CDMA-based multi-domain communications network for marine robots

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Outline

Introduction

Background

Methodology

Simulation and Results

Conclusion

References

Problem definition for research project

- design a CDMA-based communications protocol that can span above, surface and underwater with the following capabilities:

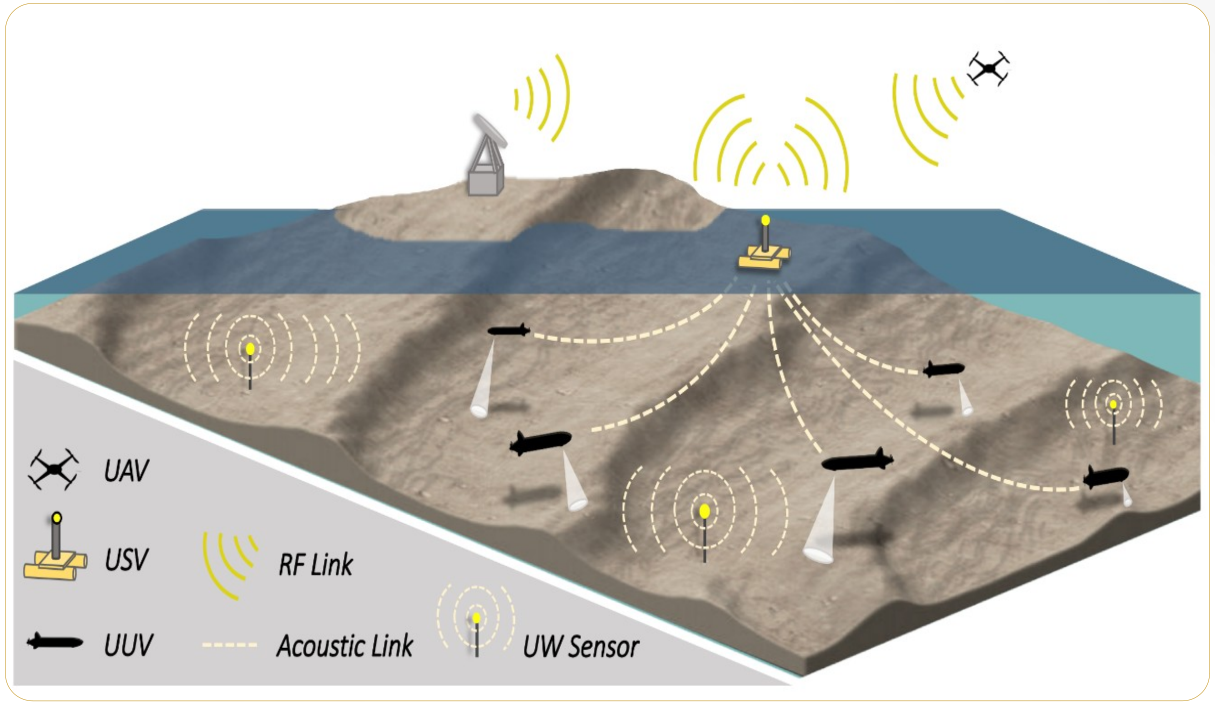


Figure 1: Robotic multi-vehicle collaboration – above and below water [7]

- robustness to frequency selective fading,
- compensates for multi-path effects at the receiver,
- allows receivers to distinguish among signals simultaneously transmitted by multiple devices.

Patel, J., Seto, M., "CDMA-based multi-domain communication network for marine robots", ACM WUWNET, Oct 2019, 2 pages.

Introduction (1/2)

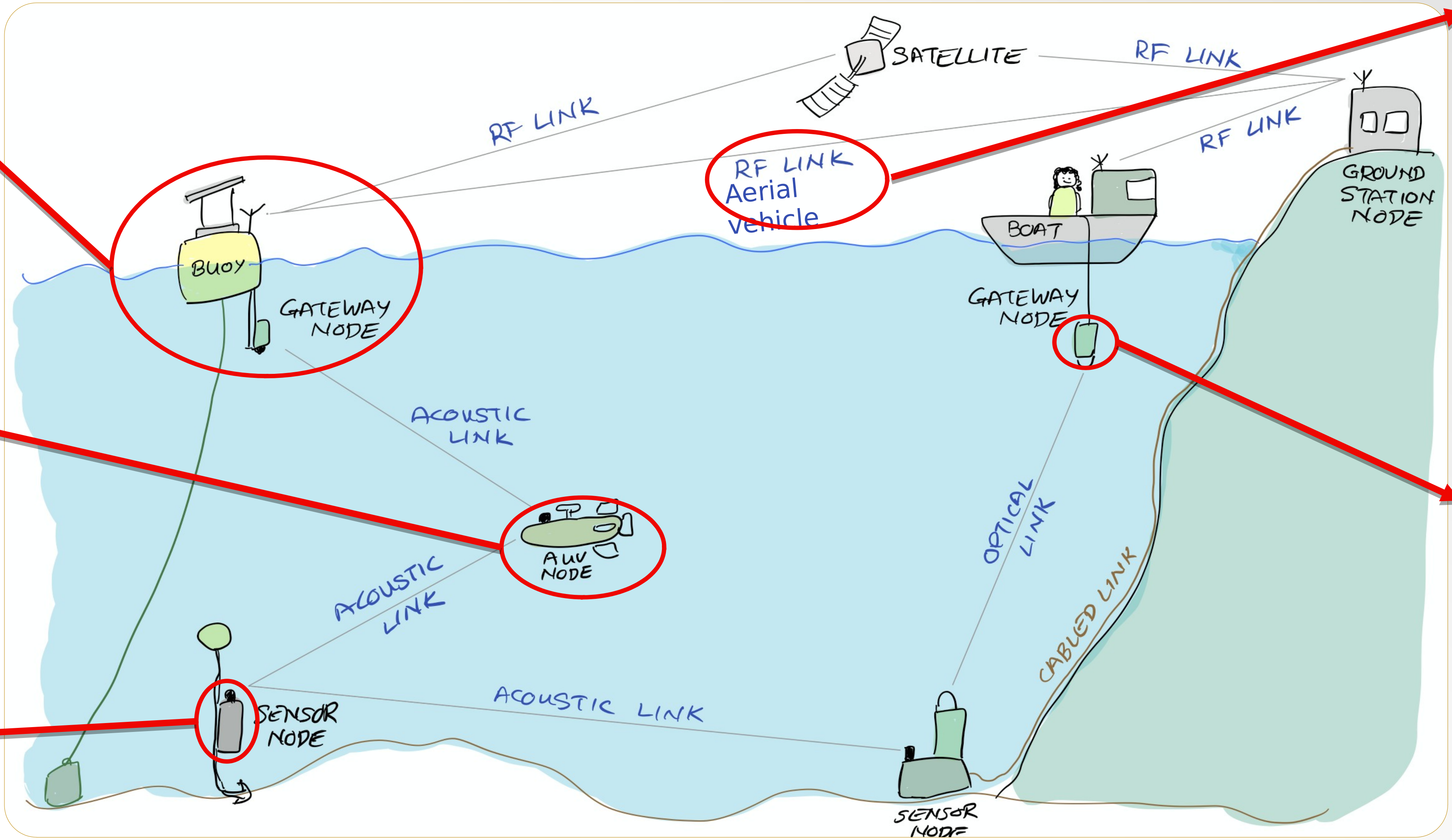


Figure 2: Network architecture of multi-vehicle collaboration above and below water +credit : subnero.com

Introduction (2/2)

Patel, J., Seto, M., "Underwater channel characterization for shallow water multi-domain communications", ACM ICUA, Sep 2020, 8 pages.

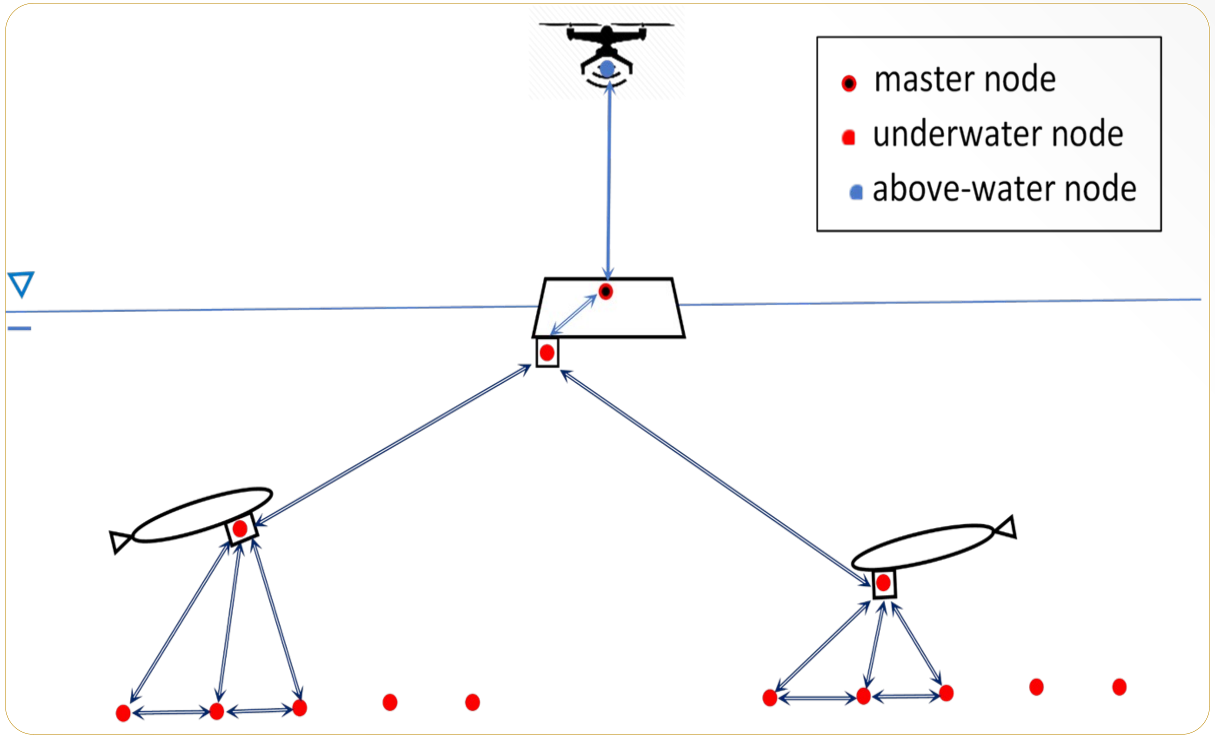
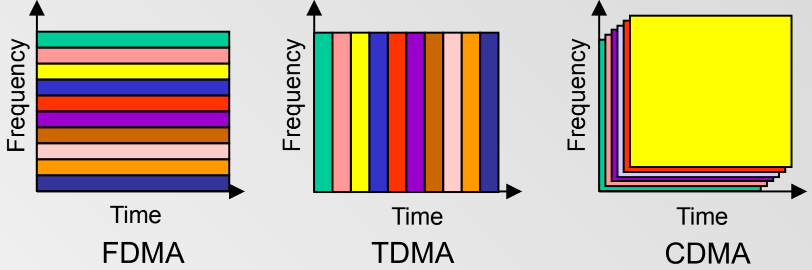


Figure 3: Heterogeneous marine sensor network architecture

- concept of operations: heterogeneous marine robots (unmanned underwater vehicle (UUV), unmanned surface vehicle (USV), and unmanned aerial vehicle (UAV)) collaboratively acquire situational awareness on a floating/any target,
- analyze impact of channel characteristics on level and quality of underwater communications .

Background



- motivation of this research follows the concept of [15] where 7-UUVs, 2-USVs, and 1-UAV collaboratively communicate underwater information using TDMA for under, on and above water.

Exercise UNMANNED WARRIOR 2016

+Credit : DRDC Canada

- proposed, is to use CDMA instead, so the full channel bandwidth is simultaneously used for multiple signals.
- following tools are integrated for simulations:
  - MATLAB (Initial stage),
  - Network Simulator-3 & WOSS,
  - Bellhop Acoustic Toolbox.

Patel, J., Seto, M., “Live RF Image Transmission Using OFDM with RPi and PlutoSDR”, Proc. IEEE CCECE, Sep 2020, 6 pages.

State of the art (1/3)

- CDMA is a spread spectrum technique for multiple access, allows

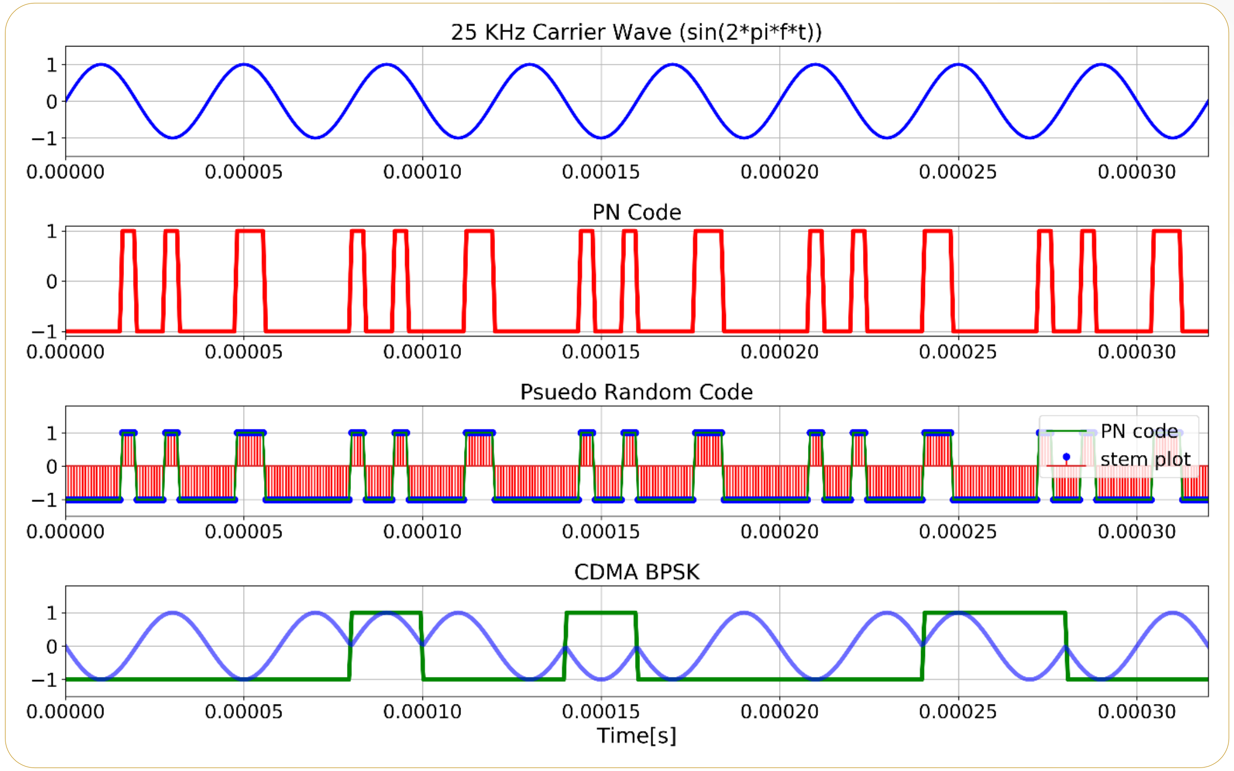


Figure 4: CDMA BPSK signal generation

- CDMA employs spread spectrum technology and a special coding scheme (each transmitter is assigned a code) to allow multiple users to be multiplexed

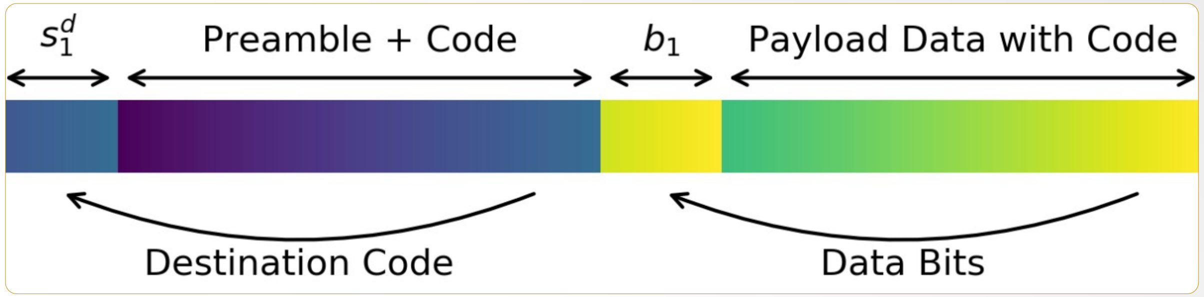


Figure 5: Modified UDP packet format

CDMA State-of-the-art (2/3)

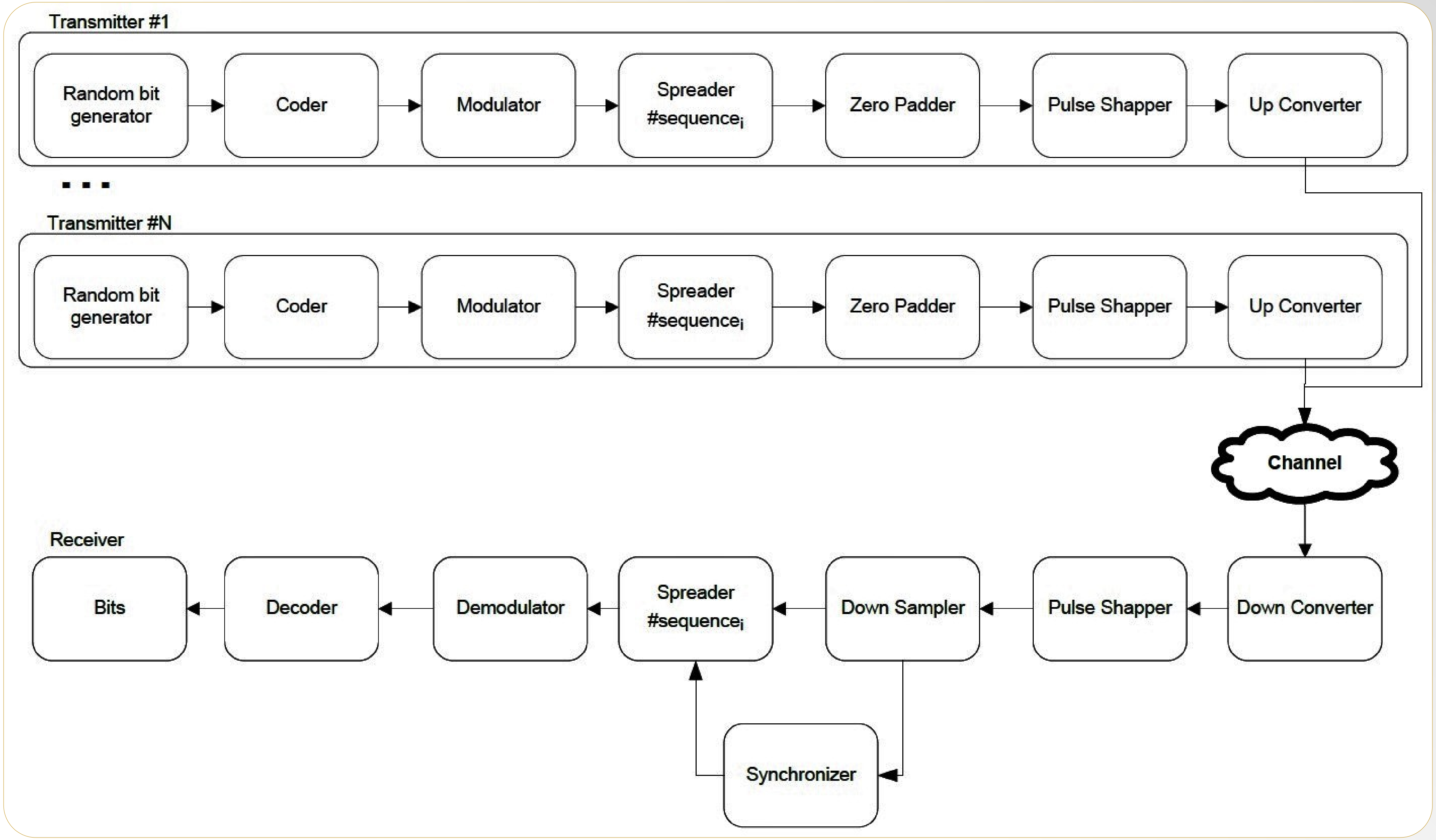


Figure 6: General structure of CDMA communication system [Thesis]

State of the art (3/3)

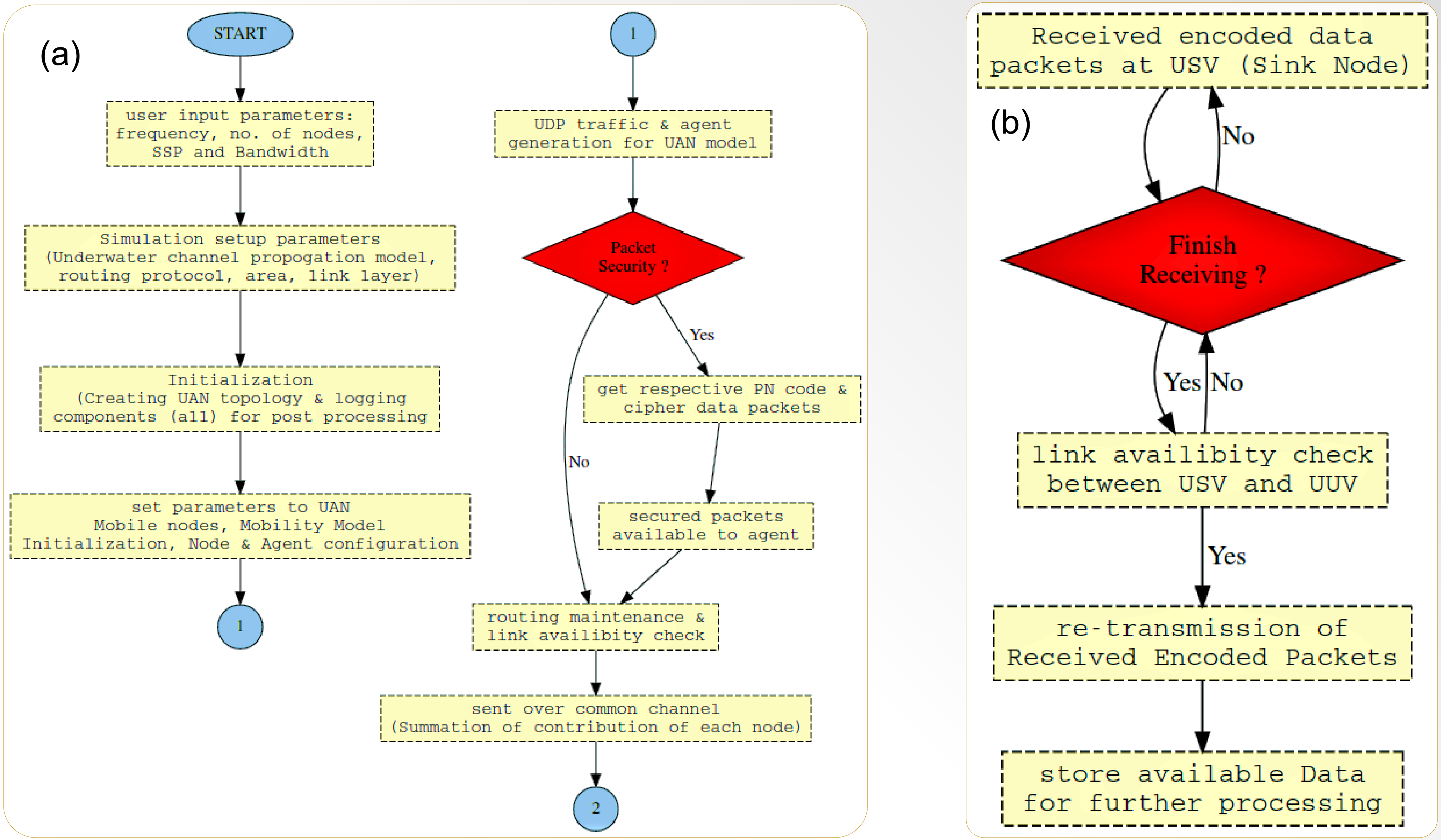


Figure 7: CDMA architecture: (a) transmit encoded signals between mobile nodes and the master node and (b) receive encoded signals between mobile nodes and master node.

Patel, J., Seto, M., "CDMA-based multi-domain communication network for marine robots", Proc. ACM WUWUNET, Oct 2019, Poster.

Methodology (1 / 5)

- custom MATLAB-based GUI+ used for simulations of test cases

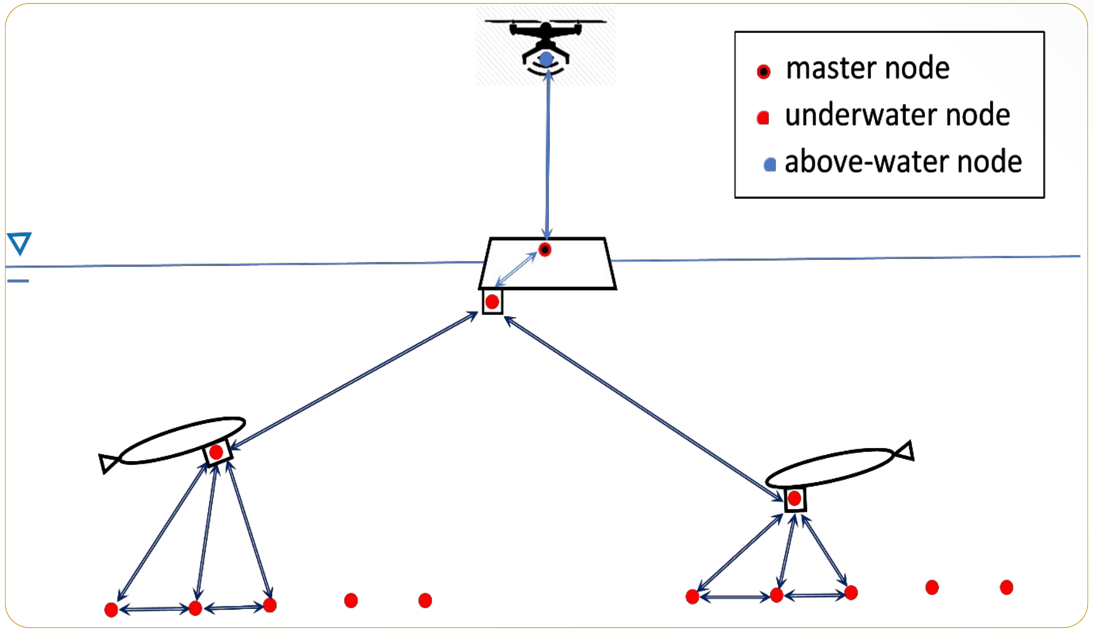


Figure 3: Heterogeneous marine sensor network architecture

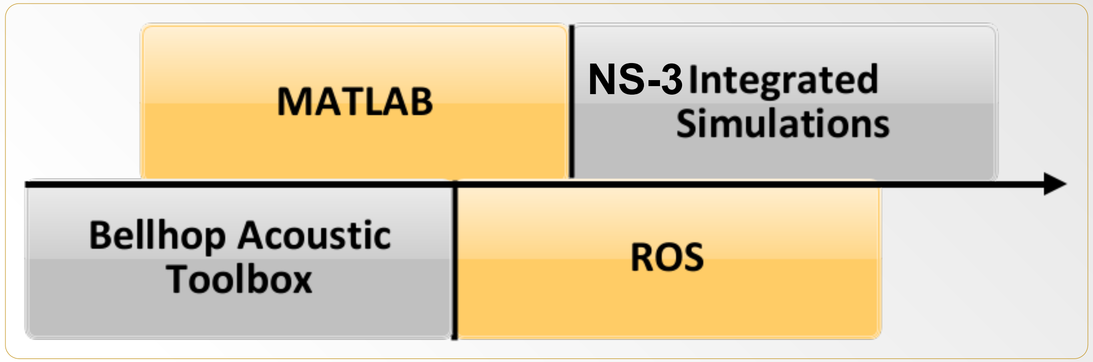


Figure 8: Software framework

+ graphical user interface

Patel, J., Seto, M., “Underwater channel characterization for shallow water multi-domain communications”, ACM ICUA, Sep 2020, 8 pages.

Methodology (2 / 5)

- GUI , planning to open source it soon to the community.

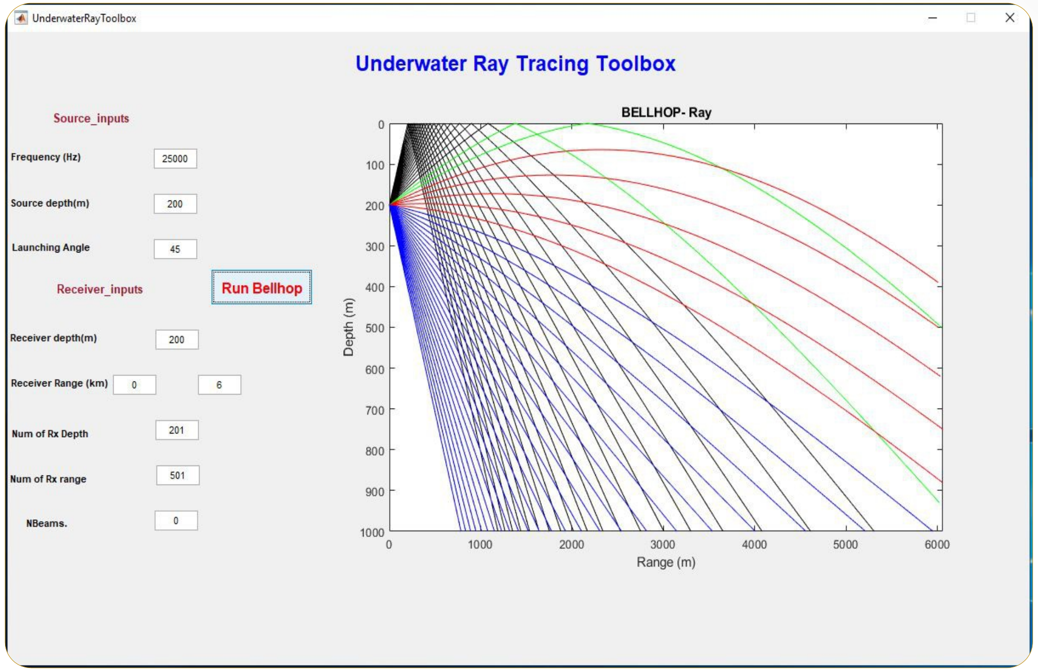


Figure 9: Ray tracing from Underwater Ray Tracing Toolbox – MATLAB custom GUI

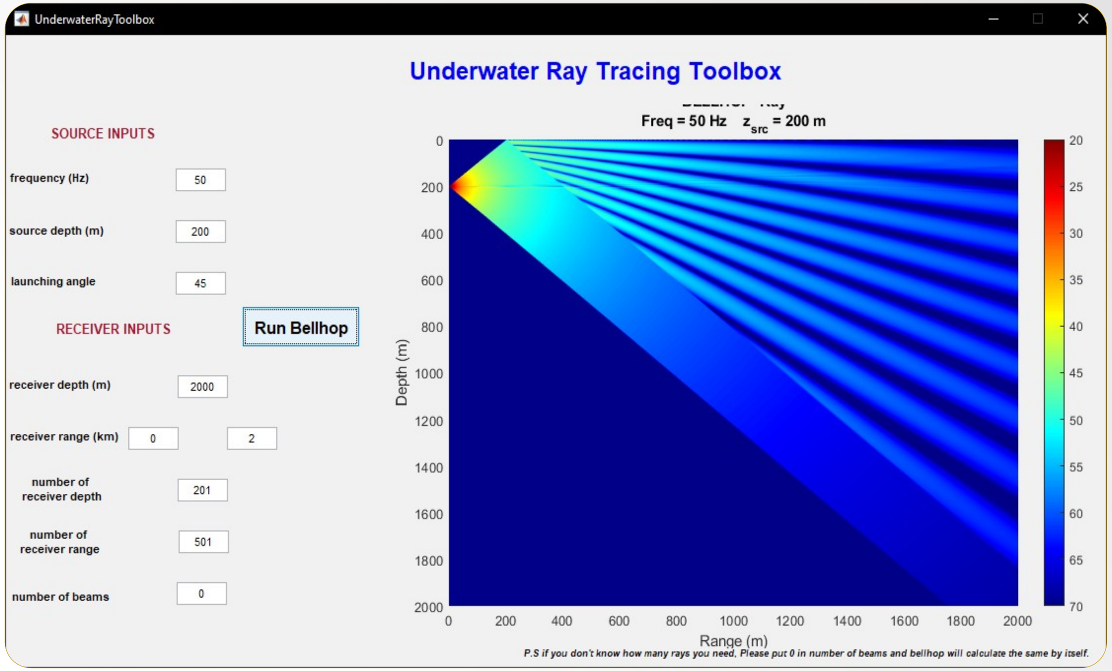


Figure 10: Transmission loss from Underwater Tracing Toolbox – MATLAB custom GUI+

Methodology (3 / 5)

- GUI developed with MATLAB, plan to open-source it soon to the community

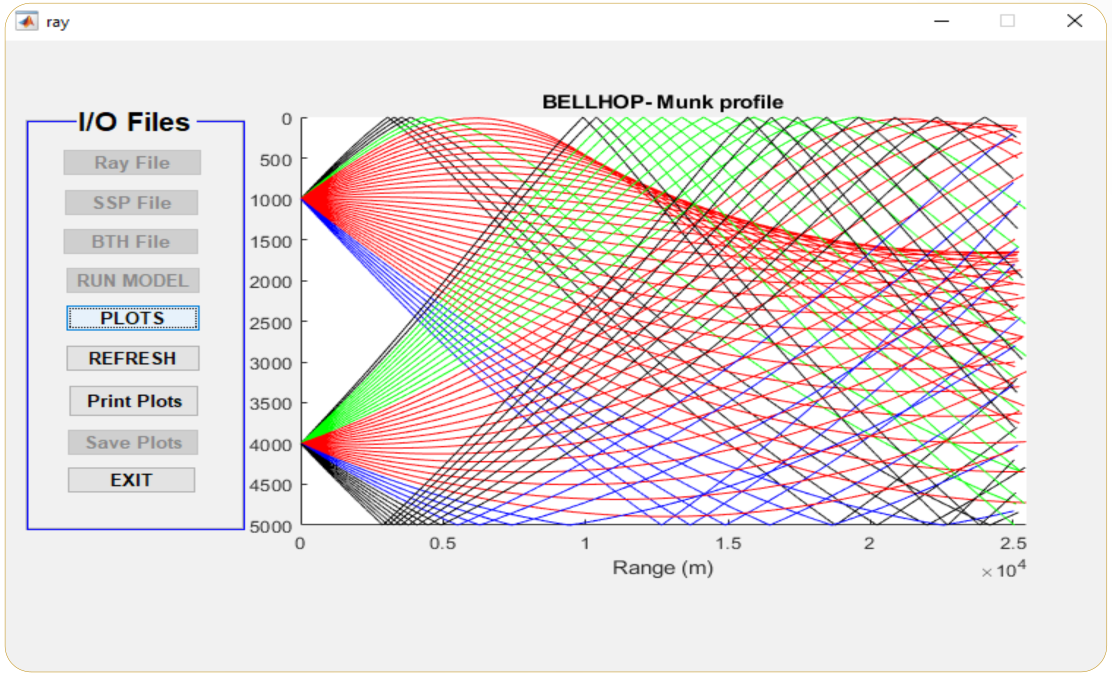


Figure 11: Ray plotting using Underwater Ray Tracing Toolbox – Plotting Toolbox

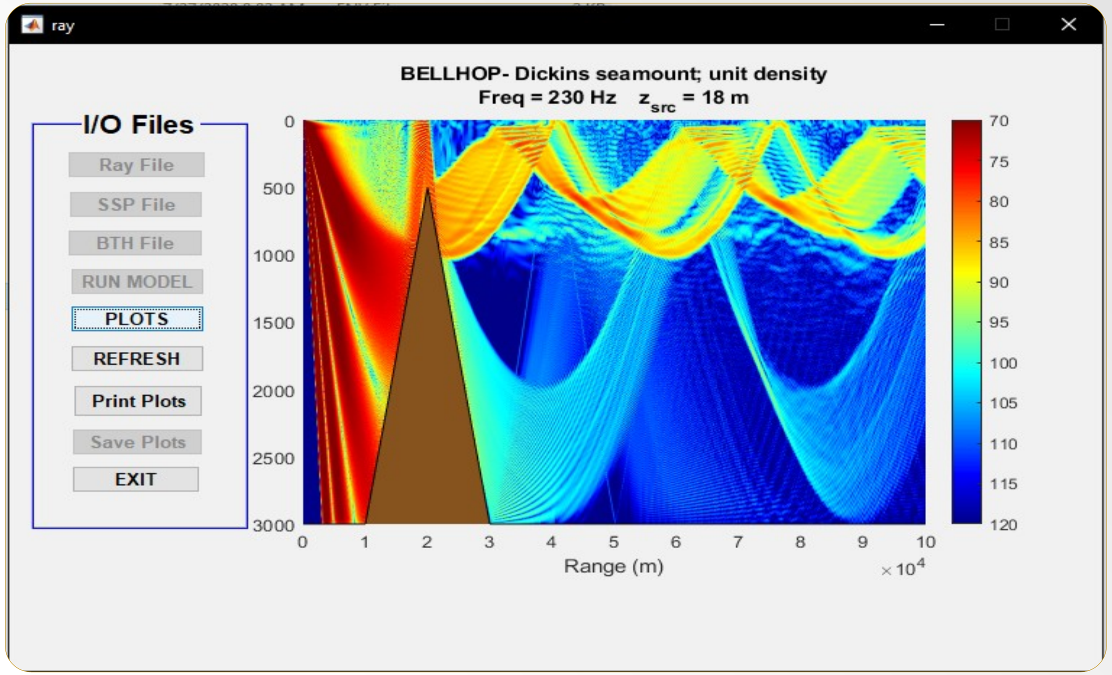


Figure 12: TL plotting using Underwater Ray Tracing Toolbox – Plotting Toolbox

Methodology (4 / 5)

- Network Simulator-3

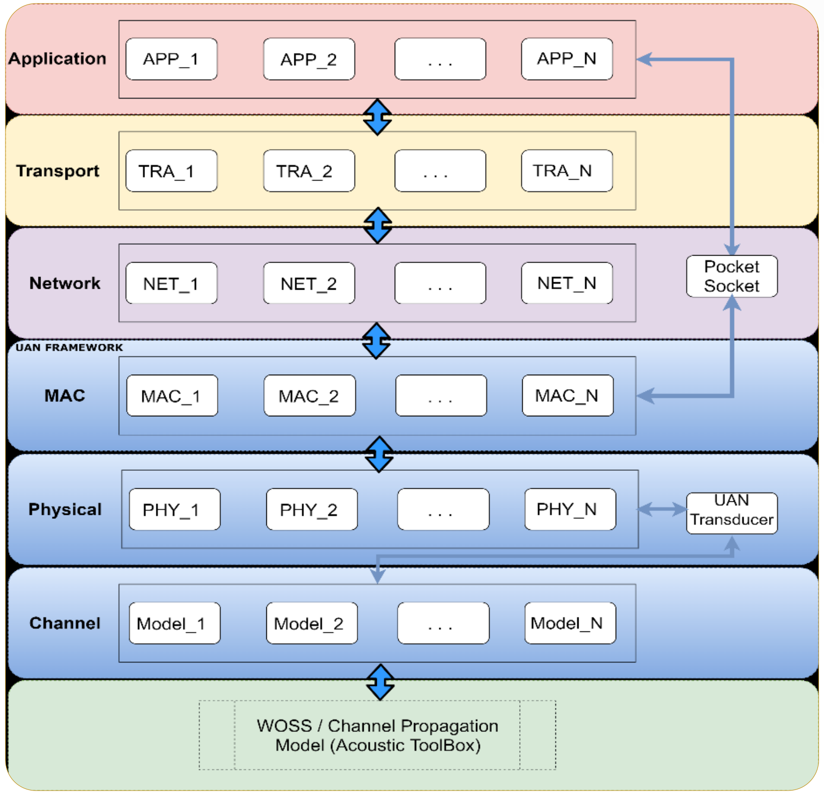


Figure 13: Proposed framework for simulation

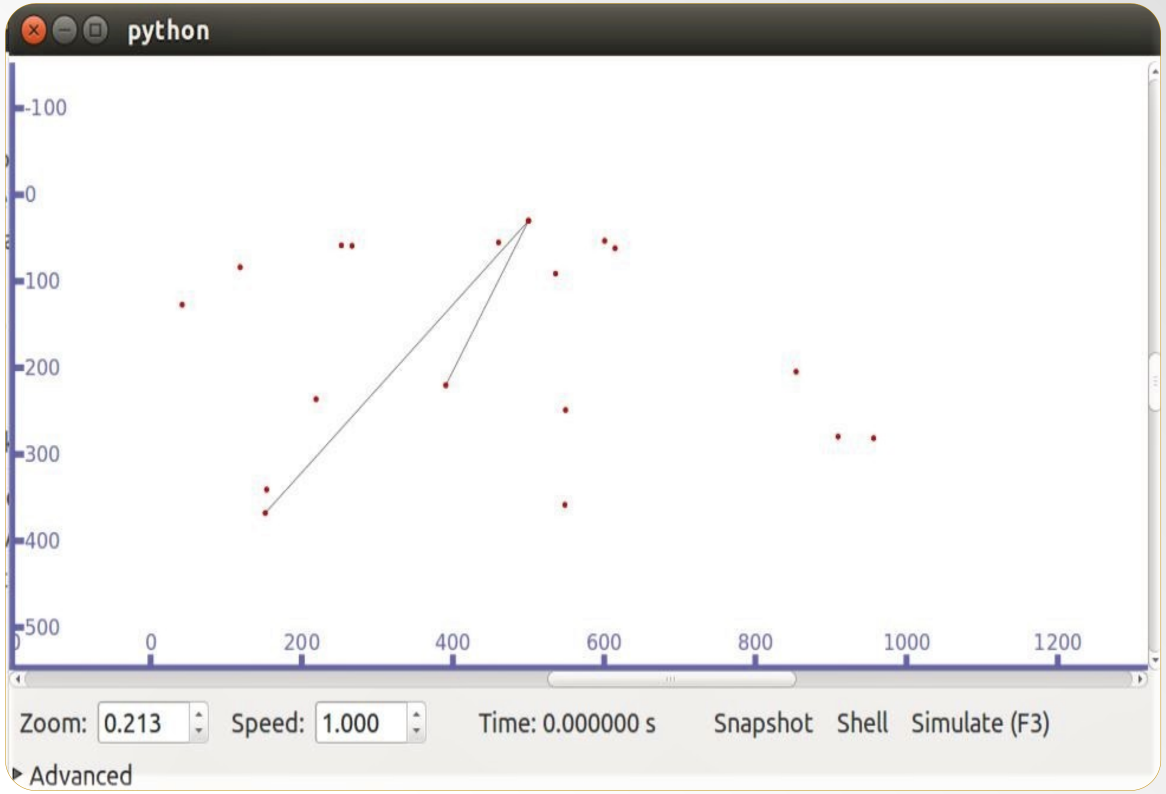


Figure 14: Python GUI (NS-3) to display simulations

Methodology (5 / 5)

- WOSS [12] integration with NS-3

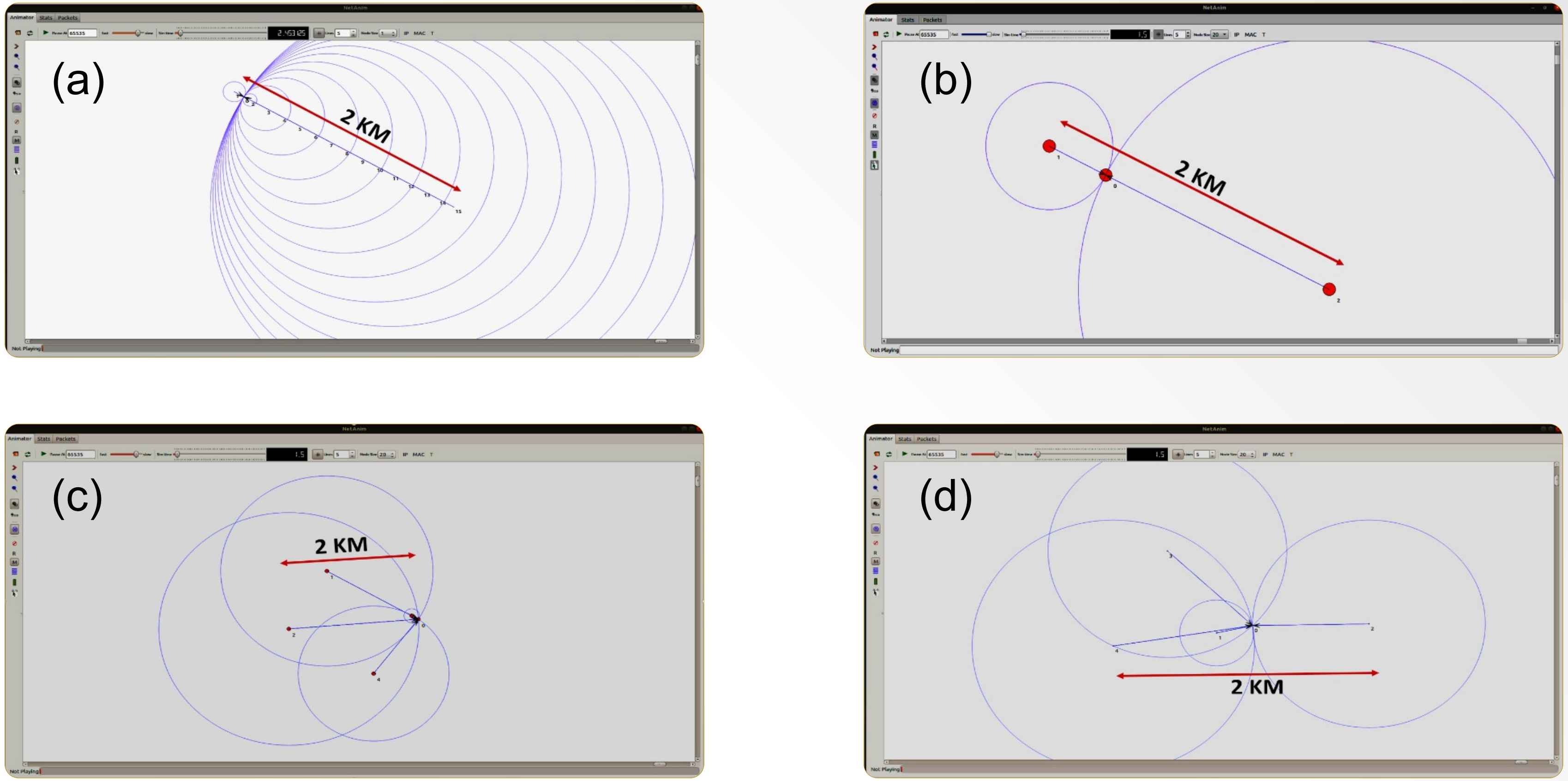


Figure 15: Various node deployments (a) List position allocation to 15 nodes (b) List position allocation to 2 nodes (c) Grid position allocation to 5 nodes (d) Random disc position allocation to 5 nodes

Simulation objectives

Patel, J., Seto, M., “Underwater channel characterization for shallow water multi-domain communications”, ACM ICUA, Sep 2020, 8 pages.

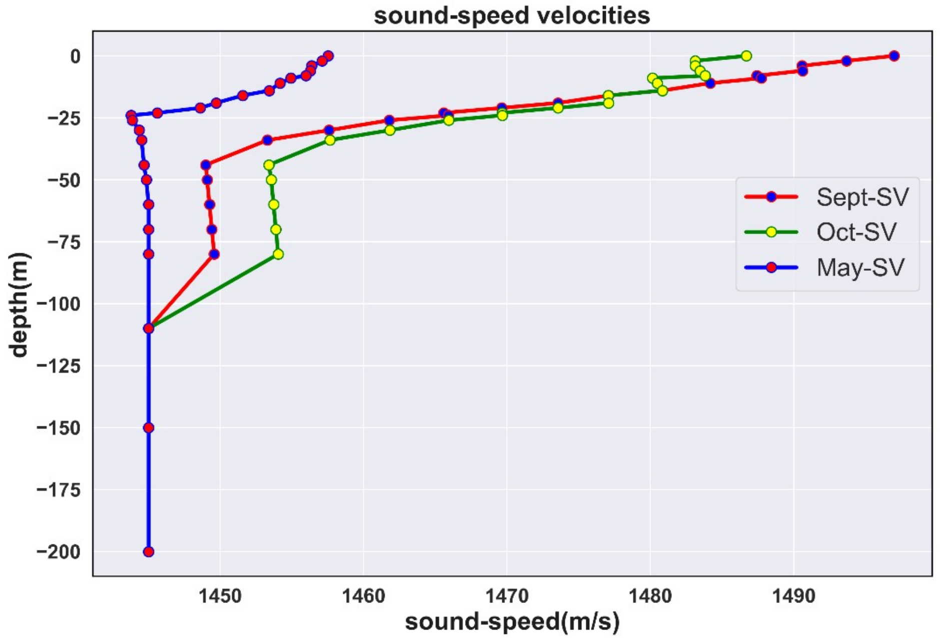
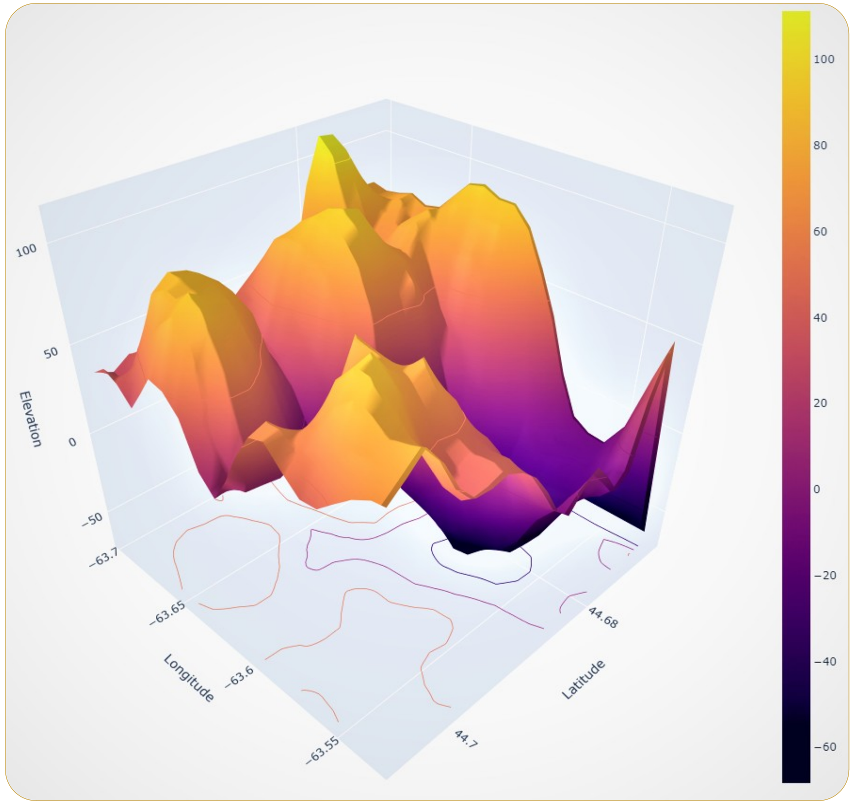
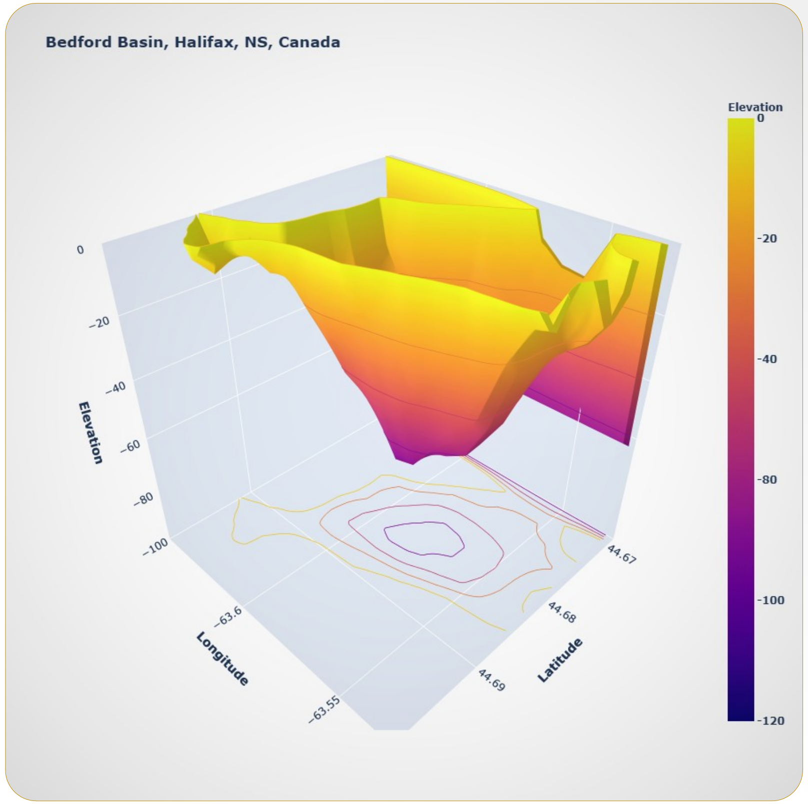


Figure 16: Sound-speed profile of Bedford Basin used in simulation test cases [3]

- prior to deploying robots, predict communication system performance
- provide guidance on best physical layout to deploy underwater vehicles given environmental conditions
- provide estimates on parameters for link budget calculation

Bedford Basin bathymetry used for simulations





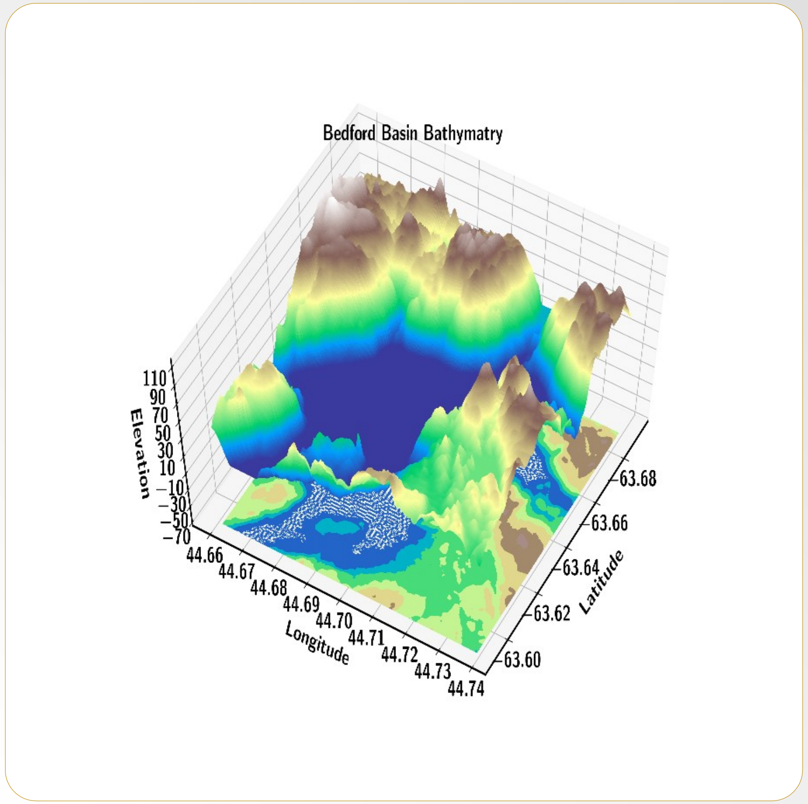


Figure 17: Detailed Bathymetry of Bedford Basin - Halifax, NS, Canada

Bellhop Simulations – Shallow water

Table 1: System parameters to simulate

parameter	value
frequency	25 kHz
water depth	20, 50 m
range	0-6 km
USV uw modem depth	1.8 m
UUV depth	3, 10 m

- from predicted transmission loss to determine the optimal range (function of water depth, UUV depth = 3, 10 m)

J. Ross, J. Lindsay, E. Gregson, A. Moore, Patel, J. and Seto, M. "Collaboration of multi-domain marine robots towards above and below-water characterization of floating targets" Proc. IEEE ROSE Conf., Apr 2019.

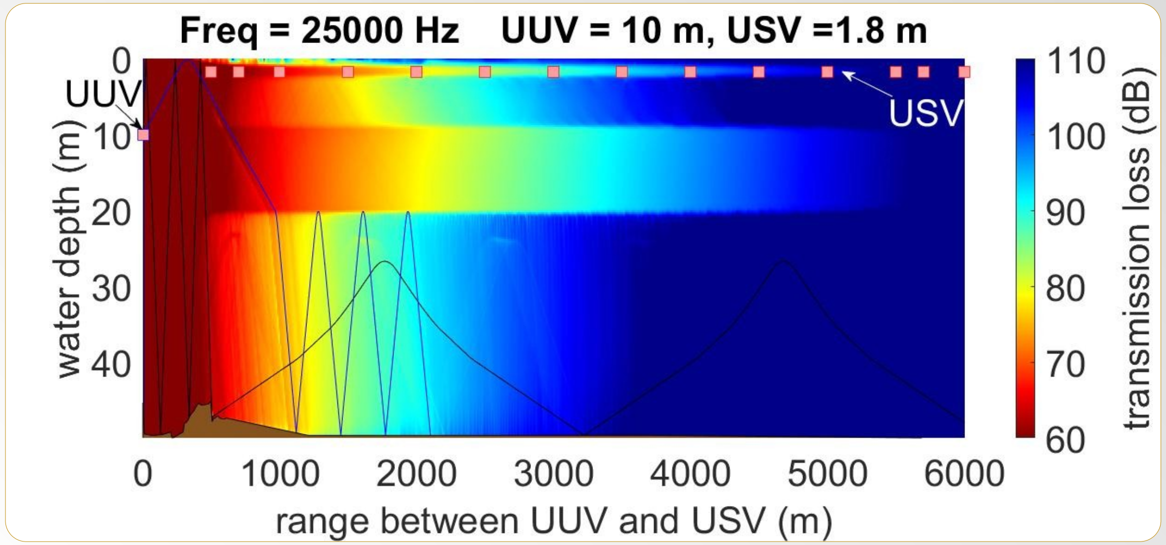


Figure 18: Ray Traced and TL with water depth = 20 m

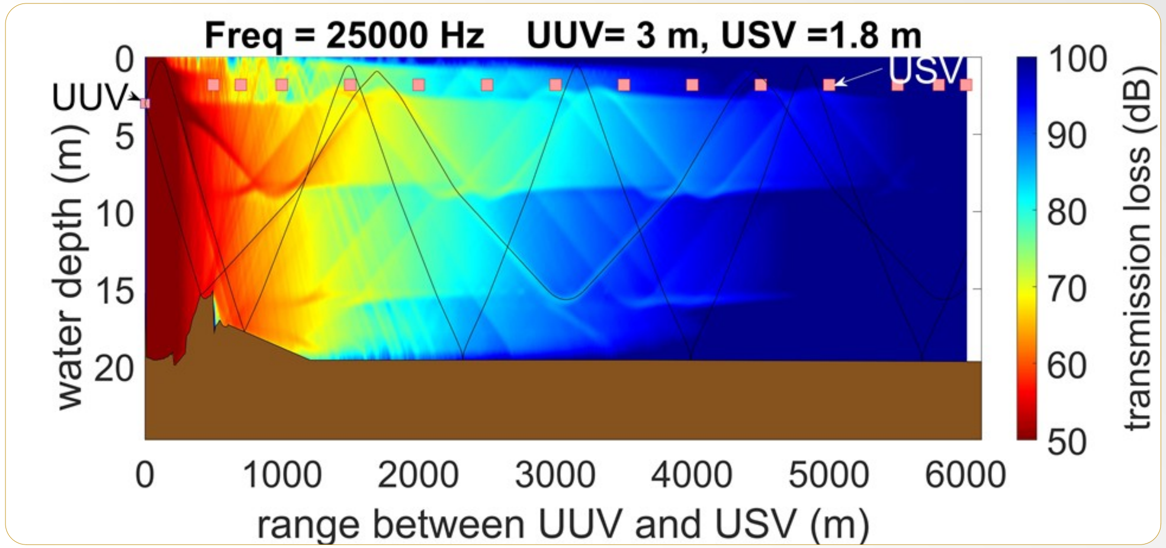


Figure 19: Ray traced and TL with water depth = 50 m

I. Communication signal generation (simulations) (1 / 2)

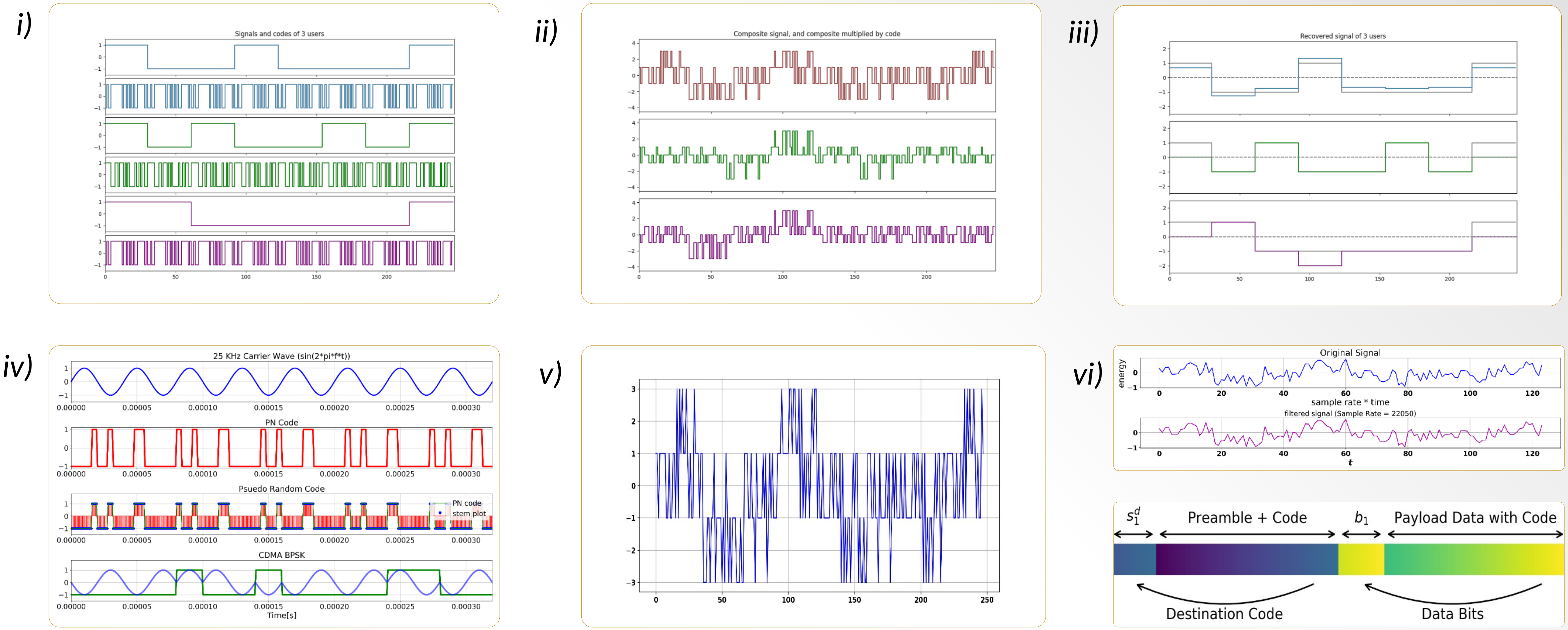
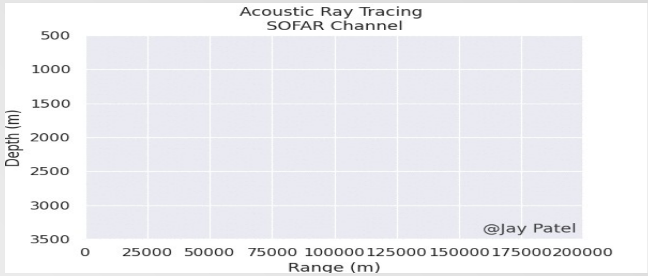


Figure 20: CDMA signal: i) signal for 3 receivers; ii) multiplexed composite signal; iii) recovered signal; iv) CDMA-BPSK signal; v) composite signal for receiver 1, and vi) generated & recovered CDMA.wav; modified packet format

II. Channel response (simulations) (2 / 2)



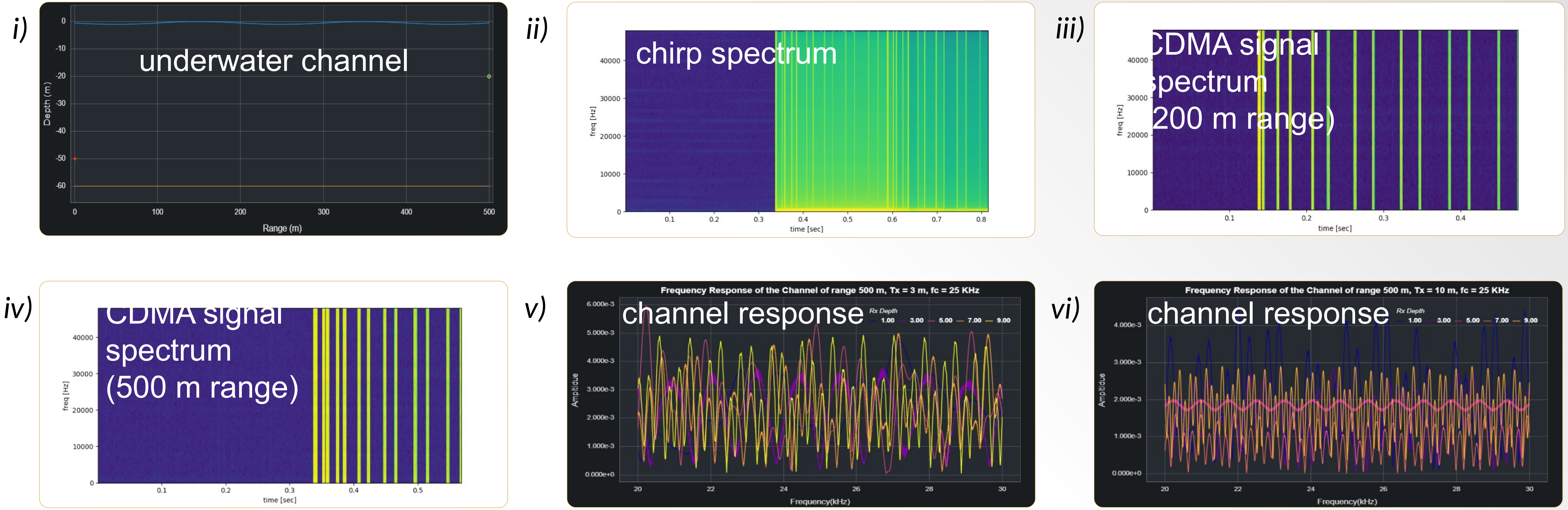
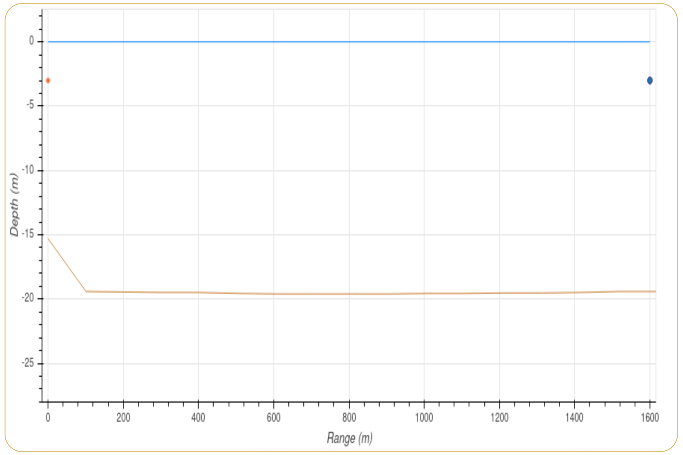


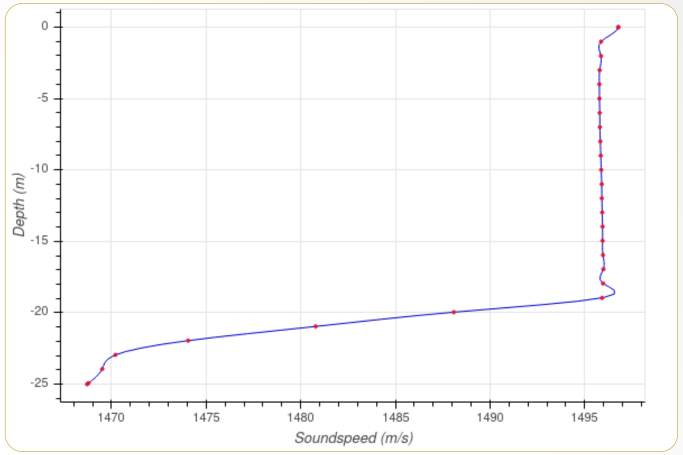
Figure 21: For water depth = 60 m; fc = 25 KHz starting from top left corner: i) UW-env; ii) spectrum of chirp signal; iii) spectrum of CDMA signal (range=200 m); iv) spectrum of CDMA signal (range=500 m); v) channel multi-frequency response (Tx=3 m), and vi) channel multi-frequency response (Tx=10 m)

III. Simulation results (water depth = 20m, Tx = 3m, Rx = 3m, range = 1.6 km) (1 / 2)

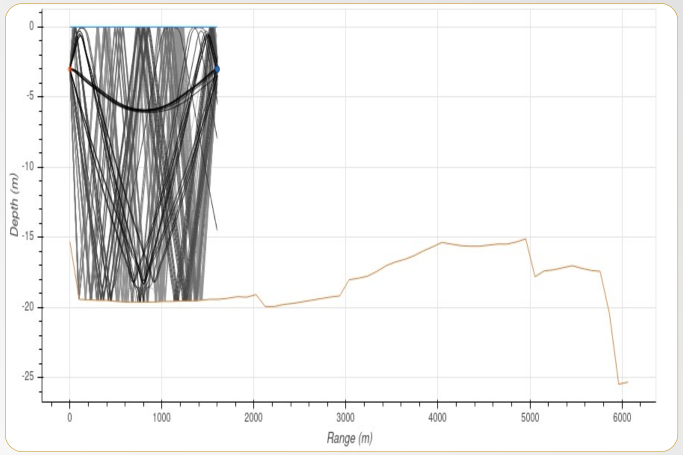
i)



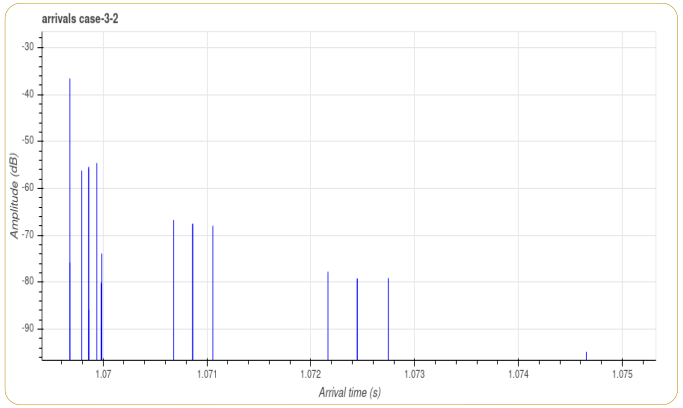
ii)



iii)



iv)



v)

	time_of_arrival	angle_of_arrival	surface_bounces	bottom_bounces
1	4.015582	-2.466159	7	8
2	4.015464	1.559378	6	8
3	4.015863	3.562261	9	8
4	4.015080	11.344101	9	8
5	4.015329	9.273050	9	8
6	4.015079	11.354420	9	8
7	4.015327	9.285923	9	8
8	4.015584	6.752951	9	8
9	4.015075	11.394584	9	8
10	4.015200	10.405143	9	8

vi)

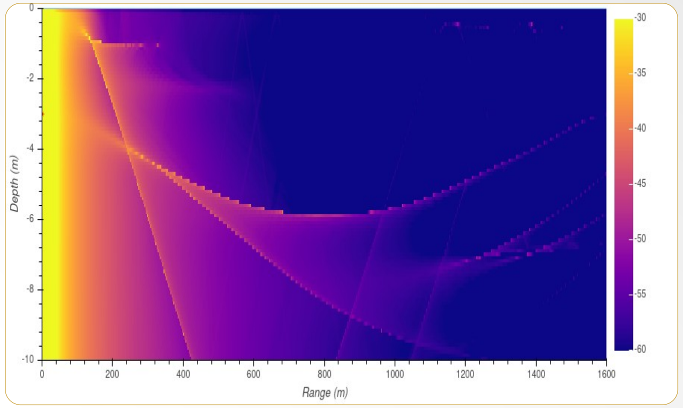
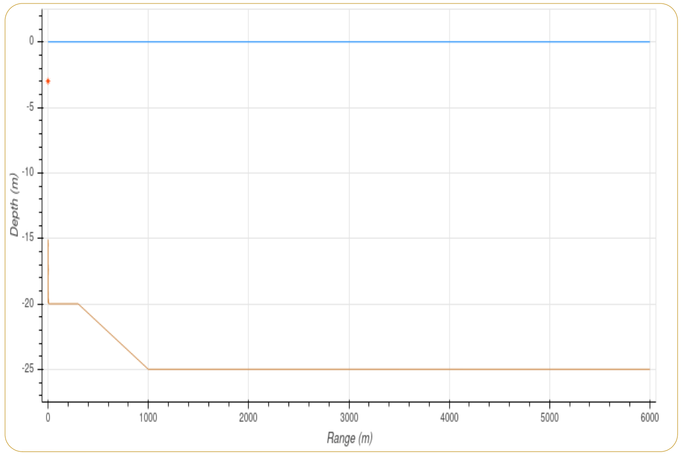


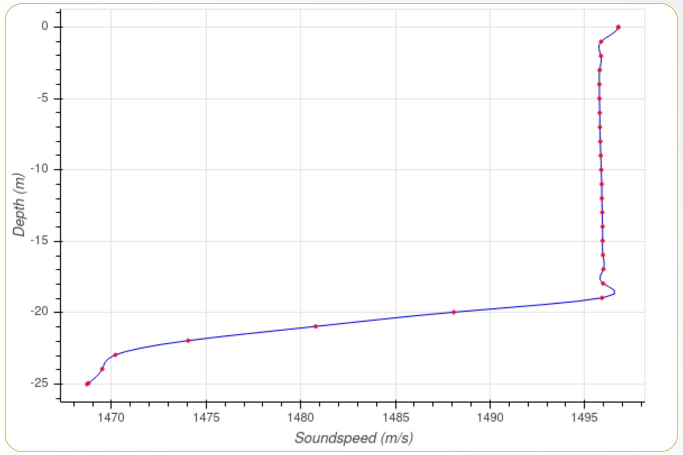
Figure 22: For water depth = 20 m; Tx=3m; Rx= 3m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) incoherent TL

III. Simulation results (water depth = 25 m, Tx = 3m, Rx=10m, range = 6 km) (2 / 2)

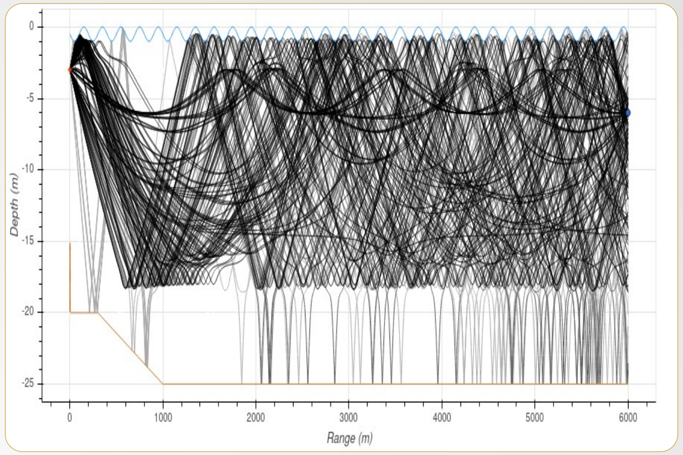
i)



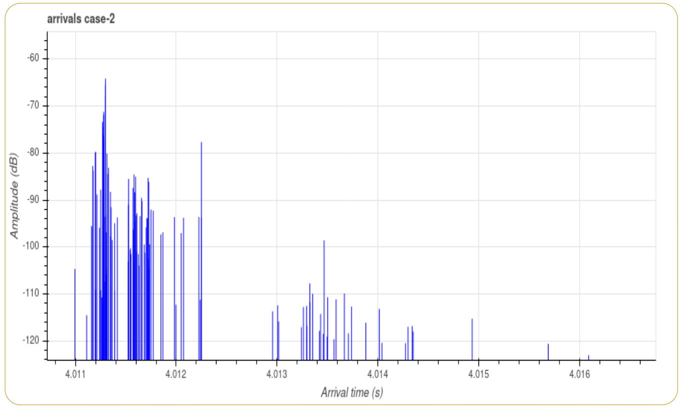
ii)



iii)



iv)



v)

	time_of_arrival	angle_of_arrival	surface_bounces	bottom_bounces
1	0.713725	-21.603680	13	13
2	0.711335	20.415777	13	12
3	0.706794	-19.402731	12	12
4	0.704646	18.202858	12	11
5	0.689760	-12.739491	9	9
6	0.694861	-17.684189	10	10
7	0.692903	16.470312	10	9
8	0.689241	-15.407454	9	9
9	0.679002	9.650291	7	6
10	0.676894	-8.537592	6	6

vi)

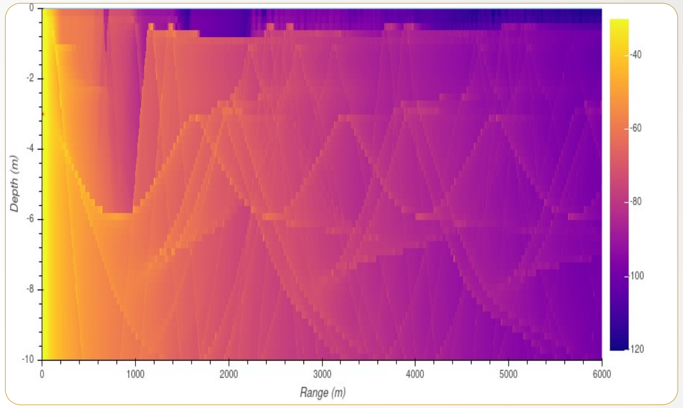


Figure 23: For water depth = 25 m; Tx=3m; Rx= 10m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) incoherent TL

CDMA and UW-GOAL Protocol performance comparison

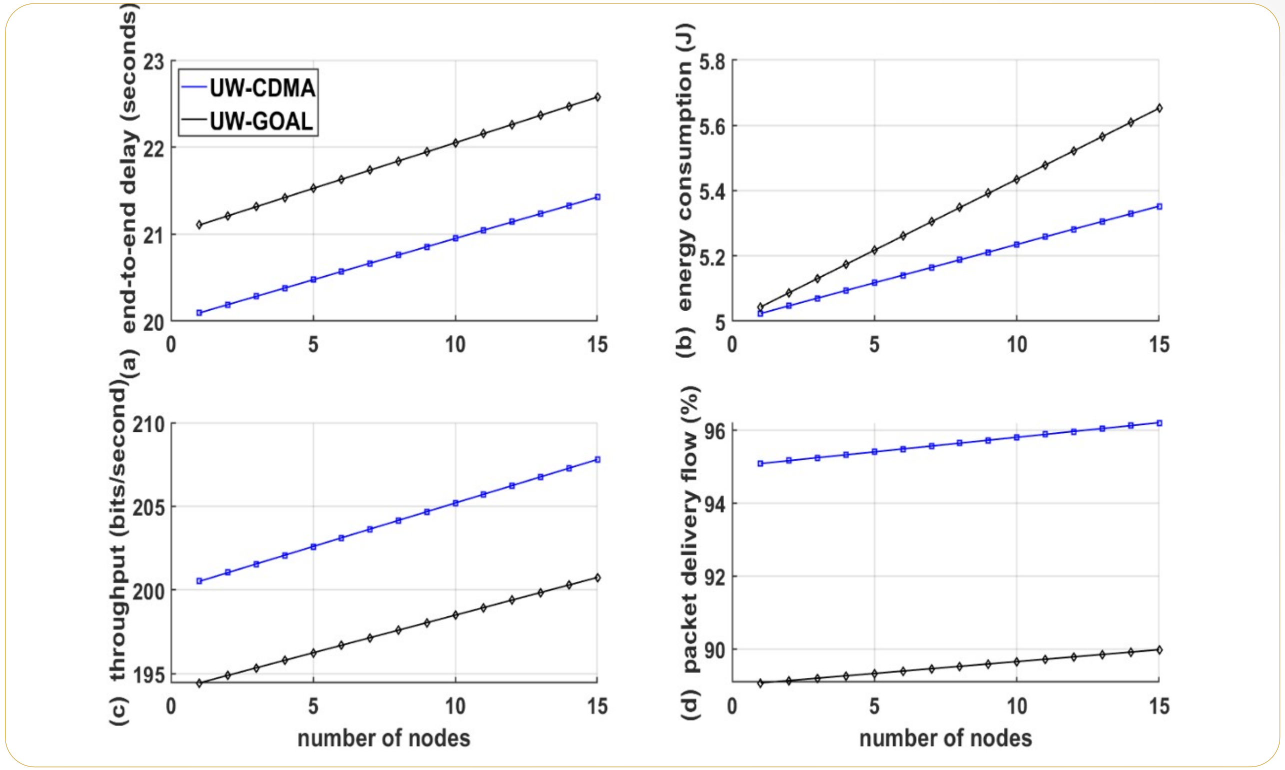
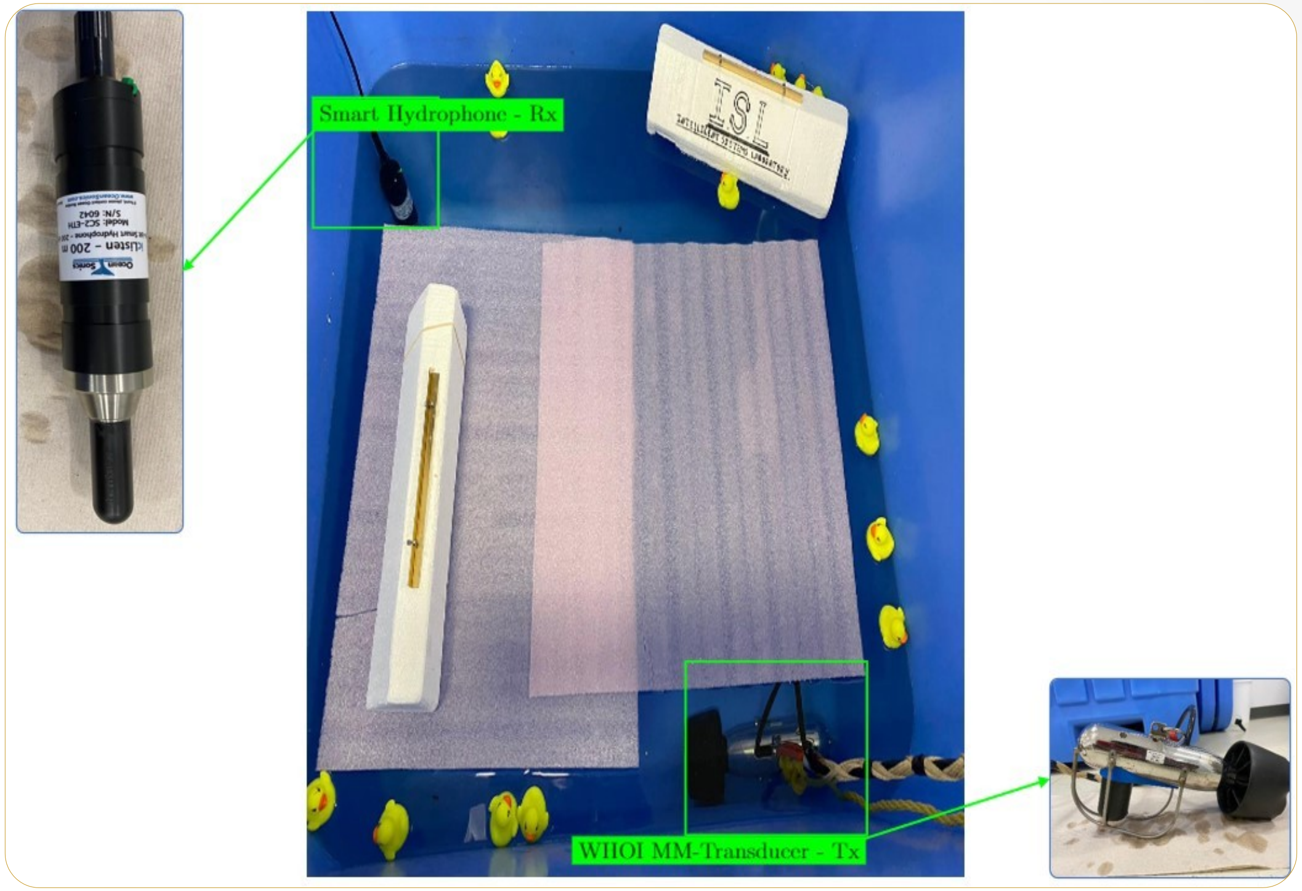


Figure 24: Performance comparison of UW-CDMA vs UW-GOAL

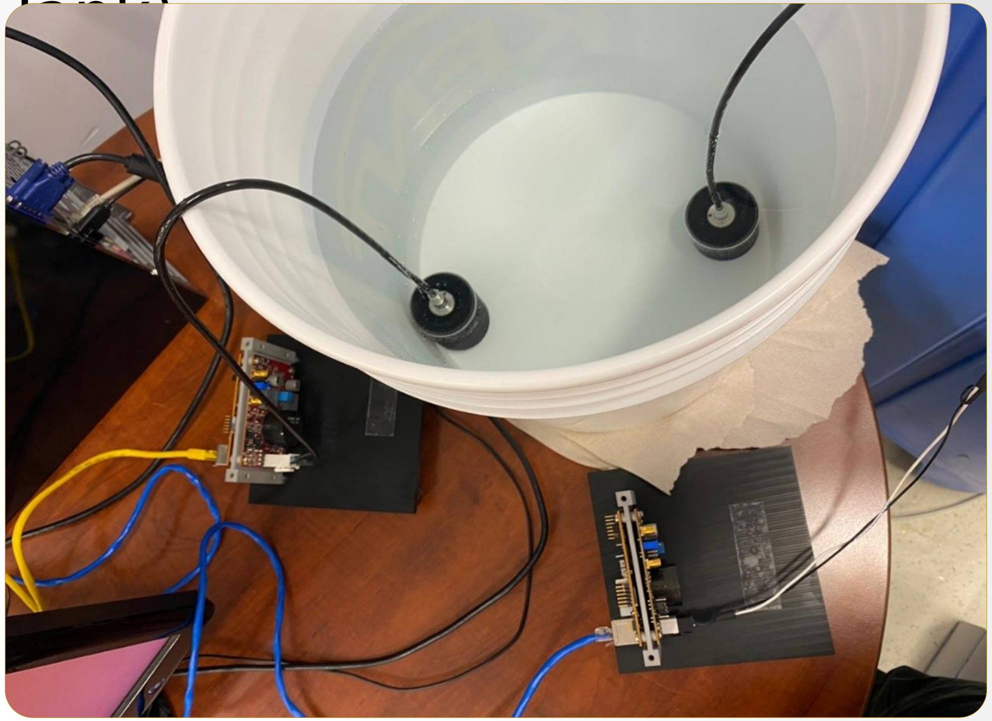
- end-to-end delay (EED) ,
- energy consumption ,
- throughput ,
- packet delivery flow .

What's Next ?

- Initial uw-modem selection and testing in water (Lab Tank)



Experimental setup of lab initial testing



Multiple OEM board (uw-modem) for lab-test

What's Next ?

Underwater Software Defined Modems +

- Hardware testing and in-water testing with minimal three nodes

Surface Node configuration +

+ *Credits : subnero.com*

Conclusion (1 / 2)

- simulating several underwater networks test case, it was observed that for the given environmental conditions, feasible range between UUV and USV as less than or equal to 1.3 km.
- simulation results are encouraging for the proposed CDMA protocol.

Gazebo simulations experimental validation of all 3 marine robots in the experimental validation.

J. Ross, J. Lindsay, E. Gregson, A. Moore, Patel, J. and Seto, M. “Collaboration of multi-domain marine robots towards above and below-water characterization of floating targets“ Proc. IEEE ROSE Conf., Apr 2019.

Conclusion (2 / 2)

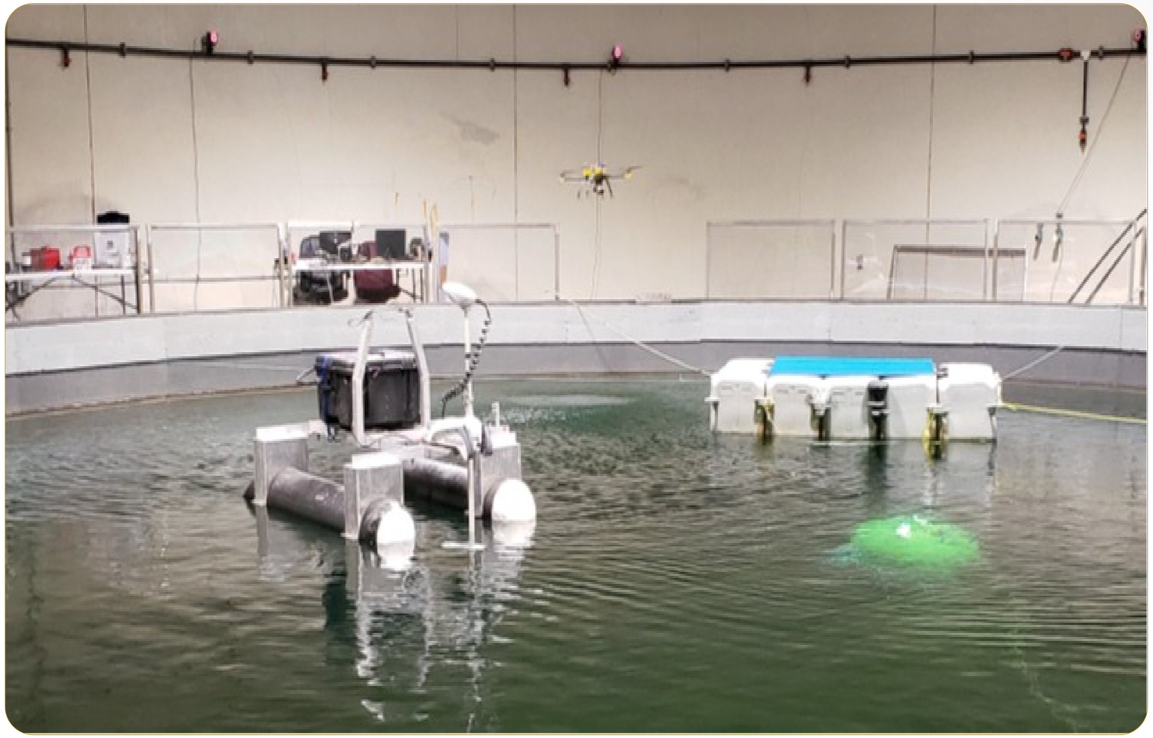


Figure 33: All 3 marine robots in the experimental validation. The USV is left in the foreground. The surfaced UUV is right in the foreground. The barge is behind both. The UAV is left of the barge. On the wall, the red LED rings are 3 of the 8 motion capture cameras installed in the Aquatron Pool tank. [6]

- Integration of hardware-in-loop simulator for multi-domain marine robots may increase the complexity.

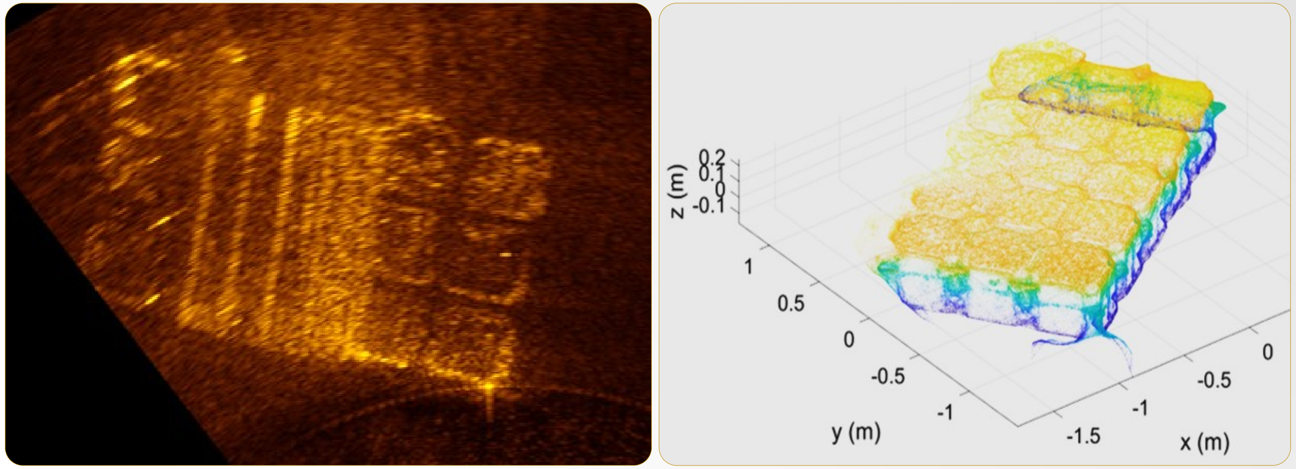


Figure 34: starting from left (a) Flexview sonar imaging of the barge underside from the IMOTUS UUV, (b) Optical camera photogrammetry reconstruction of the barge topside with the Pelican UAV on top of the bottom-side sonar (isometric view).[6]

Questions ?

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19. W. Hao et al. (2017) “A Novel Cross-Layer Routing Protocol Based on Network Coding for Underwater Sensor Networks.” Sensors (Basel, Switzerland) vol. 17,8 1821. 8 Aug. 2017, DOI:10.3390/s17081821

Relevant References from Literature Survey

Table 1: relevant literature survey

Sr No	Title	Authors	Published in
1.	Simulation and experimentation platforms for underwater acoustic sensor networks: Advancements and challenges[1]	Hanjiang Luo, KaishunWu, Rukhsana Ruby, Feng Hong, Zhongwen Guo, and Lionel M. Ni.	ACM Comput. Surv. 50, 2, Article 28 (May 2017), 44 pages
2.	Analysis of Simulation Tools for Underwater Sensor Networks (UWSNs) [2]	Nayyar A., Balas V.E.	Bhattacharyya S., Hassanien A., Gupta D., Khanna A., Pan I. (eds) International Conference on Innovative Computing and Communications. Lecture Notes in Networks and Systems, vol 55. Springer, Singapore, March 2019
3.	A CDMA-based Medium Access Control for UnderWater Acoustic Sensor Networks[3]	D. Pompili, T. Melodia and I. F. Akyildiz	IEEE Transactions on Wireless Communications, vol. 8, no. 4, pp. 1899-1909, April 2009
4.	Comparative analysis of routing protocols for under-water wireless sensor networks[4]	Hala Jodeh, Aisha Mikkawi, Ahmed Awad, and Othman Othman.	Proceedings of the 2nd International Conference on Future Networks and Distributed Systems (ICFNDS '18). ACM, New York, NY, USA, Article 33, 7 pages.
5.	Embedded systems for prototyping underwater acoustic networks: The DESERT Underwater libraries on board the PandaBoard and NetDCU[5]	I. Calabrese, R. Masiero, P. Casari, L. Vangelista and M. Zorzi,	2012 Oceans, Hampton Roads, VA, 2012, pp. 1-8.