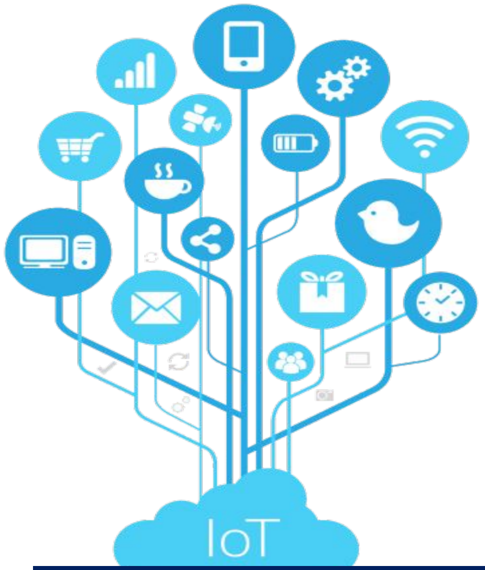

ASEAN IVO 10th Anniversary Celebration
September 25, 2025 at Bangkok

Feasibility Analysis of LoRa Mesh Network Deployment in Rural Areas

Assoc. Prof. Ir. Ts. Dr. Mau-Luen THAM

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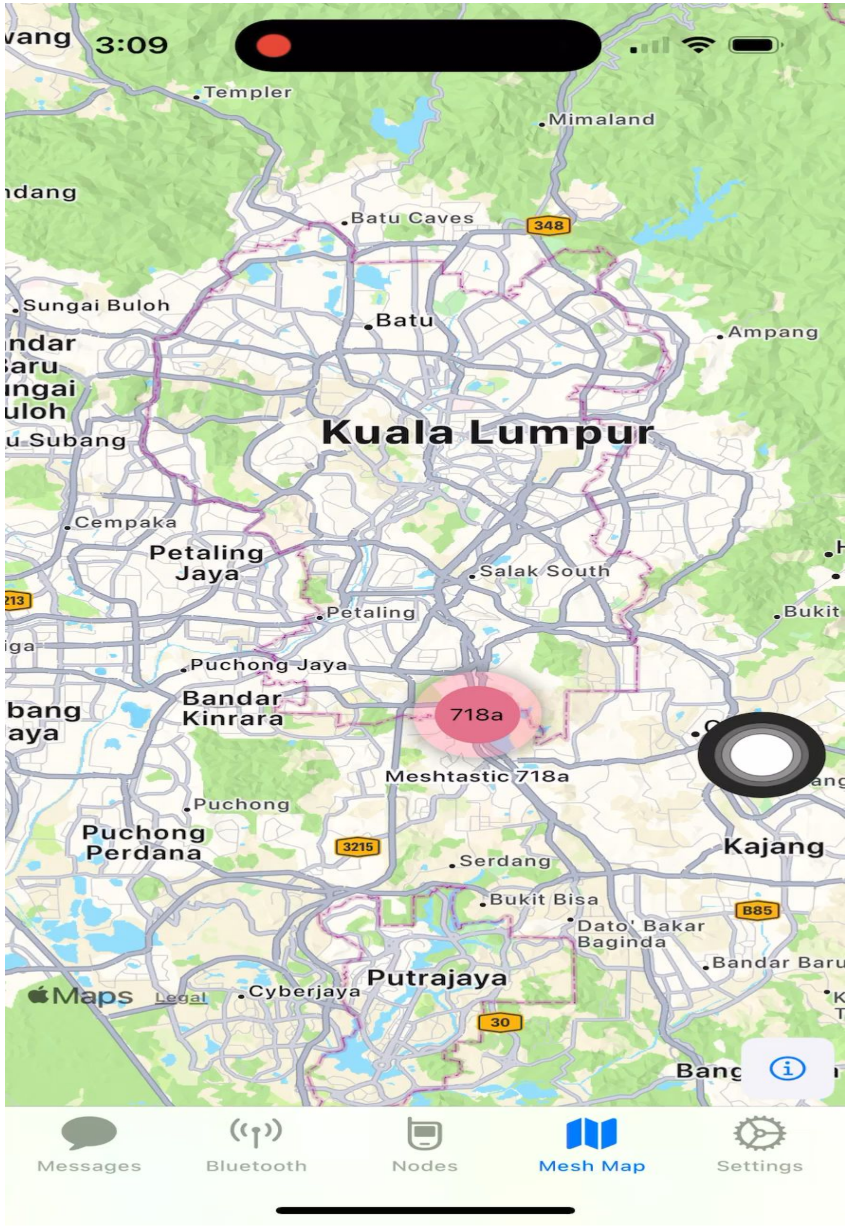
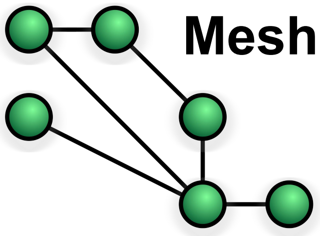


LoRa +



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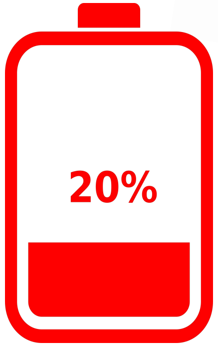
Large Coverage

High Resiliency

Deployment in Rural Areas

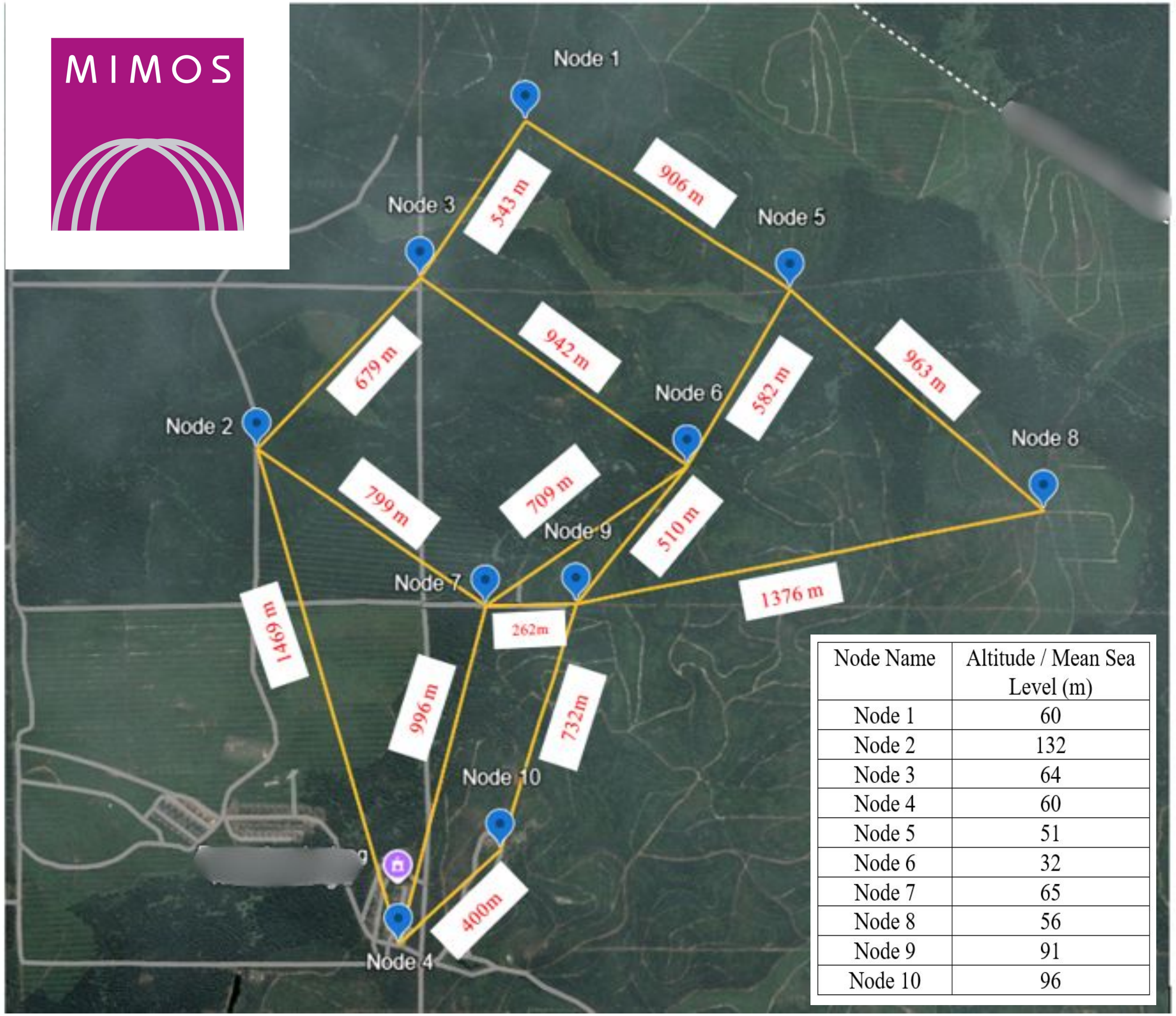


Power

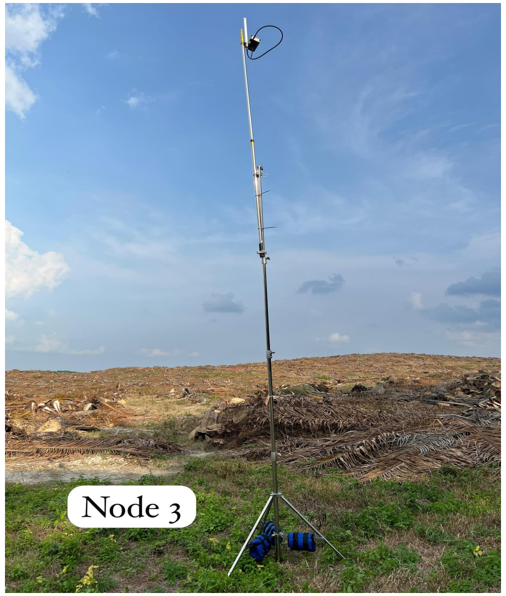
Scalability

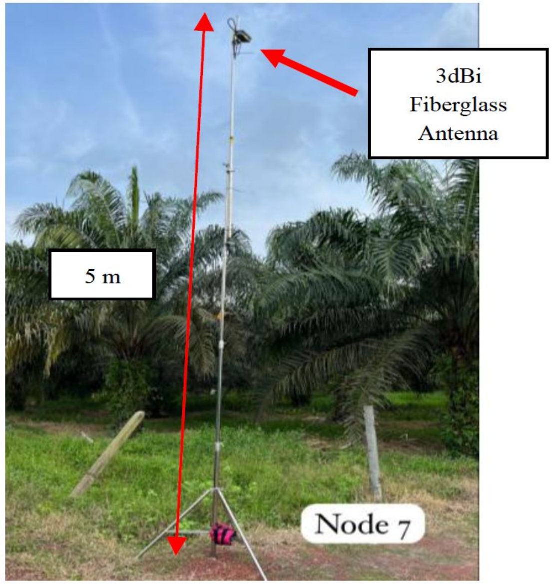
Complexity

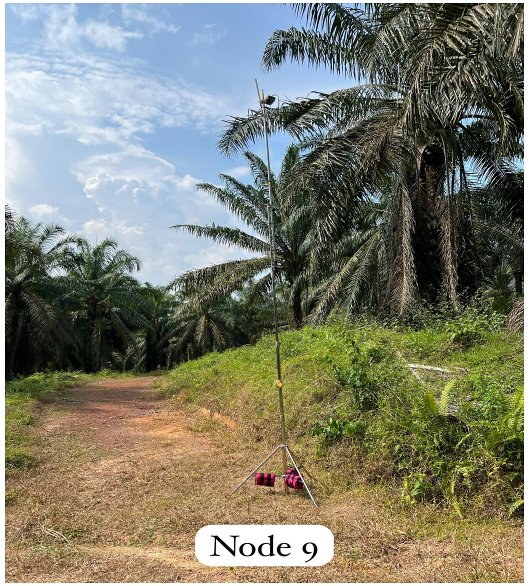
Site Deployment (Oil Palm Plantation)



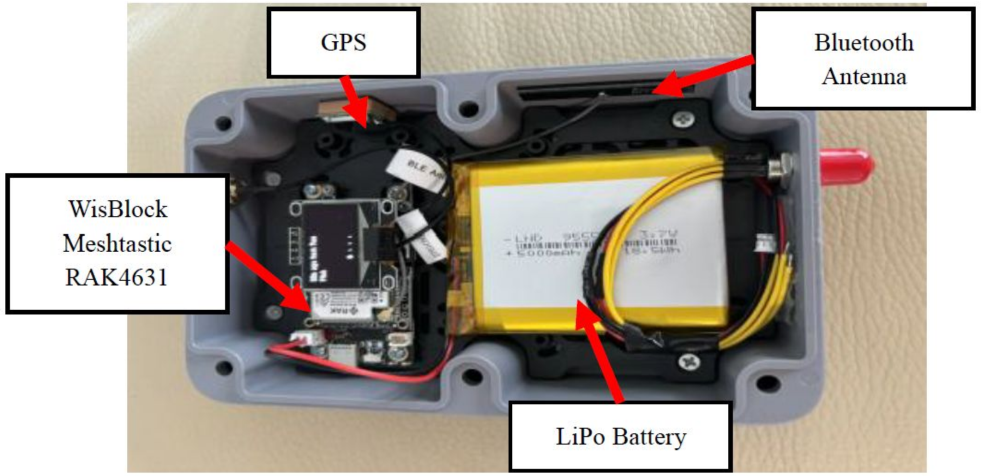
Node Name	Altitude / Mean Sea Level (m)
Node 1	60
Node 2	132
Node 3	64
Node 4	60
Node 5	51
Node 6	32
Node 7	65
Node 8	56
Node 9	91
Node 10	96







Network Configurations



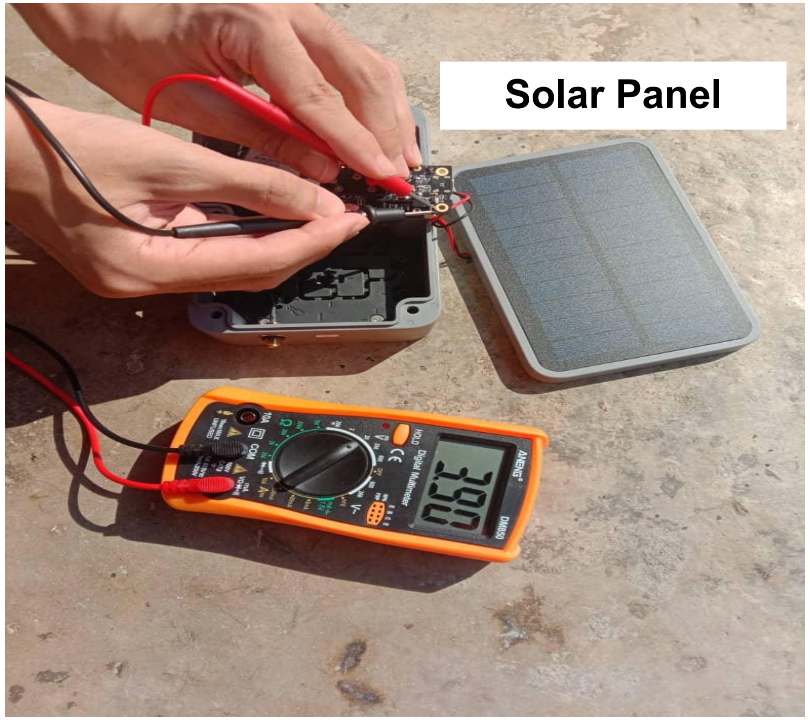


Table 4. Meshtastic configurations.

Parameter	Value
Frequency	919 MHz
Bandwidth BW	250 kHz
Transmission Power P_t	22 dBm
Coaxial Type	TMS LMR-400
Coaxial Length	1 m
Cable Loss L_c	0.1 dB
Transmit G_t and Receive Antenna Gain G_r	3 dBi
Node Height (Including Antenna)	5 m
Maximum Number of Hops	3
Radio Settings	Short Fast
RX Boosted Gain	Enabled
Power Saving Mode	Enabled
Rechargeable Battery	5000 mAh 3.7 V
Position Broadcast Interval	30 s
Telemetry Update Interval	30 s

Network Scalability: Hopping Behavior

Channel setting	Alt Channel Name	Data-Rate	SF / Symbols	Coding Rate	Bandwidth	Link Budget
Short Range / Turbo	Short Turbo	21.88 kbps	7 / 128	4/5	500 kHz[1]	140dB
Short Range / Fast	Short Fast	10.94 kbps	7 / 128	4/5	250 kHz	143dB

Distance (m)	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10
Node 1	-	1216	543	**2373**	906	1088	1386	1862	1382	2074
Node 2	1216	-	679	1469	1610	1249	799	**2281**	1023	1338
Node 3	543	679	-	1899	1073	942	954	**1920**	1032	1642
Node 4	**2373**	1469	1899	-	2182	1600	996	2236	1098	400
Node 5	906	1610	1073	2182	-	582	1261	963	1089	**1801**
Node 6	1088	1249	942	**1600**	582	-	709	1033	510	1220
Node 7	1386	799	954	996	1261	709	-	**1634**	262	693
Node 8	1862	**2281**	1920	2236	963	1033	1634	-	1376	1842
Node 9	**1382**	1023	1032	1098	1089	510	262	1376	-	732
Node 10	**2074**	1338	1642	400	1801	1220	693	1842	732	-

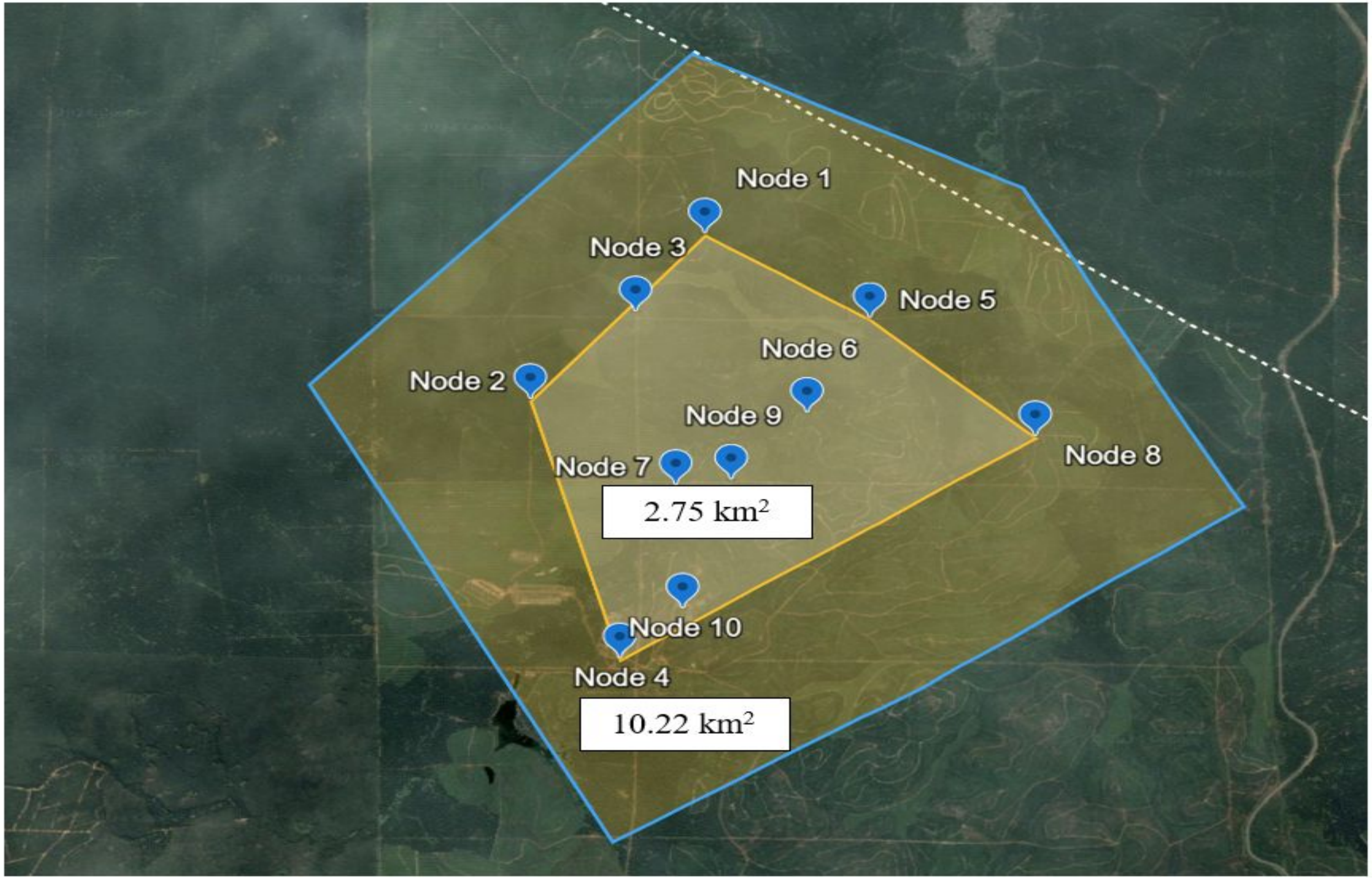
*Bold font indicates the longest distance for each row.

Table 5. Routing behavior using Short Fast

	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10
Node 1	-	2-3-1	Direct	4-7-1	Direct	Direct	7-10-1	8-10-1	9-10-1	Direct
Node 2	1-3-2	-	Direct	Direct	5-6-2	Direct	7-3-2	8-7-2	Direct	Direct
Node 3	Direct	Direct	-	Direct	Direct	Direct	Direct	8-7-3	9-7-3	10-7-3
Node 4	1-7-4	Direct	Direct	-	5-7-4	6-10-4	Direct	8-10-4	Direct	Direct
Node 5	Direct	2-7-5	Direct	4-7-5	-	Direct	Direct	Direct	Direct	Direct
Node 6	Direct	Direct	Direct	Direct	Direct	-	Direct	Direct	Direct	Direct
Node 7	1-3-7	Direct	Direct	Direct	Direct	Direct	-	8-6-7	Direct	Direct
Node 8	1-5-8	2-7-8	3-7-8	4-10-8	Direct	Direct	7-6-8	-	Direct	Direct
Node 9	1-7-9	2-7-9	3-7-9	Direct	Direct	Direct	Direct	Direct	-	Direct
Node 10	1-7-10	2-7-10	3-6-10	Direct	5-6-10	Direct	8-9-10	Direct	Direct	-

*The upper row refers to the sending nodes and the most left column refers to the receiving nodes.

Network Coverage



Network Scalability: Hopping Behavior

- Node Removal in Chronological Order

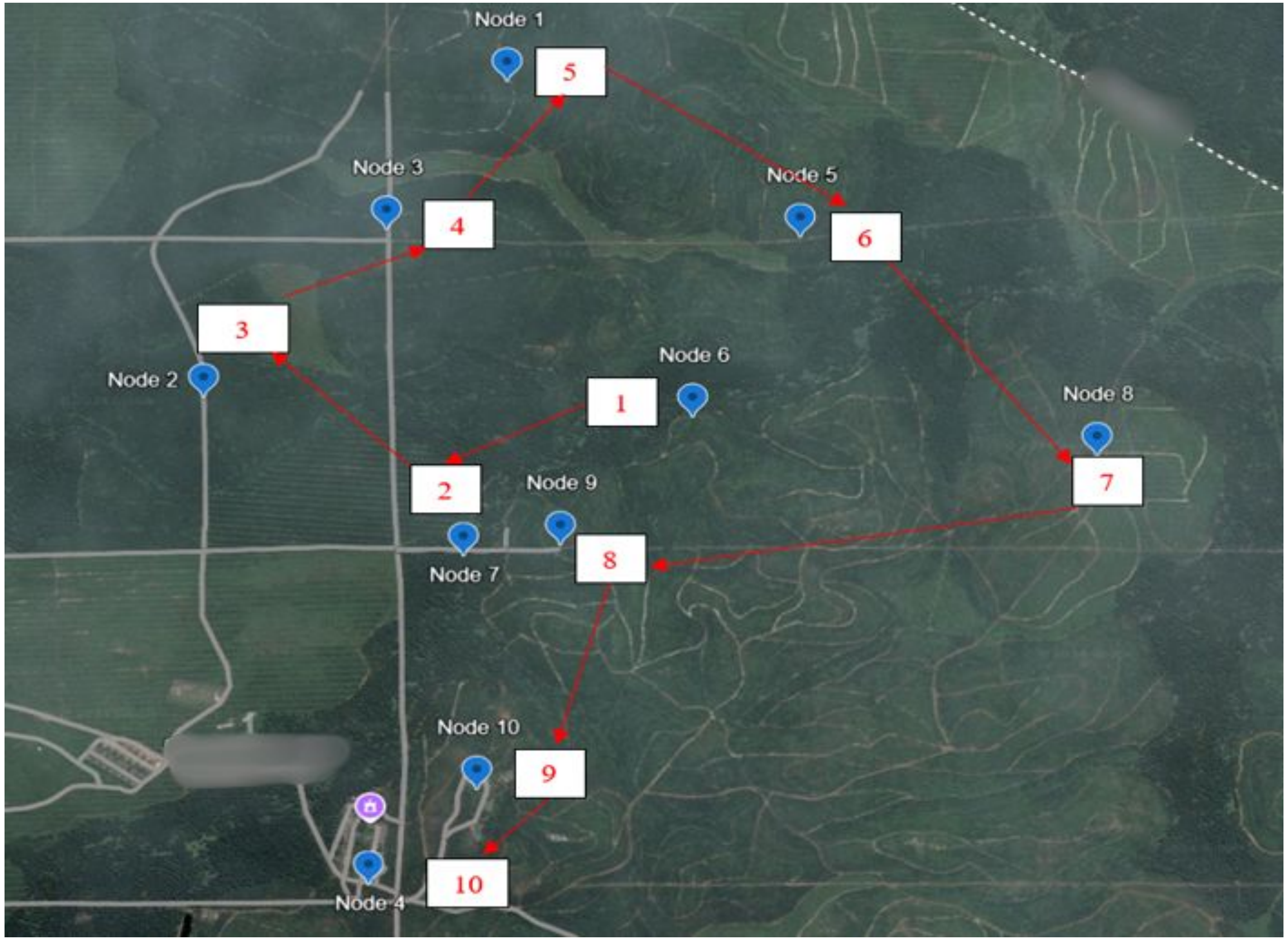


Table 6. Routing behavior during removal process

Sender in Chronological Order	Accumulated Number of Deployed Nodes	Hopping Path
Node 6	10	6 – 2 – 4
Node 7	9	Direct
Node 2	8	Direct
Node 3	7	Direct
Node 1	6	Direct
Node 5	5	5 – 10 – 4
Node 8	4	8 – 5 – 9 – 4
Node 9	3	Direct
Node 10	2	Direct

Network Performance: Received Signal Strength Indicator (RSSI)

Table 7. RSSI measured when one 'traceroute' command is sent.

RSSI (dBm)	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10
Node 1	-	-127	-105	-121	-115	-116	-125	-128	-127	-114
Node 2	-126	-	-100	-103	-120	-107	-128	-128	-109	-105
Node 3	-104	-101	-	-101	-106	-120	-128	-128	-128	-127
Node 4	-128	-103	-103	-	-128	-128	-115	-118	-106	-102
Node 5	-113	-123	-106	-119	-	-101	-108	-113	-110	-116
Node 6	-116	-101	-119	-110	-103	-	-123	-115	-107	-124
Node 7	-120	-128	-127	-100	-110	-121	-	-120	-69	-117
Node 8	-128	-128	-128	-118	-118	-112	-118	-	-87	-103
Node 9	-126	-125	-128	-110	-113	-107	-75	-90	-	-99
Node 10	-128	-114	-126	-101	-120	-125	-115	-105	-97	-

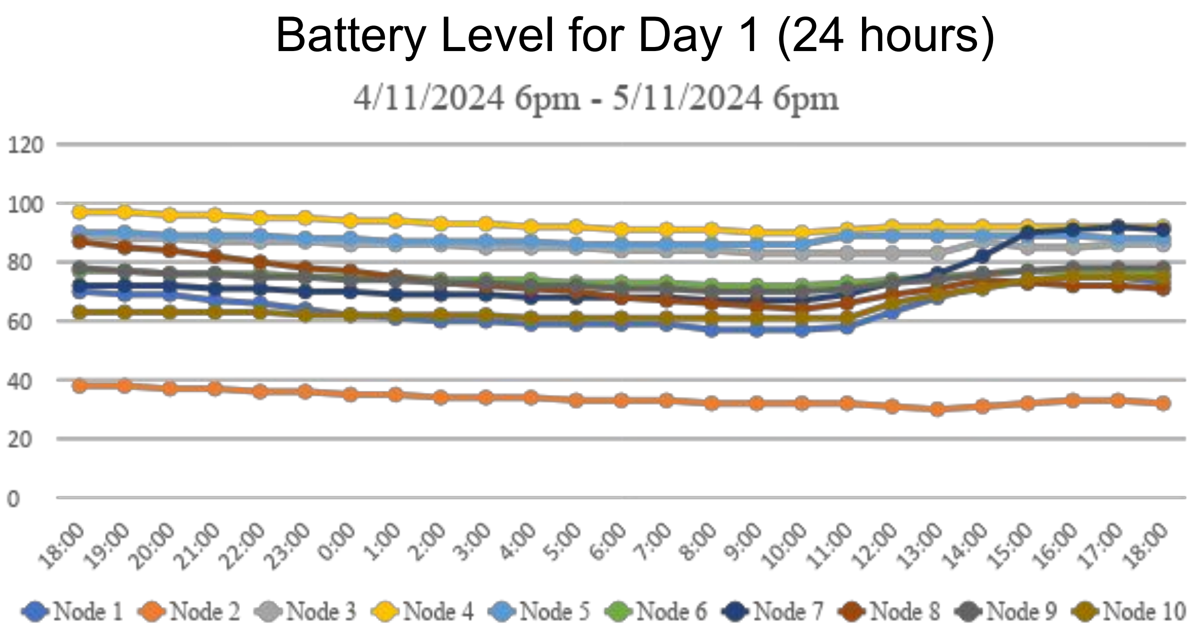
*The upper row refers to the sending nodes and the most left column refers to the receiving nodes.

Table 9. Latency between two nodes.

Latency (s)	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10
Node 1	-	6	3	5	4	4	5	6	6	4
Node 2	6	-	3	3	5	4	6	6	4	3
Node 3	4	3	-	3	4	5	6	6	6	5
Node 4	6	4	3	-	6	6	5	5	4	3
Node 5	4	5	3	6	-	3	3	5	4	4
Node 6	4	4	5	4	3	-	5	5	4	6
Node 7	5	6	6	3	4	5	-	6	3	4
Node 8	6	6	6	5	5	5	5	-	3	3
Node 9	6	6	6	4	4	4	3	3	-	3
Node 10	6	5	6	3	5	6	5	3	3	-

*The upper row refers to the sending nodes and the most left column refers to the receiving nodes.

Energy Performance: Estimated Battery Lifespan



With 5000mAh 3.7V battery, the maximum energy capacity stored is

$$5000\text{mAh} \times 3.7\text{V} = 18.5 \text{ watt-hours (Wh)} \tag{5}$$

Without any external power source attached to a Meshtastic node, the power drawn from battery for an hour is **0.4082 W**. Theoretically, it can sustain up to about 45 hours

$$\frac{18.5}{0.4082} = 45.32 \text{ hours} \tag{6}$$

Assume that the maximum solar charging lies between 12 pm – 3 pm, the total net charging energy capacity is

$$\mathbf{1.131\ W} \times 3 \text{ hours} = 3.393 \text{ Wh} \tag{7}$$

Assume that the moderate solar charging lies between 9 am – 12 pm and 3 pm – 6 pm , the total net charging energy capacity is

$$\mathbf{0.208\ W} \times 6 \text{ hours} = 1.248 \text{ Wh} \tag{8}$$

Assume that the zero solar charging lies for the remaining period, the total energy drawn is

$$-0.4082\text{W} \times 15 \text{ hours} = -6.123\text{Wh} \tag{9}$$

Based on Equations (5) to (9), the battery level after 24 hours can be estimated as follows

$$BatteryLevel_{new} = \frac{18.5\text{Wh} \times BatteryLevel_{old} + (3.393 + 1.248 - 6.123)}{18.5\text{Wh}} \tag{10}$$

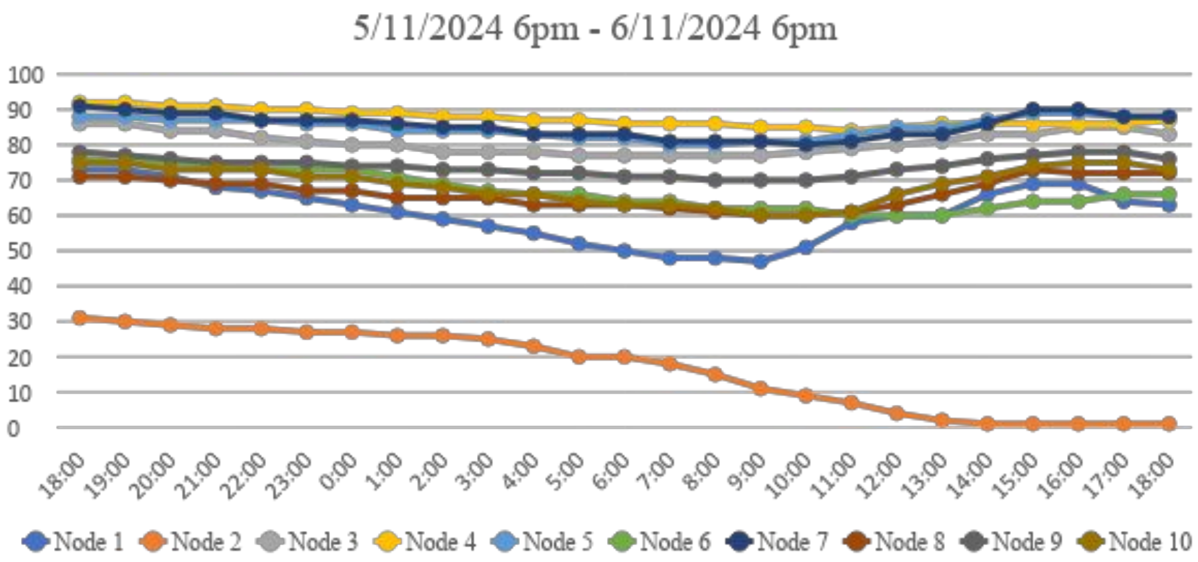
To estimate the self-powered duration, Equation (10) is simplified into Equation (11).

$$BatteryLevel_{new} = \frac{18.5BatteryLevel_{old} - 1.482}{18.5} = BatteryLevel_{old} - 0.08 \tag{11}$$

By setting $BatteryLevel_{old} = a(n-1)$ and $BatteryLevel_{new} = a(n)$, we can utilize recursive arithmetic formula as follows:

Energy Performance: Estimated Battery Lifespan

Battery Level for Day 2 (24 hours)



Given the recursive arithmetic formula:

$$a(n) = a(n-1) - 0.08 \quad \text{for } n \geq 2, \quad a(1) = 1,$$

Let's determine the specific n where $a(n) < 0$.

Explicit Formula

To solve this, derive the explicit formula:

$$a(n) = a(1) - 0.08 \times (n-1)$$

Substitute $a(1) = 1$:

$$a(n) = 1 - 0.08 \times (n-1)$$

Finding n when $a(n) < 0$

Set $a(n) < 0$:

$$1 - 0.08 \times (n-1) < 0$$

$$0.08 \times (n-1) > 1$$

$$n - 1 > \frac{1}{0.08} = 12.5$$

$$n > 13.5$$

2 weeks

Since n must be an integer, the smallest n where $a(n) < 0$ is $n = 14$.

Value at $n = 14$

The corresponding value is:

$$a(14) = 1 - 0.08 \times (14-1) = 1 - 0.08 \times 13 = 1 - 1.04 = -0.04$$

Static Scenario: Packet Loss Ratio

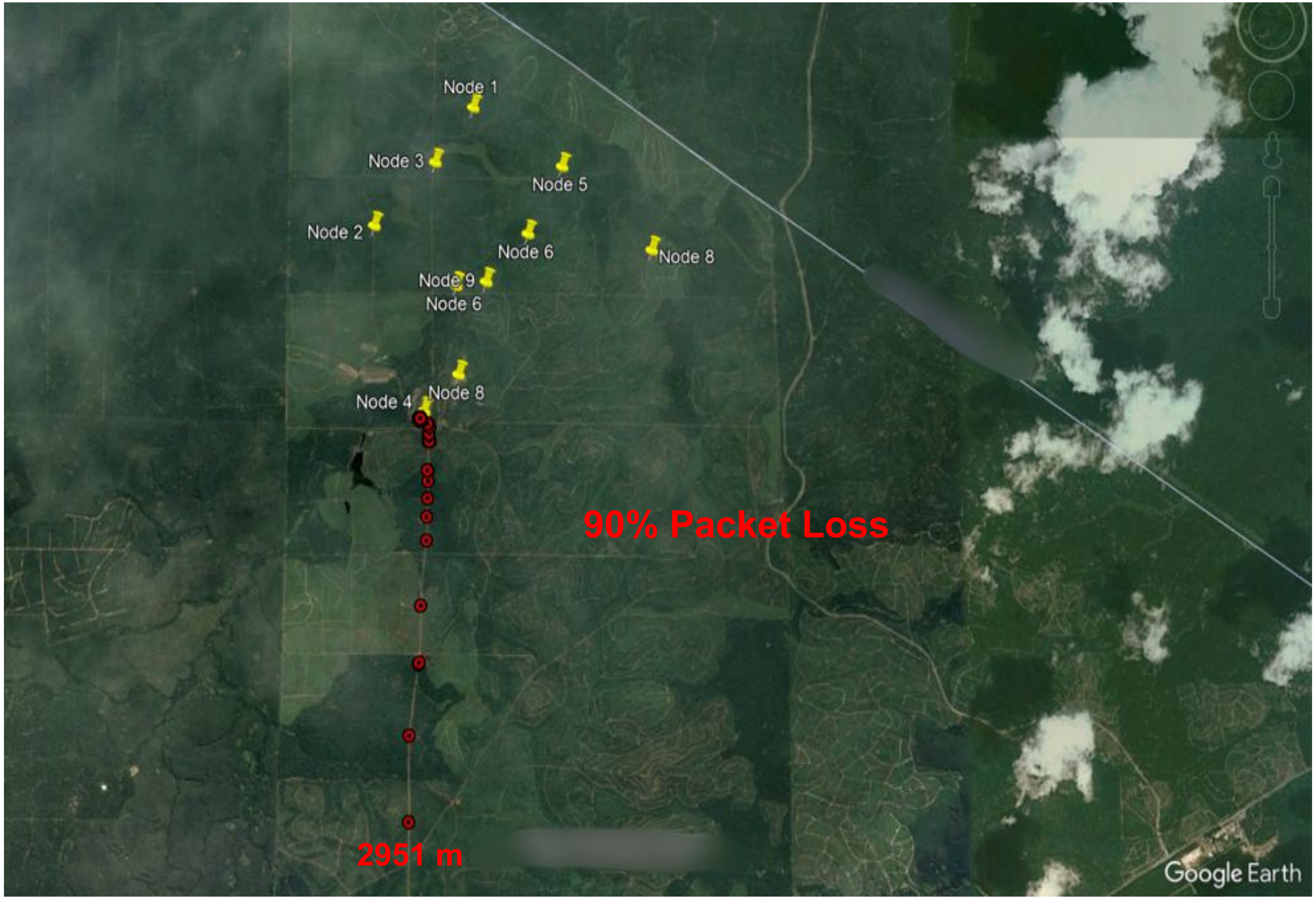
Table 11. Packet loss ratio between two nodes when 5 'traceroute' commands are sent.

Packet loss rate (%)	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10
Node 1	-	0	0	0	0	0	0	0	0	0
Node 2	40%	-	40%	20%	40%	40%	40%	40%	40%	40%
Node 3	0	0	-	0	0	0	0	0	0	0
Node 4	0	0	0	-	0	0	0	0	0	0
Node 5	0	0	0	0	-	0	0	0	0	0
Node 6	0	0	0	0	0	-	0	0	0	0
Node 7	0	0	0	0	0	0	-	0	0	0
Node 8	0	0	0	0	0	0	0	-	0	0
Node 9	0	0	0	0	0	0	0	0	-	0
Node 10	0	0	0	0	0	0	0	0	0	-

*The upper row refers to the sending nodes and the most left column refers to the receiving nodes.

Drive Testing: Packet Loss Ratio

Antenna



Conclusions

- The LoRa network has a bit rate of 10.94 kbps, which is good enough to support a wide range of IoT applications.
- RSSI lower than -121 dBm will render multi-hopping.
- When choosing the node location, it is conducive to deploy LoRa at those points with high mean sea level.
- The average and maximum one-hop transmission distance among nodes is 1 km and 2 km, respectively.
- The actual latency is found be approximately 3 s per hop. This indicates that the mesh network is not suitable for time-sensitive IoT applications.
- The solar-powered node can still operate well in harsh environments, where rains and heavy clouds exists.
- The network lifetime can last for almost 2 weeks without any external power supply.

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