Emergency Vehicle Awareness

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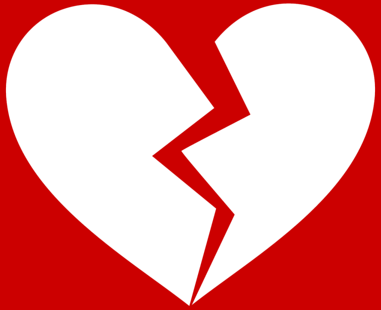
Emergency Vehicle Early Warning System

- Background
- Our Approach
- Our Models
  - Client/Server - Cellular
  - Peer to Peer - RF
- Benchmarks
- Conclusion & Future Works
- Demo

Nearly 300,000 people die each year to cardiac arrest



Nearly 300,000 people die each year to cardiac arrest

30% could be saved by faster response times


30,000 serious accidents involving fire
trucks each year

When an accident happens

in a tunnel in South Korea.

Background

- There are too many accidents that happen each year involving emergency vehicles
- Our current alert system (lights and sirens) has seen few advances in the past decades
- With modern wireless technology we should be able to alert drivers before they can even hear or see emergency vehicles

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Our Approach

- Emergency Vehicles broadcast their location, and receiving vehicles can react appropriately
- How to accomplish this?
  - Client / Server - Cellular
  - Peer to Peer - RF

Early Testing - Client / Server (Cellular)

- What does mobile data performance look like?
- How does it compare to WiFi?
- Test Application
- Lead us to three possible models

Early Testing - Peer to Peer (RF)

- Hardware experimentation

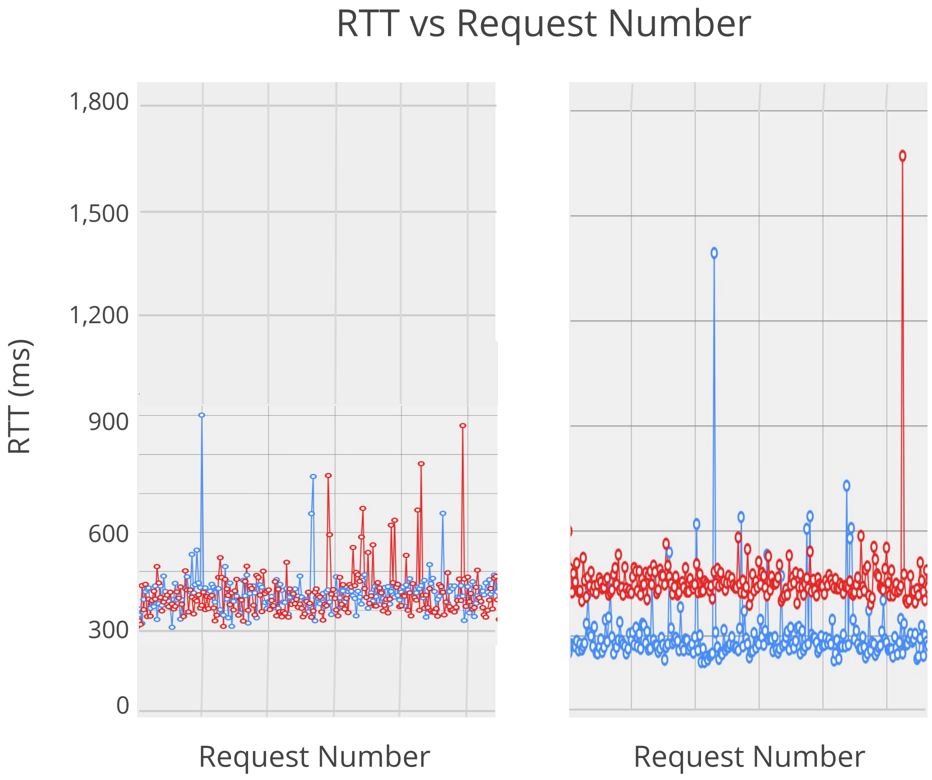
Connection Test Application

Mobile Data

4G from Malone

Mean: 442 ms
Median: 435 ms

More variability



WiFi

hopkins network in Malone

Mean: 300 - 450 ms
Median: 410 ms

More consistent, but more dependant on specific URL

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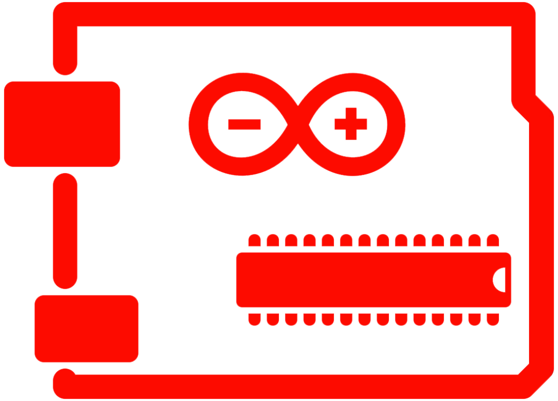
Peer to Peer (RF) Method



Prototyped with an **Arduino**

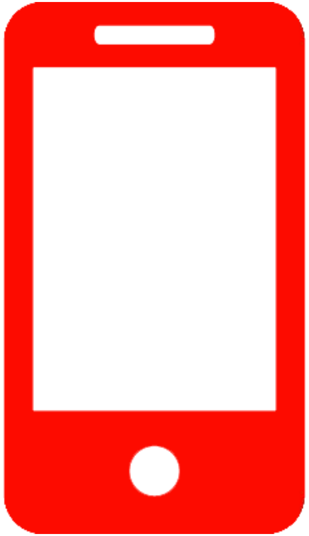
P2P between cars

Uses **smartphone** for GPS and mapping of emergency vehicles

Peer to Peer (RF) Overview

- Decentralize our alert system for faster warning propagation
  - Similar to 802.11p, which was designed for inter-car communications
  - P2P, with alerts originating from equipped emergency vehicles
- The emergency vehicle constantly broadcasts to surroundings
  - Easily scalable
  - Very fast communication (~10ms per hop)
- All devices forward any alerts they receive, propagating messages away from their sources

Client/Server (Cellular) Method



Deployed as a **smartphone app**

Client/Server Model

TCP-based protocol over **4G/LTE**

Central Server Alerts Drivers

Client/Server (Cellular) overview

- Maintain a centralized list of users and their current locations
    - Server client model
- Emergency vehicles send their messages to the server which then alerts all users near the vehicle
- Takes advantage of existing infrastructure
    - Rely heavily on 4G/LTE coverage and future innovations to wireless infrastructure to handle communications
- Use Firebase to message all clients instead of server
- Potential to give warnings even earlier than RF

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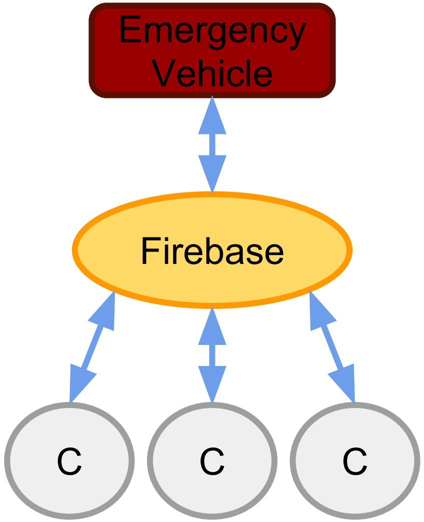
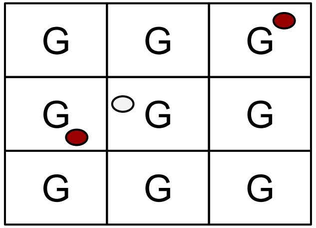
Discarded Strategy: Firebase-Only Approach

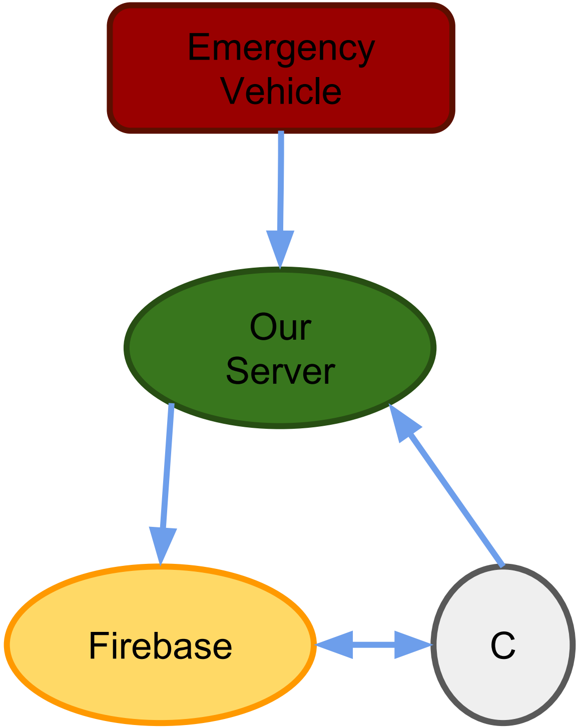
- Firebase can have users join "groups"
- We would associate a "group" with a geographical bucket
- All clients join and leave groups as their location changes
- Emergency vehicles send notifications to the nearby groups
- Jeff Dalla Tezza cautioned against this:
  - Firebase is not designed to handle the churn of our users switching groups rapidly
  - Recommends we store Firebase ID's and directly message devices





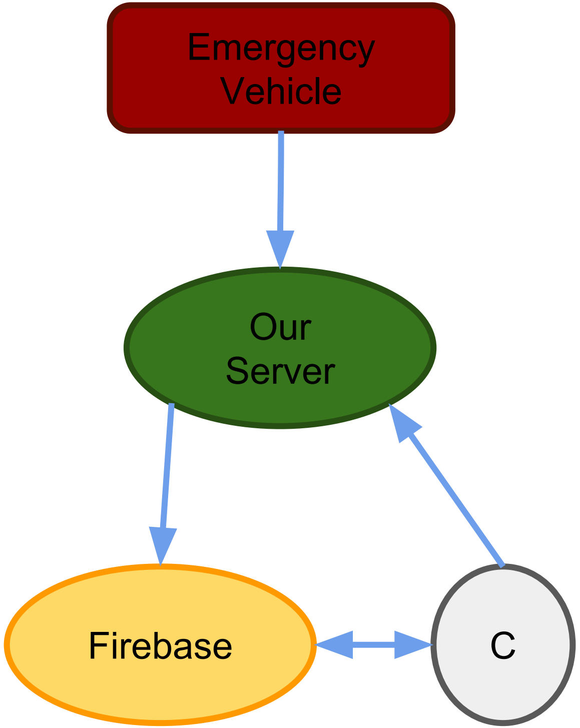
Method: Hybrid Server/Firebase

- Clients receive a unique token from Google
- Clients pass our server the token
- Clients periodically update our server with location
- On emergency, we send appropriate tokens to Google, who then manages the notifications to clients

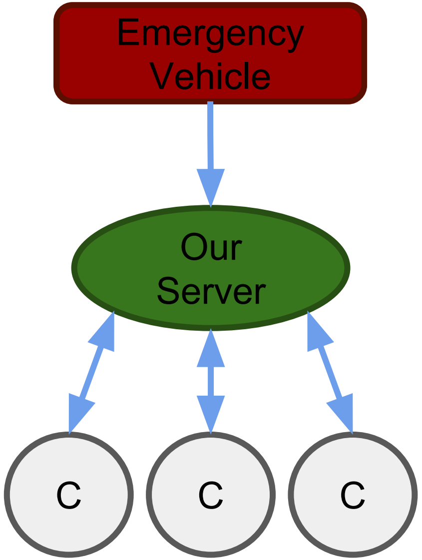


Method: Hybrid Server/Firebase

- Pros:
  - Load on our servers is lower
    - Utilize Google's resources
- Cons:
  - Need to store location of all users
  - Additional latency from using Firebase

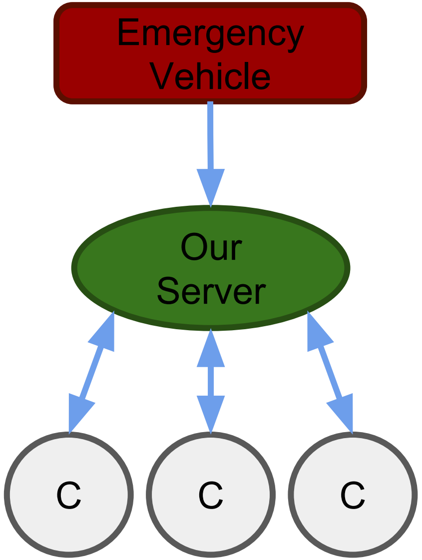


Method: Server-Only Approach



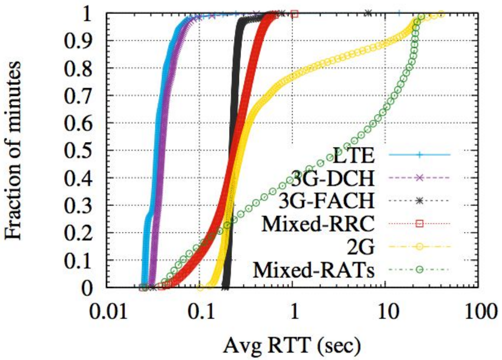
- Emergency vehicles constantly send the server their location
- Server only stores the locations of emergency vehicles
- Clients send periodically their location, and ask, "is there an emergency in my area?"
- Clients can additionally sent older locations for better heuristics on the server

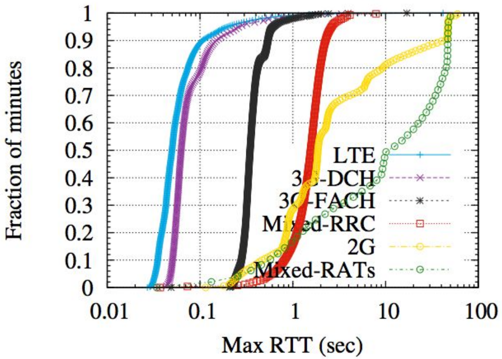
Method: Server-Only Approach



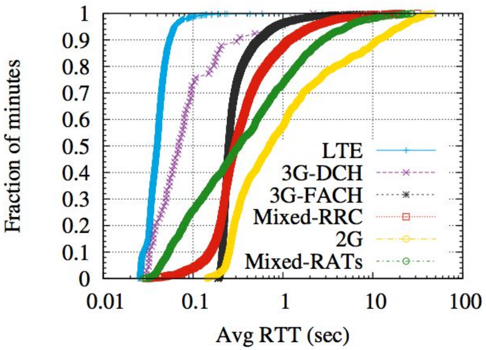
- Pros
  - Lowest expected latency from server/client approaches
  - We already round trip connections to the client for each update, so we might as well take advantage of that response
  - Less information to store server side (more scalable!)

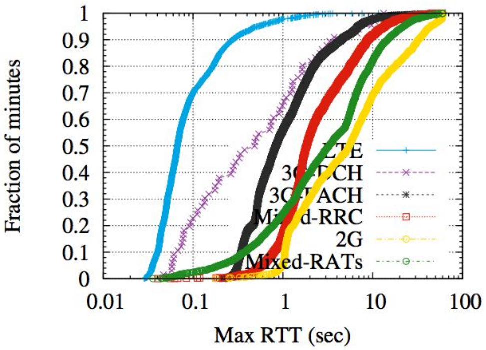
Stationary Mobile Packet Loss



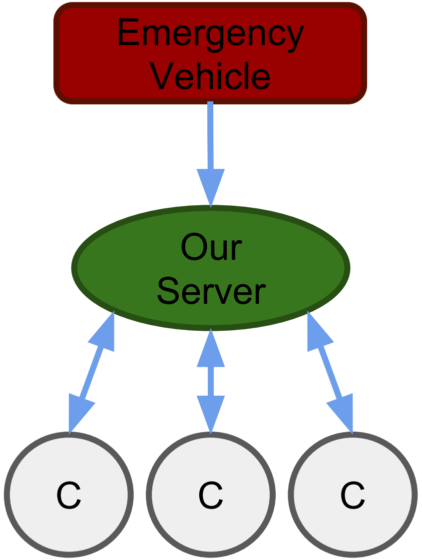


Mobile Packet Loss in a Vehicle





Method: Server-Only Approach (Faster?)



- Scaling to millions of cars making millions of TCP connections is impractical
- Car interaction with the server is stateless, side-effect free, and brief
- Replace HTTP with space efficient binary system
- Emergency vehicles still communicate over TCP
- Cars can use a simple UDP with retry protocol to avoid the 3-way handshake

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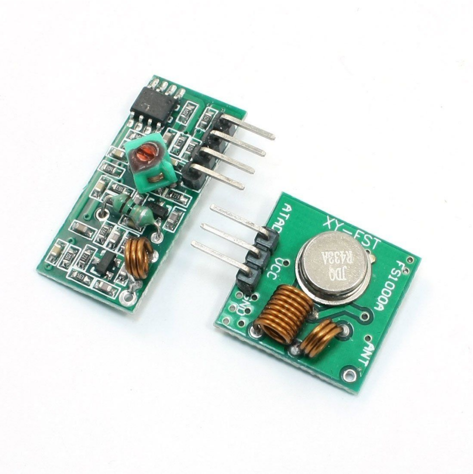
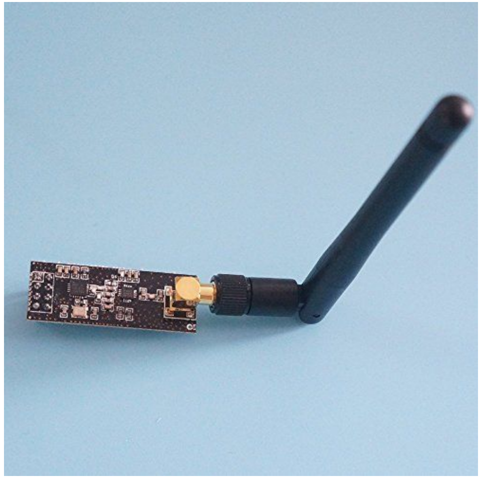
Peer to Peer (RF) approaches

- Tested with both 433MHz and nRF24l01 (2.5GHz) transmitters
- Found better range and library support for nRF24l01



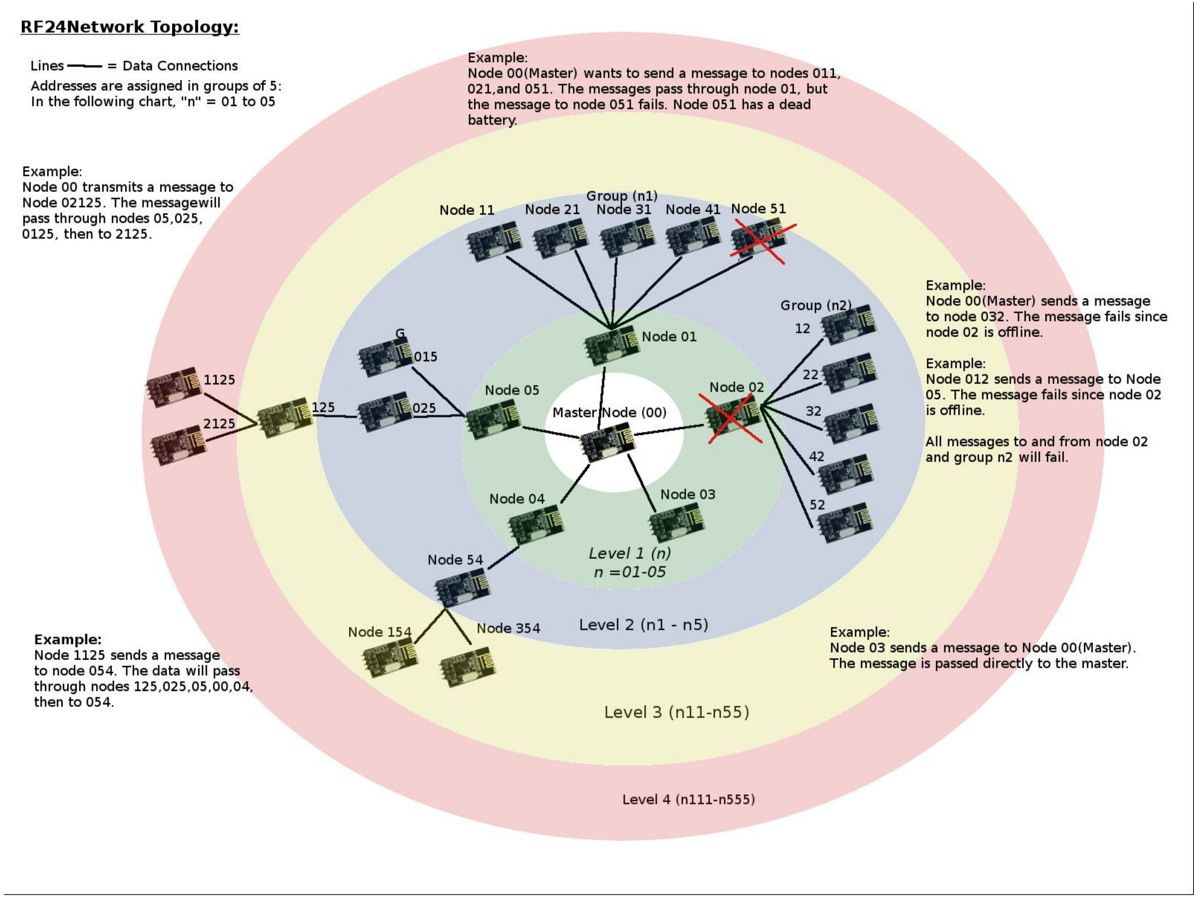


Peer to Peer (RF) Hardware Details

- nRF24l01 with line of sight has range of about a football field - 120 yards. Loss of 5-10%
- Maximum message length of 32 bytes

RF24 Details

- Used the RF24 library by TMRh20
- Library supports reads, writes, multiple channels
- Library supports IP-like addressing & mesh network, but overhead was too high for nodes in motion



Peer to Peer (RF) Protocol

- Emergency vehicles create alerts, send them out via broadcast
- Each created message has an ID and a TTL
- Messages that are received by civilian vehicles are retransmitted with probability 1/(2^n). n = times message has been retransmitted
  - In a busy environment, civilian vehicles are expected to retransmit each message 2 times:

$$\sum_{n=0}^{\infty} \frac{1}{2^n} = 2$$

Peer to Peer (RF) Protocol

- If the network is busy, transmitters will wait a random amount of time (up to 10ms) before attempting to transmit again.
  - Based on Carrier-sense multiple access (CSMA) protocols.
- Older versions displayed message paths, knowledge matrices

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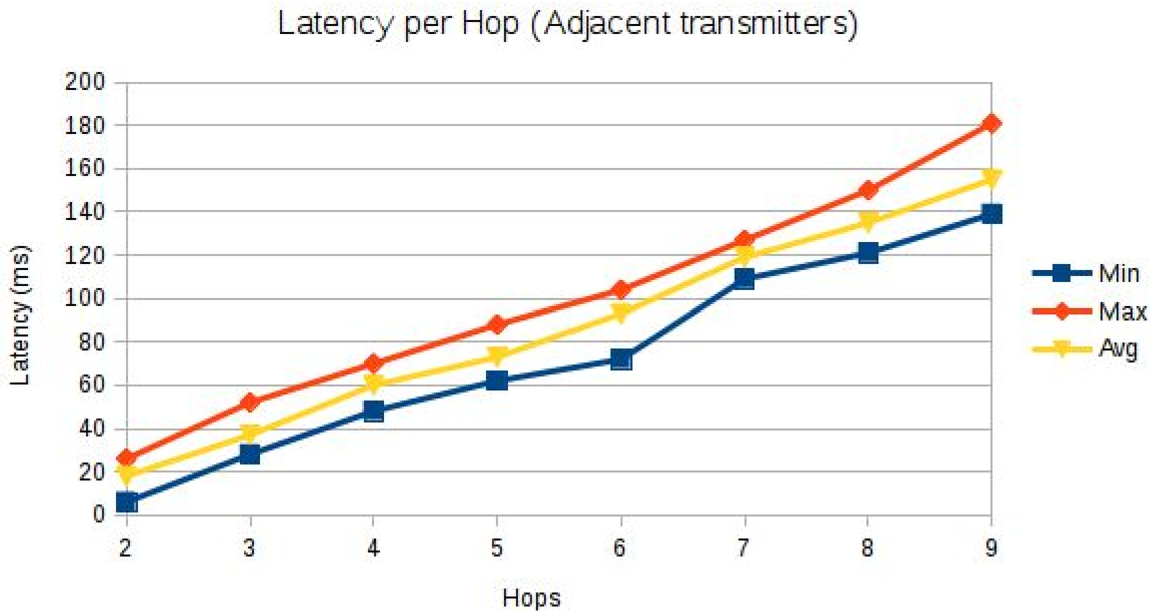
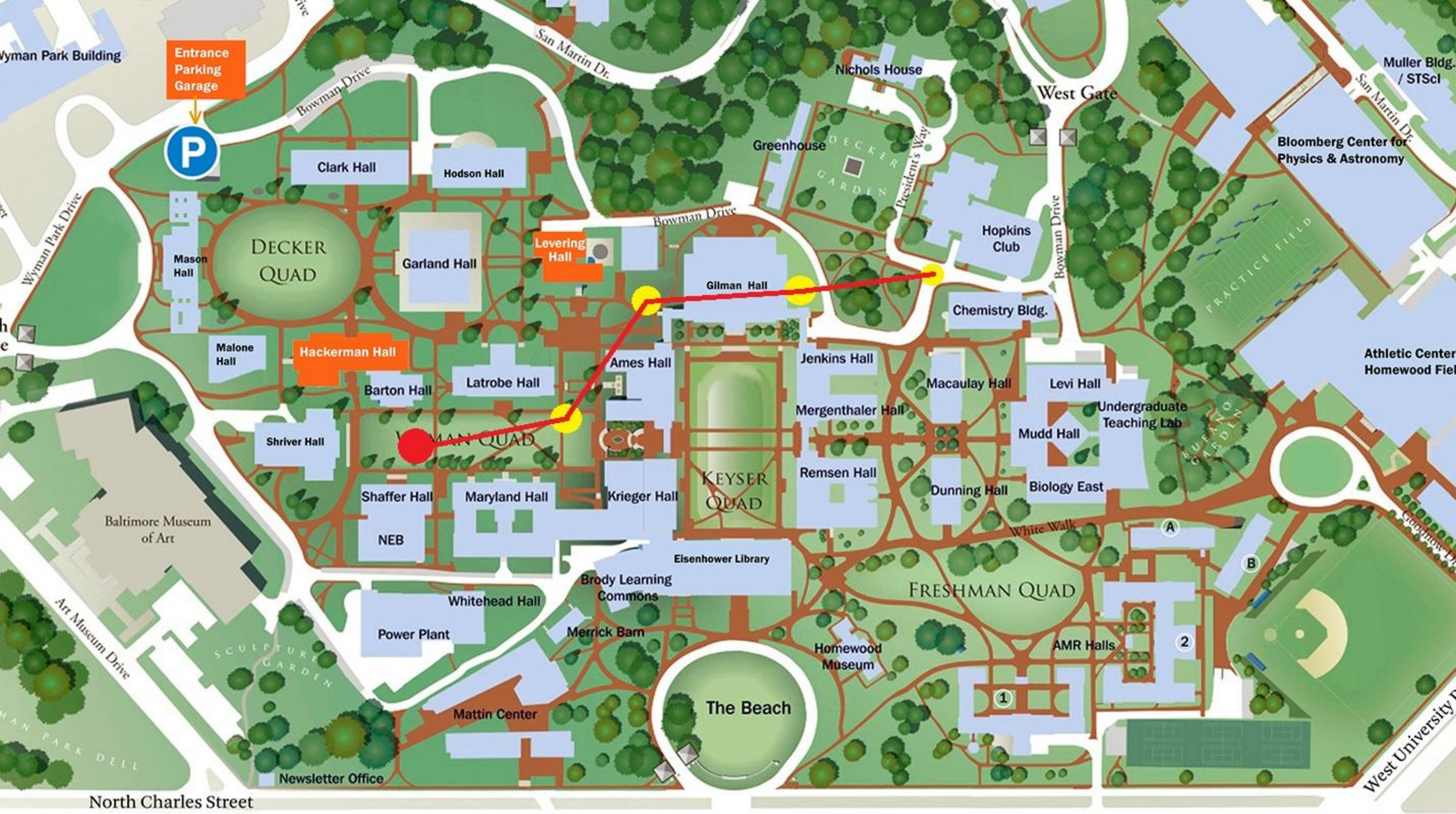
Peer to Peer (RF) Benchmarks

- On average, about 18ms per hop
- First few hops are faster (~10ms) due to lower message traffic
- With android app, much slower due to Serial communication (baud rate = 9600)




Wyman Park Building
Entrance Parking Garage
P
Bowman Drive
San Martin Dr.
Nichols House
West Gate
Muller Bldg. / STScI
San Martin Dr.
Greenhouse
Decker Garden
President's Way
Bloomberg Center for Physics & Astronomy
Clark Hall
Hodson Hall
Wyman Park Drive
Bowman Drive
Hopkins Club
Bowman Drive
Practice Field
Mason Hall
Decker Quad
Garland Hall
Levering Hall
Gilman Hall
Chemistry Bldg.
Malone Hall
Hackerman Hall
Ames Hall
Jenkins Hall
Athletic Center Homewood Fiel
Barton Hall
Latrobe Hall
Macaulay Hall
Levi Hall
Mergenthaler Hall
Undergraduate Teaching Lab
Shriver Hall
Wyman Quad
Mudd Hall
Remsen Hall
Keyser Quad
Shaffer Hall
Maryland Hall
Krieger Hall
Dunning Hall
Biology East
Baltimore Museum of Art
NEB
White Walk
A
B
Eisenhower Library
Brody Learning Commons
Freshman Quad
Whitehead Hall
Power Plant
Merrick Barn
Homewood Museum
AMR Halls
2
Art Museum Drive
Sculpture Garden
The Beach
Mattin Center
1
Newsletter Office
North Charles Street
West University

Client/Server (Cellular) Implementation Details

- Server running in the basement of Malone right now
  - 4 core Intel Xeon 3.20GHz, 3 gigabytes of RAM
- Android App (Java)
- Python Flask Server (behind uwsgi)/Golang Server
- Redis backend (Manage location data)
- Nginx reverse proxy

Emergency Vehicle Early Warning System

Conclusions

- We have a version of our system that works for both sides
- The RF side may need more tuning in the future to work in crowded situations
- The server the app communicates to may eventually need to become distributed to handle increased loads or failures
- Adoption of system is likely to be a large hurdle to overcome

Future Works

- Test in actual cars
- Smarter decisions using location on the server side
- Larger scale RF tests - play with dynamic wait periods, dynamic propagation probabilities, find/develop ways to send longer messages.
- Optimize communication between Android/Arduino, do more computation on Arduino to limit Serial communication

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Demo