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CS7NS1- Scalable Computing

Project 3

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1. Abstract

This report provides a thorough analysis of the strategies utilized and the challenges faced at various stages of the project, including choosing our use case, selecting appropriate sensors, and the development of a solution to create a peer to peer network. For this task, our use case was ‘Smart Agriculture Monitoring’.

2. Introduction

The purpose of this project is to design and develop a peer-to-peer networking protocol based on Information-Centric Networking (ICN) principles, specifically Named Data Networking (NDN), tailored for smart agriculture systems so that we can move beyond traditional IP network paradigms, facilitating secure and efficient data dissemination in scalable and disconnected environments.

In traditional networking, communication is based on a host-centric communication model that uses IP addresses. NDN is a data-centric communication in which data is assigned a unique hierarchical name which is addressed for data exchange.

To address the limitations of IP networks in highly dynamic and disconnected contexts like smart agriculture, where traditional routing and naming mechanisms are inefficient.

To prove the feasibility and benefits of ICN/NDN in supporting data-centric security, efficient content retrieval, and network scalability.

Peer-to-peer (P2P) networking is a decentralized communication model in which devices or computers also referred as peers, do not rely on a central server and communicate directly with each other.

3. Topology

There are two networks Farm1 and Farm2. Each network consists of 5 devices/nodes. 8 different sensors are connected to each device.

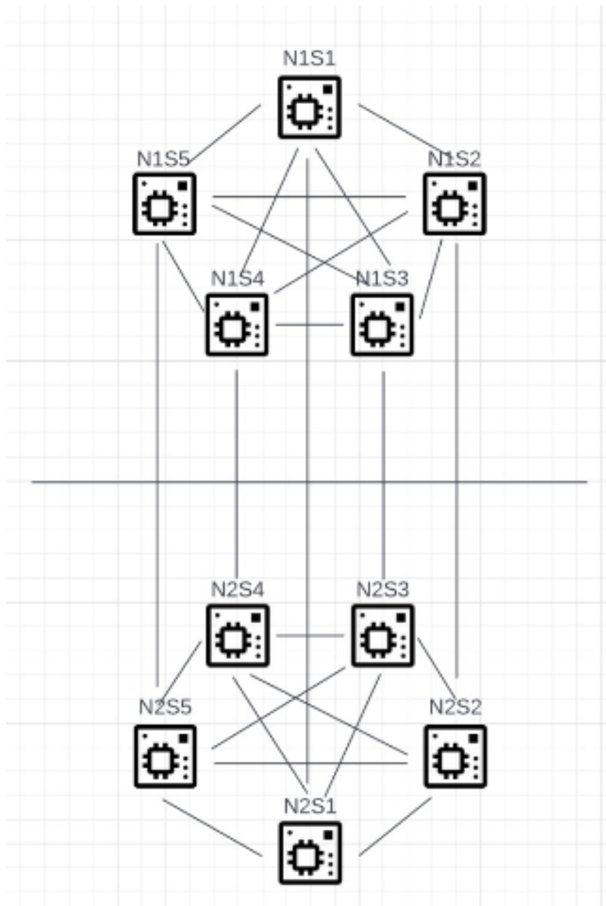

Fig1. Connection between Nodes

Our code follows a logical bus topology, which emphasizes decentralized communication. Devices share a common bus for message broadcasting. Along with that, point-to-point communication is facilitated through TCP connections, contributing to a hybrid topology.

Logical Topology:

Point-to-Point Communication: TCP connections enable direct, secure communication between devices and provide a controlled and reliable means for specific interactions.

Physical Topology:

a. **Hybrid Topology:** The physical topology is hybrid. UDP broadcasts occur globally, and local UDP broadcasts on the loopback interface enhance communication. Client-server architecture is introduced by TCP connections for point-to-point communication.

b. **Client-Server Architecture:** Devices act as servers, handling incoming connections and responding to requests. This architecture enhances security and control in communication.

Why This Topology:

a. **Scalability and Flexibility:** We chose this topology because it supports scalability. It allows devices to dynamically join or leave the network. UDP broadcasts enable global communication, while TCP connections provide reliability.

b. **Decentralized Communication:** The logical bus topology promotes decentralized communication which is crucial for devices in an agriculture network to exchange sensor data and updates.

c. **Secure Point-to-Point Communication:** TCP connections facilitate secure point-to-point communication, ensuring private data exchange between specific devices.

How It Works:

a. **UDP Announcements:** Devices broadcast UDP announcements, updating their Forwarding Information Base (FIB) based on received information. This mechanism allows devices to dynamically adapt to changes in the network.

b. **TCP Connections:** The `handle_client` method manages incoming TCP connections, decrypts messages, processes requests, and sends encrypted responses. It ensures secure and controlled communication.

c. **Sensor Data Generation:** The `generate_data` method asynchronously produces simulated sensor data. This data informs the network about various parameters like temperature and humidity, supporting the agricultural context.

4. Design Implementation

Data advertising within the same network is done with the help of the User Datagram Protocol (UDP). It's a connection-less protocol for neighbour discovery of nodes. Each device periodically broadcasts information like Host number, IP address, and device type. When a device receives a UDP packet and updates its list of neighbouring devices. Devices continue to broadcast UDP announcements at regular intervals to keep the presence active in the network. Timeout is created (TTL – Time to Leave) to remove the entries from the list if no advertisement is received after a certain time frame.

Devices present in a different network receive the broadcast when it has the same port number as that of the advertiser. By this, inter-network communication is achieved.

For handling the incoming connections from other devices, the Transmission Control protocol is used to handle the connected devices, send requests and handle the requests. Whenever there is an incoming request/response, the device decodes the data and extracts the network, sensor name and the sensor type. Based on the request, the Content store is checked first for cached data. In case the data packet is not present in CS, the FIB table is checked for the desired route and the interest packet is routed accordingly.

5. NDN Key components

1. Forwarding Information Base (FIB) is a lookup table that stores the routing information and maps the content names to the next hops.
2. Content Store (CS) caches the recently transmitted data packets that can be used again when requested. It reduces the need to fetch content repeatedly from the original source
3. Pending Interest Table (PIT) consists of the active pending requests of data packets. PIT ensures data packets are forwarded back to the requesting face along the reverse path.

Working of NDN

a. Data Naming and Categorization:

The data generated by each device is identified by a unique hierarchical and structural name. The naming convention includes the network, device name, and sensor type.

b. Expressing Interest in Data:

Consumers express interest in specific data content by sending an encrypted interest packet to the device. The interest packet contains information about the desired network, device name, and sensor type.

c. Forwarding Interest Table (FIB):

Upon receiving an interest packet, the device's FIB is consulted to determine the next-hop face. The FIB contains information about other devices in the network, including their host, port, and time-to-live (TTL) values.

d. **Forwarding Interest and receiving data:**
The device forwards the interest packet towards the next-hop face based on the FIB information. At each forwarding step, the device checks if that data is present within the same device.Once it identifies the source, it send the data to the consumer.

e. **Content Store (CS) for Caching:**
Each device has a Content Store (CS) that caches data packets. This cache allows the device to satisfy future interests without fetching the data from the original source.

```
ListeningProtocol on ('127.0.0.1', 33022)
Sending peer announcement...
{'farm2': {'weather': ['10.35.70.34', 33221, 25]}}
Sending peer announcements...
Serving (start_tcp_server) on ('10.35.70.34', 33221)
send
Enter interest package (eg. network2/bus1/temperature): farm2/soil/temperature
Sending request to 10.35.70.34:33223...
Received response from 10.35.70.34:33223 - value: -4.390511156052642
Temperature is Optimal.
Enter command (send, quit): Sending peer announcement...
{'farm2': {'weather': ['10.35.70.34', 33221, 25], 'water': ['127.0.0.1', 33225,
21], 'soil': ['127.0.0.1', 33223, 21], 'drone': ['127.0.0.1', 33227, 21], 'healt
h': ['127.0.0.1', 33229, 21]}}
```

Fig. 2 Working

6. RSA Encryption

RSA (Rivest–Shamir–Adleman) is a asymmetric cryptographic algorithm. It
is widely used for secure communication between two devices.
Each node generates an asymmetric RSA key pair which consists of a public key and a private key.
Public keys can be easily distributed within the devices while the private key remains secret.
The data that needs to be transmitted is encrypted using the public key and the received data is decrypted using the private key.

In the project, RSA encryption and decryption are used. Every time there is a broadcast/ connection request/ interest package or data response, the public key is used to encrypt the message and the private key is used to decrypt it key for secure communication between the nodes in the network.

7. Use case: Smart Agriculture Monitoring

Imagine a large agricultural setting with two distinct areas or farms, each representing a separate IoT network. In each network, there are five different types of smart devices equipped with various sensors. The goal is to monitor and optimize agricultural processes for improved yield, resource utilization, and overall efficiency.

Device Types:

a. **Weather Station (Type 1):**
Sensors: Temperature, Humidity, Atmospheric Pressure, Wind Speed, Wind Direction, Rainfall, Solar Radiation, UV Index.

Capabilities: Real-time weather monitoring and prediction.

b. **Soil Health Monitor (Type 2):**
Sensors: Soil Moisture, Soil pH, Soil Temperature, Nitrogen Level, Phosphorus Level, Potassium Level, EC (Electrical Conductivity), Soil Nutrient Composition.

Capabilities: Assessing soil conditions for optimal crop growth.

c. **Crop Monitoring Drone (Type 3):**
Sensors: RGB Camera, Infrared Camera, NDVI (Normalized Difference Vegetation Index) Sensor, Light Sensor, GPS, Altitude Sensor, Temperature Sensor, Humidity Sensor.

Capabilities: Aerial imaging for crop health analysis and pest detection.

d. **Water Quality Sensor Buoy (Type 4):**
Sensors: Water Temperature, Dissolved Oxygen, pH Level, Turbidity, Conductivity, Chlorophyll-a, Nitrate Level, Phosphate Level.

Capabilities: Monitoring water quality in irrigation ponds or water sources.

e. **Crop health monitor (Type 5):**
Sensors: Nutrients, temperature, pressure, humidity, moisture, CO2

Capabilities: Optimizing irrigation based on real-time weather and soil conditions.

Weather station	Soil health station	Drone	Water Quality monitor	Crop health monitor
Temperature	Moisture	RGB camera	Water temp	Health
Humidity	Ph	Infrared	Ph	temperature
Air pressure	Soil temp	Temperature	Dissolved o2	humidity
Wind speed	Nitrogen	humidity	pressure	Co2
Wind direction	Phosphor	pressure	humidity	pressure
Rainfall	humidity	Position	nutrients	nutrients
UV index	Potassium	Speed	Nitrate level	moisture
Solar radiation	nutrient	Altitude	phosphate	Hydration

Fig3. Device Types

Use Case Scenarios:

a. Optimized Irrigation:
The Automated Irrigation System (Type 5) utilizes data from Soil Health Monitors (Type 2) and the Weather Station (Type 1) to determine the optimal irrigation schedule based on soil moisture, weather forecasts, and crop water needs.

b. Precision Agriculture:
Crop Monitoring Drones (Type 3) fly over the fields, capturing high-resolution images using RGB and Infrared cameras. These images, combined with data from Soil Health Monitors (Type 2), help farmers identify areas with potential crop diseases, nutrient deficiencies, or pest infestations.

c. Water Management:
Water Quality Sensor Buoys (Type 4) continuously monitor water quality in irrigation ponds. The data collected, including temperature, dissolved oxygen, and nutrient levels, is used to ensure the water used for irrigation meets optimal standards, preventing potential harm to crops.

d. Adaptive Pest Control:
Crop Monitoring Drones (Type 3) equipped with NDVI sensors monitor vegetation health. If abnormal patterns indicative of potential pest infestations are detected, the system can trigger targeted pest control measures, reducing the need for broad-spectrum pesticides.

e. Climate-Responsive Farming:

The Weather Station (Type 1) continuously provides real-time weather data, helping farmers make informed decisions. For instance, if extreme weather conditions are predicted, the system can recommend protective measures such as covering crops or adjusting irrigation schedules.

Benefits:
a. Resource Optimization: By leveraging real-time data from multiple sensors, farmers can optimize resource usage, reducing water waste and minimizing the use of pesticides and fertilizers.

b. Increased Yield: Precision agriculture practices, driven by data from sensors, contribute to increased crop yield and improved overall farm productivity.

c. Environmental Sustainability: Monitoring soil health, water quality, and weather conditions allows for environmentally sustainable farming practices, minimizing the environmental impact of agricultural activities.

d. Cost Efficiency: Automation and data-driven decision-making lead to cost efficiencies by optimizing resource usage and reducing the need for manual intervention.

This use case demonstrates how a diverse set of IoT devices with various sensors can work together to create a smart agriculture system, improving decision-making and contributing to sustainable and efficient farming practices. Each type of device plays a specific role in gathering data relevant to its domain, contributing to the overall success of the agricultural operation.

8. Future Scope

From the huge amount of data generated from the sensors can be used to analyse the trends in the sensor data and predict future trends using Machine Learning models. Using ML algorithms, unusual patterns or anomalies in sensor data help in early and potential issues or dangers to the agriculture system. Artificial systems can be used to provide decision support based on sensor data.