CHAPTER-5

RESULTS AND DISCUSSIONS

The performance of underwater optical systems can be severely degraded by the absorption and scattering effects of sea water, channel turbulence, misalignment errors and other impact factors. All these are the undesirable factors for the communication. Compared with UOWC, underwater acoustic communication method benefits from its mature technology, long link range and lower pointing requirements, but suffers from low data rate, low security and bulky instruments. On the other hand, UOWC systems can achieve high speed point-to-point data transmission, but they cannot operate in long distance and turbid environment. Both the type of communications used in the underwater environments have an effect of the medium on their propagation. Therefore, before studying the real time network we implement it on the simulator which in our case is Qualnet. Since, desired environment is not built in the simulator therefore we custom create the protocols for the pathloss model of communication and the physical layer protocol. The work has been discussed in the previous chapters. In this chapter, the implementation of the custom protocols would be discussed and the performance metrics would be studied to analyze the working of the network.

The network of 100 nodes is constructed in Qualnet 5.0 to study the effect of underwater environment in optical and acoustic sensor network communication. The specifications that are used to characterize network as mentioned in chapter-4 are considered here. The effect on the network performance parameters like Average Jitter and End to End delay. The network has the nodes that make up a subnet with the all the details about each layer and its protocol specifically defined.

The network works on different protocols for different layers. While Network layer uses IPv4 and MAC layer uses CSMA, the Routing protocol chosen is AODV (Ad-Hoc On Demand Distance Vector). The details of protocols used for different layers is shown in Fig. 5.1. At the application layer the CBR is defined between 8 node pairs to study the network as shown in Table 5.1 and Fig. 5.2. It defines us the source node of information and the destination node. All the rest nodes are the part of the subnet and may act as hops for the information transferred. All the nodes are randomly placed on the cartesian plane resembling the real time scenario, connected in a wireless subnet. The communication takes place in this subnet from source node to the destination node. These source and destination are identified by the CBR links ends. Constant Bit rate (CBR) is an application layer protocol which acts as a traffic generator. It is a UDP based client server application, data is sent from a client to server at a Constant Bit Rate. We have used UDP over TCP as it does not have much overhead unlike latter, therefore for the resource constrained embedded designs it is better to be used.

Nodes | Groups | Interfaces | Networks | Applications | Hierarchies

Address	Node ID	Name	PHY Model	MAC Protocol	Network Protocol	Routing Protocol
190.0.3.1	1	Interface0	PHY-ABSTRACT	CSMA	IP	AODV
190.0.3.2	2	Interface0	PHY-ABSTRACT	CSMA	IP	AODV
190.0.3.3	3	Interface0	PHY-ABSTRACT	CSMA	IP	AODV
190.0.3.4	4	Interface0	PHY-ABSTRACT	CSMA	IP	AODV
190.0.3.5	5	Interface0	PHY-ABSTRACT	CSMA	IP	AODV
190.0.3.6	6	Interface0	PHY-ABSTRACT	CSMA	IP	AODV
190.0.3.7	7	Interface0	PHY-ABSTRACT	CSMA	IP	AODV
190.0.3.8	8	Interface0	PHY-ABSTRACT	CSMA	IP	AODV
190.0.3.9	9	Interface0	PHY-ABSTRACT	CSMA	IP	AODV

Fig 5.1 Protocols for OSI Layers of Nodes

Table 5.1 CBR Links

Source Node	Destination Node	Number of Hops
Node 7	Node 8	1
Node 12	Node 8	1
Node 22	Node 43	0
Node 60	Node 19	2
Node 64	Node 15	0
Node 86	Node 49	1
Node 92	Node 33	0
Node 100	Node 87	0

Nodes | Groups | Interfaces | Networks | Applications | Hierarchies

Type	Source ID	Destination ID	Start Time	End Time
CBR	86	49	1S	25S
CBR	64	15	1S	25S
CBR	92	33	1S	25S
CBR	60	19	1S	25S
CBR	100	87	1S	25S
CBR	7	58	1S	25S
CBR	12	8	1S	25S
CBR	22	43	1S	25S

Fig 5.2 Screenshot of Application layer Protocol-CBR

5.1 *Performance Metrics*

There are various parameters which describe the performance of the network. Since the complete network in distributed into layers of OSI model, different metrics are specified for different layers for each node as shown in Table 5.2.

Table 5.2 Performance Metrics corresponding to Network Layers

Layer	Performance Metrics
Application Layer	Average Jitter Throughput First Packet Received At Last packet Received At Total bytes Sent Total Packets Sent Average End to End Delay
Transport Layer	Packets from Application Layer Packets to Application Layer
Network Layer	Total Hop counts for all routes Number of Data packet sent as Source Number of Data packets Received Number of Routes selected
MAC Layer	Unicast Packet Received Unicast Packets Sent to Channel Broadcast Packet Received Broadcast Packets sent to Channel
Physical Layer	Signals Detected Signal Locked on by Phy Signal Transmitted Signal Received and Forwarded to MAC
Battery Model	Percentage of time in Transmit Mode Percentage of time in Receive Mode Energy consumed (in mJoule) in Receive Mode Energy consumed (in mJoule) in Idle Mode

To study the network under consideration, two parameters are focused upon namely Average End to End delay and Average Jitter. They have been described below:

1. Average End to End Delay: End to End Delay is the time taken to route the traffic or packets from source to destination. It is the difference between the time at which the sender generated the packet and the time at which the receiver received the packet.

2. Average Jitter: Jitter is defined as the difference between the expected time of arrival of a packet and the actual time of arrival. Jitter is caused primarily by delays and congestion in the packet network. Jitter causes discontinuity in the real-time data stream. To minimize the delay variations, a jitter buffer is implemented which temporarily stores arriving packets.

5.2 *Effect of Propagation Distance on Performance Metrics*

We perform the simulation for the network with 8 CBR links which characterize a constant bit rate route from source to destination. The CBR client description is given in Table 5.3.

Table 5.3 CBR Client details

Bytes Sent	12000
Packets Sent	24
Throughput (bits/sec)	4000

Corresponding to this we have the CBR server which shows the parameters i.e. Average jitter and End to End delay of the nodes. The CBR server evaluated results, for different data rates, are given in Table 5.4 to 5.7.

Table 5.4 Performance metrics for 10 Mbps Data Rate

Propagation Distance	Average Jitter	Average End to End Delay
20 m	0.0017	0.011
50 m	0.0026	0.024
100 m	0.0058	0.065
150 m	0.0138	0.09
200 m	0.0221	0.13

Table 5.5 Performance metrics for 2 Mbps Data Rate

Propagation Distance	Average Jitter	Average End to End Delay
20 m	0.0017	0.012
50 m	0.0019	0.024
100 m	0.0037	0.038
150 m	0.0088	0.069
200 m	0.014	0.098

Table 5.6 Performance metrics for 200 kbps Data Rate

Propagation Distance	Average Jitter	Average End to End Delay
20 m	0.0018	0.0116
50 m	0.0019	0.019
100 m	0.0019	0.024
150 m	0.0042	0.0368
200 m	0.008	0.054

Table 5.7 Performance metrics for 9.2 kbps Data Rate

Propagation Distance	Average Jitter	Average End to End Delay
20 m	0.0012	0.0201
50 m	0.0013	0.0281
100 m	0.0015	0.0399
150 m	0.0019	0.0439
200 m	0.0023	0.0484

The variation of both the average jitter and average end to end delay, with the propagation distance is studied. Similarly, average end to end delay is also analyzed for different data rates. The plots are shown in Fig. 5.3 and 5.4.

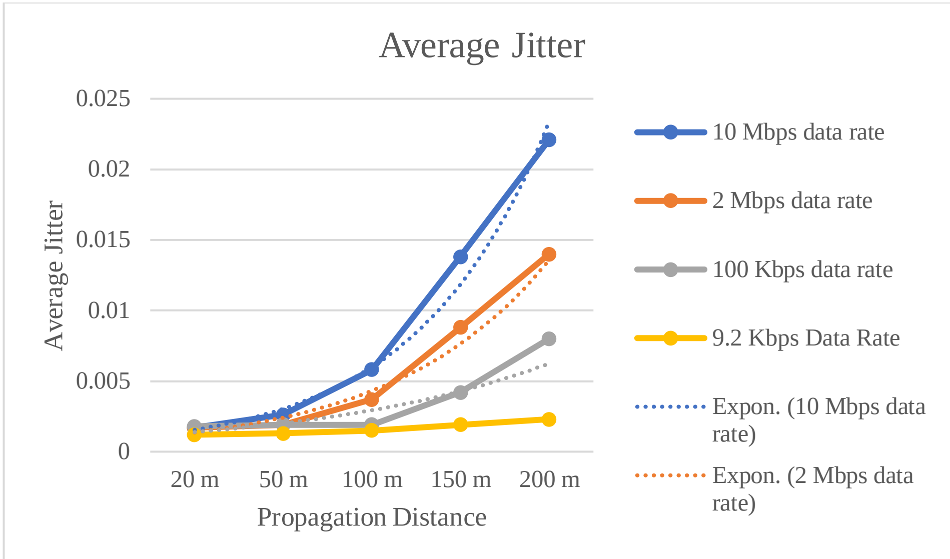

Fig 5.3 Average jitter vs propagation distance (range)

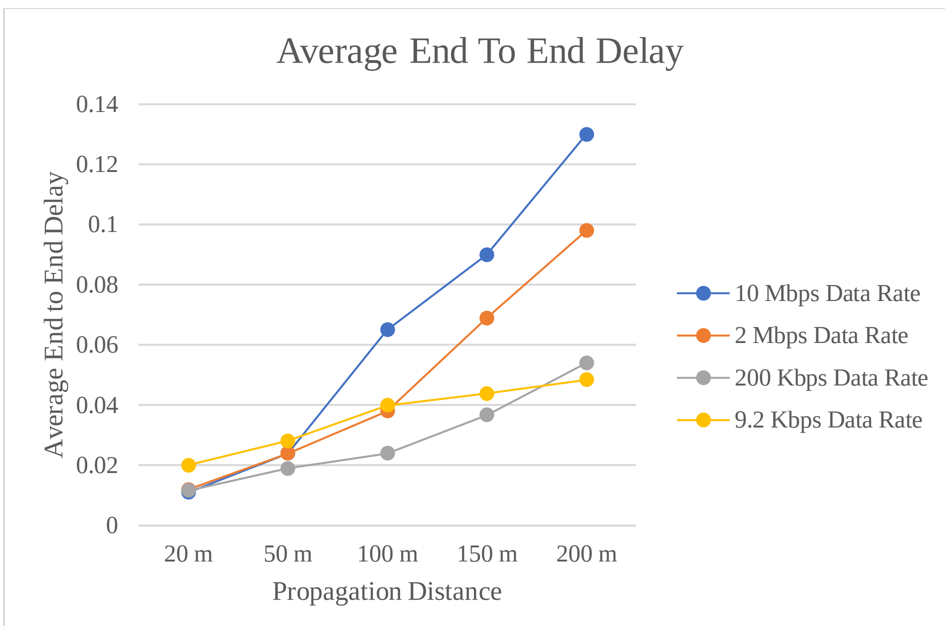

Fig 5.4 Average End to End Delay vs propagation distance (range)

Studying the results, we can say that as the we increase the propagation distance, the average jitter and the end to end delay increase more rapidly for higher data rates as compared to lower ones. So, we can conclude that, in order to get an optimized network and an efficient system, we should use higher data rates for smaller communication range and lower data rates for longer range communication range. Since higher data rates i.e in Mbps mean more information transfer, so when we need heavy data that is needed to be transferred we can use short range optical communication. And to cover longer distances acoustic communication can be used as it has lower data rate in the order of kbps.

5.3 *Effect of Transmitted Power on Performance Metrics*

Transmitted power and power consumption is big issue for underwater wireless sensor networks. Since the sensor nodes are small in size and difficult to be powered by some rechargeable source, therefore we need to use the battery model such that least amount of battery gets consumed on the transmission, reception and idle mode of the sensor. For a longer lifetime of the network, we have to study and analysis the energy consumption patterns. Therefore, we study the relation between transmitted power and the performance metrics like average jitter and end to end delay in the network. From the results in section 5.2, we choose the data rates and their corresponding propagation distances so that we can differentiate between different types of communication and the details are mentioned in Table 5.8.

Table 5.8 Data Rate and corresponding Propagation Distance

Transmission Rate	Propagation Distance
10 Mbps	30 m
2 Mbps	50 m
100 Kbps	80 m
9.2 Kbps	200 m

Different types of modems are considered as nodes which have different power capacity. Climent et al. 2014 describes various acoustic modems and their characteristics given here in Table 5.9. For optical modem, we use the properties of Evologics S2CR series 12/24 series as described in Wang. J et al. 2017.

Table 5.9 Acoustic Modem Specifications

Model	S2CR 12/24
Centre Frequency	18.5 kHz
Bandwidth	11 kHz
Distance	6000 m
Bit rate	9.2 Kbps
Transmitted power	15 W
Receiving Mode power	1.1 W
Sleep mode power	2.5 mW

We know that average jitter is difference between the expected time of arrival of a packet and the actual time of arrival. Jitter is caused primarily by delays and congestion in the packet network. Table 5.10 shows the value of average jitter for different values of data rate when transmission power is increased. The transmitted power is increased from 0.1 W (20 dBm) to 10 W (40 dbm).

Table 5.10 Average Jitter vs Transmission Power

Transmission power (dBm)	10 Mbps with 30m	2Mbps with 50m	100Kbps with 80m	9.2 Kbps with 200m
20	8.40E-04	9.00E-04	1.50E-03	2.58E-01
30	5.40E-06	3.00E-05	2.15E-04	7.40E-03
40	3.15E-06	3.30E-06	7.30E-06	1.35E-06

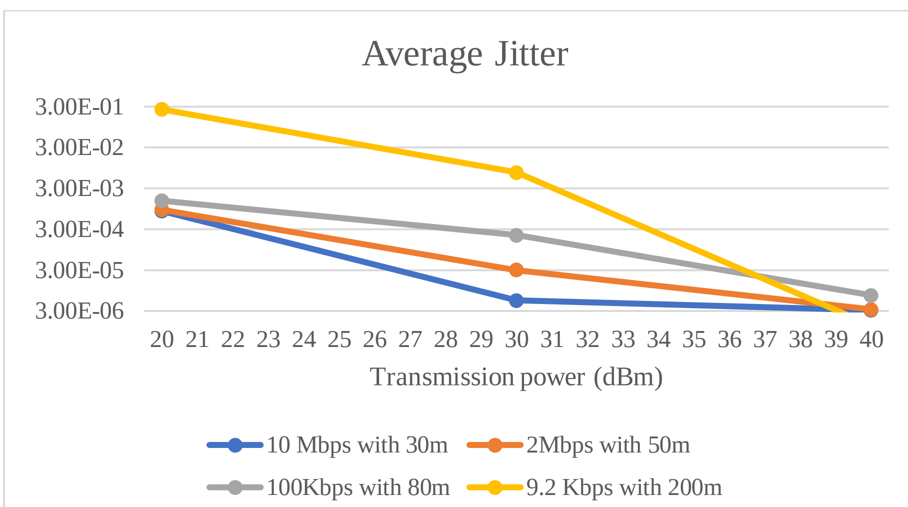

Fig 5.5 Average Jitter vs Transmission power(dBm)

The Fig. 5.5 shows that as the transmission power increases, the average jitter decreases but with different rate for different data rates. From the trends we can see that the 10 Mbps i.e high speed optical signal with propagation distance as 30m has value of jitter in the order of msec when transmission power is 0.1 W i.e 20 dBm. As the power is increased the jitter decreases further but with lesser rate, therefore optimum power value is near about 20 dBm as the jitter value is allowable and no drastic decrease is needed.

Similarly, for 2 Mbps data rate, the jitter plot has a lesser slope which means increasing the transmission power does not have a huge effect on the jitter. Seeing the plot, we could say that any value between 20dBm to 30dBm generates allowable jitter. Further, for 100 kbps any value nearer to 30dBm could be considered as the optimum transmission power value. Finally, for the 9.2 Kbps, we could use any value more than 30 dBm as the transmission power for the communicating node.

Table 5.11 Average End to End Delay

Transmission power (dBm)	10 Mbps with 30m	2 Mbps with 50m	100 Kbps with 80m	9.2 Kbps with 200m
20	6.75E-03	3.00E-02	3.10E-01	5.50E-01
30	2.10E-04	3.50E-03	7.50E-03	8.40E-02
40	7.10E-05	7.40E-04	4.15E-04	5.10E-03

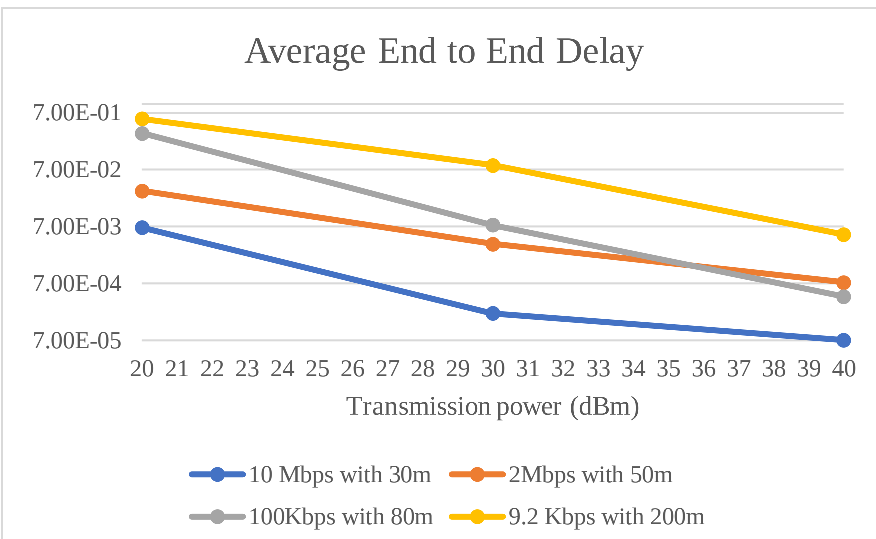

Fig 5.6 Average End to End Delay vs Transmission power(dBm)

The average end to end delay is shown in relation with the transmission power in the Fig 5.6. As the latter increases the former decreases depending upon the transmission data rate. For the optimum value of end to end delay, we see that by choosing the ranges of transmission power mentioned in Table 5.12 for the different values of data rate, we can optimized the whole network.

Table 5.12 Optimum range of transmission value for different data rates

10 Mbps with 30 m	20 dBm< P <25 dBm
2 Mbps with 50 m	25 dBm <P <30 dBm
200 kbps with 80m	30 dBm<P <35 dBm
8 kbps with 200m	35 dBm<P<40 dBm

Therefore, the energy and the battery model can be devised accordingly for a network. The battery consumption model includes power consumed in various states of the node i.e idle, transmitting, receiving and sleep. Different amount of battery charge is consumed in different states. Optimum value of power is required to be known so that we can efficiently use the power capacity of the node and increase its lifetime.