# IoT power saving using data aggregation applied in footballer's heartbeat monitoring system

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**Abstract.** In recent years, The Internet of Things (IoT) is the most popular technology that is used in many applications. So, when the IoT system is implemented, it is important to reduce the power consumption and increase the lifetime of nodes in the system. Energy efficiency becomes a vital parameter. Many factors affect energy efficiency such as distance between the transmitter (sensor node) and receiver (sink node) and the number of bits will be sent. Data aggregation plays an urgent role in power saving. In this paper, an IoT system for a stadium is implemented to monitor the health condition of football players and compare between three scenarios one of them without using data aggregation and the second with using repeaters and the third with using data aggregation to approve that applying data aggregation in an IoT system will enhance network lifetime and decrease power consumption due to reducing the packets transmitted by percent depend on the number of aggregators and the number of sensor nodes. For the study cases with using four fixed cluster heads. In the case of two player, the bytes reduction through the network by percent of 24%. This percent increase to reach 50% in the case of five players.

**Keywords:** IoT, data aggregation, energy efficiency, LEACH, MQTT, and ESP8266.

## 1. INTRODUCTION

The artificial intelligence system becomes smarter than before when adding a feature that is internet access as the result of that change the name of the system from the artificially intelligent system to the IoT system. In this way, anything can be monitored and controlled from anywhere. When a movable IoT system is implemented, the source of energy is used to power these nodes is rechargeable batteries. the batteries lifetime should be suitable for the application. The sensor nodes that are far away from the gateway will consume more power than others. Some nodes will be died and need to recharge their batteries but others are not needed for that. Because of that, data aggregation techniques are needed to reduce the power consumption in batteries of each sensor node.

## 2. LITERATURE REVIEW

The techniques for data aggregation in the IoT system were proposed as the following: in 2016, those papers [1,2] discussed and simulated the proposed data aggregation scheme using NS-2. This scheme was a combination of cluster and tree data aggregation architectures. The result showed clear improvement over LEACH, LEACH-C, and TREEPSI protocols in terms of power consumption, network lifetime, and traffic load. Then in 2017, Aniji John [3] proposed and simulated the Energy Saving Cluster Head Selection (ESCHS) technique using MATLAB 2015a that the node has residual energy higher than the average residual energy of the respective cluster is chosen to be CH. And also implemented simulation for a dynamic Cluster head selection method (DCHSM) to extend the network's lifetime of the systems implemented for IoT applications using MATLAB 2015a. DCHSM improves energy saving by about 8.12% when compared to LEACH [4,5]. In the same year, M. Ashwini and N. Rakesh [6] simulated LEACH protocol and calculated parameters such as End to End Delay, Number of Hops, Total Energy Consumption, Number of Alive Nodes, Number of Dead Nodes, Lifetime ratio and routing Overhead using MATLAB Simulink software. There was another research about Cluster head selection for energy optimization (CHSEO) algorithm that was proposed for electing the optimal cluster head within the available nodes to reduce the overall network energy. The experiment was simulated using the NS-2 Simulator and proved that the CHSEO had better performance when compared to the LEACH in terms of energy dissipation and network lifetime [7]. In 2018, [8] in this paper improved Energy Efficient by using the cache nodes between the cluster head and gateway. The cluster heads will transmit the data to the nearest cache node and then the cache forwards data to the gateway. The simulation observed that the proposed technique performed well in terms of remaining energy and the number of dead nodes. In 2019, [9] in this paper modified the classical LEACH algorithm. At the end of each round, the residual energy of the non-CH nodes is checked, and the one with the higher energy level in comparison to others has a higher probability of becoming CH for the current round. This would enhance the network lifetime. The proposed modification in CH selection simulated using MATLAB and found the modified version performed better than the LEACH protocol by enhancing the throughput by 60%, lifetime by 66%, and residual energy by 64%. In 2020, O. Said proposed an energy management scheme and simulated it using NS-2. The simulation results proved that the proposed EMS outperformed the traditional IoT system to the energy consumption rate, number of failed nodes due to energy loss, throughput, and network lifetime [10].

All previous researches proposed or analyzed the data aggregation techniques using simulation programs as MATLAB or NS-2. In [11,12] the IoT system implemented but not using data aggregation, [11] in this paper implemented an IoT health application using the ESP8266 Wi-Fi module and MQTT protocol. And in [12] implemented IoT Football architecture, which aimed to monitor football players using ZigBee and COAP protocol.

In this paper, an IoT system for a stadium is implemented to monitor the health condition of football players using the ESP8266 Wi-Fi module and compare between three scenarios one of them without using data aggregation and the second with using repeaters and the third with using data aggregation. The rest of the paper is organized into the following sections: Section 3 presents the IoT definition, application fields, and most protocols are used in this system. Energy is dissipated through the system to transmit and receive data between two nodes is discussed in section 4. Data aggregation techniques are used in IoT system are presented in section 5. The system model is described in section 6. The experimental explanation is described in section 7. The results are discussed in section 8. Section 9 concludes the paper.

## 3. IoT

The internet of things technology becomes widely used to facilitate people to device and device to device interconnection as shown in fig 1. It is a new generation of internet services. IoT provides everyone and everything to be connected and exchange information with each other, hence communication invokes certain actions based on inputs, take decisions, and provide useful services. IoT has applications in many fields [13,15,18] such as agriculture, transportation, medical, smart cities and homes, industrial applications, and natural disaster predictions.

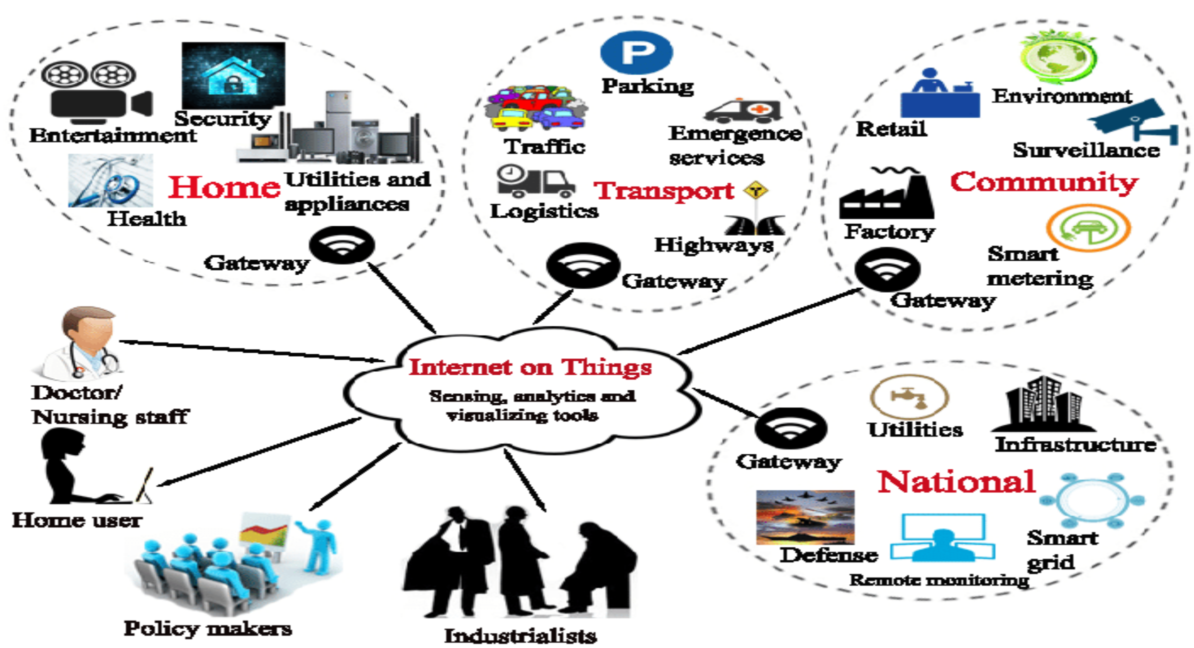



**FIGURE 1.** Internet of things (IoT)[24]

## 3.1 IoT protocols

In the IoT system, the most used protocols are Message Queuing Telemetry Transport (MQTT) and The Constrained Application Protocol (COAP) [14,15,16].

### *3.2.1 Message Queuing Telemetry Transport (MQTT)*

MQTT is based on the publish/subscribe model for that it allows one-to-one, one-to-many, and many to many communications. When any node or client in the IoT network publishes a message on a specific topic, the Broker will republish the received message to all nodes or clients that subscribe to this topic.

### *3.2.2 The Constrained Application Protocol (COAP)*

[17] this paper discussed the COAP protocol in detail, the COAP protocol is based on HTTP (Hypertext Transfer Protocol) request/respond. As with HTTP, COAP also uses GET, PUT, POST, and DELETE statements.

## 3.2 IoT Challenges

From [13,15,18,19,20], the IoT challenges can be summarized as the following:

1. *Reliability and availability:* Many applications need fast collecting data, analyze them, and making decisions when any task is not performed correctly, it's making the system unreliable. The meaning of system availability is the system can be accessed anytime from anywhere.
2. *Scalability:* The IoT system must be able to handle the growth of the number of devices and information. Any IoT application should be designed to enable extensible operations and services.
3. *Standardization and Interoperability:* All the manufacturers build devices according to their underlying technologies which may not be available to others. It is important to standardize IoT to assure the cooperation between objects and the use spread. Interoperability is challenging due to the massive number of different platforms used in IoT systems. It aims to make devices and protocols able to inter-work with each other.
4. *Naming and Identity Management:* Each device in the IoT system must be Identified with uniquely address on the Internet. So, a rugged and well-organized naming mechanism to dynamically assign is needed, monitor, and track each device's identity.
5. *Network security:* It is a massive challenge to guard the collected data from unauthorized users and guarantee data privacy via the system.
6. *Energy management:* Energy efficiency is the most critical issue in the IoT system because of the electronic devices (sensor nodes) that consume huge energy to send

data. When the network has many nodes, the redundant data will be increased through the network.

## 4. ENERGY DISSIPATION MODEL FOR SENSOR NODES

Transmitter is a node that connected to one or more sensors to convert physical phenomena to an electrical signal is named sensor node, Receiver is a node that collects data from all sensor nodes is called sink node or gateway.
To calculate the energy consumed to send messages between two nodes as shown in Fig.2 [21,22]:
Sensor node consumes energy to transmit (N) bits to the gateway at the distance (d) from it:

$$E_{TX}(N,d) = (E_{elec(TX)} \times N) + (E_{amp(TX)} \times N \times d^2) \qquad (1)$$

Where $E_{elec(TX)}$, $E_{amp(TX)}$ are transmission and amplification energy respectively for the transmitter.
To receive (N) bits, the receiver consumes:

$$E_{RX}(N) = E_{elec(RX)} \times N \qquad (2)$$

Where $E_{elec(RX)}$ is Receiver Electronics energy.
From equations 1,2 the number of bits (N) and the distance (d) are directly proportional to the energy dissipated.

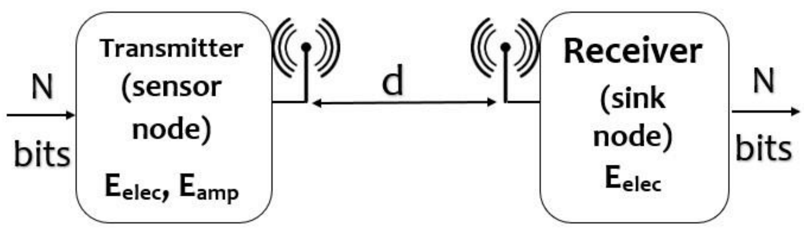



**FIGURE 2.** Energy dissipation model

## 5. Data Aggregation

Data aggregation schemes play an important role in improving the overall efficiency of the networks. The main purpose of data aggregation is to collect and aggregate data packets in an efficient way to reduce power consumption, traffic congestion, and to increase network lifetime and data accuracy. There are three architectures for data aggregation:

1. **Cluster-based architecture:** The network is divided into cells(clusters), each cell elects a cluster head that works as the aggregator. The cluster head node collects data from all sensor nodes in its cluster, aggregates all received data, and then sends it to the sink node(gateway) [23].

- *Low Energy Adaptive Clustering Hierarchy protocol (LEACH):* It is considered to be the primary and the most popular clustering algorithm for IoT networks. LEACH protocol consists of two phases that are setup phase and steady phase.
    - In the setup phase: the cluster head is selected based on the predefined percentage of CHs and the number of times that node has been elected as CH heretofore.
    - In a steady phase: the cluster head collects data from sensor nodes in its cluster, aggregates, and sends it to the gateway).
- *LEACH-C:* it differs from LEACH in setup phase which each node sends its location and current residual energy to the sink node. According to the report of all nodes, the sink node calculates the average energy among them and assigns nodes to be CH if their current energy is greater than the average energy.

2. **Centralized architecture:** Each sensor node transmits the data packet via the shortest possible path to the central sink node and this node performs aggregation.
3. **Tree-based architecture:** The nodes are most far from the sink is called children, they transmit data to their parent and so on to reach to the root which is sink node.

## 6. SYSTEM DESIGN

Many sports clubs and sports academies spend millions of dollars to contract or develop new professional footballers for that it is important to monitor their health conditions because there are health problems as Concussion, hypoglycemia, swallowing the tongue and shortness of breath that are faced the footballers during the match and even during the training. For that, the IoT system is implemented to monitor the health condition of all players. Each player wears a heartbeat measurement bracelet that contains in its pulse sensor to determine the beats per minute (BPM). The sensed data are published to the server using IoT protocol. The doctor allows monitoring the data through his laptop or mobile as shown in Fig 3.

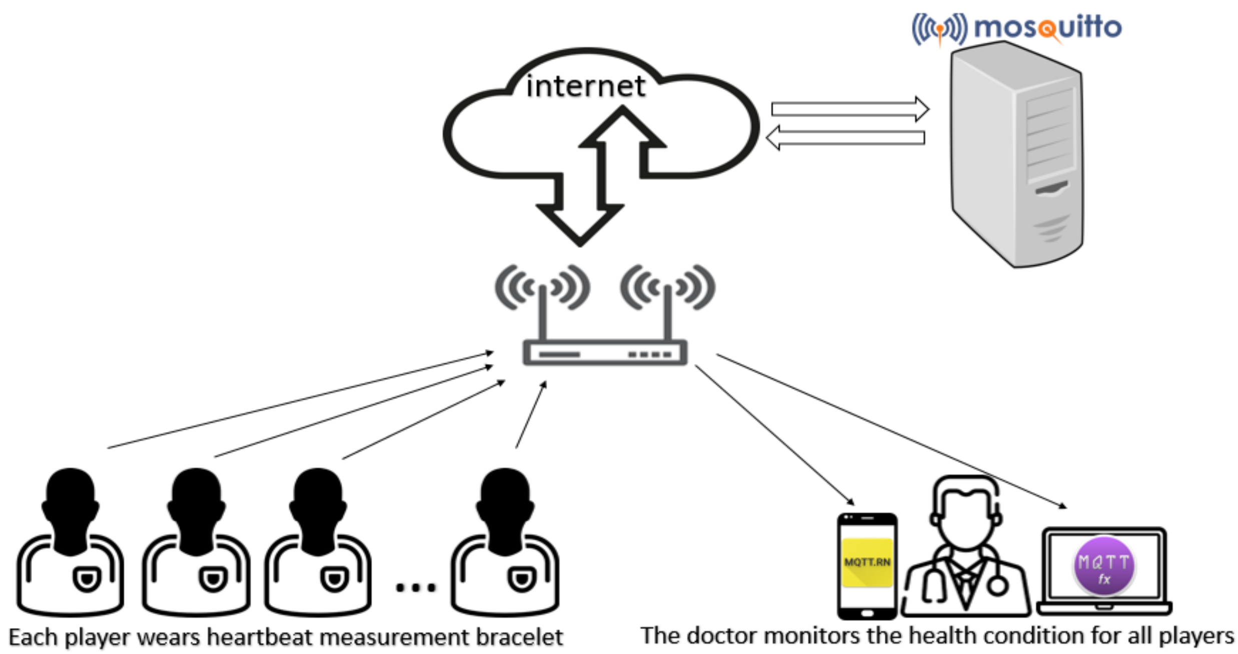



**FIGURE 3.** IoT system to monitor the health condition for football players

### 6.1 Hardware:

- *NodeMCU (esp8266):* it is a low-cost open-source IoT platform. It is a programmable Wi-Fi module because it contains a PCB antenna. From D0 to D8 are the general-purpose input/output (GPIO) pins and A0 is an analog pin with analog to digital converter. it supports serial-peripheral interface (SPI) and inter-IC (I2C) communication.
- *pulse sensor(sen-11574):* The sensor has two sides, on one side the LED is placed with an ambient light sensor and on the other side, it has some circuitry. This circuitry makes noise cancellation. The LED on the front side of the sensor is placed over a vein in our human body. This can either hold on your Fingertip or your ear tips. The LED releases light which will drop on the vein directly. The veins will have blood flow inside them only when the heart is pumping, so if the flow of blood is monitored, the heartbeats can be monitored as well. If the flow of blood is detected then the ambient light sensor will pick up lighter since they will be reflected by the blood, this minor change in received light is analyzed over time to determine our heartbeats.
- *Battery:* there are many options to provide power to esp8266. The USB cable from laptop to it but to make the node be moveable use power bank instead or carbon battery or rechargeable Lithium polymer battery (LiPo) between VIN pin and GND pin or between 3.3V pin and GND pin according to the battery value.

The heartbeat measurement bracelet connection as shown in Fig 4.

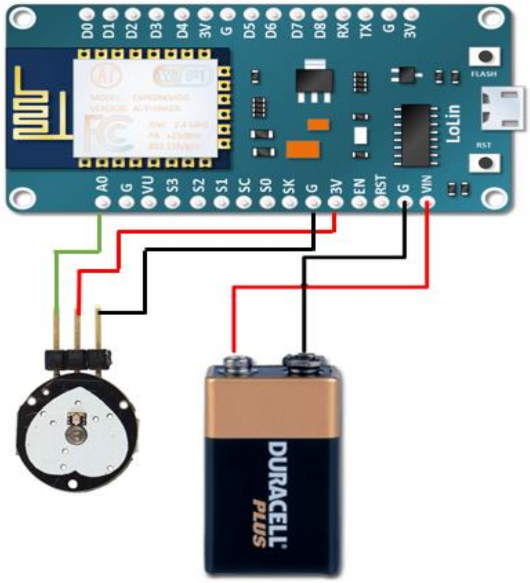


**FIGURE 4.** Components of heartbeat measurement bracelet

**6.2 Software**:

- *Broker:* Mosquitto server is an open-source message broker that implements the MQTT protocol. The server is run on a personal computer, that has intel(R) Core (TM) i5-2450M CPU @ 2.50GHz, and 4GB RAM.
- *Client:* MQTT.FX application is installed on Doctor's PC. This app connects the Mosquitto server and subscribes to the same topic that sensor nodes publish on it to allow him to monitor all players. There are many MQTT client applications on the play store that can be downloaded on the mobile phone.
- *Arduino IDE* it uses to write codes and burn it on the nodeMCU simply.

## 7. EXPERIMENTAL EXPLANATION

Three scenarios are implemented:

1. **First scenario:** IoT system is implemented without using data aggregation. All of the sensed data are transmitted to the gateway to publishing on the server as shown in Fig.5.

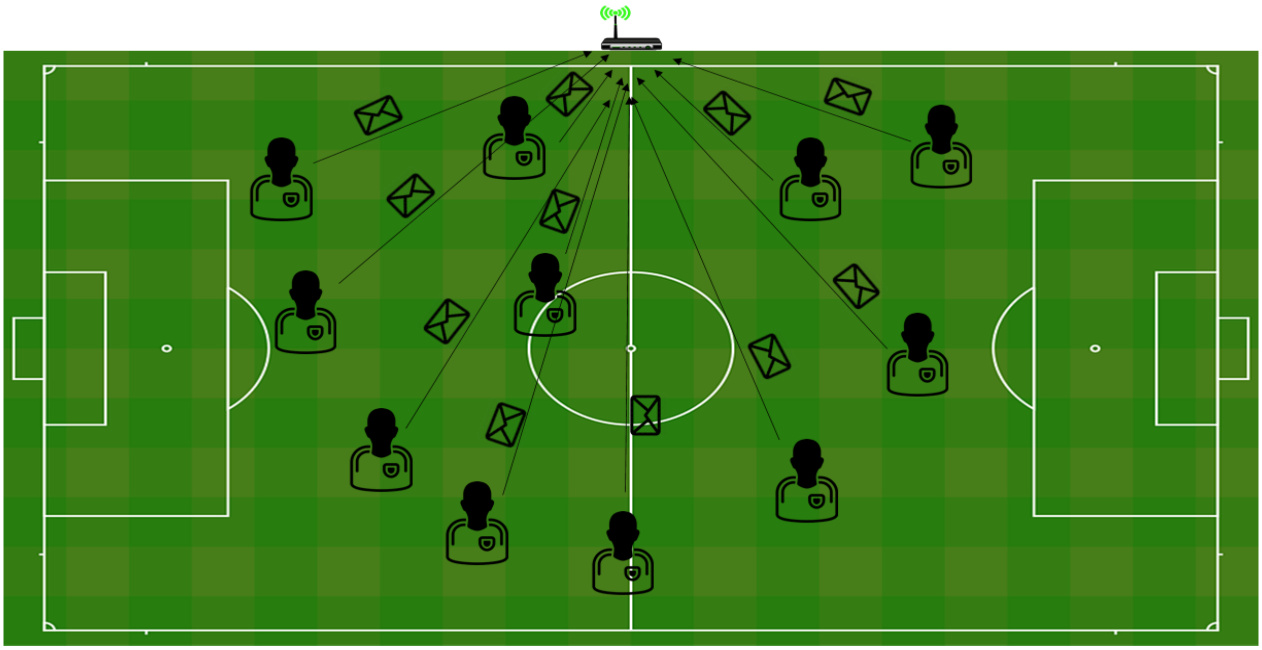


**FIGURE 5.** first scenario: without data aggregation

2. **Second scenario:** in the previous scenario, the sensed data transmits through the far distance to arrive at the gateway that causes more power consumption. For that, the second scenario implements using esp8266 as a repeater that receives data from the nearest nodes and retransmit the data to the gateway to decrease the distance as well as decrease the consumed power as shown in fig.6.

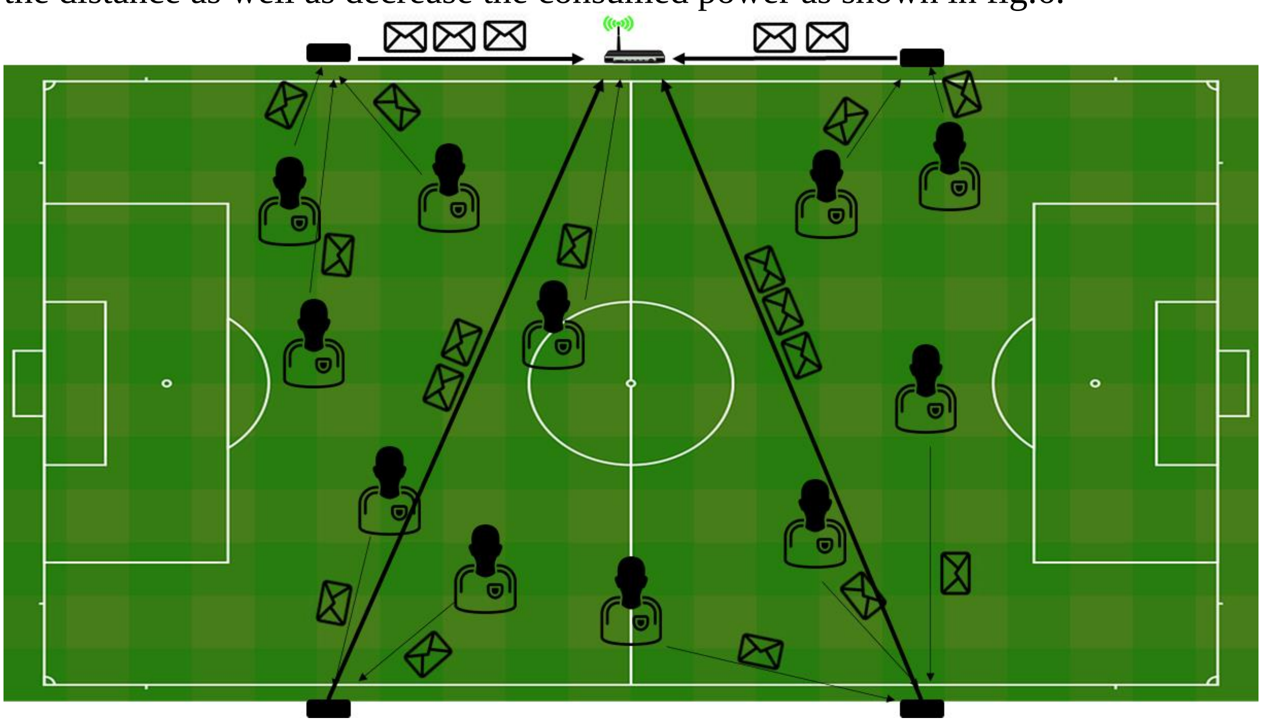


**FIGURE 6.** second scenario: using repeaters

3. **Third scenario:** IoT system is implemented using data aggregation. To save the power by decrease the distance and the packet are sent through the system as shown in fig.7. The stadium is divided into small areas (clusters) and fixed aggregator nodes (Cluster Head) in each one. Each CH works as an access point and all sensor nodes send sensed data to the nearest aggregator depend on its RSSI (Received Signal Strength Indication). Each aggregator node collects the data from players, converts itself from access point to station, and connects to the gateway to transmit the collected data packets in one packet to publish it on the server.

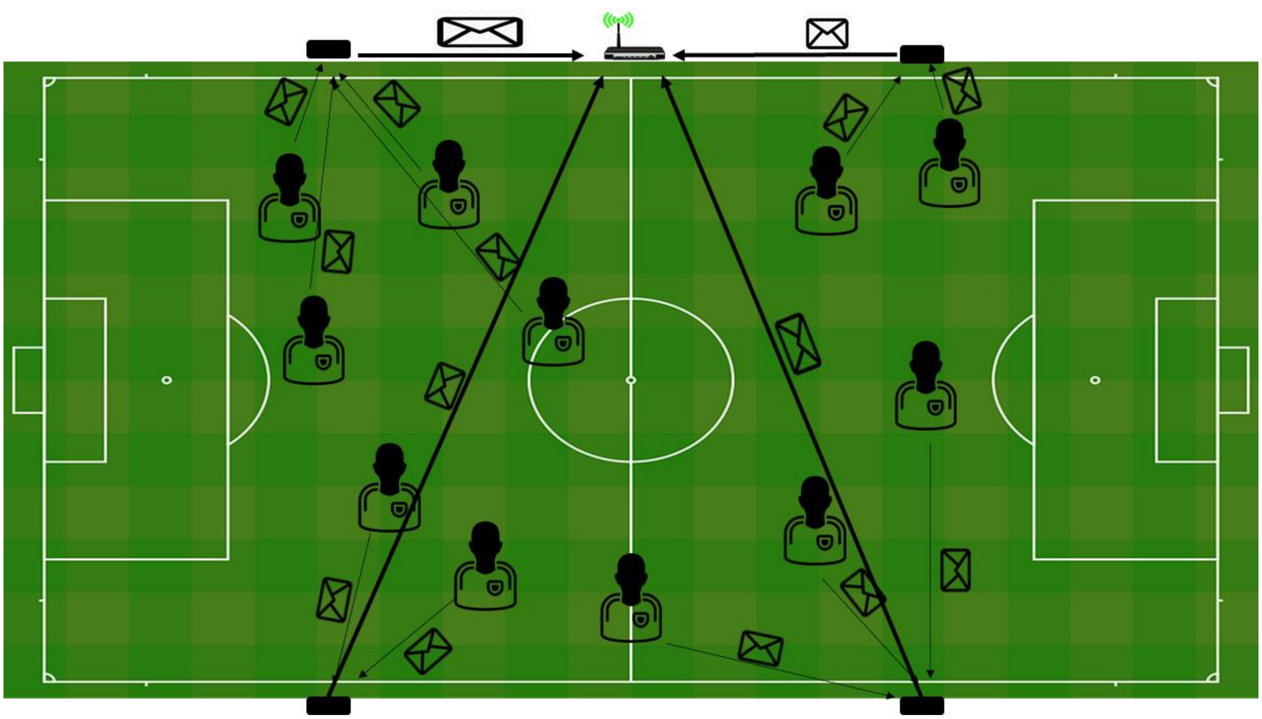


**FIGURE 7.** third scenario: with data aggregation

## 8. EXPERIMENTATION RESULT

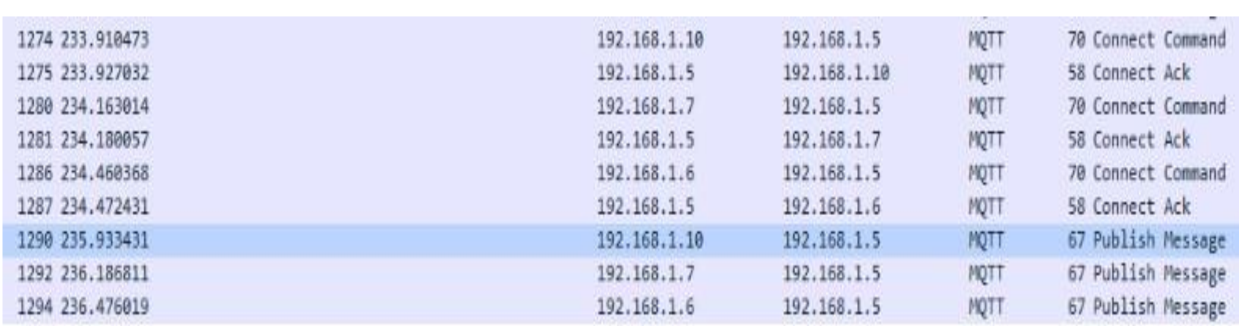
To obtain actual numbers to make a fair comparison, some variables must have the same size such as publish topic and client id. Table 1 represents the result of the first scenario that each node must be directly connected to the sink node(gateway) to transmit its sensed data. Sensor nodes have far distance from the sink node will consume more power. Besides that, each sensor node transmits connect command to the server and receive connect Ack that makes it consume more and more. For that, the second scenario is implemented to decrease the distance between the sensor node and gateway by using four repeater nodes. Sensed data is transmitted to the nearest repeater node from it. The repeater retransmits the received data to the gateway. The distance is traveled by data to reach repeater smaller than distance to the gateway. But the received packets to the server are the same as the first scenario. Table 2 represents the result of the third scenario that each sensor node transmits its sensed data to the nearest cluster head. The cluster head works as an aggregator. Each cluster head publishes all the collected data in one packet. Fig 8 and Fig 9 are the screenshots from the Wireshark program to explain the difference between without using data aggregation and with using data aggregation in the IoT application.

**TABLE 1.** Number of packets are received to the server without using data aggregation

| Number of sensor nodes | Number of packets for each 60sec | | |
|---|---|---|---|
| | transmit connect command | receive connect Ack | transmit publish message |
| 1 | 70 bytes | 58 bytes | 67 bytes |
| 2 | 2 × 70 bytes | 2 × 58 bytes | 2 × 67 bytes |
| 3 | 3 × 70 bytes | 3 × 58 bytes | 3 × 67 bytes |
| 4 | 4 × 70 bytes | 4 × 58 bytes | 4 × 67 bytes |

**TABLE 2.** Number of packets are received to the server with using data aggregation

| Number of CHs | Number of SNs | Number of packets for each 60sec | | |
|---|---|---|---|---|
| | | connect command | connect Ack | publish message |
| 1 | 1 | 70 bytes | 58 bytes | 67 bytes |
| 1 | 2 | 70 bytes | 58 bytes | 73 bytes |
| 1 | 3 | 70 bytes | 58 bytes | 79 bytes |



| | | | | | |
|---|---|---|---|---|---|
| 1274 | 233.910473 | 192.168.1.10 | 192.168.1.5 | MQTT | 70 Connect Command |
| 1275 | 233.927032 | 192.168.1.5 | 192.168.1.10 | MQTT | 58 Connect Ack |
| 1280 | 234.163014 | 192.168.1.7 | 192.168.1.5 | MQTT | 70 Connect Command |
| 1281 | 234.180057 | 192.168.1.5 | 192.168.1.7 | MQTT | 58 Connect Ack |
| 1286 | 234.460368 | 192.168.1.6 | 192.168.1.5 | MQTT | 70 Connect Command |
| 1287 | 234.472431 | 192.168.1.5 | 192.168.1.6 | MQTT | 58 Connect Ack |
| 1290 | 235.933431 | 192.168.1.10 | 192.168.1.5 | MQTT | 67 Publish Message |
| 1292 | 236.186811 | 192.168.1.7 | 192.168.1.5 | MQTT | 67 Publish Message |
| 1294 | 236.476019 | 192.168.1.6 | 192.168.1.5 | MQTT | 67 Publish Message |

**FIGURE 8.** First scenario: three sensor nodes without using data aggregation

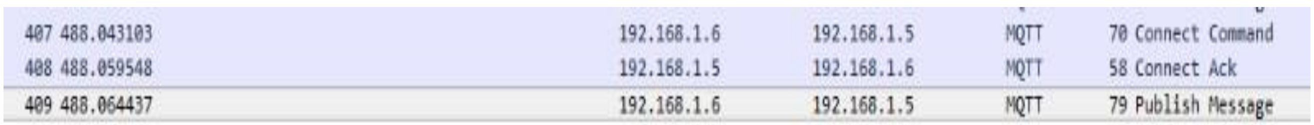



**FIGURE 9.** Third scenario: three sensor nodes with using data aggregation

The stadium divides into four clusters and there are many probabilities for players distribution because the players run during the match, move from cluster to another cluster, and connect to another aggregator (CH). Table 3 compares the number of packets received to the server without using data aggregation or using repeaters and with using data aggregation by four cluster heads with all probabilities for players distribution from one player to 5 players as a sample.

**TABLE 3.** Compare between received packets to the server without data aggregation and with data aggregation

| Total number of sensor node | First and second scenarios Without using data aggregation and with using repeaters | | | Third scenario With using data aggregation | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Connect command | Connect Ack | Publish message | No of sensor node in each cluster | | | | Connect command | Connect Ack | Publish message |
| | | | | CH1 | CH2 | CH3 | CH4 | | | |
| 1 | 70 bytes | 58 bytes | 67 bytes | 1 | | | | 70 bytes | 58 bytes | 67 bytes |
| | | | | | 1 | | | | | |
| | | | | | | 1 | | | | |
| | | | | | | | 1 | | | |
| 2 | 2*70 bytes | 2*58 bytes | 2*67 bytes | 2 | | | | 70 bytes | 58 bytes | 73 bytes |
| | | | | | 2 | | | | | |
| | | | | | | 2 | | | | |
| | | | | | | | 2 | | | |
| | | | | 1 | 1 | | | 2*70 bytes | 2*58 bytes | 2*67 bytes |
| | | | | 1 | | 1 | | | | |
| | | | | 1 | | | 1 | | | |
| | | | | | 1 | 1 | | | | |
| | | | | | 1 | | 1 | | | |
| | | | | | | 1 | 1 | | | |
| 3 | 3*70 bytes | 3*58 bytes | 3*67 bytes | 3 | | | | 70 bytes | 58 bytes | 79 bytes |
| | | | | | 3 | | | | | |
| | | | | | | 3 | | | | |
| | | | | | | | 3 | | | |
| | | | | 2 | 1 | | | 2*70 bytes | 2*58 bytes | 67+73 bytes |
| | | | | 2 | | 1 | | | | |

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| | | | | | 1 | | 2 | | | |
| | | | | | | 1 | 2 | | | |
| | | | | 1 | 1 | 1 | | 3*70 bytes | 3*58 bytes | 3*67 bytes |
| | | | | 1 | 1 | | 1 | | | |
| | | | | 1 | | 1 | 1 | | | |
| | | | | | 1 | 1 | 1 | | | |
| 4 | 4*70 bytes | 4*58 bytes | 4*67 bytes | 4 | | | | 70 bytes | 58 bytes | 85 bytes |
| | | | | | 4 | | | | | |
| | | | | | | 4 | | | | |
| | | | | | | | 4 | | | |
| | | | | 3 | 1 | | | 2*70 bytes | 2*58 bytes | 67+97 bytes |
| | | | | 3 | | 1 | | | | |
| | | | | 3 | | | 1 | | | |
| | | | | 1 | 3 | | | | | |
| | | | | | 3 | 1 | | | | |
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| | | | | | 1 | 3 | | | | |
| | | | | | | 3 | 1 | | | |
| | | | | 1 | | | 3 | | | |
| | | | | | 1 | | 3 | | | |
| | | | | | | 1 | 3 | | | |
| | | | | 2 | 2 | | | 2*70 bytes | 2*58 bytes | 2*73 bytes |
| | | | | 2 | | 2 | | | | |
| | | | | 2 | | | 2 | | | |
| | | | | | 2 | 2 | | | | |
| | | | | | 2 | | 2 | | | |
| | | | | | | 2 | 2 | | | |
| | | | | 2 | 1 | 1 | | 3*70 bytes | 3*58 bytes | 73+(2*67) bytes |
| | | | | 2 | 1 | | 1 | | | |
| | | | | 1 | 2 | 1 | | | | |
| | | | | 1 | 2 | | 1 | | | |
| | | | | | 2 | 1 | 1 | | | |
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|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | | 1 | 2 | | | |
| | | | | | 1 | 1 | 2 | | | |
| | | | | 1 | 1 | 1 | 1 | 4*70 bytes | 4*58 bytes | 4*67 bytes |
| 5 | 5*70 bytes | 5*58 bytes | 5*67 bytes | 5 | | | | 70 bytes | 58 bytes | 91 bytes |
| | | | | | 5 | | | | | |
| | | | | | | 5 | | | | |
| | | | | | | | 5 | | | |
| | | | | 4 | 1 | | | 2*70 bytes | 2*58 bytes | 85+67 bytes |
| | | | | 4 | | 1 | | | | |
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| | | | | | 1 | | 4 | | | |
| | | | | | | 1 | 4 | | | |
| | | | | 3 | 2 | | | 2*70 bytes | 2*58 bytes | 79+73 bytes |
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| | | | | | | 2 | 3 | | | |
| | | | | 3 | 1 | 1 | | 3*70 bytes | 3*58 bytes | 79+(2*67) bytes |
| | | | | 3 | 1 | | 1 | | | |
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| | | | | 1 | | 1 | 3 | | | |
| | | | | | 1 | 1 | 3 | | | |
| | | | | 2 | 1 | 1 | 1 | 4*70 bytes | 4*58 bytes | 73+(3*67) bytes |
| | | | | 1 | 2 | 1 | 1 | | | |
| | | | | 1 | 1 | 2 | 1 | | | |
| | | | | 1 | 1 | 1 | 2 | | | |

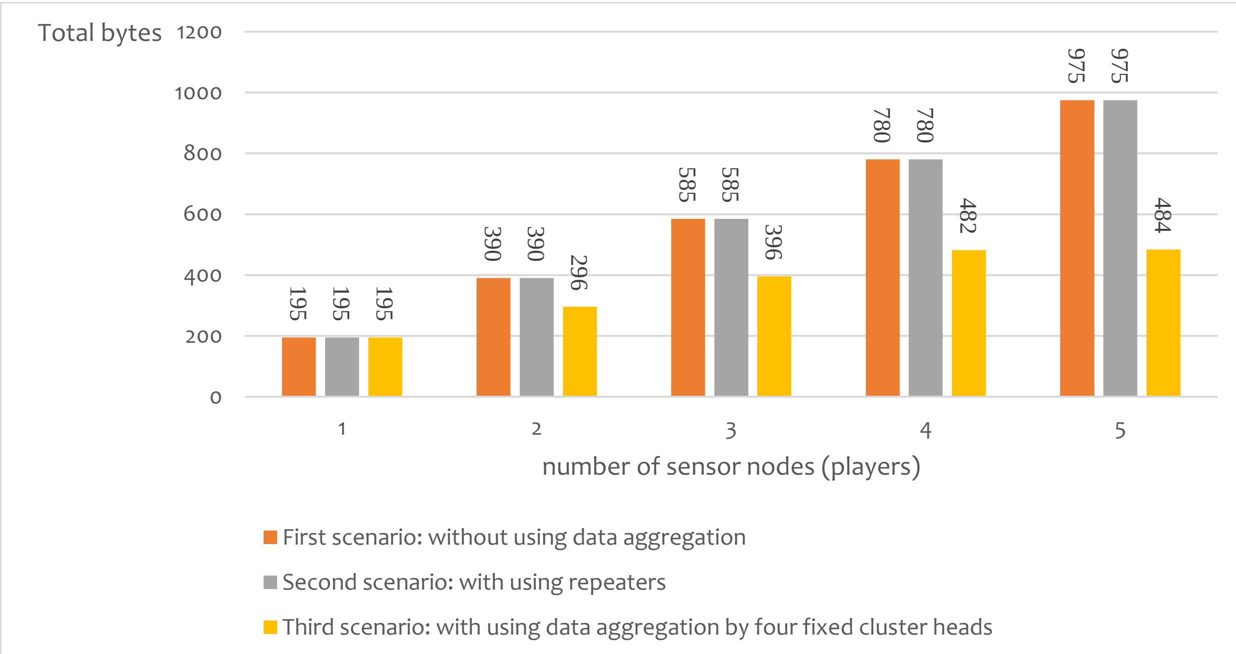


**FIGURE 10.** Comparison between three scenarios

In Fig 10, the total bytes in case of without using data aggregation, with using repeaters and the average of the total bytes for all player distribution probabilities. The first and second scenarios are the same in total packets but the second scenario when players transmit the sensed data to the nearest repeater. The distance from the player to the repeater is smaller than the distance from the player to the gateway. That causes a reduction in the power consumption. The third scenario is similar to the second scenario in the distance reduction. players transmit the sensed data to the nearest aggregator (CH). There are 24% bytes reduction in case of using data aggregation using four fixed cluster heads and there are two sensor nodes (players). The percent of bytes reduction increase with an increase in the number of sensor nodes in the system. In the case of three players, the bytes reduction becomes 32%.in the case of four players, the bytes reduction becomes 38%. When there are five sensor nodes (players) reaches to 50% reduction and also this percent alters with changes in the number of aggregators (CHs).

## 9. CONCLUSION

The power consumption through the network is a function of the number of bits and the distance between the transmitter and the receiver. The stadium IoT system is implemented to monitor the footballer health condition during the match or the training. The system is implemented with three scenarios. The first scenario without using data aggregation. The second scenario with using repeaters. The distance from the player to the repeater is smaller than the distance between the player and the gateway. In this scenario the power consumption is less than before. But the repeater retransmits all received packets. The packets are not reduced.

In the third scenario, the distance from the player to the aggregator is smaller than the distance between the player and the gateway. The power consumption in this scenario also is less than the first scenario and the total packets in the network are less than before. This scenario saves the power and increase lifetime of the network by percent depend on the number of the aggregators and the number of sensor nodes. For the study cases with using four fixed cluster heads. In the case of two players, the bytes reduction through the network by percent of 24%. This percent increase to reach 50% in the case of five players.

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