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Final Project: Deployment of communication system for smart agricultural water management

Part A: Defining Your Application

[30 pts] Part A Deliverables

Scope

The scope of this document is to define what is needed to deploy a low cost communication system that will be used to control water management for gardens and trees in UCSD campus. These devices will control watering valve actuators and provide measurements parameters as temperature, humidity and valves status feedback.
In addition to that, here we provide a breakdown of necessary materials and qualified man hours for a successful deployment that will benefit UCSD and community by optimizing water usage and keeping green areas in great condition.

Introduction

A water management system is crucial in agricultural and water management applications for several key reasons:

Efficient Water Use: Agriculture is a major consumer of freshwater. A well-designed water management system ensures that water is used efficiently, minimizing waste through methods like drip irrigation, scheduling based on crop needs, and monitoring soil moisture. This is especially important in regions with water scarcity.

Increased Crop Yields: Consistent and adequate water supply is essential for optimal plant growth and development. Proper irrigation, drainage, and water distribution systems can significantly improve crop yields and quality.

Resource Conservation: By minimizing water waste, water management systems help conserve this precious resource for other uses and future generations. This is vital in the face of growing populations and climate change.

Reduced Environmental Impact: Over-irrigation can lead to soil erosion, nutrient leaching, and waterlogging, harming the environment. Effective water management reduces these risks.

Improved Soil Health: Proper drainage and controlled irrigation prevent soil salinity and maintain a healthy soil structure, which is vital for long-term agricultural productivity.

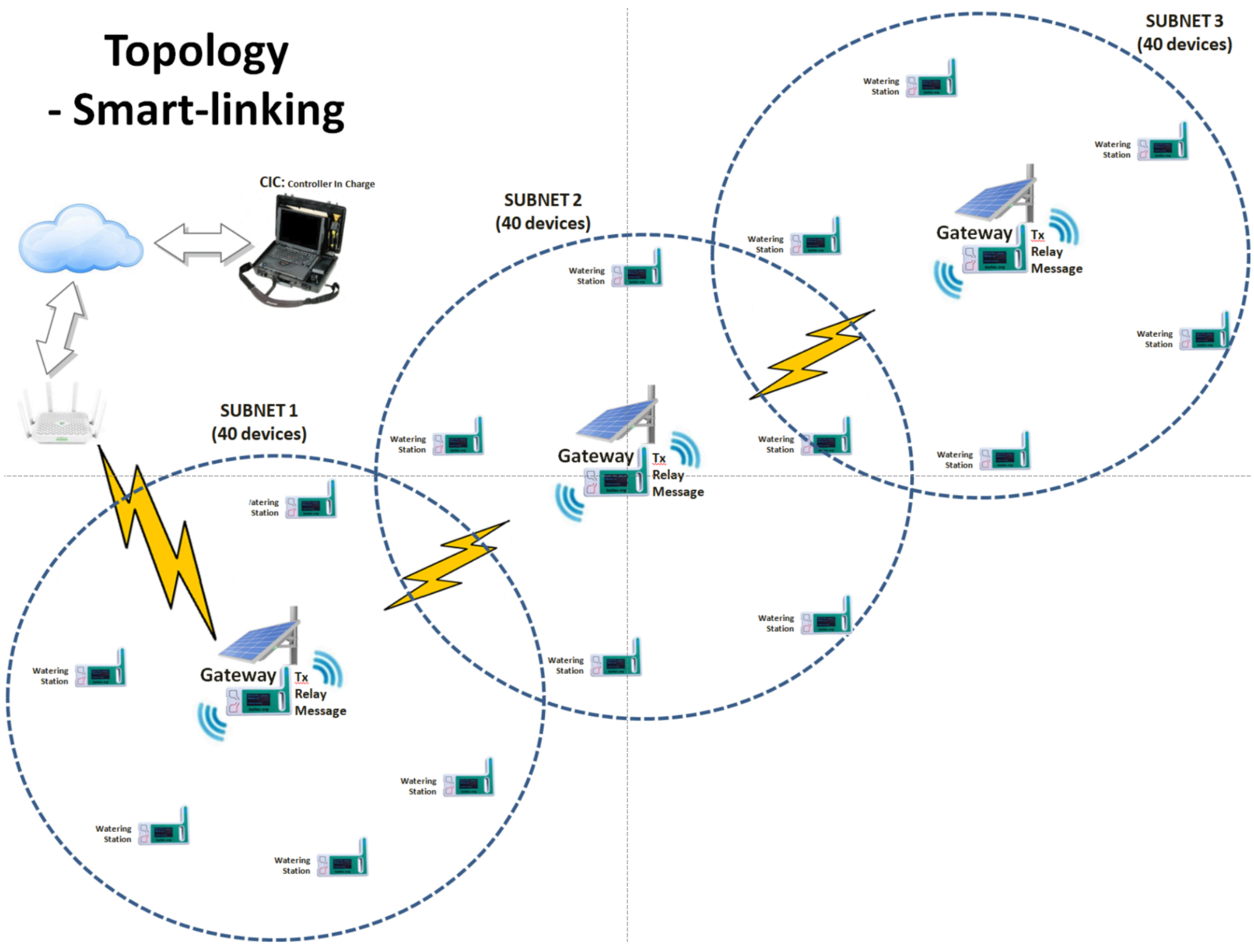
Cost Savings: Efficient water use translates to lower water bills for farmers. Additionally, improved yields and reduced fertilizer runoff contribute to economic benefits.

Sustainability: Sustainable agriculture practices, including responsible water management, are essential for ensuring food security and environmental health in the long term.
In essence, a water management system in agriculture is not just about getting water to crops; it's about optimizing water use for productivity, environmental protection, and economic viability.

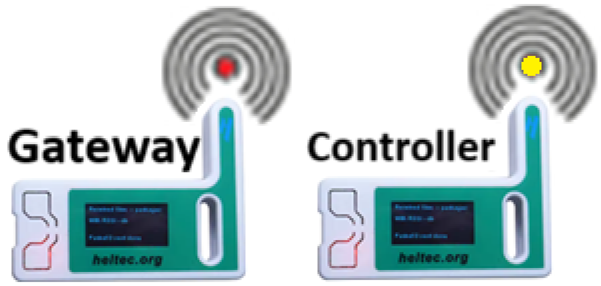
Low Cost Communication System

[5 pts]: Give a high-level description of your application.

This communication system provides an end-to-end network to control any agricultural application, specially for this water management system that will be deployed in UCSD campus.
This system works on three modes: Automated (full calendar year), Manual & Troubleshooting
Most of these areas the Wi-Fi signal is not available, but in order to be able to connect and control this communication system, it will be necessary to have at least one of the Gateways connected to Wi-Fi .



Precise location of each controller (**120**) will be defined in a separated diagram, but the Gateway devices have already been defined as its placements location, per this campus map.
Part of this deployment is to prepare necessary permits, to be submitted to the **Radio Frequency Communications Regulations UCSD office**, this is in order to comply with **UCSD** campus communication policies and **FCC** Federal agency.



[5 pts]: What constraints are there on the data your system collects for the stakeholders, e.g.:
This system uses Heltec ESP32 devices, configured to communicate **LoRa** using unlicensed **ISM bands**, this is one of the most lower cost configurations, the controller devices normally will be dormant-sleep mode, but wake up on scheduled windowing for the Gateway to collect measurements and configuration commands.
Latency device to device could be relatively high (~640 mS), however for this particular application is not critical, since scheduling window times are wide open.
Being the lowest cost possible option, it makes it very attractive to stakeholders.

[5 pts]: What constraints are there on the deployment of your system, e.g.:
In case of communication latency could be a problem, and to improve it, a second option would be to change the type of communication to **NB-IoT** (data rate up to 250 Kbps, estimated latency ~420mS).
Unfortunately the **NB-IoT** option would require a monthly subscription of a third party service provider, but this would add up approximately $400 monthly cost.
LoRa data rate (0.3-50 kbps), provides a lower cost effective solution than **NB-IoT**, since **LoRa** uses **unlicensed ISM bands** and is typically deployed as private networks or through public LoRaWAN operators.
*(See Appendix A: Comparison between **LoRa** vs **NB-IoT**)*
[5 pts]: What is another constraint you think is important to consider for your application?

Another constraint is that it will require that facilities personnel have to have the basic understanding of how the system works to properly keep it up and working as replacing batteries once per year and once in a while check for the Gateway devices solar panels to be clear of dust or sleeves.

[10 pts]: Without doing any numerical analysis (yet), rank the wireless technologies we have discussed in class [Bluetooth; 802.15.4/Thread; WiFi; Legacy Cellular (2g/3g); High-Performance Cellular (4g/5g); IoT Cellular (LTE Cat-M / NB-IoT); LoRa] from best to worst for your proposed application.

Relative to these different wireless technologies:
First, Bluetooth is commonly used for short-range communication between devices like headphones, speakers, and smartphones. It's low power, but how does it compare in terms of data rate and range? Maybe it's good for personal use.

Next, 802.15.4. That's the standard behind Zigbee and Thread. Thread is used for IoT devices, creating mesh networks. So maybe low power, mesh networking, but lower data rates compared to WiFi. What about range? Probably similar to Bluetooth but with mesh capabilities.

WiFi is familiar—used for high-speed internet in homes and offices. High data rates, but higher power consumption. Range is up to 100 meters. But definitely not suitable for battery-operated IoT devices that need to last years.

Legacy Cellular like 2G and 3G. These are older technologies. They have wider coverage, but I think 2G is being phased out. Data rates are lower than 4G/5G. Power consumption might be higher than Bluetooth or LoRa, but they can work over long distances. Good for applications that need mobility but don't require high data rates.

High-Performance Cellular: 4G and 5G. These are for high-speed data, mobile broadband, streaming, etc. Very high data rates, low latency, but again higher power consumption. 5G also has features for IoT, but maybe different from the IoT-specific cellular options.

IoT Cellular like LTE Cat-M and NB-IoT. These are designed for IoT devices. Lower power, optimized for intermittent data transmission. Longer battery life, better coverage in difficult areas (like underground), but lower data rates. They use existing cellular networks but are more efficient for IoT.

LoRa. I think LoRa is for long-range communications. It's part of LPWAN (Low Power Wide Area Network). Very long range, several kilometers, but very low data rates. Good for sensors that send small amounts of data infrequently. Uses unlicensed spectrum, so maybe cheaper but with potential interference issues.

Technology	Data Rate	Range	Power Consumption	Use Cases	Cost	Topology	Latency	Frequency Bands
Bluetooth (BLE)	1-2 Mbps (BLE)	Up to 100m (BLE)	Very Low	Wearables, audio, smart home devices	Low	P2P, Mesh (BLE Mesh)	Moderate	2.4 GHz
802.15.4/Thread	250 kbps	10-100m	Low	Home automation, industrial sensors	Low	Mesh	Moderate	2.4 GHz, 915 MHz, 868 MHz
WiFi (802.11ax/n)	10 Mbps - 10 Gbps	Up to 100m	High	Internet access, video streaming, smart home	Moderate	Star	Low	2.4 GHz, 5 GHz, 6 GHz
Legacy Cellular (2G/3G)	0.1-2 Mbps (3G)	Kilometers	Moderate-High	Older IoT, voice, basic data	Low (phasing out)	Star	High	800 MHz - 2.1 GHz
High-Performance Cellular (4G/5G)	100 Mbps - 10 Gbps	Kilometers	Very High	Mobile broadband, AR/VR, autonomous vehicles	High	Star	Ultra-Low (5G)	Sub-6 GHz, mmWave (5G)
IoT Cellular (LTE Cat-M/NB-IoT)	200 kbps - 1 Mbps	Kilometers	Low	Smart meters, asset tracking, agriculture	Moderate	Star	Moderate-High	Licensed cellular bands
LoRa/LoRaWAN	0.3-50 kbps	2-15 km (rural)	Very Low	Environmental monitoring, agriculture	Low	Star-of-Stars	High	Sub-1 GHz (unlicensed)

Key Differentiators

Range & Coverage:
LoRa and Cellular (all types) excel in long-range communication.
Bluetooth and 802.15.4 are ideal for short-range PAN/sensor networks.
WiFi balances range and speed for indoor use.

Power Efficiency:
LoRa, BLE, and IoT Cellular are optimized for battery life (years).
WiFi and High-Performance Cellular require frequent power.

Data Rate:
WiFi and 5G lead in speed for video/AR/VR.
LoRa and NB-IoT prioritize low-data IoT sensors.

Network Topology:
Thread and BLE Mesh enable resilient mesh networks.
Cellular and WiFi rely on centralized infrastructure.

Cost & Deployment:
LoRa and BLE are low-cost for DIY/private networks.
Cellular requires subscriptions and licensed spectrum.

Latency:
5G and WiFi support real-time applications.
LoRa and IoT Cellular tolerate delays.

Use Case Recommendations:
Smart Home: Thread, BLE, or WiFi for balance of range and speed.
Industrial IoT: LoRa (long-range sensors) or NB-IoT (cellular coverage).
Consumer Devices: WiFi (high-speed) or 5G (mobility).
Agriculture/Environment: LoRa for vast, low-power monitoring.
Legacy Systems: 2G/3G (phasing out; migrate to Cat-M/NB-IoT).

Part B: Energy Modeling

[25 pts] Part B Deliverables

[5 pts]: As a final step, what is one example of a consumer-grade battery solution (i.e. 1 AA, 3 AAA's, a D cell, 2 CR2032's, etc)

Part C: Making Your Case

[35 pts] Part C Deliverables

[25 pts] Present a comparison of the expected performance for the two wireless technologies you are studying. You do not necessarily need to present graphs for every single constraint, only the ones that are most relevant for comparison given your application and your technology. *Convince a fellow engineer that your analysis covers the important tradeoffs*.

[10 pts] Give a final assessment on how you think your application should be built given the tradeoffs you have analyzed. Which technology should you use, how should it be deployed, what kind of data should it send, how often should it send it, and what will it cost to keep your deployment alive for one full year?

Cost

??????????????

Equipment & accessories

Qty	Description	Unitary price	Ext. price
4	Gateway devices	$ 25	$ 100
120	Controller devices	$ 25	$ 3,000
4	Solar panel with Built-in Rechargeable Battery (for Gateways)	$ 14	$ 56
20	Battery case with AA batteries (for controllers)	$ 9	$ 180
24	Outdoors, water case for each device	$ 6	$ 144
		Subtotal	**$ 3,480**

Man power

Hours	Description, Working Hour (including administrative cost)	Unitary price	Ext. price
20	Tecnician to assembly, installation and configuration	$ 35	$ 700
9	Sr. Engineer fine configuration, testing, troubleshooting	$ 80	$ 720
5	Prepare Permits, then submit it to Radio Frequency Communications Regulations UCSD of	$ 80	$ 400
4	Training before finalizing deployment	$ 9	$ 36
		Subtotal	**$ 1,856**

Total cost materials & man power

Total	**$ 5,336**

Agreed contract price per quote

Total	**$ 22,000**

Profit

Total	**$ 16,664**

Part B: Energy Modeling

We have mentioned several times that a primary reason IoT devices use different wireless technologies is due to resource constraints, of which energy is critical. We haven't done so much to quantify that yet, however.

One task you have is to figure out how much energy your sensor will spend on communication over the lifetime of its operation. To make this a bit easier, we're just going to consider the energy spent on communication related activities, that is, for the energy analysis you can assume that the platform does no sensing and has no application to run other than just waking and sending data that is ready. You should consider the major energy needs for each mode of operation of your sensor node. For example:

- Energy/latency to power on, off? If you turn off the radio between events
- Energy consumed between events? If you leave the radio on (in sleep mode?) between events
- Energy during firmware-update event This is primarily a downlink communication
- Energy during data-send event This is primarily an uplink communication

[25 pts] Part B Deliverables

[20 pts]: Present a comparison of the expected energy performance for the two wireless technologies selected in Part A that you are studying. Be sure to consider how data length and transmission frequency affect your results here. Your analysis should answer, "in what cases is technology A better and in what cases is technology B better"? Your answer must be **quantitative** and cite sources.

[5 pts]: As a final step, what is one example of a consumer-grade battery solution (i.e. 1 AA, 3 AAA's, a D cell, 2 CR2032's, etc) that would be a reasonable choice (cost, form factor…) to power each case? You may use a simple battery capacity model—every battery chemistry has a nominal voltage, and batteries are rated in mAh of capacity. The old cell phone battery (lithium polymer, 3.7 V nominal) on my desk is rated for 1800 mAh, so it has 1800 mAh * 3.7 V ~= 24 kJ of energy. Your answer must be **quantitative**, cite sources, and justify *why* this battery solution works.

Part C: Making Your Case

In Part A, you developed a list of application constraints. Now your job is to apply those constraints to the two wireless technologies you are considering.

[35 pts] Part C Deliverables

[25 pts] Present a comparison of the expected performance for the two wireless technologies you are studying. You do not necessarily need to present graphs for every single constraint, only the ones that are most relevant for comparison given your application and your technology. *Convince a fellow engineer that your analysis covers the important tradeoffs*.

• You must compare on at least three different metrics.

• Some comparisons may result in proof that a certain metric is not relevant for this application, but at least some metrics will be relevant.

[10 pts] Give a final assessment on how you think your application should be built given the tradeoffs you have analyzed. Which technology should you use, how should it be deployed, what kind of data should it send, how often should it send it, and what will it cost to keep your deployment alive for one full year?

Appendix A: Comparison between LoRa vs NB-IoT

Narrowband IoT (NB-IoT) and LoRa (Long Range) are both low-power wide-area network (LPWAN) technologies designed for IoT applications, but they have distinct differences in terms of network architecture, coverage, cost, and use cases. Here's a comparison:

1. Network Architecture
NB-IoT: Operates over licensed cellular spectrum and is deployed by mobile network operators (MNOs) using existing LTE infrastructure.

LoRa: Uses unlicensed ISM bands and is typically deployed as private networks or through public LoRaWAN operators.

2. Range & Coverage
NB-IoT: Has good penetration in urban environments and indoors due to licensed spectrum but generally has a range of up to 15 km in rural areas.

LoRa: Offers a longer range (up to 20 km in rural areas) but may suffer from interference in dense urban settings due to unlicensed spectrum use.

3. Data Rate & Latency
NB-IoT: Higher data rate (up to 250 kbps) and lower latency (1-10 seconds), making it suitable for real-time applications.

LoRa: Lower data rate (0.3-50 kbps) and higher latency (up to several seconds), suitable for intermittent data transmissions.

4. Power Consumption
NB-IoT: Consumes more power due to cellular connectivity but supports extended battery life (up to 10 years) in power-saving modes.

LoRa: More power-efficient than NB-IoT, with devices lasting over 10 years on a small battery.

5. Deployment & Cost
NB-IoT: Requires a subscription to a mobile network operator (higher cost) but benefits from carrier-grade reliability.

LoRa: Can be deployed as a private network at a lower cost, but coverage depends on gateway placement and interference.

6. Use Cases
NB-IoT: Smart meters, connected streetlights, industrial IoT, asset tracking, smart agriculture (when cellular coverage is available).

LoRa: Smart cities, remote agriculture, environmental monitoring, logistics, and use cases where private deployment is preferred.

7. Scalability & Ecosystem
NB-IoT: Limited by operator coverage but benefits from a standardized, global cellular ecosystem.

LoRa: More flexible for private deployments but may require additional investment in gateways and infrastructure.

Conclusion
Choose NB-IoT if you need reliable cellular connectivity, better security, higher data rates, and are willing to pay for a mobile subscription.

Choose LoRa if you want long battery life, lower deployment costs, and the flexibility of private network setups in remote areas.