Smart Monitoring of Greenhouses using Wireless Sensor Network

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***Abstract*— In order to improve the crop yield and quality in the greenhouses, certain methods should be employed to closely monitor the environmental conditions. Humidity, light intensity, temperature and soil moisture are the most important environmental factors for the crop growth thus it is vital to monitor these factors accurately and efficiently. Traditionally, wired systems were employed for greenhouse monitoring and controlling, however, these wired systems limited the extensibility and ease of installation also increased the cost of maintenance. Owing to the advance of Wireless Sensor Network technology (WSN), it is believed to overcome the drawbacks of wired control systems by applying WSN-based systems in greenhouses. WSN allows a great number of measurements in the greenhouses with relatively lower cost and ease of installation and maintenance.**

In this paper, a wireless sensor network is presented for fire detection and monitoring the environmental factors of greenhouses based on IEEE 802.15.4 standards. Sensor nodes are deployed for measurement of environmental factors, for this CSMA MAC protocol is implemented. However, since the fire detection needs higher priority ALOHA MAC protocol is used. For implementation Contiki operating system is chosen and using COOJA simulator the proposed network will be evaluated. Finally, the performance metrics are going to be analyzed with respect to the estimated values.

***Index Terms*—Wireless Sensor Network (WSN), Carrier sense multiple access(CSMA)**

I. INTRODUCTION

Today our world is connected by smart and intelligent infrastructure systems more than ever, the Wireless Sensor Network (WSN) and Internet of Everything (IOE) are the common answers for this vision . Using WSN, which is a particular network composed by distributed sensor nodes that communicates data, it is possible to manage and monitor a large amount of real world information. WSN allows the possibility to improve the multiplicity of issues that can be monitored, and provide an easy extendibility of the production due to the lower cost of electronics for sensing, actuating and communicating parts with an intrinsic modularity and scalability.

Due to the ascend development in smart agriculture, it is necessary to use wireless sensor network for improving the efficiency of greenhouses. In fact, WSN have more advantages compared to cabled systems, like installing WSN is faster, cheaper and easier, even the maintenance has a lower cost in comparison with wired networks. Furthermore, applying efficient algorithms to WSN allows to perform faster communication and computation between sensor nodes during dangerous occurrences and it is possible to improve the lifetime of sensor batteries to operate for several years without any interrupt. These also guarantee a better robustness and reliability of network. In the greenhouses, the most significant factors in growth of plants are temperature, light and humidity. Therefore, by intelligently monitoring these parameters involving WSN it is possible to increase the quality of products and allows a considerably easier monitoring for agriculture company.

The aim of the presented project is to design and implement an efficient WSN for greenhouses which can be used for monitoring the greenhouses and to implement a better mechanism for fire detection in the greenhouses.

The following section outlines some of the related works of the greenhouse monitoring, while section III outlines application and hardware description. Section IV illustrates network and protocol design, Section V outlines requirements and expected performance of the network design and finally section VI illustrates Implementation plan of the greenhouse monitoring and fire detection mechanisms.

II. RELATED WORK

In [3], Ahonen et al. developed a node using Sensinode sensor platform including temperature, light-intensity and humidity based on 6LoWPAN protocol which enables transmission of compressed Internet Protocol version 6 (IPv6) packets over IEEE 802.15.4 networks. In order fulfill the requirements of the energy efficient wireless sensor network architecture, periodical sleep and wake modes were applied. The coordinator node took care of data requesting and acted as a master device, which polled data from the sensor nodes in certain time periods. Collisions between other node transmissions were easily avoided in this way. Even in this project a master node is used to collect data from their child nodes in timely manner to avoid collisions and to transmit the acquired data to the base station for further evaluation.

Similarly, In [2], for continuous monitor of the greenhouse signal dynamics, they used a periodic sampling with averaged delayed transmission (PSDT) data-acquisition and transmission algorithm. This technique improves the reliability with which signals are sampled and is power efficient also It supports high latency operation and averaging to compress data samples without sacrificing measurement accuracy and data integrity. In [3] a fire emergency detection and response for building environments is proposed.

In [1], a more robust routing and Medium Access Control (MAC) layer design is presented to endure a quick transmission of this high priority data avoiding collisions. Where they implemented hybrid MAC protocol called ER-MAC. In this MAC protocol two approaches are considered based on the situations like in ordinary situation where there are no emergency operations are performed with a larger tolerance towards delays which allows a low power usage during transmission of data packets and increases the battery lifetime of nodes. The second approach is taken when the emergency is detected, during this all nodes change their behavior and wake up at the beginning of each TDMA slots in order to receive and transmit higher priority packets.

III. Application and Hardware Requirement Description

In this paper, a new low-cost wireless sensor network based system is proposed for monitoring and controlling greenhouses. Using WSN, the below mentioned parameters,

- Temperature,
- Light intensity and
- Humidity

are measured and monitored efficiently by sensor nodes. Also, a fire detection system is incorporated for detecting plant fires. A greenhouse with area around 2000 square meters which is divided into in small grids of dimensions 12 X 5 meters as shown in Fig3.1, is considered for the experiment.

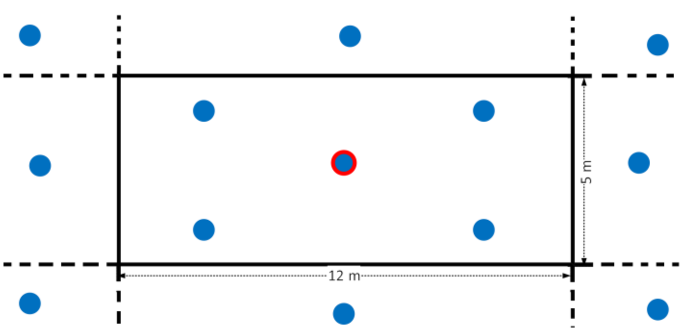

Fig.3.1-The schematic representation of the 12 X 5 meter grid of the greenhouse

In each grid of the greenhouse the four sensor nodes are deployed for measuring the above mentioned parameters and detecting fire. Also, there is one cluster head per grid responsible for collecting data.

As it is illustrated in Fig 3.2, the whole greenhouse has around 30 grids. The cluster heads of each grids transfer the collected data to the base station for monitoring the parameters and controlling actuators. The actuators used are

- Pumps for irrigation
- Sprays to extinguish fire
- Recirculating fans for cooling
- Lighting system.

The cluster head nodes are always connected to AC source supply because it is essential to keep them awake all the time. However, the remaining nodes are operating on battery source.

Environmental parameters are sampled every 1 min and based on the measured values the respective actuators will be triggered. Moreover, when a fire is detected an emergency situation will take place to eliminate the fire immediately. In this situation, the fire alarm should be sent to the cluster head immediately.

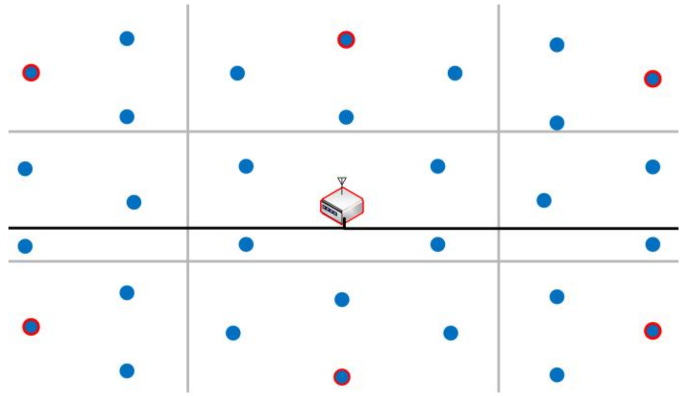

Fig.3.2-The schematic representation of the whole greenhouse and mentioned sensor nodes

After obtaining successful results through simulation, then the algorithm can also be tested in the real environment. For simulation purposes, emulated version of Tmote sky known as sky mote is considered and the calculations for power consumption of CPU, radio transmitter and receiver are all based on the this sensor data sheet. In Fig.3.3 Tmote sky module is shown. This sensor is a low power mote with integrated sensors, radio, antenna, microcontroller and programming capabilities. This sensor node supports IEEE 802.15.4, which makes it a suitable choice for Zigbee and low power wireless personal area networks (6LoWPAN) applications. In addition, it supports 10 low-power sensors such as, ambient light, infrared temperature, ambient temperature, accelerometer, gyroscope, magnetometer, pressure, humidity, microphone and magnetic sensor. Also, the dimensions of the sensor tags are small enough to be mounted anywhere in the greenhouse.

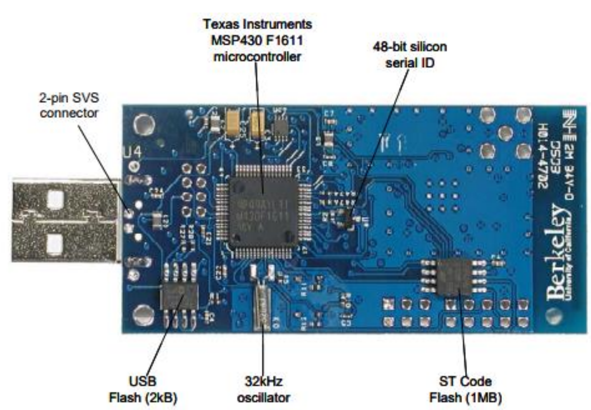

Fig.3.3- Tmote sky module.

Tmote sky communication module operates in the 2.4 GHz - 2.483 GHz frequency range. Also, its nominal output power is -3dBm and receiver sensitivity is -90dBm. During the idle mode, the current consumption is 20µA and in transmitting and receiving mode it is 17.4mA and 19.7 mA.

IV. Network and protocol design

In this section, the network architecture and the MAC protocols for the system is explained. The five sensors in each grid are deployed and are operated on the basis of star topology as shown in Fig.4.1. Child nodes only communicates with their own cluster head. The cluster head collects data from the child nodes and periodically communicates with the base station.

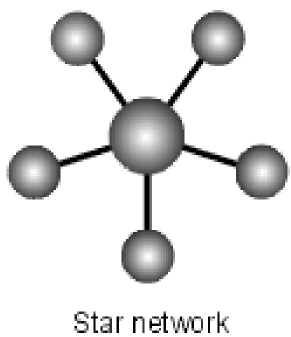

Fig.4.1-Schematic of star topology

As it is illustrated in Fig.4.2, in each grid five nodes are deployed. One node in each cluster is responsible for detecting fire. The other three child nodes have the capability to monitor temperature, humidity, light intensity and transmit the monitored data to the cluster head. Cluster head processes the received data and transmits it to the base station for further processing. In order to improve the probability of successful data transmission CSMA is applied for communicating the sensor environmental data values. Also to fulfill the latency constraints ALOHA protocol is chosen for communicating the fire alarm.

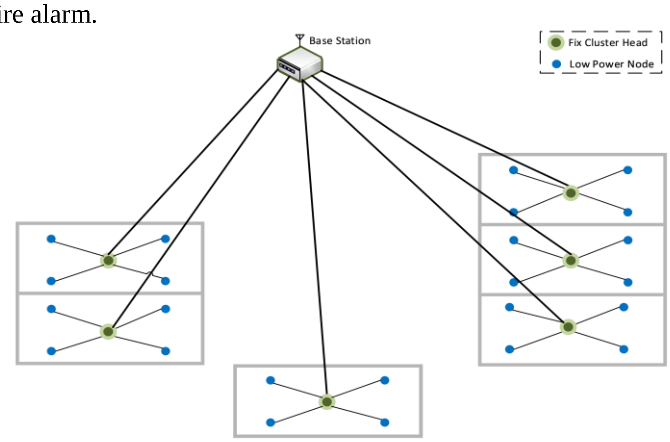

Fig. 4.2- Network topology of the greenhouse system

CSMA MAC protocol is used for the direct communication between sensor nodes and the cluster head. Also, it is for the communication between cluster head and base station. The main advantage of applying CSMA is its simplicity for implementation. Since CSMA employs sleep mechanism and acknowledgments in transferring, it satisfies the reliability and energy efficiency requirements of this greenhouse application.

In each grid, whenever a sensor node has to transmit data frames, it waits for a certain period. If the channel is found to be idle, the node transmits its data. However, if the channel is found to be busy, the device waits for another random period before trying to access the channel again. Also child nodes use acknowledgements for ensuring the successful transmission of their data to the cluster head. If a collision is detected, the data is retransmitted at a later point in time.

When the data arrives at the cluster head it is processed and transmitted to the base station. Since the cluster head is always awake, without concerning about any kind of data loss such as multipath fading, it receives the data from each sensor nodes and stores them in a buffer. Then, periodically it transmits all the stored data to the base station. Owing to the use of CSMA protocol, previously mentioned characteristics are preserved in this communication, too.

On emergency, that is when a fire is detected in the greenhouse there should be a mechanism which can immediately detect and take necessary actions to quench the fire as soon as possible. Therefore, in this emergency situation, CSMA is not a good solution for the network mainly because of two reasons. Firstly, fire detector sensor needs higher priority for transmitting its data but listening to the channel would result in transmission delay. Secondly, there is a possibility that when the fire is detected the node is in sleep mode. Therefore, for fire detector sensor node ALOHA protocol is implemented.

In the ALOHA protocol, a device transmits without sensing the medium or waiting for a specific time slot. Therefore, when a fire is detected the sensor transmits immediately to the cluster head without waiting for a particular time. Thus, the cluster head can transmit to the base station an alarm message and appropriate actions are taken immediately.

V. Requirement and expected performances

Considering the application requirement is a vital for designing any WSN. In this application, one the main goal is to achieve a higher Quality of Service (QoS) in the case of fire detection in comparison to the ordinary day-to-day service in transmitting monitored environmental data.

In normal operational life, each child node of the network samples and transmits to the fix cluster head its environmental parameters of the covered area. These actions are performed with a low rate of one transmission per minute using the CSMA protocol to preserve battery lifetime. Owing to this design, the network traffic is considered to be light and the end-to-end latency from a child node to the base station in the worst case is expected to be 5 minutes.

In case of emergency, when fire detector nodes detect a fire occurrence, a high priority packet is transmitted to the cluster head using ALOHA. This behavior is expected to reduce the end-to-end latency to a value less than 10 seconds. This high priority packet transmission is characterized by a low collision probability while the fire does not extend in areas covered by the other sensors. Therefore, the centralized actuation system can quickly mitigate the damage caused by the fire.

Generally, the most challenging communication within the designed network is the child to cluster head transmission because of low power constraints of the child node. However, the cluster head to base station communication is very robust and reliable because no power constraints restrict the rate of success in transmission and receiving packets of data.

Moreover, the maximum distance from the low power node to the cluster head is at most 8 meters. Therefore, the PRR is expected to be at least 85% in standard conditions.

Also, other performance metrics that should be considered in simulation result analysis are, reliability based on End-to-End Packet Delivery Ratio (PDR) and battery lifetime.

VI. Implementation plan

The Operating System for WSN is a very challenging system as it demands high memory and processing power constrained environment with a need for battery conservation. The selection of operating system depends on parameters such as Scheduling, Dynamic Re-programming and Programing language. The Contiki OS, which uses Preemptive scheduling, dynamic re-programming and C language for programming with an event-driven mechanism, proto-thread execution model and active community of developers is the best choice for the implementation of the proposed WSN.

Contiki OS in comparison to TINY OS – another popular operating system with nesC framework, in WSN market, is considered as a faster performer owing to its structured C framework, direct hardware support and real-time simulation capability.

One of the remarkable advantages of Contiki OS is that the code once written need not be changed for deployment. The code analyzed and debugged in simulator will work directly in hardware implementation as a result, it allows a considerably more efficient application development with regards to time and cost factors. Also using real hardware is not necessary for application development, therefore Contiki OS is the most suitable choice as a low cost, royalty free development platform.

Another main advantage of Contiki OS is the real time simulation of various hardware platforms using Cooja simulator. In this paper Cooja will be used for simulation which makes it possible to simulate the nodes of designed WSN for greenhouses.

Contiki supports two types of MAC protocols called null-mac and CSMA. The null-mac is a simple pass-through protocol that simply transmits the data when the node senses something without worrying about other communication or waiting for medium access. CSMA protocol implements addressing, sequence number and retransmissions and it keeps track of number of retransmission, collisions and deferrals.

In the simulation of the proposed WSN, CSMA MAC driver of Contiki is used for all nodes except fire detector node which uses Nullmac driver. To assert that the expected performance metrics are satisfied in high traffic situations, the simulation is performed with higher data rate.

For the implementation of the proposed WSN, four algorithms are developed. The first algorithm is for the communication between the sensor nodes of each cluster to their own cluster head. The second algorithm is for the communication between the cluster head nodes and the base station. In each cluster, the third algorithm is for communicating the fire alarm to the cluster head and specifying the period at which cluster head should send its data buffer to the base station. The last algorithm is for the base station to receive the data from cluster heads.

VII. Algorithm Description

For developing the algorithms, Contiki unicast example is used. Based on the requirements of the proposed WSN, this unicast example is modified.

For measuring temperature and humidity, sht11-sensor.h library is included in the program. Similarly, light-sensor.h library is used for measuring the intensity of light. Since fire detection is event based, its activation is simulated by pressing a button and for this button-sensor.h library is included. In the following an overview of the implementation of the algorithm is given.

Each node based on its own ID has a specific value called, ClusterID. Using this value, every child node knows its cluster head and communicates data to it with a specific transmission rate. This transmission rate is defined using a timer which is set based on the value of ClusterID for each node.

Each sensor node measures temperature, humidity and light intensity. The reading values of temperature and humidity sensors are converted to SI units as follows:
For Temperature, Oscilloscope returns a 14-bit value that can be converted to degrees Celsius:

$$\text{Temperature} = -39.60+0.01 \times SO_t$$

where SO_t is the raw output of the sensor.
Humidity is a 12-bit value that is not temperature compensated.

$$\text{Humidity} = -4+0.0405 \times SO_{rh}+(-2.8\times10^{-6}\times SO_{rh}^{2})$$

where SO_{rh} is the raw output of the relative humidity sensor.

As mentioned before, CSMA is applied as the MAC layer of these nodes. Therefore, acknowledgement is supported and in order to ensure energy efficiency, these nodes only wake up when their timer is expired. In the proposed implementation, the timer is set for 15 seconds.

Each cluster head has a data buffer which stores all the received data of its child nodes and periodically sends the whole buffer to the base station in order to reduce the data traffic. Instantly forwarding the received data from the child nodes to the base station clearly results in high traffic at base station.

In each cluster one of the child node is implemented as the fire detector. The algorithm for this node is divided in two main parts. The first part is the implementation of the fire detecting event. For this purpose, the occurrence of fire event is simulated by clicking the button of this node. Therefore, whenever the button of the fire detector node is pressed, the node sends the fire message to its cluster head. On the other hand, the fire detector node is responsible for notifying its cluster head the exact moment of sending the data buffer to the base station. Therefore, in the second part of the implementation algorithm of fire detector node, a timer is set with a value related to the ClusterID and after the expiration of this timer the fire detector node forwards a message to its cluster head to inform that the data buffer should be send to the base station. Avoiding collision in sending the data buffer is essential since these packets are large and the cost of retransmitting them is high. Hence, as mentioned above, the ClusterID value is used in timer in order to specify a unique period for transmission of data buffer of the respective cluster head.

Whenever cluster head receives a message from its fire detector node, it would check to see whether the received message is a time out for sending its data buffer or if it is a fire alarm. In case of fire alarm, the cluster head will send the fire message to the base station. Otherwise, it transmits all the stored data in its buffer to the base station.

The implemented algorithm in the base station is only a receiver which collects data from the cluster heads.

VIII. Results and Evaluation of the Network

In order to evaluate and check the performance of the network in different scenarios, a radio model called as Multi-Path Ray-tracer Medium (MRM) can be considered. Contiki supports four radio models; among them one is completely silent radio medium mostly for debugging purposes. The second model is called Unit Disk Graph Medium (UDGM) and allows only to change the transmission distance as well as success ratio. In MRM model it is possible to change the environment parameter by changing noise-related parameters as noise variance, SNR, receiver sensitivity and noise threshold, etc. Using MRM area viewer and MRM Formula viewer a simulation that take in account several environmental disturbances can be performed. Therefore, for evaluation of the robustness of the communication, this model is chosen.

In order to evaluate the network, 4 scenarios were considered. In each scenario Expected Transmission Count (ETX), Packet Reception ratio (PRR), End-to-End latency and power consumption is calculated and compared with each scenario.

In the first scenario, only one cluster and a base station was considered for showing the basic behavior of the unit that is replicated in the entire network.

In the second scenario, one cluster and the base station are tested in presence of a higher noise variance using MRM to the simulation. This affects the channel characteristic which make a more hostile environment for the network reliability due to disturbing in transmission and reception.

In the third scenario, a network composed by 5 clusters and a base station is proposed in maintaining the same noise condition of the previous scenario. This is representative about the ordinary operative life of the network, when it is intended to show the low energy consumption regimes and the overall Quality of Service that are performed when there are no fire alarms.

Finally, in fourth scenario represent almost the same network configuration of the third scenario, in which a fire event occurs.

➢ Scenario 1

As mentioned previously, a single child node communicates sending data messages to its cluster head. Consequently, cluster head first collects the data related to each child node and after does not transmit the whole packet to the base station until all the environmental data are completely received from all the child nodes.

For provide evidence of the success of the communication and the fairness of the behavior, the log text of Cooja Simulator is imported in MATLAB development environment, to use the features of the graphic tools and to aid the large data manipulation. The transmission and reception successful of the messages between the cluster head and the child node and between the cluster head and base station are as well carried out.

Scenario-1 is shown in Fig.8-3 where one cluster is communicating to the base station.

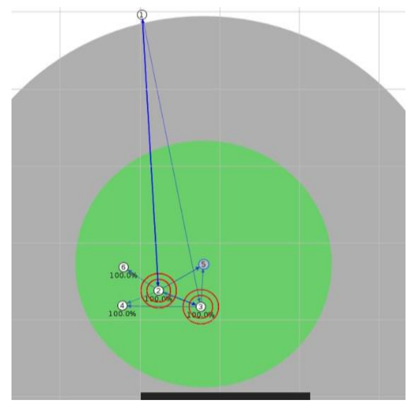

Fig.8.2-Network structure for Scenario 1

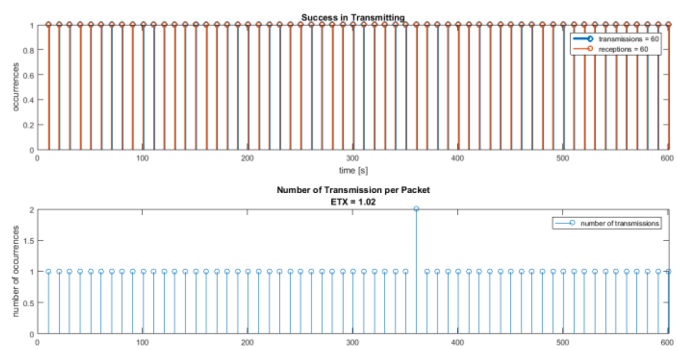

Fig.8.2-Scenario 1- Transmission and reception success rate between the child node and the cluster head.

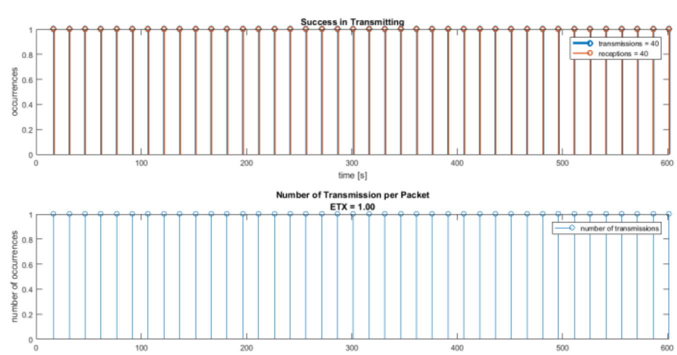

Fig.8.3- Scenario 1- Transmission and Reception success rate between the Fire detector node and the cluster head

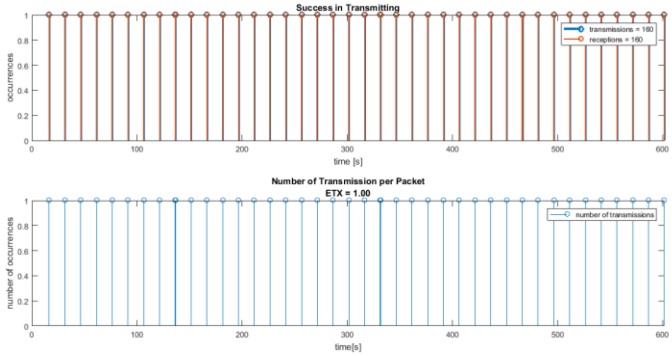

Fig.8.4 - Scenario 1- Transmission and Reception success rate between the cluster head and base station

The graphs above show the transmission and reception between each representative nodes of the network. The graphs in the top part of each figure show that the success in the communication related to reception of the destination node (red) and the instant of transmission of the sending node (blue). The graphs in the bottom of each figure show how many data were retransmitted at one particular time, so it is possible to understand if any retransmission occurs due to collisions. They describe respectively the communication between normal child node to cluster head (Fig-8.2), between fire detector node to cluster head (Fig-8.3), between cluster head to base station (Fig-8.4).
As can be seen in the Fig-8.2-8.4 there is 100% success between transmission and reception of data packets from respective nodes to their own destination; only one retransmission occurs at after 350 seconds from a normal child node to cluster head.
It can also be seen that normal child node has different timing (periodicity of 10 sec) in comparison with fire detector node (moved by ALOHA timing). Even in cluster head the transmission take place with a different timing that follows the same periodicity of the fire detector node; the waiting of data from fire detector child affects the whole cluster data packet timing, as shown in Fig-8.3-8.4.

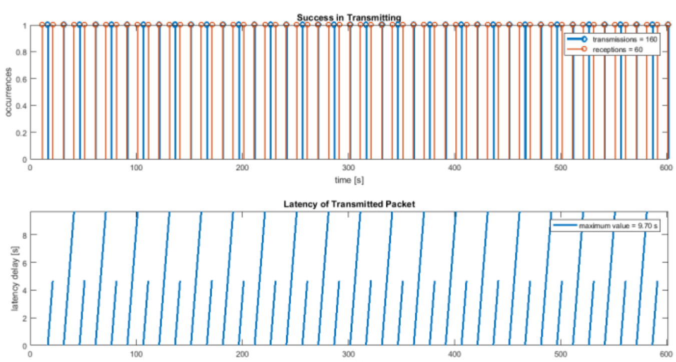

Fig.8.5- Scenario 1- End- End delay between the child node and base station

Fig-8.5 shows the end to end latency from the child node to the base station. The maximum latency between the child to the base station is 9.70 seconds. This latency occurs because of the different timing, as mention above, the cluster head is affected by a different timing compared to the normal child. This is necessary in order to collect all the packets from the cluster. This behavior is translated in an increase of the end-to-end latency.

- Scenario 2

Similarly, to Scenario 1, the configuration is one cluster to the base station, with an increasing of the noise variance of the channel ($\sigma = 3$) that is expected to worsen the quality of service. However, in this case, as seen in the Fig-8.6 Fig-8.8 there is 100% in success of reception of messages between the child node and cluster head, cluster head to base station.
The disturbances affect only the ALOHA child node which detects fire when sends data packet (no fire) to the cluster head. In this case PRR=91.1% because of no retransmission happens (Fig-8.7).

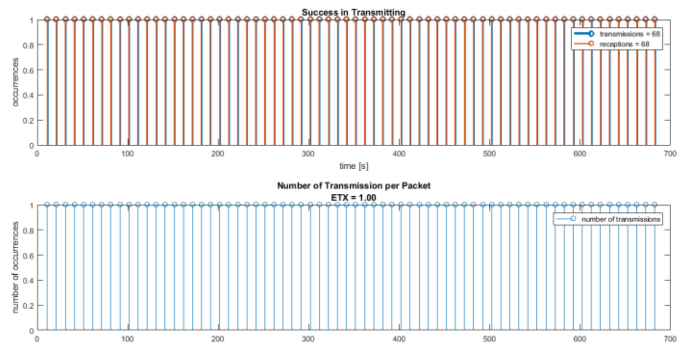

Fig.8.6 - Scenario 2- Transmission and Reception success rate between child node and the cluster head

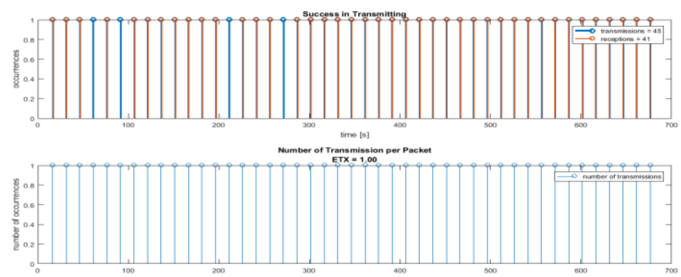

Fig.8.7 - Scenario 2- Transmission and Reception success rate between the fire detector node and cluster head

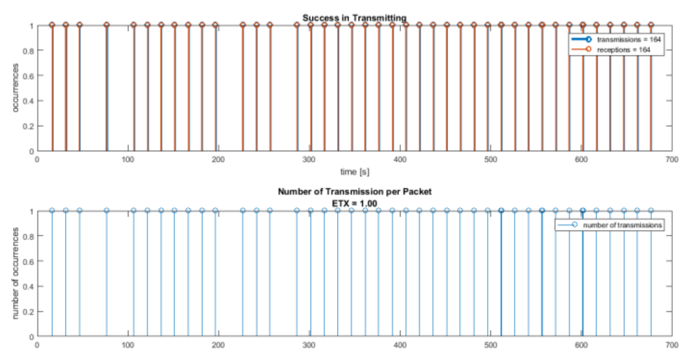

Fig.8.8 – Scenario2- Transmission and Reception success rate between the cluster head and base station

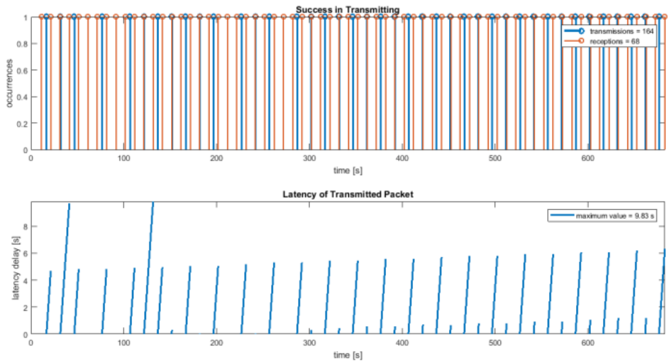

Fig.8.9 - Scenario 2- End- End delay between the child node and base station

In above Fig-8.9 the end-to-end latency between the child node and the base station denote how the lost messages of the fire detector node affect the delay in transmitting the whole cluster data packet. As seen in the Figure compared to Scenario-1 the latency has increased for around 0.13 sec.

- Scenario 3

In this scenario, five clusters, base station as well as noisy environment was created as shown in Fig8.10. In this particular scenario, no fire events occur. Similar to other scenarios, even here the transmission and reception success ratio was plotted and are shown below in Fig8.11-13.

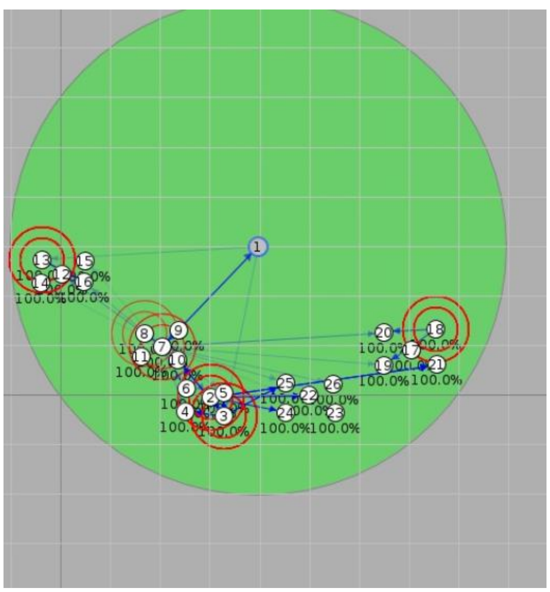

Fig.8.10-Network structure for scenario 3

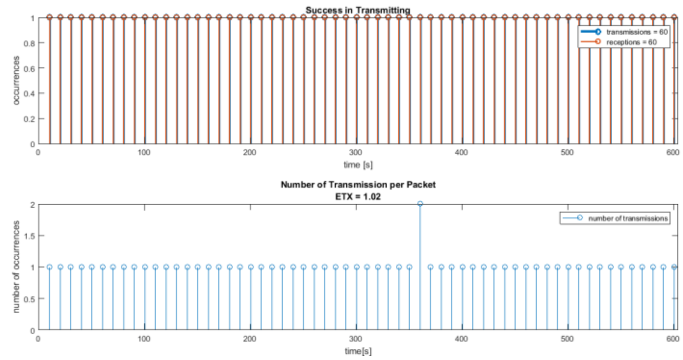

Fig.8.11 - Scenario 3 - Transmission and Reception success rate between the child node and cluster head

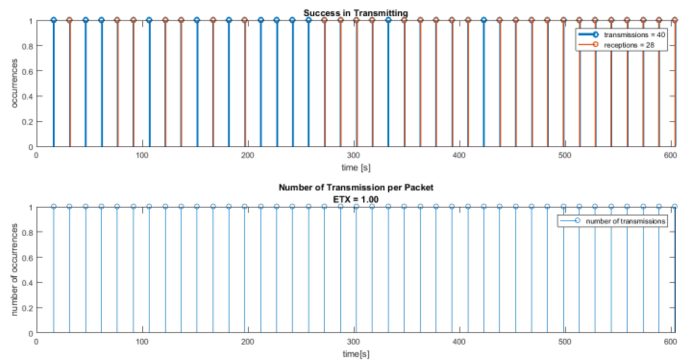

Fig.8.12 - Scenario 3 - Transmission and Reception success rate between the fire detector node and cluster head

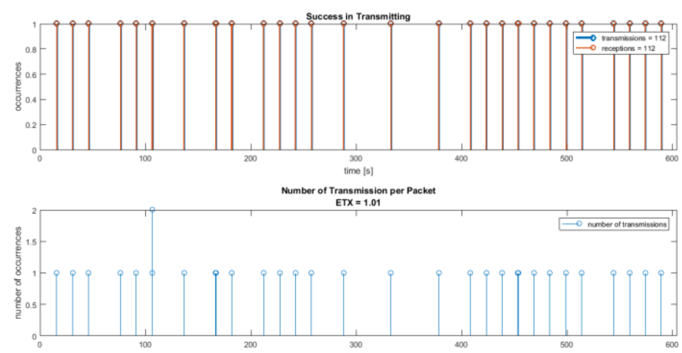

Fig.8.13 - Scenario 3 - Transmission and Reception success rate between the cluster head and base station

As per the Fig- 8.11 there is only a lost data packet during the transmission between normal child node to the cluster node. It can be easily attribute at the increased number of collision between cross-cluster unwanted interferences.

An PRR = 70% is affecting fire detector child node to cluster head environmental data communication as it is shown in Fig 8.12 (28 received up to 40 transmitted packets). Thus, the cluster head will be triggered by the fire detector node with a non-periodic timing.

Fig-8.13 shows for the transmission and reception success between the cluster head and the base station. From figure, it can be seen that there is a retransmission of the packet around 100th second. Since there is more traffic between cluster heads and base station, as well as a noisy environment in this scenario, thus there is a collision but however as per the figure there is almost 100% transmission during that time line (ETX = 1,01).

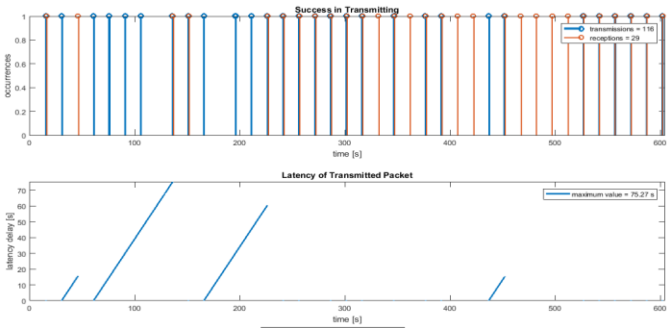

Fig.8.14 -End-End latency between the child node and base station

Fig- 8.14 shows end-to-end latency between the child node to the base station during this scenario. Compared to all other scenarios the maximum latency has increased to 75.27s.
This latency can be attributable to the PRR of the fire detector node, that provoke an extra waiting time for the already collected cluster data that has to be forwarded to the base station.
In Fig-8.15 power consumption and battery lifetime is estimated using the log file obtained from the simulation and the nominal current performances of the TMote sensor taken from its datasheet are integrated up to the correct sleep and active sensor mode timing. This estimation is done in order to obtain performances of energy constrained child node in normal condition. It can be seen that the main contributions that are on the average total power of 64.17 mW are related to receiving a transmitting actions. The battery lifetime (double AA each with 2000mAh capacity) is greater than 7 days, so for the actual data rate of the intended network (presented in section V) is expected to be greater than 14 days.

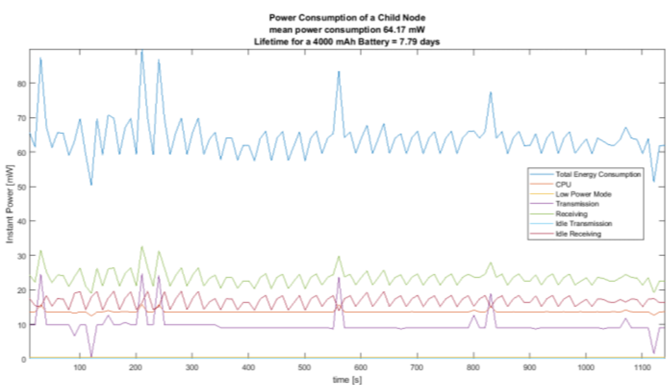

Fig.8.15 - Scenario 3 – Power Consumption and Battery Lifetime of child node

- Scenario 4

This scenario is tested specially for the case of fire emergency. As mentioned in the previous sections, the fire is triggered in the network through the use of button, thus, when the button is pressed on the node 3 which is used for fire detection, the node starts to transmit immediately. The pressed button event is the analogy of fire event for the network. Since in emergency situation, it is using nullMAC (ALOHA-like) protocol there will be continuous transmission of packets to the cluster head without waiting for time or without asking for channel access.

During this situation, the communication behavior of the other ordinary child nodes towards cluster head and the communication behavior of the cluster head towards base station are plotted in the following figures below.

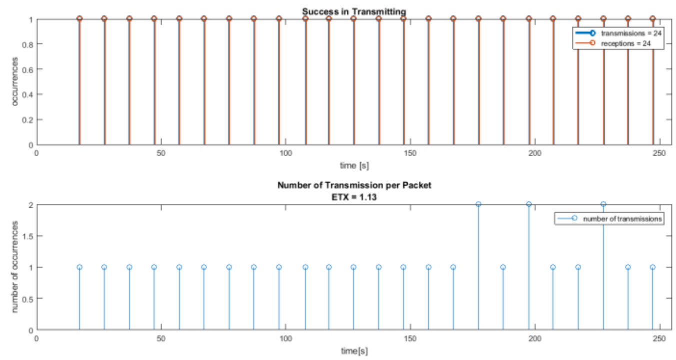

Fig.8.16- Scenario 4 - Transmission and Reception success rate between the child node and cluster head

Fig-8.16 shows the transmission and reception plot for the communication between the normal child node and the cluster head. As seen in the figure the number of retransmissions between the ordinary child node and the cluster head is slightly increased (ETX = 1.13). This is due to the node transmits the data alerting the cluster head without checking other transmissions with consequence of heavier traffic condition. Since the cluster head cannot receive data packets from both the nodes at the same time, thus the data packets from the ordinary child node is dropped thus the node has to retransmit the packets again thus increasing the retransmissions and it can be seen in the Fig-8.16.

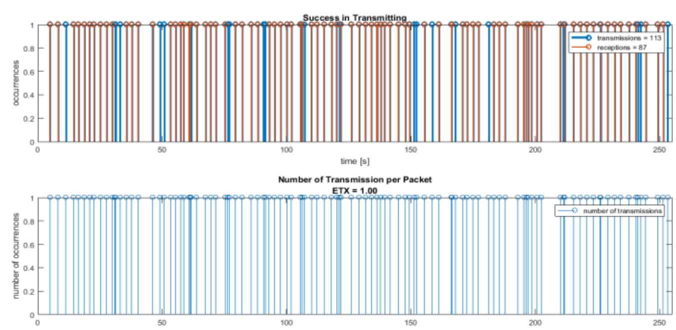

Fig.8.17 - Scenario 4 - Transmission and Reception success rate between the fire detector node and cluster head

Fig-8.17 shows the plots for the communication between the fire detector node and the cluster head. In this it can be seen that there is a PRR = 76.9% between the sender and the receiver, but the frequency in sending the alert message is very high for taking necessary precautions to deplete the fire as soon as possible, as seen in the figure.
In Fig-8.18 the end-to-end latency between fire detector node and base station is shown. It can be seen how the fast rate of the ALOHA communication allows to reduce drastically the usual latency; intercepting the medium is not necessary and the triggering of the cluster head forwarding is quickly performed by fire node. In fact, the fire alert arrive at the base station with a maximum delay of 5.15 seconds.

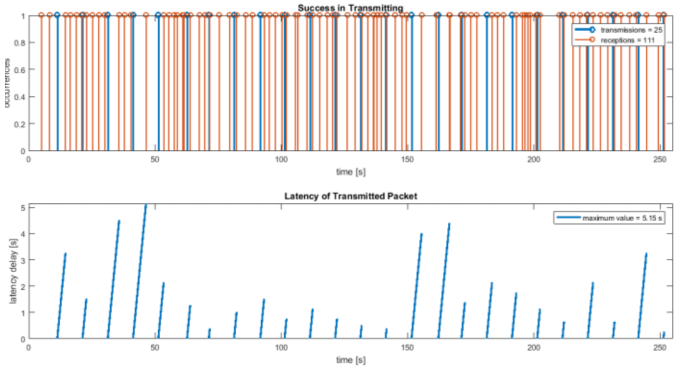

Fig.8.18 - Scenario 4 - End-End latency between the fire detector node and base station

In Fig-8.19 power consumption and battery lifetime is estimated similar to the previous scenario. This estimation is done in order to obtain performances of energy of fire detector child node in case of emergency. It can be seen that the contribution related to transmission is higher than the previous case; the average total power is 105.64 mW. The battery lifetime is about 5 days, so for the actual network presented in section V is expected to be greater.

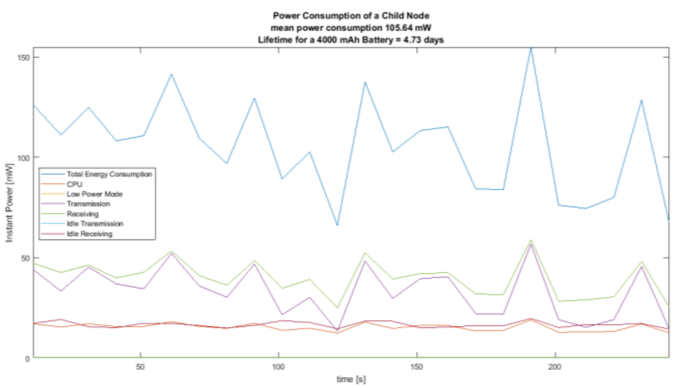

Fig.8.20 - Scenario 4 – Power Consumption and Battery Lifetime of fire detector node

IX. CONCLUSION

The smart greenhouse monitoring was simulated on Contiki OS using Cooja simulator. The simulation voluntarily has been carried out with higher data rate for investigating several worst-case scenarios.

Four different algorithms were developed for communication between different nodes:

First algorithm is developed for communicating normal packets between child node. Second algorithm is for cluster head and third algorithm was developed for transmitting high priority packets during fire emergency and normal data in ordinary lifetime. Fourth algorithm was developed for allow the communication between the cluster head and the base station and its fair reception of data packet.

Using these algorithms different clusters were developed as mentioned in the above sections and different environment scenarios was built to analyze the network.

Finally, the simulation was performed in each scenario and the obtained results were elaborated using MATLAB for analyzing the network and evaluate estimators related to Expected Transmission Count (ETX), Packet Reception ratio (PRR), end-to-end latency, average power consumption and battery lifetime.

An overview of the result obtained from the simulation is shown below,

From → To	*Scenario 1- Single Cluster*	*Scenario 2 –Single Cluster + Noise*	*Scenario 3- Five Clusters + Noise*	*Scenario 4– Five Clusters + Fire*
CHILD to CLUSTER HEAD	ETX: 1.02	ETX:1	ETX:1.02	ETX:1.13
FIRE DETECTOR NODE to CLUSTER HEAD	ETX:1 PRR: 100%	ETX:1 PRR: 91.11%	ETX:1 PRR: 70%	ETX:1 PRR: On fire: 76.99% Other fire: 62.5%
CLUSTER HEAD to BASE STATION	ETX:1	ETX:1	ETX:1.01	ETX:1
CHILD NODE to BASE STATION	Maximum Latency:9.70s	Maximum Latency:9.83s	Maximum Latency:75.27s	Maximum Latency when :5.15s

Table-9.1 – Overview of the results

The obtained result shows that, the proposed WSN is suitable for green house application since it satisfies the expected requirement mentioned in section V.

X. FUTURE WORKS AND IMPROVEMENTS

The current work and the results are obtained only through simulations, so in the future this work is going to be implemented in the real environment using real sensor nodes.

For achieving better performances in end-to-end data communication, acknowledgements in nullMAC protocol can be added; This will improve the whole performance of the network and will reduce latency.

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