NetSim UWAN Library
Depth Based Routing (DBR)

Reference: DBR: Depth-Based Routing for Underwater Sensor Networks, *Hai Yan, Zhijie Jerry Shi, and Jun-Hong Cuia*, NETWORKING 2008, LNCS

Applicable Release: NetSim v14.0.34 or higher
Applicable Version(s): NetSim Standard and NetSim Pro
Project download link: https://github.com/NetSim-TETCOS/DBR_IN_UWAN_v14/archive/refs/heads/main.zip
The URL has the configuration files (scenario, settings, and other related files) of the examples discussed in this analysis for users to import and run in NetSim

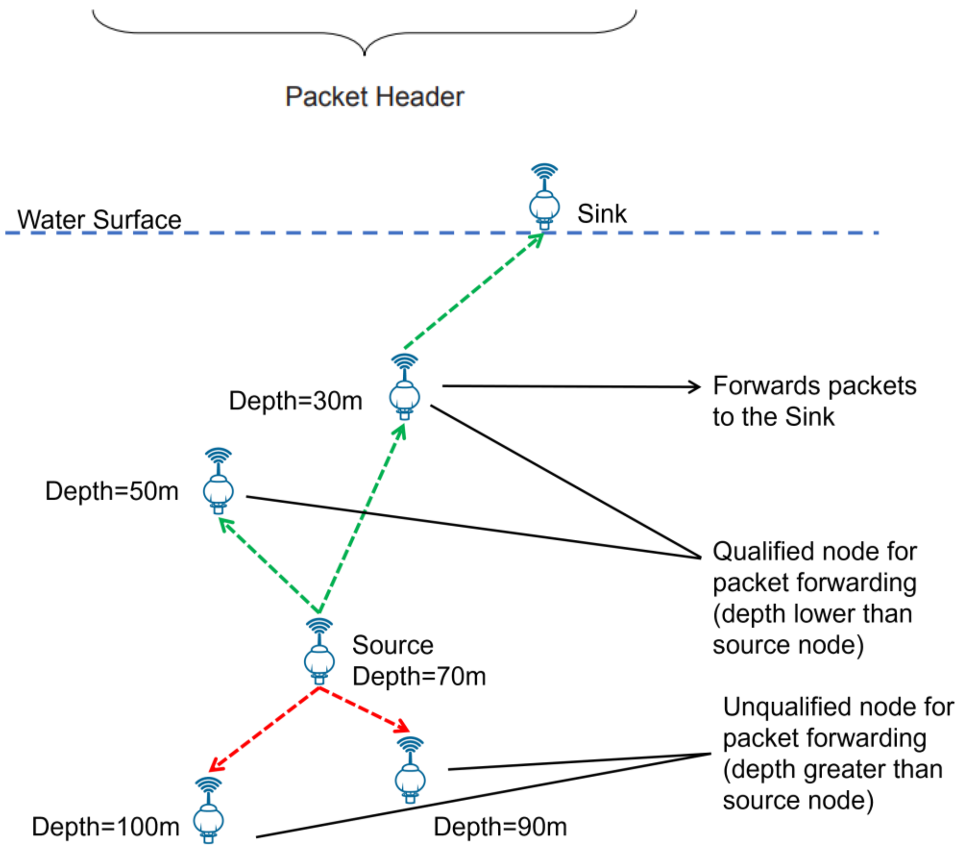
How to set up the DBR project in NetSim?

- Download the project from Github link provided in slide 1.
- Follow the instructions provided in the following link to setup the project in NetSim
  - https://support.tetcos.com/support/solutions/articles/14000128666-downloading-and-setting-up-netsim-file-exchange-projects
- Go to <NetSim_Install_Directory>\Docs\UI_xml\Validators path and rename the already existing Logs.xml file to Logs_original.xml as a backup.
  - Copy and paste the Logs.xml file from the downloaded project folder in the <NetSim_Install_Directory>\Docs\UI_xml\Validators path.
  - The modified xml file adds DBR Log to the GUI logs option.
- Go to <NetSim_Install_Directory>\Docs\UI_xml\Calculator path and rename the already existing selectAll.xlsx file to selectAll_original.xlsx as a backup.
  - Copy and paste the selectAll.xlsx file from the downloaded project folder in the <NetSim_Install_Directory>\Docs\UI_xml\Calculator path.
- Go to <NetSim_Install_Directory>\Docs\UI_xml\Device_Properties path and rename the already existing Underwater_device.xml file to Underwater_device_original.xml as a backup.
  - Copy and paste the Underwater_device.xml file from the downloaded project folder in the <NetSim_Install_Directory>\Docs\UI_xml\Device_Properties.
  - The modified xml file adds Dynamic Source Routing (DSR) protocol to Network layer of UWAN devices.
  - The code modifications are done to DSR project to implement Depth Based Routing (DBR) protocol.

DBR: Introduction

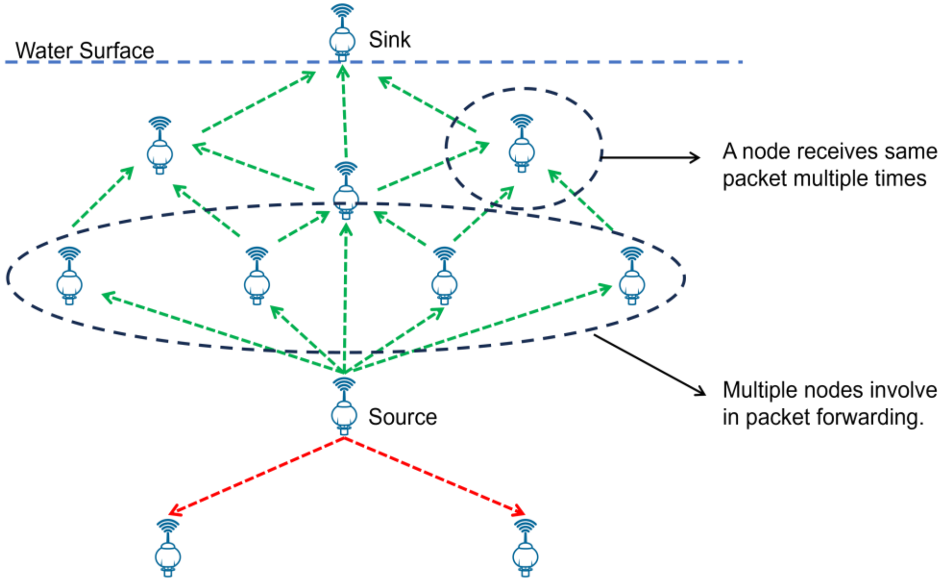
- Depth based routing (DBR) is an ad hoc routing protocol for under water acoustic networks
- Key concept: when a node receives a packet, it forwards it only if its own depth is lower than the depth recorded in the packet. Otherwise, it drops the packet.
- When node receives a packet, it compares the depth of the previous hop (d_p), against its own depth (d_c).
  - If the receiving node is closer to the water surface ($d_c < d_p$), it considers itself eligible to forward the packet.
  - If the receiving node is farther from the surface ($d_c > d_p$) it drops the packet because the packet comes from a node that is already closer to the surface.
- DBR packet header has three fields: Sender ID, Packet Sequence Number, and Depth

Sender ID	Packet Sequence Number	Depth	Data



DBR: Packet forwarding

- When a node forwards a packet
  - There may be several nearby nodes that can also forward it. If all these nodes simultaneously broadcast the packet, it can cause collisions. This also leads to more energy consumption.
  - Since packets are broadcast, a node may receive the same packet multiple times.
- To avoid this
  - The number of forwarding nodes need to be controlled.
  - A node receiving redundant packets should be suppressed.
- Solution:
  - Priority Queue Q1 is used for controlling number of forwarding nodes.
  - Packet History Buffer Q2 ensures a node receives same packet only once.
- Priority Queue (Q1):
  - Q1 contains two items: Packet and scheduled Sending Time for the packet.
- Packet History Buffer (Q2):
  - Q2 contains two items: Packet Sequence Number and Sender ID (source ID)



DBR: Holding Time

- When a node receives a packet, it does the following:
  - It doesn't send it immediately. Instead, it holds the packet for a specific period known as the holding time.
  - The scheduled sending time of the packet is determined by the time packet is received and the holding time.
  - If the packet is new (not sent by the node before i.e., not in Q2) and comes from a node with a larger depth, it is added to Q1.
  - If a packet already in Q1 is received again during the holding time, it is removed from Q1 if the new copy comes from a lower or similar depth node ($d_p \leq d_c$), or its scheduled sending time is updated if the new copy comes from a higher depth node ($d_p > d_c$).
  - After a node sends out a packet as scheduled, it is removed from Q1, and its unique ID is added to Q2.
- Holding Time Computation

$$f(d) = \frac{2\tau}{\delta} \cdot (R - d)$$

where, R → is the maximal transmission range of a sensor node.

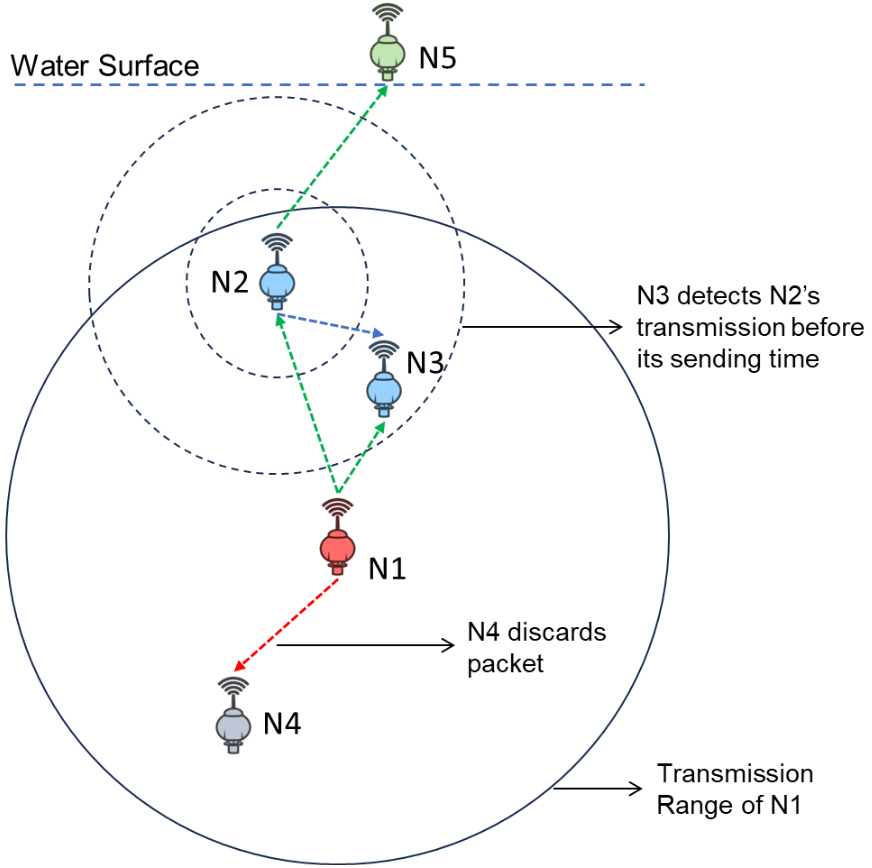
δ → is a value between 0 and R,

$\tau = \frac{R}{V_0}$ → is the maximal propagation delay of one hop (V_0 is the sound propagation speed in water)

d → is the depth difference of the current node and the previous hop.

DBR: Depth Threshold

- Consider the scenario shown in the fig. Node N1 broadcasts and the packet reaches N2, N3, and N4.
  - N4 discards packet.
  - N2 broadcasts the packet which reaches N5 and N3,
  - N3 is prevented from re-sending because N2's packet reaches before N3's sending time
- The holding time satisfies two conditions:
  - As depth difference (d) increases holding time increases.
  - The holding time gap between neighboring nodes must be sufficiently long for the lower-depth node to hear the higher-depth node's forwarding promptly.
- Depth Threshold (d_{th})
  - A global parameter, Depth Threshold d_{th}, regulates packet forwarding.
  - A node forwards a packet only if the difference between the packet's previous hop depth (d_p) and its own depth (d_c) exceeds d_{th}.
  - When d_{th} is set to zero, nodes with smaller depths are eligible forwarders.
  - When d_{th} is set to -R DBR protocol act as a flooding protocol, with R representing the maximum transmission range of a sensor node.



DBR: Algorithm

Algorithm 1 Algorithm for packet forwarding in DBR

```
ForwardPacket(p)
Get previous depth d_p from p
Get node's current depth d_c
Compute Δd = (d_p − d_c)
IF Δd < Depth Threshold d_th THEN
    IF p is in Q1 THEN
        Remove p from Q1
    ENDIF
    Drop p
    return
ENDIF
IF p is in Q2 THEN
    Drop p
    return
ENDIF
Update p with current depth d_c
Compute holding time HT
Compute sending time ST
IF p is in Q1 THEN
    Get previous sending time of p ST_p
    Update p's sending time with min(ST, ST_p)
ELSE
    Add the item <p, ST> into Q1
ENDIF
```

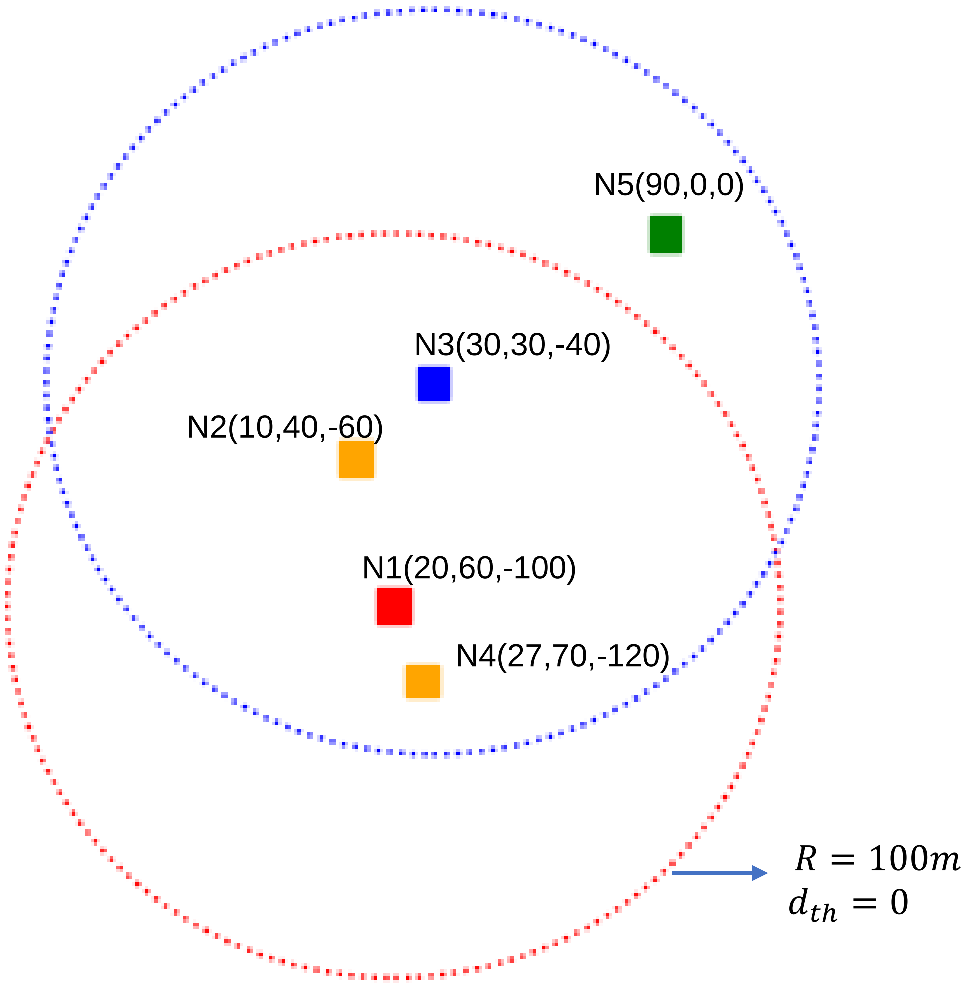
- When a node receives a packet, it first checks if it's eligible to forward it based on depth information and a depth threshold, d_{th}.
- If the node is not eligible, it looks for the packet in Q1 and removes it if another node has already forwarded it.
- If the node is eligible but the packet is in Q2, it discards the packet since it was recently forwarded.
- Otherwise, the node calculates when to send the packet using the current system time and a holding time and adds the packet to a priority queue called Q1.
- If the packet is already in Q1, its sending time is updated.
- Later, the packets in Q1 will be sent out based on their scheduled sending times.

Ignore this warning

```
Select C:\Users\PETER\Documents\NetSim\Workspaces\DBR_IN_UWAN_v14\bin_x64\NetSimCore.exe
Error: App metrics is NULL in destination side. Unicast case

*****


******
In 234 line of D:\Code\13.3\Simulation\ApplicationLib\App_Metrics.c file following error occurs
Error: App metrics is NULL in destination side. Unicast case

*****


******
In 234 line of D:\Code\13.3\Simulation\ApplicationLib\App_Metrics.c file following error occurs
Error: App metrics is NULL in destination side. Unicast case

*****


******
In 234 line of D:\Code\13.3\Simulation\ApplicationLib\App_Metrics.c file following error occurs
Error: App metrics is NULL in destination side. Unicast case

*****
100 % is completed... Simulation Time = 100000.000 ms  Event Id=0
Total time taken (wall clock) = 15 ms
Total events processed = 6590
Average events per sec (wall clock) = 439333.33
Simulation complete
***
```

- Users will notice the following warning when running simulation
- This is shown because of the DBR code modifications carried out.
- These warnings can be ignored.

DBR: An Example

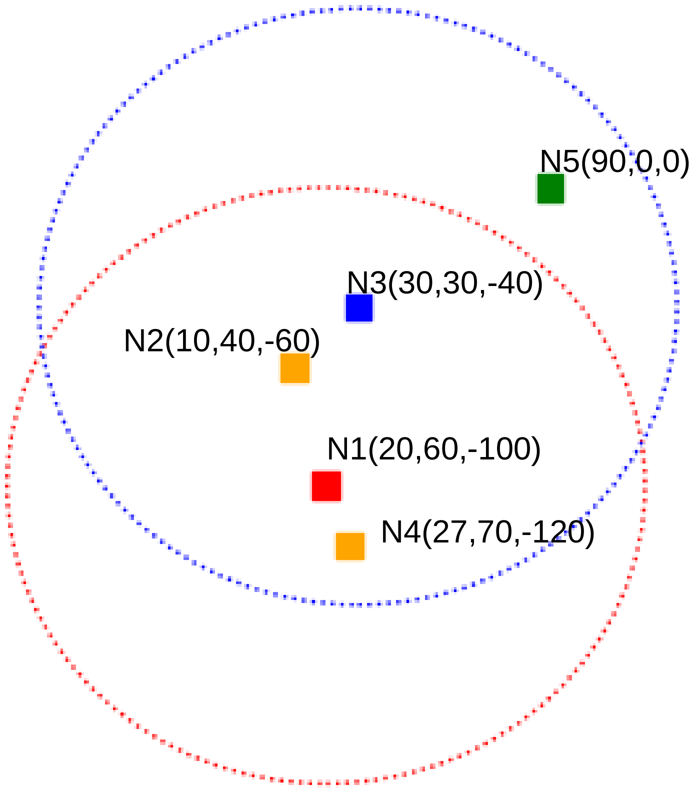


- N1 is the source node and N5 is the destination node.
- Both nodes N2 and N3 will receive the packet from N1. They are qualified nodes for forwarding packet since they are "above" N1, i.e., $d_p - d_c > d_{th}$ with d_{th} set to 0.
- Compute holding time, H_t for node N2: $d_p = 100m, d_c = 60m$
  - $\tau = \frac{R}{V_s}$ where the range, R has been set to $100m$ for our example.
  - V_s the speed of sound in water is assumed to $1500m/s$.
  - δ *is set as* $\frac{R}{10}$, which is $= \frac{100}{10} = 10m$
  - $H_t\ (s) = \frac{2\tau}{\delta} \times (R - d)$ where $\tau = \frac{R}{V_s} = \frac{100}{1500}$
  - $H_t(s) = \frac{2\times100}{1500\times10} \times (100 - 40)$ where d is depth difference. $d = d_p - d_c = 100 - 60 = 40m$
  - Hence $H_t = \frac{2\times100}{1500\times10} \times (60) = 0.8\text{s} = 800\text{ms}$
- Computing sending time for node N2:
  - Assuming current time =0
  - $sending\ time = current\ time + holding\ time = 800\ ms$
  - Add packet to Q1 which consists of packet and sending time.

DBR: An Example (contd.)

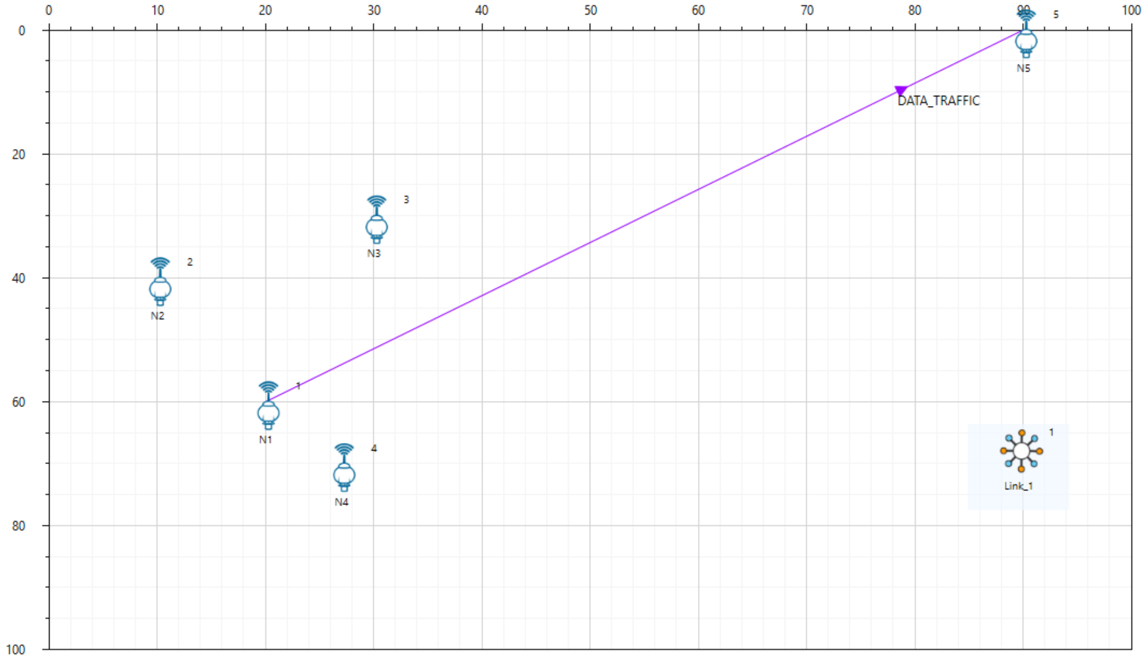
- Compute holding time for node N3: $d_p = 100m, d_c = 40m$
  - $\tau = \frac{R}{V_s}$ where the range, R has been set to $100m$ for our example. V_s the speed of sound in water is assumed to $1500m/s.$
  - δ is set as $\frac{R}{10}$, which is $= \frac{100}{10} = 10m$
  - $H_t(s) = \frac{2\tau}{\delta} \times (R - d)$ where $\tau = \frac{R}{V_s} = \frac{100}{1500}$
  - $H_t(s) = \frac{2 \times 100}{1500 \times 10} \times (100 - 60)$ where d is depth difference. $d = d_p - d_c = 100 - 40 = 60m$
  - Hence $H_t = \frac{2 \times 100}{1500 \times 10}(40) = 0.5333s = 533.3\ ms$
- Computing sending time for node N3:
  - Assuming current time =0
  - $sending\ time = current\ time + holding\ time = 533.3\ ms$
  - Add packet to Q1 which consists of packet and sending time.
- Now N3 forwards the packet first as per earlier sending time. dp is updated to current node depth that is dc= $d_p = 40m$. It inserts the packet history i.e) unique id to Q2.
- When N2 receives the same packet from N3 since they are in range. N2 is not a qualified node hence it checks the packet is in Q1 and removes packet present in Q1 and drops the incoming packet. N5 receives packet from N3.

Case 1: Single Hop Transmission



Scenario of interest

N1 is the source node, N5 is the destination Node. N2 and N3 are qualified node for forwarding packets. N4 has a higher depth than source node hence it is unqualified node. N3 forwards the packet to destination node N5 since it has lower depth.



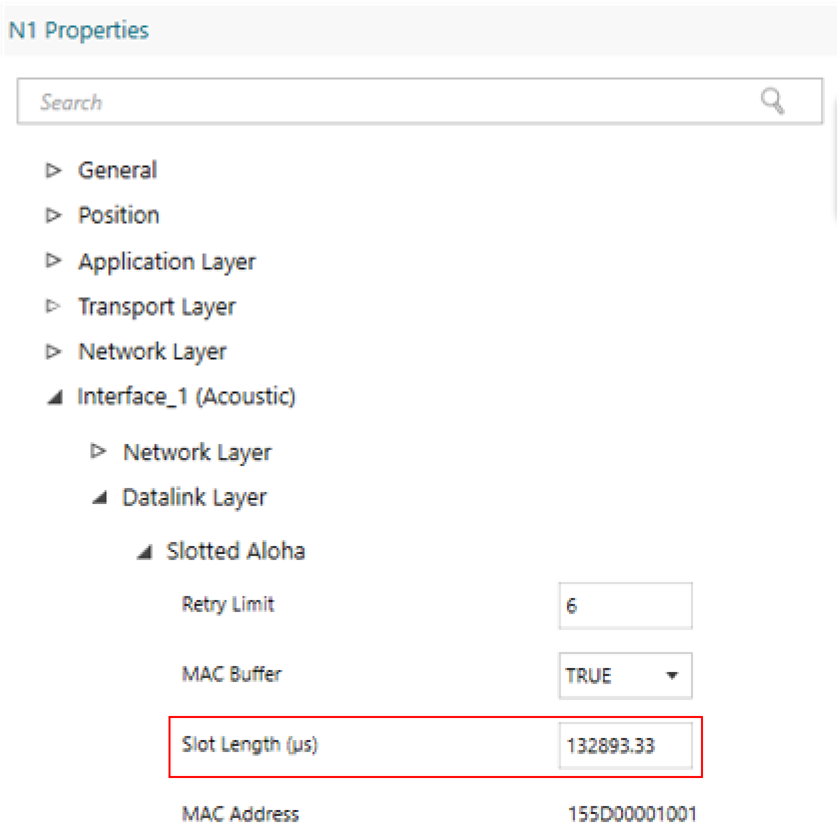
Scenario created in NetSim

Simulation Parameters in NetSim

Application Properties	
Packet Size (Bytes)	50
Inter Arrival Time (µs)	1000000 µs
Generation Rate	1 packet / sec
Simulation Time (s)	100
Adhoc Link Properties	
Number of temperature zones	1
Zone (max) depth (m)	120
Channel Characteristics	PATHLOSS_ONLY
Path Loss Model	RANGE_BASED
Range (m)	100

- These are a set of common simulation parameters used in all cases.
- All other properties are either
  - Kept at default, or
  - Varied in each case. The modifications are explained in the respective simulation example.

Slot length computation



- Slot length (L_{slot}) is estimated as transmission time plus propagation delay of largest Tx-Rx pairs.
- Transmission time (µs) $\mathrm{T_{tx}} = \frac{(App.pkt\ size+overhead)\times 8}{phy\ rate}$
- Propagation delay (µs) $\Delta = \frac{distance}{speed}$
- $L_{slot} = \mathrm{T_{tx}} + \Delta$
- For case 1,
  - Transmission time (µs) $\mathrm{T_{tx}} = \frac{(50+8+20)\times 8}{0.02} = 31200\ \mu s$
  - Largest Tx-Rx pair is N4-N5.
  - Propagation delay (µs) $\Delta = \frac{152.54}{1500} = 101693.33\mu s$
  - $L_{slot} = 31200 + 101693.33 = 132893.33\mu s$

DBR Metrics Table in NetSim

DBR_Metrics_Table

DBR_Metrics

Device Name	Packets Originated	Packets Txed/Fwded	Packets Received	Un Qual Pkt. Drop	Q1 Pkt. Drop
N1	100	100	145	145	0
N2	0	65	167	82	19
N3	0	97	152	54	0
N4	0	0	206	206	0
N5	0	0	97	0	0

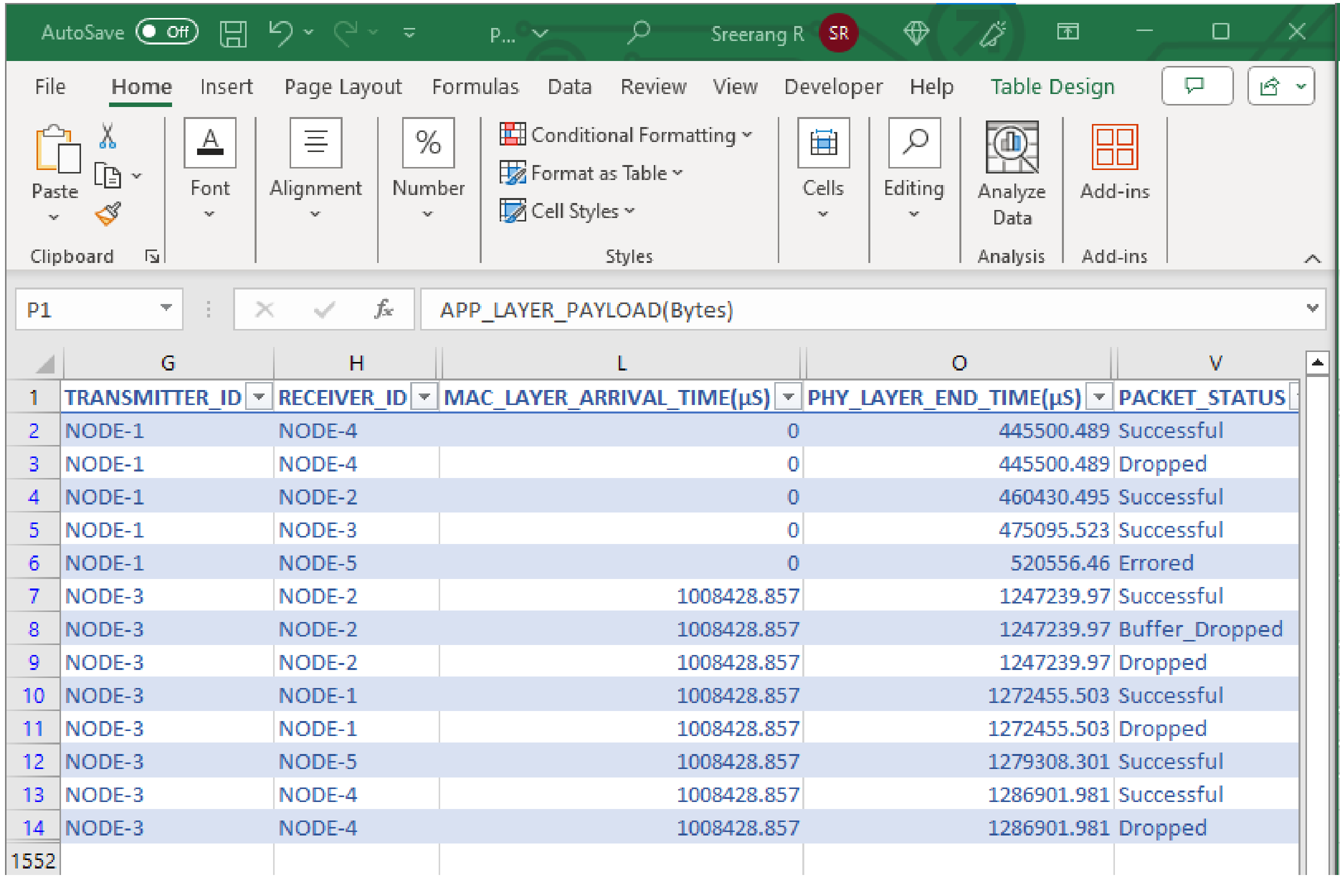
- Source node N1 generates 100 packets which are transmitted to N2, N3 and N4.
- N2 receives 167 packets from neighboring nodes and forwards 65 packets. 82 packets are dropped which are consider as unqualified packet dropped and 19 packets are dropped from q1.
- N3 forwards 97 packets which has the lowest depth to destination. It receives 152 packets and drops 54 packets which are consider as unqualified packet drop.
- N4 receives 206 packets and drops the packets since its unqualified node in packet transmission.
- N5 is the destination node and receives 97 packets from N3.

DBR log file in NetSim

	Time(µs)	Application ID	Packet ID	Tx ID	Rx ID	Tx Depth=dp (m)	Rx Depth=dc (m)	SendTime(µs)	Remarks
2	0	1	1	1	0	100	nan	nan	Broadcasts packet from Source (Tx Id). Depth of Tx Id is dp.
3	445500.489	1	1	1	4	100	120	nan	Rx Id is an unqualfied node since (dp-dc) <= depth threshold. Packet dropped.
4	460430.495	1	1	1	2	100	60	1260430.495	Rx Id is a qualified node since (dp-dc) > depth threshold. Packet is not present in Q2(History buffer) and Q1(Priority queue) of Rx I
5	475095.523	1	1	1	3	100	40	1008428.857	Rx Id is a qualified node since (dp-dc) > depth threshold. Packet is not present in Q2(History buffer) and Q1(Priority queue) of Rx I
7	1008428.86	1	1	3	0	40	nan	nan	Tx Id has earlier sending time in its Q1. Hence packet is forwarded from Q1. Depth embedded in packet is updated to recent forwa
8	1247239.97	1	1	3	2	40	60	nan	Rx Id is an unqualifed node since (dp-dc) <= depth threshold. Packet present in Q1 of Rx ID. Hence unqualified pkt and Q1 pkt dro
9	1272455.5	1	1	3	1	40	100	nan	Rx Id is an unqualfied node since (dp-dc) <= depth threshold. Packet dropped.
10	1279308.3	1	1	3	5	40	0	nan	Rx Id is the destination node. Packet reached destination successfully.
11	1286901.98	1	1	3	4	40	120	nan	Rx Id is an unqualfied node since (dp-dc) <= depth threshold. Packet dropped.
031									

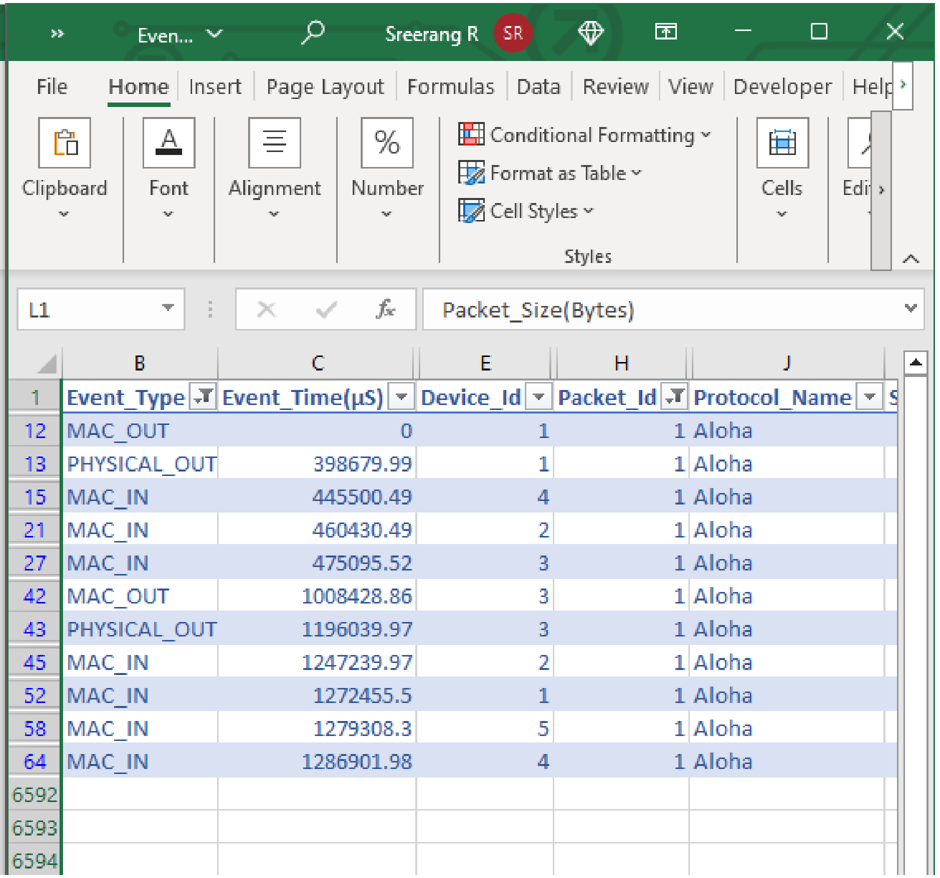
- DBR log file gives us route information in DBR protocol.
- First column indicates the time stamp which shows the time at which packet reception takes place at receiver node.
- E.g.: Node 4 received packet from Node 1 at $45500.489 \mu s$
- Second column indicates Application Id. Third column indicates Packet Id for each packet sent from source.
- Fourth column indicates Transmitter Id. Fifth column indicates Receiver Id.
- Sixth column indicates Transmitter Depth or Depth embedded in packet(d_p).
- Seventh column indicates Receiver Depth or current Node's depth (d_c).
- Eighth column indicates the sending time of the packet from Receiver Id.
- Ninth column indicates Remarks that gives information on packet route information using DBR protocol.

NetSim Results



	TRANSMITTER_ID	RECEIVER_ID	MAC_LAYER_ARRIVAL_TIME(µS)	PHY_LAYER_END_TIME(µS)	PACKET_STATUS
2	NODE-1	NODE-4	0	445500.489	Successful
3	NODE-1	NODE-4	0	445500.489	Dropped
4	NODE-1	NODE-2	0	460430.495	Successful
5	NODE-1	NODE-3	0	475095.523	Successful
6	NODE-1	NODE-5	0	520556.46	Errored
7	NODE-3	NODE-2	1008428.857	1247239.97	Successful
8	NODE-3	NODE-2	1008428.857	1247239.97	Buffer_Dropped
9	NODE-3	NODE-2	1008428.857	1247239.97	Dropped
10	NODE-3	NODE-1	1008428.857	1272455.503	Successful
11	NODE-3	NODE-1	1008428.857	1272455.503	Dropped
12	NODE-3	NODE-5	1008428.857	1279308.301	Successful
13	NODE-3	NODE-4	1008428.857	1286901.981	Successful
14	NODE-3	NODE-4	1008428.857	1286901.981	Dropped
1552					

Packet Trace



	Event_Type	Event_Time(µS)	Device_Id	Packet_Id	Protocol_Name
12	MAC_OUT	0	1	1	Aloha
13	PHYSICAL_OUT	398679.99	1	1	Aloha
15	MAC_IN	445500.49	4	1	Aloha
21	MAC_IN	460430.49	2	1	Aloha
27	MAC_IN	475095.52	3	1	Aloha
42	MAC_OUT	1008428.86	3	1	Aloha
43	PHYSICAL_OUT	1196039.97	3	1	Aloha
45	MAC_IN	1247239.97	2	1	Aloha
52	MAC_IN	1272455.5	1	1	Aloha
58	MAC_IN	1279308.3	5	1	Aloha
64	MAC_IN	1286901.98	4	1	Aloha
6592					
6593					
6594					

Event Trace

Packet trace gives us detail packet flow information. Event trace gives us information on event occurring at each layer in IP stack.

Observations

- Node 1 broadcasts the packet to Nodes 2, 3, and 4 at time 0 s + Initial backoff time. We get this from the MAC_ OUT and PHY_OUT entries in the event trace. $Initial\ backoff\ time = 398679.99\mu s$ (see in PHY_OUT from event trace)
- Packet is received (see PHY_IN in event trace) at 2, 3, and 4 at a time that equals transmission time + propagation delay + initial backoff time.
  - Transmission time (µs) $= \frac{(App.pkt\ size + overhead) \times 8}{phy\ rate}$. Packet size and phy rate can be set in GUI.
  - Propagation delay (µs) $\Delta = \frac{distance}{speed}$. In this project we assume the speed of sound in water is fixed at 1500 m/s
  - The distance is the calculated from device positions of transmitter and receiver. These parameters which can be set in GUI.
- Each of these nodes (2, 3, and 4) check if $(d_p - d_c) = d > d_{th}$[qualified node]. If yes, then compute holding time and send time. $Holding\ Time\ (s) = \frac{2\tau}{\delta} \times (R - d)\ where\ \tau = \frac{R}{V_s}$
- At Node 3. $d_p = 100m, d_c = 40m$ $(100 - 40 = 60\ > 0)$ [Qualified Node]
  - Transmission time (µs)$= \frac{(50+8+20)\times 8}{0.02} = 31200\ \mu s$
  - Propagation delay (µs)$= \frac{67.8233}{1500} = 45{,}215.53\mu s$. Total = $475095.52\mu s$
  - Node 3 receives packet from Node 1 at 475095.52 µs (see in MAC_IN in event trace)
  - $Holdingtime = 2 \times \frac{100}{1500\times 10}(100 - 60) = 533333.33\mu s$
  - $SendTime = CurrentTime + HoldTime = 475095.52 + 533333.33 = 10{,}08{,}428.86\mu s$
  - Packet is not present in Q2 of Node 3, hence add packet and sending time to Q1 of Node 3

Observations

- At Node 2. $d_p = 100m, d_c = 60m$ $(100 - 60 = 40 > 0)$ [Qualified Node]
  - $TransmissionTime\ (\mu s) = \frac{(50+8+20)\times 8}{0.02} = 31200\ \mu s$
  - $PropagationDelay\ (\mu s) = \frac{45.8257}{1500} = 30550.46\ \mu s$. Total $=460430.49 \mu s$
  - Node 2 receives packet from Node 1 at 460430.49 µs (see in MAC_IN in event trace)
  - $Holdingtime = 2 \times \frac{100}{1500\times 10}(100 - 40) = 800000 \mu s$
  - $SendTime = CurrentTime + HoldTime = 460430.49 + 800000 = 1260430.49 \mu s$
  - Packet is not present in Q2 of Node 2, hence add packet and sending time to Q1 of Node 2.
- At Node 4. $d_p = 100m, d_c = 120m$ $(100 - 120 = -20 > 0)$ [Not a Qualified Node]
  - $TransmissionTime\ (\mu s) = \frac{(50+8+20)\times 8}{0.02} = 31200\ \mu s$
  - $PropagationDelay\ (\mu s) = \frac{23.4307}{1500} = 15620.46 \mu s$. Total $= 445500.49 \mu s$
  - Node 4 receives packet from Node 1 at 445500.49 µs (see in MAC_IN in event trace)
  - Since Node 4 is not a qualified the packet is dropped.
- Node 3 has earlier sending time hence Node 3 broadcasts the packet at $10{,}08{,}428.86 \mu s$ from Q1 (can be seen in MAC_OUT in event trace.) d_p is updated to d_c, $d_p = d_c = 40m$ added to Q2
- Transmission commences for the next slot from Node 3.
  - $Slot\ time\ = 1196039.97 \mu s$ can be seen in PHY_OUT.

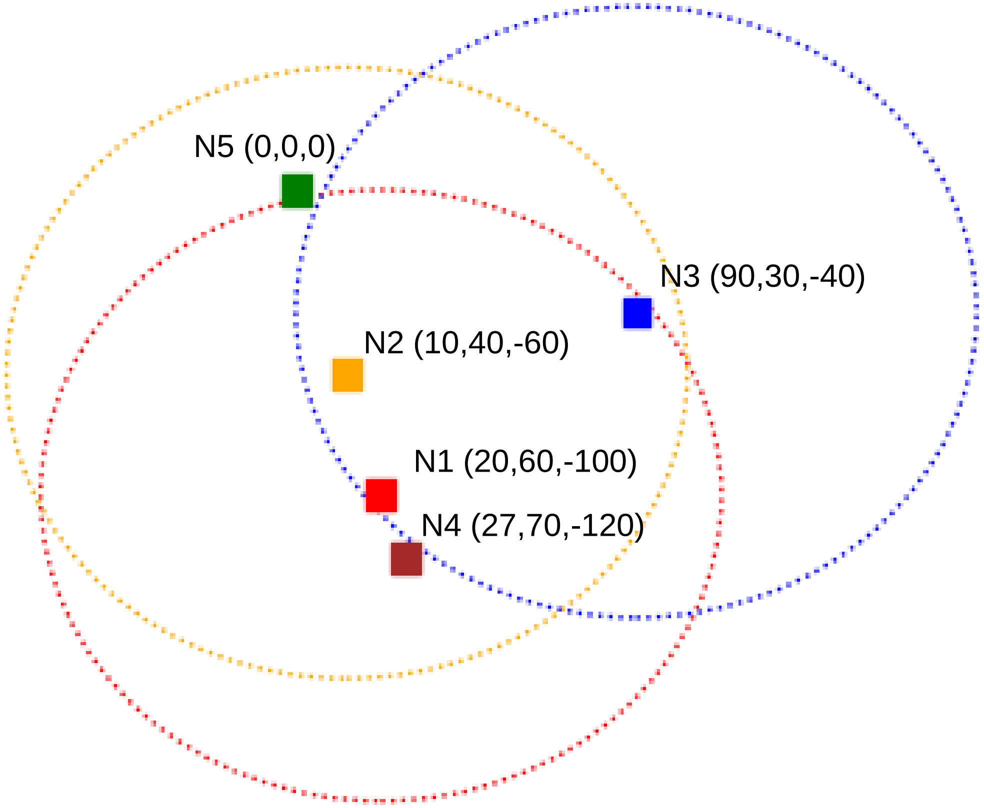
Observations

- At Node 5 is a destination node the packet is received from Node 3.
  - $Slot\ Time\ (\mu s) = 1196039.97\mu s$
  - $TransmissionTime\ (\mu s) = \frac{(50+8+20)\times 8}{0.02} = 31200\ \mu s$
  - $PropagationDelay\ (\mu s) = \frac{78.10}{1500} = 52068.33\ \mu s$. Total = $1279308.3\ \mu s$
- Node 5 receives packet from Node 3 $d_p = 40m\ d_c = 0m$ at $1279308.3\mu s$ (see in MAC_IN in event trace).[Destination]
- At Node 2, packet is received from Node 3 $d_p = 40m\ d_c = 60m$ [Not a Qualified node]
  - $Slot\ Time\ (\mu s) = 1196039.97\mu s$
  - $TransmissionTime\ (\mu s) = \frac{(50+8+20)\times 8}{0.02} = 31200\ \mu s$
  - $PropagationDelay\ (\mu s) = \frac{30}{1500} = 20000\ \mu s$. Total = $1247239.97\ \mu s$
  - Checks packet in Q1 of Node 2, present which has sending time (1260430.49µs). Removes from Q1 and drops the received packet at 1247239.97µs which can be seen as (Buffer Dropped) in packet trace.
- At Node 1, packet is received from Node 3 $d_p = 40m\ d_c = 100m$ [Not a Qualified node]
  - $Slot\ Time\ (\mu s) = 1196039.97\mu s$
  - $TransmissionTime\ (\mu s) = \frac{(50+8+20)\times 8}{0.02} = 31200\ \mu s$
  - $PropagationDelay\ (\mu s) = \frac{67.8233}{1500} = 45{,}215.53\mu s$. Total = $1272455.5\ \mu s$
  - Checks packet in Q1 of Node 1 not present. Drops the packet at $1272455.5\mu s$.

Observations

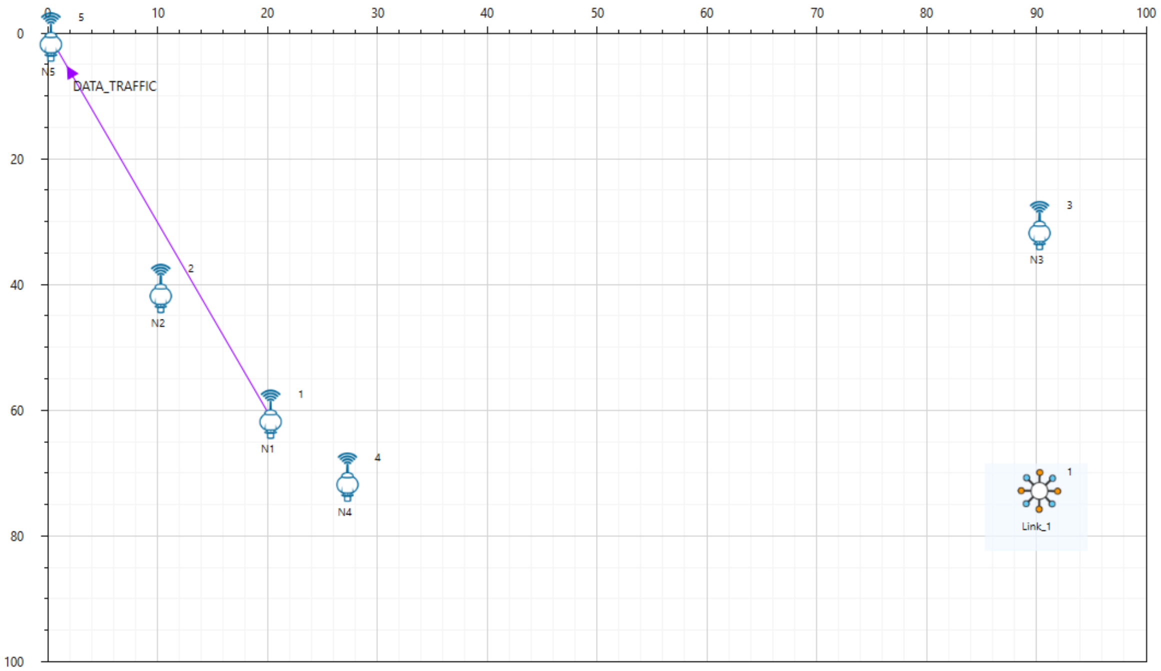
- At Node 4 packet is received from Node 3 $d_p = 40m$ $d_c = 120m$ [Not a Qualified node]
  - $Slot\ Time\ (\mu s) = 1196039.97\mu s$
  - $TransmissionTime\ (\mu s) = \frac{(50+8+20)\times 8}{0.02} = 31200\ \mu s$
  - $PropagationDelay\ (\mu s) = \frac{89.493}{1500} = 59662\ \mu s$. Total = $1286901.98\mu s$
  - Checks packet in Q1 of Node 4 not present. Drops the packet at $1286901.98\mu s$.

Case 2: Next hop is a void zone



Scenario of interest

N1 is the source node. N5 is the destination node which is not in range with forwarding node N3 but is in range with other qualified node N2. Since next hop from N3 is a void zone, packets do not reach destination from N3. N2 forwards packet as per scheduled time.



Scenario created in NetSim

- Largest Tx-Rx pair is (N4,N5)
- Slot length = 125546.66 µs

NetSim Results

DBR_Metrics_Table

DBR_Metrics

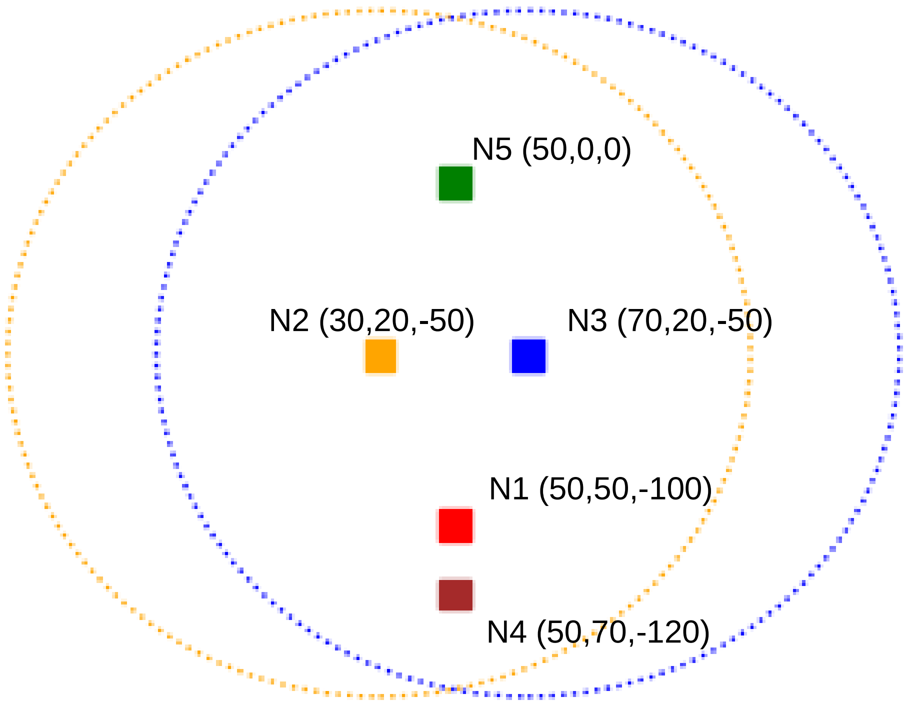
Device Name	Packets Originated	Packets Txed/Fwded	Packets Received	Un Qual Pkt. Drop	Q1 Pkt. Drop
N1	100	100	148	148	0
N2	0	75	181	89	16
N3	0	97	151	53	0
N4	0	0	151	151	0
N5	0	0	75	0	0

- N1 is the source node which generates 100 packets. It receives 148 packets from neighboring nodes and discards the packets since it is an unqualified node.
- N3 has the lower depth which is the qualified node, it receives 151 packets and forwards 97 packets. It drops 53 packets which is an unqualified node drop.
- N2 receives 181 packets, 89 packets are unqualified node drop which are received from higher depth nodes,16 packets dropped from Q1, forwards 75 packets which reaches destination node N5 which has the next lowest depth.

Observations

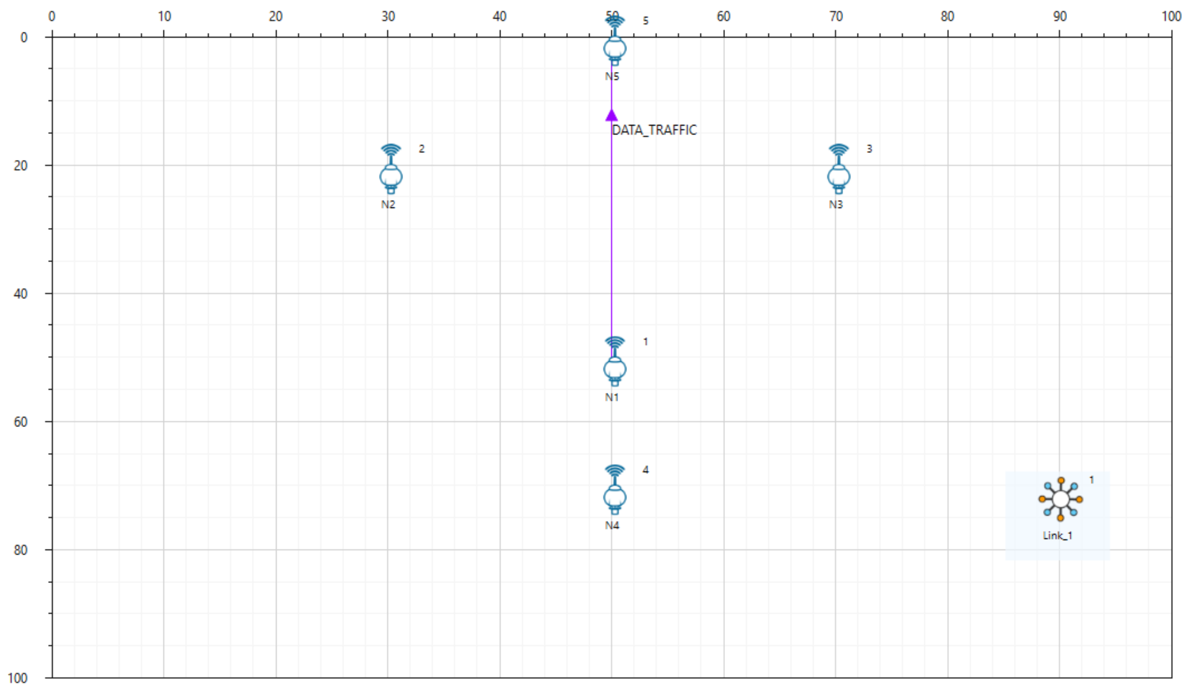
- Node N1 broadcasts the packet at $0s$ + $376639.98\mu s$ [initial backoff time]. Previous hop embedded in packet(d_p)= $100m$
  - N2 receives the packet from N1 at 438390.85 µs. [qualified node]. Sending time= 1238390.485µs. Packet is not present in Q2 of N2, hence add packet and sending time to Q1 of N2.
  - N4 receives the packet from N1 at 423460.49 µs . Packet is dropped.[not a qualified node]
  - N3 receives the packet from N1 at 472475.11 µs. [qualified node]. Sending time=1005809.045µs. Packet is not present in Q2 of N3, hence add packet and sending time to Q1 of N3.
- Node N3 broadcasts the packet at $1005809.045\mu s$ which has earlier sending time. Update $d_p = 40m$.
- Node N2 broadcasts the packet at 1238390.485µs which has the next earlier sending time. Update $d_p = 60m$.
  - N1 receives the packet from N3 at 1351302.331 µs [not a qualified node] not in Q1 of N1 drop packet.
  - N2 receives the packet from N3 at 1342044.092µs. Already forwarded packet from N2 at 1238390.485µs. Present in Q2 of N2 drop the packet.
  - N5 do not receive packet from N3 which is the least depth to destination since it’s not in range. Packet gets errored.
  - N5 receives packet from N2 at 1837387.306µs which is the next least depth to destination node.

Case 3: If nodes are in same depth and equidistant from source node



Scenario of interest

N2 and N3 are at same depth 50m from N1 source node. Both have same holding time.



Scenario created in NetSim

- Largest Tx-Rx pair is (N4,N5)
- Slot length = 123813.33 µs

NetSim Results

DBR_Metrics_Table

DBR_Metrics

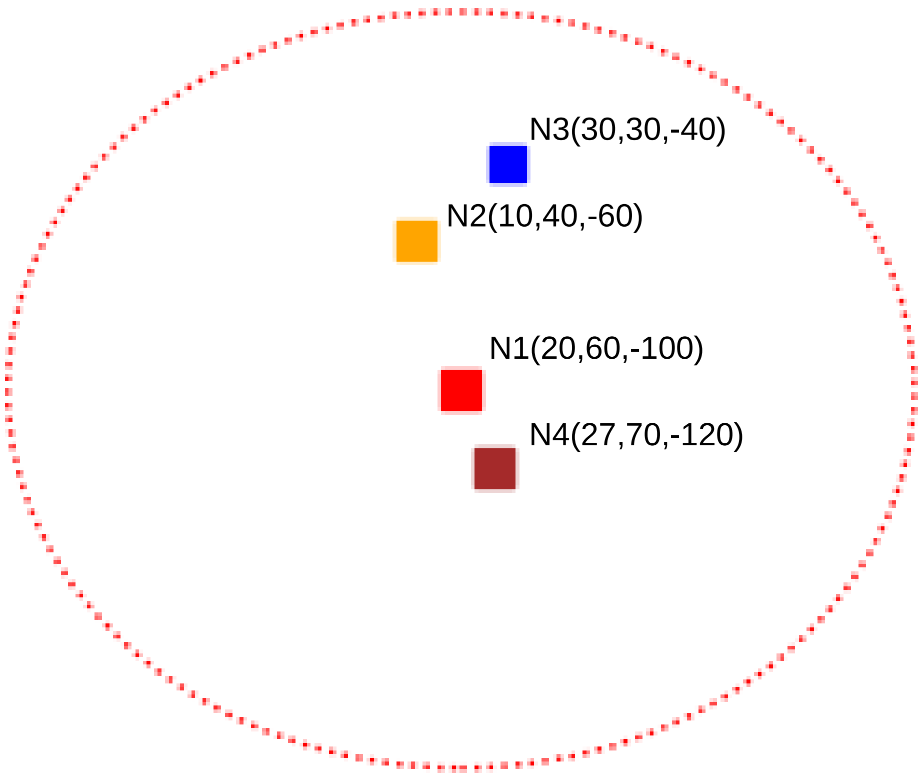
Device Name	Packets Originated	Packets Txed/Fwded	Packets Received	Un Qual Pkt. Drop	Q1 Pkt. Drop
N1	100	100	158	158	0
N2	0	86	166	79	0
N3	0	93	174	80	0
N4	0	0	223	223	0
N5	0	0	158	71	0

- N1 is the source node which generates 100 packets. It receives 158 packets from neighboring nodes and discards the packets since it is an unqualified node.
- N2 has the lowest depth which is the qualified node, it receives 166 packets and forwards 86 packets. It drops 79 packets which is an unqualified node drop.
- N3 has the same lowest depth which is the qualified node, it receives 174 packets and forwards 93 packets. It drops 80 packets which is an unqualified node drop.
- N5 is the destination node which receives 158 packets from both N2 and N3 but drops 71 packets from N5 which is a duplicate packet.

Observations

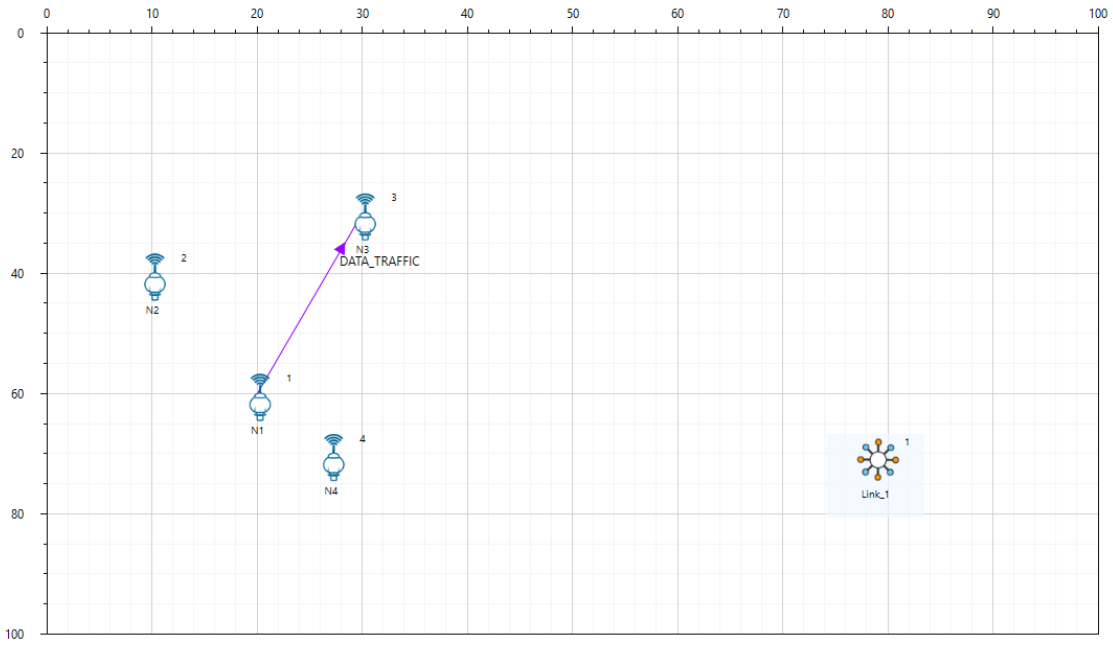
- Node N1 broadcasts the packet at $0s$ + $371439.99\mu s$ [initial backoff time]. Previous hop embedded in packet(d_p)= $100m$
  - N2 and N3 receives the packet from N1 at 443736.083µs. [qualified node]. Sending time= 1110402.75µs. Packet is not present in Q2 of N2, hence add packet and sending time to Q1 of N2.
  - N4 receives the packet from N1 at 421496.171µs . Packet is dropped.[not a qualified node]
- Both N2 & N3 broadcasts the packet at $1110402.75\mu s$ which has earlier sending time. Update $d_p = 50m$.
  - Due to earlier initial backoff time at N2, N3 receives the packet from N2 at 1342044.092µs. Already forwarded packet from N3 at 1110402.75µs. Present in Q2 of N3 drop the packet.
  - N5 receive packet from N2 which is the destination at 1307630.38µs.
  - Next N2 receives packet from N3 at 1667439.95µs. Already forwarded packet from N2 at 1110402.75µs. It is present in Q2 of N2 drop the packet.
  - N5 receives packet from N3 but packet already received. Hence duplicate packet dropped.

Case 4: If next hop is destination



Scenario of interest

N3 is the destination which is in range with source node N1 and is the next hop.
N2 is qualified node for forwarding packets.
Hence it forwards packets as per its sending time



Scenario created in NetSim

- Largest Tx-Rx pair is (N4,N3)
- Slot length = 90860 µs

NetSim Results

DBR_Metrics_Table

DBR_Metrics

Device Name	Packets Originated	Packets Txed/Fwded	Packets Received	Un Qual Pkt. Drop	Q1 Pkt. Drop
N1	100	100	99	99	0
N2	0	99	100	0	0
N3	0	0	183	85	0
N4	0	0	183	183	0

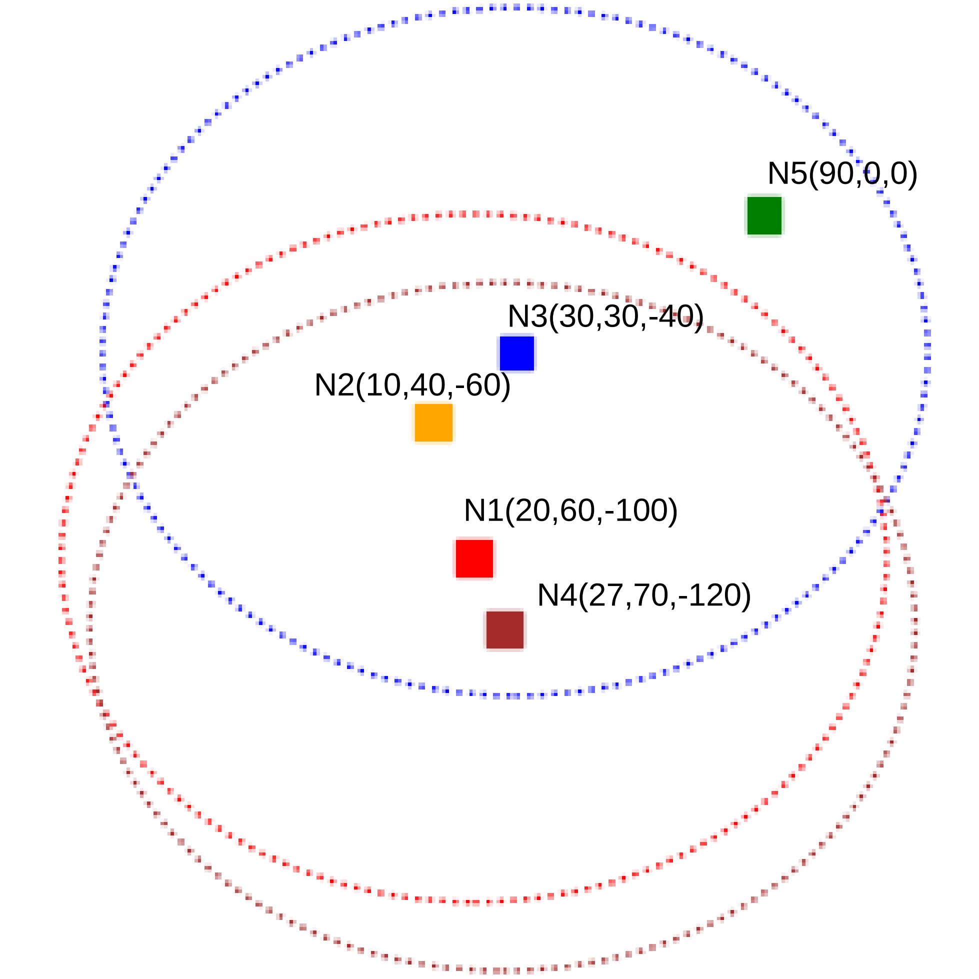
- N1 transmits 100 packets. Receives 99 packets from neighbor nodes and drops 99 packets which is an unqualified node drop.
- N3 is the destination which receives 183 packets, and 85 packets are duplicate packets received from N2 which are dropped.
- Since N2 is a qualified node from transmission it transmits packets as per scheduled sending time. It receives 100 packets and forwards 99 packets.
- N4 receives 183 packets and drop all the packet since it is an unqualified node.

Observation

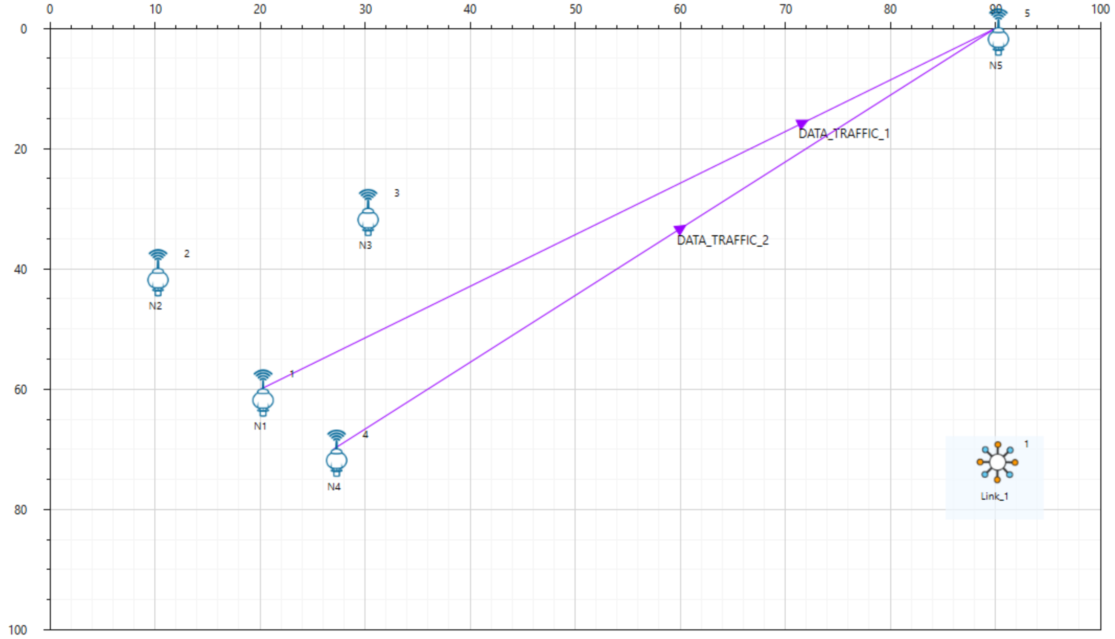
	A	E	G	H	L	O	V
1	PACKET_ID	SOURCE_ID	TRANSMITTER_ID	RECEIVER_ID	MAC_LAYER_ARRIVAL_TIME(µS)	PHY_LAYER_END_TIME(µS)	PACKET_STATUS
2	1	NODE-1	NODE-1	NODE-4	0	319400.499	Successful
3	1	NODE-1	NODE-1	NODE-4	0	319400.499	Dropped
4	1	NODE-1	NODE-1	NODE-2	0	334330.505	Successful
5	1	NODE-1	NODE-1	NODE-3	0	348995.533	Successful
6	1	NODE-1	NODE-2	NODE-3	1134330.505	1323240	Successful
7	1	NODE-1	NODE-2	NODE-3	1134330.505	1323240	Dropped
8	1	NODE-1	NODE-2	NODE-1	1134330.505	1333790.505	Successful
9	1	NODE-1	NODE-2	NODE-1	1134330.505	1333790.505	Dropped
10	1	NODE-1	NODE-2	NODE-4	1134330.505	1349375.067	Successful
11	1	NODE-1	NODE-2	NODE-4	1134330.505	1349375.067	Dropped
966							

- N1 broadcasts packet at 0sec. ($d_p = 100m$)
  - N2 receives packet from N1 at $334330.505\mu s$. [Qualified Node]. Send time = $1134330.505\mu s$.
  - N4 receives packet from N1 at $319400.499\mu s$ [not a qualified node] packet dropped.
  - Since next hop is destination node N3 it receives packet at $348995.533\mu s$.
- N2 is the qualified node which forwards packet at $1134330.505\mu s$. Depth is updated. ($d_p = 60m$)
  - N3 receives packet at $1323240\mu s$. As packets have already reached destination node from N1 at $348995.533\mu s$, duplicate packets are dropped.

Case 5: Two Applications



Scenario of interest



Scenario created in NetSim

- Largest Tx-Rx pair is (N4,N5)
- Slot length = 132893.33 µs

Observations

- N1 and N4 is the source node. Both nodes are in range with qualified forwarding nodes N2 and N3.
- N3 has the lowest depth to destination node N5. Hence it forwards the packet.
- From packet trace we can observe that,
  - N1 forwards packet to N3, N3 forwards to destination node N5. $[N1 \rightarrow N3 \rightarrow N5]$
  - Similarly, N4 forwards packet to N3 and N3 forwards packet to N5. $[N4 \rightarrow N3 \rightarrow N5]$
  - For Data_Traffic_1 and Data_Traffic_2, packets transmitted from N2 are dropped at N3 because N3 has already transmitted packet at earlier sending time.
  - Similarly, for Data_Traffic_2, packets transmitted from N1 are dropped at N3 because N3 has already transmitted packet at earlier sending time.

Insights from NetSim simulations

We implemented DBR protocol in NetSim. On simulating different cases we observe the following issues:

- If the next hop from source node is destination, the neighboring nodes that don't have the packet history, broadcast the same packet as per scheduled sending time.
- If two nodes, N2 and N3, are positioned nearly equidistant vertically but are widely separated horizontally, their holding times for packets are nearly equal.
  - When a lower-depth node like N2 receives a packet from N1, it will rebroadcast it. However, due to the substantial horizontal distance between N2 and N3, there will be a delay in the packet reaching N3. Since N3 is positioned at nearly the same depth as N2, it may end up rebroadcasting the received packet from N1 before receiving the packet from N2.
- Holding time does not take into account MAC layer issues such as
  - Packet collisions
  - Initial back off: Due to initial backoff time at PHY_IN the holding time might not be large before the neighboring nodes receives the packet from lower depth hence, these nodes broadcasts as per scheduled sending time.