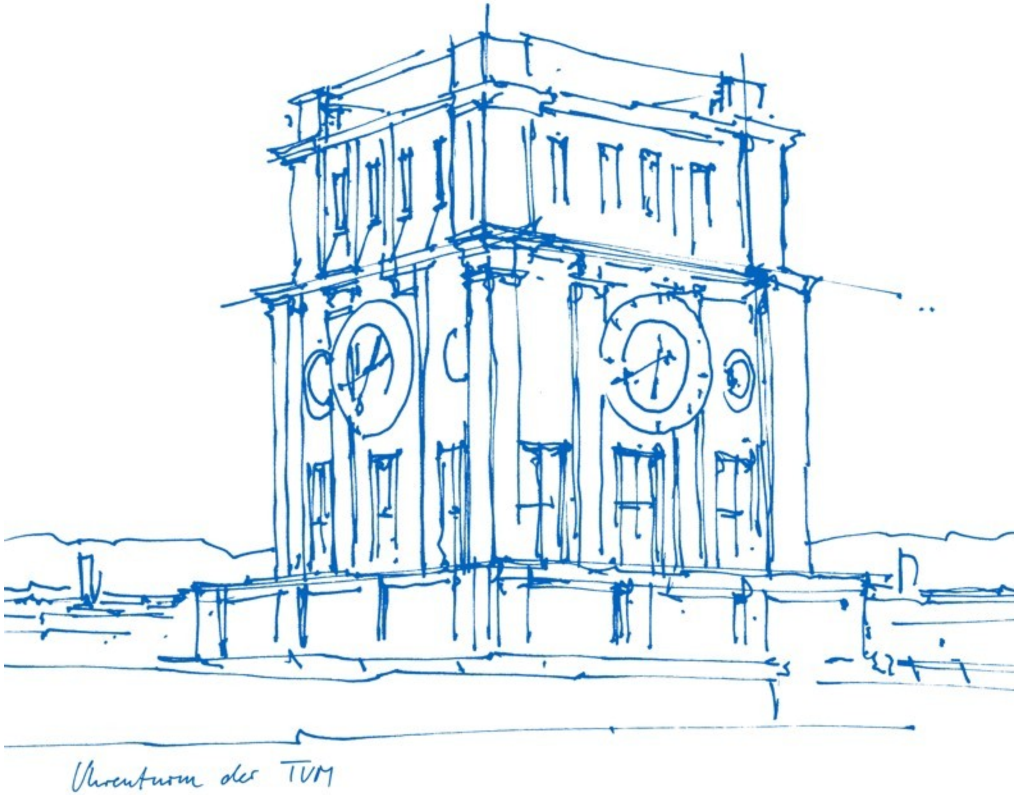
Chair of Communication Networks
Department of Electrical and Computer Engineering
Technical University of Munich

Intelligent Transportation System with Wireless Sensor Networks

WSN Project



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Motivation

- The growth in the mobility → The increase in traffic congestion
  - many social, environmental and economic effects
  - In 2017, the people of Munich have spent the highest hours in congestion in Germany
    - Total cost of the congestion was almost 2.9 billion Euro for Munich. [1]

RANK	CITY	PEAK HOURS SPENT IN CONGESTION	INRIX CONGESTION INDEX	AVERAGE CONGESTION RATE	TOTAL COST PER DRIVER	TOTAL COST TO THE CITY
1	Munchen	51	9.1	16%	€ 2,984	2.9bn
2	Hamburg	44	8.0	14%	€ 2,646	3.5bn
3	Berlin	44	8.3	14%	€ 2,811	6.9bn
4	Stuttgart	44	7.9	13%	€ 2,386	918m
5	Ruhrgebiet	40	7.5	10%	€ 2,129	2.2bn
6	Cologne	40	7.0	11%	€ 2,107	1.4bn
7	Heilbronn	38	7.6	14%	€ 2,317	154m
8	Frankfurt	36	5.9	10%	€ 1,820	906m
9	Würzburg	35	7.3	14%	€ 2,382	241m
10	Karlsruhe	34	6.4	12%	€ 2,166	468m

Motivation

- The increasing traffic volume increases the risk of car accidents.
  - In 2017, 3180 people have died in Germany because of car accidents. [2]
  - Early medical intervention

- Many approaches
  - to reduce the traffic congestion in roads
  - to intervene in emergencies as soon as possible

- The emerging technologies of Wireless Sensor Networks revolutionized
  - traffic management, control
  - response to emergencies on the road

Overview

- Introduction
- Network Description and Routing Technique
  - Update Mechanism
  - Stability and robustness
- Scenarios
  - Sectoral Localization
  - Accident Detection
- GUI
- Conclusion

Introduction

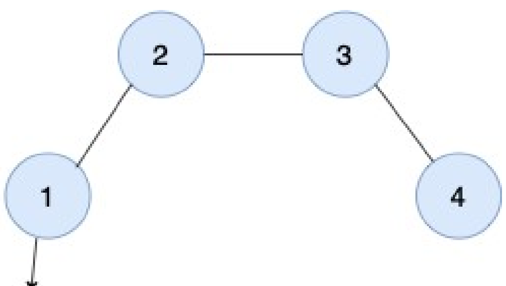
- Intelligent Transportation System with Wireless Sensor Networks, by using Zolertia ™ Re-Mote wireless motes
  - support IEEE Std. 802.15.4 specification for Low-Rate Wireless Personal Area Networks(LR-WPANSs)
- Aims
  - reduction of the cost by estimating traffic congestion on the road
  - Sense the accident as soon as possible
  - Early intervention to emergencies, saving more lives
  - Warn other cars on the road about the accident
- Characteristics of the network
  - Low delay
  - High reliability
- The first thing we need to provide clear communication between nodes is the routing.

Network Description and Routing Technique

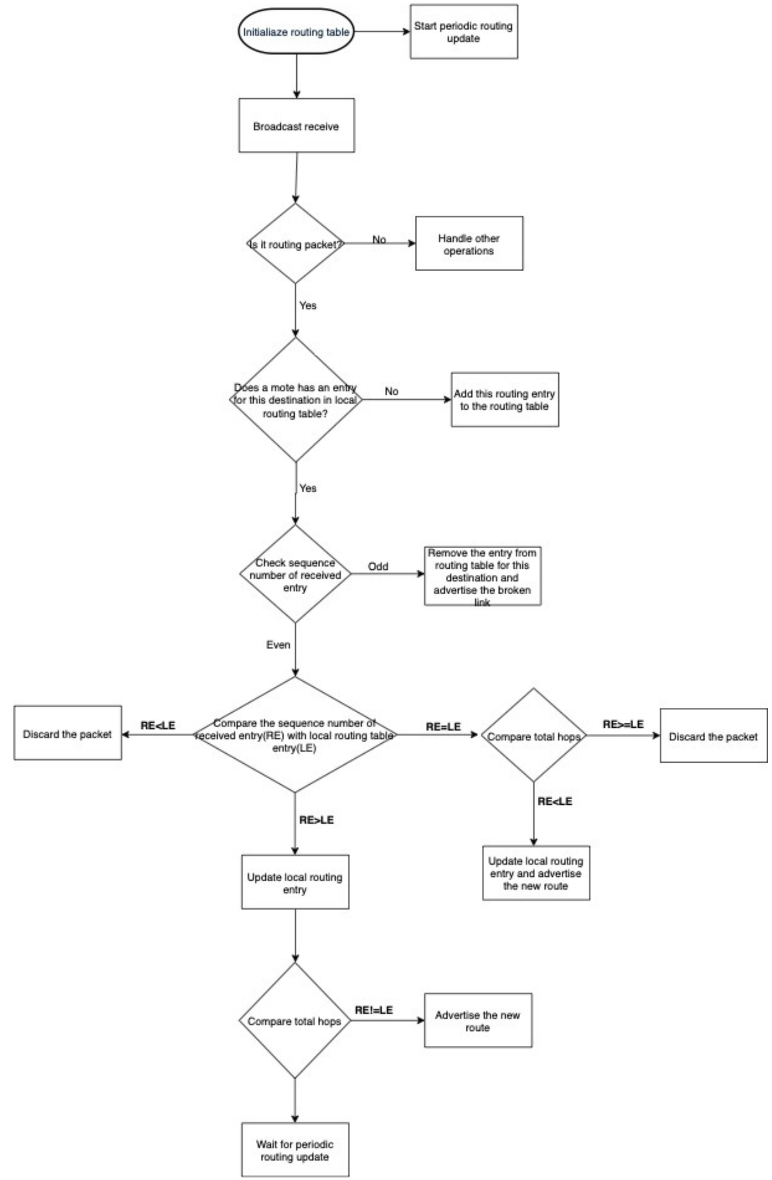
- **Destination-Sequenced Distance Vector(DSDV)**
  - DSDV is proactive(table-driven) routing algorithm which is based on Bellman-Ford algorithm.
  - Shortest path routing based on total hop number.
  - Each mote contains routing table for the other motes in the network.
  - The routing entries contain the following pieces of information:
    - The destination's address.
    - The next hop address.
    - The number of hops to reach the destination.
    - Metric (weighted RSSI)
    - The sequence number which is originated by the destination mote and increased by 2 in each periodic update.
- DSDV uses sequence number to encounter count-to-infinity problem.
- Odd sequence number indicates failed links, whereas even sequence number indicates valid link.
- Network always converges to higher sequence number.

Network Description and Routing Technique

- Update Mechanism
  - Full routing table update:
    - Each mote in the network broadcasts its routing table *periodically* e.g. 15 sec.
  - Triggered update:
    - If a link in the network changes i.e. finds a better route, failure detection, a mote sends this update to other motes without waiting full routing table update.



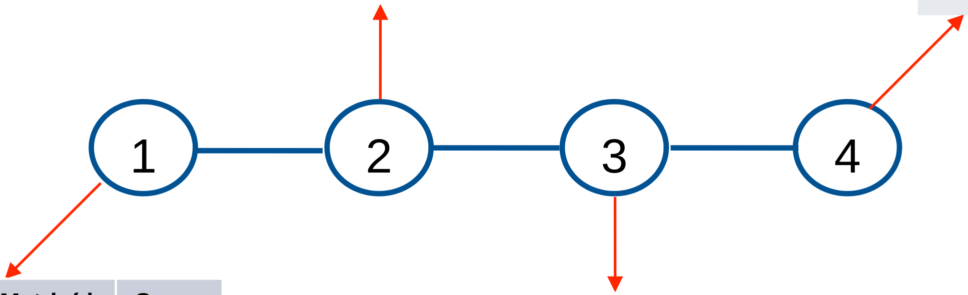
Dest. Id	Next Hop	Total Hop	Metric(dB)	Sequence Number
1	0	0	0	16
2	2	1	-57	18
3	2	2	-110	32
4	2	3	-167	28



Initialize motes

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
2	0	0	0	0

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
4	0	0	0	0



Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
1	0	0	0	0

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
3	0	0	0	0

After first periodic update

New routes
Triggered Update!!!

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
2	0	0	0	2
1	1	1	-57	2
3	3	1	-60	2

New route
Triggered Update!!!

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
4	0	0	0	2
3	3	1	-54	2

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
1	0	0	0	2
2	2	1	-58	2

New route
Triggered Update!!!

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
3	0	0	0	2
2	2	1	-61	2
4	3	1	-52	2

New routes
Triggered Update!!!

After the triggered update

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
2	0	0	0	2
1	1	1	-57	2
3	3	1	-60	2
4	3	2	-120	2

New route
Triggered Update!!!

New route
Triggered Update!!!

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
4	0	0	0	2
3	3	1	-54	2
2	3	2	-116	2

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
1	0	0	0	2
2	2	1	-58	2
3	2	2	-112	2

New route
Triggered Update!!!

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
3	0	0	0	2
2	2	1	-61	2
4	4	1	-52	2
1	2	2	-110	2

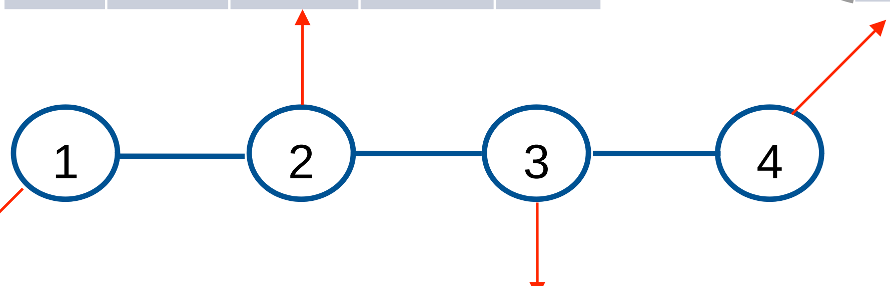
New route
Triggered Update!!!

After the triggered update

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
2	0	0	0	2
1	1	1	-57	2
3	3	1	-60	2
4	3	2	-120	2

New route
Triggered Update!!!

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
4	0	0	0	2
3	3	1	-54	2
2	3	2	-116	2
1	3	3	-170	2



Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
1	0	0	0	2
2	2	1	-58	2
3	2	2	-112	2
4	2	3	-174	2

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
3	0	0	0	2
2	2	1	-61	2
4	4	1	-52	2
1	2	2	-110	2

New route
Triggered Update!!!

Link Failure after some time

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
2	0	0	0	28
1	1	1	-57	28
3	3	1	-60	28
4	3	2	-120	28

1

Mote 3 does not receive periodic update message from mote 4.

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
4	0	0	0	28
3	3	1	-54	28
2	3	2	-116	28
1	3	3	-170	28

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
1	0	0	0	28
2	2	1	-58	28
3	2	2	-112	28
4	2	3	-174	28

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
3	0	0	0	28
2	2	1	-61	28
4	∞	∞	∞	29
1	2	2	-110	28

2

Updates sequence number of mote 4 by 1 and advertise this entry.

Link Failure Convergence

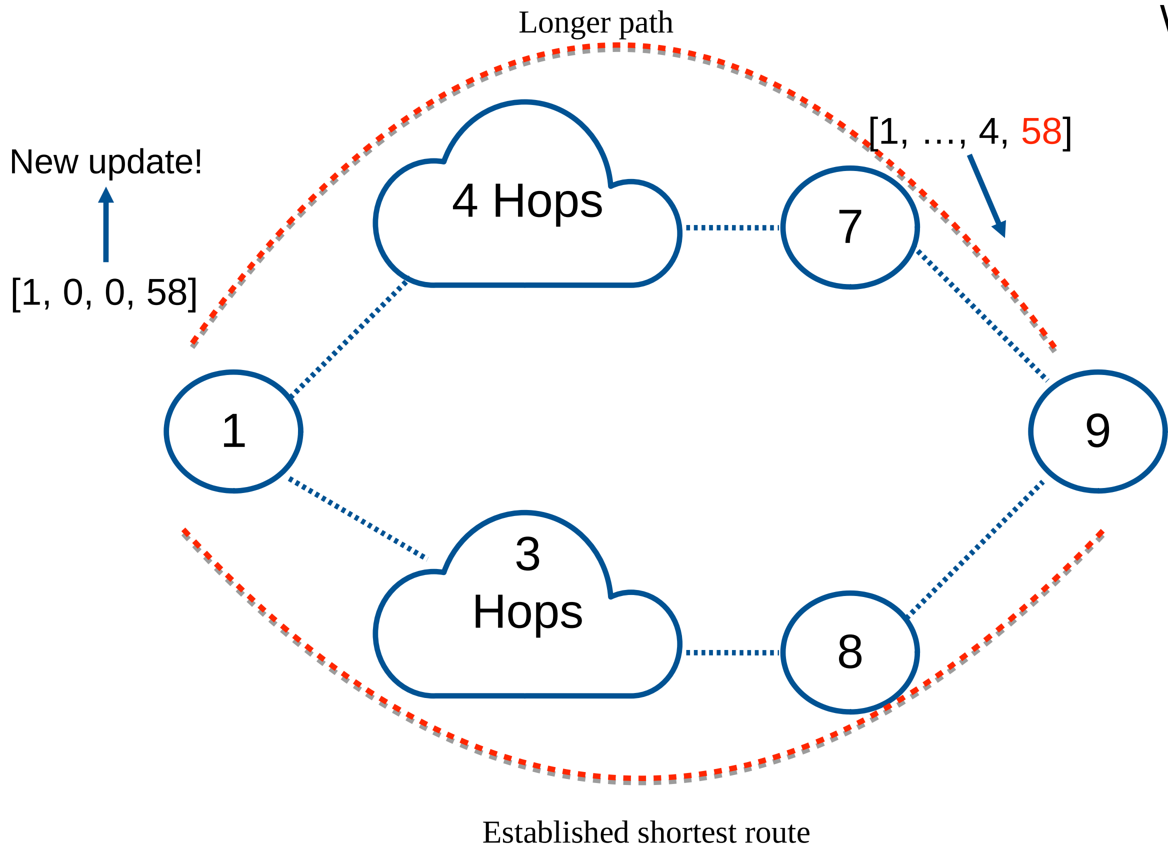
Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
2	0	0	0	28
1	1	1	-57	28
3	3	1	-60	28
4	∞	∞	∞	29

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
4	0	0	0	28
3	3	1	-54	28
2	3	2	-116	28
1	3	3	-170	28

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
1	0	0	0	28
2	2	1	-58	28
3	2	2	-112	28
4	∞	∞	∞	29

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
3	0	0	0	28
2	2	1	-61	28
4	∞	∞	∞	29
1	2	2	-110	28

Damping Fluctuations



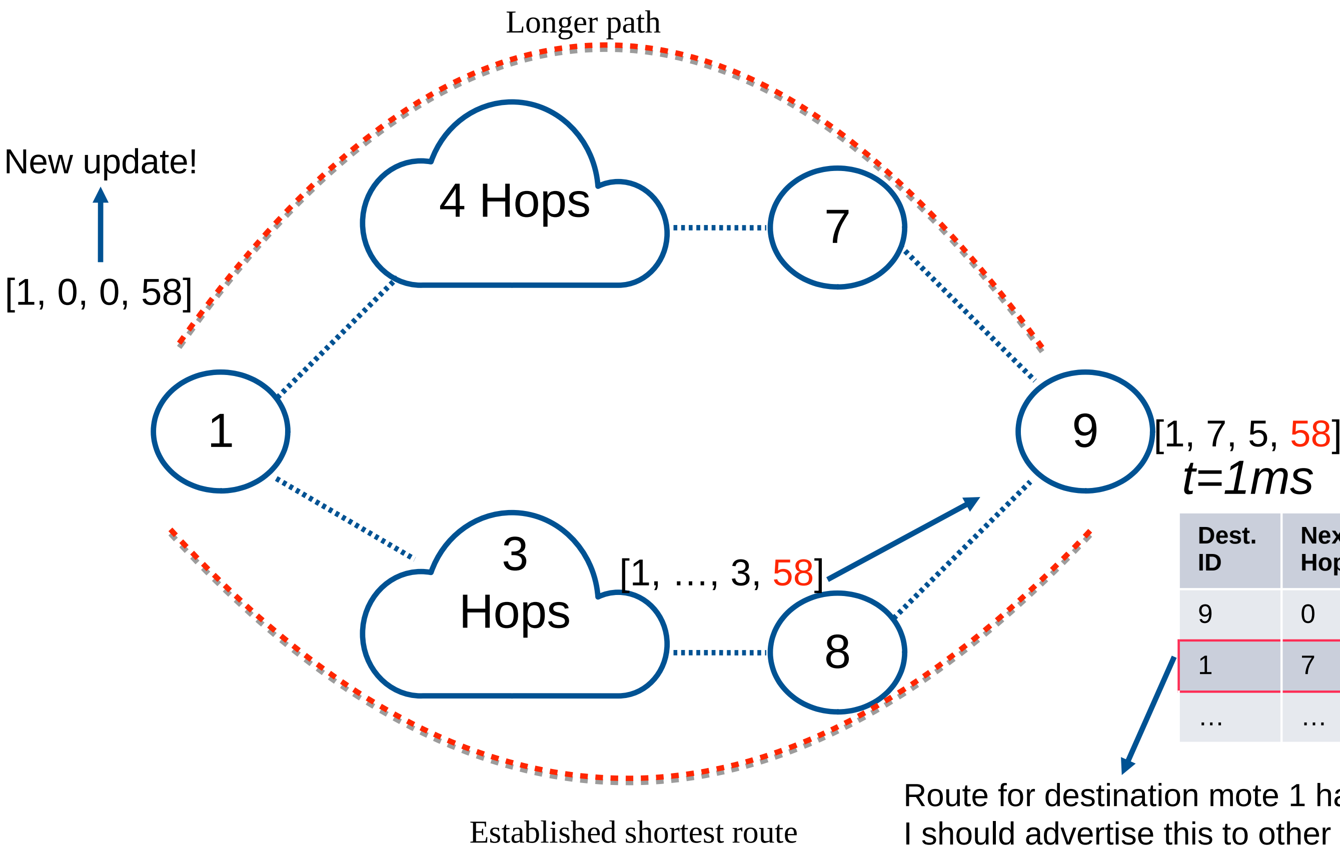
What are Fluctuations?

- In some cases, due to interference among motes or difference in periodic routing update intervals, update of mote 1 can reach earlier from ***longer path***.

t=0ms

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
9	0	0	0	34
1	8	4	-202	56
…	…	…	…	…

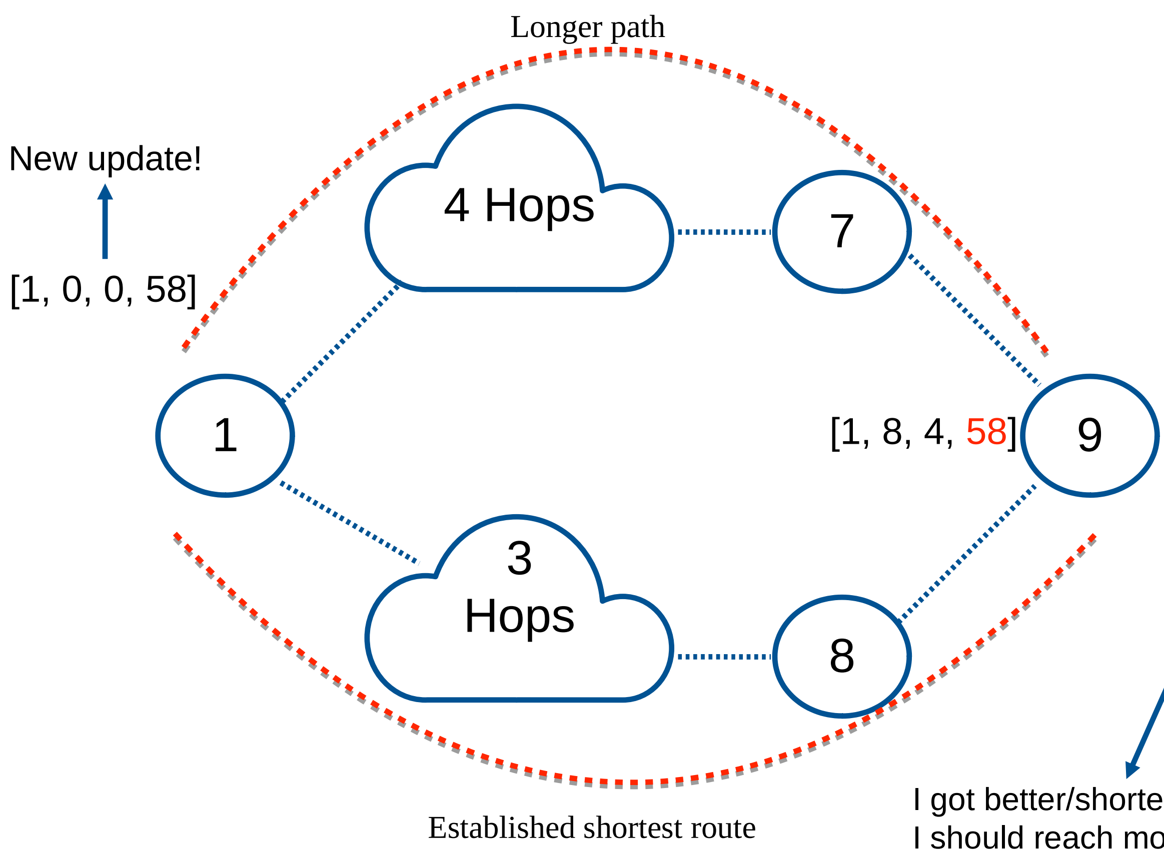
Damping Fluctuations



Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
9	0	0	0	34
1	7	5	-254	58
…	…	…	…	…

Route for destination mote 1 has changed.
I should advertise this to other motes in the network immediately.

Damping Fluctuations



t=2ms

Dest. ID	Next Hop	Total Hop	Metric(dB)	Seq. No
9	0	0	0	34
1	8	4	-202	58
…	…	…	…	…

I got better/shorter route for mote 1 with the same sequence number, I should reach mote 1 via this route advertise this to other motes.

Damping Fluctuations

- This leads to unnecessary route advertisements, so called ***fluctuations***.
- How can we avoid this?

Solution: Settling time

- Motes wait for predefined interval, settling time, before they advertise a new route.
- In this way, only stable routes will be advertised to the network.
- The overhead will be reduced and the network becomes more stable.

Failure Recovery Mechanism

- What happens if a mote restarts or rejoin the network after it has removed?
  - The mote synchronizes itself with the highest sequence number that is used in the network and start to count from this number.

Weighted RSSI

- In order to dampen the high oscillations of the RSSI measure the routing algorithm implements a Weighted Sum mechanism.
- The weights of the sum are stored in the weight vector $W = [w_1,w_2]$
- Formula: $RSSI_{weighted} = RSSI_{old} * w_1 + RSSI_{new} * w_2$
- Depending on the network mobility and convergence time different values of W can be used.

DSDV: Advantages & Disadvantages

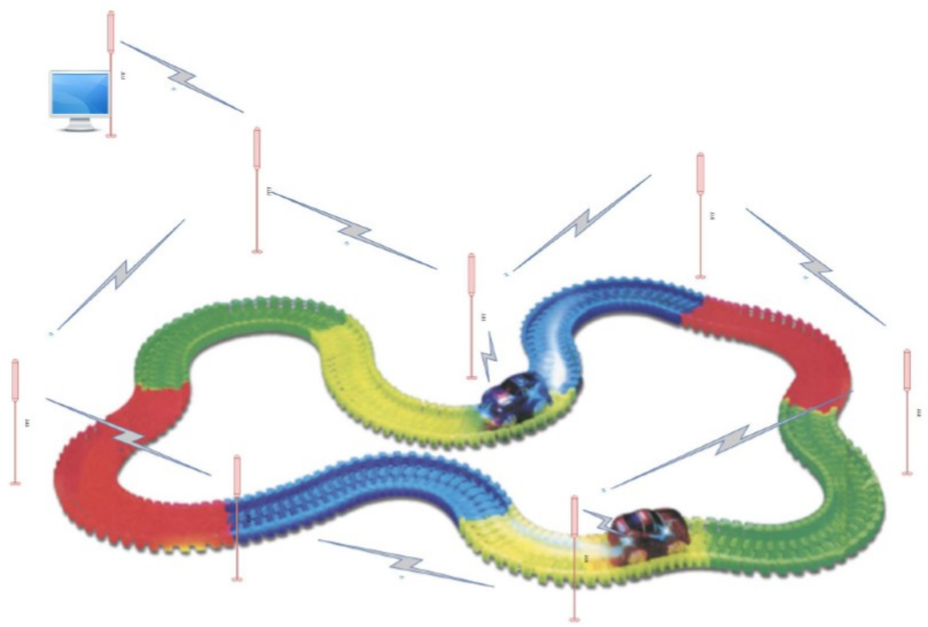
- (+) DSDV guarantees loop free path.
- (+) DSDV outperforms the other routing algorithms in terms of end-to-end delay and normalize routing load(NRL)[3].
- (-) DSDV requires periodic updates which reduces battery life.
- (-) Small amount of bandwidth is allocated even when the network is idle.

Scenarios

- Two main scenarios:
  - Sectoral Localization
    - to calculate the number of cars on each sector of the road
  - Accident Detection
    - to inform everyone on the road, including the traffic center
    - to create a direct communication channel between the traffic center and the crashed car for the early intervention

Sectoral Localization

- Motes are placed on the roadside at regular intervals
  - are equipped with IR Distance sensor.
    - to detect on object
  - When a RSU senses an object, it increments its counter by 1.
    - sends the counter to the traffic center
      - when it senses an object
      - periodically



- With the help of these counters, the traffic center calculates the number of cars on each sector of the road.

Accident Detection

- Each car on the road is equipped with a wireless mote
  - integrated with a force sensor
    - which is able to sense the crash

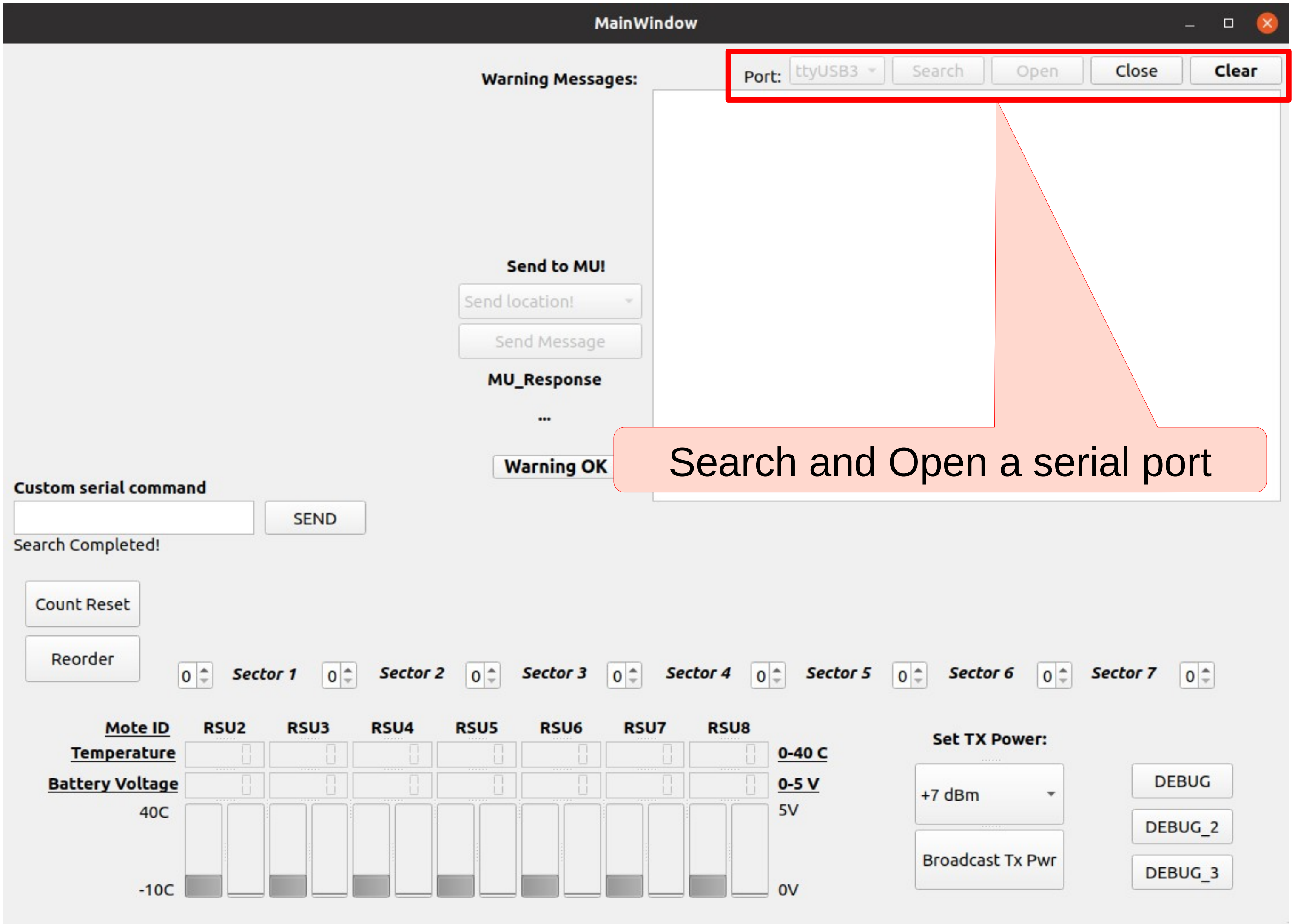
- If a mote senses a crash, it informs everyone on the network with a crash message
  - each RSU receiving this crash message rebroadcasts it with a controlled rebroadcast mechanism to avoid broadcast storm
  - As soon as this car detects the collision, after broadcasting the collision message, it will enable its routing algorithm
    - to involve on the network of RSUs
  - When the traffic center has the crashed MU in its routing table
    - can create a multi-hop communication channel to the passengers in the car
    - learn the details of the accident

Graphical User Interface

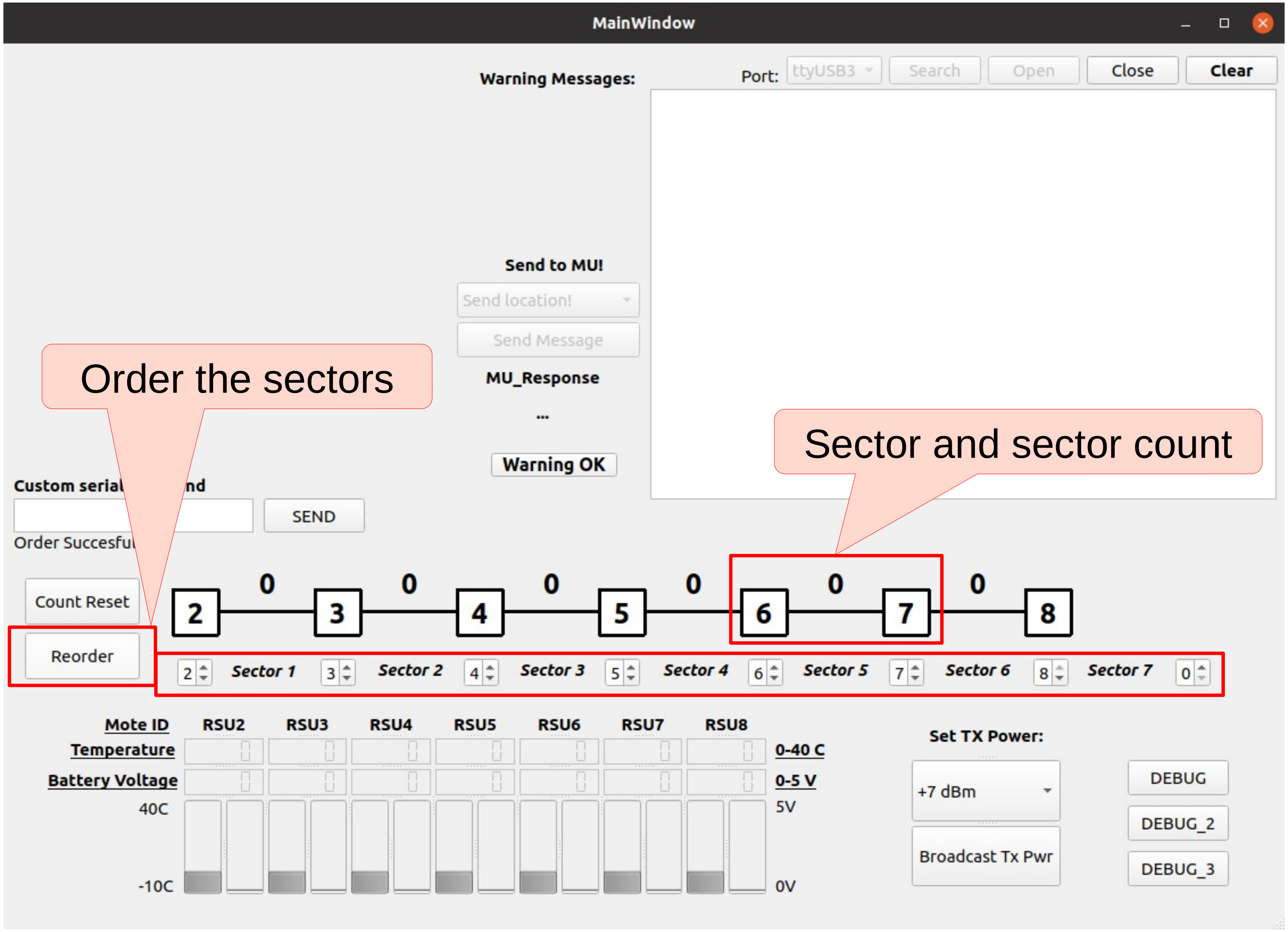
- GUI is used to :
  - Visualize the routing table
  - Display sectors and sector object count
  - Display temperature and battery level of the RSU
  - Display collision warning messages
  - Send and receive messages from the collided MU
  - Reset the collided MU after accident is resolved

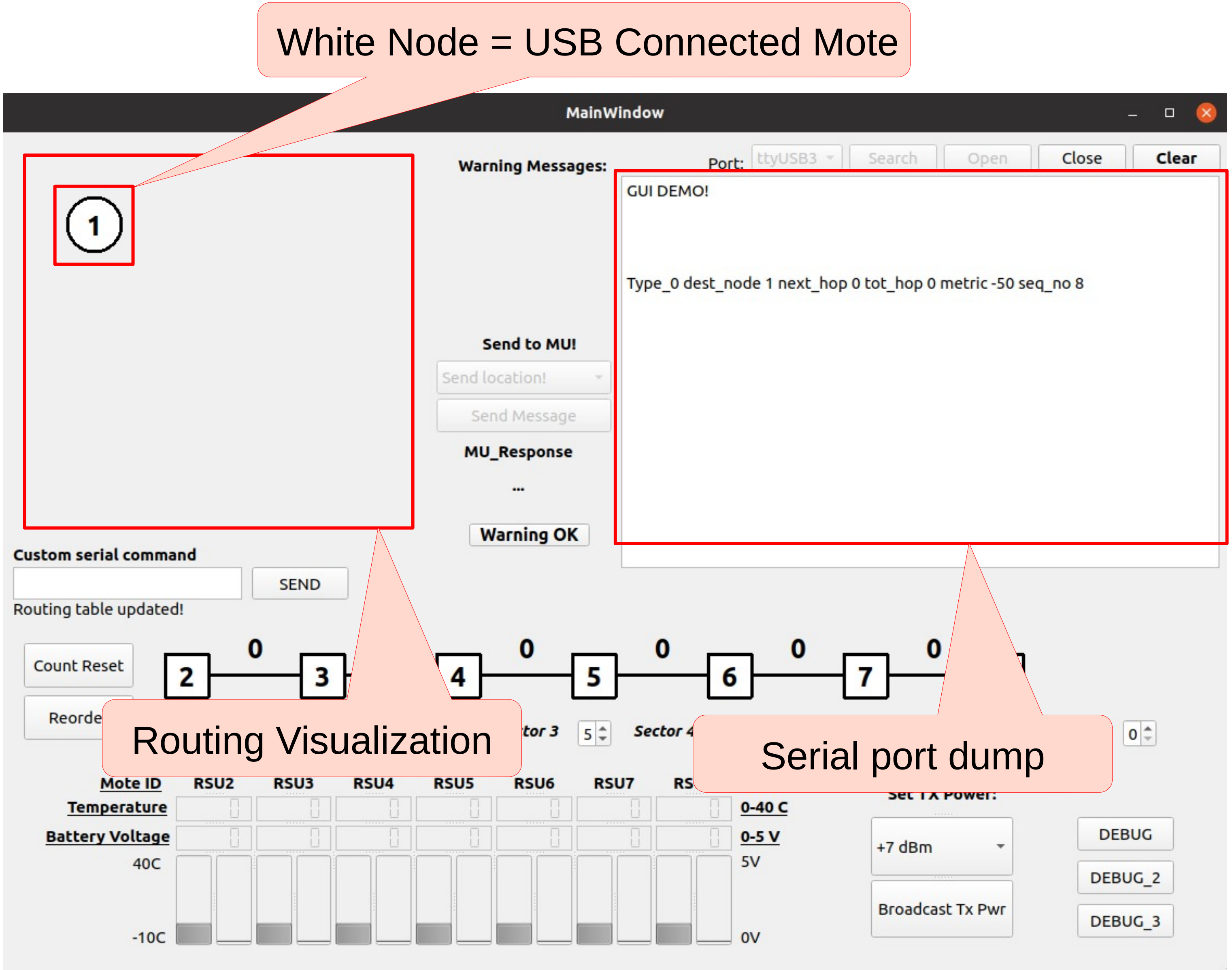
- GUI will be explained by means of an example case in the following slides

Graphical User Interface



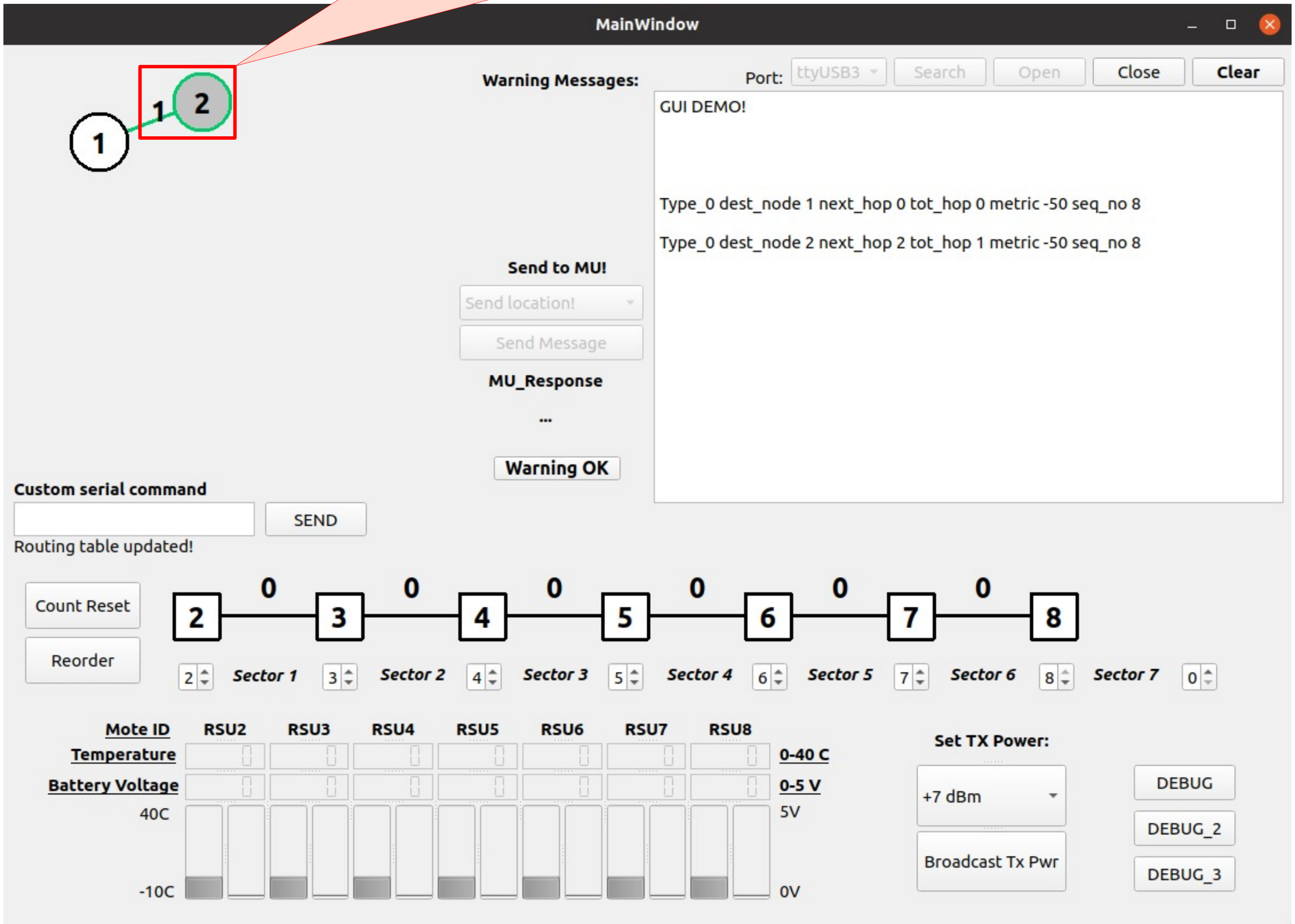
Graphical User Interface

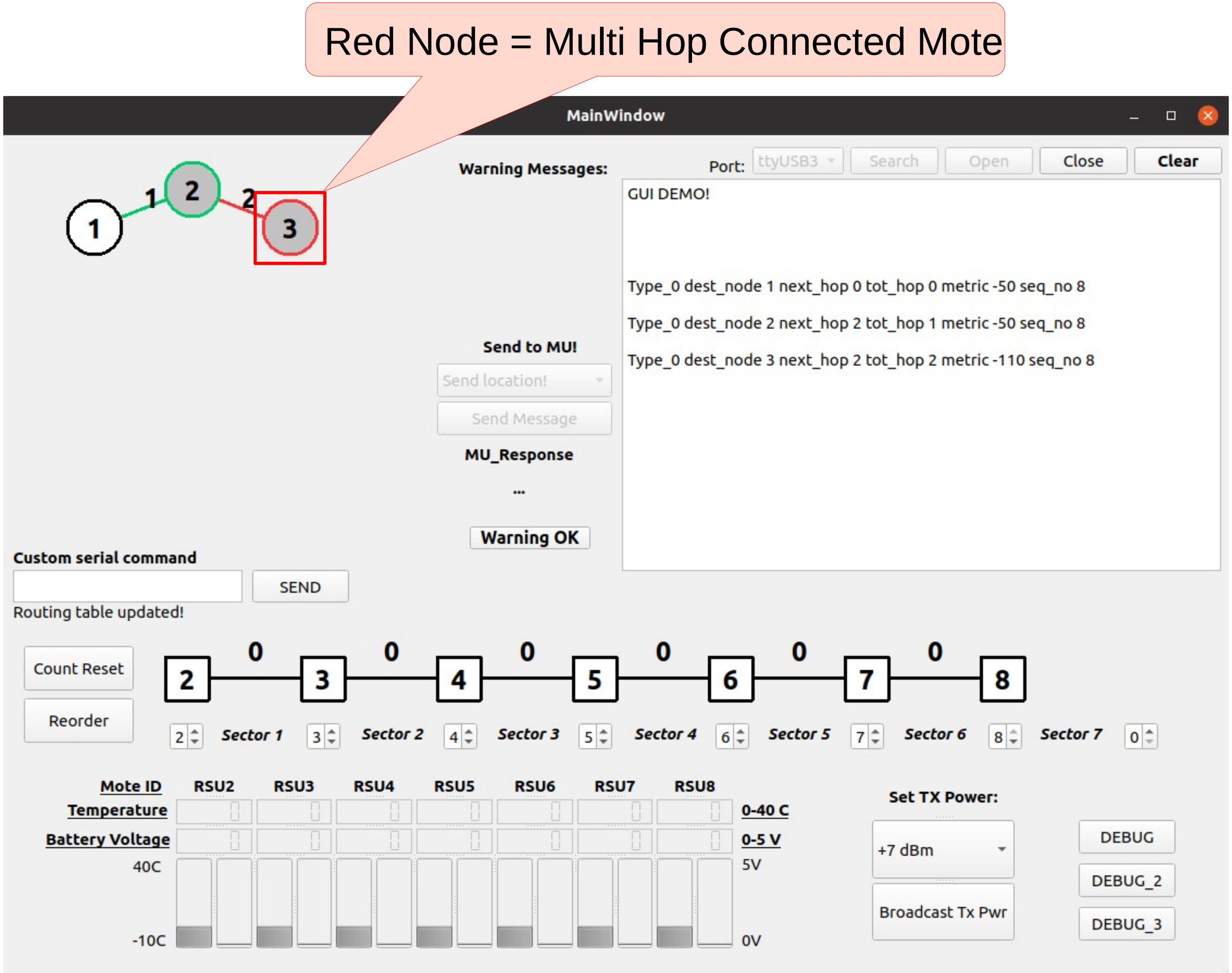




White Node = USB Connected Mote
MainWindow
Warning Messages:
Port:
ttyUSB3
Search
Open
Close
Clear
GUI DEMO!
Type_0 dest_node 1 next_hop 0 tot_hop 0 metric -50 seq_no 8
Send to MU!
Send location!
Send Message
MU_Response
...
Warning OK
Custom serial command
SEND
Routing table updated!
Count Reset
Routing Visualization
Serial port dump
Mote ID
RSU2
RSU3
RSU4
RSU5
RSU6
RSU7
Temperature
Battery Voltage
0-40 C
0-5 V
40C
-10C
5V
0V
+7 dBm
Broadcast Tx Pwr
DEBUG
DEBUG_2
DEBUG_3

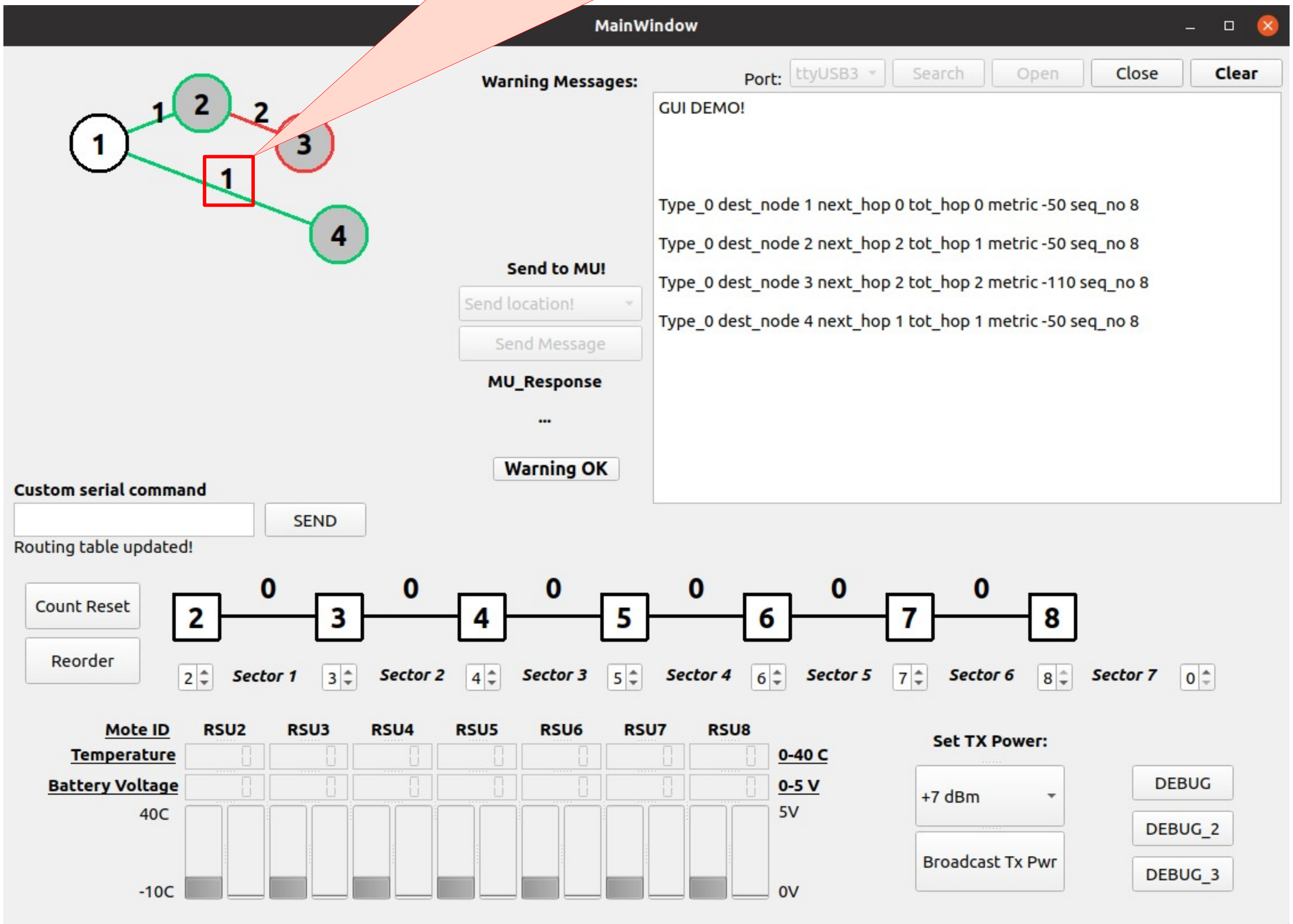
Green Node = 1 Hop Connected Mote



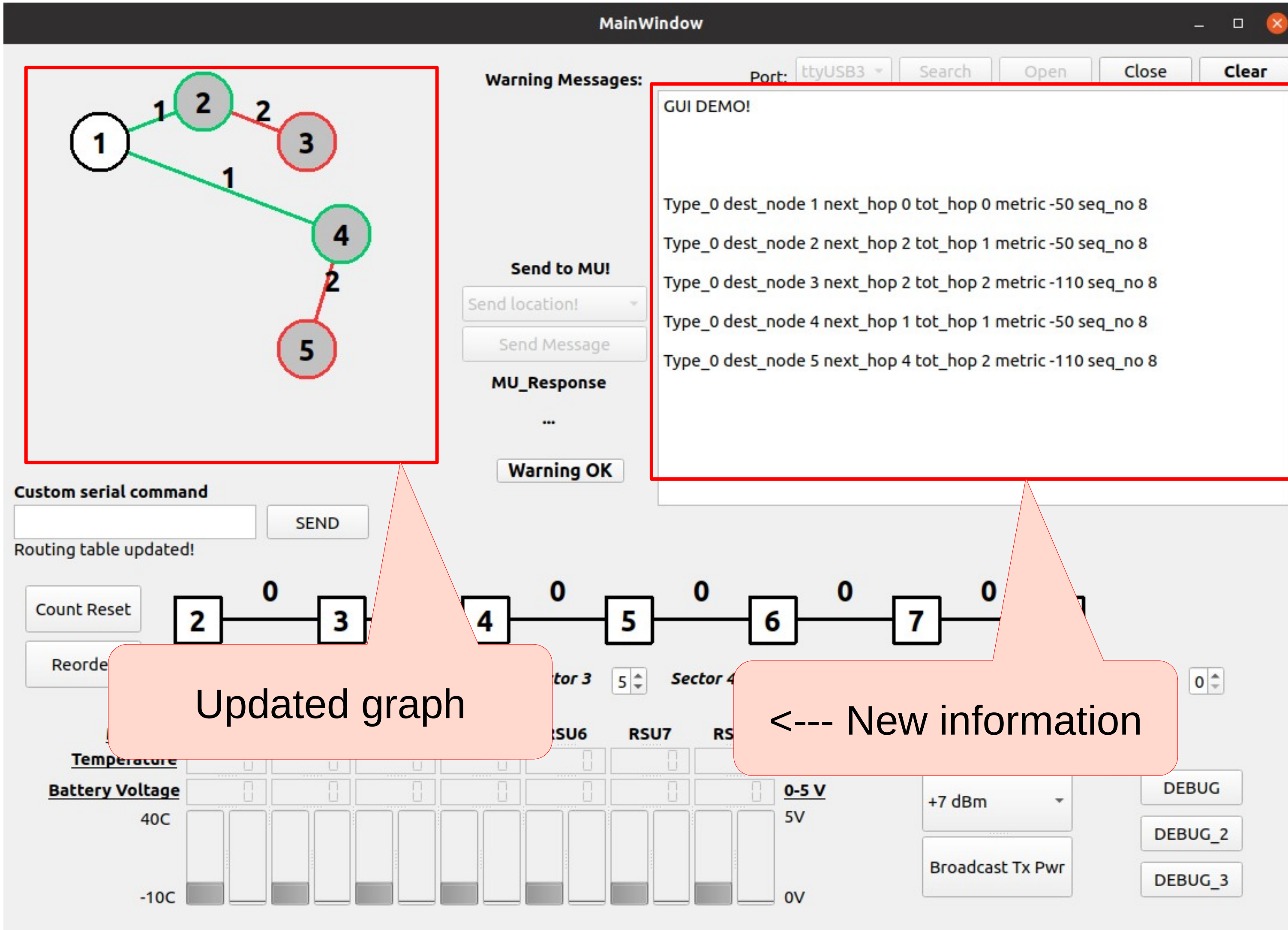


Red Node = Multi Hop Connected Mote
MainWindow
Warning Messages:
Port:
ttyUSB3
Search
Open
Close
Clear
GUI DEMO!
Type_0 dest_node 1 next_hop 0 tot_hop 0 metric -50 seq_no 8
Type_0 dest_node 2 next_hop 2 tot_hop 1 metric -50 seq_no 8
Type_0 dest_node 3 next_hop 2 tot_hop 2 metric -110 seq_no 8
Send to MU!
Send location!
Send Message
MU_Response
...
Warning OK
Custom serial command
SEND
Routing table updated!
Count Reset
Reorder
Sector 1
Sector 2
Sector 3
Sector 4
Sector 5
Sector 6
Sector 7
Mote ID
RSU2
RSU3
RSU4
RSU5
RSU6
RSU7
RSU8
Temperature
Battery Voltage
0-40 C
0-5 V
40C
-10C
5V
0V
Set TX Power:
+7 dBm
Broadcast Tx Pwr
DEBUG
DEBUG_2
DEBUG_3

Total Hop Count



Graphical User Interface



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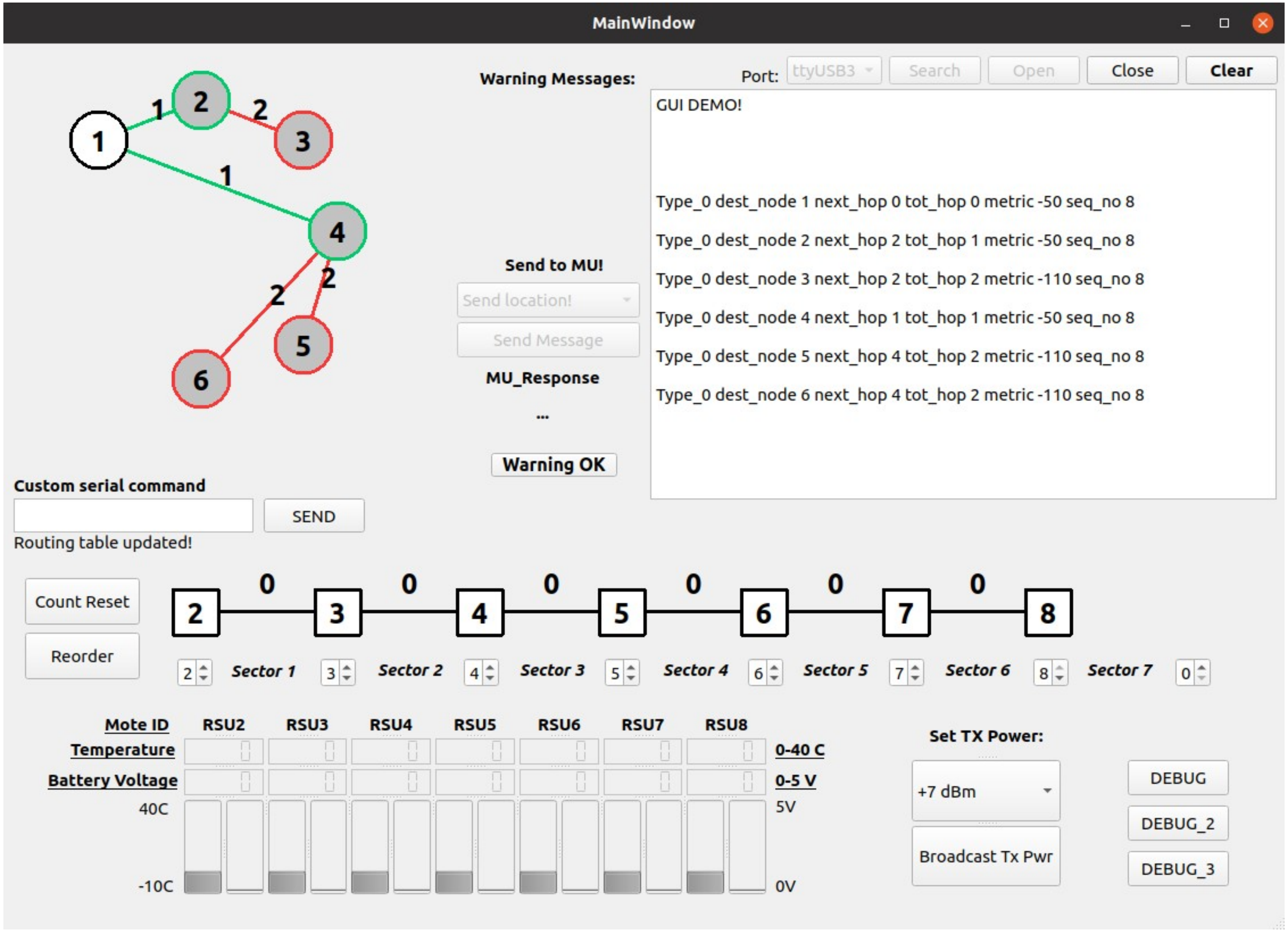

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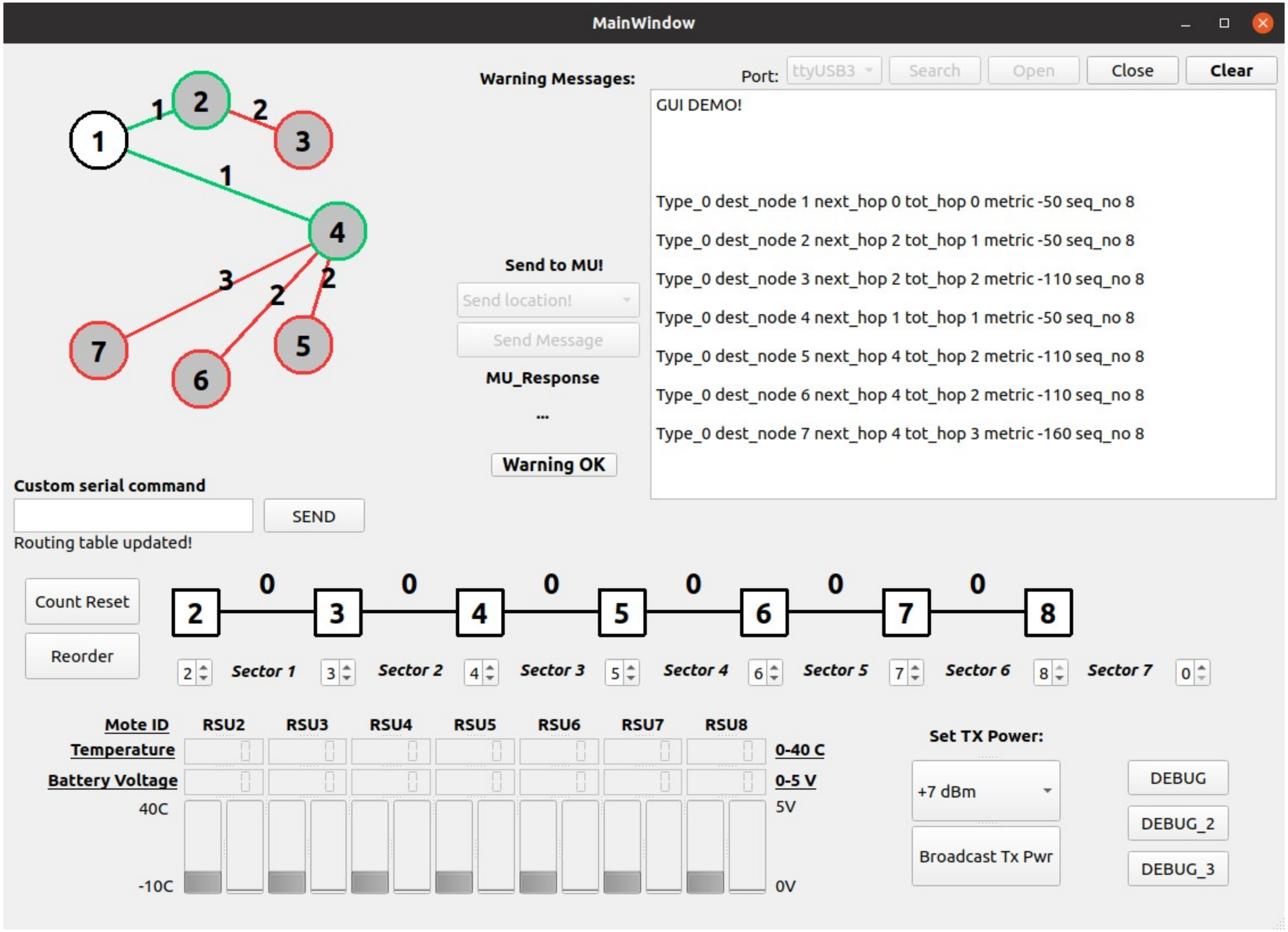

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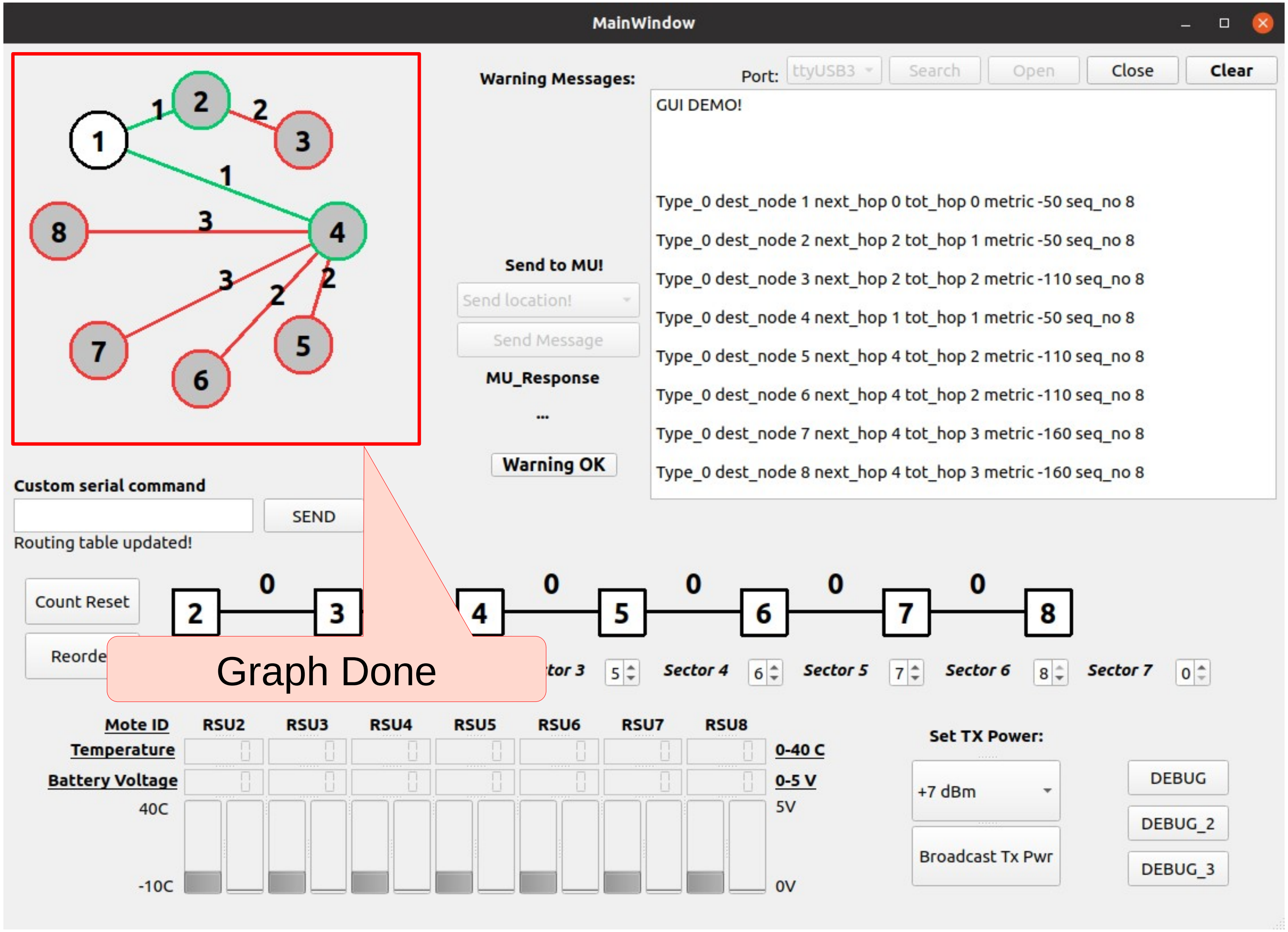

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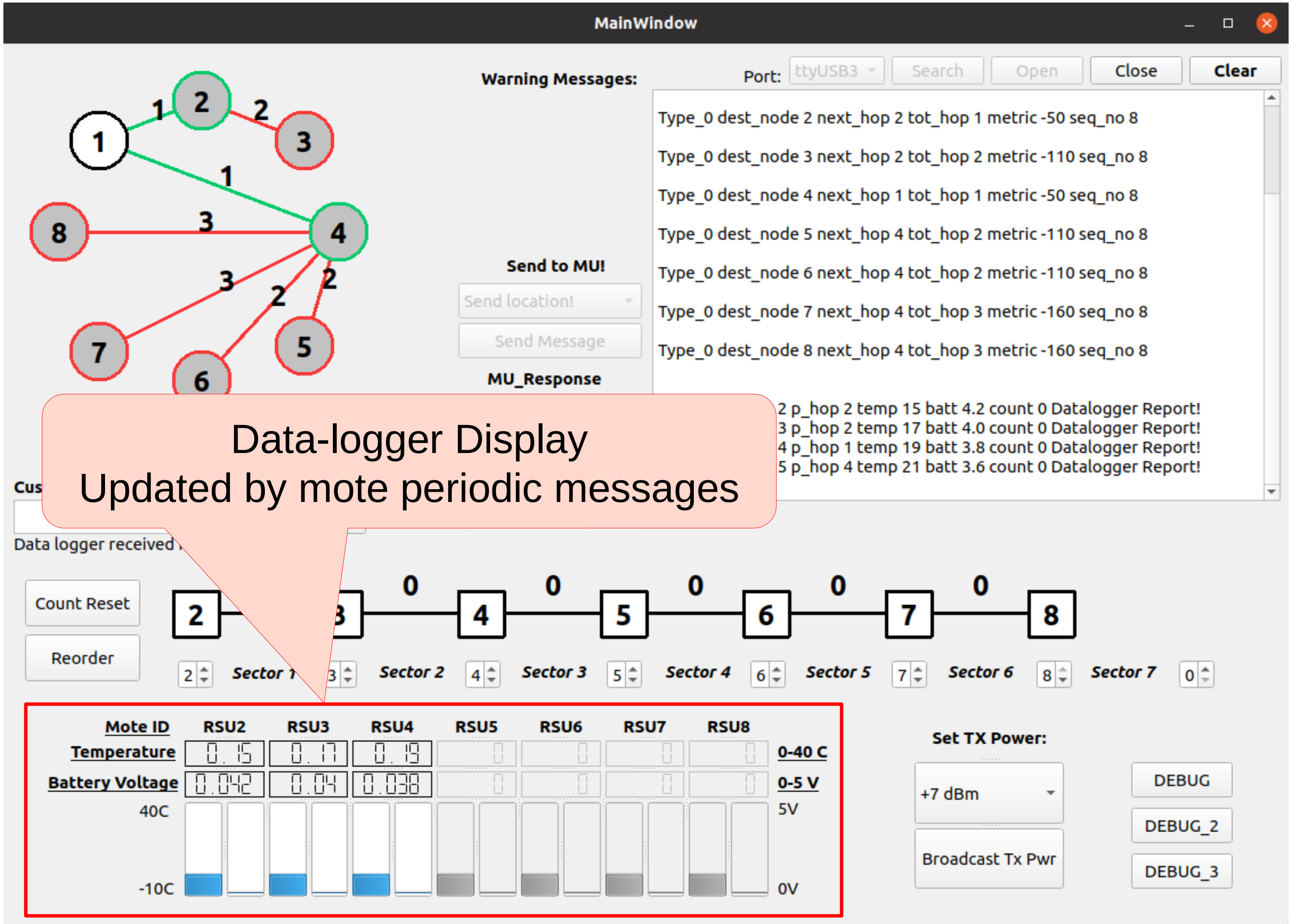

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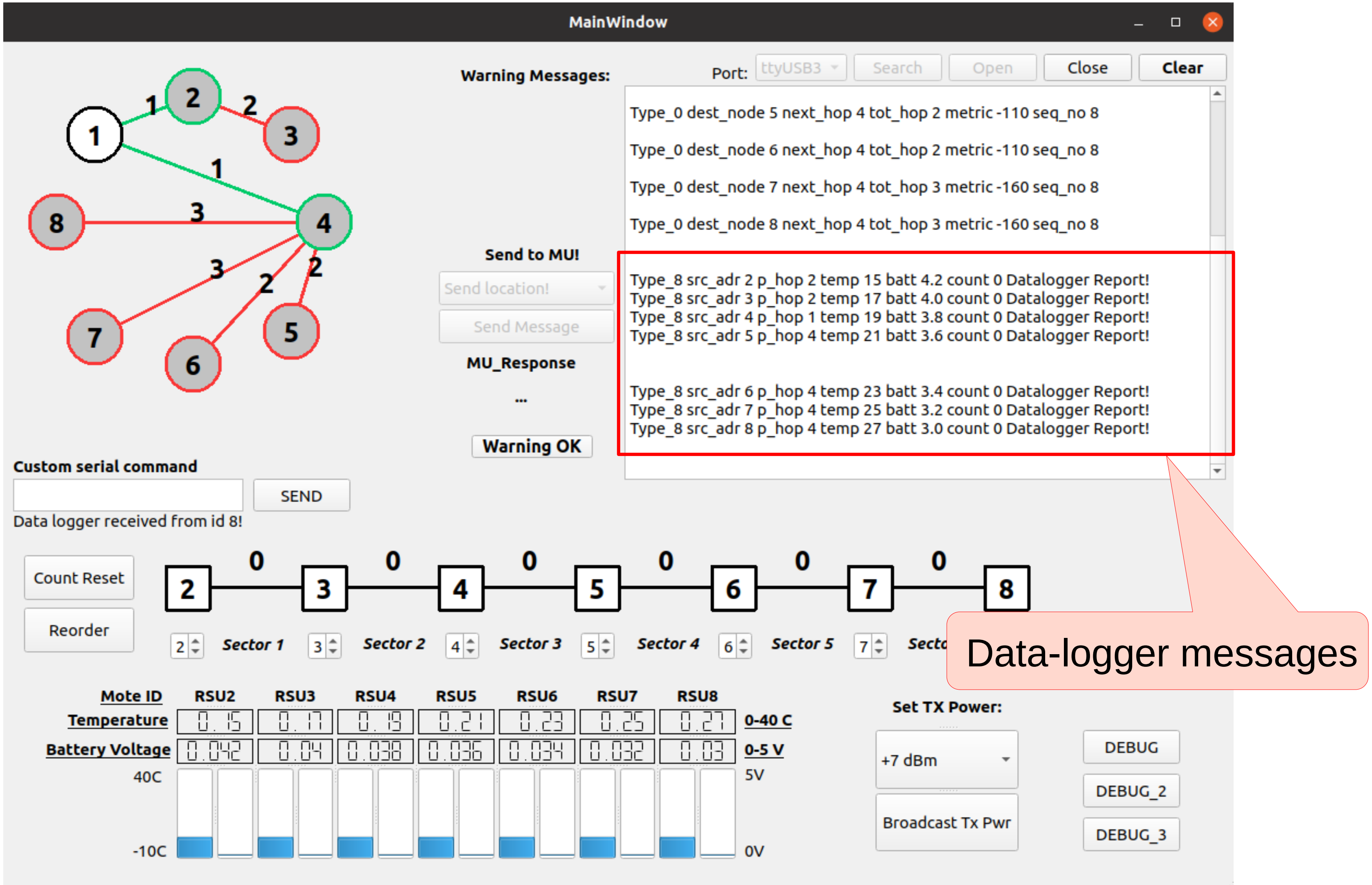

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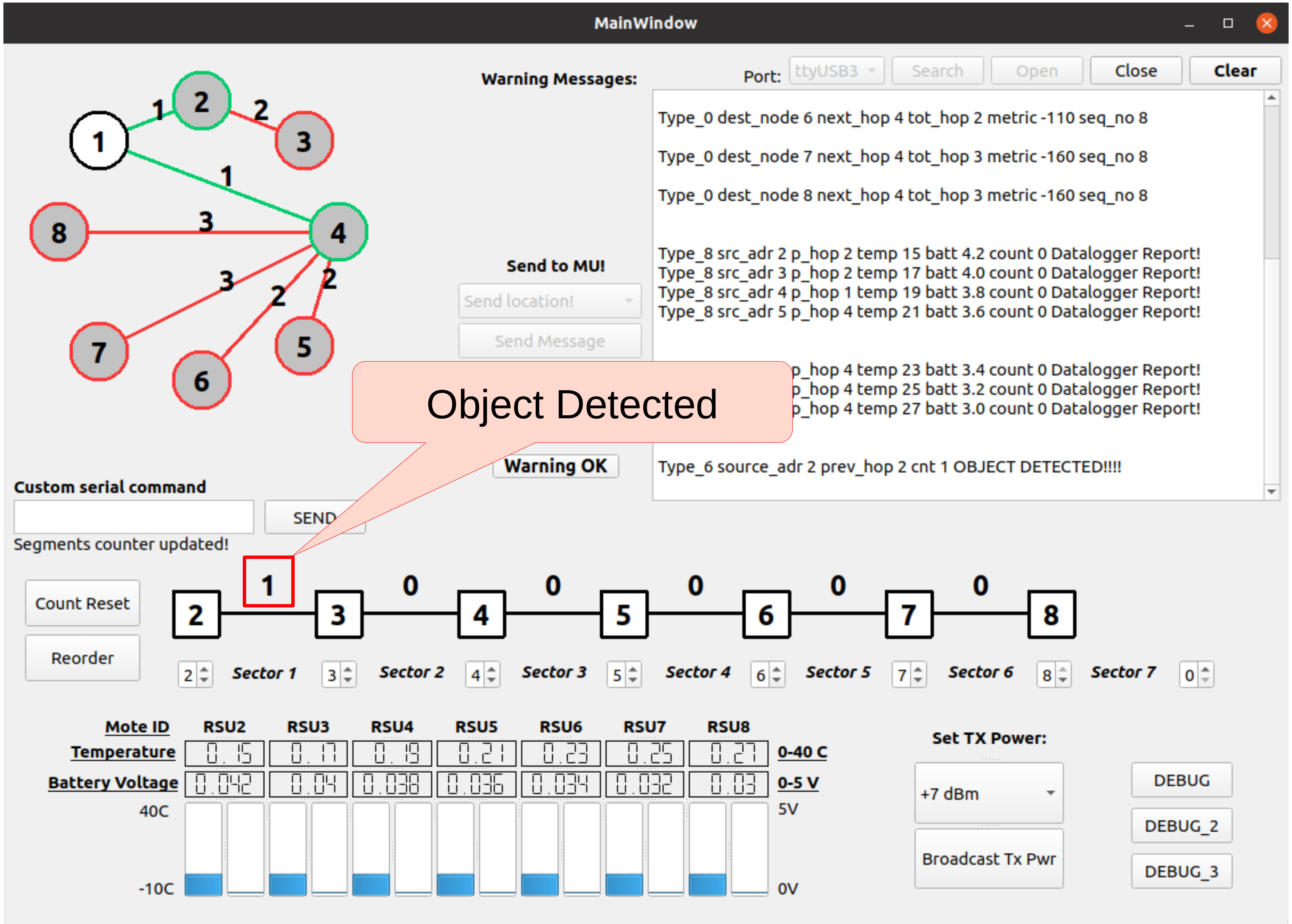

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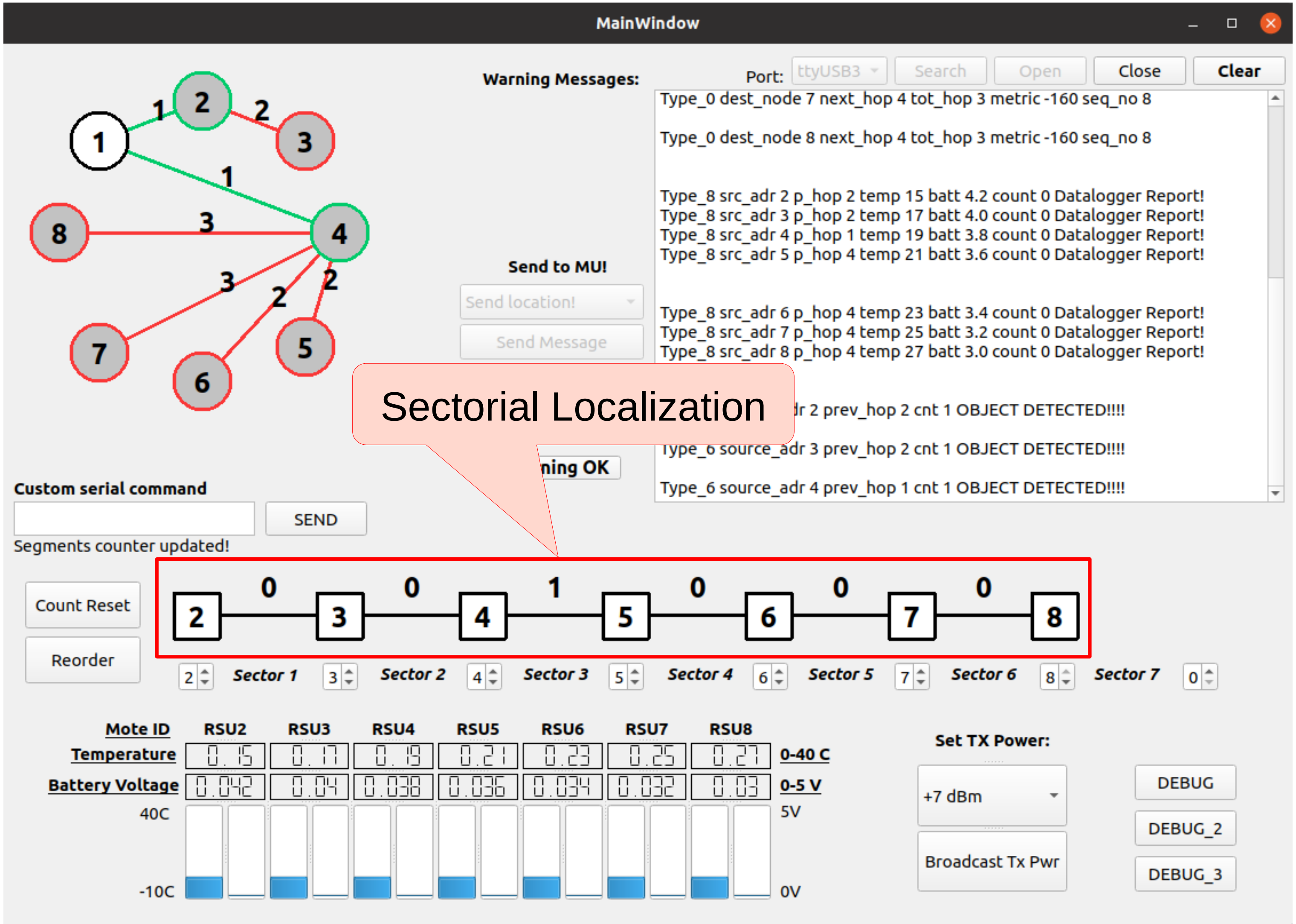

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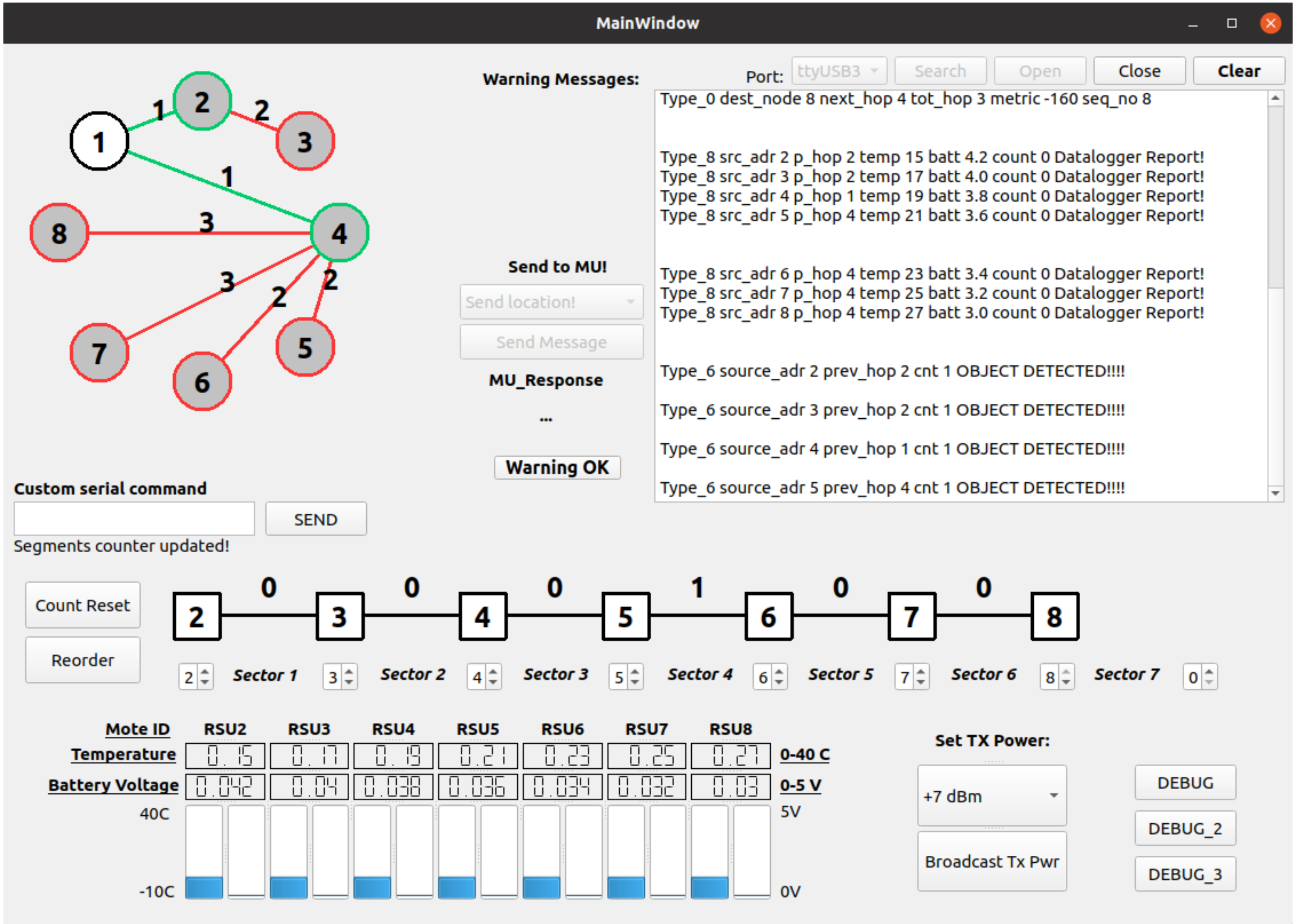

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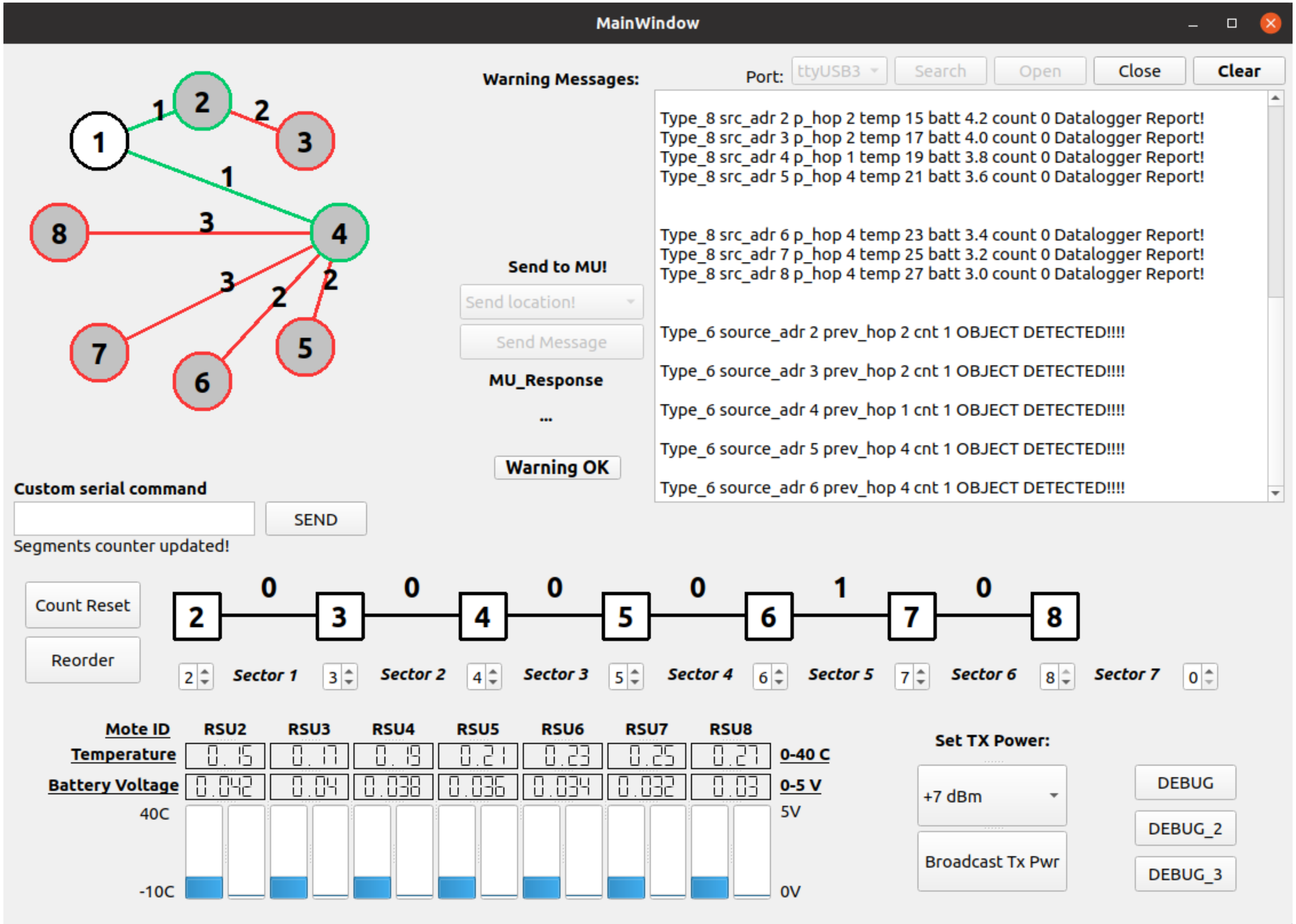

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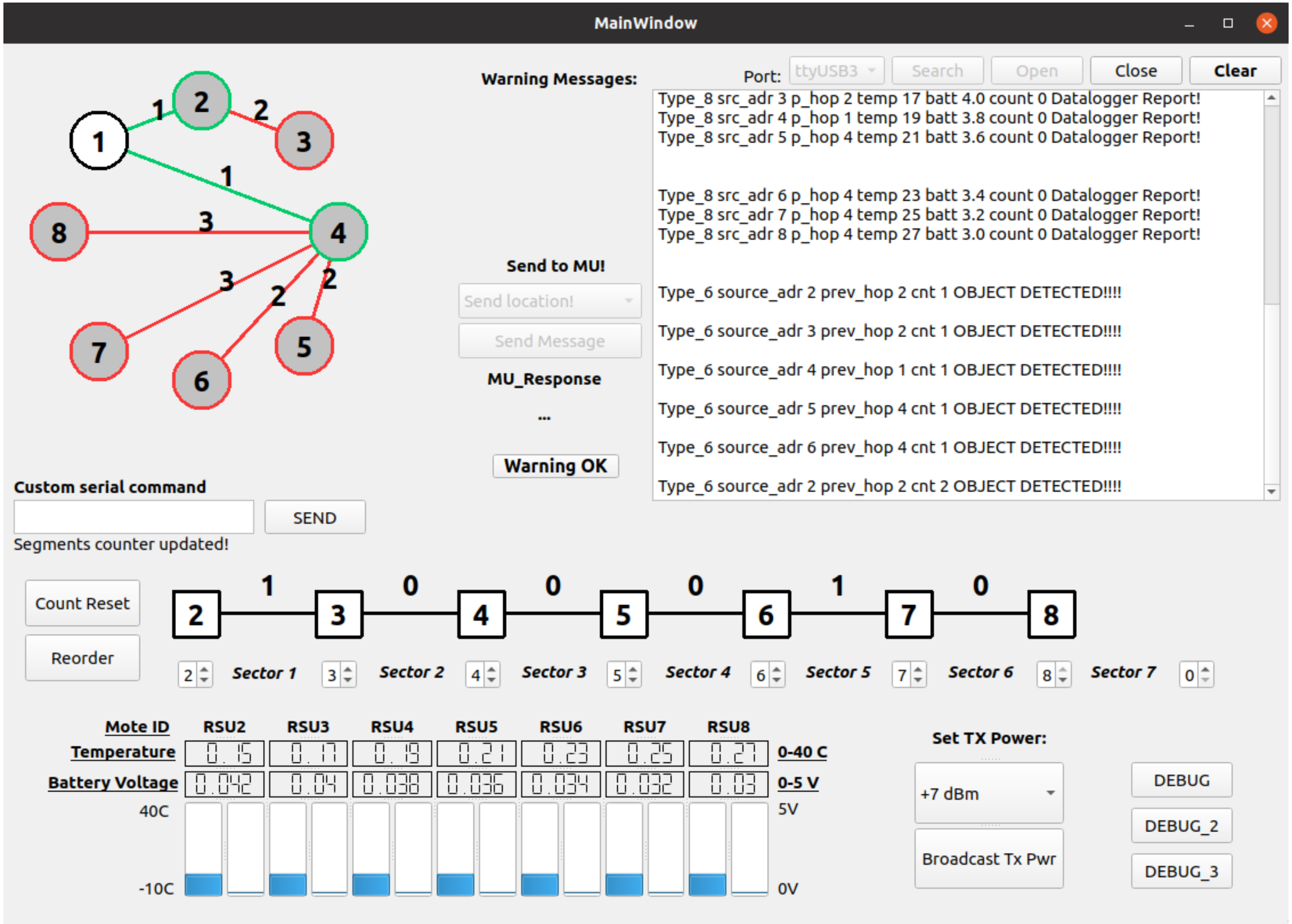

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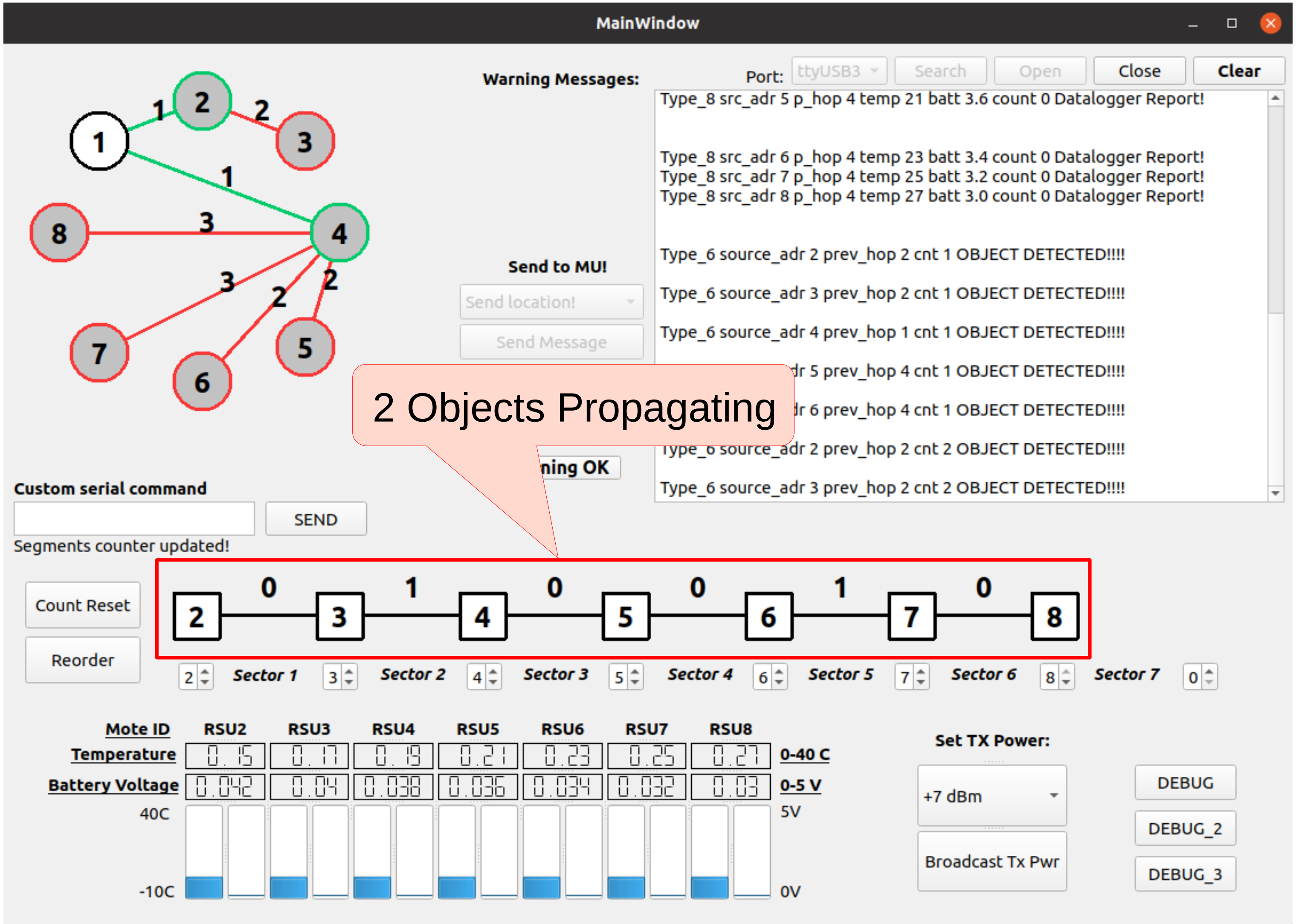

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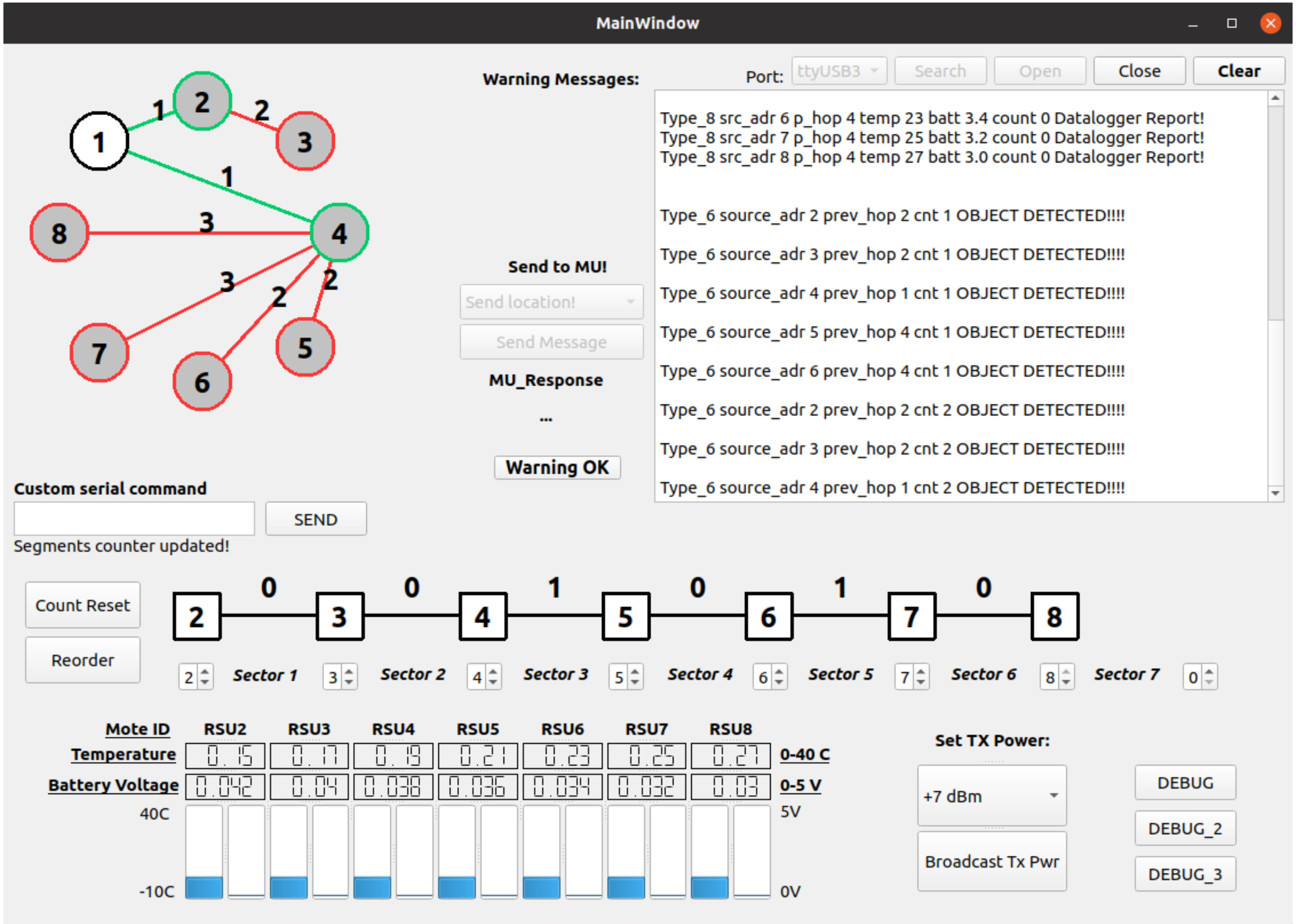

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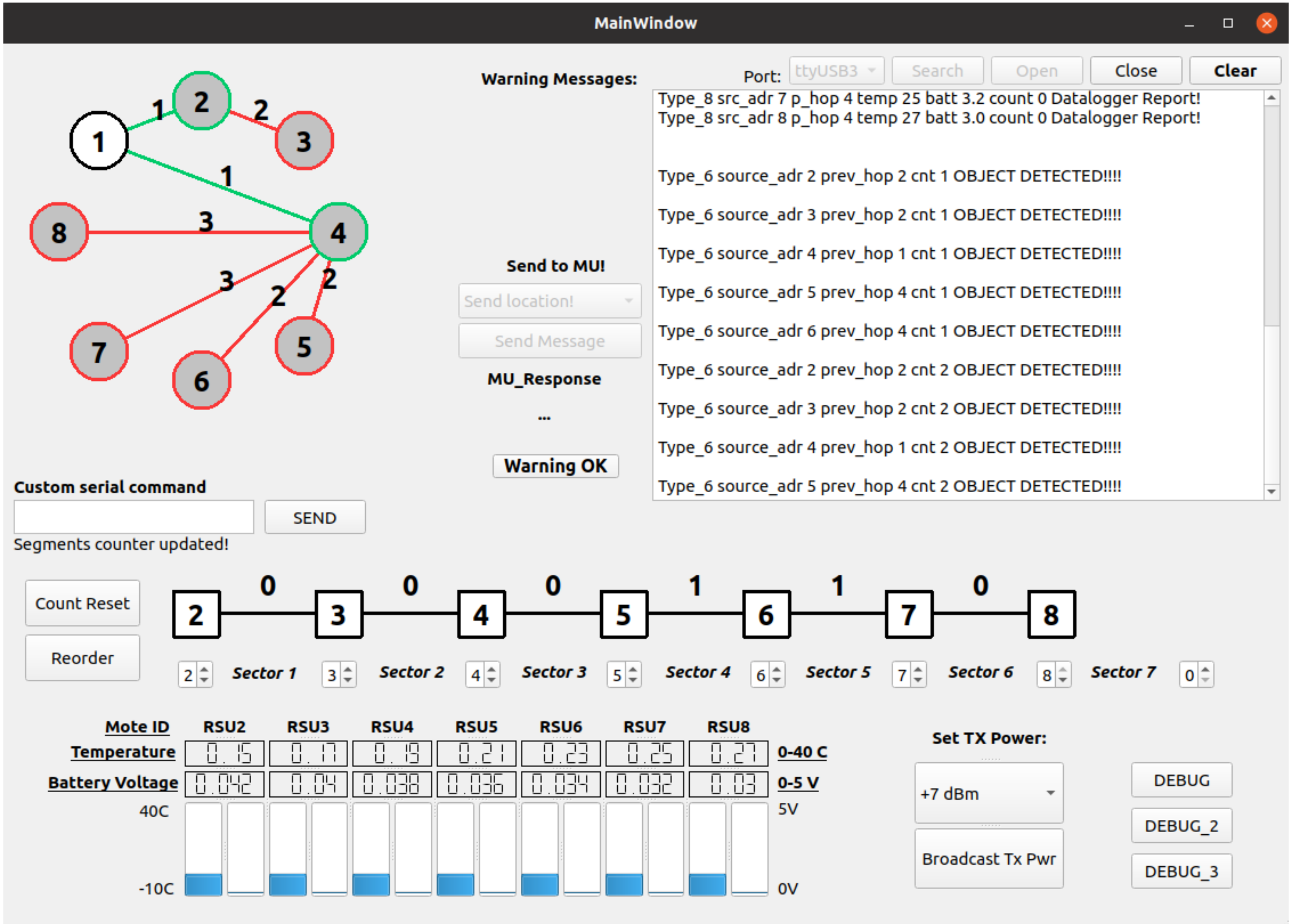

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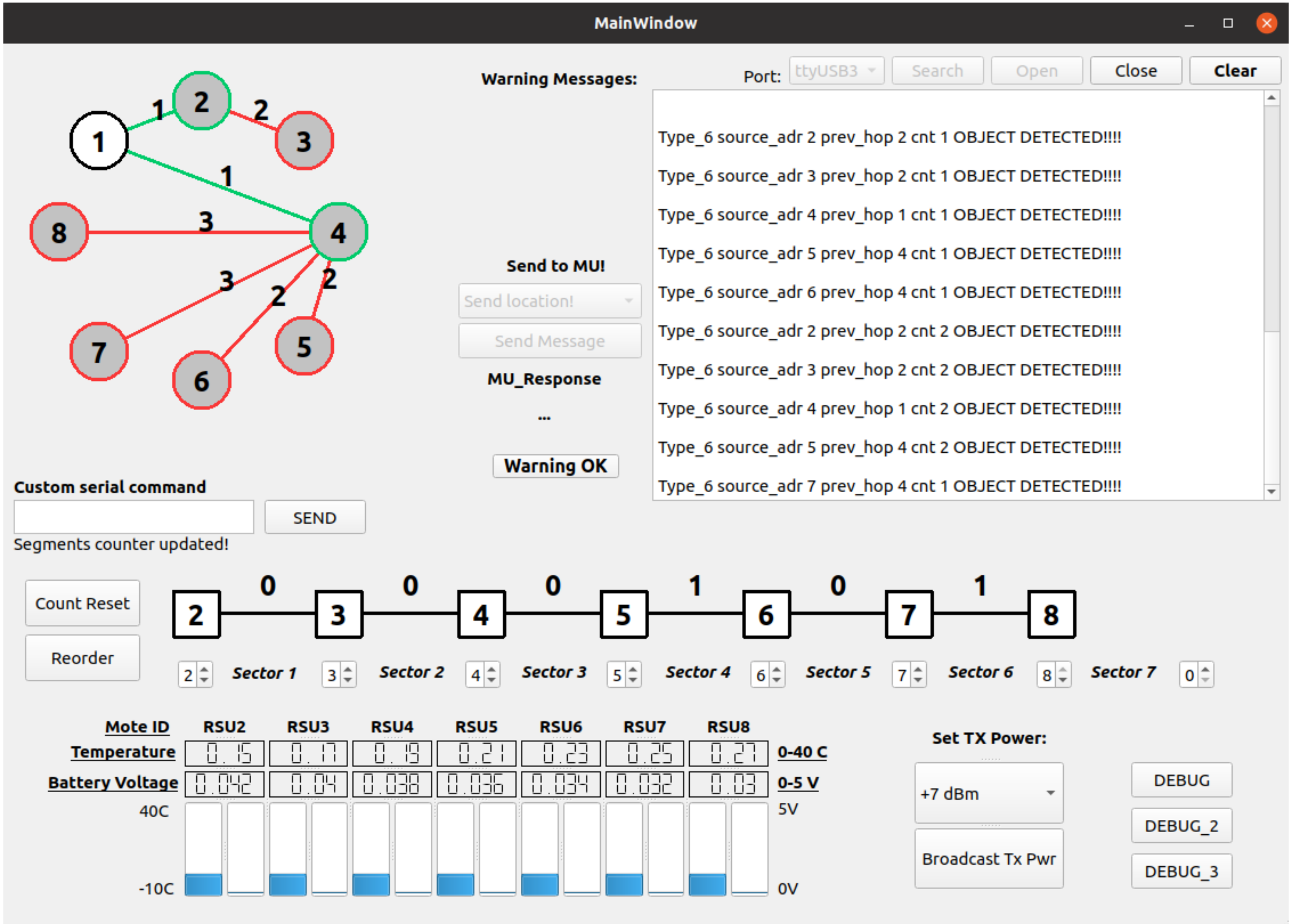

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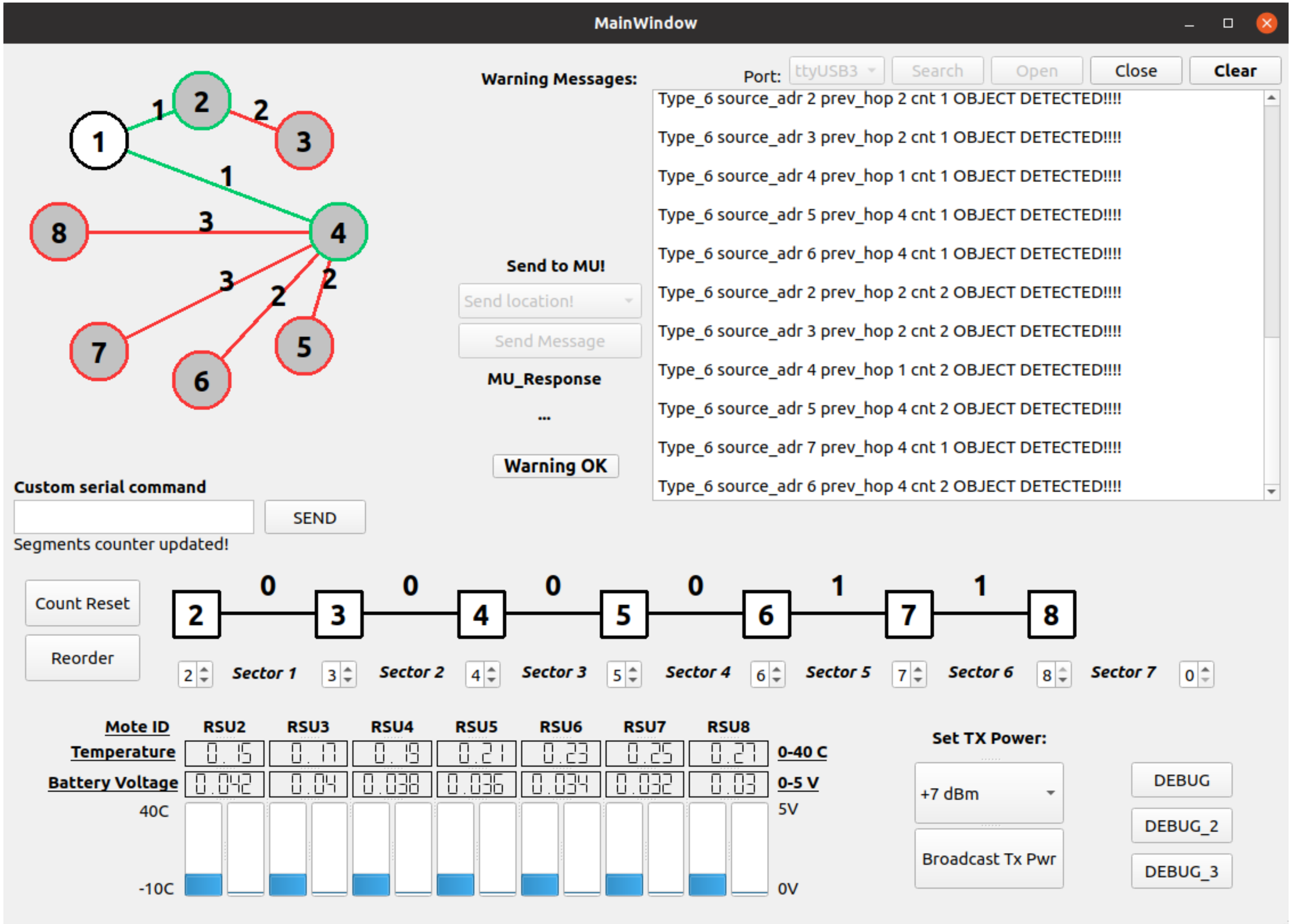

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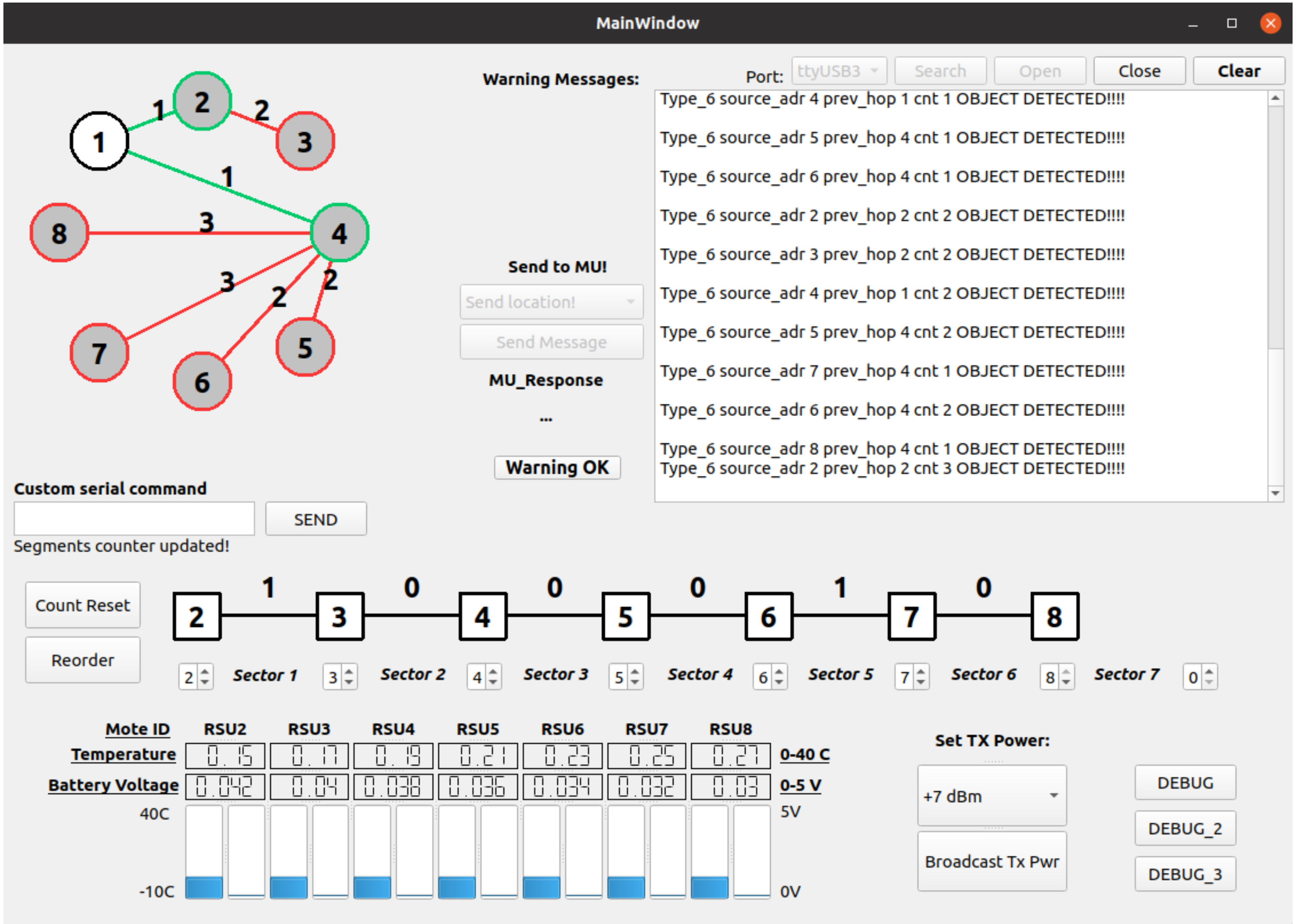

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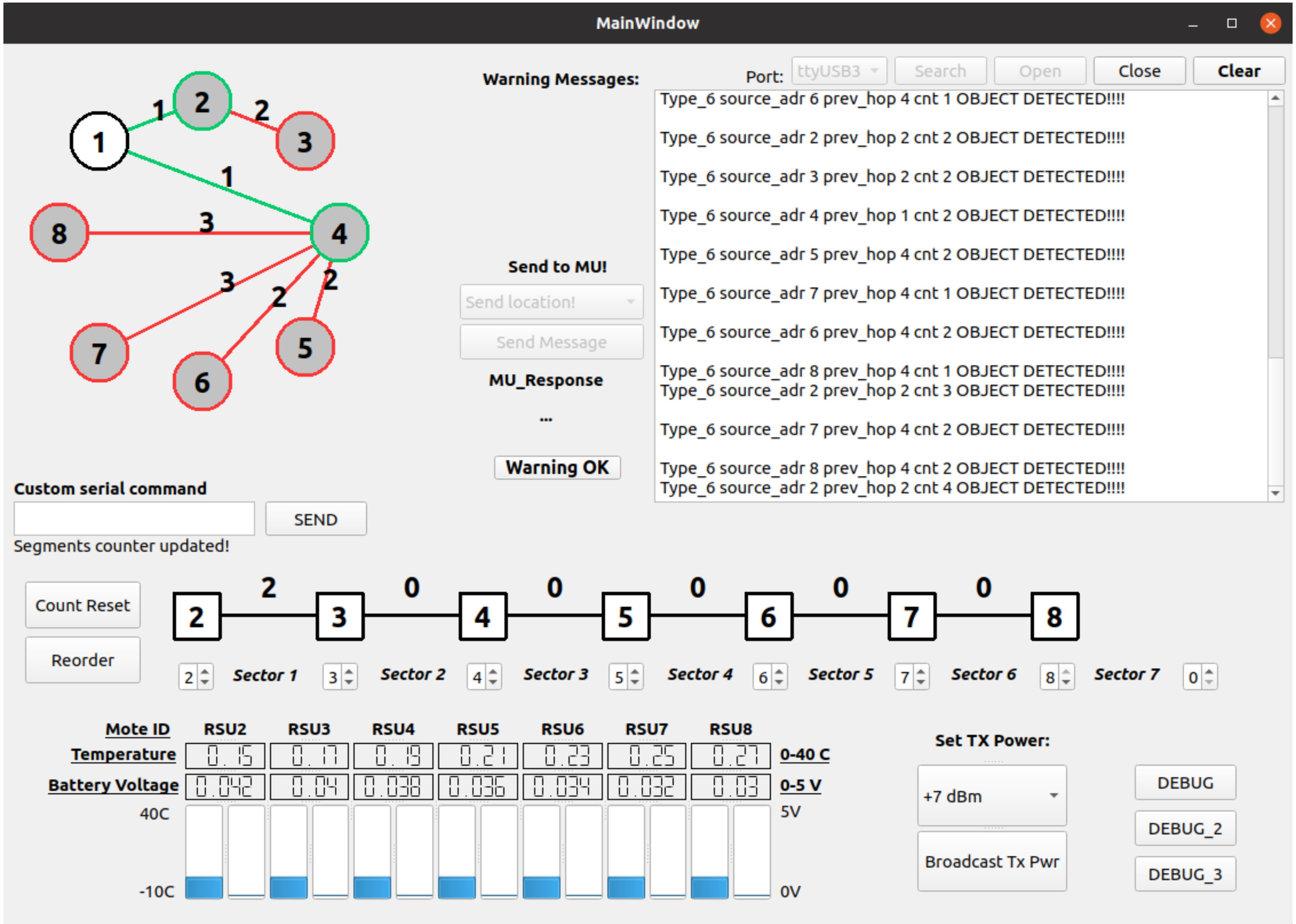

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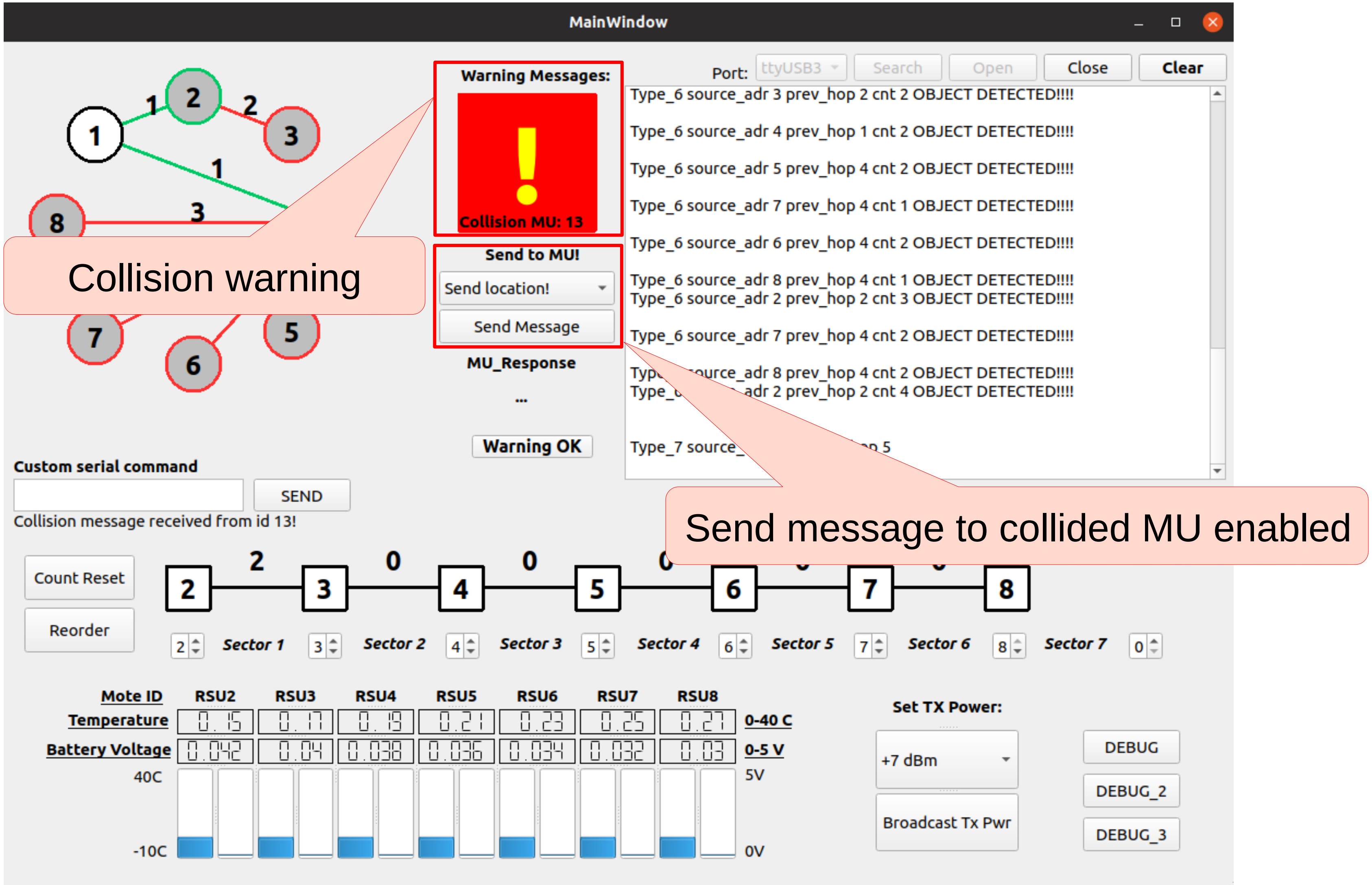

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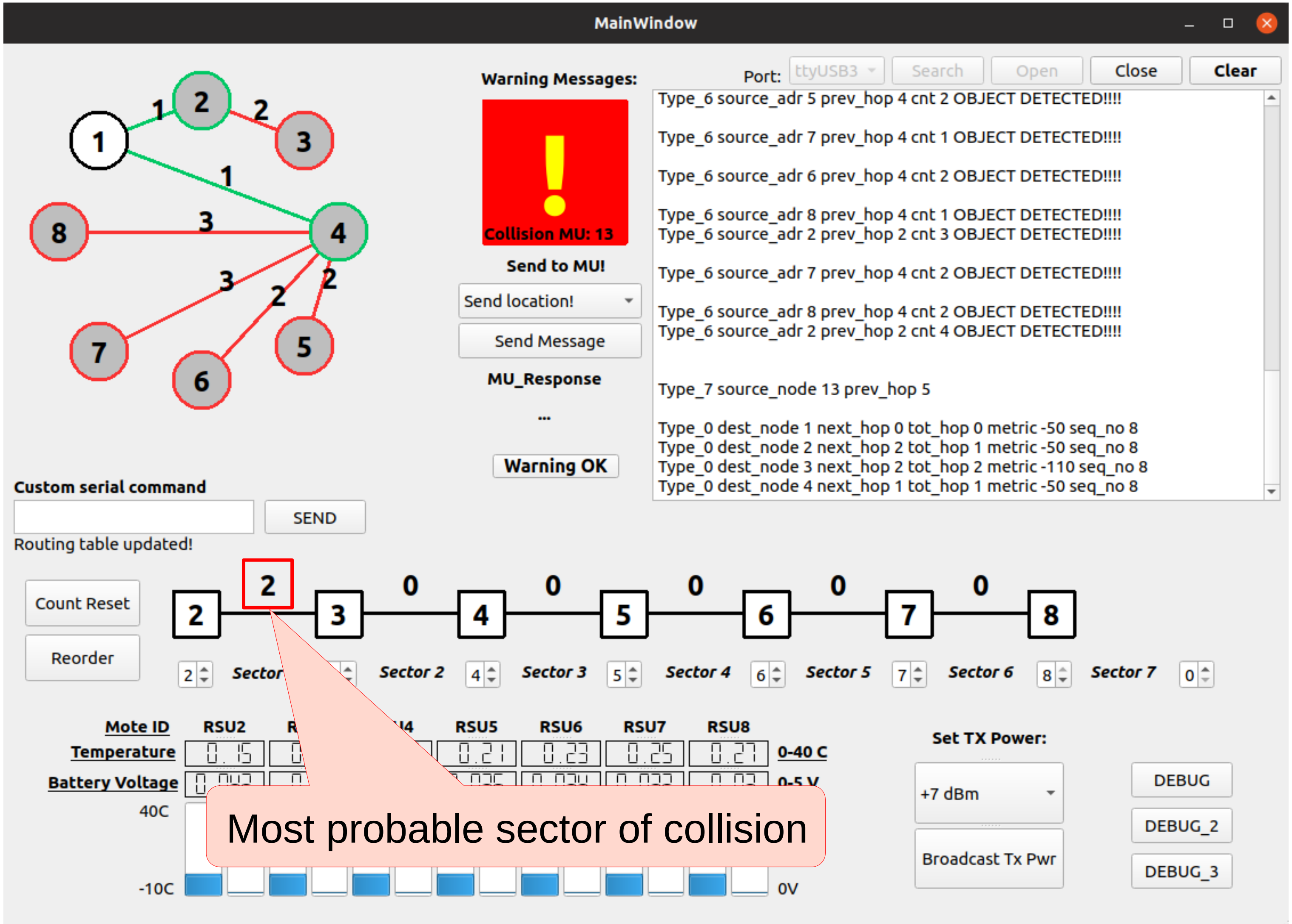
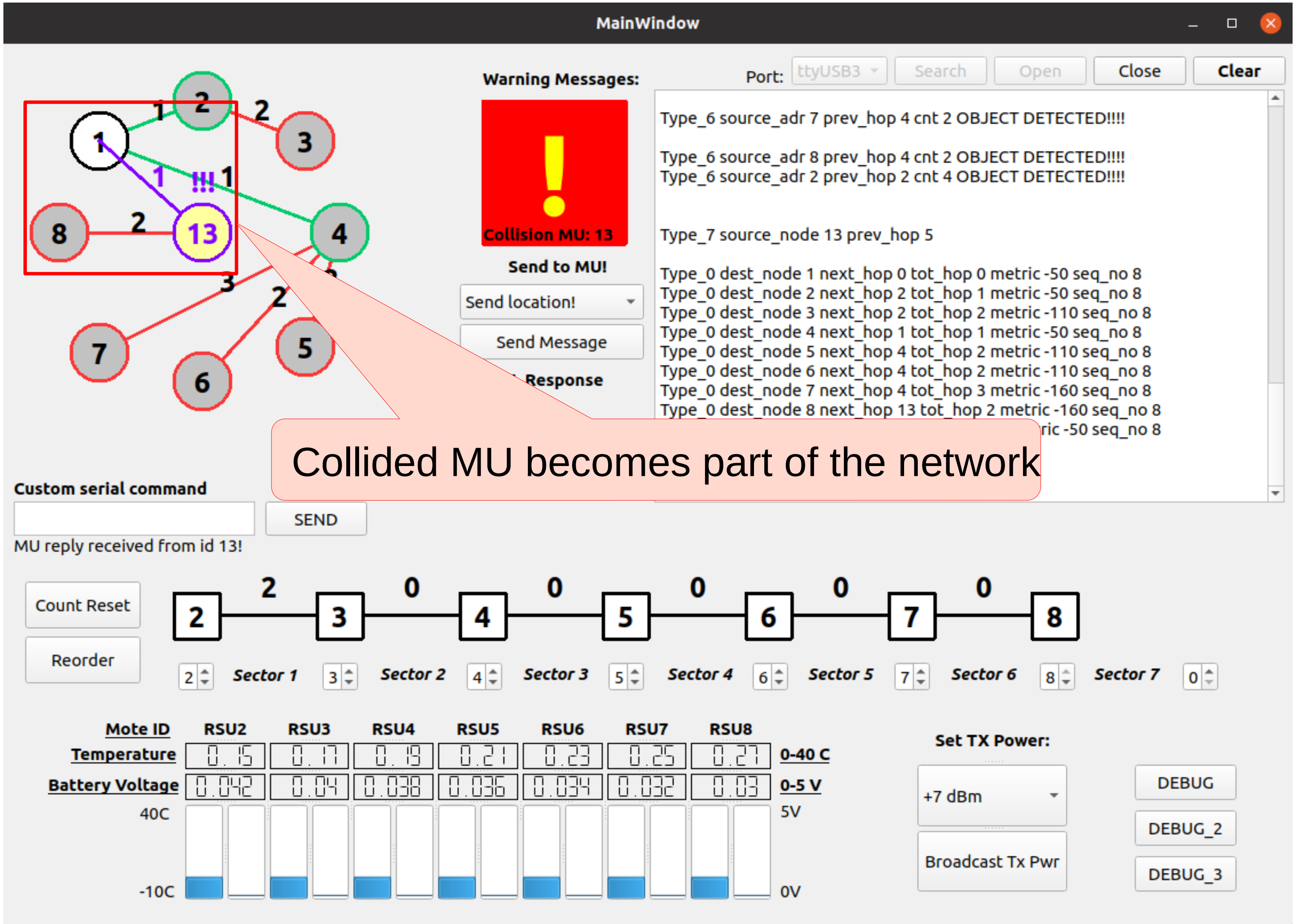
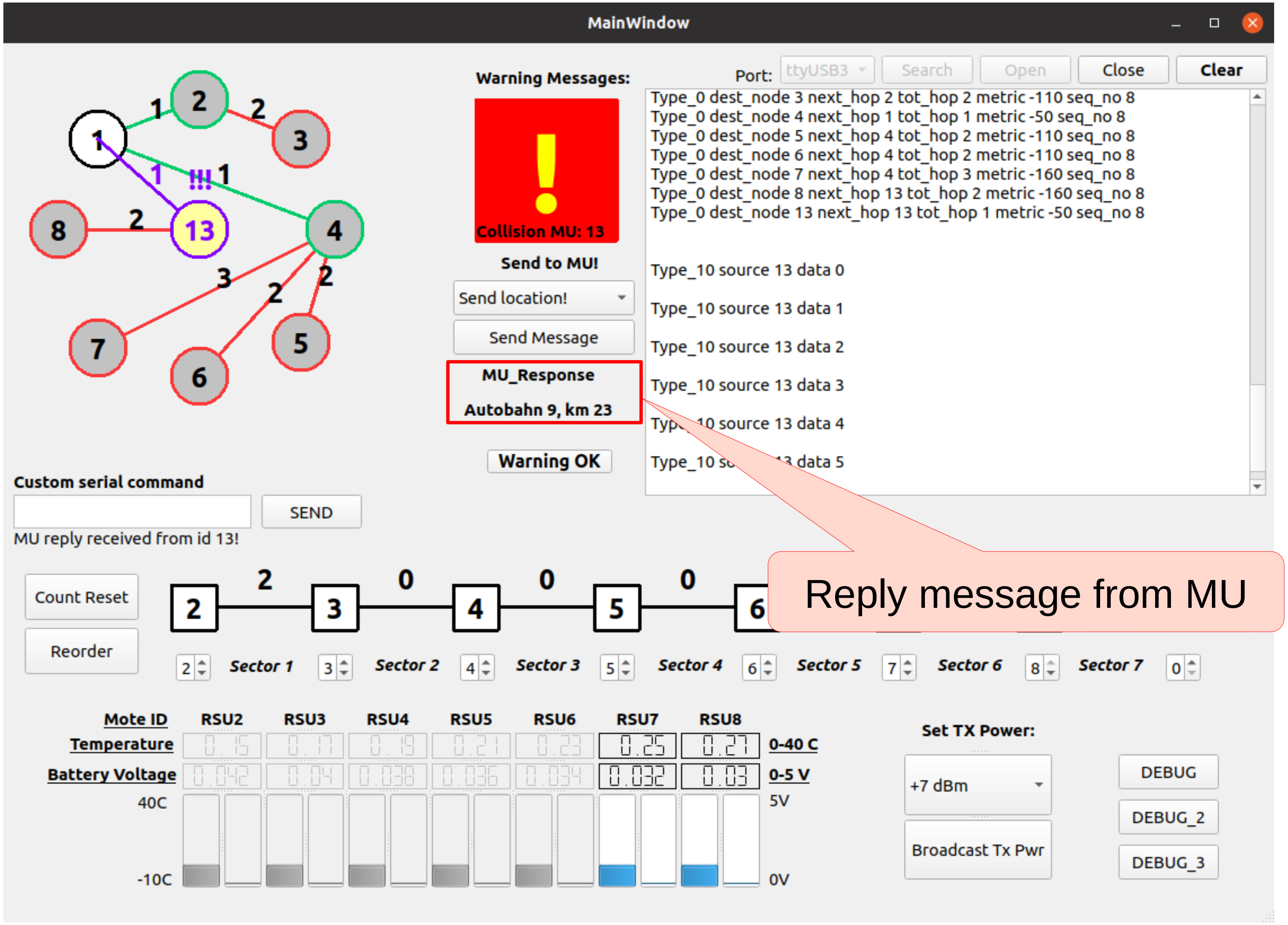


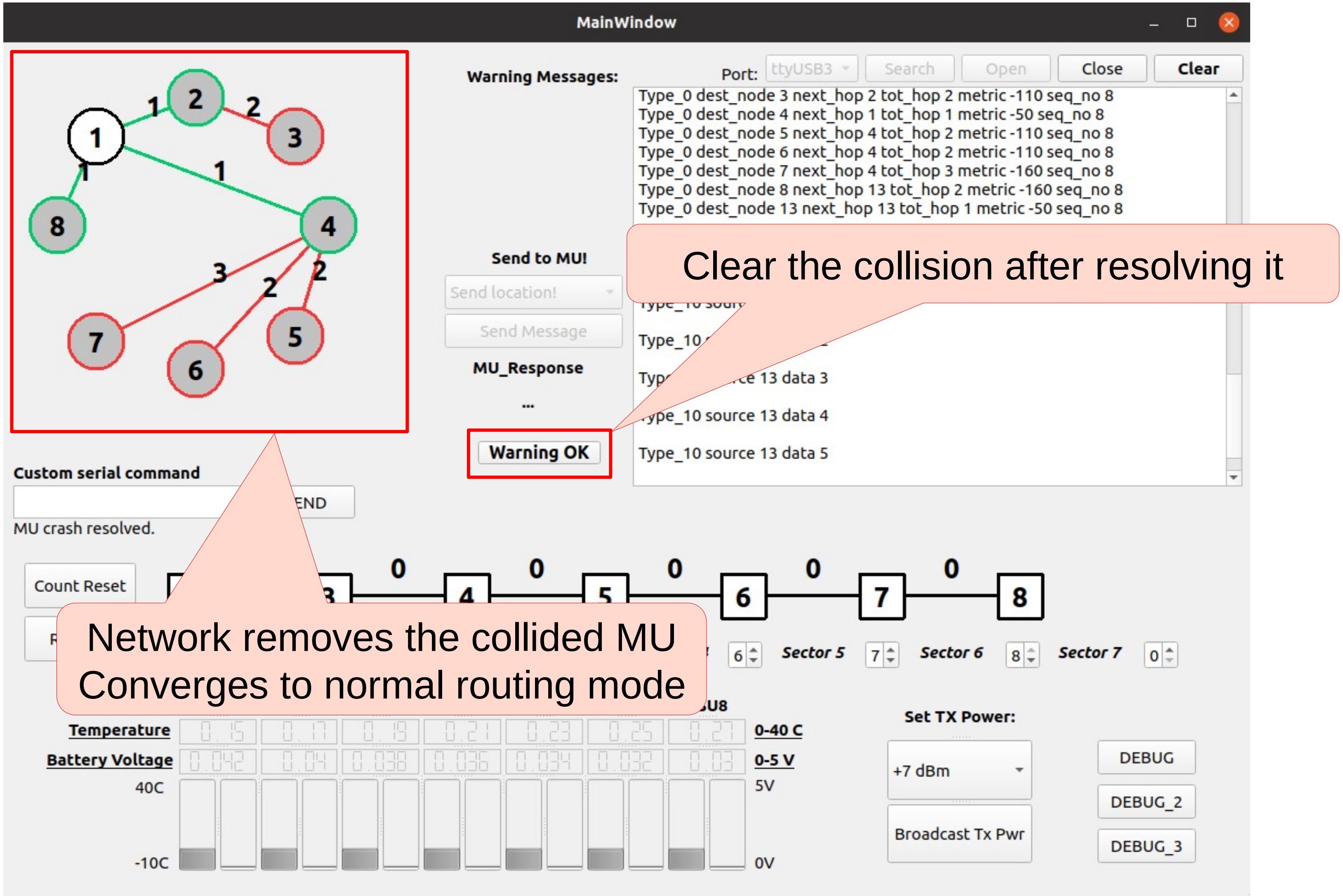
Graphical User Interface



Graphical User Interface



Graphical User Interface



Conclusion

- DSDV routing algorithm was implemented in the transportation system by using wireless sensor networks.
- Routing algorithm provides high reliability, low latency, failure recovery and emergency channel capabilities.
- Emergency condition cases, e.g. car accidents are considered:
  - to warn other entities in the vicinity.
  - to communicate with the collided vehicle
- RSUs provide an intuition to estimate traffic congestion on the road.
- Road conditions e.g. temperature, can be monitored using data-logger.

Demo ...

Questions?

References

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