 5.8. Average delay for 24 nodes and -10 dbm power.

### 5.4.2.4. Average Delay for 24 Nodes and -20 dBm Power

The average delay for 24 sensors and -20 dBm power is shown as a histogram in Figure 5.9.

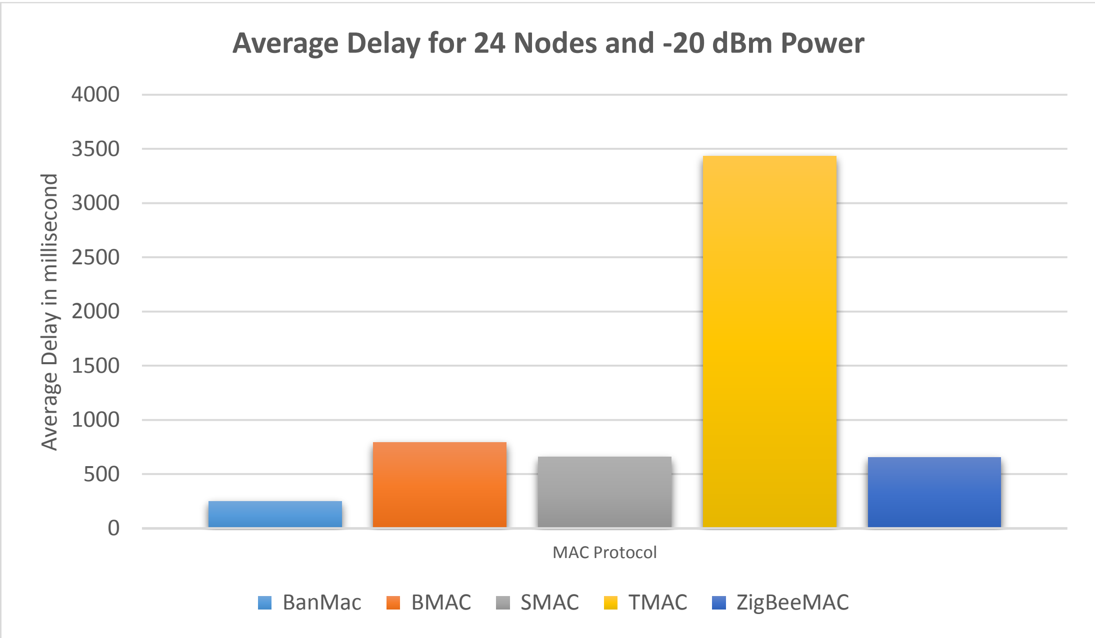


Figure 5.9. Average delay for 24 nodes and -20 dbm power.

In the average delay chart for -20 dBm power in 24 sensors, all the packets are delivered within 0.5 sec by using BanMAC protocols. Using BMAC, the packets are delivered almost within 3 sec. Using ZigBeeMAC, the packets are delivered almost within 4 sec. Using SMAC, the packets are delivered almost within 4.5 sec. Using TMAC, almost 52% of the packets are delivered within 5 sec. the rest of packets take longer time to be delivered.

### 5.4.3. Power Consumption

We calculate the power consumed by the sensors with the five different MAC layer protocols and two different power.

#### 5.4.3.1. Average Power Consumption for 6 Nodes

The average power consumed by the sensors in 6 sensors and two different power is shown in Figure 5.10.

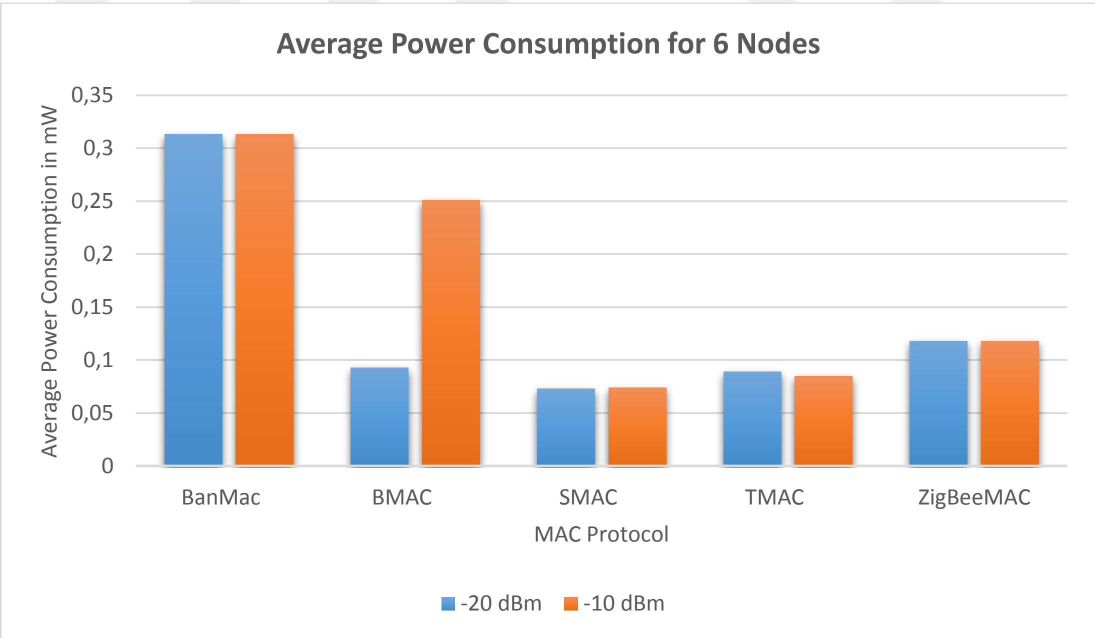


Figure 5.10. Average power consumption for 6 nodes.

In the average power consumption output graph in six sensors, using SMAC protocol lets the average power consumption of the sensors to be almost 0.07 mW in both -20 dBm and -10 dBm power. Using the TMAC protocol lets the average power consumption of the sensors to be almost 0.09 mW in both -20 dBm and -10 dBm power. Using the ZigBeeMAC protocol lets the average power consumption of the sensors to be almost 0.12 mW in both -20 dBm and -10 dBm power. Using BMAC protocol, the average power consumed in -20 dBm power is almost 0.09 mW, while in -10 dBm power it is almost 0.25 mW. This is because when using higher power, the probability packets congestion will be higher and led to resend more packets and more power consumption. Finally, we get the same high average power consumption of 0.31 mW using BanMAC protocol in both -20 dBm and -10 dBm power.

#### 5.4.3.2. Power Consumption for 6 Nodes and -10 dBm Power

The power consumption per node for six sensors and -10 dBm power is shown in Figure 5.11.

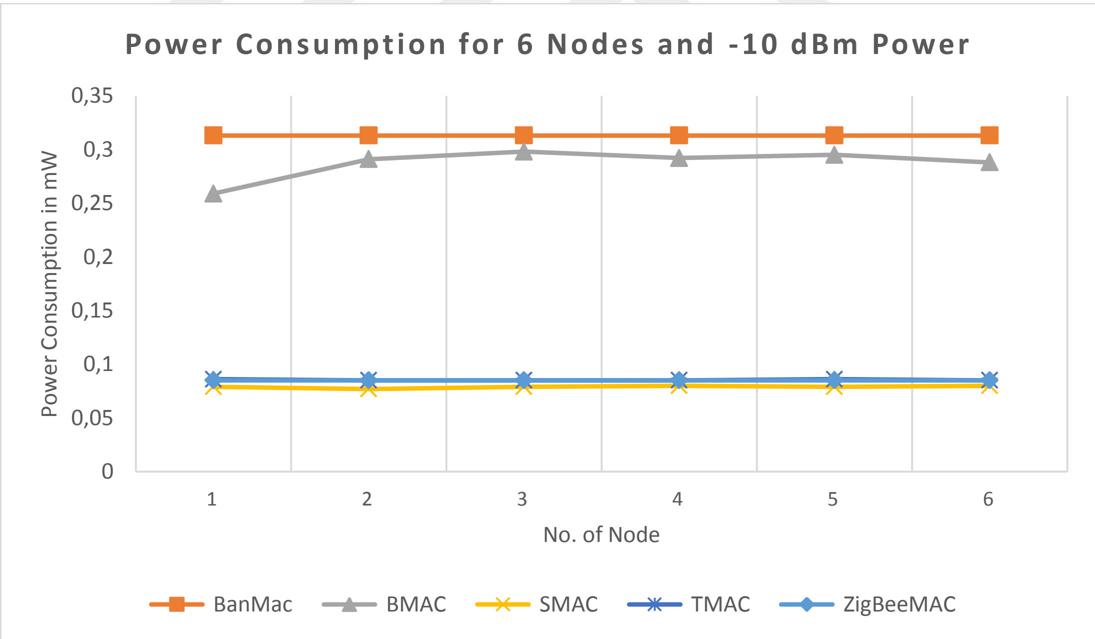


Figure 5.11. Power consumption for 6 nodes and -10 dbm power.

In the power consumption per node graph with -10 dBm power in six sensors, using the SMAC protocol keep the sensors power consumption between 0.077 mW and 0.080 mW per node. Using TMAC protocol and ZigBeeMAC protocol, we get almost identical sensors power consumption between 0.085 mW and 0.086 mW per node. Using BMAC protocol, the power consumption varies between 0.288 mW and 0.298 mW per node except the power consumption for node of index one, which consumed 0.259 mW. Finally, by using the BANMAC protocol we get identical power consumption of 0.313 mW per node.

#### 5.4.3.3. Power Consumption for 6 Nodes and -20 dBm Power

The power consumption per node for six sensors and -20 dBm power is shown in Figure 5.12.

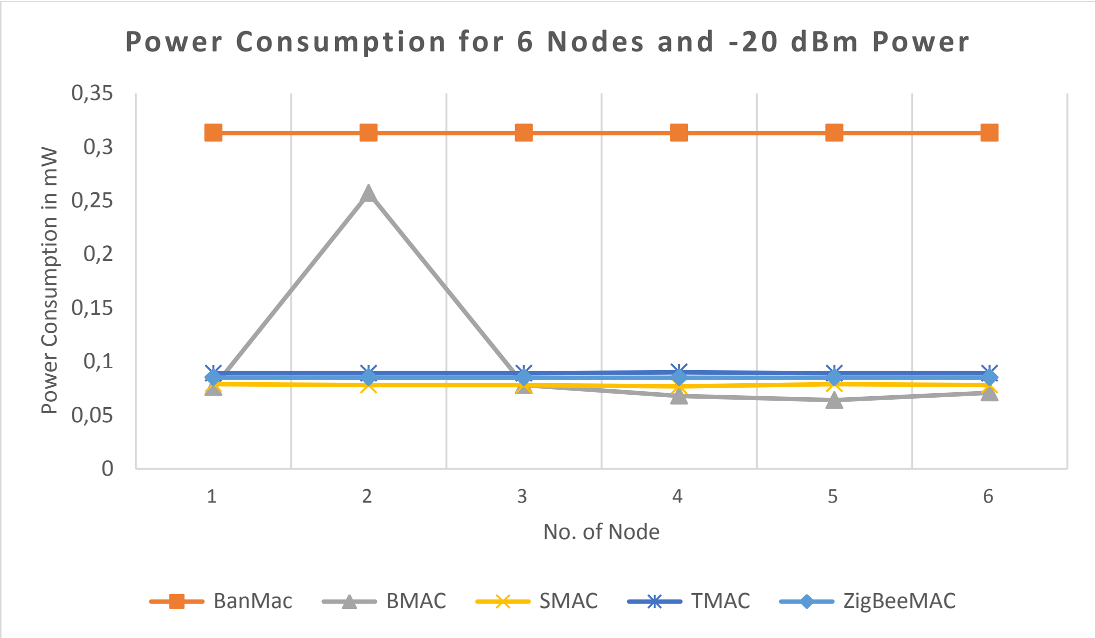


Figure 5.12. Power consumption for 6 nodes and -20 dbm power.

In the power consumption per node graph with -20 dBm power in six sensors, using the SMAC protocol keep the sensors power consumption between 0.077 mW and 0.079 mW per node. Using TMAC protocol, the power consumption per node was 0.089 mW for all nodes except for node of index four, which was 0.090 mw. Using ZigBeeMAC protocol gives the same power consumption of 0.085 mW for all nodes. Using BMAC protocol, the power consumption varies between 0.064 mW and 0.078 mW per node except the power consumption for node of index two, which consumed 0.257 mW because it located in a high traffic area and a lot of packets congestion occur. Finally, by using the BANMAC protocol we get identical power consumption of 0.313 mW per node.

#### 5.4.3.4. Average Power Consumption for 24 Nodes

The average power consumed by the sensors in 24 sensors and two different power is shown in Figure 5.13.

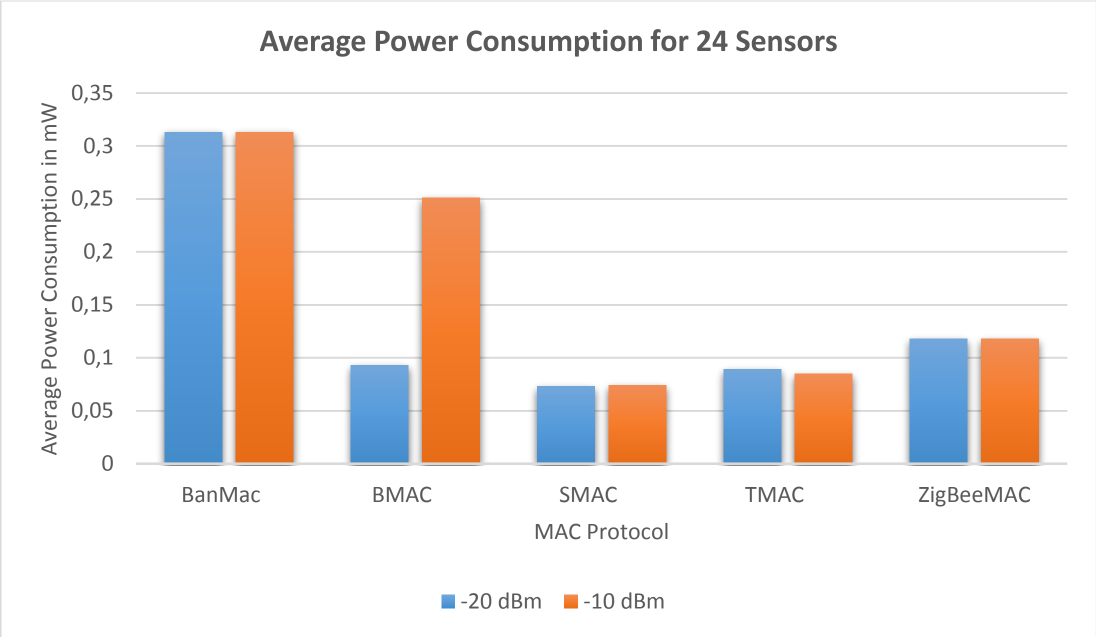


Figure 5.13. Average power consumption for 24 nodes.

In the average power consumption output graph in 24 sensors, using SMAC protocol lets the average power consumption of the sensors to be almost 0.07 mW in both -20 dBm and -10 dBm power. Using the TMAC protocol lets the average power consumption of the sensors to be almost 0.09 mW in both -20 dBm and -10 dBm power. Using the ZigBeeMAC protocol lets the average power consumption of the sensors to be almost 0.12 mW in both -20 dBm and -10 dBm power. Using BMAC protocol, the average power consumed in -20 dBm power is almost 0.09 mW, while in -10 dBm power it is almost 0.25 mW. Finally, we get the same high average power consumption of 0.31 mW using BanMAC protocol in both -20 dBm and -10 dBm power.

### 5.4.3.5. Power Consumption for 24 Nodes and -10 dBm Power

The power consumption per node for 24 sensors and -10 dBm power is shown in Figure 5.14.

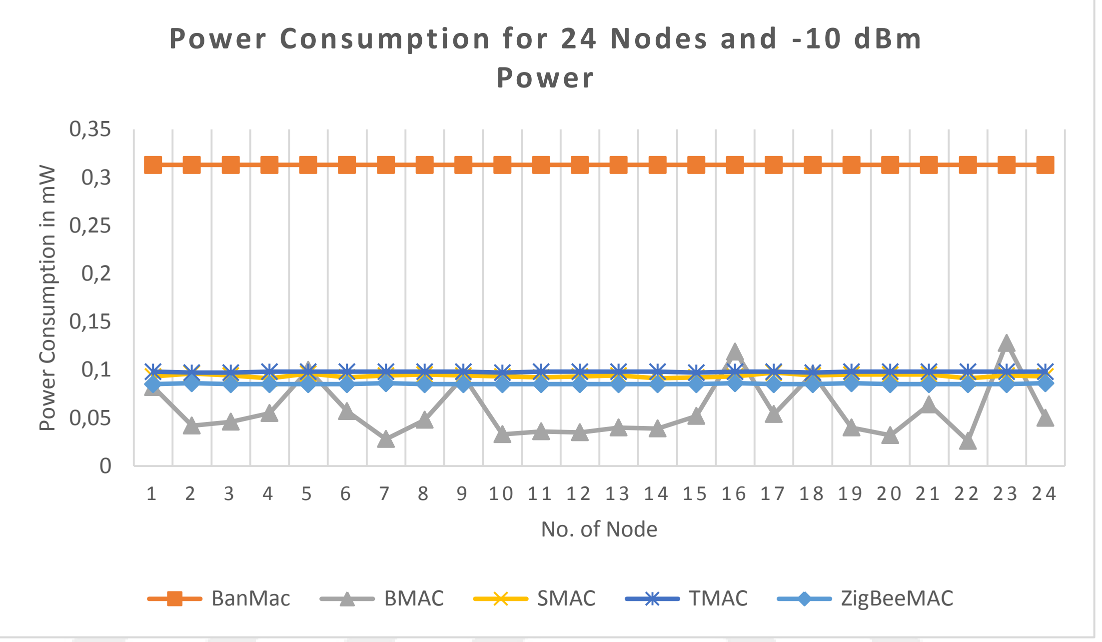


Figure 5.14. Power consumption for 24 nodes and -10 dbm power.

In the power consumption per node graph with -10 dBm power in 24 sensors, using the SMAC protocol keep the sensors power consumption between 0.091 mW and 0.097 mW per node. Using the TMAC protocol keep the sensors power consumption between 0.097 mW and 0.098 mW per node. Using ZigBeeMAC protocol, the power consumption varies between 0.085 mW and 0.086 mW per node. Using the BMAC protocol keep the sensors power consumption between 0.026 mW and 0.128 mW per node. Finally, by using the BANMAC protocol we get identical power consumption of 0.313 mW per node.

### 5.4.3.6. Power Consumption for 24 Nodes and -20 dBm Power

The power consumption per node for 24 sensors and -20 dBm power is shown in Figure 5.15 In the power consumption per node graph with -20 dBm power in 24 sensors, by using the BMAC protocol the power consumption varies between 0.015

mW and 0.017 mW per node except the power consumption for nodes of indexes 12, 14, 19, and 21 which consumed between 0.253 mW and 0.296 mW per node because they located in a high traffic area and a lot of packets congestion occur. Using ZigBeeMAC protocol gives the same power consumption of 0.085 mW for all nodes except the power consumption for nodes of indexes 2, 19, and 20 which consumed 0.313 mW per node.

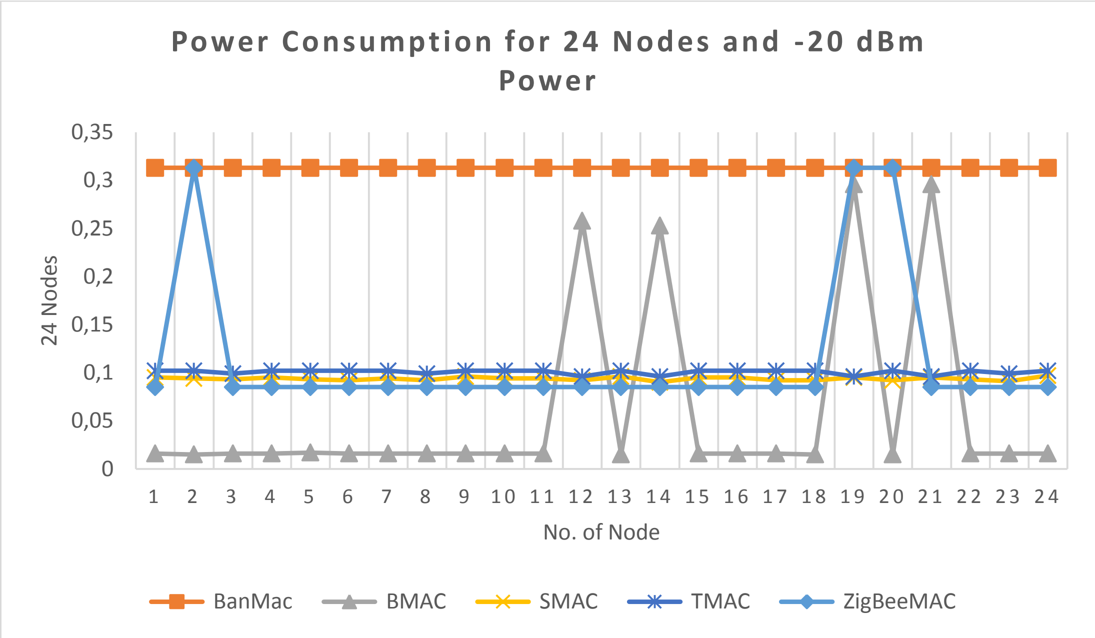


Figure 5.15. Power consumption for 24 nodes and -20 dBm power.

Using the SMAC protocol keep the sensors power consumption between 0.090 mW and 0.097 mW per node. Using the TMAC protocol keep the sensors power consumption between 0.096 mW and 0.102 mW per node. Finally, by using the BANMAC protocol we get identical power consumption of 0.313 mW per node.

### 5.4.4. Packets Congestion

We calculate the congestion of the packets with the five different MAC layer protocols and two different power.

### 5.4.4.1. Packets Congestion for 6 Nodes and -10 dBm Power

The congestion of the packets per node for six sensors and -10 dBm power is shown in Figure 5.16. In the congestion packets per node output graph in six sensors and -10 dBm power, using the TMAC protocol lets all the packets to be delivered without any congestion.

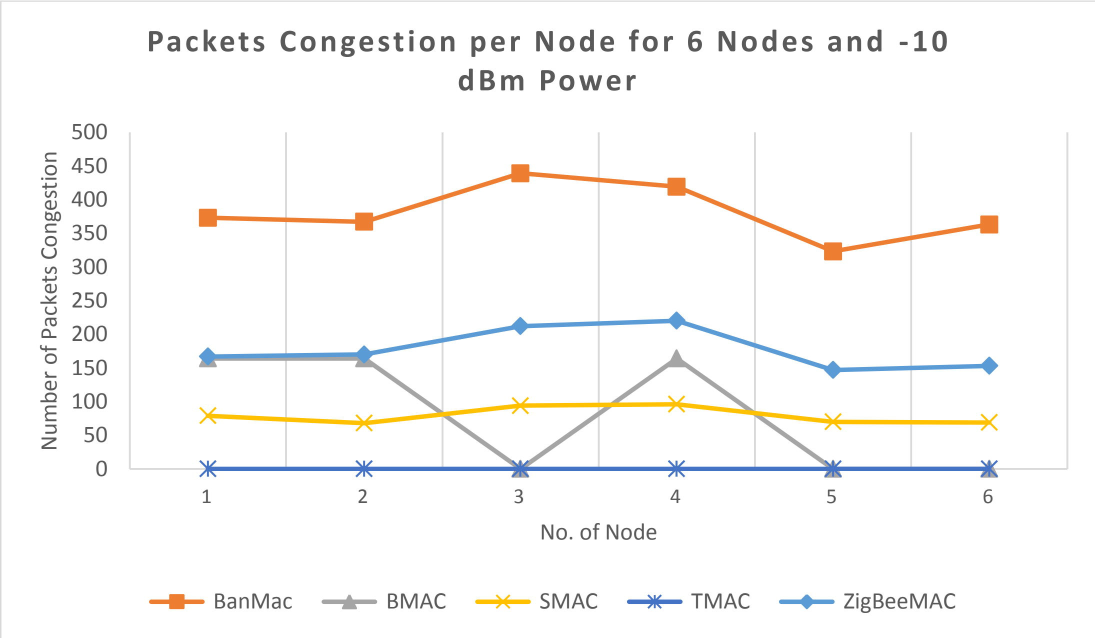


Figure 5.16. Packets congestion per node for 6 nodes and -10 dbm power.

This is because T-MAC allows wireless sensor node switch on its wireless at harmonized periods, and switch it off later of a firm time-out— once no message happens through some period. Using SMAC protocol, the packets congestion varies between 68 packets and 96 packets per node. Using BMAC protocol, the packets congestion for node of indexes 1, 2 and 4 is 164 packets because they located in a high traffic area and a lot of packets congestion occur, while there is no packets congestion for nodes of indexes 3, 5, and 6. Using ZigBeeMAC protocol, the packets congestion varies between 147 packets and 220 packets per node. Finally, the using of BanMAC protocol lets the packets congestion varies between 323 packets and 439 packets per node.

### 5.4.4.2. Packets Congestion for 6 Nodes and -20 dBm Power

The congestion of the packets per node for six sensors and -10 dBm power is shown in Figure 5.17.

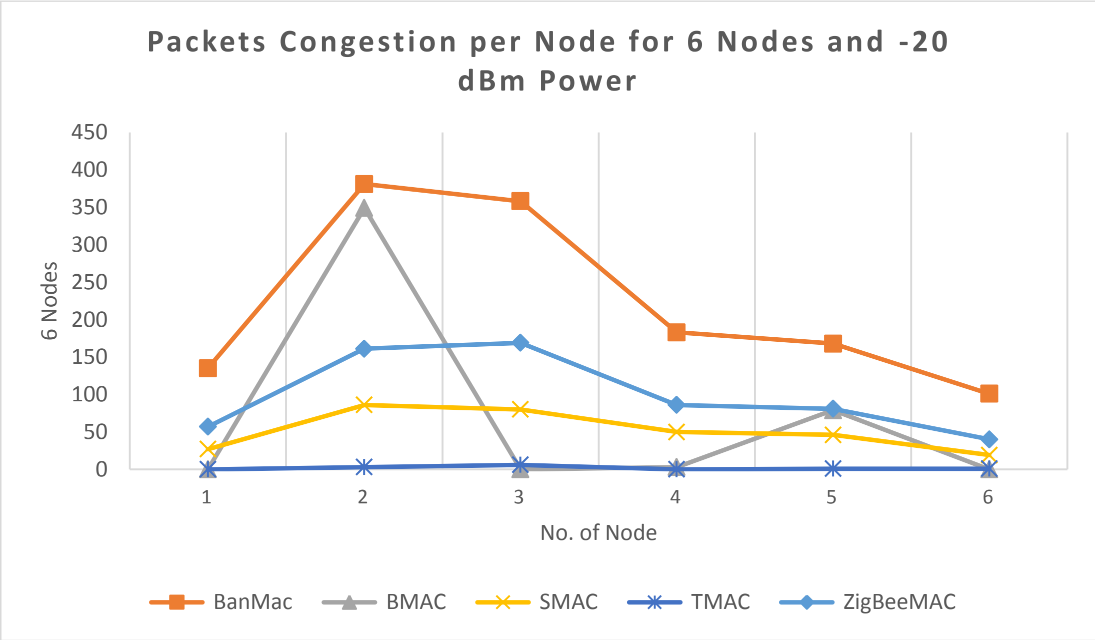


Figure 5.17. Packets congestion per node for 6 nodes and -20 dbm power.

In the congestion packets per node output graph in six sensors and -20 dBm power, using the TMAC protocol lets the packets form the nodes of indexes 1 and 4 to be delivered without any congestion, while the packets congestion of the other nodes varies between 1 packet and 6 packets per node. This is because T-MAC allows wireless sensor node switch on its wireless at harmonized periods, and switch it off later of a firm time-out— once no message happens through some period. Using SMAC protocol, the packets congestion varies between 19 packets and 86 packets per node. Using BMAC protocol, the packets congestion for node of indexes 2, 4 and 5 varies between 3 packets and 349 packets per node while there is no packets congestion for nodes of indexes 1, 3, and 6. Using ZigBeeMAC protocol, the packets congestion varies between 40 packets and 169 packets per node. Finally, the using of BanMAC protocol lets the packets congestion varies between 101 packets and 381 packets per node.

### 5.4.4.3. Packets Congestion for 24 Nodes and -10 dBm Power

The congestion of the packets per node for 24 sensors and -10 dBm power is shown in Figure 5.18. In the congestion packets per node output graph in 24 sensors and -10 dBm power, using the TMAC protocol lets the packets congestion to be between 6 packets and 22 packets per node. This is because T-MAC allows wireless sensor node switch on its wireless at harmonized periods, and switch it off later of a firm time-out— once no message happens through some period.

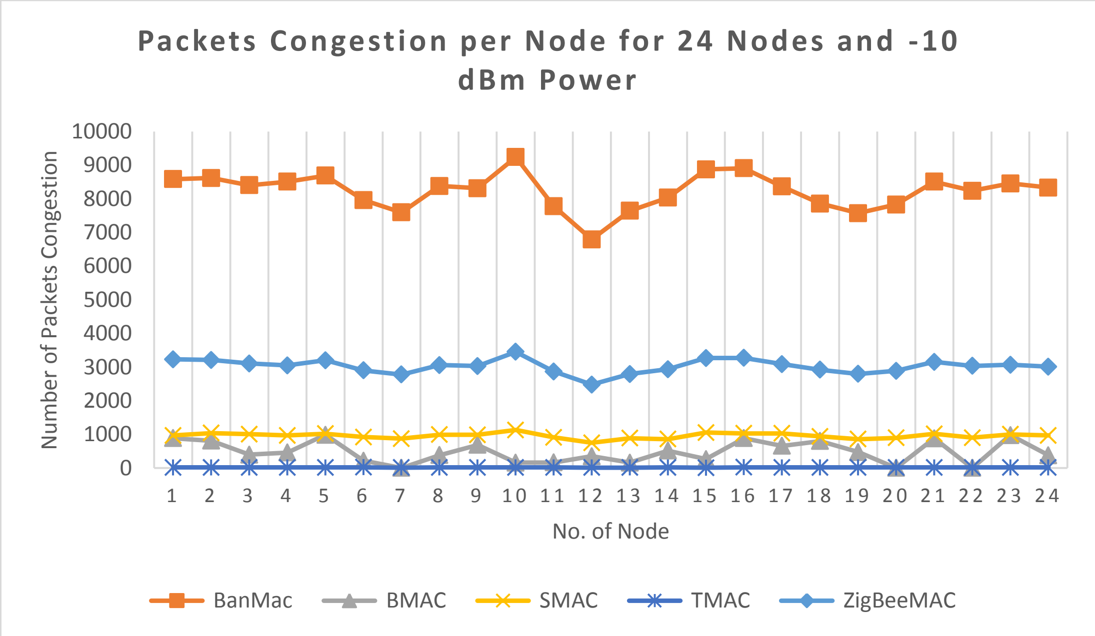


Figure 5.18. Packets congestion per node for 24 nodes and -10 dbm power.

Using SMAC protocol, the packets congestion varies between 748 packets and 1,126 packets per node. Using BMAC protocol, there is no packets congestion for nodes of indexes 7, 20, and 22, while the packets congestion for other nodes varies between 158 packets and 984 packets per node. Using ZigBeeMAC protocol, the packets congestion varies between almost two thousand packets and four thousand packets per node. Finally, the using of BanMAC protocol lets the packets congestion varies between almost six thousand packets and ten thousand packets per node.

#### 5.4.4.4. Packets Congestion for 24 Nodes and -10 dBm Power

The congestion of the packets per node for 24 sensors and -20 dBm power is shown in Figure 5.19. In the congestion packets per node output graph in 24 sensors and -20 dBm power, using the TMAC protocol lets the packets congestion varies between 22 packets and 493 packets per node. This is because T-MAC allows wireless sensor node switch on its wireless at harmonized periods, and switch it off later of a firm time-out— once no message happens through some period.

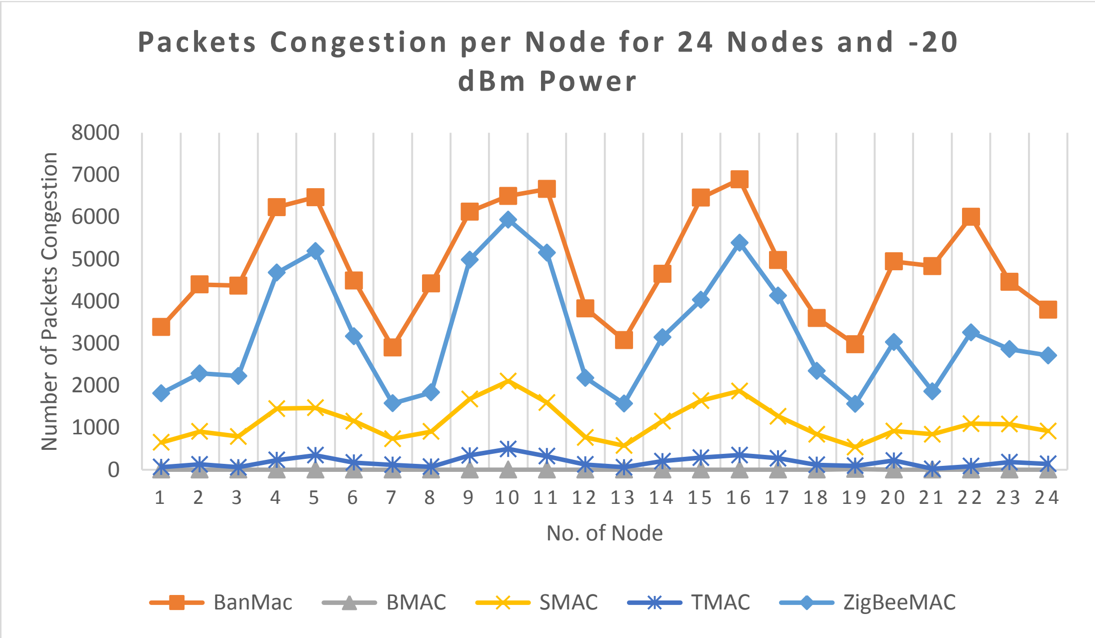


Figure 5.19. Packets congestion per node for 24 nodes and -20 dbm power.

Using SMAC protocol, the packets congestion varies between 538 packets and 2,102 packets per node. Using BMAC protocol, all the packets are delivered without any congestion except 16 packets congestion for node of index 19. Using ZigBeeMAC protocol, the packets congestion varies between one thousand packets and six thousand packets per node. Finally, the using of BanMAC protocol lets the packets congestion varies between three thousand packets and seven thousand packets per node.

## 5.5. THE DISCUSSION

To be more clear to understand the differences between the MAC protocols, we make a comparision as shown in Table 5.2.

Throughput Evaluation: For the two scenarios, the ZigBeeMac protocol gives the highest nodes average throughput using both the -20 dBm and -10 dBm power. If we compare node by node throughput, we can see that also using the ZigBeeMAC protocol almost gives the highest throughput. This is because ZigBeeMAC is beacon-enabled network, the network coordinator periodically broadcasts beacon frames, equipment in BAN network is synchronized per the beacon frames from coordinator.

Average Delay Evaluation: In the six sensors, the BanMAC and ZigBeeMAC protocols give the least delay in application level in both -20 dBm and -10 dBm power. While in the 24 sensors, the BanMAC protocol gives the least delay in application level in both -20 dBm and -10 dBm power. This is because BanMAC standard in a beacon mode with superframe boundaries, a hub divides the time into multiple superframes. Each superframe structure is sub-divided into various access phases.

Power Consumption Evaluation: In the six sensors, the SMAC protocol gives the least average power consumption level in both -20 dBm and -10 dBm power. While in the 24 sensors, the BMAC protocol gives the least average power consumption level in both -20 dBm and -10 dBm power. This is because BMAC does not have the RTS-CTS mechanism or synchronization requirements of other MAC protocols like SMAC and TMAC, the implementation is both simpler and smaller.

Packets Congestion Evaluation: In the six sensors, the TMAC protocol gives the least average packets congestion level in both -20 dBm and -10 dBm power. While in the 24 sensors, the TMAC and BMAC protocols give the least average packets congestion level in both -20 dBm and -10 dBm power. This is because T-MAC allows wireless sensor node switch on its wireless at harmonized periods, and switch it off later of a firm time-out— once no message happens through some period.

Table 5.2. Mac protocols comparison.

| **Consideration** | **Average Throughput** | | | | **Average Delay** | | | | **Power Consumption** | | | | **Packets Congestion** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Power** | **-10 dBm** | | **-20 dBm** | | **-10 dBm** | | **-20 dBm** | | **-10 dBm** | | **-20 dBm** | | **-10 dBm** | | **-20 dBm** | |
| **of Nodes** | **6** | **24** | **6** | **24** | **6** | **24** | **6** | **24** | **6** | **24** | **6** | **24** | **6** | **24** | **6** | **24** |
| **BANMAC** | Mid | Bad | Mid | Bad | Very Good | Good | Very Good | Very Good | Bad | Bad | Bad | Bad | Bad | Bad | Bad | Mid |
| **BMAC** | Bad | Mid | Bad | Mid | Mid | Mid | Mid | Good | Bad | Very Good | Good | Very Good | Good | Good | Mid | Very Good |
| **SMAC** | Mid | Mid | Mid | Mid | Good | Good | Good | Mid | Good | Good | Very Good | Good | Good | Good | Good | Good |
| **TMAC** | Mid | Good | Mid | Good | Bad | Bad | Bad | Bad | Very Good | Good | Very Good | Good | Very Good | Very Good | Very Good | Very Good |
| **ZigBee MAC** | Very Good | Good | Good | Good | Very Good | Very Good | Very Good | Good | Very Good | Good | Good | Good | Mid | Mid | Mid | Mid |

# CHAPTER 6

## CONCLUSION AND FUTURE WORK

WBAN deliver talented applications in health monitoring systems to amount stated physiological information and deliver position based info. In this thesis, we offered an overview of the present MAC protocols for wireless sensor network and Body Area Network namely ZigBee (IEEE 802.15.4), BANMAC (IEEE 802.15.6), TMAC, SMAC, and BMAC. We also studied the performance of these protocols under two different number of sensors in terms of power consumption, throughput, packets congestion, and average delay using Castalia under OMNET++ simulator.

The analysis shows that nodes radio transmission power doesn't obviously effect the throughput of the nodes under different scenarios. ZigBee and SMAC shows high number of end to end packets delay at application level in high traffic. TMAC and SMAC shows better average power consumption than the other protocols in different scenarios. TMAC gives the best results for congestion avoidance in different traffic load comparing to the rest four protocols.

For future work, we can use more different scenarios with mobile nodes or static and mobile nodes at the same scenario and analyses how this will be affective in term of throughput, average delay, power consumption, and packets congestion. Since we assumed that all the persons that carry the sensors in our scenarios are not moving which will be totally different effect on the interference between the nodes in case of moving nodes. Also, we can implement same scenarios and the other mobile and static nodes on different simulation tools like NS3. More protocols may also be involved in these scenarios to find better MAC layer protocol that gives best results like WiseMAC, SCP-MAC, and Body sensor network MAC (BSN-MAC).

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# APPENDIX A.

# MODEL CODES

```
# 6 Nodes Star Topology Static
[General]
include ../Parameters/Castalia.ini
sim-time-limit = 60s
SN.numNodes = 7
SN.field_x = 2
SN.field_y = 2
SN.deployment = "[0]->center;[1..6]->2x2"
SN.node[*].ApplicationName = "ThroughputTest"
SN.node[*].Application.startupDelay = 1
SN.node[0].Application.latencyHistogramMax = 5000
SN.node[0].Application.latencyHistogramBuckets = 10
SN.node[0].Application.packet_rate = 0
SN.node[1..6].Application.packet_rate = 10
SN.node[*].Communication.Radio.RadioParametersFile =
"../Parameters/Radio/BANRadio.txt"
SN.node[*].Communication.Radio.symbolsForRSSI = 16
SN.node[*].ResourceManager.baselineNodePower = 0
[Config SMAC]
SN.node[*].Communication.MACProtocolName = "TMAC"
SN.node[*].Communication.MAC.listenTimeout = 61
SN.node[*].Communication.MAC.disableTAextension = true
SN.node[*].Communication.MAC.conservativeTA = false
SN.node[*].Communication.MAC.collisionResolution = 0
SN.node[*].Communication.MAC.phyDataRate = 1024
[Config TMAC]
SN.node[*].Communication.MACProtocolName = "TMAC"
SN.node[*].Communication.MAC.phyDataRate = 1024
SN.node[*].Communication.MAC.collisionResolution = 1
SN.node[*].Communication.MAC.listenTimeout = 15
SN.node[*].Communication.MAC.disableTAextension = false
SN.node[*].Communication.MAC.conservativeTA = true
[Config BMAC]
```

```
SN.node[*].Communication.MACProtocolName = "TunableMAC"
SN.node[*].Communication.MAC.dutyCycle = 0.1
SN.node[*].Communication.MAC.listenInterval = 10
SN.node[*].Communication.MAC.backoffType = 0
SN.node[*].Communication.MAC.beaconIntervalFraction = 1
SN.node[*].Communication.MAC.txAllPacketsInFreeChannel = true
SN.node[*].Communication.MAC.phyDataRate = 1024
[Config ZigBeeMAC]
SN.node[*].Communication.MACProtocolName = "Mac802154"
SN.node[0].Communication.MAC.isFFD = true
SN.node[0].Communication.MAC.isPANCoordinator = true
SN.node[*].Communication.MAC.phyDataRate = 1024
SN.node[*].Communication.MAC.phyBitsPerSymbol = 2
[Config BanMac]
SN.node[*].Communication.MACProtocolName = "BaselineBANMac"
SN.node[*].Communication.MAC.phyDataRate = 1024
SN.node[0].Communication.MAC.isHub = true
SN.node[*].Communication.MAC.macBufferSize = 48
[Config varyRate]
SN.node[*].Application.packet_rate = ${rate=1,5,10,15,20,25,30,50,100}
[Config varyPower]
SN.node[*].Communication.Radio.TxOutputPower = ${power="-10dBm","-
20dBm"}

# 24 Nodes Star Topology Static
[General]
include ../Parameters/Castalia.ini
sim-time-limit = 60s
SN.numNodes = 25
SN.field_x = 6
SN.field_y = 4
SN.deployment = "[0]->center;[1..24]->6x4"
SN.node[*].ApplicationName = "ThroughputTest"
```

```
SN.node[*].Application.startupDelay = 1
SN.node[0].Application.latencyHistogramMax = 5000
SN.node[0].Application.latencyHistogramBuckets = 10
SN.node[0].Application.packet_rate = 0
SN.node[1..24].Application.packet_rate = 10
SN.node[*].Communication.Radio.RadioParametersFile =
"../Parameters/Radio/BANRadio.txt"
SN.node[*].Communication.Radio.symbolsForRSSI = 16
SN.node[*].ResourceManager.baselineNodePower = 0
[Config SMAC]
SN.node[*].Communication.MACProtocolName = "TMAC"
SN.node[*].Communication.MAC.listenTimeout = 61
SN.node[*].Communication.MAC.disableTAextension = true
SN.node[*].Communication.MAC.conservativeTA = false
SN.node[*].Communication.MAC.collisionResolution = 0
SN.node[*].Communication.MAC.phyDataRate = 1024
[Config TMAC]
SN.node[*].Communication.MACProtocolName = "TMAC"
SN.node[*].Communication.MAC.phyDataRate = 1024
SN.node[*].Communication.MAC.collisionResolution = 1
SN.node[*].Communication.MAC.listenTimeout = 15
SN.node[*].Communication.MAC.disableTAextension = false
SN.node[*].Communication.MAC.conservativeTA = true
[Config BMAC]
SN.node[*].Communication.MACProtocolName = "TunableMAC"
SN.node[*].Communication.MAC.dutyCycle = 0.1
SN.node[*].Communication.MAC.listenInterval = 10
SN.node[*].Communication.MAC.backoffType = 0
SN.node[*].Communication.MAC.beaconIntervalFraction = 1
SN.node[*].Communication.MAC.txAllPacketsInFreeChannel = true
SN.node[*].Communication.MAC.phyDataRate = 1024
[Config ZigBeeMAC]
SN.node[*].Communication.MACProtocolName = "Mac802154"
```

```
SN.node[0].Communication.MAC.isFFD = true
SN.node[0].Communication.MAC.isPANCoordinator = true
SN.node[*].Communication.MAC.phyDataRate = 1024
SN.node[*].Communication.MAC.phyBitsPerSymbol = 2
[Config BanMac]
SN.node[*].Communication.MACProtocolName = "BaselineBANMac"
SN.node[*].Communication.MAC.phyDataRate = 1024
SN.node[0].Communication.MAC.isHub = true
SN.node[*].Communication.MAC.macBufferSize = 48
[Config varyRate]
SN.node[*].Application.packet_rate = ${rate=1,5,10,15,20,25,30,50,100}
[Config varyPower]
SN.node[*].Communication.Radio.TxOutputPower = ${power="-10dBm","-
20dBm"}
```

## RESUME

Hatem A. M. Musa from Libya, I born in 1974 in Libya – Tubruk, I studied the primary school in Tubruk after that I studied in 7th of April secondary school. I graduated from Omar Almuhtar University, Computer Science Department. I started in 1999 and finished in 2003. After That I worked in High Technical Institute for Whole Occupations as lecturer. Now days, I study Master in Computer Engineering in Karabuk University.