Intelligent Self-Healing Wireless Mesh Network for Sound Transit Rail Trains

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SOUNDTRANSIT

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Motivation

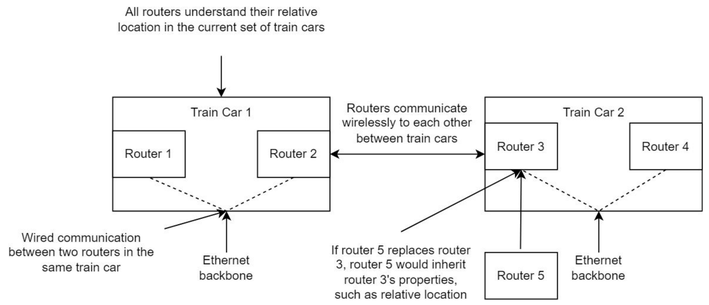
- Sound Transit has several commuter train carriages that are shuffled regularly to form a consist (a set of carriages forming a train).
- Currently, each carriage has 3 information systems that independently upload their data to a back-end using separate cellular connections.
- In order to track a consist, GPS data from each carriage is used to stitch a consist. There is no consist-wide network which makes broadcasting consist-wide messages cumbersome.
- Creating a consist-wide dynamically forming (to account for shuffling) network would allow easier message broadcasts and streamline the information flow.

Objectives

- To build a consist-wide network that updates dynamically as carriages are shuffled around.
- Formation of a consist network should require minimal manual input, ideally no human input.
- Adjacent consists (trains on side-by-side rail tracks) should not form connections to each other.
- Ideal end-end throughput speed around 250 Mbps.

Model & Approach

- Wireless connections between neighboring carriages using WiFi.
- Ethernet backbone throughout a single carriage to connect the front and rear ends of a carriage.



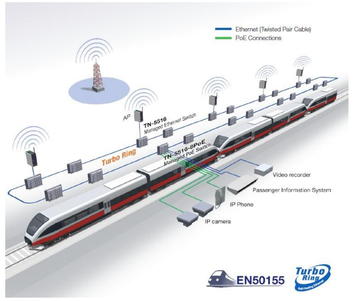
UML Diagram of how a train consist is built and its self healing capabilities.

Implementation

- Linksys EA8300 routers equipped with two 5 GHz radios and one 2.4 GHz radio used to implement a node in the network.
- OpenWRT firmware flashed on all routers to improve configurability and flexibility to use a large selection of software packages and tools.
- Notable Packages used:
  - Batman-adv: B.A.T.M.A.N. mesh networking protocol used to manage the consist network
  - Batctl: suite of tools to configure and monitor mesh network
  - Wpad-mesh-openssl: provides support for WPA encryption needed to encrypt mesh connection
  - alfred: User space daemon used to create network maps on demand
  - ttyd: Support for a terminal to the over a web browser, forgoing the need to SSH into the router to modify settings or obtain information
- 5 GHz radios are configured in 802.11s mesh mode which only connect to other mesh nodes given matching parameters: mesh name, password, channel
- Received Signal Strength Indicator (RSSI) threshold and radio power tuned to determine when two carriages connect:
  - o Sufficient radio power to have good SNR at ~4 ft apart
  - o RSSI threshold tuned to allow connection at ~4 ft apart, **but not** ~20 ft apart

Future Work

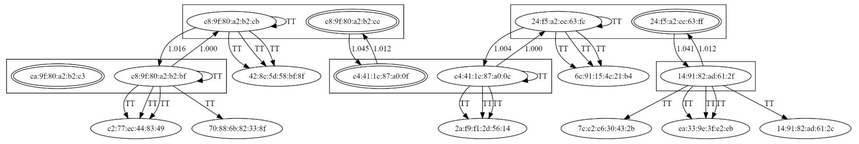
- We were able to successfully develop a self-healing and intelligent network across multiple consists. Each consist network is a combination of wired connections and wireless hops.
- Currently, our setup uses a daisy-chain of routers linked in a linear fashion with no redundancy.
- In case one of the routers gets damaged or fails, the entire network will get cut off from that point. The next step of this project would be to experiment with a ring network topology to provide some redundancy across the length of a consist.



Depiction of a ring topology version of a network like ours

Results

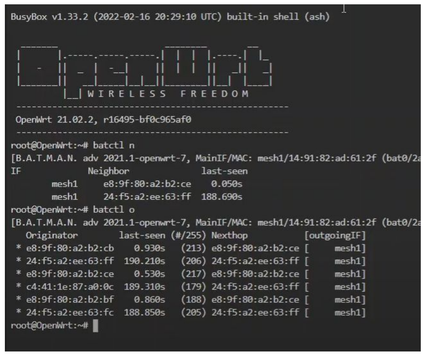
- End-end throughput of 50 - 190 Mbps tested across 5 nodes, simulating 3 carriages with 2 wired connections and **2 wireless hops**.
- Carriages reliably connect to one another by simply coming into close proximity - if the distance between two routers is < 5 ft.
- Any permutation of train carriages can connect and create a unique mesh network at any time upon rebooting (self-healing).
- Automated a script to run on router boot such that a network map of currently connected routers can be generated.



Sample network map generated with two train carriages in the network. Nodes in boxes represent routers, and nodes (other than boxes) represent devices connected to the network.

- Successfully created a local consist-wide network that can be used for local file transfers and broadcasts, as well as provide internet access across all nodes (given one of the nodes is an internet gateway).
- Handshake time (i.e. the time required to establish connection between two carriages) is about 5 seconds.

Our set up for the physical test, with our cars simulating train carriages being shuffled to form different consists.



Terminal output displaying MAC addresses of other routers detected in the network

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