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1.0 Introduction :Identifying Value

1.1 Problem Recap

There is a big problem of farmers in smallhold farms accessing reliable agricultural information in most rural areas. A large number of systems of precision agriculture require the presence of continuous internet network, consistent electricity supply, and access of smart phones, which are usually inaccessible in rural farming areas. Consequently, farmers often tend to make decisions based upon paucity of information with regard to irrigation, crop protection and environmental risks. The absence of available technology is a contributor to the poor use of resources and high susceptibility to climatic events.

ROOT aims to fulfill this need by offering an offline-first IoT monitoring platform with rural agricultural climate in mind. This system relies on solar powered sensor nodes, LoRa peer-to-peer communication to gather environmental data and send it to a village gateway. Instead of storing the processed data on the cloud, ROOT executes edge-based analytics in real-time on the device and sends warnings to farmers through SMS. In this way, the farmers would not be denied the chance to get timely warnings and options, regardless of the lack of the internet connectivity.

1.2 Stakeholders

The major stakeholders of the ROOT system are small holder farmers who use the environmental information to make everyday farming decisions. Such farmers are the ones who are positively affected by early notification of cases of drought, frost, or unusual weather conditions. Another stakeholder group is known as cooperative administrators who can also take care of the community-level implementations of ROOT and organize data exchange between farmers. The agricultural extension officers are also significant as appropriate since they can utilize data gathered through ROOT to provide advisory services to the region and enhance agricultural planning in the region using aggregated data.

1.3 Value Delivered by the ROOT System

The ROOT system is valuable in providing dependable environmental surveillance and a decision aid in areas where conventional precision agriculture systems cannot exercise their functions. The system allows distribution sensing, edge processing, and communication

through SMS whereby the alerts are generated locally and sent to farmers within a short time. The simulation adopted in Cisco Packet Tracer illustrates the flow of sensor data in the system, the actions that are triggered by automation rules, and the triggering of alerts depending on environmental limits. This is a simulation that confirms the ability of ROOT to do sensing, processing and automated responses even when continuous connections to cloud are not needed.

1.4 Measurable Outcomes (KPIs)

KPLs	How Simulation Demonstrates It
False positive reduction via sensor corroboration	In the simulation, when the sensor that only shows abnormal values whilst other nearby sensors register normal values the system fails to trigger irrigation and alarm functions. This proves that the system will not give false alerts due to faulty sensor.
Water savings through precision irrigation	The irrigation actuator is only activated once the situation is droughty by numerous soil moisture sensors. This will make sure that the irrigation is done when needed, which will ensure that water is not wasted.
Offline system resilience	The offline test enables disabling of the cloud router and keeping sensors, automation rules and actuators local. This proves the fact that the system operates in the absence of internet.
Universal alert delivery	Alerts are processed locally and sent to the gateway using the cellular network, so farmers can get notifications on the simplest mobile phones, without the use of the internet.
Fast response to environmental conditions	The simulation environment shows that near real-time alerts can be generated by the automation rules as they activate immediately upon the crossing of environmental thresholds.

2.0 System Overview and Network Topology

2.1 Overall System Topology

The ROOT IoT system will be created in such a way that it monitors the environment of several farm plots and regulated irrigation and alerts. The simulated topology will comprise of five farm plots, which will have environmental sensors and irrigation pumps. These sensor nodes measure temperature value and soil moisture and send the data to a peer-to-peer mesh network based on LoRa-like wireless communication.

Sensor data is sent to a central village gateway which is the primary point of communication and processing of the system. The gateway performs edge processing such as filtering the sensor data, checking threshold conditions and triggering alerts or irrigation commands when needed. The gateway then links to an edge server to which the logs are saved, and the automation logic is controlled.

An optional cloud communication route to store and monitor data across advisory distances is also included in the system. Nonetheless, the ROOT is programmed such that when connections with the internet fail, it works anyway. In this situation, messages about alerts are sent via an independent GSM communication channel in which farmers can accept messages via their mobile phones as SMS. To have a visual representation of long-range mesh communication between distributed sensor nodes and the village gateway, a relay node is also incorporated in the topology.

2.2 Mapping Between Real ROOT System & Packet Tracer Simulation

Real ROOT Component	PT Representation	Why
LoRa P2P mesh network	Wi-Fi wireless communication	Packet Tracer does not support LoRa communication as such, Wi-Fi is employed to communicate the concept of wireless connectivity between the sensor nodes and the gateway.
ESP32 sensor nodes	Humidity Monitor + Temperature Monitor	These devices serve as the nearest possible environmental sensors in Packet Tracer to simulate the temperature and the readings of the soil moisture.
Village gateway (Raspberry Pi)	DLC100 ROOT_Gateway + Server-PT Edge_Server	The gateway is used to conduct wireless communication and the server represents edge computing and IoT automation logic.
SIM800L GSM modem (SMS alerts)	GSM_Cell_Tower + Farmer_Phone	Packet Tracer involves cellular tower and smartphone to symbolize SMS alert delivery to farmers.
LoRa relay node	DLC100 Relay_Node_Ridge	It is used as a graphical representation of long-range wireless relay communication between farm nodes and the gateway.
Solar panel + $LiFePO_4$ battery	Smart Solar Panel + Smart Battery	These elements replicate the supply of renewable power that is needed to run sensor nodes in distant areas at the farms.
Optional cloud server	Cloud_Server via	Represents remote cloud storage applied to optional

(InfluxDB)	Cloud_Router	monitoring and backup of data.
Capacitive soil moisture sensor	Humidity Monitor (% humidity ≈ % moisture)	Packet Tracer does not give a specific soil moisture sensor and thus humidity is taken as the nearest value.
DH22 temperature sensor	Temperature Monitor	Direct mapping since Packet Tracer offers a temperature monitoring gear.
Irrigation valve / pump	Lawn Sprinkler (x5< one per plot)	The automated sprinklers that are part of the system are lawn sprinklers.
Frost / heat / fault alerts	Siren (blue/red/yellow)	The Sirens are graphically simulated warnings in Packet Tracer.

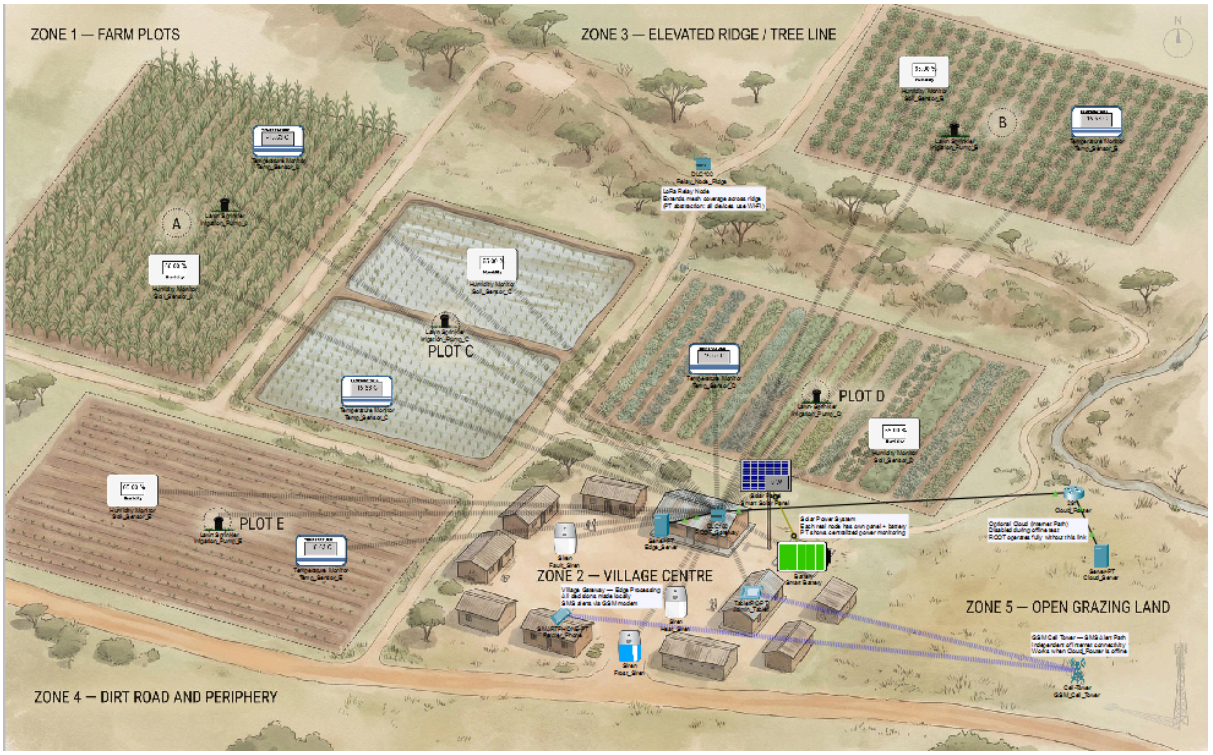


Figure 1: Full ROOT IoT System Topology in Logical View

In this screenshot, the entire network topology of the ROOT IoT system is displayed in Packet Tracer. The system comprises of 5 agricultural plots that have environmental sensors and irrigation pumps. The plots have temperature and soil moisture sensors which gather the environmental data and send it wirelessly to village gateway. The village centre gateway is the one making the edge processing and automation decisions. There is optional cloud

connectivity which is achieved via a cloud router and also GSM communication in which alerts can still be sent to farmers even in the absence of internet connectivity.

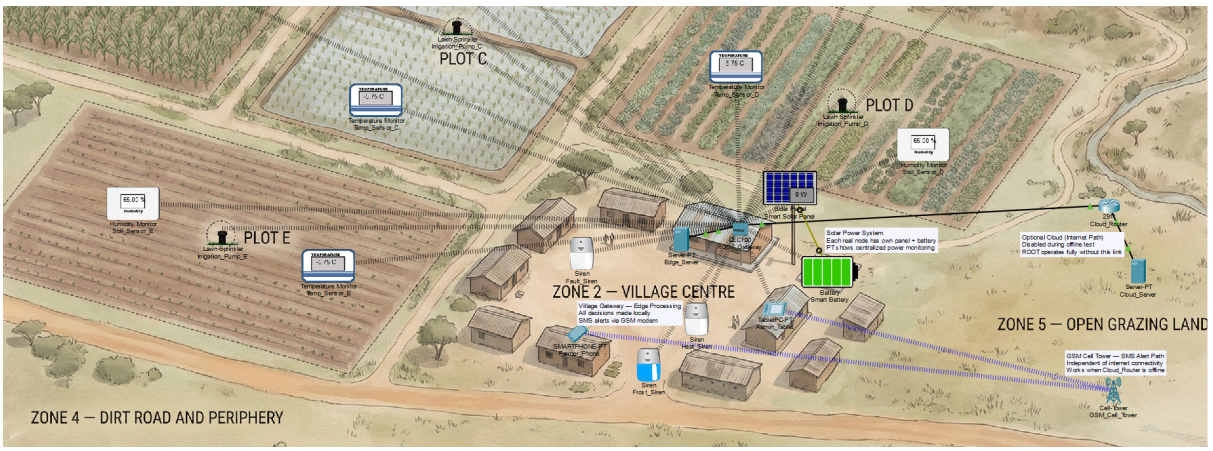


Figure 2: Village Centre Gateway and Edge Processing Components

In this screenshot, the village centre is highlighted in which the key processing units of the ROOT system can be found. The gateway device gathers information provided by the distributed sensor nodes over the farm plots and transmits the same to the edge server to process it. The edge server performs automation code like threshold control and irrigation control. Other elements including solar power system, battery storage and alert sirens are also evident in this section illustrating the infrastructure that supports the operation of the system and delivering alerts.

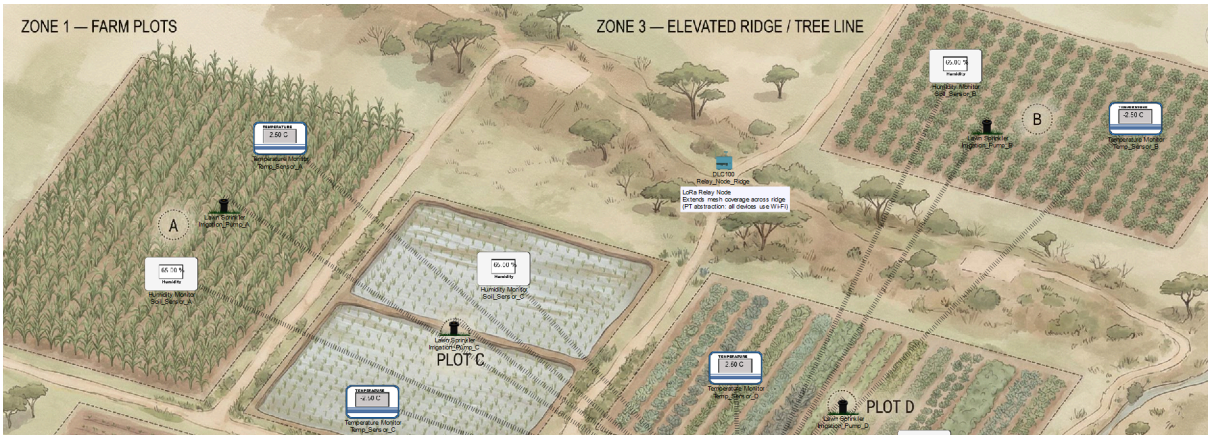


Figure 3: Sensor Node Deployment in Farm Plot

This screenshot shows a single farm plot that captures the environmental monitoring and irrigation system. The soil moisture sensor, temperature sensor and irrigation pump actuator are fitted in each plot. The sensor networks measure the environment and send the

information to the village gateway via the wireless network. In case soils have less moisture than the established limit, the automated system triggers the irrigation pump to irrigate the plants. This shows the local environmental monitoring allows the accurate control of irrigation.

3.0 Device Configuration

3.1 IP Addressing and Wireless Configuration

The ROOT IoT system has a private IPv4 addressing system employed in the local network to enable communication between sensors, gateway devices, servers, and user devices. The main gateway of the IoT network is the central ROOTGateway that serves as the general access point and the distributor of DHCP. The IP addresses of all sensor nodes and client devices are automatically allocated by the gateway with DHCP. This makes it easier to configure the network, as well as enable the devices to be added to the network dynamically.

The system relies on a secure Wi-Fi network whose SSID is ROOTMESH in case of wireless connectivity. WPA2-PSK authentication and AES encryption of the wireless network is used, so only certified devices will access the IoT infrastructure. This setup offers fine equilibrium between safety and simplified deployment in the rural setting where the technical help might be scarce.

The EdgeServer is set up with a fixed IP address such that all IoT gadgets would depend on it to depend on a fixed position in the network to send and receive sensor information as well as control commands. Under this implementation, the **Edge_Server** makes use of the IP address **192.168.1.10** whereas **ROOT_Gateway** is **192.168.1.1** and the default gateway used by the local network.

3.2 Device Configuration Table

Device	**Type**	**IP address**	**Connection Method**	**IoT Server**
ROOT_Gateway	DLC100	192.168.1.1	Access Point (Wi-Fi)	-
Edge_Server	Server-PT	192.168.1.10 (Static)	Wired to ROOT_Gateway	Runs IoT Service

Cloud_Server	Server-PT	10.0.1.10	Wired to Cloud_Router	Cloud Data Storage
Cloud_Router	Cisco 2911	10.0.0.1 / 10.0.1.1	Wired Routing	Internet connectivity
GSM_Cell_Tower	Cellular Tower	Provider network	Wireless cellular link	SMS transmission
Frost_Siren (blue)	Siren	192.168.1.118 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Heat_Siren (red)	Siren	192.168.1.119 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Fault_Siren (yellow)	Siren	192.168.1.111 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Smart Solar Panel	IoT Power Device	192.168.1.138 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Smart Battery	IoT Power Device	192.168.1.132 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Admin_Tablet	Tablet PC	192.168.1.102 (DHCP)	Wi-Fi (ROOT_MESH)	Client monitoring
Farmer_Phone	Smartphone	Cellular network	GSM_Cell_Tower	SMS recipient
Relay_Node_Ridge	IoT Relay Node	DHCP	Wi-Fi (ROOT_MESH)	Data forwarding
Temp_Sensor_A	Temperature Monitor	192.168.1.134 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Temp_Sensor_B	Temperature Monitor	192.168.1.141 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Temp_Sensor_C	Temperature Monitor	192.168.1.110 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Temp_Sensor_D	Temperature Monitor	192.168.1.133 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server

Temp_Sensor_E	Temperature Monitor	192.168.1.109 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Soil_Sensor_A	Humidity Monitor	192.168.1.100 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Soil_Sensor_B	Humidity Monitor	192.168.1.124 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Soil_Sensor_C	Humidity Monitor	192.168.1.106 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Soil_Sensor_D	Humidity Monitor	192.168.1.127 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Soil_Sensor_E	Humidity Monitor	192.168.1.105 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Irrigation_Pump_A	Lawn Sprinkler	192.168.1.112 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Irrigation_Pump_B	Lawn Sprinkler	192.168.1.115 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Irrigation_Pump_C	Lawn Sprinkler	192.168.1.122 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Irrigation_Pump_D	Lawn Sprinkler	192.168.1.126 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server
Irrigation_Pump_E	Lawn Sprinkler	192.168.1.129 (DHCP)	Wi-Fi (ROOT_MESH)	Edge_Server

The remaining sensors and actuators use the same configuration options settings and can automatically receive a unique IP address by DHCP issued by the ROOT_Gateway.

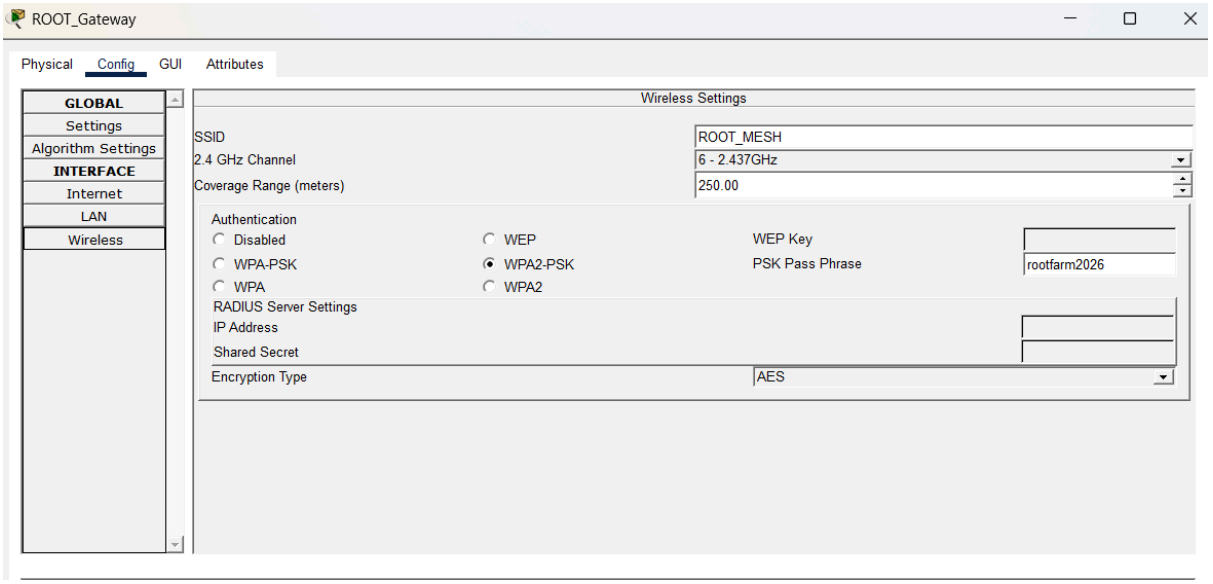


Figure 4: ROOT Gateway Wireless Configuration

This is a screenshot that presents the wireless control of the ROOT_Gateway device. The SSID of the gateway is ROOT_MESH, and its authentication is WPA2-PSK where the encryption is based on AES to provide safe wireless connectivity to all IoT sensors and devices in the farm network.

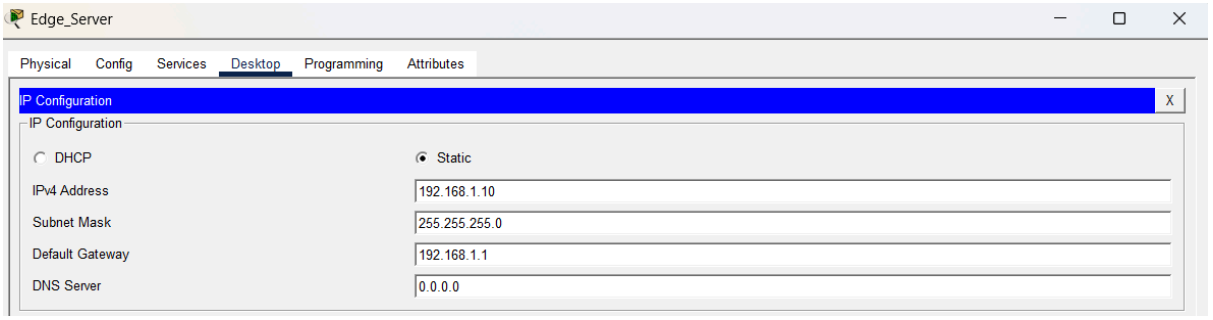


Figure 5: Edge Server Static IP Configuration

In this screenshot, the IP settings on the Edge_Server are displayed. The server will have an assigned statistical IP address(192.168.1.10) with a subnet mask 255.255.255.0 and default gateway 192.168.1.1 which all IoT devices can send sensor data on to a fixed processing server.

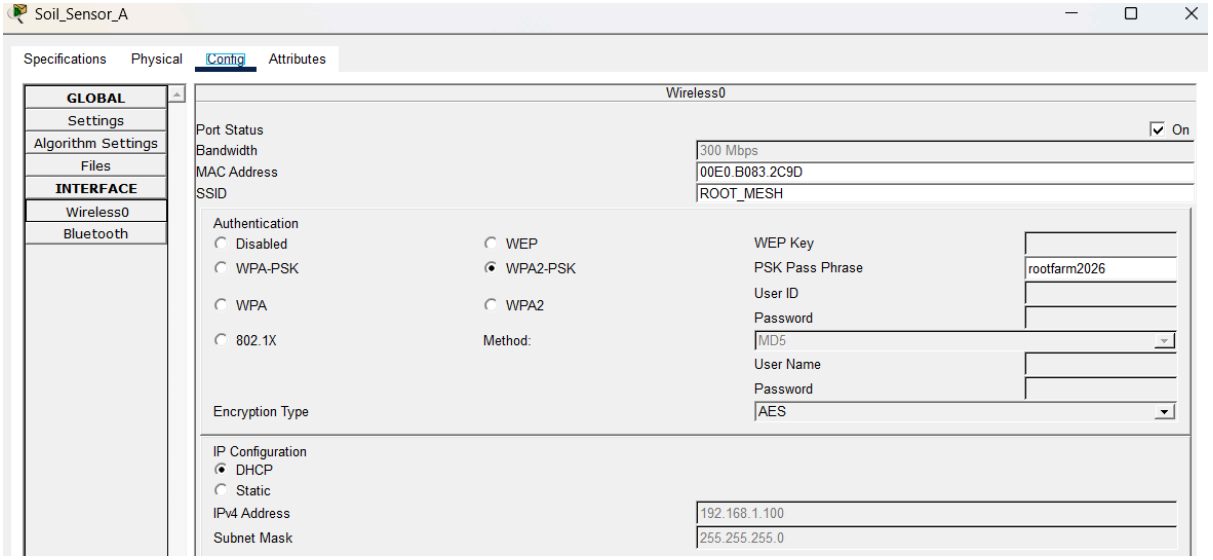


Figure 6: Sensor Device Configuration Example

This screenshot indicates wireless configuration of Soil_Sensor_A. Environmental data is sent to the system through WPA2-PSK security and AES encryption which provides security and safety to the sensor when connecting it to the ROOT_MESH wireless network.

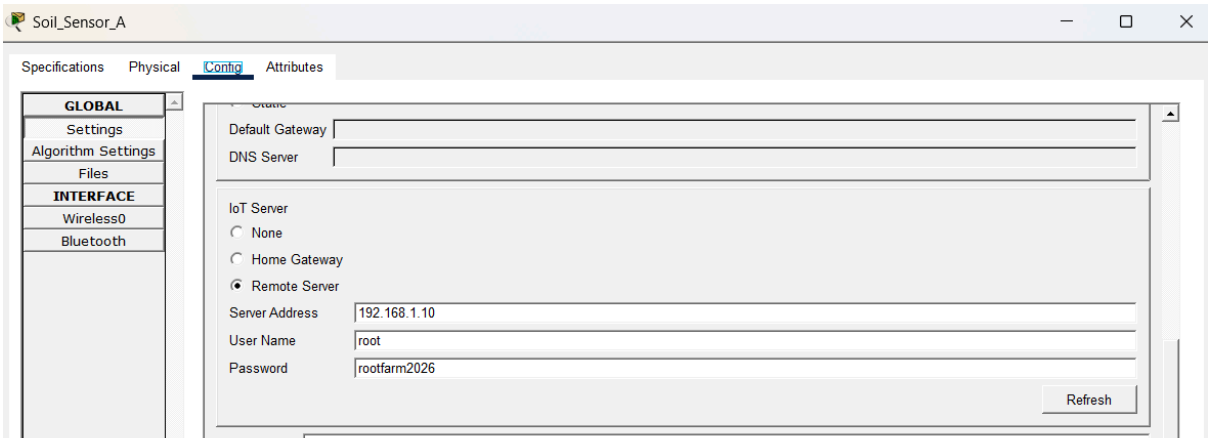


Figure 7: Sensor Device Configuration Example

This screenshot displays the sensor device IoT server setup. The sensor is set to transmit its data to the Edge_Server (192.168.1.10), and the central processing and monitoring of the environmental conditions can be made.

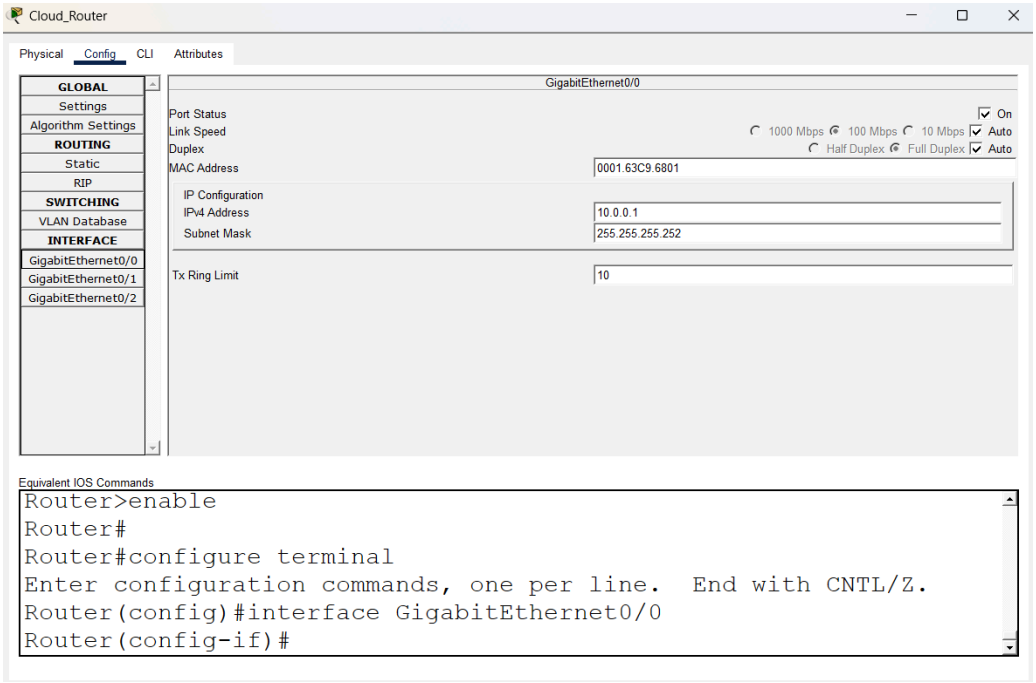


Figure 8: Cloud Router Interface Configuration (Interface 1)

This screenshot displays the configuration of the **GigabitEthernet0/0** on the Cloud_Router. To facilitate communication between the IoT network and the external cloud infrastructure, the interface has an IP address and subnet mask.

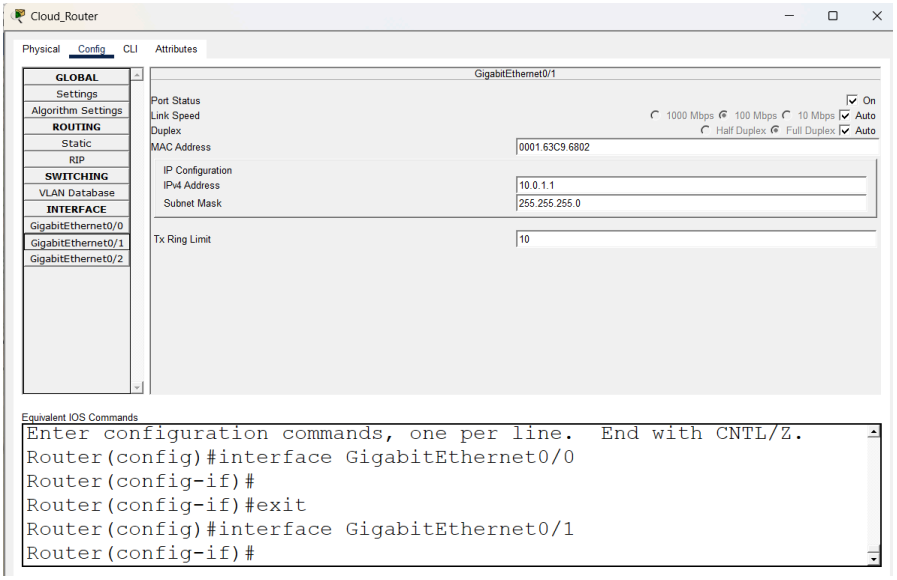


Figure 9: Cloud Router Interface Configuration (Interface 2)

This is a screenshot of GigabitEthernet0/1 of the Cloud_Router. The interface is used to route between various segments of the network and also to communicate between the local IoT system and external services.

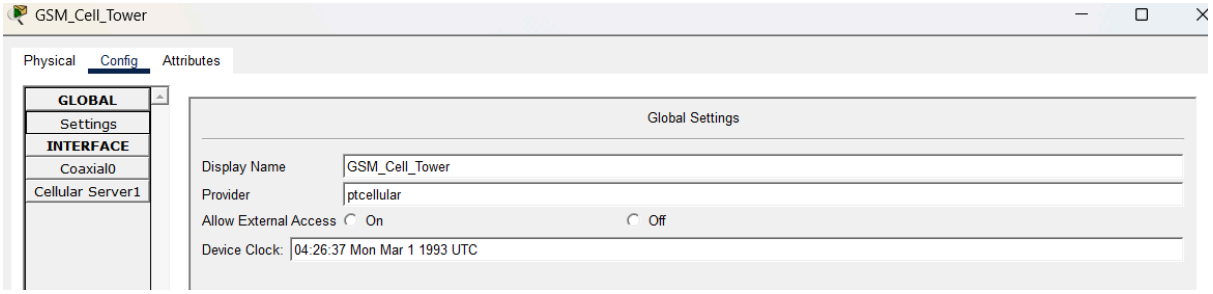


Figure 10: GSM Cell Tower Configuration

In this screenshot, the configuration of the GSM_Cell_Tower in the simulator is displayed. The tower simulates a mobile network with the help of the ptcellular provider that sends SMS alerts and notifications to the farmer.

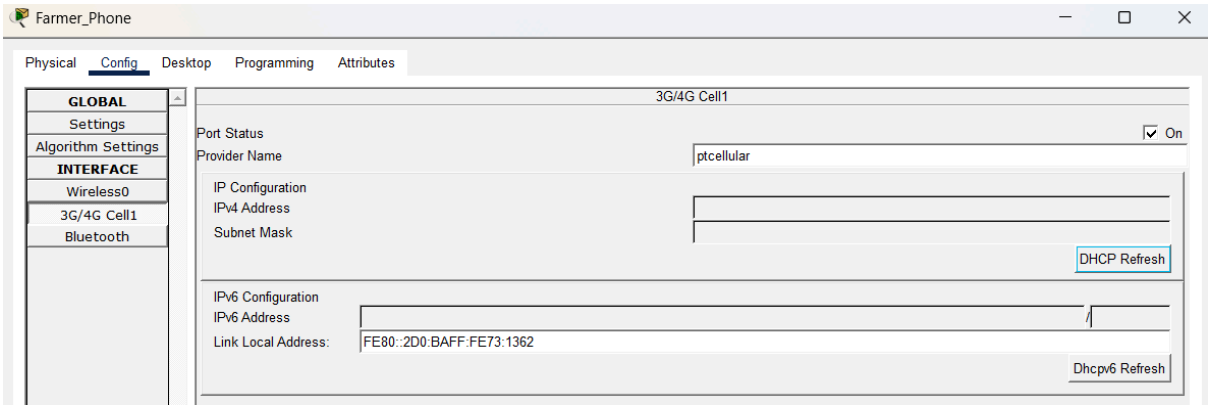


Figure 11: Farmer Phone Cellular Connection

This is a screenshot of the cellular configuration of the Farmer_Phone device. The phone uses the 3G/4G interface connecting it to the GSM cellular network (ptcellular) enabling the farmer to get a notification and system alerts when not present.

4.0 Sensor Simulation

In this simulated IoT system, we have to change the sensor values manually through the device properties in Cisco Packet Tracer. Packet Tracer has no provision of fully scripted dynamic simulation of sensors on most IoT devices, and thus sensor values are driven manually to experiment with the system. To modify a sensor value the user may simply click on the sensor device and use the slider or value field in the device properties panel. This enables the modeling of various scenarios within the environment as well as showing how the system responds to varying circumstances.

Every type of sensor in the simulation is an environmental parameter of the agricultural monitoring system. The Humidity Monitor devices reflect the percentage of soil moisture.

These sensors are used to show the amount of water in the soil, and it is utilized to know when they need to irrigate their farms. The Temperature monitor devices are the ambient air temperature in degrees Celsius (**°C**). Temperature sensations are significant to identify the extreme weather conditions like frost or heat waves. The Smart Solar panel device is a product of solar power production, which is taken as a proxy measure of solar radiance or daylight strength. The value is useful in finding out the amount of solar energy that can be utilized in charging the smart battery system.

In the simulation, a number of value ranges were utilized to test the system behavior. In normal conditions of operation, the soil moisture values lie between **40%** and **70%** which implies that soil is in healthy operating conditions to support crops. Once the soil moisture becomes less than **30%,** it will be treated as a drought condition and the irrigation automation will be activated. In temperature checking, the normal temperature of the environment lies between **15°C** and **30°C**. Below **5°C** a frost condition is simulated and the frost warning system becomes active and over **35°C** extreme heat is simulated and the heat alert mechanism activated.

There was as well a fault scenario which was simulated to signify a sensor failure or an unnatural soil environment. An unrealistic reading value that was set to under **5%** of soil moisture was attributed to a single sensor device in this case. This enables the system to make an identification of abnormal sensor action and send a fault signal via the monitoring system. Such simulated values can be used to show how the IoT system responds to various environmental conditions and how automated reaction to sensor data happens.

Parameter	Normal Range	Drought Trigger	Frost Trigger	Heat Trigger	Fault Simulation
Soil Monitor	40-70%	< 30% (all sensors)	-	-	< 5% (one sensor)
Temperature	15-30°C	-	< 5°C (all sensors)	> 35° °(all sensors)	-

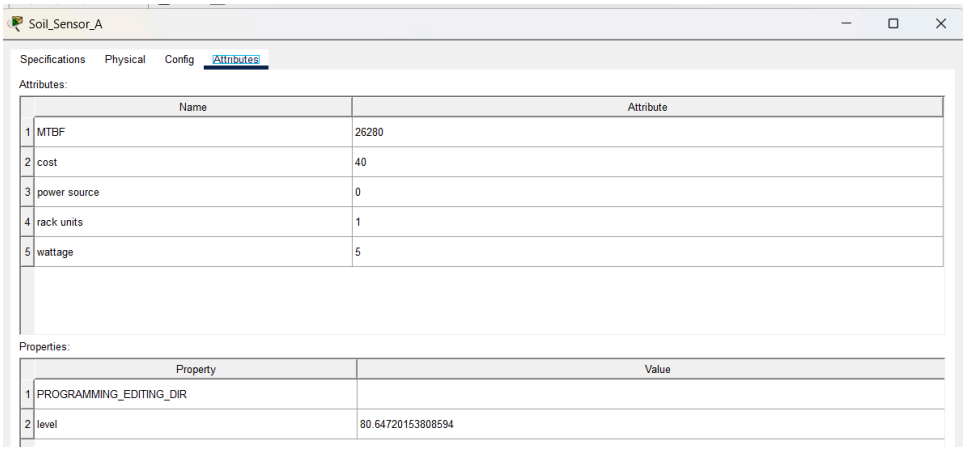


Figure 12: Sensor Properties Panel

Displays sensor properties panel of a device like **Soil_Sensor_A,** where the sensor value can manually be modified through the slider to create the environmental conditions.

5.0 Automation Logic

The ROOT system applies to four automation scenarios that operate on the edge gateway without involving cloud connectivity. The edge server does not stop and constantly tracks environmental measurements, obtained with a distributed sensors, analyzing a predetermined rule condition. An automatic triggering of the relevant actuators like irrigation pumps or alert sirens is activated when particular thresholds are present. This edge processing towns also means that the system will be able to operate even though there is no internet connection.

5.1 Drought Detection & Irrigation Control

In this automation, the drought condition is identified through the soil moisture reading of various sensors planted within the plots of land. The system measures the values of soil moisture recorded by the sensors of Soil_Sensor_A, Soil_Sensor_B, Soil_Sensor_C, Soil_Sensor_D and Soil_Sensor_E constantly.

When all five sensors report the soil moisture below 30%, the water situation is identified as a drought condition. This collective confirmation mechanism helps ensure that the event that was detected is a real condition in the environment and not just some isolated sensor error.

Hysteresis logic is used to avoid switching the irrigation system fast between high and low. The pumps that control the irrigation are turned on when the moisture content of the soil

drops to below 30% and turned off when it goes above 40%. Two sets of thresholds are used to stabilizer the system and avoid continuous on-off cycling.

Once the drought condition has been confirmed, the system starts all irrigation pumps Irrigation_Pump_A, Irrigation_Pump_B, Irrigation_Pump_C, Irrigation_Pump_D and Irrigation_Pump_E at the same time, where this allows water to be spread to the farm plots.

This automation case is associated with the drought detection algorithm that was outlined in Assignment 2.

5.2 Frost Alert

The frost alert system records very low temperatures which can be destructive to crops. The system is used to monitor temperature readings of all temperature sensors deployed. There is a frost condition that is induced when the temperature falls below 5°C over the monitored sensors. This temperature is the approximate temperature of crops that can undergo frost damage. Under this condition, Frost Siren (blue) is triggered, which issues an immediate warning sign to the farmers, enabling them to take appropriate precautionary measures, e.g. wrapping the crops or turning on the frost protective measures.

This warning system helps to identify the possible threat of weather in time.

5.3 Heat Stress Alert

Heat stress is another of the most essential environmental conditions that are tracked by the system. Together with high temperatures, it can have great impact on plant growth and crop productivity. The system will check the temperature readings of all the temperature sensors and will provide a heat alert when the temperature rises above 35°C. Such a degree is the point of temperature at which, after long exposure, crop stress may occur.

Hysteresis is also used in this case in order to prevent frequent activation as well as deactivation of the alert. The heat alert is made to go off when the temperature exceeds 35°C and it is made to turn off when the temperature exceeds 30°C. The Heat-Siren (red) is provided when the heat condition is triggered so that there is a visual and auditory alert of excessive heat conditions.

5.4 Sensor Fault Detection

The ROOT system further provides a sensor fault detection system that utilizes collective corroboration among a number of sensors. This aspect gives one the ability to distinguish between actual environmental caprice and sensor failures. Whenever one of the soil sensors indicates a very low soil moisture level (say below 5) and the rest indicate a normal level above 30, the system considers this case to be sensor failure and not a case of drought.

What is not activated by the irrigation rule in this situation is that the drought situation has all the sensors report low level of moisture. Rather the system triggers Fault_Siren (yellow) to tell that the sensor can be incorrect and it should be checked.

This system works to eliminate the false irrigation event and provide a higher quality of system operation.

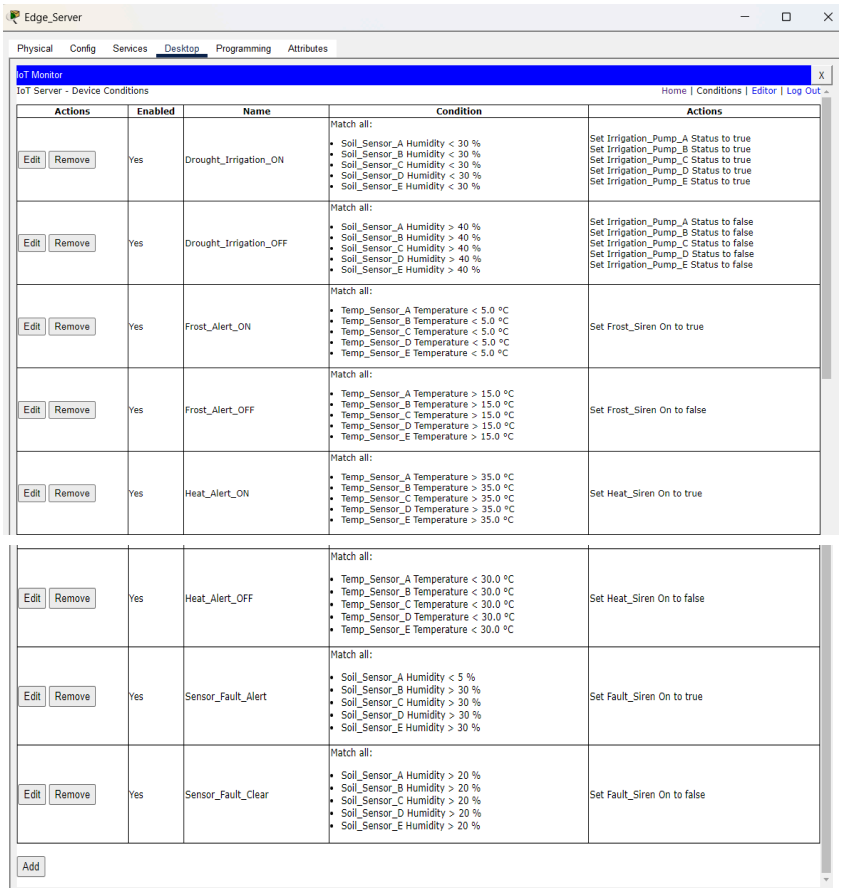


Figure 13: Full Automation Condition Page

Displays the automation conditions that are set in the Edge_Server IoT Monitor. The rules specify the environmental levels on which irrigation pumps and alarm sirens are activated according to sensor readings.

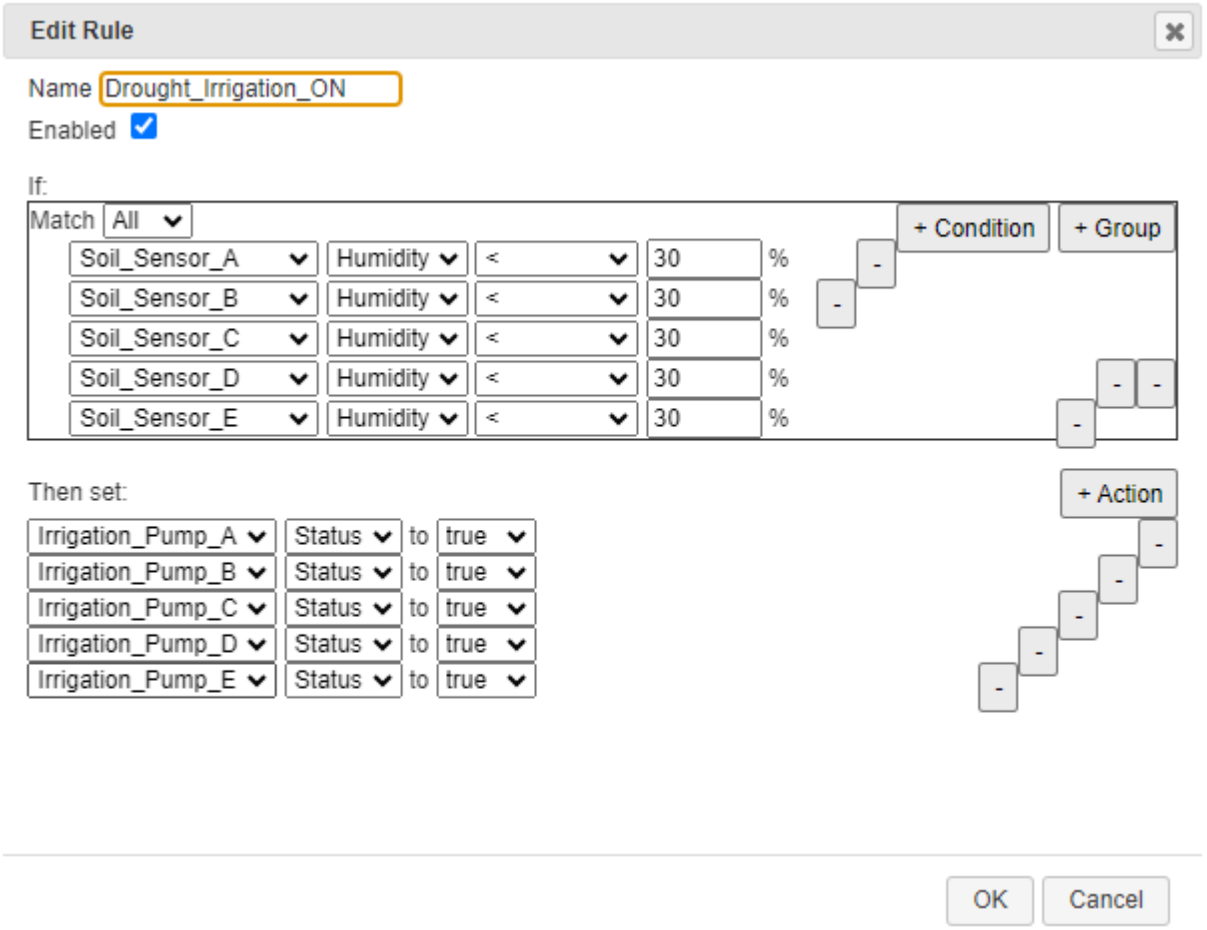


Figure 14: Condition Rule Configuration

Displays the state setup that identifies the situation of drought. The rule switches on irrigation when all the soil moisture sensors report the values below the established level.

6.0 Actuator Control

6.1 Actuators in the ROOT System

The ROOT IoT system is an automatic system utilizing a number of actuators in response to the environment as detected by the sensors. These actuators are devices that can be used to take physical activities like turning on the irrigation system or sending notifications to farmers in the event of some hazardous environmental events. The IoT devices that represent actuators in the Packet Tracer simulation include the sirens and the lawn sprinklers. Such devices are activated by the commands of the edge server once the automation rules set in **Section 5** are activated. The actuators play the role of carrying out system responses, to make

sure that the environmental risks like drought, frost, heat stress, or sensor failures are managed speedily and efficiently.

6.2 Actuator Devices

The table below shows the number of actuators that are being simulated in the ROOT IoT model, and their representation in the actual agricultural system.

Actuator	PT Device	Colour When Active	Represents
Irrigation_Pump_A-E	Lawn Sprinkler x5	Animated water spray	Per-plot irrigation valves
Frost_Siren	Siren	Blue	SMS frost warning to farmers
Heat_Siren	Siren	Red	SMS heat stress alert
Fault_Siren	Siren	Yellow	SMS sensor maintenance alert

These actuators enable the system to make physical responses to environmental incidences as detected by the sensations.

6.3 Control Modes

ROOT system has two control modes on actuators.

6.3.1 Automatic Control

The automation logic on the IoT server conditions (Section 5) activates actuators in the automatic mode.

The edge server constantly checks sensor values like water content and temperature of the soil. A condition rule is met and the system takes the form of automatically transmitting the relevant actuator commands.

For example:

- ➢ When the soil moisture reduces to a drought level, the pumps that irrigate the soil will come into force.

- ➢ When the temperature is below the frost threshold, the frost alert siren is activated.
- ➢ When the temperature becomes greater than the heat stress threshold the heat alert siren switches on.

This automated behaviour enables this system to react fast to changes in the environment without the human intervention.

6.3.2 Manual Control

System administrators can directly manage the actuators in the ieOT Monitor dashboard in the manual mode.

The administrator connects to the IoT server with the help of the Admin_Tablet device and opens the services of the interface with the help of a web browser, the IoT Monitor. Through the dashboard, the administrator can be able to choose a device and be able to turn it on/off manually.

Manual control can help in system testing, system maintenance or when special circumstances may be involved, start irrigation.

6.4 Manual Override in ROOT

The control of actuators during automation breaks can be used manually to enable the administrator to have a temporary control of the actuators.

Throughout the system testing or when the equipment is undergoing regular maintenance, a cooperative administrator can manually turn on irrigation pumps irrespective of sensor feedback. This is to make sure that the irrigation infrastructure can be tested without having to wait until a drought condition takes place.

Manual override enhances the flexibility of the system whilst automated monitoring of normal operations exists.

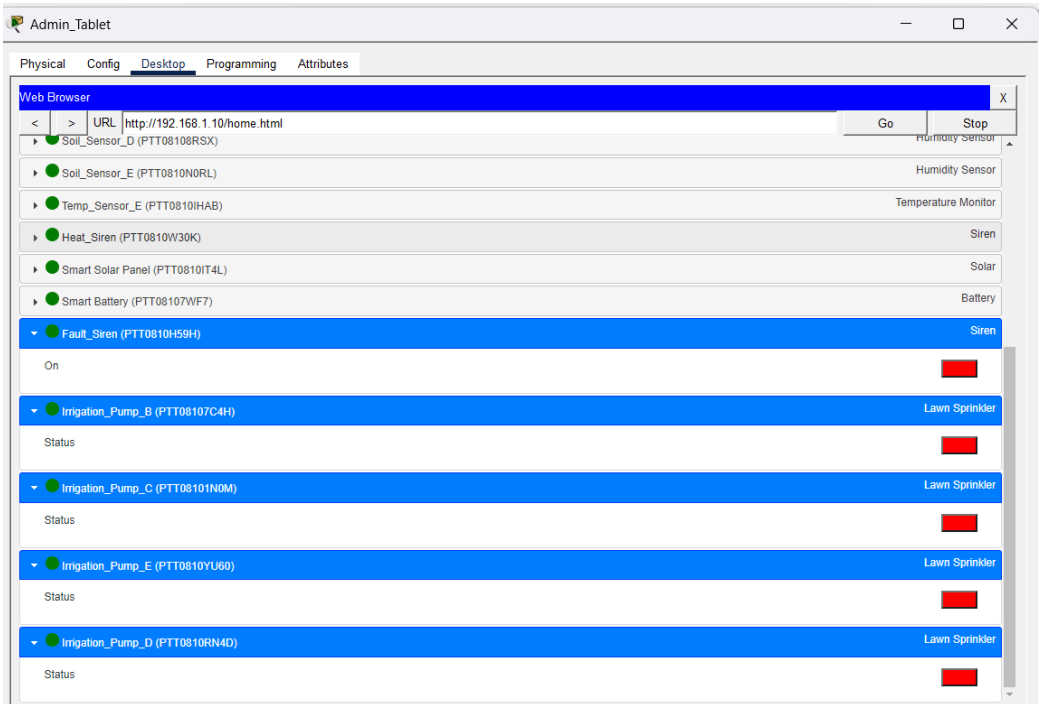


Figure 15: Manual Override (before activation)

The system shows all the actuators in the initial state prior to their actuation by hands. The irrigation pumps are not active, which indicates the normal conditions of the system before it is controlled by the administrator.



Figure 16: Manual Override (after activation)

The automated system is controlled manually by the administrator using the Admin Tablet to turn on the irrigation pumps. This is an example of the direct control of actuators that do not depend on predetermined automation regulations.

7.0 Test Cases & Demonstration Results

The below test cases confirm the fundamental automation cases in ROOT. All tests show the reaction of the system to sensor readings and actuator reaction by automation logic and manual controls.

Test Case 1: Drought Detection

Purpose: Check the irrigation on at the condition that all the sensors signal that the moisture level is low.

Input: Each of the 5 soil sensors programmed to around 15% moisture (lower than 30% drought parameter).

Measured Aspect: The lower five irrigation pumps Irrigation_Pump_A - Irrigation_Pump_E should be turned ON and the sprinklers should start.

Measurement: After the soil sensors gave all low moisture readings, the system on its own turned on the five irrigation pumps. In the simulation, there was sprinkler animation.

Result: Pass

Significance: It adds weight to the fact that ROOT effectively identifies drought conditions and automatically triggers irrigation in case a number of sensors report the same.

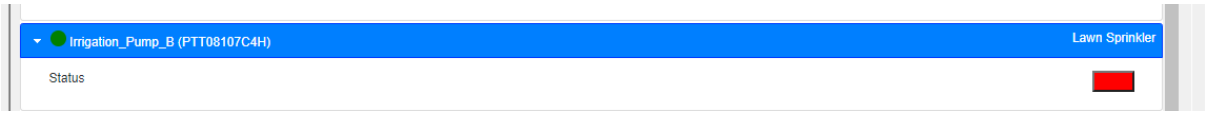


Figure 17: System State Before Trigger (OFF)

The pump control is off at the usual condition of operation of the pump before any test input has been applied, and thus no automation rule was activated.

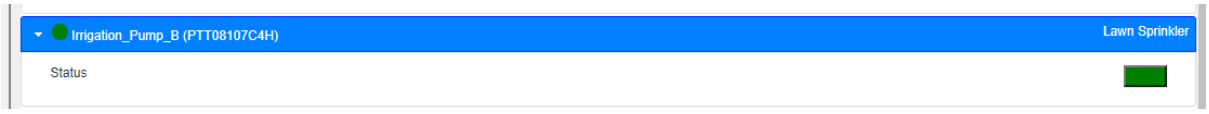


Figure 18: System State After Trigger (ON)

When the test condition is used, the system will automatically switch on the irrigation pump, as it shows a positive and responsible response to sensor input.

Test Case 2: Frost Alert

Purpose: To confirm that frost sirens work when all of the temperature sensors have detected cold conditions.

Input: All the five temperature sensors set around 1°C (below the 5°C frost threshold)

Measured Aspect: Frost_Siren gets activated & achieves blue indicator.

Measurement: Sensors have not responded to hot temperature and frost sirens was triggered automatically.

Result: Pass

Significance: Show that ROOT can be used to detect frost risk and trigger warning signs to protect crops.

Edit Remove	Yes	Frost_Alert_ON	Match all: • Temp_Sensor_A Temperature < 5.0 °C • Temp_Sensor_B Temperature < 5.0 °C • Temp_Sensor_C Temperature < 5.0 °C • Temp_Sensor_D Temperature < 5.0 °C • Temp_Sensor_E Temperature < 5.0 °C	Set Frost_Siren On to true
Edit Remove	Yes	Frost_Alert_OFF	Match all: • Temp_Sensor_A Temperature > 15.0 °C • Temp_Sensor_B Temperature > 15.0 °C • Temp_Sensor_C Temperature > 15.0 °C • Temp_Sensor_D Temperature > 15.0 °C • Temp_Sensor_E Temperature > 15.0 °C	Set Frost_Siren On to false

Figure 19: Frost Alert Configuration and Validation

The figure demonstrates the setup and successful test of the frost alert system whereby the frost alert system automatically switches the siren on once the temperature reaches a minimum of 5°C and switches off once the temperature reaches beyond 15°C which ensures that the frost alert system is operating properly.

Test Case 3: Heat Stress Alert

Purpose: Check heat siren operating under high temperature.

Input: The heat sensors are all set to around 40°C (heat thermostat at 35°C).

Measured Aspect: Heat Siren switches on and have red indicator.

Measurement: Temperature sensors were registering high values of heat and heat siren triggered.

Result: Pass

Significance: Confirmed that ROOT is able to measure dangerous heat levels and send messages to avoid heat stress on crops.

Edit Remove	Yes	Heat_Alert_ON	Match all: • Temp_Sensor_A Temperature > 35.0 °C • Temp_Sensor_B Temperature > 35.0 °C • Temp_Sensor_C Temperature > 35.0 °C • Temp_Sensor_D Temperature > 35.0 °C • Temp_Sensor_E Temperature > 35.0 °C	Set Heat_Siren On to true
Edit Remove	Yes	Heat_Alert_OFF	Match all: • Temp_Sensor_A Temperature < 30.0 °C • Temp_Sensor_B Temperature < 30.0 °C • Temp_Sensor_C Temperature < 30.0 °C • Temp_Sensor_D Temperature < 30.0 °C • Temp_Sensor_E Temperature < 30.0 °C	Set Heat_Siren On to false

Figure 20: Stress Alert System Configuration and Validation

The figure demonstrates the setup and validation of the heat stress alert system with the system engaging the siren when the system reaches 35°C and switching off when it passes the temperature of 30°C, which proves the correct functioning of the system.

Test Case 4: Sensor Fault Detection

Purpose: Check whether the system is able to differentiate sensor malfunction and actual drought.

Input: Soil_Sensor_A is set at 2% moisture and Soil_Sensor_B - Soil_Sensor_E are set at 45%.

Measured Aspect: Fault_Siren is on yellow and all irrigation pumps are off.

Measurement: The system detected the sensor fault of SoilSensorA in the abnormal reading as such and not as a drought. There was a fault siren on and the irrigation pumps remained off.

Result: Pass

Significance: This illustrates the co-verification facility of ROOT that thwarts the false irrigation episodes due to fault sensors.

Edit Remove	Yes	Sensor_Fault_Alert	Match all: • Soil_Sensor_A Humidity < 5 % • Soil_Sensor_B Humidity > 30 % • Soil_Sensor_C Humidity > 30 % • Soil_Sensor_D Humidity > 30 % • Soil_Sensor_E Humidity > 30 %	Set Fault_Siren On to true
Edit Remove	Yes	Sensor_Fault_Clear	Match all: • Soil_Sensor_A Humidity > 20 % • Soil_Sensor_B Humidity > 20 % • Soil_Sensor_C Humidity > 20 % • Soil_Sensor_D Humidity > 20 % • Soil_Sensor_E Humidity > 20 %	Set Fault_Siren On to false

Figure 21: Sensor Fault System Configuration and Validation

That figure demonstrates how the sensor fault alert system is configured and validated, such that out of the ordinary readings of humidity control the fault siren and the normal readings turn off the fault siren, indicating the proper functioning of the system.

Test Case 5: Manual Automatic Control

Purpose: Confirm that administrators can manually operate actuators using the client device.

Input: Admin opens the browser on Admin_Table and poems the IoT dashboard and switches Irrigation_Pump_A

Measured Aspect: The Pump A switch takes place depending on the manual instruction.

Measurement: The administrator was able to use the IoT dashboard interface on the tablet to control the irrigation pump.

Result: Pass

Significance: Displays distant actuator control to the system administrators.

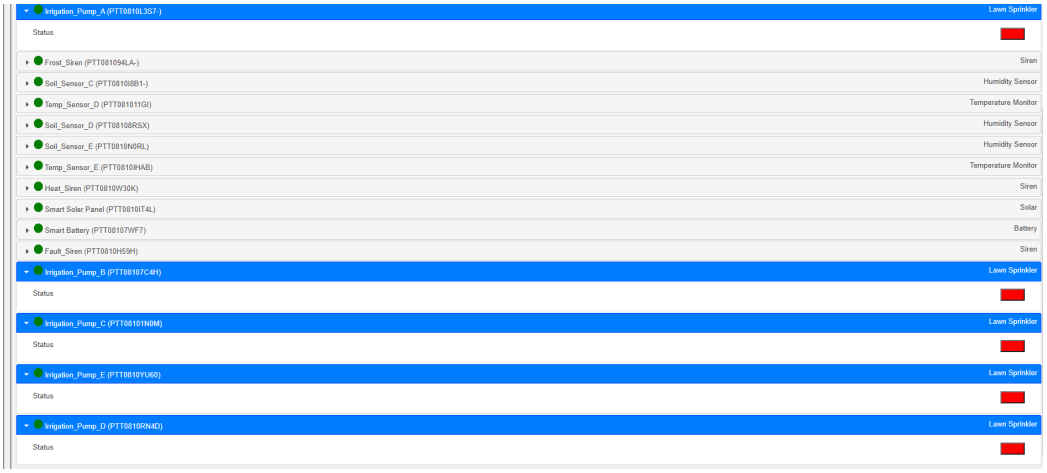


Figure 22: Manual Control Irrigation Pump (OFF)

This figure will be the initial one depicting the initial conditions in the irrigation system with all the pumps being switched to OFF using the IoT dashboard. The administrator is yet to impose manual control which shows that the system is in default inactive state before a user acts on it.

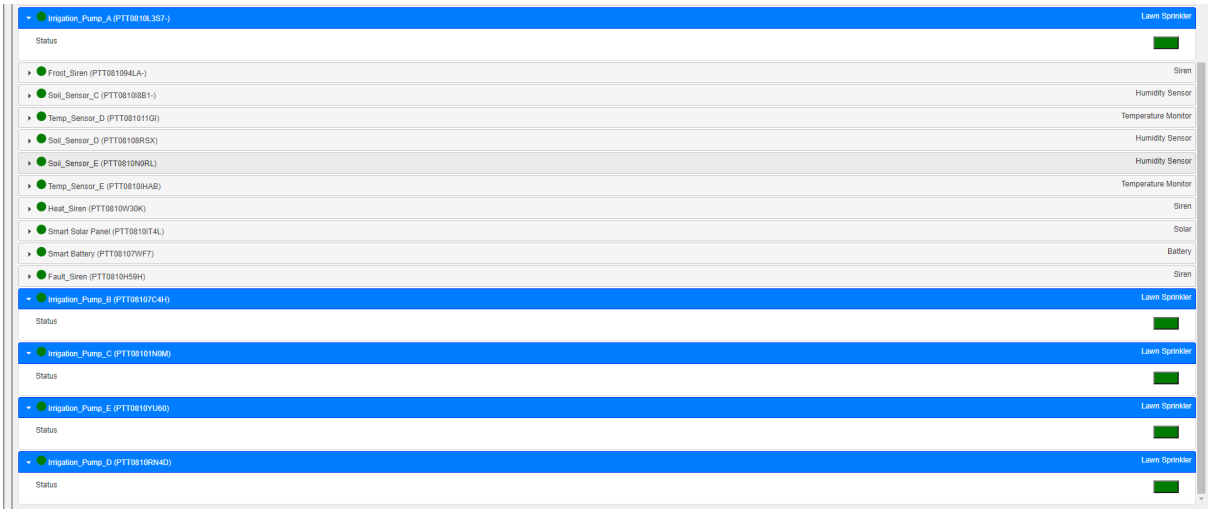


Figure 23: Manual Control Irrigation Pump (ON)

This statistic is to show how the irrigation system can be turned on manually using the IoT dashboard. The administrator is notified by simply flicking the pumps ON, which ensures that manual control is achieved and the real-time system is responsive.

Test Case 6: Offline Resilience

Purpose: Check that the system remains functional without cloud connectivity

Input: Set Cloud_Router GigabitEthernet0/0 port off, provoke drought (soil sensors below 30%).

Measured Aspect: Cloud disconnection (red X) with the activation of irrigation pumps at the local level.

Measurement: despite the loss of connection with the cloud, the local automation system remained functional and irrigation pumps did start according to normal.

Result: Pass

Significance: Shows ROOT is based on the offline-first architecture, and local automation is permitted even in the absence of an internet connection

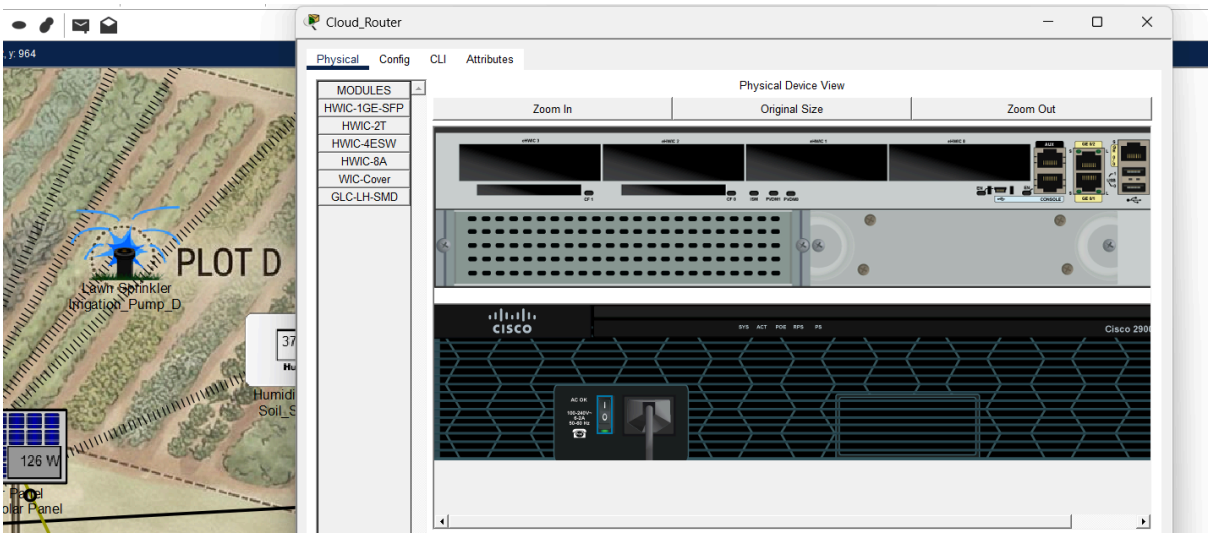


Figure 24: Cloud Router Active (System Online Mode)

This figure presents a representation of a condition in which the system is operating with the cloud router active. The irrigation pump is working properly showing that the system acts as expected in case there is an opportunity to be connected.

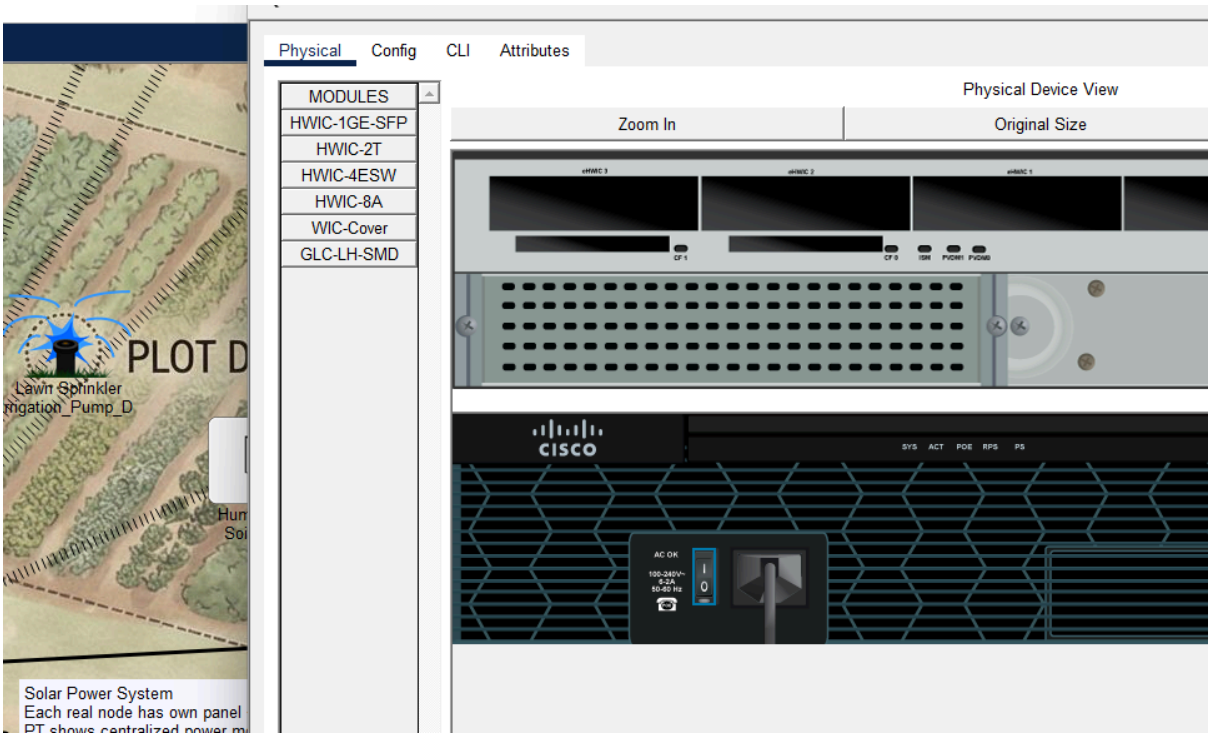


Figure 25: Cloud Router Disabled (Offline System operation)

This figure illustrates how the system would still work even at a time when the cloud router would be off. Even after the connectivity is lost, the irrigation pump is kept running according to the logic of local control which validates that offline resilience and system reliability have been achieved.

Test Case 7: Data Communication

Purpose: Register a packet stream between sensors, gateway and server.

Input: Packet Tracer to Simulation Mode, adjust sensor value and monitor packet transmission.

Measured Aspect: Packet traffic between sensor and ROOTGateway and Edge Server.

Measurement: Simulation mode showed the packets being transmitted with wireless network and to the server.

Result: Pass

Significance: Shows the intra design data flow of the IoT system.

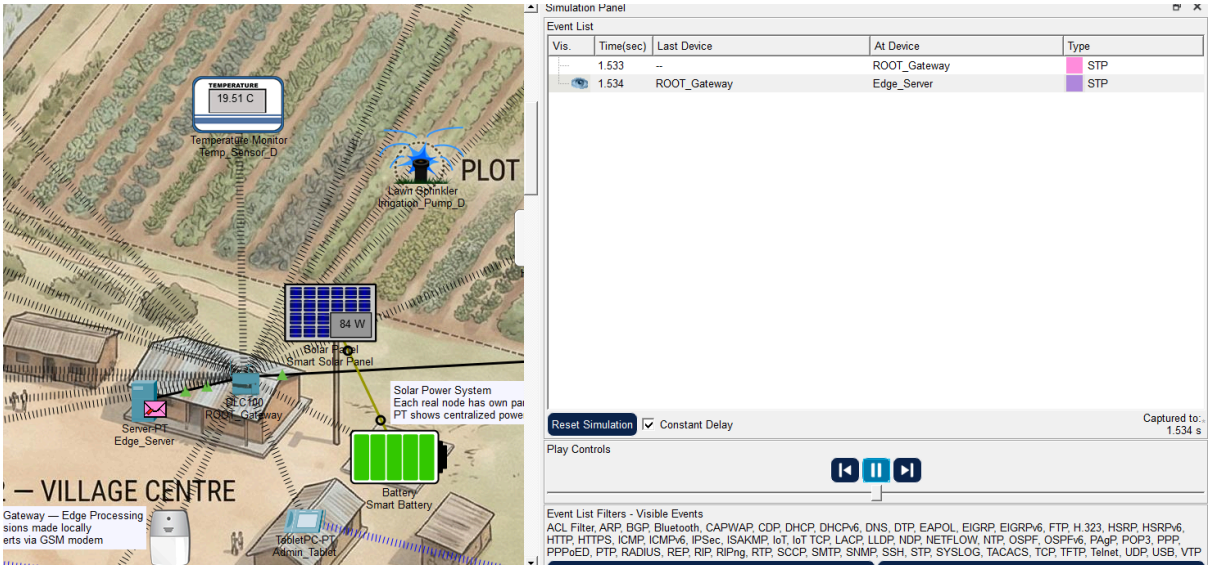


Figure 26: First received Packet Transmission (Gateway to Server)

This figure illustrates the first stage of data communication in simulation mode that due to which the packets are sent through ROOT_Gateway and Edge_Server. The event list will tell that the exchange of packets has been successful and the gateway is indeed communicating with the server. This reflects the creation of connectivity in the IoT system.

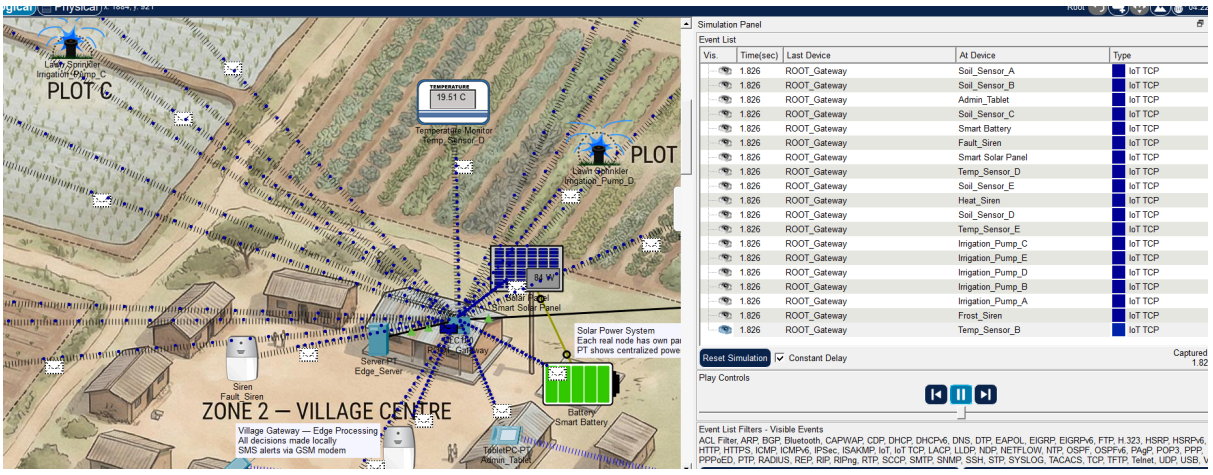


Figure 27: Complete Network Packet River (Sensor to System Communication)

This icon demonstrates the entire flow of data communications in the IoT system. There are several packets sent between the ROOT_Gateway and the connected devices, i.e. soil sensors, temperature sensors, irrigation pumps and actuators. The simulation panel shows that the communication is established throughout the network and between the sensors, the gateways and the system components in real time through the use of the IoT TCP communication.

8.0 Resources, Challenges & Troubleshooting

8.1 Packet Tracer Limitations & Justified Workarounds

During the process of creating the ROOT IoT system with the help of Cisco Packet Tracer, a number of limitations were experienced as the platform does not focus on complete simulation of the IoT but only on networking. Practical workarounds were used to ensure the validity of the system although the fundamentals of sensing, communication, and actuation were not compromised.

Absence of LoRa communication that is critical in the actual system was one of the main limitations. This was solved by the means of employing Wi-Fi instead of wireless communication because even in this case, it still allows the logical data flow between wireless sensors and the gateway to exist. It was also provided with a relay node (RelayNodeRidge) conceptually representing multi-hop communication. In the same matter, Packet Tracer does not cater to the SMS functionality, therefore, GSMCellTower and FarmerPhone devices were used to emulate the cellular communication and sirens worked as visual alert indicators to represent the notification.

The other limitation had a connection with the photo sensor that cannot simulate changes in the environment by providing a remote control API. To combat this, the Smart Solar Panel output, which was an indirect measure of the sunlight intensity, was utilized and this gave a realistic estimation of the light conditions. Packet Tracer lacks distributed power model in terms of energy modeling, and thus to model the entire energy infrastructure, a single solar panel and a battery was utilized. Also, the mesh routing protocols like aodv is not supported and every device is linked to one access point. To conceptually illustrate the manner in which multi-hop routing will work in an actual deployment, a relay node was added. Lastly, the platform can barely handle simple rule-based logic and cannot use time-based conditions. To reduce this one representative fault scenario was applied to show sensor fault detection, all the conditions were set to trigger instantly. It is observed that the real world systems would have more sophisticated algorithms and time-based logic. Though limited, the implemented workarounds maintain the real behavior of the system and make it consistent with the desired design of the IoT.

8.2 Challenges Encountered During Implementation

The implementation of the ROOT IoT system presented a number of practical issues which necessitated changes in the design and simulation strategy. The problem with the photo sensor which cannot be controlled dynamically in Packet Tracer was one of the major ones. This rendered it challenging to emulate the altering environmental circumstances, and therefore the Smart Solar Panel output was taken up as a proxy though real-world of the sunlight intensity. One more difficulty was the sensor fault detection logic design. Preferably, the system needs to support the several fault cases on the various sensors, but using Packet Tracer, which was restricted to rules, was too complicated to implement all the possible combinations. To deal with this, the simplified method was followed by providing only one of representative fault cases but nevertheless, clearly revealing how the system identifies abnormal behavior.

The threshold tuning was also to be carefully adjusted since the original values did not give explicit differences between normal and extreme conditions when tested. These thresholds were adjusted to make sure that a system in each case, say drought or abnormal readings produces a visible system response. Also, there were certain problems of the background picture fitting into the network layout that were fixed by making the workspace small and moving the devices to enhance clarity and realism. On the whole, all of these difficulties were

overcome with the help of realistic changes that enhanced the functionality of the system and the way it looked without losing a distinct illustration of the desired IoT behavior.

8.3 Resource Planning

Several tools and resources were used to complete this project.

Resource	Purpose
Cisco Packet Tracer 9.0.0	Used to design and simulate the IoT system, including network setup, devices, and automation logic
AI Image Generator	Used to create a farm background image to improve the visual presentation of the system
Assignment 2 Report	Provided the main reference for automation logic, algorithms, and threshold values

These resources were important in helping us build a system that is both functional and easy to understand.

9.0 Conclusion and Limitations

The applied simulator of IoT is effective to represent the main functionality of the ROOT smart agriculture monitoring system. The simulation will have several automation conditions like drought, frost, heat stress, and sensor fault. It also shows how to control manual actuators with the help of the admin interface, data interchange between sensors and the server, and monitoring with the help of a client device. The simulated deployment is a five plot farm monitoring system that includes several sensors and actuators in the environment. The sensor data are sent to the IoT server where the data are processed by automation logic and leads to the necessary actuator response like irrigation pumps and alerts. The simulation works out the principle of the ROOT system by illustrating the complete IoT workflow comprising of sensing, edge processing, actuators control, and alert generation. The simplification of the systems in the simulation platform is limited but the basic structure and behaviour of the operational system are equivalent to the real world IoT implementations.

The simulation environment however has a number of limitations. Cisco Packet Tracer is unable to model LoRa communication, GSM SMS messaging, time-based threshold logic, and algorithm execution that is dynamically run. Although there are these limitations, the main concepts of IoT sensors monitoring, data communication, automation logic, and actuator control are effectively shown. The hardware that would be used in addition to ESP32 microcontrollers and SX1276 LoRa modules in Raspberry Pi edge gateway and SIM800L GSM modules would make the system fully operational in a real deployment environment.