signet.dei.unipd.it

Electromagnetic communications

UNWiS - Padova (Italy)

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Pros and cons of EM comm.

Radio frequency electromagnetic waves against acoustic/optic transmissions:

- Pros
  - Less Doppler
  - Less Multipath
  - Less shipping noise
  - Less affected by water turbidity and sunlight noise
  - Able to cross water-air boundary
  - Cheaper devices
- Cons
  - Affected by strong attenuation
  - Difficulty of propagation

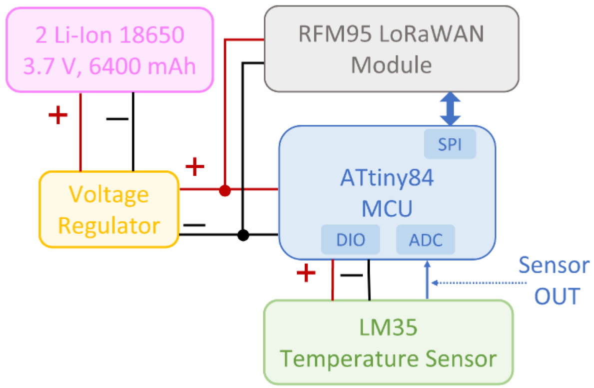
Case study: LoRaWAN

- Modulation technique: spread spectrum modulation (derived from chirp spread spectrum)
- Carrier frequency (EU): 863-870 MHz
- Bandwidth: (125-250) KHz
- Spreading Factor: (7..12)
- Code Rate: (1/2-4/5)

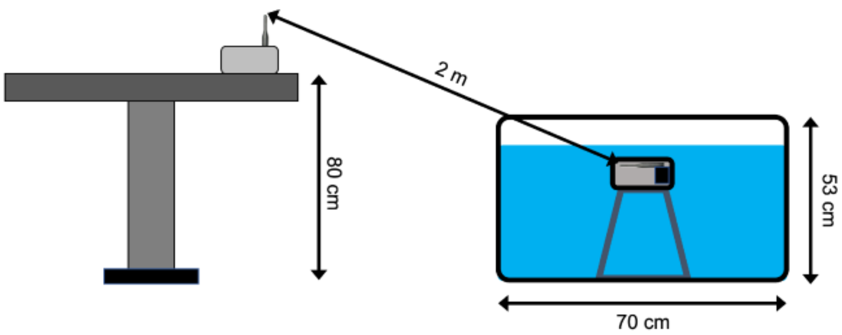
We want to study how this technology works underwater

Preliminary Laboratory test

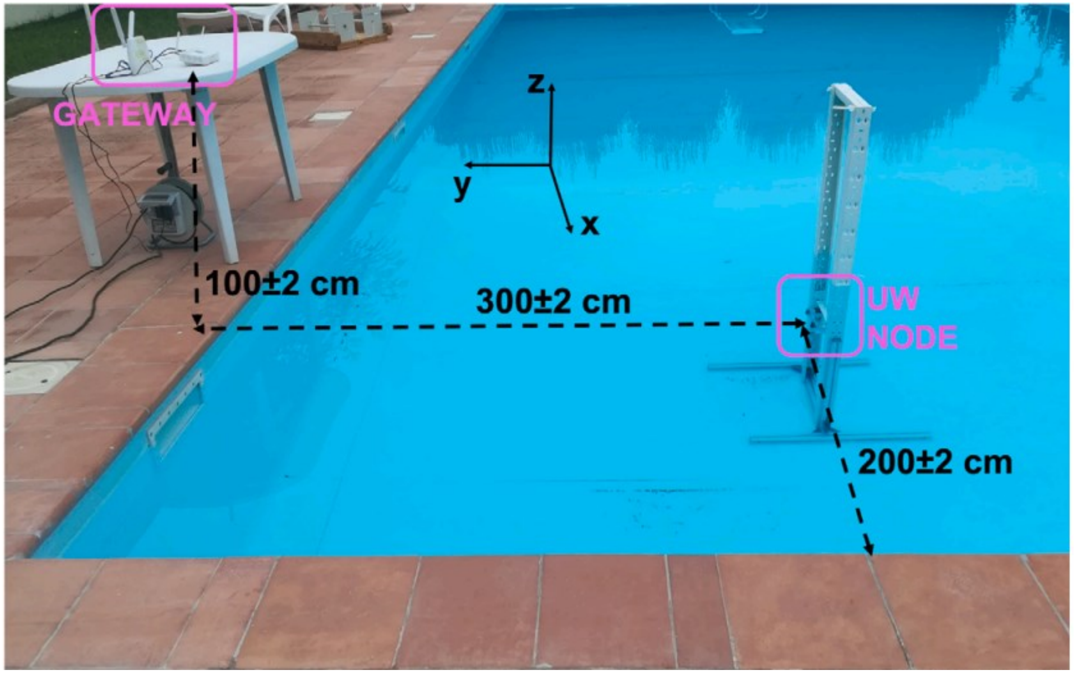
Architecture of the transmitter node:

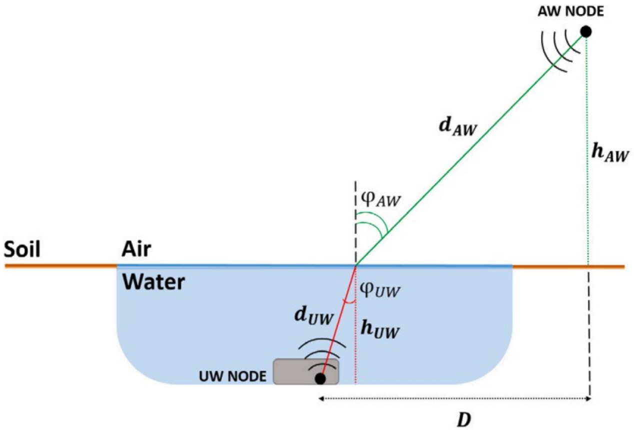


Laboratory test setup:

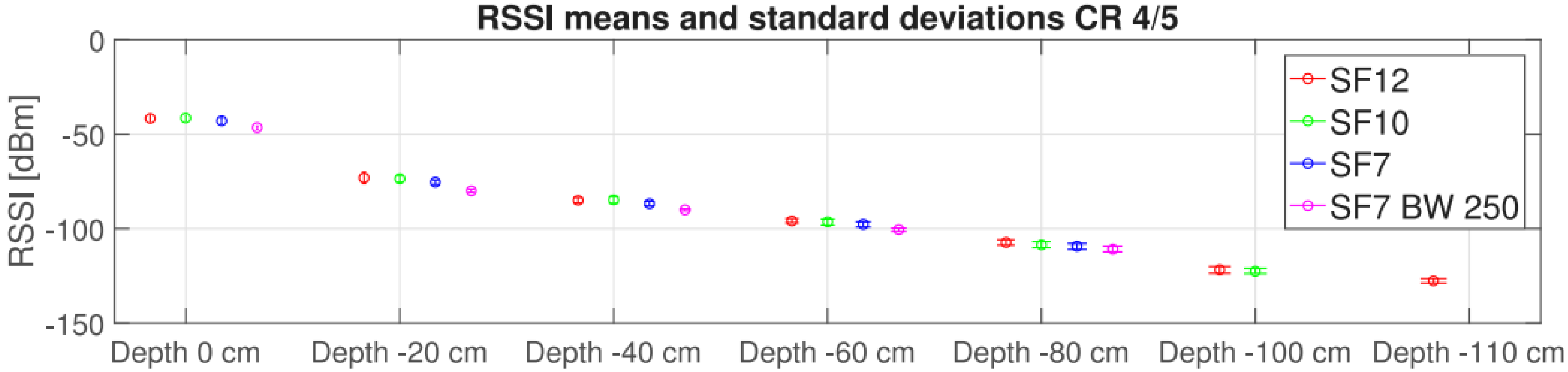


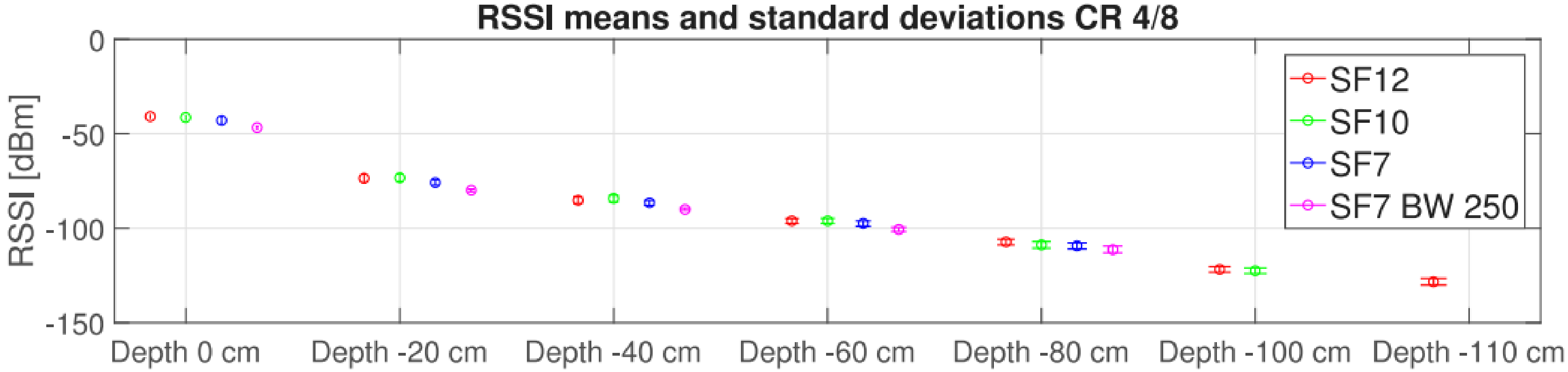
Pool test (fresh water)





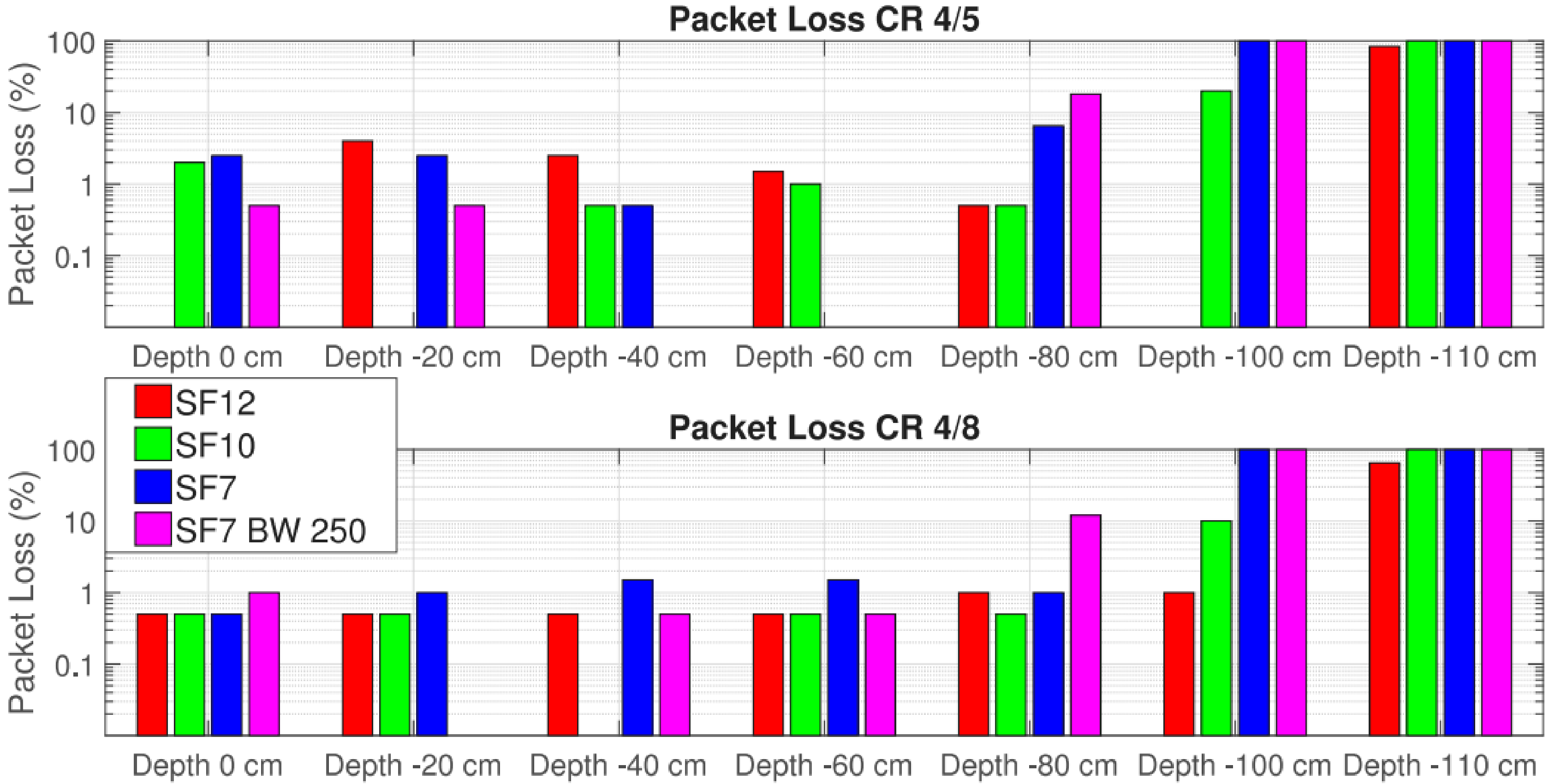
RSSI vs Distance – pool tests





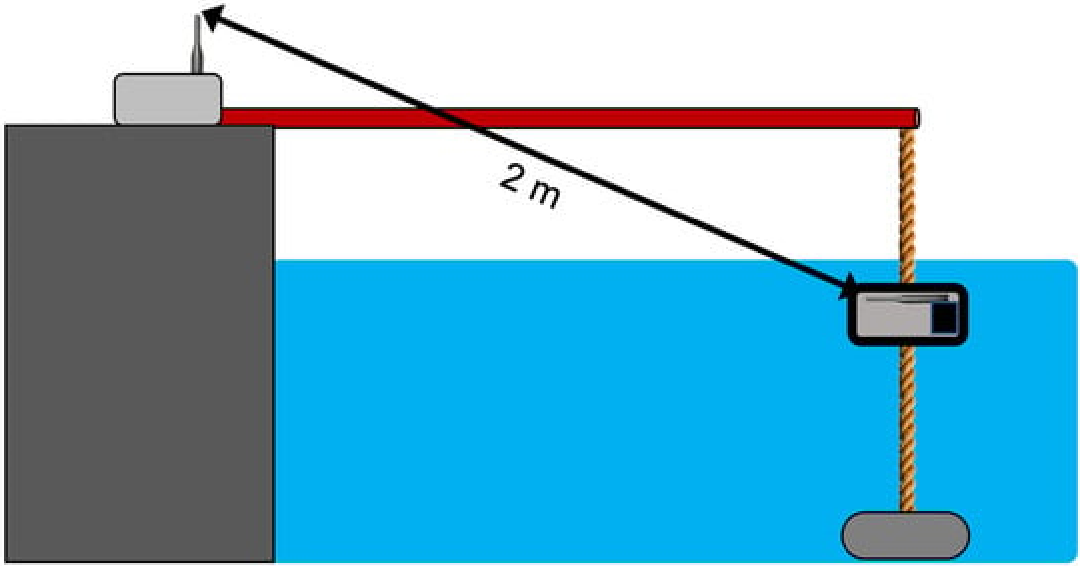
Irene Cappelli, Ada Fort, Marco Mugnaini, Stefano Parrino, Alessandro Pozzebon, Underwater to above water LoRaWAN networking: Theoretical analysis and field tests, Measurement, 2022

Packet loss vs Distance – pool tests

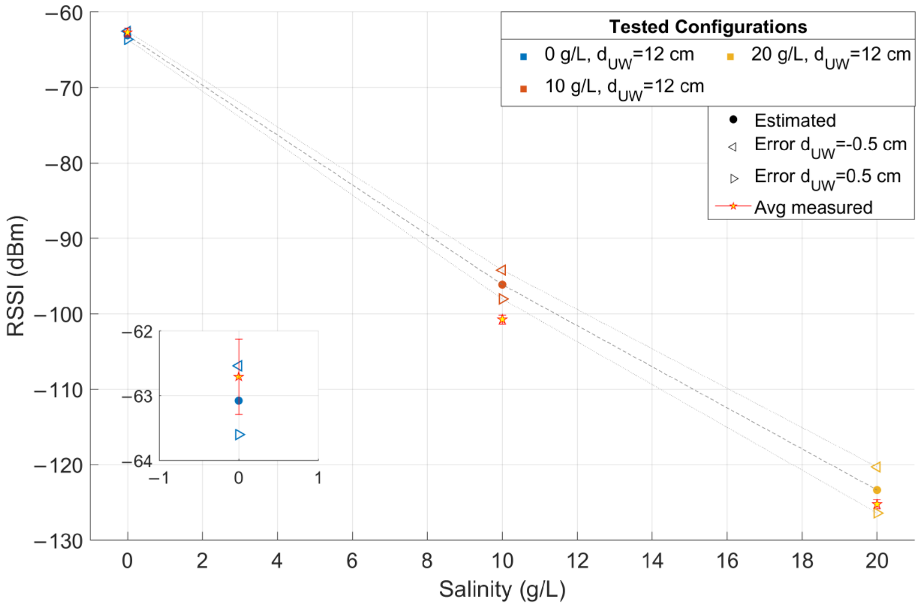


Irene Cappelli, Ada Fort, Marco Mugnaini, Stefano Parrino, Alessandro Pozzebon, Underwater to above water LoRaWAN networking: Theoretical analysis and field tests, Measurement, 2022

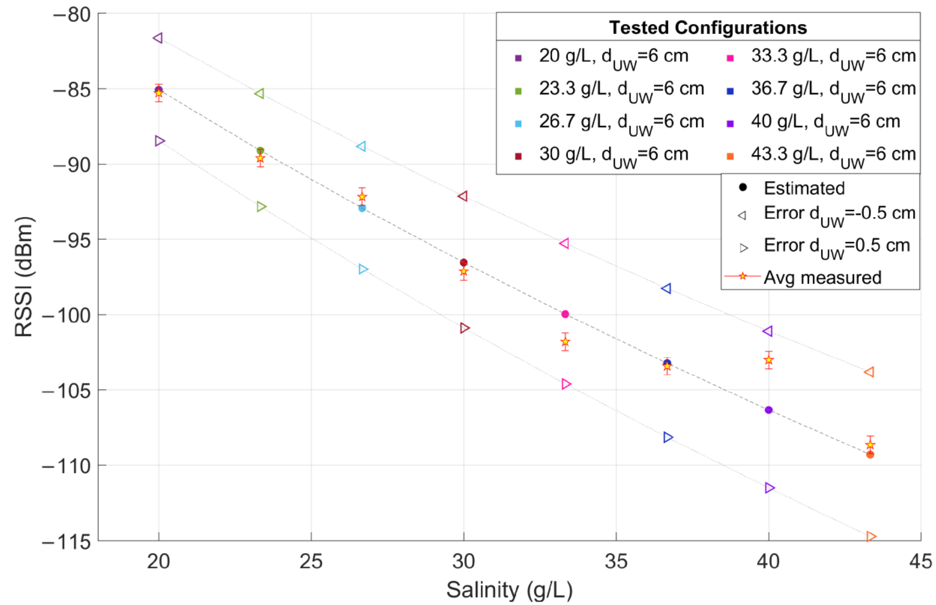
Tests in Chioggia harbor (salt water)



RSSI vs Salinity – Chioggia tests



(a)



(b)

Pozzebon, A.; Cappelli, I.; Campagnaro, F.; Francescon, R.; Zorzi, M. LoRaWAN Transmissions in Salt Water for Superficial Marine Sensor Networking: Laboratory and Field Tests. *Sensors* **2023**

Recap: LoRa underwater

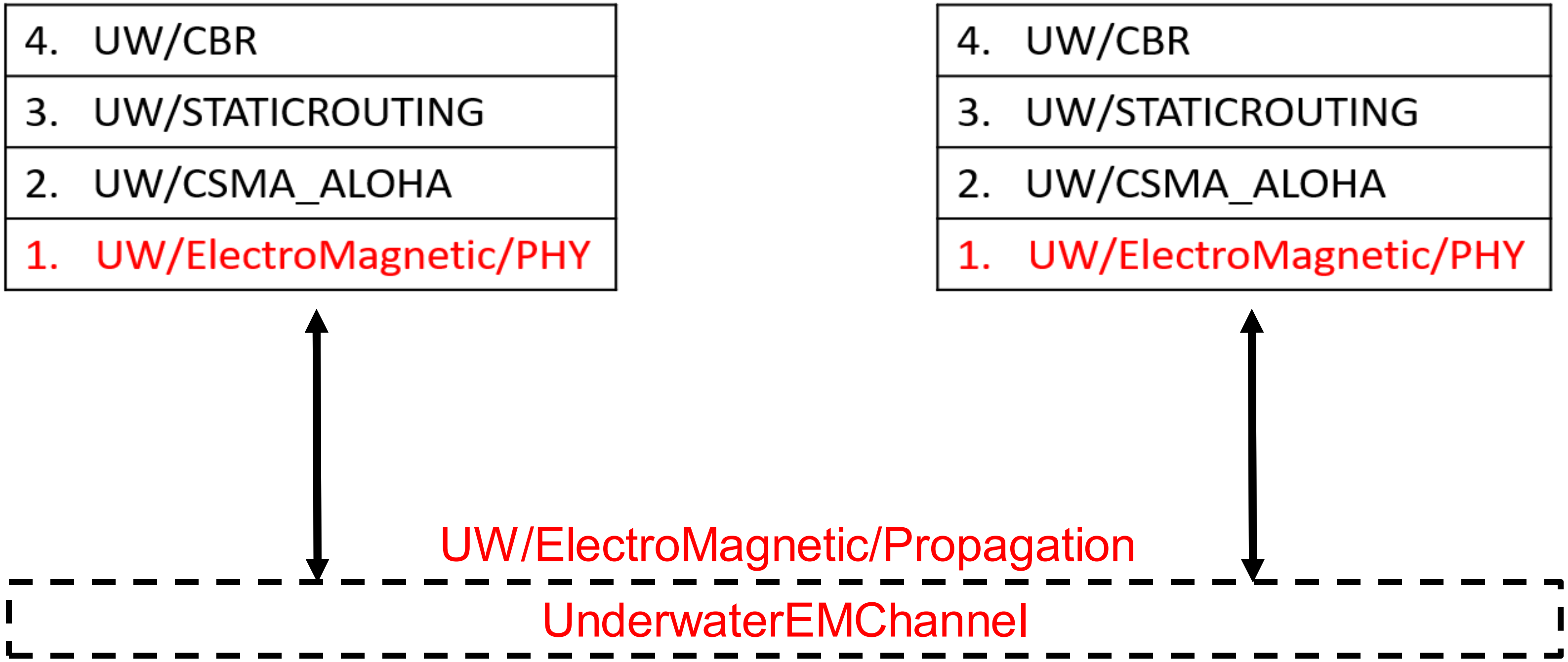
- Case fresh water: approximate reachable distance is 2m.
- Case salt water: performance hugely degrades. The maximum distance becomes about 10-15 cm
- For what is suitable LoRa underwater?
  - Low-cost water surface sensors, occasionally submerged by waves

Objective: modeling in DESERT

- **DESERT**: DEsign, Simulate, Emulate and Realize Test-beds for Underwater network protocols: http://desert-underwater.dei.unipd.it

- Starting from the theoretical model and field tests, we wanted to simulate this kind of transmissions.

Devices protocol stack



In red new modules introduced in DESERT Underwater

UnderwaterEMChannel

UnderwaterEMChannel

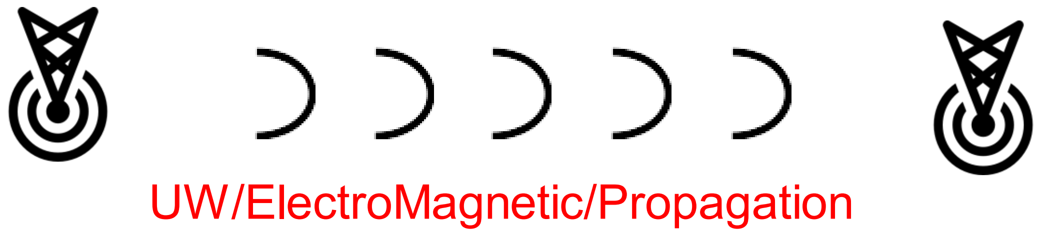
Channel functionalities:

- Send up the packets to the physical layer of each node connected to the channel
- Derive propagation delay between source and destination with:

$$PropDelay = \frac{Distance}{SpeedOfLight}$$

SpeedOfLight in water: 2.26 * (10^8) m/s

UW/ElectroMagnetic/Propagation



Derives the total attenuation of the communication using the formula:

$$PL_{tot} = PL_{aw} + PL_{uw2aw} + PL_{uw} + L_m$$

- *PLaw*: path loss above water
- *PLuw2aw*: path loss due to water-air cross
- *PLuw*: path loss under water
- *Lm*: miscellaneous losses

Parameters affecting this final terms:

- *T*: water temperature
- *f*: carrier frequency
- *B*: bandwidth
- *S*: water salinity

Focus on link budget model

- $$PL_{aw} = 20\log_{10} d_{aw} + 20\log_{10} f - 147.5$$
- $$PL_{uw2aw} = 10\log_{10}(|\tau|^2 Re\{\frac{\eta_{water}}{\eta_{air}}\})^{-1}$$
- $$PL_{uw} = 8.69\alpha d_{uw} + 20\log_{10} d_{uw} + 20\log_{10}\beta + 6$$

- d = distance
- f = frequency
- τ = reflection coefficient
- η = intrinsic impedance of the medium
- α = attenuation constant
- β = phase constant (concerning wave oscillation)

“Electrical characteristics of the surface of the Earth,” Network Working Group, ”International telecommunication union (ITU)” 527-6, September 2021.

Irene Cappelli, Ada Fort, Marco Mugnaini, Stefano Parrino, Alessandro Pozzebon, Underwater to above water LoRaWAN networking: Theoretical analysis and field tests, Measurement, 2022

UW/ElectroMagnetic/PHY

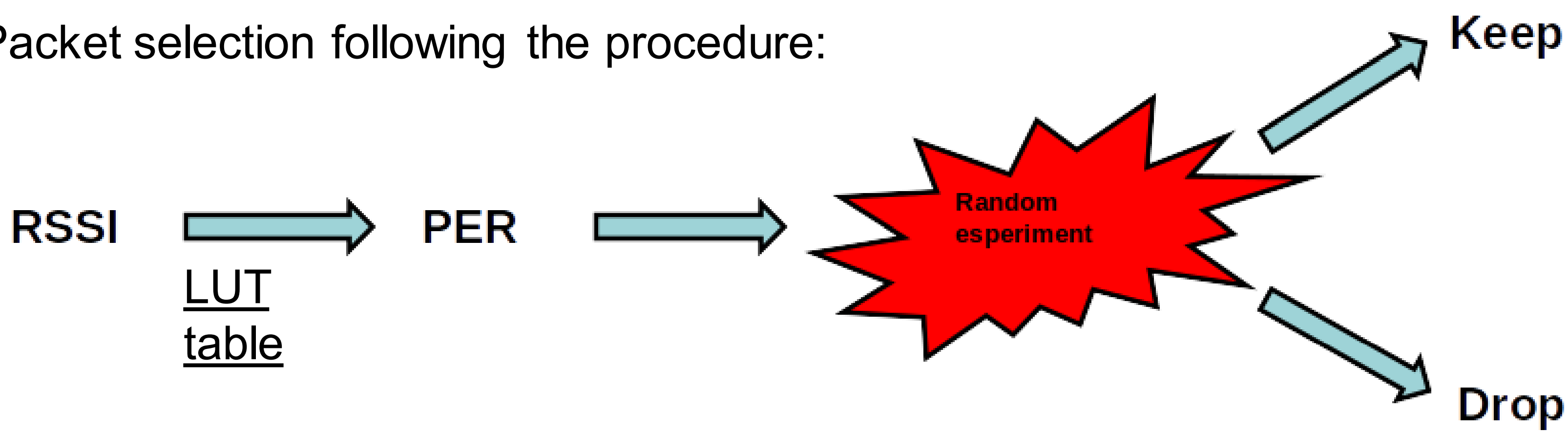
1. UW/ElectroMagnetic/PHY

It estimates the final Received Signal Strength Indicator (RSSI) as:

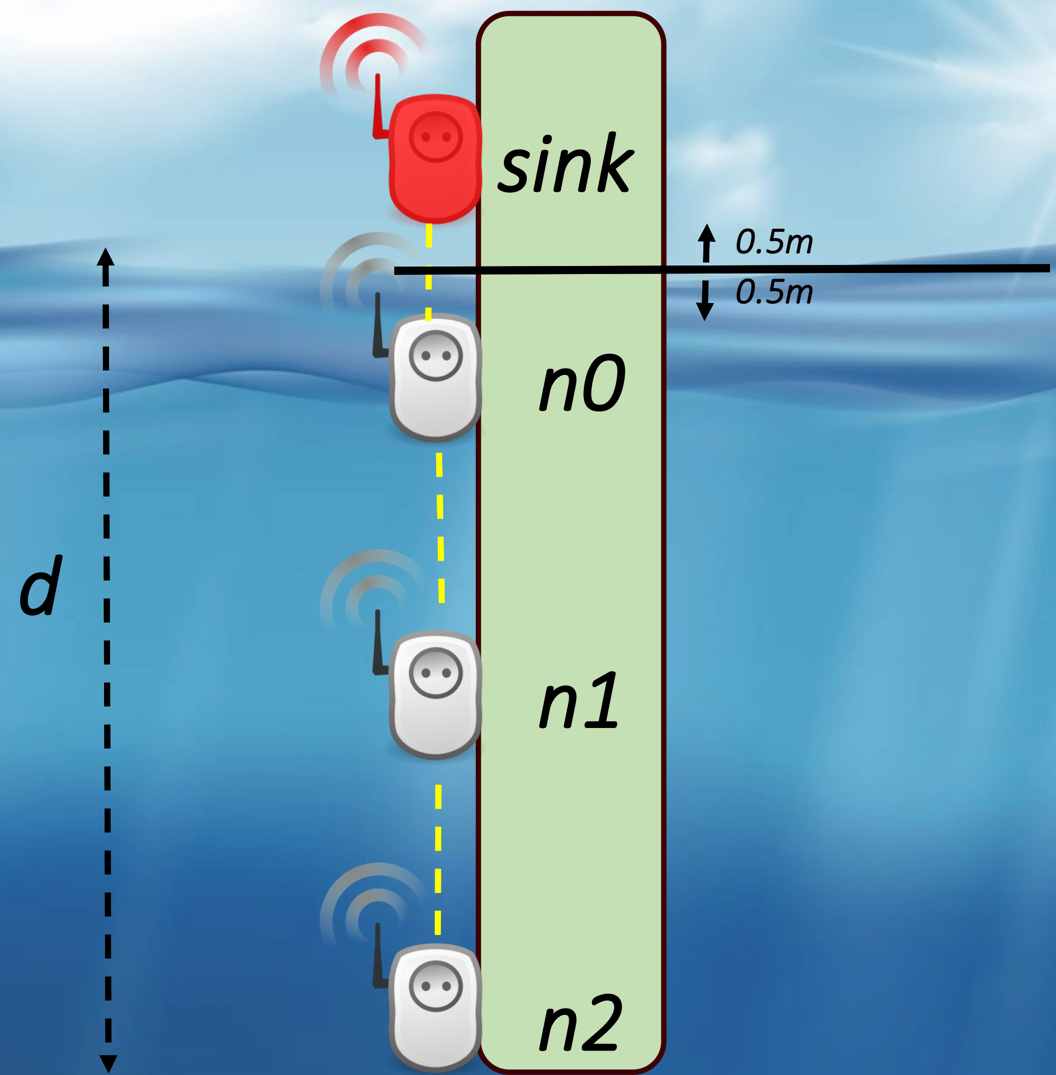
$$RSSI = P_t + G_t + G_r - PL_{tot}$$

- *Pt*: transmission power
- *Gt*: transmitter antenna gain
- *Gr*: receiver antenna gain
- *PLtot*: total attenuation

Packet selection following the procedure:



Simulation Scenario

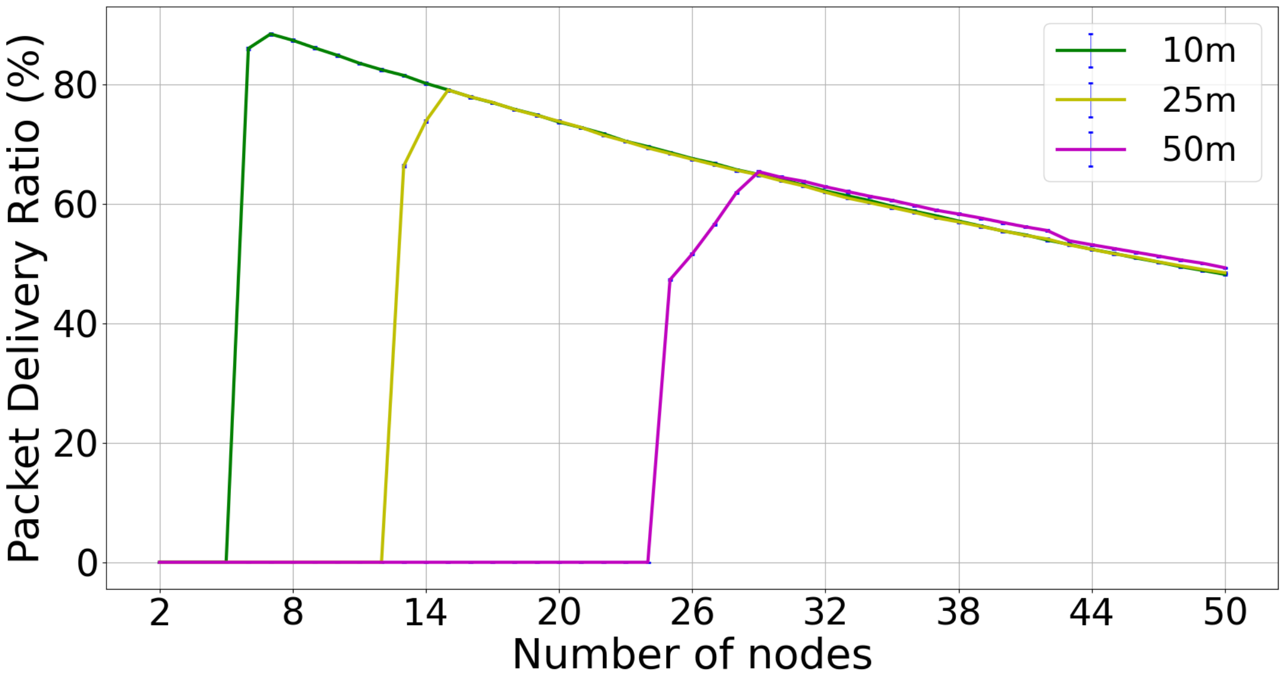


1) DESERT simulation

- Parameters and settings:

Notation	Meaning	Value
Pkt	Packet size	25 B
T_{CBR}	CBR period	180 s
T	Simulation period	10000 s
f	Carrier frequency	868 MHz
B	Bandwidth	125 kHz
R	Physical bit-rate	5470 bit/s
$Temp$	Temperature of the water	20°C
S	Salinity of the water	0 $(g/kg)^2$
G	Antenna gain	2 dBi
P_{tx}	Transmitting power	14 dBm
CR	Coding rate	4/5
SF	Spreading factor	7
c	Speed of light	$2.26 \cdot 10^8$ m/s
w	CSMA wait constant	0.04 s
l	CSMA listen time	0.0001 s
N	Number of intermediate nodes (sink excluded)	2:50
n	Index of the node	0:$(N-1)$
d	Total communication distance	{10,25,50}
N_{RTX}	Max. number of retransmissions at layer 2	0

Optimal number of nodes per d



- Running simulations (fixed settings and no retransmissions) we derived:
  - Constant optimal internode distance: j = *1.75m*
  - Optimal number of nodes: $N = ((d - 0.5)/j) + 1$

2) DESERT simulation

- Parameters and settings:

Notation	Meaning	Value
Pkt	Packet size	25 B
T_{CBR}	CBR period	180 s
T	Simulation period	10000 s
f	Carrier frequency	868 MHz
B	Bandwidth	125 kHz
R	Physical bit-rate	5470 bit/s
$Temp$	Temperature of the water	20°C
S	Salinity of the water	0 $(g/kg)^2$
G	Antenna gain	2 dBi
P_{tx}	Transmitting power	14 dBm
CR	Coding rate	4/5
SF	Spreading factor	7
c	Speed of light	$2.26 \cdot 10^8$ m/s
w	CSMA wait constant	0.04 s
l	CSMA listen time	0.0001 s
N	Number of intermediate nodes (sink excluded)	115
n	Index of the node	0:$(N-1)$
d	Total communication distance	200
N_{RTX}	Max. number of retransmissions at layer 2	0:2

PDD for 200m scenario

Fixed internode distance: 1.75. Number of retransmissions: 0,1,2.

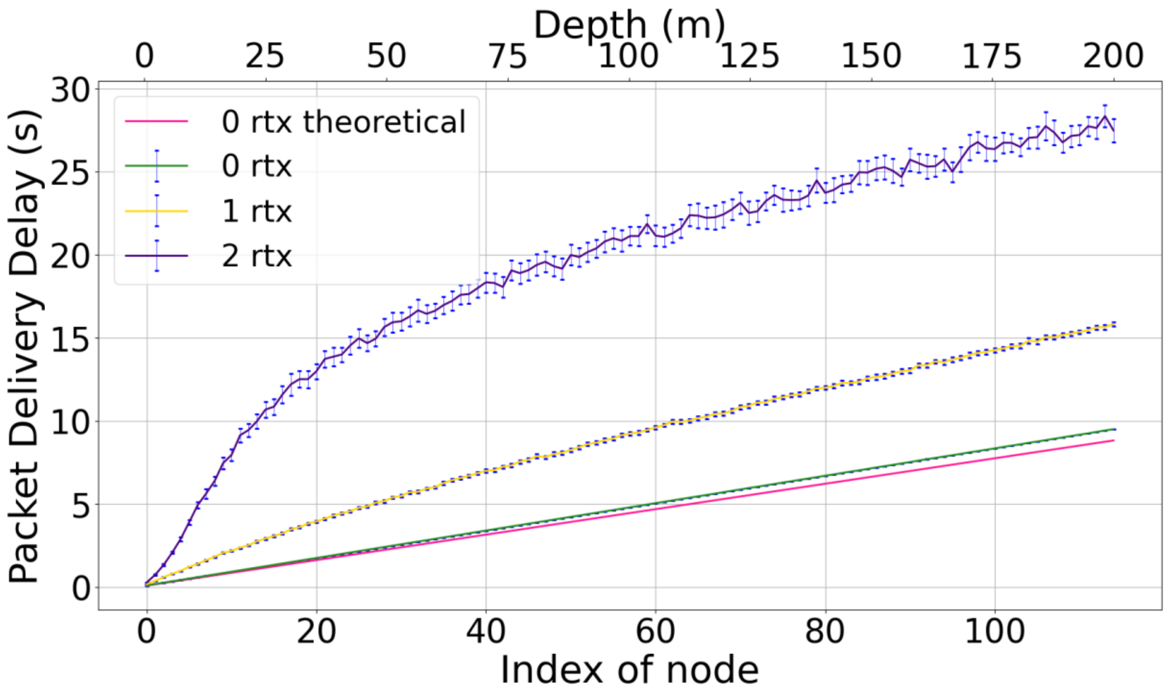


Fig: Packet Delivery Delay vs index of node

Theoretical 0 rtx PDD curve derived as:

$$pdd = (i + 1) * (\tau + T_{tran} + E[T_l] + T_{queue})$$

- *i*: index of the node
- *Tau*: propagation delay
- *Ttran*: transmission time
- *E[Tl]*: expected CSMA listen time
- *Tqueue*: time spent in queue (supposed to be 0)

PDR for 200m scenario

Fixed internode distance: 1.75. Number of retransmissions: 0,1,2.

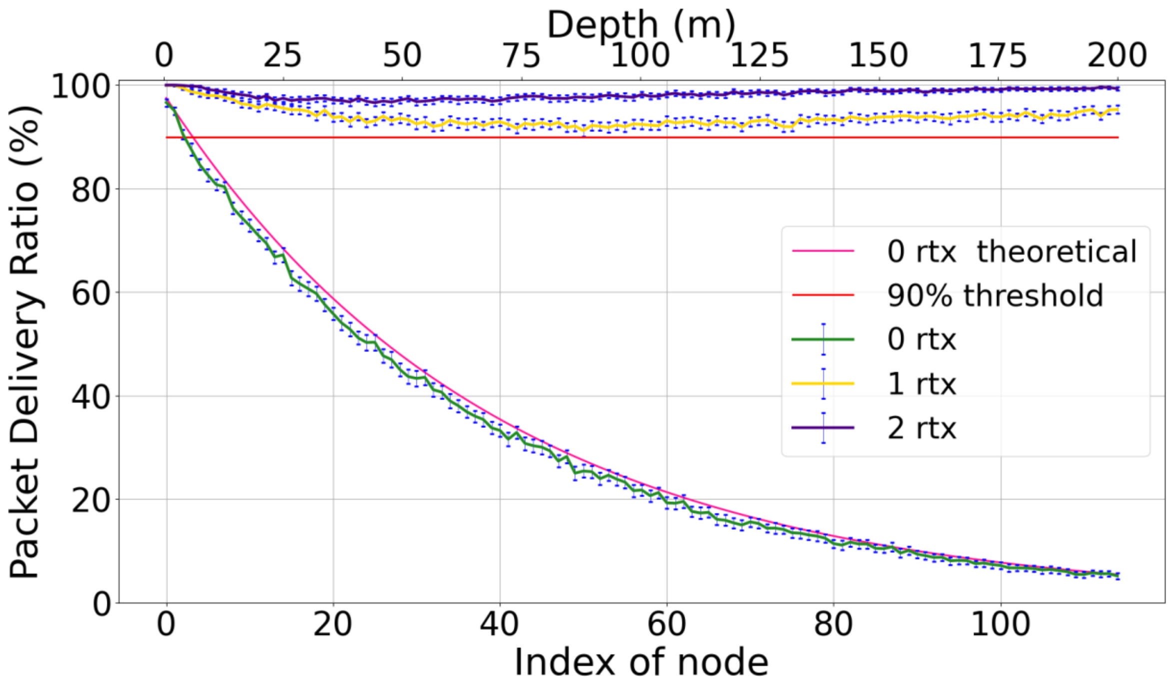


Fig: Packet Delivery Ratio vs index of node

Theoretical 0 rtx PDR curve derived as:

$$pdr = 100 * (1 - pl)^{i+1}.$$

- *i*: index of the node
- *pl*: single hop packet loss probability

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Throughput for 200m scenario

Fixed internode distance: 1.75. Number of retransmissions: 0,1,2.

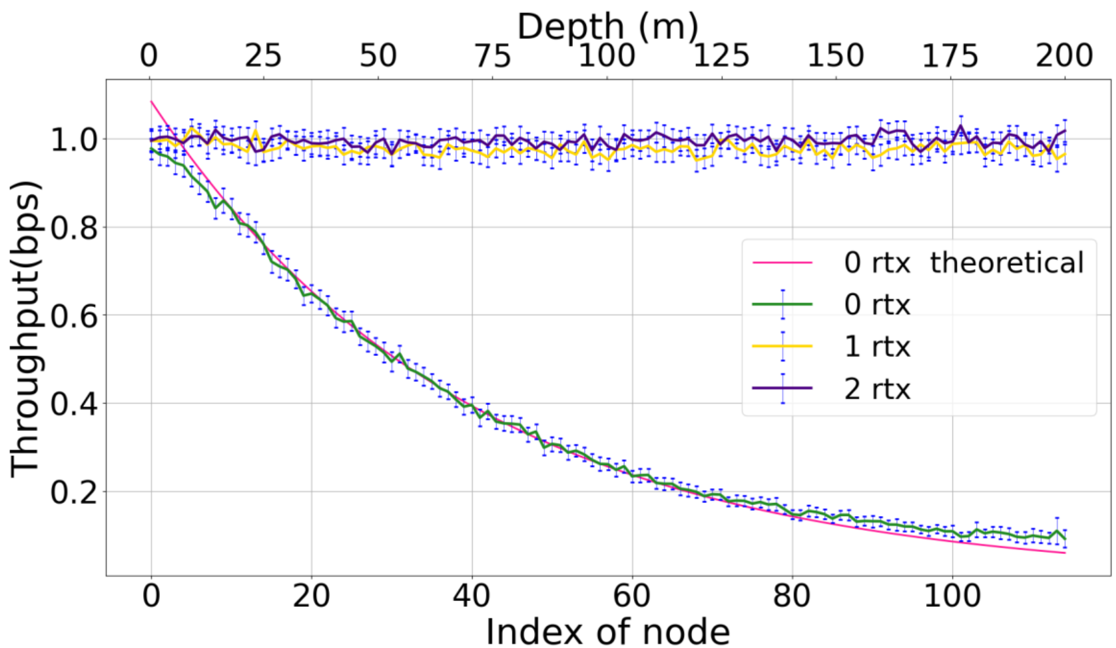

Fig: Throughput vs index of node

Data generation rate: *Dr* = 1.11 bps
Theoretical 0 rtx throughput curve derived as:

$$thr = pdr * D_r$$

References

- R. Tumiati, F. Campagnaro, I. Cappelli, A. Pozzebon and M. Zorzi, "Modeling the underwater electromagnetic radio frequency channel in the DESERT Underwater network simulator," *OCEANS 2023 - Limerick*, Limerick, Ireland, 2023
- Pozzebon, A.; Cappelli, I.; Campagnaro, F.; Francescon, R.; Zorzi, M. LoRaWAN Transmissions in Salt Water for Superficial Marine Sensor Networking: Laboratory and Field Tests. *Sensors* **2023**
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