NetSim Under Water Acoustic Networks (UWAN) Experiments and Measurements Workspace

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1 Introduction

This is a NetSim “workspace” which contains saved experiments. These experiments can be directly “imported” into NetSim. Further, the workspace has some code modifications that enabled users to log acoustic measurements such as Acoustic pathloss, Received Signal Level, SNR, BER etc.

2 Importing the Workspace

1. Use the following download Link to download a compressed zip folder which contains the workspace <GITHUBLINK>
2. Extract the zip folder.
3. The extracted project folder consists of a NetSim workspace file (UWAN experiments and measurements.netsimexp).
4. Go to NetSim Home window, go to Your Work, and click on Import.

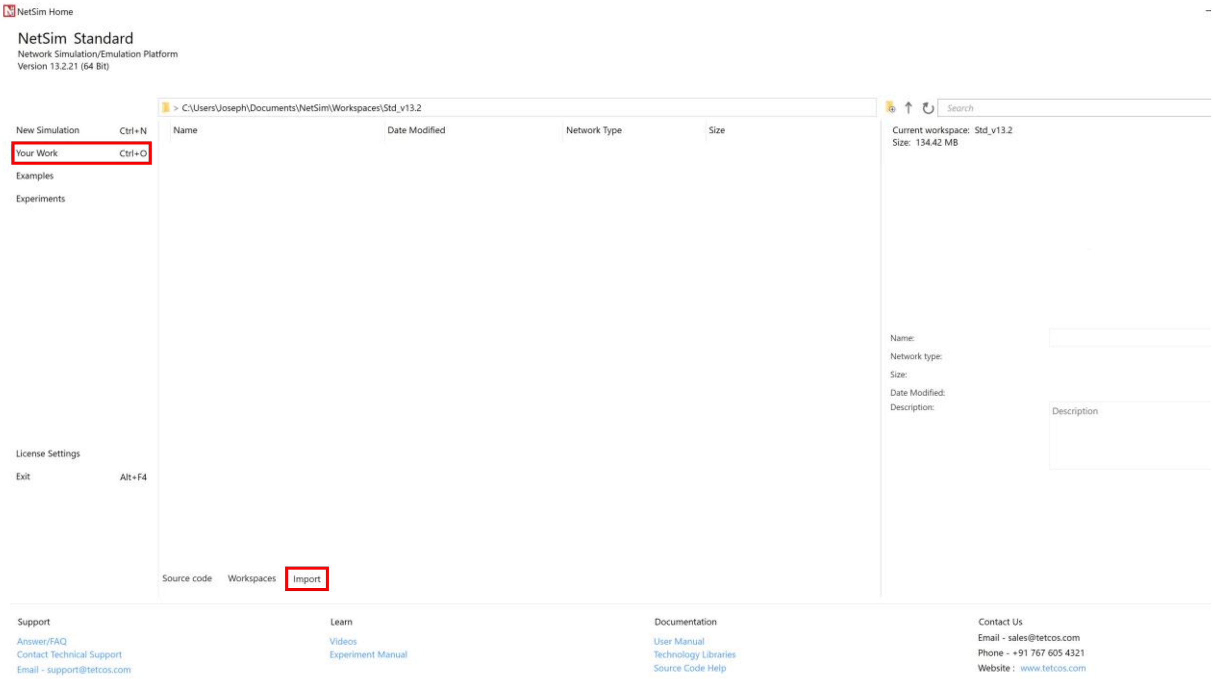


Fig 1: NetSim Home Window

5. In the Import Workspace Window, browse and select the UWAN experiments and measurements. netsimexp. file from the extracted directory. Click on create a new workspace option and browse to select a path in your system where you want to set up the workspace folder.
6. Choose a suitable name for the workspace of your choice. Click Import.

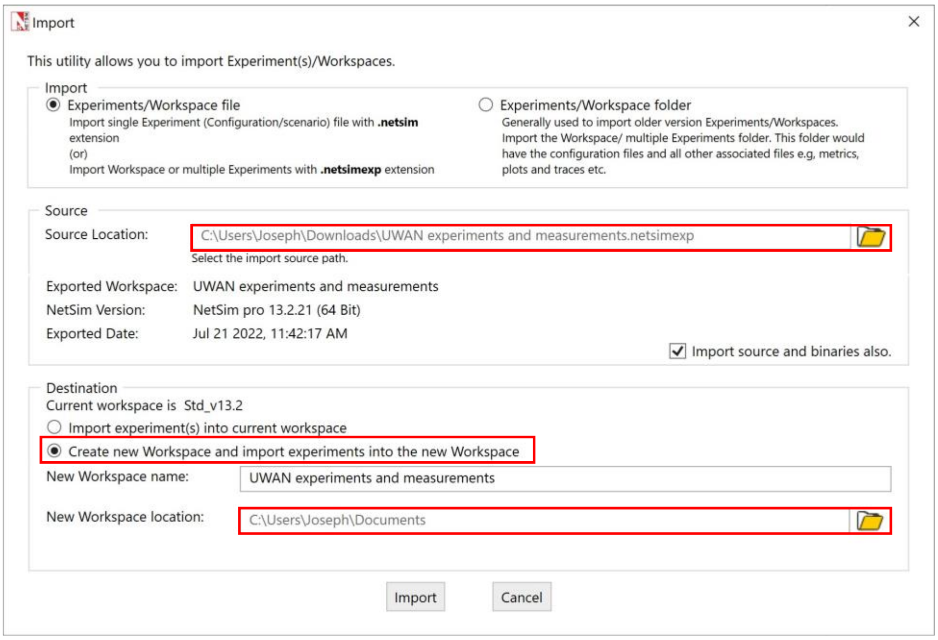


Fig 2: NetSim Import workspace window

7. The imported workspace will automatically be set as the current workspace.
8. The list of experiments will be loaded onto the selected workspace.

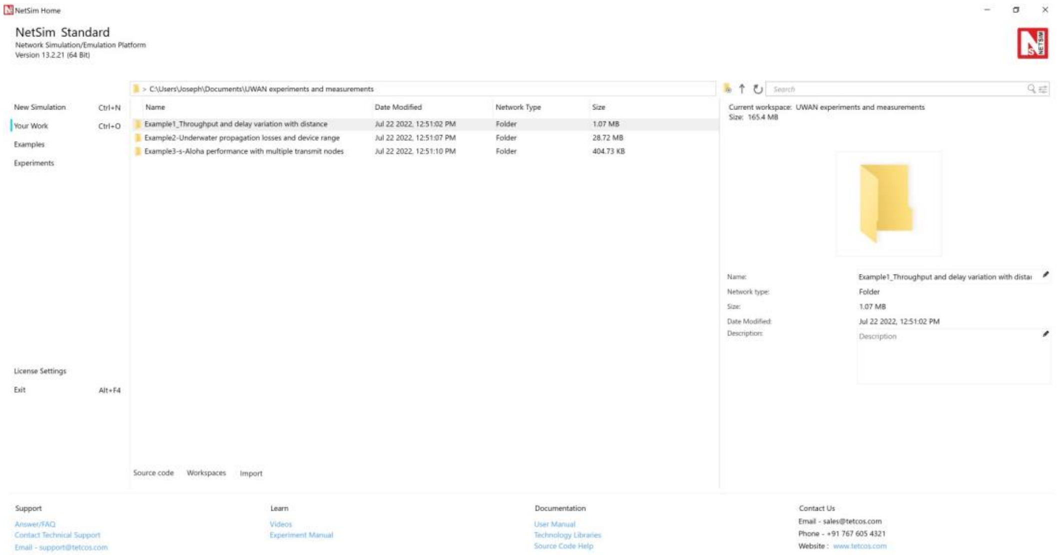


Fig 3: List of experiments shown inside the workspace

3 Multi-Parameter Sweeper

The multi-parameter sweep program enables users to automatically sweep process across multiple input parameters, simulate each run, save each result, and compare specific output metrics via a spreadsheet software like MS Excel. The sweep program runs NetSim via its CLI interface. Documentation and code is available in the link given.

Utility Download Link: https://tetcos.com/pdf/v13.1/NetSim-Multi-Parameter-Sweeper_v13.1.pdf

4 Experiments available in this workspace

4.1 Throughput and delay variation with distance

In this example, we understand how UWAN throughput and delay varies as the distance between 1 transmitter and 1 receiver is varied. Even with *No pathloss* the throughput in UWAN varies with Tx-Rx distance which is not the case in terrestrial RF based transmissions. The two parameters that affect throughput and delay are the speed of sound and the slot length of s-Aloha. The speed of sound in water is given by the formula

$$c_{sound} = 1449.05 + 45.7t - 5.21 \times t^2 + 0.23 \times t^3 + (1.333 - 0.126t + 0.009 \times t^2)(S - 35) + 16.3 \times z + 0.18 \times z^2$$

where t is one-tenth of the temperature of the water in degrees Celsius, z is the depth in km and S is the salinity of the water. Then using $t = \frac{25}{10} = 2.5$, $z = 50$, and $S = 35$ - where t is one-tenth of the temperature of the water in degrees Celsius, z is the depth in meters and S is the salinity of the water, we get $c_{sound} = 2799.33\ m/s$. When the transmitter receiver distance is $d = 2km$, the propagation delay, $\Delta = \frac{2\times10^3}{2799.33} = 714{,}456.4\ \mu s$

Next, as explained in section **Error! Reference source not found.**, we consider ideal slot lengths for different transmitter receiver distances. In the case when $d_{Rx}^{Tx} = 2\ km$ the slot length turns out as

$$L_{Slot} = T_{tx} + \Delta = 16{,}800 + 714{,}456.4 = 731{,}256.4\ \mu s = 0.73$$

Table 4-4 shows the ideal slot length settings for $d_{Rx}^{Tx} = 4\ km$ and $d_{Rx}^{Tx} = 6\ km$.

Network setup:

- Create a scenario with 2 Underwater Devices

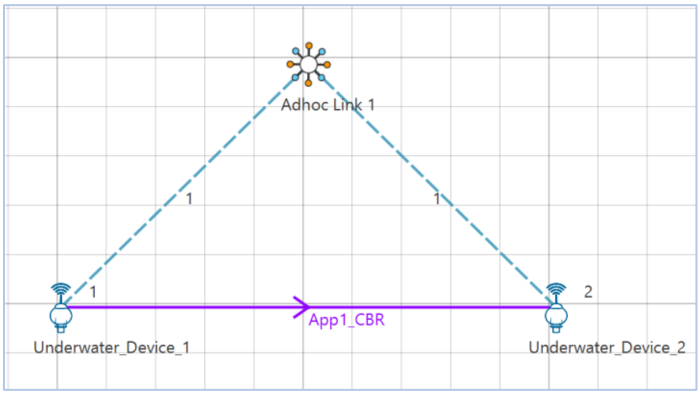


Figure 4-1: Network Scenario. Two underwater devices connected via an acoustic ad hoc link

- In case #1, distance between the underwater devices is set to be 2km. In case #2 the distance is 4km, while in case #3 it is set to 6 km
- Channel characteristics as NO_PATHLOSS
- Change the Following parameters, Right Click on Underwater_Device_1 →Properties

Device Configuration:

Device > Interface (ACOUSTIC) > Datalink Layer	
Slot Length(μs)	16800
Device> Interface (ACOUSTIC) > Physical Layer	
Source Level ($dB//1\mu Pa$)	200
Modulation	QPSK
Data Rate (kbps)	20

Table 4-1 : Device properties set for this example

Application Configuration:

We run simulations for different traffic generation rates. The generation rate depends on the inter-packet arrival time is a GUI input in NetSim – in the following way

$$Generation\ Rate\ (Mbps) = \frac{Packet\ Size\ (Bytes)\ \times\ 8}{Interarrival\ Time\ (\mu s)}$$

Application Properties		
Application Method	App1_CBR	
Source ID	1	
Destination ID	2	
Packet Size (Bytes)	14	
	Inter arrival Time (µs)	**Generation rate (bps)**
Case-1	4480000	25
	2240000	50
	1120000	100
	896000	125
	746666.6666	150
	640000	175
	560000	200
Case-2	5600000	20
	2800000	40
	1866666.6666	60
	1400000	80
	1120000	100
Case-3	5600000	20
	3733333.333	30
	2800000	40
	2240000	50
	1866666.6666	60
	1600000	70

Table 4-2: Application properties for the different samples in each case studied in this example

- Click on Packet Trace option and select the Enable Packet Trace check box.
- Run the Simulation for 100 sec.

Theoretical Predictions

The predicted propagation delay when the speed of sound $c_{sound} = 2799.33\ m/s$ is

Distance between devices	**Propagation delay (Δ in μs)**
2km	714456.4
4km	1428912.7
6km	2143369.1

Table 4-3: Theoretically predicted propagation delay for different Tx-Rx distances

Transmission delay and Saturation Throughput

Considering a slot length of $731{,}256.4\ \mu s$ refer section **Error! Bookmark not defined.Error! Reference source not found.** in UWAN Manual, we see that one packet exactly fits one slot and hence the predicted saturation throughput would be

$$\theta_{sat}^{2km} = \frac{(L_{pkt} \times 8)}{L_{slot}} = \frac{(14 \times 8)}{731256.4 \times 10^{-6}} = 153\ bps$$

Proceeding similarly for 4 km and 6 km, the predictions for saturation throughput are

Distance between devices	Slot Length (L_{slot})	Saturation Throughput (θ_{sat} in bps)
2 km	731256.4	153
4 km	1445712.7	77
6 km	2160169.1	52

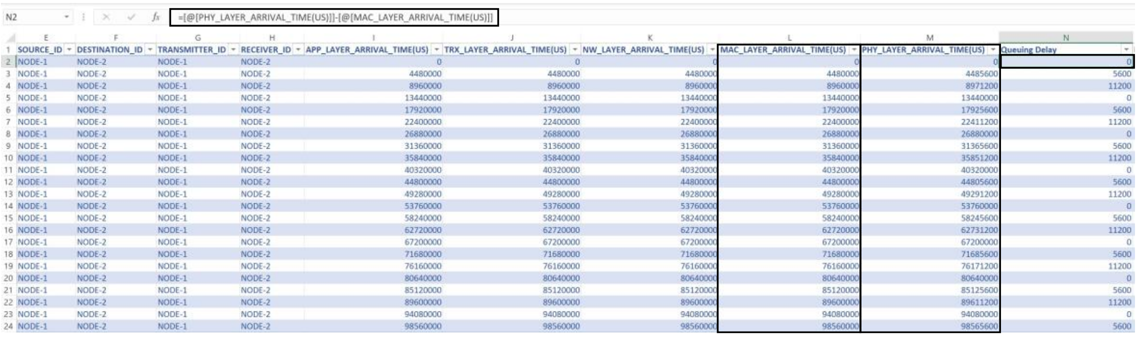
Table 4-4: Ideal slot lengths and theoretically predicted saturation throughputs (θ_{sat}) for different Tx-Rx distances

Simulation results

We calculate of queuing delay, transmission delay, propagation delay from the packet trace. The steps are:

- Open Packet Trace file using the Open Packet Trace option available in the Simulation Results window.
- The difference between the PHY LAYER ARRIVAL TIME(US) and the MAC LAYER ARRIVAL TIME(US) will give us the delay of a packet. Refer Figure 4-2

$$Queuing\ Delay\ (\mu s) = PHYSICAL\ LAYER\ ARRIVAL\ TIME(\mu s) - MAC\ LAYER\ ARRIVAL\ TIME\ (\mu s)$$


N2 =[@[PHY_LAYER_ARRIVAL_TIME(US)]]-[@[MAC_LAYER_ARRIVAL_TIME(US)]]

	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID	APP_LAYER_ARRIVAL_TIME(US)	TRX_LAYER_ARRIVAL_TIME(US)	NW_LAYER_ARRIVAL_TIME(US)	MAC_LAYER_ARRIVAL_TIME(US)	PHY_LAYER_ARRIVAL_TIME(US)	Queuing Delay
2	NODE-1	NODE-2	NODE-1	NODE-2	0	0	0	0	0	0
3	NODE-1	NODE-2	NODE-1	NODE-2	4480000	4480000	4480000	4480000	4485600	5600
4	NODE-1	NODE-2	NODE-1	NODE-2	8960000	8960000	8960000	8960000	8971200	11200
5	NODE-1	NODE-2	NODE-1	NODE-2	13440000	13440000	13440000	13440000	13440000	0
6	NODE-1	NODE-2	NODE-1	NODE-2	17920000	17920000	17920000	17920000	17925600	5600
7	NODE-1	NODE-2	NODE-1	NODE-2	22400000	22400000	22400000	22400000	22411200	11200
8	NODE-1	NODE-2	NODE-1	NODE-2	26880000	26880000	26880000	26880000	26880000	0
9	NODE-1	NODE-2	NODE-1	NODE-2	31360000	31360000	31360000	31360000	31365600	5600
10	NODE-1	NODE-2	NODE-1	NODE-2	35840000	35840000	35840000	35840000	35851200	11200
11	NODE-1	NODE-2	NODE-1	NODE-2	40320000	40320000	40320000	40320000	40320000	0
12	NODE-1	NODE-2	NODE-1	NODE-2	44800000	44800000	44800000	44800000	44805600	5600
13	NODE-1	NODE-2	NODE-1	NODE-2	49280000	49280000	49280000	49280000	49291200	11200
14	NODE-1	NODE-2	NODE-1	NODE-2	53760000	53760000	53760000	53760000	53760000	0
15	NODE-1	NODE-2	NODE-1	NODE-2	58240000	58240000	58240000	58240000	58245600	5600
16	NODE-1	NODE-2	NODE-1	NODE-2	62720000	62720000	62720000	62720000	62731200	11200
17	NODE-1	NODE-2	NODE-1	NODE-2	67200000	67200000	67200000	67200000	67200000	0
18	NODE-1	NODE-2	NODE-1	NODE-2	71680000	71680000	71680000	71680000	71685600	5600
19	NODE-1	NODE-2	NODE-1	NODE-2	76160000	76160000	76160000	76160000	76171200	11200
20	NODE-1	NODE-2	NODE-1	NODE-2	80640000	80640000	80640000	80640000	80640000	0
21	NODE-1	NODE-2	NODE-1	NODE-2	85120000	85120000	85120000	85120000	85125600	5600
22	NODE-1	NODE-2	NODE-1	NODE-2	89600000	89600000	89600000	89600000	89611200	11200
23	NODE-1	NODE-2	NODE-1	NODE-2	94080000	94080000	94080000	94080000	94080000	0
24	NODE-1	NODE-2	NODE-1	NODE-2	98560000	98560000	98560000	98560000	98565600	5600

Figure 4-2 : Screen shot of NetSim trace showing the Queuing Delay column

- Now, calculate the mean queuing delay by taking the average of the queueing delays of all the packets. This is nothing but the column average. (Refer Figure 4-2)
- Similarly, users can get the Mean Transmission Delay and Mean Propagation Delay from the packet trace using the formulas

$$Transmission\ Delay\ (\mu s) = PHY\ LAYER\ START\ TIME(\mu s) - PHY\ LAYER\ ARRIVAL\ TIME(\mu s)$$

$$Propagation\ Delay\ (\mu s) = PHY\ LAYER\ END\ TIME(\mu s) - PHY\ LAYER\ START\ TIME(\mu s)$$

	Generation Rate (bps)	Throughput (bps)	Delay (µs)	Mean Propagation Delay(µs)	Mean Transmission Delay(µs)	Mean Queuing Delay(µs)
Case #1: Distance between underwater devices is 2km	25	26	736612.9	714456.4	16800	5356.52
	50	50	736856.4	714456.4	16800	5600
	100	100	736793.4	714456.4	16800	5537.08
	125	124	736856.4	714456.4	16800	5600
	150	149	738666.9	714456.4	16800	7410.53
	175	151	7377656.4	714456.4	16800	6646400
	200	151	12737656.4	714456.4	16800	12006400
Distan ce betwe en under water	20	20	1451313	1428912.7	16800	5600
	40	40	1451313	1428912.7	16800	5600
	60	59	1453285	1428912.7	16800	7572.33

	80	76	3509313	1428912.7	16800	2063600
	100	76	12889313	1428912.7	16800	11443600
Case #3: Distance between underwater devices is 6km	20	20	2165769	2143369.1	16800	5600
	30	30	2167636	2143369.1	16800	7466.67
	40	39	2165609	2143369.1	16800	5440
	50	49	2165769	2143369.1	16800	5600
	60	52	8922169	2143369.1	16800	6762000
	70	52	14922169	2143369.1	16800	12762000

Table 4-5: Tabulated results (throughput and delays) for 3 different Tx-Rx distances

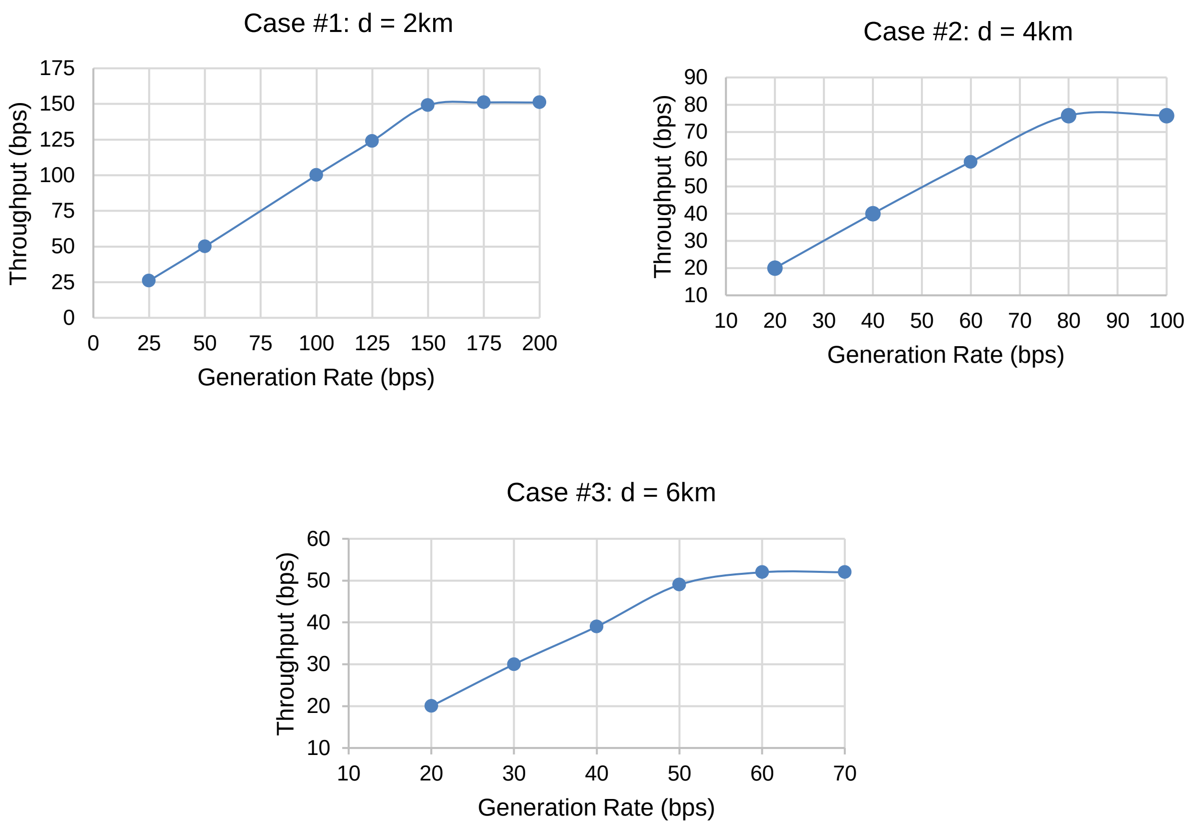


Figure 4-3: Throughput vs. Generation rate plotted for Tx-Rx distances of 2km, 4km and 6km based on earlier table

From Table 4-5, we see that the propagation delays from simulation match predictions in Table 4-3. Then from the below table we observe that saturation throughput (the Y axis value once the curve flattens) matches prediction.

Distance between devices	Saturation Throughput. Predicted (θ_{sat} in bps)	Saturation Throughput. Simulation (θ_{sat} in bps)
2 km	153	151
4 km	77	76
6 km	52	52

Table 4-6: NetSim UWAN Simulation results vs. theoretical prediction of saturation throughput, for different Tx-Rx distances

4.2 Underwater propagation losses and device range

In this example, we understand the Thorp propagation model, the sources of under-water noise, the passive sonar equation and how device range can be estimated based on received SNR. Refer to section 3.1 in UWAN Manual for the underlying theory on signal level, transmission losses, and the passive sonar equation.

Network setup

- Create a scenario with two underwater devices

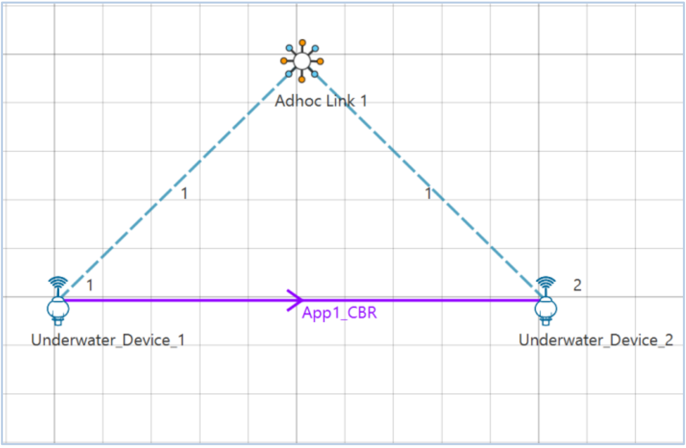


Figure 4-4:Network Scenario

- Channel characteristics as PATHLOSS_ONLY
- Change the Following parameters, Right Click on Underwater_Device_1 →Properties

Device Properties > Physical Layer	
Source Level ($dB//1\mu Pa$)	190.8, 187.78,183.91
Data Rate (kbps)	20
Modulation Technique	QPSK, BPSK, FSK, 16QAM, 64QAM, 256QAM

Table 4-7: Device Properties

- Create a CBR Application with Default Properties with Source ID as 1 and Destination ID as 2.
- Run the Simulation for 1000 sec.

Analytical computations

In the Thorp model, the db/km attenuation is given by.

$$10\,log_{10}\,\alpha(f) = \begin{cases} 0.11 \times \left(\dfrac{f^2}{1+f^2}\right) + \; +44 \times \left(\dfrac{f^2}{4100+f^2}\right) + 2.75 \times 10^{-4} \times f^2 + 0.003 & f \geq 0.4\,kHz \\ 0.02 + 0.11 \times \left(\dfrac{f}{1+f}\right) + 0.011 \times f & f < 0.4\,kHz \end{cases}$$

For this example, substituting $f = 20$, we get $10\,log_{10}\,\alpha(f) = 4.133\,db/km$, we see that the total pathloss is

$$10\,log\,A(d,f) = \; k \times \; 10\,log\,(d_m) \; + d_{km} \times 10\,log\,\alpha(f)$$

Using input parameters $K\,(spread\ coefficient) = 2, f \; = 20\,kHz$ and distance between the source and destination, $d = 18\,km$, and we get the total transmission loss, TL, as

$$TL = \; 10\,log\,A(d,f) = 153.51\,dB$$

Next, we turn to noise level NL. The turbulence, shipping, wind, and thermal, noise level in dB is given by

$$10\ log N_t(f) = 17 - 30 log\ (f)$$

$$10\ log N_s(f) = 40 + 20 \times (s - 0.5) + 26\ log\ f - 60 \times log(f + 0.03)$$

$$10\ log N_w(f) = 50 + 7.5 \times \sqrt{w} + 20\ log\ f - 40\ log(f + 0.4)$$

$$10\ log N_{th}(f) = -15 + 20\ log\ f$$

Substituting $f = 20\ kHz$, shipping factor $s = 0.5$, surface windspeed $w = 0\ m/s$, we get $N_t = -22.03\ dB$, $N_s = -4.27\ dB$, $N_w = 23.63\ dB$, and $N_{th} = 11.02\ dB$. As explained in section 3.1.4 we see that wind noise has the most impact. After adding these noises in the linear scale and then converting back to dB, Total noise, $N_{Total}^{dB} = 23.87$. From the passive sonar equation

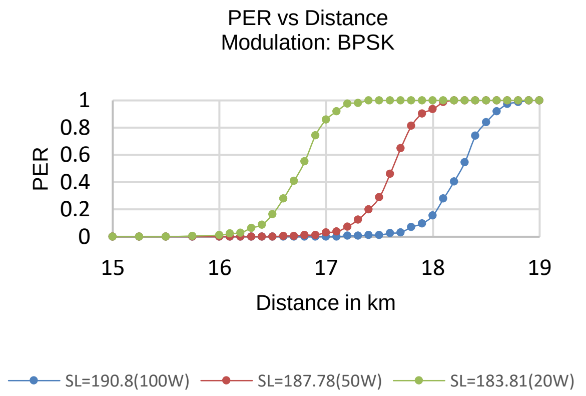
$$SNR = SL - TL - (NL - DI)$$

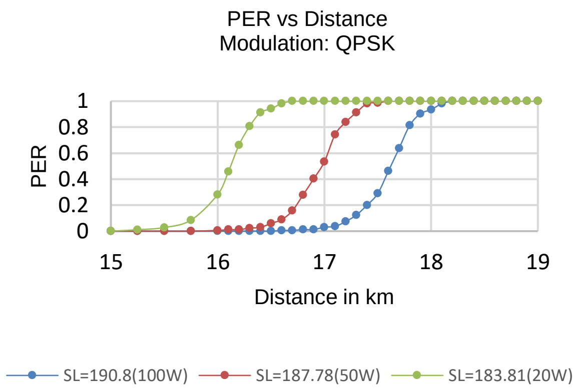
Substituting we get

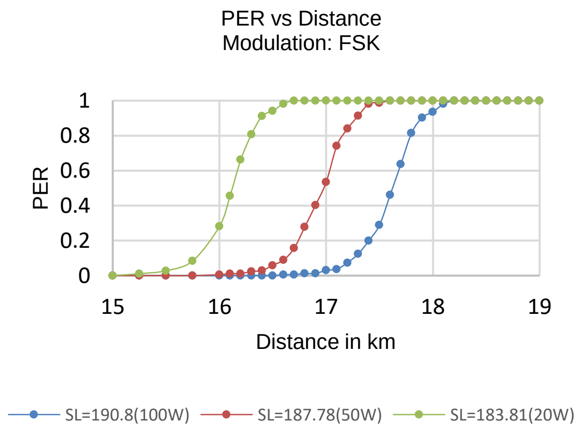
$$SNR = 190.80 - 153.51 - (23.87 - 0) = 7.41\ dB$$

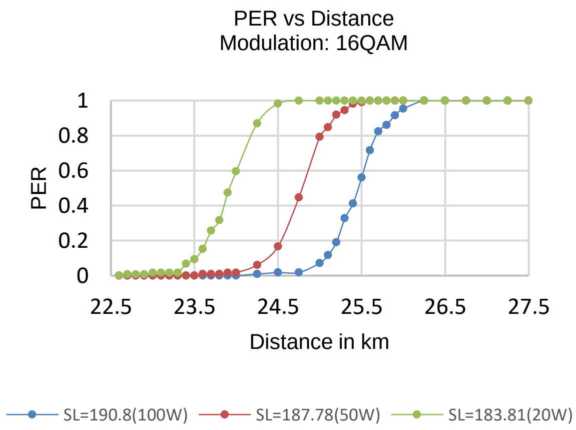
Results: Packet Error Rate vs Distance

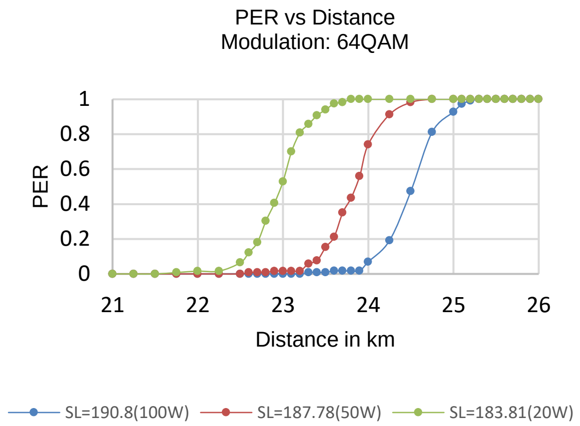
For the above SNR, we plot PER vs. distance for different modulation schemes given default packet size of 14B.

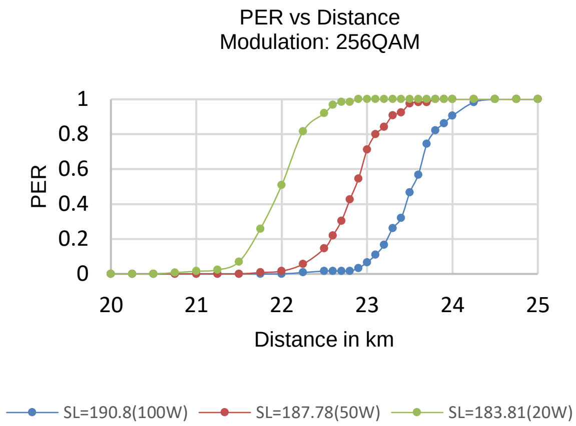












Generally, range is defined as the Tx-Rx distance at which the PER is 10 %. From these plots we can determine a device's range. In summary, we see how the device range is dependent on Source Level, Noise, MCS and packet size.

4.3 s-Aloha performance with multiple transmit nodes

Network setup

We consider three scenarios as shown in the figure below, with 2, 3 and 4 transmitting nodes.

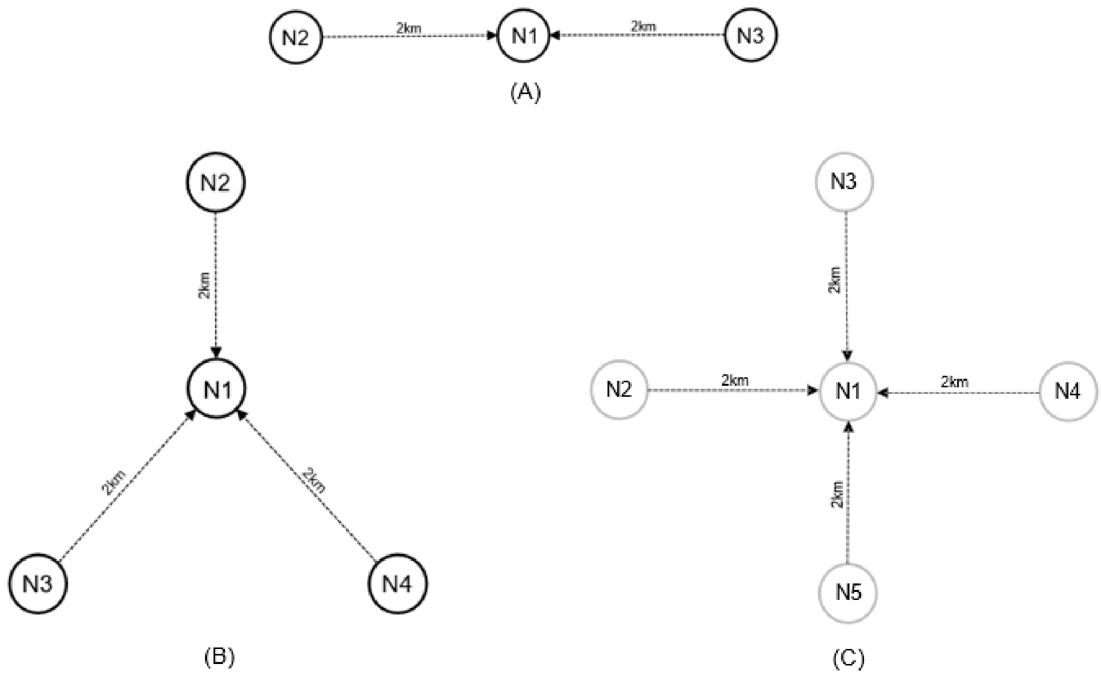


Figure 4-5: Simulation scenarios with 2 transmitting nodes in (A), 3 transmitting nodes in (B) and 4 transmitting nodes in (C). In all cases there is a single receiver.

Properties

Then we set the UWAN device properties as shown below

Device Properties
Device > Interface (ACOUSTIC) > Datalink Layer

Retry Limit	0,4,6
Slot Length(µs)	741256.4
Device> Interface (ACOUSTIC) > Physical Layer	
Source Level ($dB//1\mu Pa$)	190.8
Modulation	QPSK
Data Rate (kbps)	20

Table 4-8: UWAN Device Properties

- Here, we set the Slot Time as 741256.4 μs, which is the ideal value of 731256.4 μs plus a guard interval of 10,000 μs
- Create a CBR Application from the source nodes (2, 3, 4 and 5 per the cases) to the destination (Node 1) with a packet size of 14 bytes and Inter arrival time as 560000μs.
- Run the Simulation for 10000sec.

Results

We observe throughputs from network metrics and packets transmitted and packets collided from the Link Metrics. We collision probability as $P_c = \frac{Collision\ Count}{Packet\ Transmitted}$ and tabulate the results in the different cases.

Case #1: Two transmitting nodes						
Retry Limit	**Throughput N1 (bps)**	**Throughput N2 (bps)**	**Aggregate Throughput(bps)**	**Collision Count**	**Packet Transmitted**	P_c
0	0	0	0	26980	26980	1
4	55	51	106	7104	16624	0.427
6	71	65	136	2548	14647	0.173

Table 4-9: Simulation Results with 2 transmitting nodes

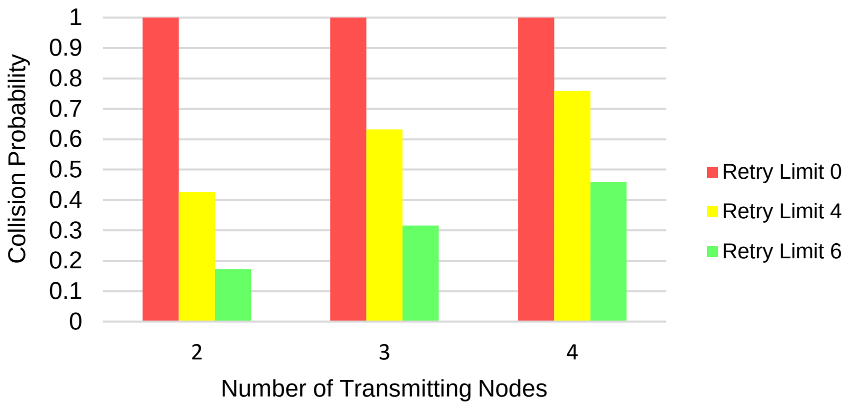
Case #2: Three transmitting nodes							
Retry Limit	**Throughput N1 (bps)**	**Throughput N2 (bps)**	**Throughput N3 (bps)**	**Aggregate Throughput (bps)**	**Collision Count**	**Packet Transmitted**	P_c
0	0	0	0	0	40470	40470	1
4	26	26	27	79	12234	19348	0.632
6	43	41	37	121	4969	15726	0.316

Table 4-10: Simulation Results with 3 transmitting nodes

Case #3: Four transmitting nodes								
Retry	**Throughput N1**	**Throughput N2**	**Throughput N3**	**Throughput N4**	**Aggregate**	**Collision**	**Packet Transmitt**	P_c
0	0	0	0	0	0	53960	53960	1
4	15	15	14	16	60	16942	22293	0.76
6	28	27	26	26	107	7202	16756	0.43

Table 4-11: Simulation Results with 4 transmitting nodes

We carry out simulations with different settings of Retry Count. The final results are plotted below. When Retry count is set to zero, all packets collide even when just two nodes are transmitting. With retry count set to 0, the node attempts a packet transmission. If it fails, there is no retry and the packet



is dropped. Recall, that in s-Aloha the transmitter does not back off before the first transmission attempt for a packet. With backlogged queues, the two transmitting nodes keep attempting at each slot. This leads to continuous collisions.

When the retry count is set to 4 (or 6) a transmitting node back off per the exponential backoff algorithm, before every retransmission. The back off algorithm is explained in section **Error! Reference source not found.** in UWAN Manual . Hence there is an element of randomness in packet transmissions at each slot. Nodes may or may not transmit. The probability of transmission at a particular slot reduces as the Retry Count is increased. Hence, we see lower collision probabilities for Retry count of 6.

Advanced: s-Aloha works as expected only if the slot time is greater than transmission time plus the propagation delay. What happens when slot length is lower than this limit? Under this condition a new slot is available for transmission even before completion of an existing packet transmission. Thus, if an idle node completes its back off before the transmission (where transmission time equals $T_{tx} + \Delta$) of one another node is complete, it will attempt to transmit at the start of a new slot. The two packets collide and are lost. One would therefore expect higher collision probabilities with smaller slot lengths. NetSim simulation results for 2-node transmitting case with slot time, 250 ms is given below

Retry Limit	**Throughput N1 (bps)**	**Throughput N2(bps)**	**Aggregate Throughput(bps)**	**Collision Count**	**Packet Transmitted**	P_c	P_c **(Ideal slot time)**
0	0	0	0	26666	26666	1	1
4	20	20	40	14102	17696	0.79	0.427
6	45	46	91	6987	15109	0.46	0.153

Observe the significant increase in collision probability when the slot time is set lower than the ideal slot time. Next, we fix the retry count at 6 and vary the slot time from 50 ms to 750 ms in steps of 50 ms. In the plot below showing collision probability vs. slot time, we again observe how low slot times lead to higher collision probabilities.

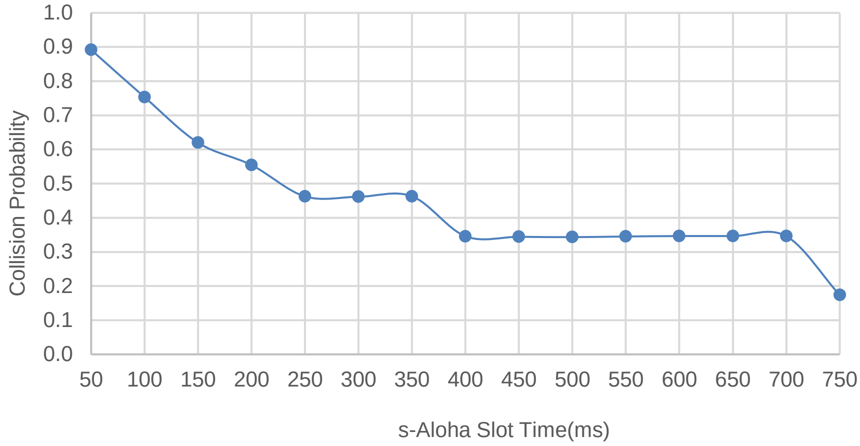


Figure 4-6 : Collision probability vs slot time