

BLUETOOTH MESH

DEVELOPMENT AND OPTIMIZATION OF A BLUETOOTH LOW ENERGY (BLE) MESH NETWORK FOR ENVIRONMENTAL MONITORING AND ALERTING

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MMK

INTRODUCTION

This thesis develops an IoT smart system for integrating devices and sensors, such as air quality, temperature sensors, etc as well as control systems such as lights, gates, fire systems, etc. within a large network. The aim of this thesis is to evaluate the range and data accuracy across various nodes within Bluetooth network.

Challenges:

Data Accuracy and Reliability:

· Sending sensor data over long distances can lead to incorrect data delivery.

Real-Time Data Processing:

- Delays in data transmission and processing can hinder timely alerting and response actions.
- High volumes of data from numerous sensors require robust and efficient processing systems.

Scalability Issues:

- Expanding monitoring systems to cover larger or more varied areas can be technically and financially challenging.
- Integrating new sensors or expanding network coverage often requires significant system reconfiguration.

Power Management:

- Remote sensors and devices often have limited power sources, requiring efficient power management to ensure continuous operation.
- · Energy consumption becomes a critical issue as the network of sensors expands.



OBJECTIVES



1. Create a BLE Mesh Network:

Design and implement a robust BLE mesh network specifically tailored for environmental monitoring using nRF52 semiconductors microcontrollers.

2. Ensure Data Reliability

Monitor and record the forwarding of messages by each relay node to adjacent nodes within the network.

3. Optimize Network Performance:

Enhance scalability and power efficiency to ensure the network can handle increasing loads with minimal energy consumption.

4. Test and Validate the System:

Conduct comprehensive testing in real-world environments to validate the performance and effectiveness of the BLE mesh network.





SOLUTION

Development of a BLE Mesh Network: Suitable specifically for monitoring, alerting and control, leveraging the unique properties of Bluetooth Low Energy technology.

Scalability:

- Supports up to 32,767 nodes /sensors within the network.
- Ideal for complex and extensive environmental monitoring systems.

Reliability

• Data can be relayed across multiple paths, enhancing the network's robustness and reducing the risk of data loss.

Energy Efficiency:

- Optimized for minimal power usage, significantly prolonging battery life in deployed sensor devices.
- Reduces maintenance frequency and operational costs.

Wide Area Coverage:

- Capable of covering large geographical areas.
- Ensures comprehensive environmental data collection across diverse locations.

WHAT IS BLUETOOTH MESH ?

Bluetooth mesh is a network protocol designed for creating large-scale device networks. It is ideal for building automation, sensor networks, and other IoT (Internet of Things) solutions where hundreds or thousands of devices need to reliably and securely communicate with one another.

DIFFERENCES:

- Bluetooth classic
 - exchange data over short distances using radio waves 2.4GHz (10 meters range).
 - Topology : point-to-point or at best star
- BLE
 - Compared to Classic Bluetooth, Bluetooth Low Energy is intended to provide considerably reduced power consumption and cost while maintaining a similar communication range. (10-meter range).
 - Topology: point-to-point or at best star
- BLE mesh
 - is a protocol build on BLE stack to connect and communicate in mesh network (The more nodes in network, more range).
 - Topology : flooded mesh





Bluetooth low energy



BLE-mesh



FEATURES AND ROLES

- Relay Node
 - Enables a node to relay messages over the advertising bearer.
- Low Power Node (LPN)
 - conserves energy by allowing devices to sleep, waking only to check for messages with a Friend node.
- Friend Node
 - will listen for any messages that are relayed in the network and intended for an associated Low-Power Node.
- Proxy Node
 - The Proxy feature allows a node to relay messages between the GATT (General ATTribute) and advertising bearers.
- Provisioner
 - is a device that add unprovisoned nodes in the network



RELAYING

Relay devices retransmit messages

- Maximum of 127 hops
- Enough to relay across an enormous physical area

Managed flooding

- Retransmit the message to all other devices in range
- All packets include a time-to-live (TTL)
- Message cache to reduce overhead

PROVISIONING

Provision is the process of providing new devices in the Bluetooth mesh network with the information they need to join a network. To become a node and participate in the Bluetooth mesh communication, each device must be provisioned. Provision following two roles:

- The provisioner represents the network owner, and is responsible for adding new nodes to the mesh network.
- The provisionee is the device that gets added to the network through the Provisioning process. Before the provisioning process starts, the provisionee is an unprovisioned device.



SECURITY

Network layer

- Every packet is encrypted and authenticated
- Sequence numbers to avoid replay attacks
- Man-in-the middle protection
- Protection against trash-can attacks
- Security keys are refreshed on regular basis

Access layer

 Separation into network keys, application keys and device keys.

ENCRYPTED DATA

Table Califier for Plustanth IE COM14

DECRYPTED DATA

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		20452 2024-05-18 20:41:17.802388 0.004594 23:4d:df:4a:ad:cb Broadcast BT Mesh 58 Generic OnOff Set UnacinouLedged) Totarfara id: 0 (COLA_A 2)
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2292 2024-05-21 16:36:21.066838 0.0000000 2e:3e:02:41:c0:10 Broadcast BT Hesh 54 ADV_NONCONN_IND	Section number: 1	2004 2004-0-18 0/14119/20028 0/242/20090110 00042/20090110 000010 0/2004 0/2004 0/2004000000000000000000	Epoch Arrival Time: 1716054114.079495000
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2295 2024-05-21 16:36:121.090927 0.001137 Zer56:02:241:06108 Broadcast BT Pesh 9 4 AUX NONCOUNT IND	Encapsulation type: nRF Sniffer for Bluetooth LE (186)	2000 200-0-16 0/11110.00002 0.000410 2/2003010/01100 Productat 0 Hearing Subjects of Augustation	[Time delta from previous displayed frame: 1.030404000 seconds]
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2303 2024-05-21 16:36:21.115556 0.000386 2e:3e:02:41:c0:10 Broadcast BT Mesh 54 ADV_NONCONN_IND	[Time shift for this packet: 0.000000000 seconds]	28/2 28/4-9-18 26/4119-812595 9.000418 11/2/27100700129 PODGCAST 81 MEM 32 General UNIT Set Unacholizegen	Capture Length: 58 bytes (464 bits)
3626 2024-05-21 16:36:28.506642 7.391086 7e:b0:2e:7b:64:9a Broadcast BT Hesh 55 ADV_IND[Walformed Packet]	[Time delta from previous captured frame: 0.002301000 seconds]	28/8/2284-0-18-28-1222.084192-3.04392/442287.0182100154 BinosCast 81 Pism Selements. Unit Set Unacimovilated	[Frame is marked: False]
4430 2024-05-21 16:36:33.152652 4.646010 17:e2:a6:7e:c3:a1 Broadcast BT Hesh 58 ADV_NONCONN_IND	[Time certa from previous displayed frame: 1.01405/000 seconds] [Time cinca reference on first frame: 138.000657000 seconds]	28/42 ZML=-0-18 ZML=-0-18 ZML=25.055/W 1.001/78 IT:ZMLE:SDIT:SV2 BTOBCZEST B1 PEIN SB GENERAL UNUTT SET UNKUTT SET UNKUTT SET UNKUTT SET	[Frame is impored: False]
4440 2024-05-21 16:36:33.179535 0.0208883 17:e2:a6:7e:c3:a1 Broadcast BT Mesh SB ADV_NONCOMPLIND	Frame Number: 25885	28/97 28/4-0-18 26/12.04 ABONS 8 (ABONS) 1250 34/0311 and access 8 Mesm is beliefed UNUT Set Unachalanged	[Protocols in frame: nordic ble:btle:btcommon:btmesh]
4441 2024-05-21 16:36:33.179955 0.0000418 37:62:36:7e:C3:a1 Broadcast BT Pesh S ADV_NONCOUNT_IND	Frame Length: 58 bytes (464 bits)	2841 284-05-18 28-4122-865/44 1.012081 04-38-41:02:26:09 Broadcast 81 Pesh 38 General Unit's Set Unacinoxiloged	✓ nRF Sniffer for Bluetooth LE
4442 2024192721 10:50:50:00972 0.4099419 17:02:007210310 20040494 01 Number 30 AUV/NUMCUNIE_IND	Capture Length: 58 bytes (464 bits)	29928 2004-05-18 20:41:27.894-81, 2.630/37 22:86:00:26:42:57 Broadcast 01 Pesh Sa General UnOTF Set Unactionaledged	Roard: 14
447 2024 (5-2) 16:56333,20881 0,000415 17:22:652-2534 Broadcast D Festi O Rob Twicking_IND	[Frame is marked: False]	2095/2014-05-18 20:4128.87/138 0.980657 0d:0e:b0:52:21:35 Broadcast 8T Pesh 58 General: 0nOTF Set Unactional/edged) Header Version: 3. Parket counter: 13049
4448 2824-85-21 16:36:33.288980 8.080419 17:e2:a6:7e:C3:a1 Broadcast BT Nesh 58 ADV NONCONN IND	[Frame is ignored: False]	29812 2884-85-18 28:41:29.913283 1.836865 31:82:83:27:8e:dc Broadcast 8T Mesh 58 General UnOTH Set Unachnowledged	length of nacket: 18
4688 2824-85-21 16:36:34.169345 0.968445 08:cf:b0:c8:cd:90 Broadcast BT Mesh 58 ADV_NONCONN_IND	[Protocols in frame: nordic_ble:btle:btcommon:btmesh]	29013 2024-05-18 20:41:29.913621 0.000418 31:82:03:27:30:dc Broadcast 8T Mesh 58 General: OnOff Set Unacinoulleged) Flags: 8v81
4689 2824-85-21 16:36:34.169763 0.000418 00:cf:b0:c8:cd:90 Broadcast BT Mesh 58 ADV_NONCONN_IND	In NF Shiffer for Bluetooth LE	29014 2024-05-18 20:41:29.914040 0.000419 31:82:03:27:30:cd Broadcast 87 Mesh 58 Generic OnOFF Set Unacknowledged	Channel Today: 37
4620 2024-05-21 16:36:34.195540 0.025777 00:cf:b0:c8:cd:90 Broadcast 8T Mesh 58 ADV_NONCONN_IND	Board: 14	29660 2024-05-18 20:41:30.894868 0.9088623 20:81:9d:8e:8b:2b Broadcast BT Mesh 58 Generic OnOff Set Unacknowledged	BCCT - ED de
4621 2024-05-21 16:36:34.195959 0.0000419 00:cf:b0:c8:cd:90 Broadcast BT Hesh 58 ADV_NONCONN_IND	/ Header Version: 5, Packet counter: 20015	29188 2024-05-18 20:41:31.834604 0.999736 13:77:f9:97:dc:01 Broadcast 87 Mesh 58 Generic OnOFF Set Unacknowledged	Light contact 0
5027 2024-05-21 16:36:36:593293 2.397334 3e:0a:f3:21:87:4e Broadcast BT Mesh 58 ADV_NCNCONN_IND) Flace: 9x91	29106 2024-05-18 20:41:32.931301 1.0306097 03:87:5d:3c:10:e2 Broadcast 8T Mesh 58 Generic OnOFF Set Unacknowledged	EVEIL COULET: 0
5934 2024-05-21 16:36:36.616490 0.023197 3e:0a:r3:21:87:46 Broadcast BT Mesh S8 ADV_NONCONN_IND	Channel Index: 37	29187 2024-05-18 20:41:32.931719 0.000413 03:0F:5d:3c:10:e2 Broadcast BT Mesh 58 Generic OnOff Set Unacknowledged	Declet Alex (attent to cells 22/cell
5955 2024 HS-21 16:55:06.015968 0.000418 3e:08175:21:87:4E Broadcast 01 HERT 38 AV NORKONIL_INU	RSSI: -57 dBm	29282 2804-85-18 20:41:34.941860 2.000141 2b:f1:7d:e5:85:4d Broadcast BT Mesh 58 Generic OnOff Set Unacknowledged	[Packet time (start to enu): coops]
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527 2024 - 95-11 15-15-15-17, CARGON B. (A) DALLAR 21-11-16-16-16-108-108 Recorder at T T Mech S R ADV INONCOM THE	Timestamp: 2302951469µs	29328 2024-05-10 20:41:35-923456 0.000417 3e:54:b4:cl:dc:el Broadcast 8T Mesh 58 ADV_NONCONN_IND	[Delta time (start to start): 2/24µs]
5228 2824-85-21 16:36:37.697357 0.080419 23:12:00:61:00:b0 Broadcast 8T Mesh 58 ADV NONCONN IND	[Packet time (start to end): 336µs]	29329 2024-05-18 20:41:35.923074 0.000418 3e:54:b4:cl:dc:el Broadcast BT Mesh 58 Generic OnOff Set Unacknowledged	 stuetooth Low energy Link Layer
5229 2824-05-21 16:36:37.607775 0.000418 23:1c:0c:61:08:b0 Broadcast BT Mesh 58 ADV NONCONN_IND	[Delta time (end to start): 1925µs]	29375 2024-05-18 20:41:36.953780 1.023906 34:0F:9b:d1:46:de Broadcast 8T Wesh 58 Generic OnOFF Set Unacknowledged	Access Address: Bx8e89bed6
5366 2024-05-21 16:36:38.566886 0.959111 39:d9:10:97:f6:62 Broadcast 8T Mesh 58 ADV_NONCONN_IND	[Delta time (start to start): 2301µs]	29565 2024-05-10 20:41:40.963006 4.010026 0e:17:7c:7d:16:eb Broadcast BT Mesh 50 Generic OnOFF Set Unacknowledged	> Packet Header: 0x2042 (POU Type: ADV_NONCONN_IND, TxAdd: Random)
5367 2024-05-21 16:36:38.567305 0.0000419 39:d9:10:97:F6:62 Broadcast BT Mesh 58 ADV_NONCONN_IND	 Bluetooth Low Energy Link Layer Adverse Addresse Andresse Andresse 	29683 2024-05-18 20:41:41.980939 1.025113 1d:00:bd:50:62:e1 Broadcast 07 Mesh 58 Generic OnOff Set Unacknowledged	Advertising Address: 13:tc:83:89:88:56 (13:tc:83:89:88:56)
5368 2824-85-21 16:36:38.567722 0.000417 39:d9:10:97:f6:62 Broadcast BT Mesh 58 ADV_NONCONN_IID	ALLESS ADDIESS: EXECUTUO V Dacket Hander: 0/2012 (2011 Tune: ADV NONCOM THD. Tyldd: Bandon)	29684 2824-85-18 28:41:44.813671 2.824752 0b:17:21:e1:d3:a9 Broadcast BT Wesh \$8 Generic OnOFF Set Unacknowledged	> Advertising Data
5378 2024-05-21 16:36:38.593085 0.025363 39:d9:10:97:f6:62 Broadcast BT Nesh 58 ADV_NONCONN_IIN	PRIME PRI Type: By2 ANV NON-THE THE	29720 2024-05-18 20:41:45.016173 1.002502 NS-WLB-PhysServ. Broadcast 8T Mesh 58 Generic OnOFF Set Unacknowledged	CRC: Bra12d4b
5379 2024-65-21 15:35:35.59358 8.000418 39:d9:16:97:76:52 Broadcast 87 Mesh 88 AV/ NONCOM 110	0 = Reserved: 0	29855 2024-05-18 20:41:40.016364 3.000191 25:d0:00:6d:34:24 Broadcast 8T Mesh 58 Generic OnOFF Set Unacknowledged	✓ Bluetooth Vesh
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11933 2024-05-21 16:37:14-105335 35-485476 Apple 34:1b:83 Broadcast 8T Nesh 49 ADV IND[Ha]formed Packet]	Length: 32	30020 2024-05-18 20:41:52.057081 2.012544 16:15:11:05:1e:a2 Broadcast 8T Mesh 58 General: 0x07f Set Unachrowledged	0 = CTL: Access Hessage (0)
20986 2024-05-21 16:38:01.422322 47.317007 48:e9:c4:36:ae:28 Broadcast BT Mesh 49 ADV_IMD[Walformed Packet]	Advertising Address: 39:98:b6:d5:cc:d1 (39:98:b6:d5:cc:d1)	30655 2014-05-18 20:41:53,049051 0.951400 39:d6:2b:3d:34:d6 Broadcast 8T Pesh S8 General: OnOFF Set Unacimoniaded	.000 0101 = TTL: 5
25020 2024-05-21 16:38:25.910835 24.488513 67:9c:f5:79:89:e1 Broadcast BT Hesh	Advertising Data	30104 2024-05-18 20:41:54.075405 1.036404 13:fc:83:80:30:56 Broadcast 87 Mesh 58 Generic OnOff Set Unacional dead	SEQ: 16687
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25621 2024-05-21 16:38:29.381354 0.0000418 14:c5:41:08:44:6b Broadcast BT Mesh 58 ADV_NONCONN_IND	Type: Nesh Nessage (Ry2a)	30247 2024-05-18 20:41:56.101180 0.000075 02:b7:63:24:00:dd Broadcast 81 Pesh 58 General: OrOFF Set Unachnowledged	D5T: 65535
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25814 2024-05-21 16:38:38.422752 0.025486 39:98:b6:d5:cc:d1 Broadcast BT Mesh 58 A0V MONCOM 100	0 = IVI: 0	3944 201-65-18 29-415-86 8610 - 8, 62147 3a-39-46-51/-51-64 Research R Huch - 58 Generic 0.007F 64 Usering-leded	0 = SEG: Unsegmented Access Message (0)
25815 2824-85-21 16:38:30.423171 0.080419 39:96:b6:d5:cc:d1 Broadcast 8T Mesh 58 ADV NONCONN IND	.101 0010 = NID: 82	38364_3010_4,65,18_30-41-50_665301_0_000077_10-48-71-65-00-80 Renderant 87 Nach 58_070_N000700_T00	.1 = AKF: Application key (1)
25816 2024-05-21 16:38:30.423588 0.000417 39:98:b6:d5:cc:d1 Broadcast BT Mesh 58 ADV_NONCONN_IND	Obfuscated: 32270574a007	3013 2014 57 18 20 4 21 40 17 21 20 17 12 20 17	11 0000 = AID: 48
25987 2024-05-21 16:38:31.375860 0.952272 1c:f3:b8:f7:95:7d Broadcast 8T Mesh 58 ADV_NONCONN_IDD	Encrypted data and NetVilc: adai800526Tabd125e419/918T9/3e0404	Server and the server	✓ Upper Transport Access POU
25988 2024-05-21 16:38:31.376279 0.000419 1c:f3:b8:f7:95:7d Broadcast BT Mesh S8 ADV_NONCONN_IND		34/5 100.45.11 30.41.94 114/10 a 000013 60-55-13-06-44-15 Broadrart 87 Back 53 Sasarir 0/07 for Incrimination	Encrypted Access Payload: 9fa0641cabda
25992 2024-05-21 16:38:31.399911 0.023632 12:73:306:77:95:7d Broadcast BT Mesh SB ADV_NONCOMM_IND		30/13 10/16/18 10/14/19 10/00/19 00/17/19/16/19/19/10/10/10/10/10/10/10/10/10/10/10/10/10/	Trans/IIC: b9845b83
2595 2024-05-21 10:53:51.400550 0.000419 12:15:50:70 07000C851 01 0651 - 58 AUV NUKLUME_INU		Serve and to be constructed on the server and the server at the server a	✓ Access POU
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26000 2024-05-21 16:38:31.423265 0.000418 1c:f3:b8:f7:95:70 Broadcast BT Mesh 58 ADV NONCONN IND		and a second sec	Opcode: Generic OnOff Set Unacknowledged (0x8203)
26158 2024-05-21 16:38:32.386958 0.963693 16:1d:af:18:11:41 Broadcast BT Mesh 58 ADV_NONCONN_IIND		3005 200° 0512 201° 2000 1 000° 1 21 21 201° 201° 20	OnOff: Off (0)
26159 2024-05-21 16:38:32.387376 0.000418 16:1d:af:18:11:41 Broadcast BT Mesh 58 ADV_NONCONN_IND		36/14 68(470716 26)-62716 2(14)-6210 (16)-6200 (16)-6210	TID: 46
26160 2024-05-21 16:38:32.387794 0.000418 16:1d:#f:18:11:41 Broadcast BT Mesh 58 ADV_NONCONN_IND		3070 200-0712 20-201 20000 - 1000-01 27300-00-0137 (1000-051 0) 1000 - 30 (2001 20 0) 170 (1000-051 0) 1000-051 0) 1000-051 0) 1000-051 0)	> Transition Time: 0 ms
31590 2024-05-21 16:39:05.409513 33.101719 Apple_34:1b:83 Broadcast BT Mesh 49 ADV_IND[Nalformed Packet]		36/02 2024-05-26 07:47:00:155509 05:55522 05:51126102 05:01 06:01 05:00 06:01 06:000	Delay: 225 ns
33695 2024-05-21 16:39:17.205655 11.796142 Apple_30:1b:43 Broadcast 0T Mesh 177 ADV_IND		3900 26(4)(5)12 2(4)(26)10000 2.00(25) 20(3)(4)(5)(10) (10)(35) 0.00(11) 50 (10)(11) 50 (10)(11) 50 (10)(11)(10)(10)(10)(10)(10)(10)(10)(10)	
		39940 2014-05-10 20142111.00000 0.46590/ /0.00100120140100 Broadcast 0 inesn 49 40/110[na10080 Packet]	
		persit and the second s	
		Jampa deverative constraint company of calculated and constraints and constrai	
		1407 2407 14 CT 4407 14 CT 4407 14 CT 4407 14 CT 4008 CT 41 CT 4008 CT 41 CT 41 CT 4008 CT 41 CT	
		31242 WWW-WD-10 07424101312122 2.02020100121131 070806351 01 PEIN 35 0649101 0011 541 UNECONVERGED	
		11222 ANNUMENTIA CONTRACTORIZZONE CONTRACTORIZZO DE DE CONTRACTORIZZO DE LA CONTRACTORIZ	
		11/1/2 CONTENTING CONTENTING AND	
8018 50 45 ha 50 50 47 10 41 rr 45 h6 50 10 10 10 10 10 10 10 10	2	312/2 408-05-10 407-02112-493700 40-95310 5/1712010807877 Broddcast DI Pietn SB Generals VIDIT Set Unachrowledged	
		3444 444-07-10 474-10 3000 34-095393 (105030411/10) 07084C8T 01 (HEN 32 44/1 10)	
Z Length (btcommon.eir_adentry-length), 1 byte	Packets: 37634 · Displayed: 63 (0.2%)	1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	
		31320 THE-LOCATE TO ALTO THE ALTO ALTO ALTO ALTO ALTO ALTO ALTO ALTO	

PUBLISH AND SUBSCRIBE

Publishing

 Devices may send messages to addresses (group), all the other devices that subscribed to that address will receive a copy of it, process it and react in some way.

Subscribing

 Devices can be configured to receive messages which were sent to addresses (group) by other device.



BLE MESH ARCHITECTURE



BLE MESH NETWORK DATA FLOW



MODELS

The applications are implemented as a set of mesh models. The Bluetooth SIG defines some generic and reusable models in the Bluetooth Mesh model specification, but vendors are free to define their own models.

generics

- generic onoff client generic onoff server generic level client generic level server
- generic default transition time client
- generic default transition time server
- generic power onoff client
- generic power onoff server
 generic power onoff setup server
- generic power onon setup servi
 generic power level client
- generic power level server
- generic power level setup server
- · generic battery client
- generic battery server
- · generic location client
- generic location server
- · generic location setup server
- generic admin property server
- generic manufacturer property server
- generic user property server
- generic admin property server
- generic property client

time and scenes

- time client
- time server
- time setup server
- scene client
- scene server
- scene setup server
 scheduler client
- scheduler client
 scheduler server
- scheduler setup server

sensors

- sensor client
- sensor server
 sensor setup server

- lighting
 Ight lightness client
- light lightness server
- lightness setup server
- · light CTL client
- light CTL server
- · light CTL setup server
- light HSL client
- light HSL server
- light HSL setup server
- light xyL client
 light xyL server
- light xyL setup server
- light LC client
- · light LC server
- light LC setup server

EXPERIMENT SETUP

System contains 3 roles: **B:** broadcaster

R: Relay

L: Listener

- Broadcaster initiate a sequence of messages to all nodes.
- Relays receives and calculate PLR (Packet Lose Ratio) and forward them to adjacent nodes.
- Listeners will record these messages and calculate PLR also.



SCENARIOS TESTS

Links between the nodes will be 15 and 30 meters.

Scenario 1:

The broadcaster will send 60, 120, and 600 messages over a 60second period. Each node will record the Packet Loss Ratio (PLR).

Scenario 2:

Two relay nodes will be positioned centrally to facilitate message forwarding to the listeners.

Scenario 3:

One listener will receive messages through a single hop, while another listener will receive messages through two hops.



PLR CALCULATION

struct net_buf_simple *buf)

if (buf->len < 4) {
 printk("Buffer too short\n");
 return -EINVAL;</pre>

uint8_t val = net_buf_simple_pull_u8(buf); uint16_t seq = net_buf_simple_pull_le16(buf); uint8_t tid = net_buf_simple_pull_u8(buf);

int32_t trans = 0; int32_t delay = 0; printk("Receiving onoff:%d, tid:%d ,src:%d ,seq:%u \n", val, tid, ctx->addr ,seq);

PLR(seq);

/*if (ctx->recv_ttl < 1) {
 rebroadcast(model, ctx, seq, ctx->recv_ttl);
}*/

if (buf->len) {

trans = model_time_decode(net_buf_simple_pull_u8(buf)); delay = net_buf_simple_pull_u8(buf) * 5;

/* Only perform change if the message wasn't a duplicate and the * value is different. */ if (tid == onoff.tid && ctx->addr == onoff.src) { /* Duplicate */ return 0; } if (val == onoff.val) { /* No change */

return 0;

tatic int PLR(uint16_t seq_num) { static uint16_t last_seq_num = 0; static uint16 t first seq seq = 0; static bool is first packet = true; static uint16 t total missed packets = 0; static uint16 t total received packets = 0; // Handling the first packet received if (is_first_packet) { first_seq_seq = seq_num; last seq num = seq num ; // Initialize the last sequence number with the first received sequence is first packet = false; // Mark that the first packet has now been received total received packets++; // Start counting packets with the first one received // Normal handling for all subsequent packets if (seq num > last seq num) { // Calculating missed packets if there's a gap total_missed_packets += (seq_num - last_seq_num - 1); last_seq_num = seq_num; // Update the last received sequence number total received packets++; // Increment the total received packets count } else if (seq num == last seq num) { // Handle duplicate packet printf("Duplicate packet received, seq num: %u\n", seq num); printf("Out of order packet received, seq num: %u, last seq num: %u\n", seq num, last seq num);

// Calculate Packet Loss Ratio (PLR)

uint32_t total_packets_considered = total_received_packets + total_missed_packets; uint32_t plr = (total_missed_packets * 10000) / total_packets_considered;

printk("First received packet: %u\n", first_seq_seq); printk("Total missed packets: %u\n", total_missed_packets); printk("Total received packets: %u\n", total_received_packets); printk("Received seq_num %u, PLR: %u.%02u%\n", seq_num, plr / 100, plr % 100); printk("......\n");

return 0;

RESULTS

Scenario1:

•At ~15 meters:

- Packet Loss Ratio (PLR) was minimal across all message sizes (60, 120, 600), with nearly zero loss at the relay nodes and minor loss at the listener.
- Received Signal Strength Indicator (RSSI) ranged from 60dBm to -53dBm, indicating strong signal strength.

•At ~30 meters:

- PLR increased notably, especially with higher message counts (120, 600), showing increased loss primarily at the listener.
- RSSI decreased to as low as -81dBm, suggesting weaker signals at greater distances.

Distance	payload	PLR/L	PLR	PLR	PLR	RSSI
			/R3	/R2	/R1	
~15m	60	1.44%	0%	0%	0%	~-60dBm
	120	0.83%	0%	0%	0%	~-52dBm
	600	0.17%	0.34%	0.52%	0.0%	~-53dBm
~30m	60	16.3%	11.7	3.27%	3.27%	~-68dBm
	120	26%	4.68%	0%	0%	~-81dBm
	600	14.74%	5.16%	5.16%	1.06%	~-77dBm



RESULTS

Scenario2:

•At 15 meters:

 Very low to zero PLR across all nodes and message sizes, with excellent RSSI values around -51dBm to -54dBm.

•At 30 meters:

- PLR varied, with higher message sizes showing increased loss, particularly notable in messages directed to listeners.
- RSSI showed some decrease but remained relatively strong, suggesting that the double relay setup helps maintain signal integrity over greater distances.

Distance	payload	PLR /L1	PLR/L2	PLR /R2	PLR/R1	RSSI
15m	60	0%	0%	0%	0%	~-51dBm
	120	1.3%	0.78%	6.3%	3.9%	~-57dBm
	600	0%	0%	0.16%	0.16%	~-54dBm
30m	60	0	0%	4.76%	0%	~-57dBm
	120	8.13	0.80%	0%	0%	~-60dBm
	600	1.98%	1.32%	1.48%	0.49%	~-64dBm



----PLR/L1 ----PLR/L2

RESULTS

Scenario 3:

•At **15 meters**:

- Higher PLR for the listener requiring more hops (L1), especially as message size increased, indicating that additional hops can lead to increased packet loss.
- RSSI was slightly lower but still within a good range, averaging around -57dBm to -63dBm.

•At 30 meters:

- Significant PLR increase for both listeners as message size increased, particularly for L2.
- RSSI values showed more substantial drops, highlighting challenges with signal strength at longer distances and multiple hops.







Q & A



THANK YOU