

**MODELING OF MESH COMMUNICATION
UTILIZING STRESS INDUCED LINK EVALUATION
FOR NETWORK TACTICAL MESHES (SILENT-
MESH)**

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RESEARCH TOPIC, QUESTIONS, AND ENGINEERING GOALS

SILENT-MESH IS THE DEVELOPMENT AND DEPLOYMENT OF LOW-POWER MESH COMMUNICATION WITH THE CAPACITY TO MAINTAIN CONNECTIVITY IN DEGRADED ENVIRONMENTS WITHOUT CENTRALIZED INFRASTRUCTURE.

RATIONALE:

COMMUNICATION SYSTEMS OF TODAY ARE CONSTRUCTED USING CENTRALIZED FRAMEWORKS SUCH AS CELL TOWERS, ROUTERS, BASE STATIONS, AND SATELLITES. WHEN THESE FEATURES BECOME COMPROMISED, THE ENTIRETY OF THE NETWORK FAILS, LEADING TO LIMITED SITUATIONAL AWARENESS AND OFTEN MISSION FAILURE.

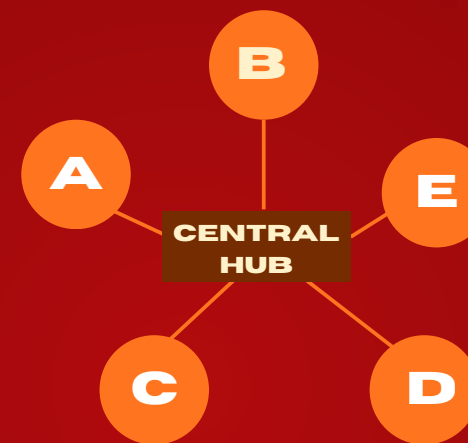
DECENTRALIZED ADAPTIVE MESH TOPOLOGY ESTABLISHES A SYSTEM WHERE NODES RELAY PACKETS OF DATA, FACILITATING COMMUNICATION DURING NODE FAILURE WHILE SIMULTANEOUSLY ELIMINATING DIRECT LINE-OF-SIGHT COMMUNICATION.

ENGINEERING QUESTION:

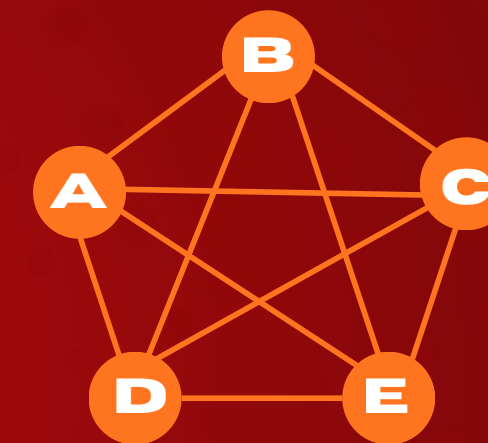
CAN A DECENTRALIZED MESH COMMUNICATION SYSTEM CONSTRUCTED WITH LOW-POWER COMPONENTS MAINTAIN ACCURATE AND EFFICIENT PACKET TRANSMISSION AT DIFFERENT DISTANCES AND ENVIRONMENTAL CONDITIONS?

HYPOTHESIS 1: IF SILENT-MESH OPERATES ON THE UHF-ISM BAND THEN, IT WILL FUNCTION IN LIEU OF DIRECT LINE OF SIGHT (LOS) COMMUNICATION.

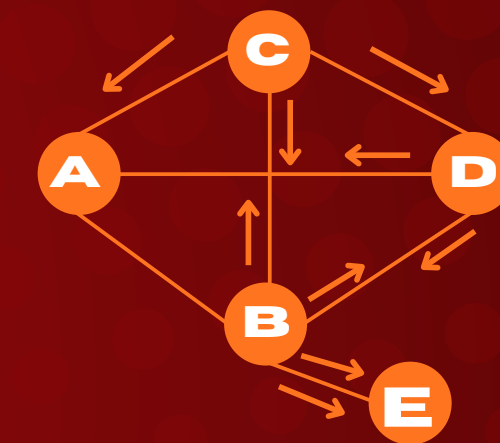
HYPOTHESIS 2: IF THE DISTANCE BETWEEN THE SMN NODES INCREASES, THEN THE SIGNAL STRENGTH AND CONNECTIVITY RATIO WILL DECREASE.



**STAR
TOPOLOGY**



**MESH
TYPOLOGY**



**BROADCAST
FLOODING**

HYPOTHESIS 3: IF THE COMPOUND STRESSORS BETWEEN THE SMN NODES INCREASE, THEN THE SIGNAL STRENGTH AND CONNECTIVITY RATIO WILL DECREASE.

HYPOTHESIS 4: IF AN SMN NODE BECOMES INOPERATIVE, THEN THE IMPLEMENTED ADAPTIVE MESH ROUTING WILL RELAY PACKETS THROUGH OTHER NODES.

EXPERIMENTAL METHODOLOGY AND VARIABLES

- EACH NODE IN SILENT-MESH IS CONFIGURED USING A ESP32 MICROCONTROLLER, 915 MHZ LORA TRANSCEIVER, GPS POSITIONING MODULE, AND USER INTERFACE
- AN ADAPIVE DECENTRALIZED MESH COMMUNICATION NETWORK CREATED UTILIZING 3 PORTABLE NODES
- SILENT-MESH USES MULTIHOP MESH TYPOLOGY WHERE EACH NODE ACTS AS A TRANSMITTER AND A RECEIVER TO ELIMINATE FOREIGN INTERFERENCE AND PREVENT PACKET LOSS

INDEPENDENT VARIABLES:

- NODE DISTANCE
- ENVIRONMENTAL CONDITIONS (E.G CLEAR WEATHER, SNOW, RAIN)
- PHYSICAL ENVIRONMENT (E.G CLEAR OPEN FIELD, URBAN AREA)
- NODE ELVEVATION
- TYPOLOGY
- NODE AMOUNT

DEPENDENT VARIABLES:

- PACKET RATIO (PDR)
- END-TO-END DELAY
- RECEIVED SIGNAL STRENGTH INDICATOR
- NETWORK LATENCY
- PACKET LOSS



CONTROLLED VARIABLES:

- TRANSMISSION POWER
- HARDWARE
- RADIO FREQUENCY BAND
- PACKET SIZE
- TESTING DURATION
- BATTERY POWER
- ANTENNA ORIENTAION

EXPERIMENTAL DESIGN

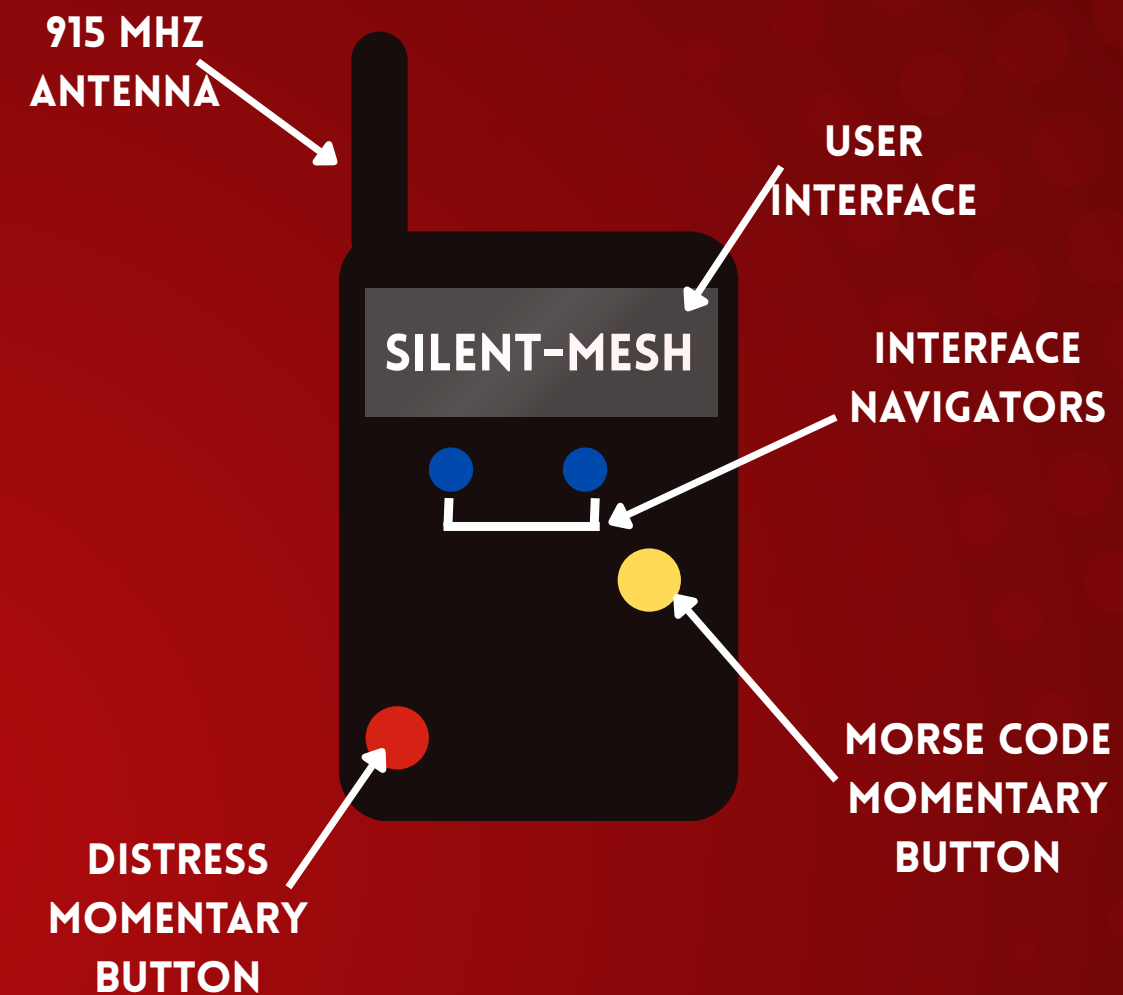
SILENT-MESH'S NODES WERE DEPLOYED AT VARIOUS DISTANCES SPANNING 3 METERS AND 3 MILES TO DEPICT REAL COMMUNICATION ENVIRONMENTS

MULTIPLE PACKETS WERE SENT TO NODES IN THE NETWORK DURING:

- **MULTIHOP ROUTING**
- **PARTIAL NODE FAILURE**
- **DIRECT COMMUNICATION**

AFTER A SUCCESSFUL TRANSMISSION, THE NODE CONTINUOUSLY LOGGED:

- **SIGNAL STRENGTH**
- **SUCCESSFULLY TRANSMITTED PACKETS**

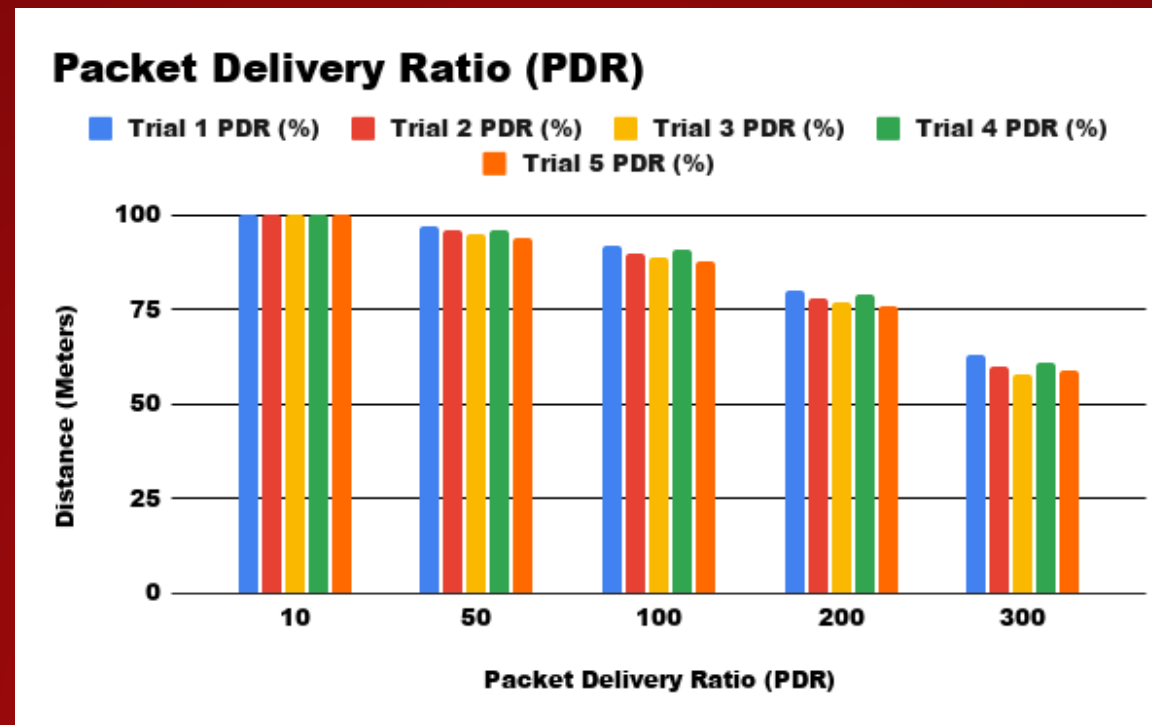


DATA COLLECTION:

- **RECEIVED SIGNAL STRENGTH VALUES PER PACKET TRANSMISSION**
- **SILENT-MESH'S NODES SELF HEALING UNDER FAILURE**
- **SUCCESSFUL PACKETS PER TRANSMISSION**

EMPIRICAL OBSERVATIONS

- **SIGNAL STRENGTH BETWEEN TRIALS SHOWED CONSISTENT ATTENUATION IN RELATION TO RANGE**
- **PACKET DELIVERY GRADUALLY DECREASED AS DISTANCE BETWEEN NODES INCREASED**
- **UTILIZATION OF MULTIHOP ROUTING EXTENDED THE RANGE OF EFFECTIVE COMMUNICATION**



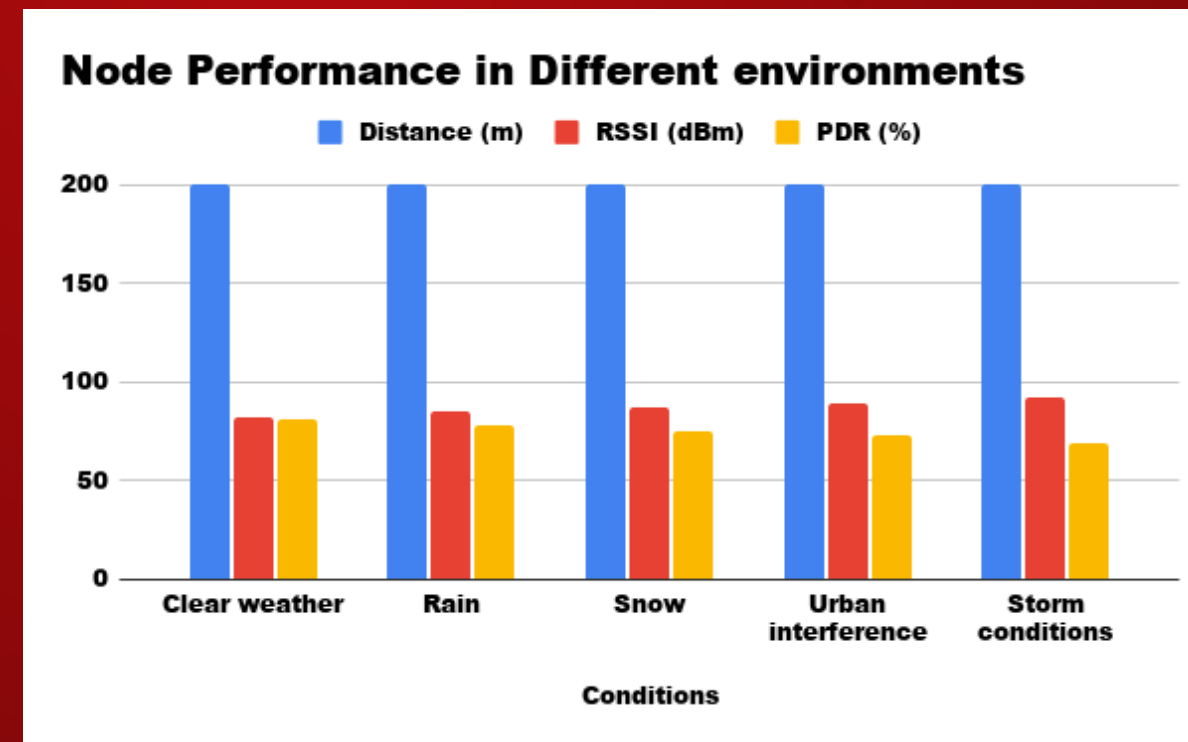
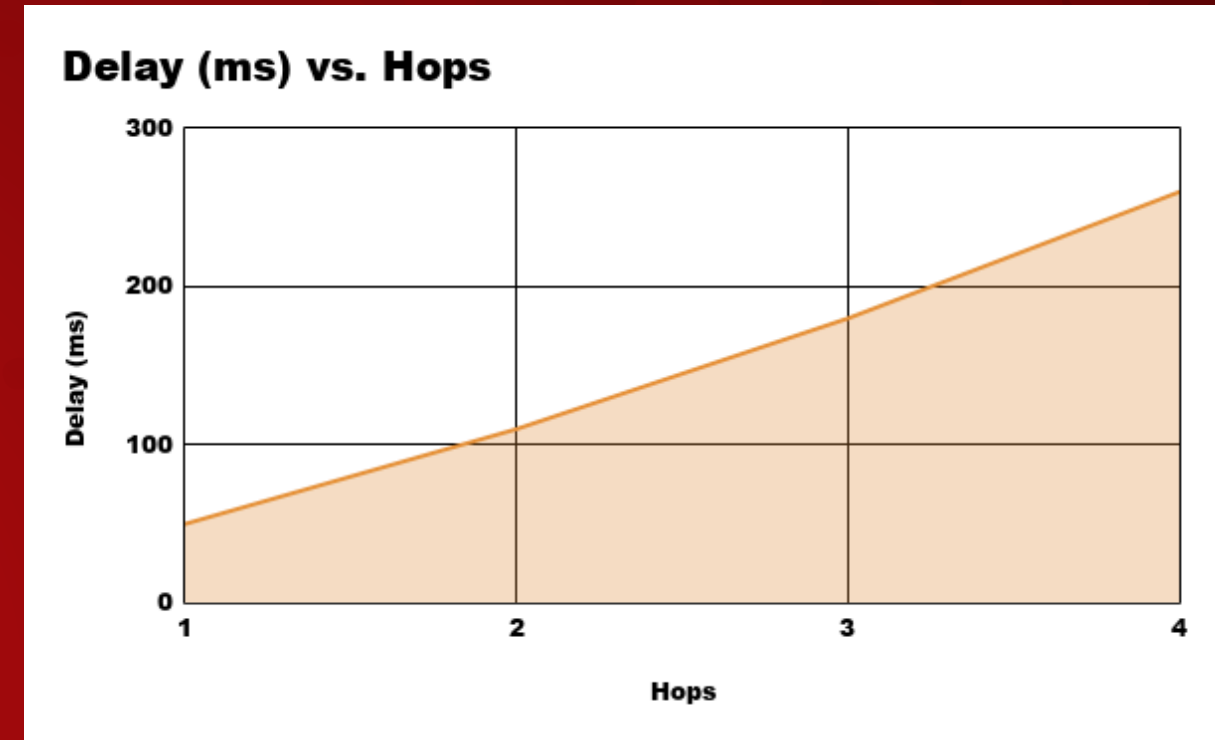
TRANSMISSION DURING OPTIMAL CONDITIONS:

DISTANCE (M)	PACKETS SENT	PACKETS RECEIVED	PDR (%)
10	100	100	100%
50	100	96	96%
100	100	90	90%
200	100	78	78%
300	100	60	60%

EMPIRICAL OBSERVATIONS

(CONTINUED)

- **MULTI-HOP ROUTING SUCCESSFULLY TRANSMITTED PACKETS TO DISTANT NODES.**
- **SILENT-MESH REMAINED FUNCTIONAL UNDER NODE FAILURE**
- **THE NETWORK MAINTAINED COMMUNICATION SURPASSING SINGLE NODE RANGE.**
- **REDUNDANT ROUTING IMPROVED OVERALL PACKET CONTINUITY IN THE NETWORK.**



DATA INTERPRETATION & SYNTHESIS

AFTER CALCULATING THE PDR AND RSSI VALUES BETWEEN THE TRIALS, IT WAS OBSERVED THAT:

- PDR AND RSSI VALUES HAVE CONSTANT ATTENUATION AS THE RANGE INCREASES.
- PDR GRADUALLY DECREASED AS RANGE INCREASED.
- MULTIHOP ROUTING EXTENDED THE RANGE OF TRANSMISSION.
- DESPITE THE ATTENUATION, SILNET-MESH CONSISTENTLY MAINTAINED COMMUNICATION ACROSS THE TOPOLOGY.

BY CONDUCTING A T-TEST, CHI-SQUARED TEST, AND REGRESSION ANALYSIS BETWEEN THE VALUES YIELDED FROM THE TRIALS, IT WAS REVEALED THAT:

- NEAR AND FAR DISTANCE RSSI VALUES SHOWED A STATISTICALLY SIGNIFICANT DIFFERENCE BETWEEN THE TWO DISTANCES.
- A CHI-SQUARE TEST PORTRAYED A PERFECT POSITIVE RELATIONSHIP BETWEEN DISTANCE AND PACKET TRANSMISSION.
- BY ANALYZING LINEAR REGRESSION, A STRONG INVERSE RELATIONSHIP BETWEEN RSSI AND DISTANCE OF PACKET TRANSMISSION WAS DISCOVERED

Near distance <100m
Far distance >100m

$$T = 6.37$$

$$P = 2.47 \times 10^{-5}$$

$$RSSI = -0.148(Distance) - 52.35$$

$$R = -0.976$$

$$p = 5.76 \times 10^{-10}$$

STATISTICAL ANALYSIS & FIELD APPLICATION

- **THE TRIAL RESULTS INDICATE THAT THE UTILIZATION OF A DECENTRALIZED MESH COMMUNICATION ARCHITECTURE IMPROVES AND MAINTAINS CONTINUITY IN DEGRADED ENVIRONMENTS.**
- **MULTIHOP ROUTING IMPLEMENTED IN THE COMMUNICATION PROTOCOL FACILITATES FAST TRANSMISSION.**
- **THE SYSTEM PERFORMANCE ALIGNS WITH MY HYPOTHESES REGARDING LATENCY, PACKET TRANSMISSION, AND ROBUSTNESS.**

STATISTICAL ANALYSIS & FIELD APPLICATION

(CONTINUED)

FUTURE IMPROVEMENTS:

- IMPROVING END TO END ENCRYPTION AND NETWORK SECURITY
- NODE AMOUNT
- PCB MINIATURIZATION
- SOFTWARE OPTIMIZATION
- HARDWARE OPTIMIZATION

FIELD APPLICATION:

- EMERGENCY RESPONSE
- AMATEUR RADIO
- SEARCH AND RESCUE
- TACTICAL OPERATIONS
- FIELD REPORTING
- NETWORK SCIENCE
- REMOTE COMMUNICATION

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