Implementing Wireless Mesh Network Topology between Multiple Wi-Fi Powered Nodes for IoT Systems

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Abstract - *Here in this work a wireless mesh network topology was integrated with an IoT network to establish communication between ESP-32 radio nodes without using any router in between. Implementation was carried out over a hardware experimental set-up developed. The system comprised of three NodeMCU ESP-32 boards connected in a mesh network topology. Here the data were acquired from two different sensors interfaced to two NodeMCU ESP-32 boards. The purpose was to transfer this acquired data collectively to a third NodeMCU ESP-32 board without subscribing to any internet and without deploying any router in between them. There was no parent node as here each node was talking to every other node in the network as long as a valid route was available. The experimental results proved that the system connected in a mesh network topology has an inherent characteristic to establish communication between each node automatically and would be able to self-heal in case any route becomes disabled.*

Key Words: WLAN, NodeMCU, Mesh Network, WiFi, IoT, etc.

1. INTRODUCTION

The development of the Internet-of-Things (IoT) sets enormous opportunity for new computing paradigms and is serving as a catalyst for profound change in the evolution of the Internet [1]. The recent advancement of the Internet of Things (IoT) enables the possibility of data collection from diverse environments and set control interfaces using multi-sensor networks and other IoT devices. However, despite the rapid advancement of low-power communication technologies, the deployment of IoT networks still faces many challenges [1, 2]. Wireless mesh networks, a network topology that has been in discussions for decades haven't been put into use in large scale. This wireless mesh networking can make a big difference when it comes to the effective and efficient networking solutions in the IoT world today. This work presented a brief introduction and demonstration of how these technologies has the possibility to come together and how to integrate the mesh network into existing IoT networks to potentially make a difference in the new era. We here in this work propose a methodology to tap into this resource pool by coupling data communication and processing. By exploiting the principle of locality inherent to many IoT applications, the proposed approach can reduce the latency in delivering processed information [2]. The integration of mesh clients with the Internet of Things (IoT) has gained significant importance to connect billions of machines and achieve fast coverage with minimum network cost [3]. A hardware prototype consisting of active and passive nodes is developed to demonstrate the working of the system. The experiments for the low-cost Wi-Fi microchip ESP8266 were performed with the aim of Mesh networks investigation as well as scrutiny of the Wi-Fi connectivity between different nodes sharing the same Wi-Fi credentials for sharing of data without any internet or router in between [4, 5].

2. OBJECTIVE

The objective behind this work was to integrate wireless mesh networking topology with that of an IoT network. The purpose was to demonstrate the practical aspects of integrating these two networks by implementing a system around ESP-32 devices with some sensors and other input/ output devices. The proposed work was to establish a wireless communication between three Wi-Fi enabled ESP-32 nodes sharing the same Wi-Fi credentials (ssid, password and port) for the transfer of data between them without using internet and without using any router. The Wi-Fi credentials used here in this mesh network must be arbitrarily chosen by the user and it should not entail user's mobile Wi-Fi hotspot credentials for its operation. The system should be able to connect automatically with all the nodes. Each node connected in this wireless mesh network should be able to talk and hear from other two nodes in real-time. The experimental set-up as well as the real time data and status running live on the serial port monitor window should validate the work.

3. PROBLEM FORMULATION

- To choose and acquire knowledge about the computational platform with integrated Wi-Fi SoC for the implementation of proposed work
- To gather information about the basic characteristics of wireless mesh network topology and its implementation so that the remotely deployed nodes in the system could be able to communicate with each other remotely without any internet or router in between
- To design an architecture of the proposed system with all the components properly organized
- To study about some sensors, relay, push buttons, OLED display and LED deployed here in the

hardware experimental set-up for the demonstration

- To design the schematic and develop the hardware for all three nodes centered around the NodeMCU boards along with input/ output devices
- To design algorithm and write firmware for every individual node in the Arduino IDE (Integrated Development Environment)
- To calibrate the system for the desired results by performing multiple iterations of testing and debugging the source code and finally uploading it in each node
- To observe the response of experimental set-up and validate the work with desired experimental results

4. PROPOSED WORK

An IoT system was proposed here that embraces design and development of three individual Wi-Fi enabled nodes around the NodeMCU ESP8266 boards. The three nodes were to interface with input/ output peripherals and sensors so as to interact with each other. To establish communication between these nodes the mesh network topology was required to be integrated with this IoT network. All the nodes were to connect in a Wi-Fi network. To implement this mesh network user was required to choose its own Wi-Fi credentials to establish a wireless adhoc network and also it should be taken care of that all the nodes must share the same Wi-Fi credentials in their source code, otherwise the communication between those would never be possible.

5. SYSTEM ARCHITECTURE

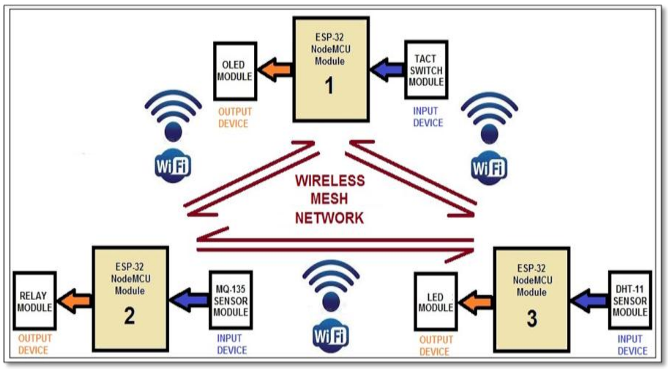

FIG 1: System Architecture

In this system architecture, three individual nodes were developed and centered around three ESP32 NodeMCU Modules as shown in figure below. The three nodes of this IoT network were interfaced to some trigger and action devices and also with some sensors to measure environmental parameters and acquire data for monitoring purpose here.

NodeMCU 1 module was interfaced to:

- Input Device: Two tactile Push Buttons
- Output Device: OLED Display Module

NodeMCU 2 module was interfaced to:

- Input Device: MQ-135 Sensor Module
- Output Device: Relay Switch Module

NodeMCU 3 module was interfaced to:

- Input Device: DHT-11 Sensor Module
- Output Device: LED Indicator Module

All these nodes were connected in a mesh network topology and establish wireless connectivity to interact with each other using the Wi-Fi protocol. Each node was transmitting as well as receiving the data from other two nodes within this network without using any internet and router in between.

6. RESEARCH METHOD

This work had utilized the experimental set up based method of research as it was aimed to demonstrate three hardware modules interacting with each locally using a Wi-Fi network. These modules were expected to transfer data remotely via a mesh network specifically for monitoring and control purpose. Overall it's an IoT system with some sesnors, actuators and Wi-Fi powered computational boards to implement a networking technique that doesn't require any router or internet in between. The hardware used here comprised of a high performance low cost Wi-Fi enabled NodeMCU board. It has multiple digital Input/ Output pins and one analog pin to interface sensors and actuators. The components used here to realize the proposed work were three NodeMCU boards with ESP12 WiFi SOC, OLED display module , a CO_2 gas sensor module, a single channel relay module, a temperature and humidity sensor module, a pair of tactile push button module, a bulb and +5V DC power source. The experimental results obtained from this hardware experimental set-up should validate the work. The research work had demanded sincere efforts to gather data from the datasheets about various components used in developing the hardware. Data gathered from these resources were used to formulate the overall procedure to design, develop and implement the system. Appropriate tables, flowcharts and figures were included in the final report along with the snapshots of working prototype.

S.No.	Component	Specification	Qty.
1	NodeMCU Module	ESP-8266	3
2	DHT11 Sensor Module	3-PIN	1
3	MQ-5 Gas Sensor	4-PIN	1
4	SPDT Relay	+5V	2
5	IN4007 Diode	1A	4
6	Resistor 10K	Quarter Watt	6
7	Resistor 1K	Quarter Watt	4
8	Voltage Regulator IC	LM7805	3
9	Copper Clad	130 x 85 mm²	3
10	Transformer	12-0-12 / 200mA	3
11	Berg Strip	Male Connector	6
12	Connector	2-PIN	4
13	NPN Transistor	BC-547	2
14	Tact Switch	10mm	2

Table 1: List of Components

7. IMPLEMENTED SYSTEM

Node 1			Node 2		Node 3	
OLED Display Message	Push Button		MQ-135 Sensor	Relay Module	DHT-11 Sensor	LED Module
	PB-1	PB-2				
"MANVI MTECH BRCM"	OFF	OFF	OFF	OFF	OFF	OFF
"TEMP – 31" "HUMI – 15" "GAS – 934"	OFF	OFF	ON	OFF	ON	OFF
	OFF	OFF	ON	OFF	ON	OFF
	OFF	OFF	ON	OFF	ON	OFF
	ON	OFF	ON	ON	ON	OFF
	OFF	ON	ON	OFF	ON	ON

Table 2: Expected Outcome

Node-1: As it could be observed that there were three different devices/ nodes in this system. Therefore three separate hardware units centered on NodeMCU modules were designed and developed. As shown below in Fig.-3.2 a NodeMCU module was interfaced to two push buttons and an OLED display module. The push buttons acted as system inputs and OLED acted as system output. The NodeMCU along with the OLED and push buttons used 3.3V dc power supply for its operation. As OLED was an I2C device, only two pins SDA and SCL were required to interface it with the NodeMCU. Rest two pins were the power pins. Two push buttons were interfaced to the two digital I/O pins of the NodeMCU via two pull-up resistors of 10K in between. This was required to prevent any false triggering over these pins during high-impedance state.

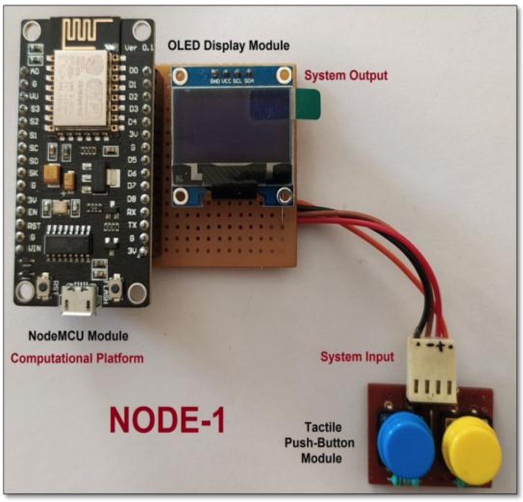

FIG 2: Node-1 Architecture

Node-2: Node-2 architecture as shown below in Fig.-3.3 was also implemented around a NodeMCU module. Here a commonly used temperature and humidity sensor module DHT-11 was interfaced to the NodeMCU. As DHT-11 module used here was a digital output type so instead of using an analog input channel it utilized a simple digital I/O channel. The sensor was made to operate on 3.3V dc and acted as an input for pin D7 of the NodeMCU. On the other side a SPDT relay was also interfaced to one of the digital I/O pins of the NodeMCU. The SPDT relay acted as an output device and was connected on pin D0 of the NodeMCU. The relay acted as an electromagnetic switch and was used here to switch 220V AC load connected, bulb in this case. Here as the relay power consumption was more so the system was fed with a higher power source 5V/ 1A.

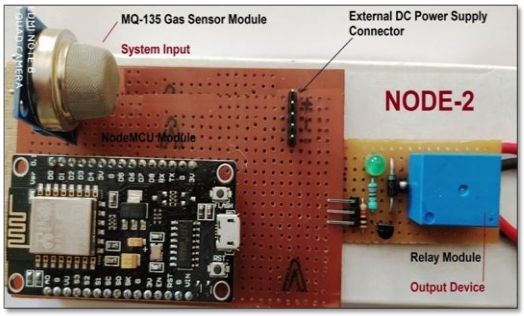

FIG 3: Node-2 Architecture

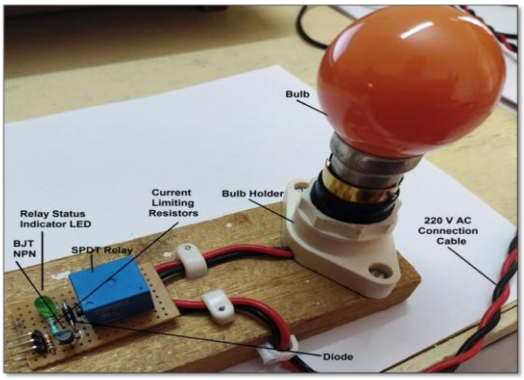

FIG 4: Node-2 Relay Circuit

Node-3: Node-3 architecture as shown below in Fig.-3.4 was implemented around another NodeMCU module. Here a commonly used gas sensor module MQ-135 was interfaced to the NodeMCU. As MQ-135 module used here was an analog output type so instead of using a digital input channel it utilized the only analog input channel A0 of NodeMCU. This channel fed internal ADC with the analog values and converted those values to their digital equivalents for further processing. The sensor was made to operate on 3.3V dc and acted as an input device here. On the other side another SPDT relay was interfaced to one of the digital I/O pins of the NodeMCU. The SPDT relay acted as an output device and was connected on pin D0 of the NodeMCU.

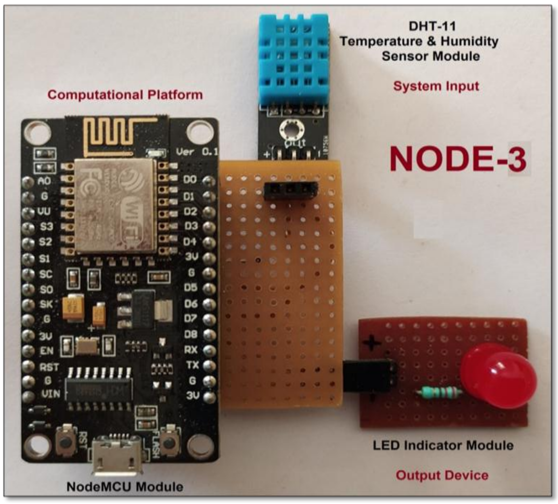

FIG 5: Node-3 Architecture

8. EXPERIMENTAL RESULTS

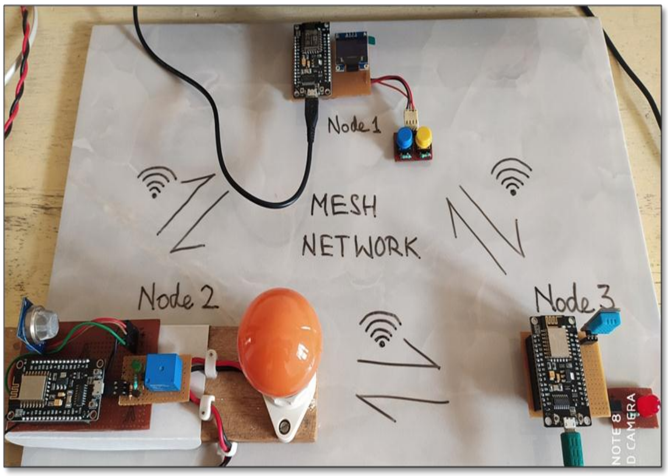

FIG 6: Experimental Set-up for the Proposed Work

Here the output response of hardware prototype was verified for each input to match the desired output. The working prototype should validate the work. Another way to check the results was by getting the outputs of each node connected in this mesh network over a serial port monitor. The serial port monitor used here was inbuilt in Arduino IDE. But here PuTTY was used. Here to power up the system as well as to serially monitor these nodes, each NodeMCU board was connected through laptop USB COM ports via cables. Each serial monitor window had a different COM port address and but the baud rate used by all the nodes was same i.e. 115200 bps. The Serial monitor window displayed the data of each node like the first node displayed the status of two outputs actuated by the push buttons. The second node displayed the DHT-11 sensor outputs over a different screen and similarly, the third was displaying the CO_2 Gas value over another screen.

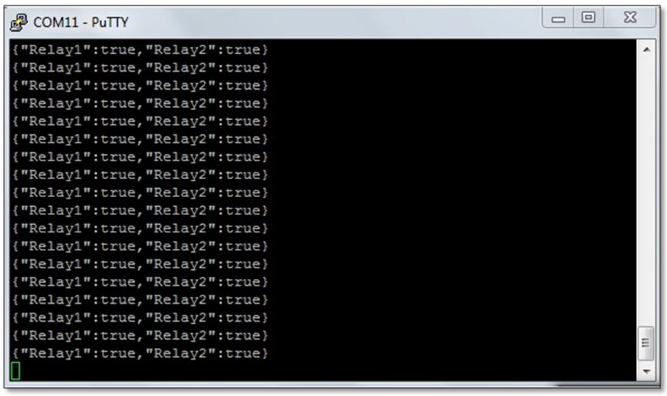

FIG 7: Node-1 Results Obtained on a Serial Monitor

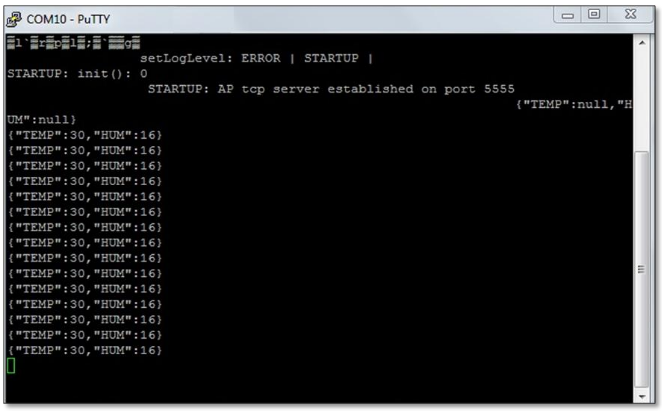

FIG 8: Node-2 Results Obtained on a Serial Monitor

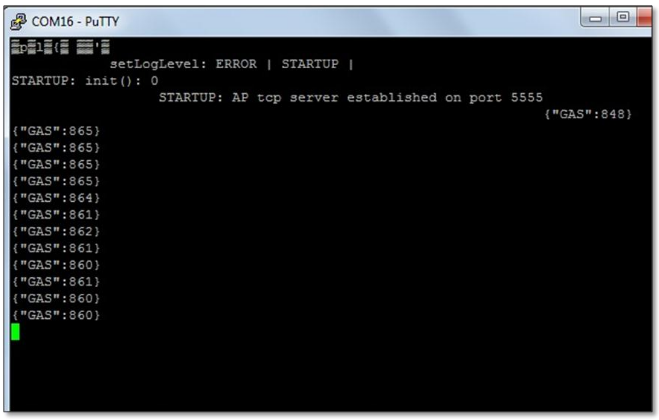

FIG 9: Node-3 Results Obtained on a Serial Monitor

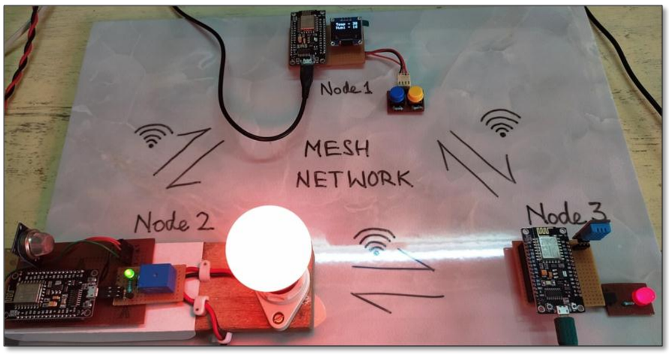

FIG 10: System in Operation

9. CONCLUSION

In this work the wireless mesh network topology was integrated with an IoT network where a set of nodes were made to share their data with each other acquired from the sensors and other input devices for performing corresponding actions over the output devices without using any internet or router in between. The IoT system was developed around NodeMCU which is a high performance low power low cost computational platform integrated with ESP8266 Wi-Fi SoC. The 'things' used here in this IoT network were input as well as output devices. Input devices included one DHT-11 sensor to measure zonal temperature and humidity values, another sensor to measure CO_2 Concentration levels in a particular area, and push buttons to trigger certain actions. Output devices were a relay switch module, OLED display module and an LED module for the demonstration of output results. Each node was uploaded with a different source code but the Wi-Fi credentials entered in each source code were the same for all the nodes. Here the demonstration was carried out on three nodes only. The number of nodes could increase to a significant level using this mesh network topology as here the nodes are mutually responsible for relaying each other's transmissions and these interconnected nodes resulted in a much larger coverage area. Also it was observed that the self healing property of mesh network The Hardware experimental set-up developed and demonstrated validated the work.

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