

Configuring and Testing Mesh Radios for Air-To-Ground Communications

Project: ACERO (Advanced Capabilities for Emergency Response
Operations)

Project Team: Second Shift Capabilities

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INITIAL CONFIGURATIONS

The initial mesh network used to demonstrate a simple mesh network for the air-to-ground challenge will consist of 4 mesh radios purchased from DoodleLabs. The multiband radios operate in both the 915MHz and 2450MHz frequencies and can use Wi-Fi to connect to deployed devices. The DoodleLabs radios come preconfigured with unique IP addresses but to make sure of compatibility each radio will be assigned an IP address. For initial testing configurations will be changed using the built-in local web server interface that DoodleLabs radios provide. To access the webserver a computer connects to the radios broadcast Wi-Fi network using the default credentials, then enter the default IP address into a browser. This webserver will allow the user to monitor the radio performance and make changes to the various systems. The simple configuration page will allow an operator to make many of the initial changes to place each radio on the network and secure each connection with a new password.

Further testing will then be performed by building out a simulated virtual network of 26 nodes and connecting the 4 DoodleLabs radios into this simulation. This will give insight into the radio's performance in the larger system they will likely operate in given the project requirements. This testing will focus on multi-hop throughput, latency and the resiliency to packet loss.

The screenshot displays the Doodle Labs webserver interface for configuring a Mesh Rider Radio. The browser address bar shows the URL <https://10.223.96.98/cgi-bin/luci/admin/simpleconfig/index>. The page title is "For first time configuration, choose your profile and options below".

Configuration

Profile Configuration:

- Select Profiles: General Profile

Wireless Configuration:

Configuration for Mesh Rider Radio:

- Active frequency band: 915 MHz
- Select Scenario: Mesh on radio0
- Mesh ID: simpleconfig
- Wireless Password: [masked]
- Channel: 12 (915.000000 MHz)
Some channel and bandwidth combinations are not valid due to regulatory restriction
- Bandwidth: 10 MHz
- Operating Distance (m): 4000

Configuration for Wi-Fi Radio:

- Select Scenario: unmodified
- SSID: DoodleLabsWiFi-505347
- Wireless Password: [masked]

Left Sidebar:

- DOODLE LABS
- Mesh Rider Radio
- MAC #00301a506062
- Status
- System
- Services
- Simple Configuration (highlighted)
- Simple Configuration
- Network Configuration
- Basic Settings
- Logout

Figure 1: Doodle Labs webserver simple configuration page

NETWORK MANAGEMENT

After completing the initial setup and getting the radios connected the advanced setting tab will allow the user to make specific tweaks to the configuration. Here the user will choose the transmit power, bandwidth and channel for each radio. The user can also change mesh network characteristics, routing, firewall, DNS and traffic priorities. The advanced tab also allows the user to monitor network performance, mesh characteristics, and link strength. In addition to the configuration options, the advanced settings enable the users to make targeted tweaks to the mesh network. Fine-tuning the mesh characteristics involves optimizing routing, minimizing the number of rebroadcasts needed, and developing traffic priority. Network management settings can also be used to add additional security through firewall changes and authentication requirements. Traffic prioritization may become pivotal in ensuring consistent communication if there is a data hierarchy. While the current proposal expects no guarantee of data delivery using a best effort model, the testbed will still investigate stricter communication standards.

Configuration Parameter	Setting Description
Transmit Power	Adjustable power level to allow operators to save battery life at the cost of wireless range
Bandwidth Allocation	Adjustable bandwidth allowing operator to change throughput on data transfers at the cost of frequency congestion
Channel Selection	Specifying the intended communications frequency
Mesh Routing Configurations	Parameters to allow adaptability and optimization of the mesh routing connections
Firewall Settings	Security settings
Traffic Priorities	Allows user to specify protocols or types of data as different bandwidth priorities
Performance Monitoring	Real-time graphic data and logging of radio performance and health

Table 1: Advance Network Configuration Parameters

RADIO SETTING VARIATIONS FOR TESTING

To ensure comprehensive testing of the mesh network performance, various radio setting variations will be tested to help determine optimal settings for a given operational environment and operational requirements. This will include adjusting transmit power levels to simulate different communication ranges, analyzing data transfer by adjusting bandwidth allocation, and investigating interference resilience with different channel frequencies. Figure 2 shows the expected shape for a range and transmit power graph after testing. Different channels should offer similar ranges given the same transmit power, but battery longevity should be affected given different transmit powers. Additional testing will also include mesh network configuration changes, routing and priority testing, and network structure experiments. These setting changes aim to illuminate an optimal configuration for the doodle labs network, however understanding power use, heat management and ease of setup will also be important metrics tracked for the purpose of creating an overall recommendation for the mesh network.

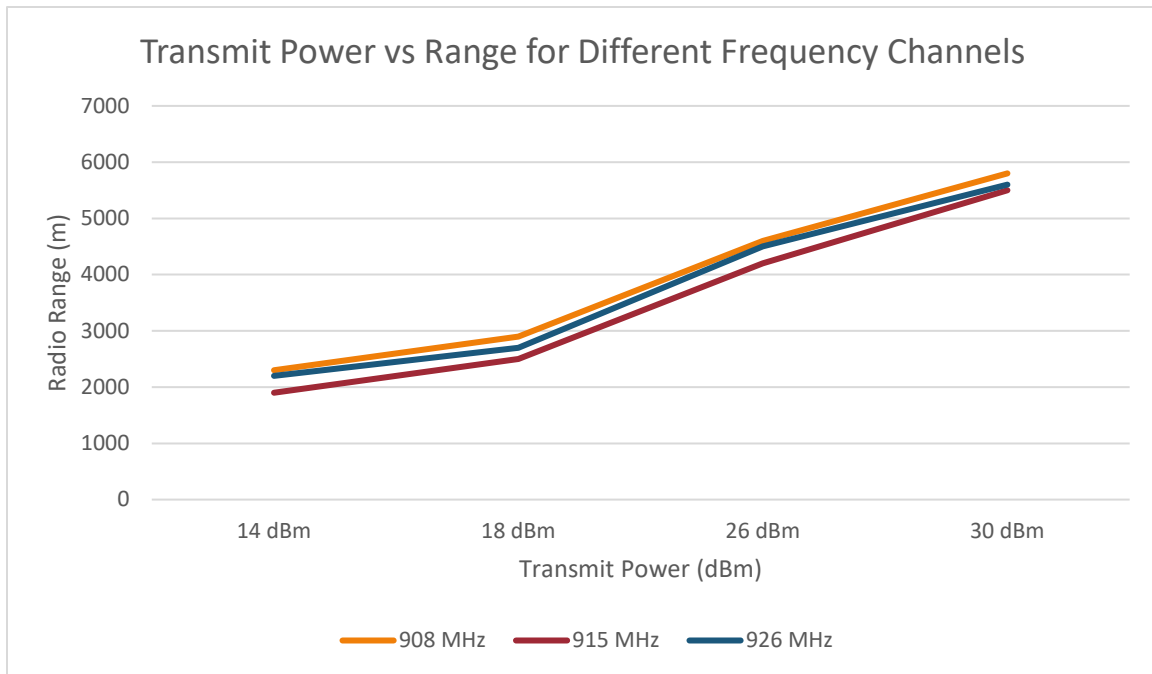


Figure 2: Calculated Transmit Power to Range Based on Frequency Chart

RADIO TESTING PLANS AND GOALS

The main goals of radio testing will be to get a baseline understanding of the radio capabilities and assess effects configuration has on performance. Testing will remain simple to inform more complex future testing and to allow easier comparison with other radio options and the simulation results to follow. The testbed's results combined with the simulation conclusions will be analyzed to create recommendations for hardware and network configurations for larger-scale deployments of mesh networks in a wildlands fire operation. Table 2 outlines a general schedule for radio testing and setup of the mesh radio network. The setup testing will involve node to node mesh network analysis done at various distances between radios. The priority will be determining the data rates between nodes, signal to noise drop off with distance, and data travel time. Larger mesh characteristics can then be approximated with the data and future recommendations can be made. Once setup testing is completed the radios will be integrated into a 30 node virtual network to get a better understanding of larger mesh network performance, primarily multi-hop performance.

Tentative Testing Schedule						
Timeline	Week 1		Week 2	Week 3	Week 4	
Hardware	Setup initialization of radio hardware	Battery life, temp monitoring	Battery life, temp monitoring	Battery life, temp monitoring	Battery life, temp monitoring	Battery life, temp monitoring
Baseline tests	Simple default range baseline test	Min setting testing	Max setting testing		Optimized setting testing	Optimized setting testing
Power tests		Min power	High power	Range/Power optimization	Range/Power optimization	Range/Power optimization
Networking tests			Network configuration testing	Network configuration testing	Network configuration testing	Network configuration testing
Mesh tests				Traffic priority	Routing Optimization	Routing Optimization

Table 2: Tentative testing schedule for mesh radio system

DEMONSTRATION TESTING AND RESULTS

Following the test plan data was collected from a simple mesh network connection between two Doodle Labs radios. Connections between the radios was confirmed with ping messages between radios and monitoring using the webserver hosted by one of the radios on the mesh network. Priority in testing was given to understanding the variations in possible default configurations and their performance with respect to the default provided by the manufacturer. The radios were separated at 4 different distances each with line-of-sight views and four different readings were taken at each location: Data rate, Signal to noise ratio, ping and temperature. During testing the temperature of the stationary radio was taken, it averaged out to 44.25C° with a range of 39-47. Data rate dropped with distance and the channel frequencies trended together with higher frequencies seeming to lower data rates at closer distances compared to the default frequency. However, the signal to noise ratio for each test trended together much closer with only slightly higher performance going to the lower frequency tests. Ping was much more variable with the default configuration performing the worst, with other testing increasing ping slightly with the increase in radio distance. Overall, the testing agrees with the theoretical slight distance advantage that the lower frequencies within the ISM band has assuming limited to no obstruction.

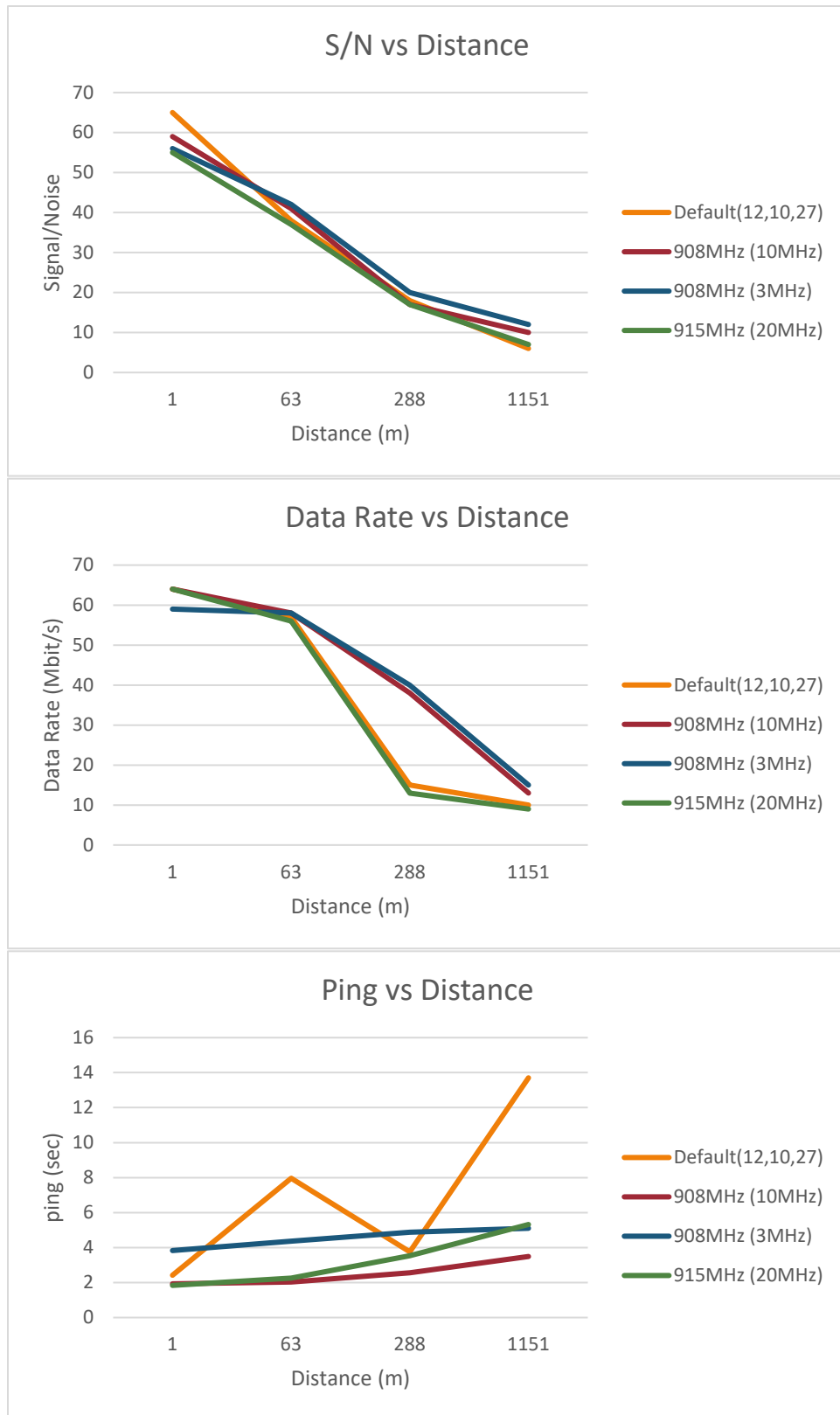


Figure 3: Charts for Results from Mesh Radio to Mesh Radio Testing at Various Distances and Frequencies

Following the radio to radio testing all 4 DoodleLabs radios were integrated into a 30 node simulation along with 26 simulated nodes. The simulation is built in CORE (Common Open Research Emulator) a network simulation tool that enables network testing using virtual networks. This software also allows real network interface connection that enables integration of real networking hardware and networks with the virtual network. The primary aim of this testing is to evaluate the throughput of the simulated network under various connection statuses and routing conditions. The network performance will be assessed at different connection qualities (excellent, good, and poor) and with routing paths requiring 1 to 4 hops.

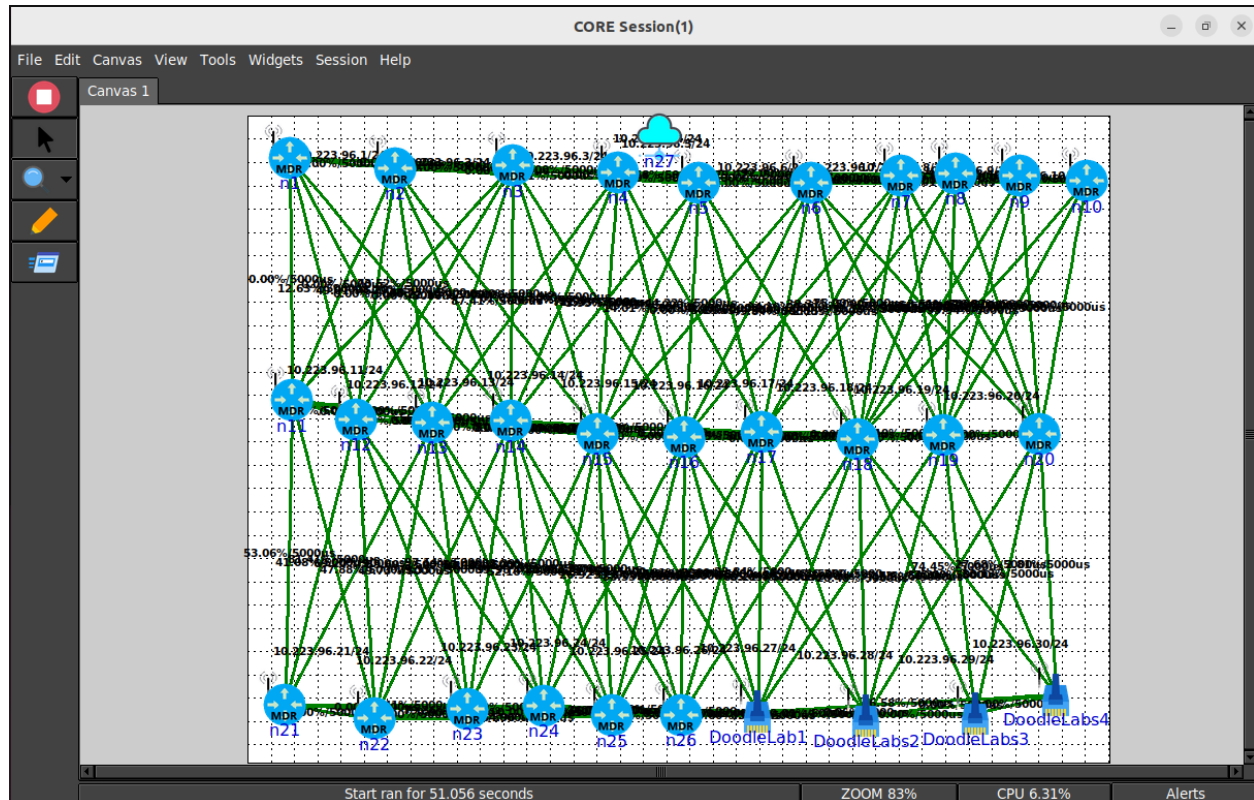


Figure 4: CORE Simulated Network With DoodleLabs Radio Interfaces

The setup includes a combination of real and simulated nodes to replicate a comprehensive network environment. Each virtual node is a MANET designated router and uses the OSPFv3MDR routing protocol. This approach ensures that the simulation closely mimics real-world conditions, providing reliable data on network performance.

The throughput testing will be conducted under the following connection statuses:

1. **Excellent Connection:** Represents optimal conditions with minimal interference and maximum signal strength.
2. **Good Connection:** Reflects conditions with moderate signal strength and some interference.
3. **Poor Connection:** Represents challenging conditions with low signal strength and significant interference.

Each connection status will be tested with routing paths requiring 1 to 4 hops. The variation in hops will help in understanding the impact of network path length on overall throughput and latency.

Connection Status	Hops	Throughput (Mbps)	Latency (ms)	Packet Loss (%)
Excellent	1	37.9	20.439	0%
Excellent	2	5.6	10.537	1%
Excellent	3	1.2	15.488	1%
Excellent	4	0.3	20.439	1.5%
Good	1	37.1	13.375	0%
Good	2	5.56	17.305	4%
Good	3	1.1	20.34	6%
Good	4	0.28	23.375	8%
Poor	1	38.4	19.017	33%
Poor	2	5.64	27.972	34%
Poor	3	1.13	35.011	35%
Poor	4	0.3	42.017	36%

Table 3: Results Table for Hop and Connection Quality Testing

Generally, this testing showed the network was able to maintain throughput even with significant packet loss although latency generally gets higher as the connection worsens and the number of hops increases. Pushing packet loss above 60% yielded unstable connections and unpredictable throughput, therefore keeping packet loss well under 50% should allow for data to be sent relatively consistently. These throughput numbers will be more consistent with the final mesh radio wired to an internet backhaul as the interfacing bridge was a wired connection between the radios and simulated nodes.

However, the data trends will still be similar to an all-wireless network as the software is able to simulate packet loss and interference.

TESTING CONCLUSIONS

After examining the testing results node to node performance within the mesh network was not meaningfully impacted by small variations in frequency or bandwidth. Battery life and temperature were also not impacted differently by these changes in settings. Furthermore, the consistency in signal-to-noise ratios across different frequency tests highlights the resilience of the mesh network to environmental interference. This resilience is crucial, particularly in dynamic and challenging operational settings where signal integrity is essential for mission-critical communications. Overall, the testing outcomes affirm the effectiveness and reliability of the mesh network design. These conclusions provide confidence in the network's suitability for deployment in air-to-ground communication challenges, offering a robust solution capable of meeting the demanding requirements of such environments. Moving forward, further testing and validation of the larger simulated mesh system will give better real-world results and network performance for packets sent through multiple nodes. Future testing could also test the limits of bandwidth and the amount of data that could be sent through the network. From testing lower frequencies within the band yielded consistent improvements over default and higher frequency channels. However, increasing user ergonomics may mean that the default configuration is best suited for deployment as its performance was not significantly worse than the best configurations found.

FUTURE TESTING AND THOUGHTS

The maximum number of required hops for the network is a key factor in determining the expected throughput of the network. Operational data may allow for estimation of this requirement and integrating this knowledge into future iterations of the simulation could allow for a more accurate assessment. The CORE software also can have a mobility script added on top of the network simulation so that a virtual simulation could be run with realistic movement of the nodes. This could be a great tool to utilize for operational simulations before real operations are performed. DoodleLabs radio to radio testing could also be expanded to include more radios which would improve the network throughput estimations given real-world conditions. One issue to investigate is the consistency of the simulation results as compared to the DoodleLabs mesh network results because the simulation requires an alternate communication method with the DoodleLabs radios (either USB cable or WiFi connection).