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Flomosys: A Flood Monitoring System

Disaster Mitigation#2: Communications and Remote Sensing

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Motivation

- Between 1995 and 2015, flooding affected 2.3 billion people and claimed more than 150,000 lives across the globe
- Since 2000, the US has spent over $107 billion on the damages caused by floods
- In 2017 alone, the US spent $60.7 billion on floods, which accounts for 57% of the cumulative seventeen-year total
- Reports predict that flood damage worldwide will cost up to $1 trillion per year by 2050

Motivation

- In 2017, San Jose suffered a flooding of the Coyote Creek which amounted to around $100 million in total damage and displaced 14,000 residents

Design Goals and Contributions

We present the design, development, and evaluation of ***Flomosys***

Design goals

Reliability

- Sampling
- Software
- Communication

Scalability

- Easy to Extend
- Low Cost per Node

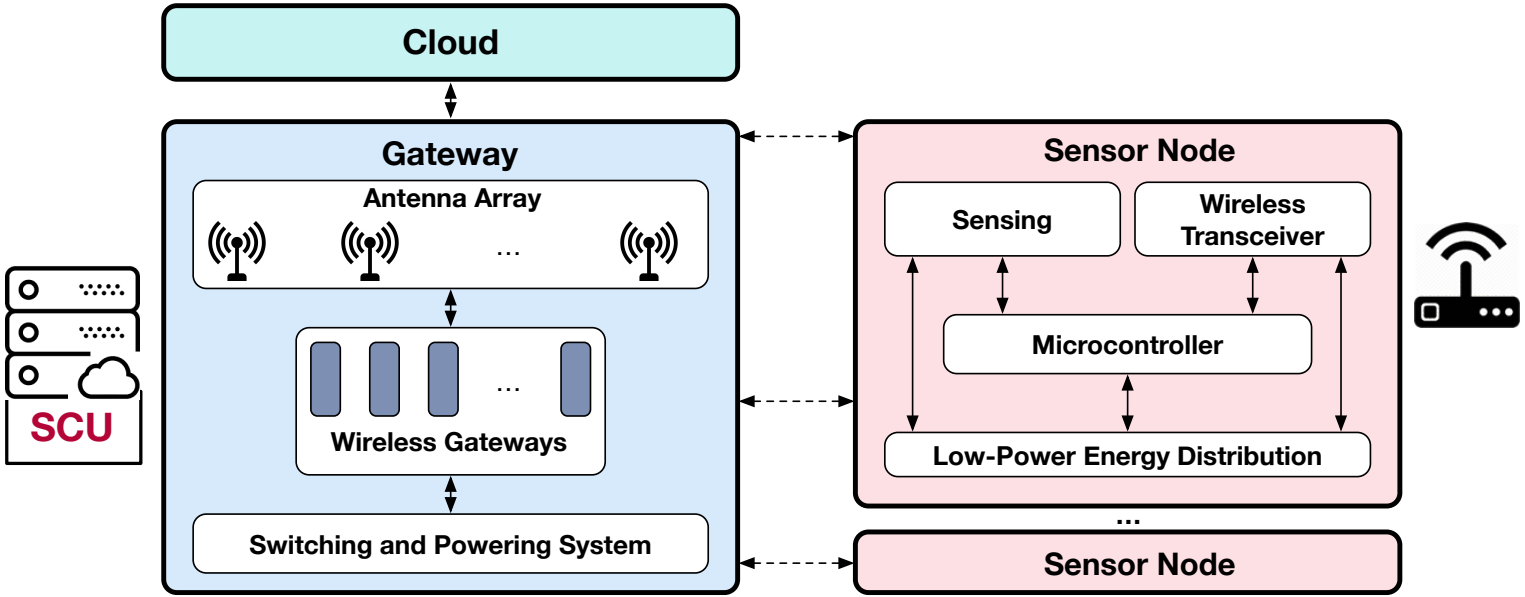
Energy Efficiency

- Battery and Solar
- Reduce Cost

Security

- Secure Communication
- Authentication
- Integrity

Architecture



Architecture

Sensor Node: Periodically samples river characteristics (e.g., water height) and sends the information securely to one or multiple Gateways

Base Station: Decrypts the received data packets and forwards them through a secure channel to the Cloud Platform

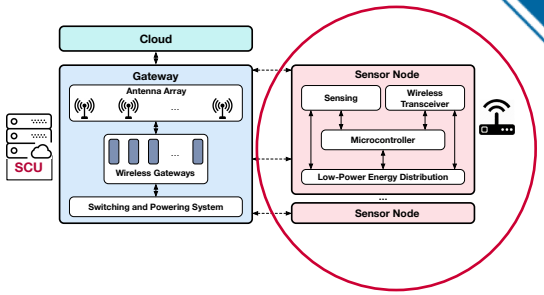
Cloud Platform: Managing the Gateways, processing, and visualization

Contributions

- Low-Power Hardware Design
- Long-Range and Reliable Wireless
- Gateway Arrays and High Reliability
- Novel Security Protocol
- Cloud-Based Management

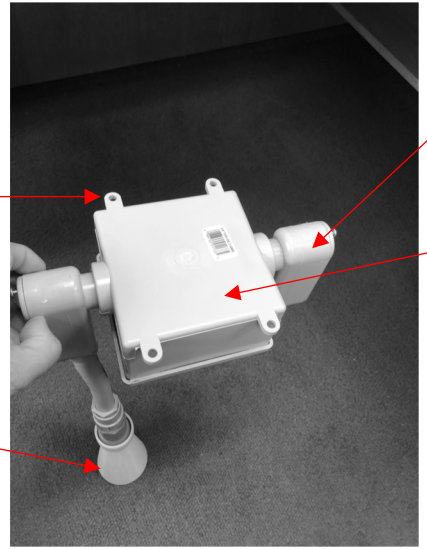
Implementation:
https://github.com/SIOTLAB/Flomosys

Sensor Node

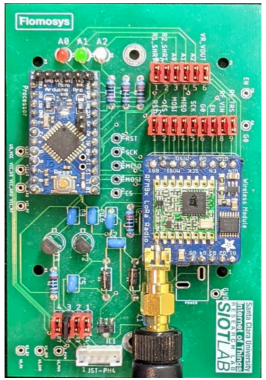


Antenna and Power Connection

Mounting Holes
(attachment to bridge)



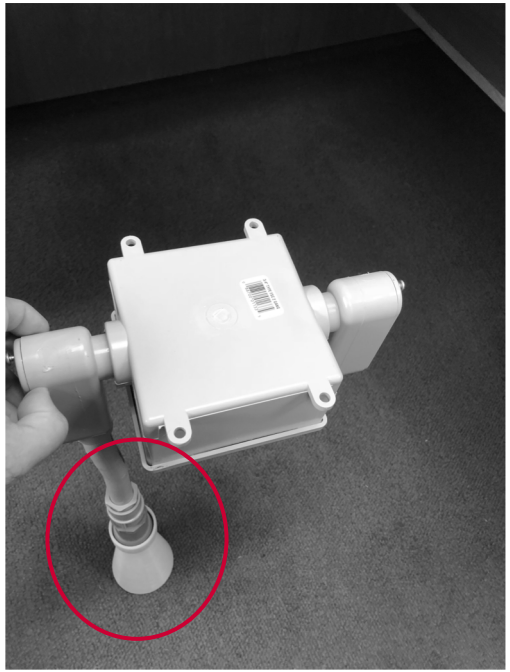
Sensor
(pointing to the river)



Control Boards
(inside)

Several hardware and software improvements were performed to reduce the sleep energy consumption of the board to 30 uA

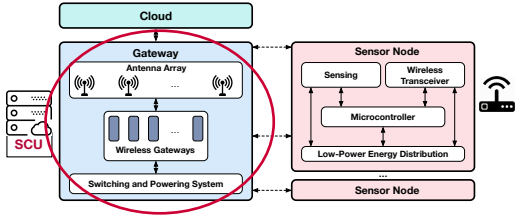
Sensor Node



- **Various types of sensors can be used with our node design**
- **We used a high-accuracy ultrasound sensor**

- Ultrasound sensors send a set of very short pulses and detect the reflection of these signals
- Measure the time it takes between the sending and receiving of these pulses to compute distance

Gateway



Gateway is responsible for:

- Collecting sensor data readings from Nodes
- Filtering duplicate receptions
- Forwarding data to the Cloud

A Gateway implementation includes multiple Linux-based boards, such as the Raspberry Pi, where each is connected to a wireless transceiver and an antenna

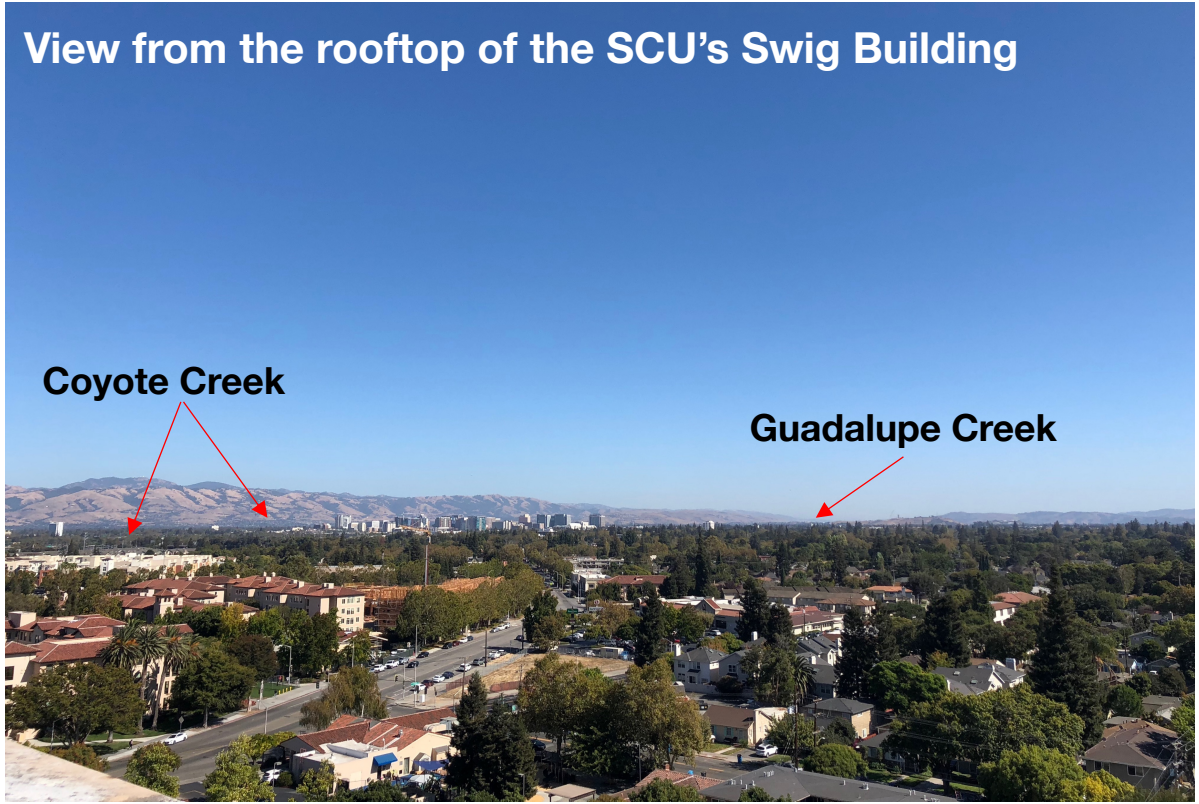
Gateway

Inside a Gateway

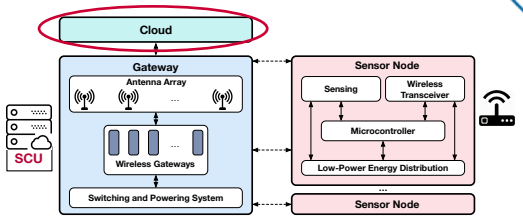
Gateway

Directional Antennas to Cover Long Distances

Gateway



Cloud



Back-end

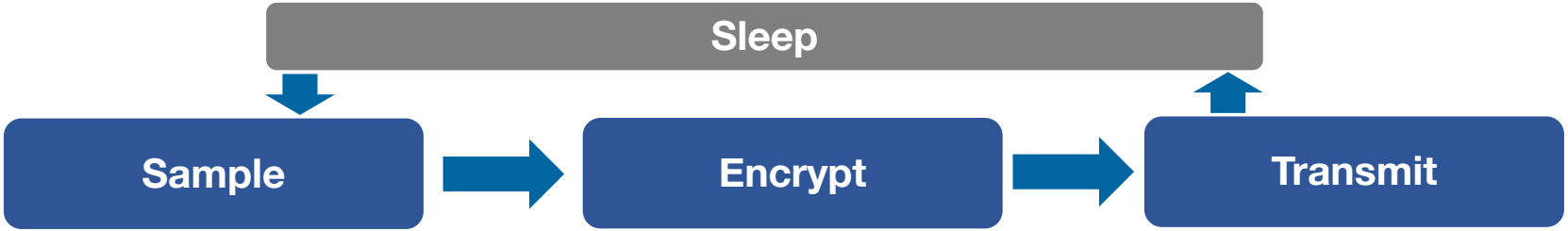
- Implemented in Golang
- Accepts authenticated incoming connections from Gateways
- Serves requests for the data to the front-end

Front-end

- Implemented in VueJS
- Displays graphs

An administrator console allows vendors such as water districts to register webhooks to receive raw data or events

Sensor Node



- Collect 7 samples and compute the average of the last 4 samples

- Using HMENC to encrypt data

- First on 914 MHz
- If no ACK, then proceeds with 915 MHz
- If no ACK, then proceeds with 916 MHz

Wireless Communication

Options

- **Cellular: not available in remote areas, subscription required**
- **BLE, 802.15.4, and WiFi: short range**

Wide-Range Networks

LoRa, SigFox, Ingenu

LoRa satisfies our system requirements in terms of message rate, range, and energy efficiency

Wireless Communication

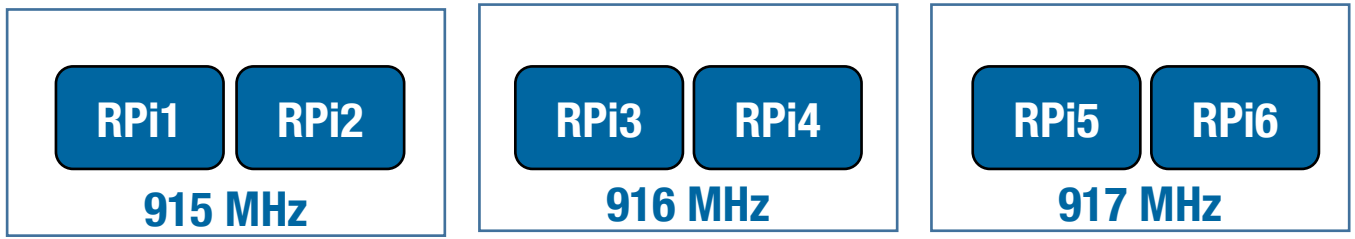
LoRa

- Data rate
  - Typical data rates are between 300 bps and 27 Kbps
  - Depend on Coding Rate (CR) and Spreading Factor (SF) used
  - Adjusted based on distance
- A maximum dwell time of 400 ms per channel per 20-second interval is enforced

- **We profiled the employed LoRa module - Semtech 1276**
- At 20 dBm transmission power:
  - **Energy per packer varies between 0.7 J to 0.96 J, depending on SF and CR**

Wireless Communication

- The current Gateway deployment includes six RPi boards
- These RPi boards operate on three different frequencies with two boards operating on each frequency, providing redundancy in case of failure



- The three frequencies used are 914, 915, and 916 MHz
- The transceivers use a SF of 1024 Chips-Per-Second (CPS), a 4/7 CR, and a transmission power of 20 dBm

Wireless Communication

Packet format

Preamble	Mandatory Preamble	Explicit (PHY) Headers	Payload	CRC
8 Symbols	4.25 Symbols	3 Bytes	16 Bytes	2 Bytes

- **HMENC, the encryption solution implemented in *Flomosys*, uses Hash-based Message Authentication Code (HMAC)**
- **HMENC is only defined for small data payloads, such as those under 64 Bytes**

Cyphertext

rand_seqno	client_id	msg_type	seq_no	retries	data	checksum
44 Bits	12 Bits	8 Bits	8 Bits	8 Bits	32 Bits	16 Bits

Checksum is computed based on these fields

Wireless Communication

If we choose to add a feature that adds 2 bytes to the payload:

- **AES-128**
  - Requires us to transmit a ciphertext that is a multiple of 16 bytes
  - 32 bytes in this case
  - **Reducing the probability of packet reception**
- **HMENC:**
  - **We can simply send an 18-byte message**

Energy

- No HMENC: 0.071 mJ per packet
- w/ HMENC: 0.299 mJ per packet

Lifetime

- It must be feasible to power the system with renewable energy
- **How long the system can survive powered by a 2400 mAh battery?**
- **The energy cost of each operation**, including sampling, packet encryption, and wireless transmission, have been recorded and analyzed

$$\text{lifetime} = \frac{E_{bat}}{(E_u + (E_e + E_t) \times (R+1) + E_s) \times N}$$

$$= \frac{3600 \times 2400 \times 10^{-3} \times 5}{(E_u + (E_e + E_t) \times (R+1) + E_s) \times N}$$

Cycles/hour

Sensor Sampling

Encryption

Transmission

Average number of Retransmissions/Packet

Lifetime

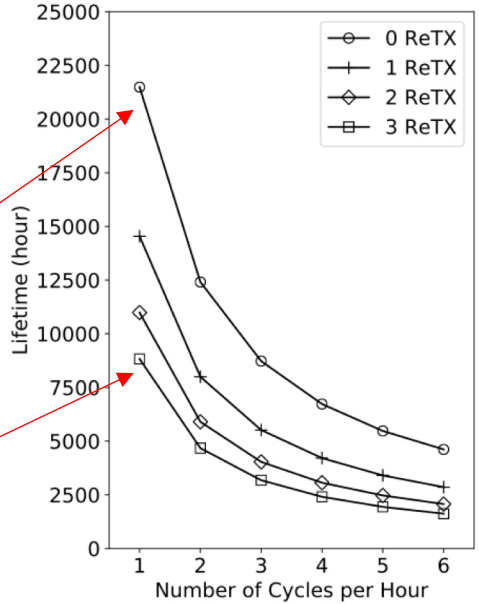
Lifetime assuming a 2400 mAh battery for different average retransmissions, SF, and CR

~2.4 year

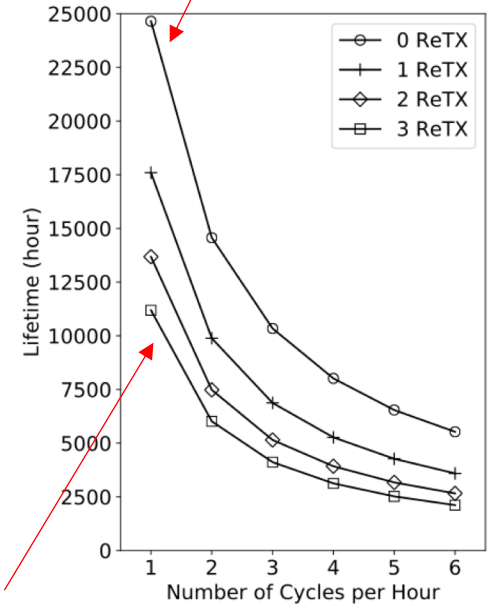
~360 days

~2.7 year

~460 days



(a) CR: 4/7; SF: 1024 CPS



(b) CR: 4/5; SF: 128 CPS

Conclusion

- ***Flomosys* is a low-cost, low-power, secure, scalable, reliable, and extensible flood monitoring solution**

- Unlike other solutions Flomosys
  - Can be built **inexpensively** with off-the-shelf components
  - **Scales** across vast territories at a low cost per Node
  - Continuously reports data over several miles for years using a 2400 mAh battery, marking it a very **low-power** solution

- HMENC, the low-power encryption algorithm, **secures** all data sent between Nodes and Gateways, and the protocol supports adding new message types in case additional modules need to be added to the board

Acknowledgement

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