DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

UNIVERSITÀ DEGLI STUDI DI PADOVA

SIGNET

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Underwater Multimodal Networks

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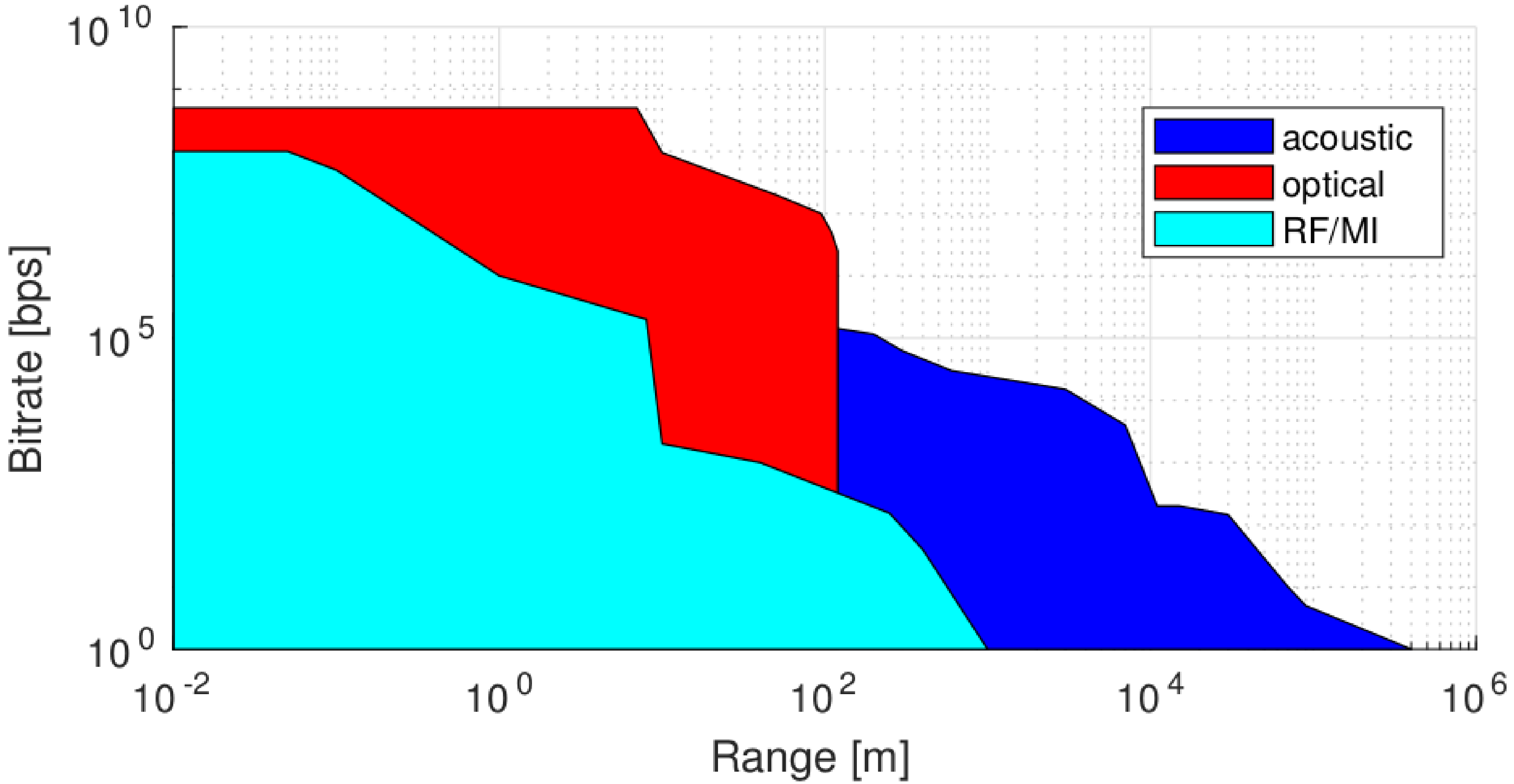
Acoustic – Pro and Cons

Advantages	Disadvantages
Proven technology	Affected by acoustic noise and multi-path
No need for LOS	High power consumption
Range up to 30 km	Order-of kb/s bit rates
Robust in deep water vertical link	Poor in shallow waters
Good channel models for simulation	Affected by sound speed gradient
	High latency
	May impact marine life

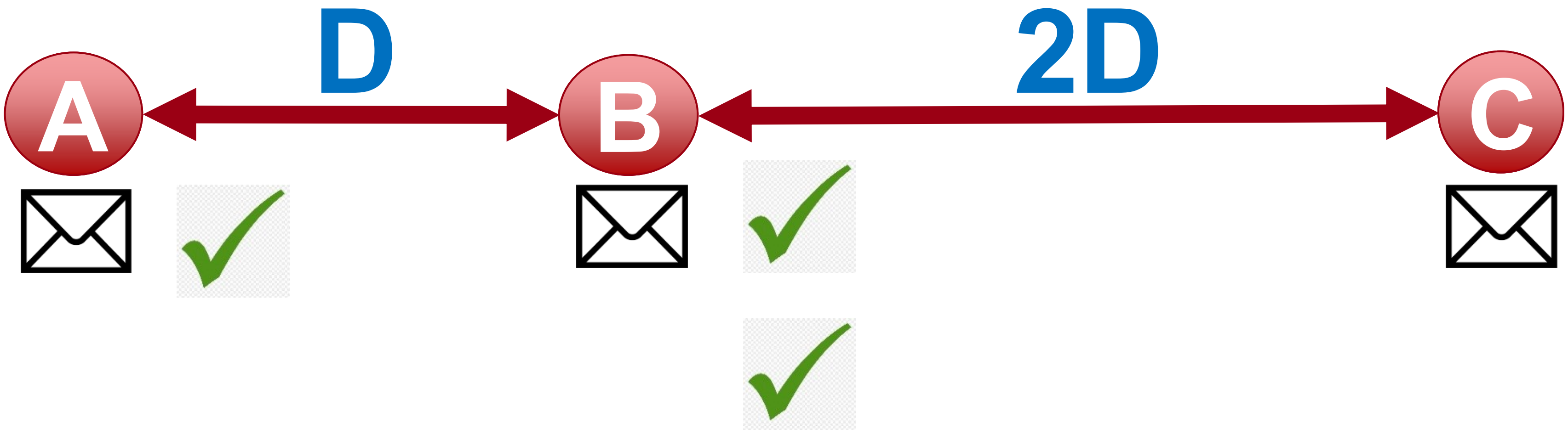
- Applications in all long range communication scenarios:
  - Underwater sensors networks (byology, marine science).
  - Coastal erosion monitoring.
  - Survelliance, platforms monitoring, etc..

Existing Transmission Technologies



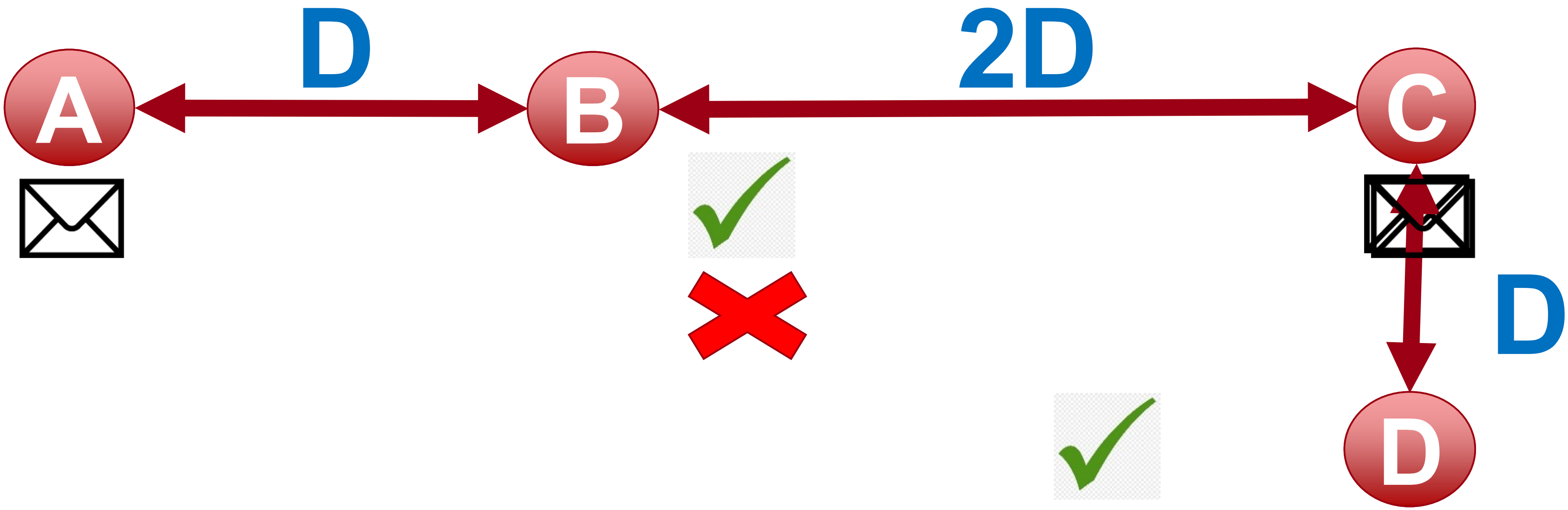
Propagation delay

Acoustics: long delay



- Propagation delay A→B = 1 s, B→C = 2 s
- Packet duration = 0.5 s
- Parallel transmission without colliding!

Acoustics: near-far



- A→B, C→D, collision happens at B
- Near-far interference let B receiving from A despite the interference from C

PER: mathematical model

DESERT physical layer

APIs

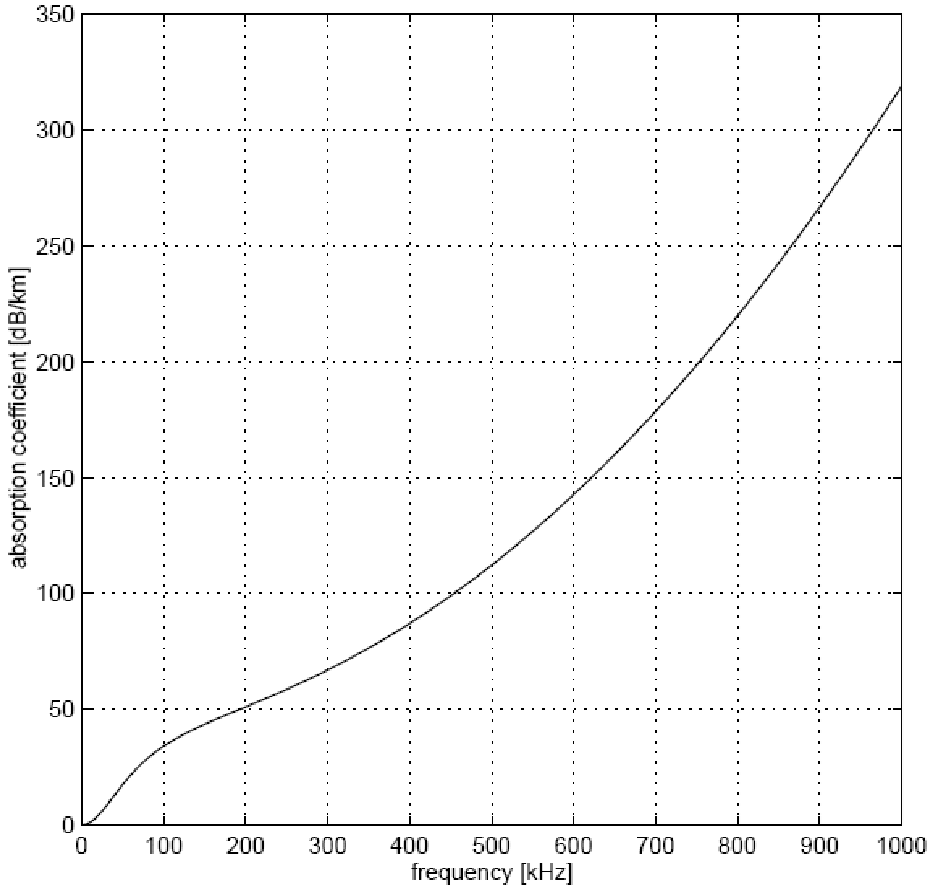
- startTx(Packet* p); // t0
- endTx(Packet* p); // t0 + pckt duration
- startRx(Packet* p); // t0 + prop. time
- endRx(Packet* p); // t0 + prop. time + pckt duration
- Half duplex: if transmission is pending, no reception.
- Synchronization on the first packet that arrives
  - If a second packet arrives, it is considered as interferer
  - You can extend the model if interference cancellation

DESERT standard physical layer

- Propagation: Urick-Thorp formula
- Noise computed as contribute of shipping activity, wind waves and thermal noise
  - M. Stojanovic, “On the Relationship Between Capacity and Distance in an Underwater Acoustic Communication Channel”, ACM SIGMOBILE Mobile Computing and Communications Review (MC2R), vol.11, Issue 4, October 2007, pp.34-43
- Half duplex modems
- Two interference models available
  - MEANPOWER
  - CHUNK

DESERT propagation models

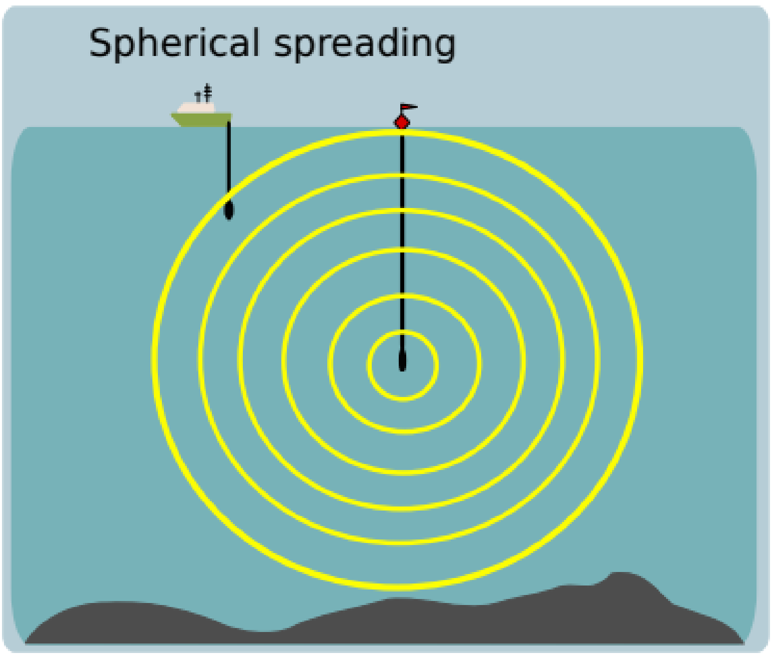
- Path loss equation $10 \log A(\ell, f) = k \cdot 10 \log \ell + \ell \cdot 10 \log a(f),$
- Absorption (Thorp) $10 \log a(f) = 0.11 \frac{f^2}{1+f^2} + 44 \frac{f^2}{4100+f} + 2.75 \cdot 10^{-4} f^2 + 0.003,$

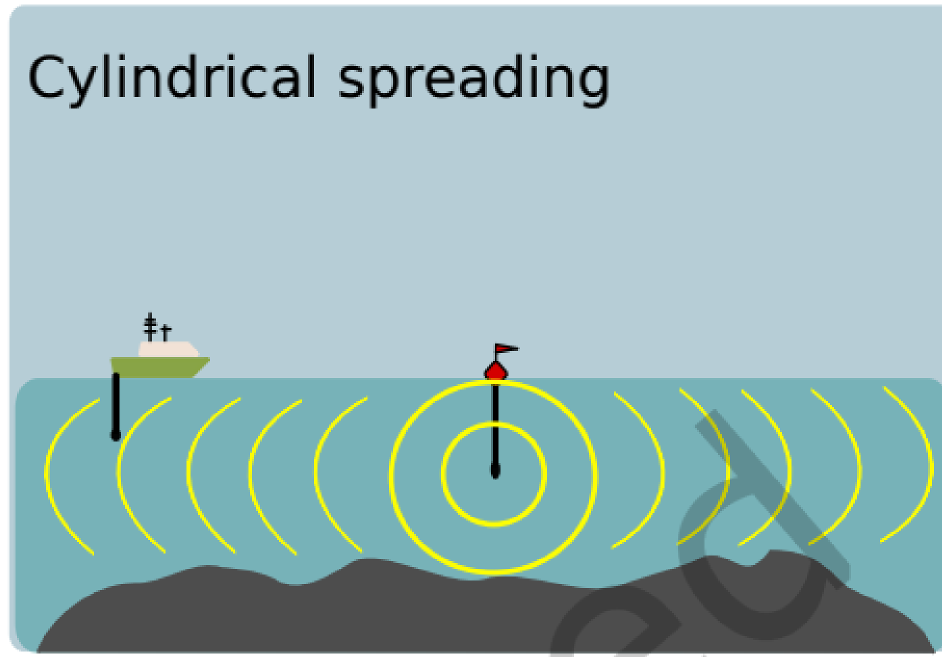


(adapted from Stojanovic)

DESERT geometry

- Path loss equation $10 \log A(\ell, f) = k \cdot 10 \log \ell + \ell \cdot 10 \log a(f),$
- k = 2 spherical, k = 1 cylindrical, k = 1.5 practical spreading





A. Pal, F. Campagnaro, K. Ahraf, R. Rahman, A. Ashok, H. Guo, “Communication for Underwater Sensor Networks: A Comprehensive Summary”, ACM Transactions on Sensor Networks 2022

DeSERT – noise model

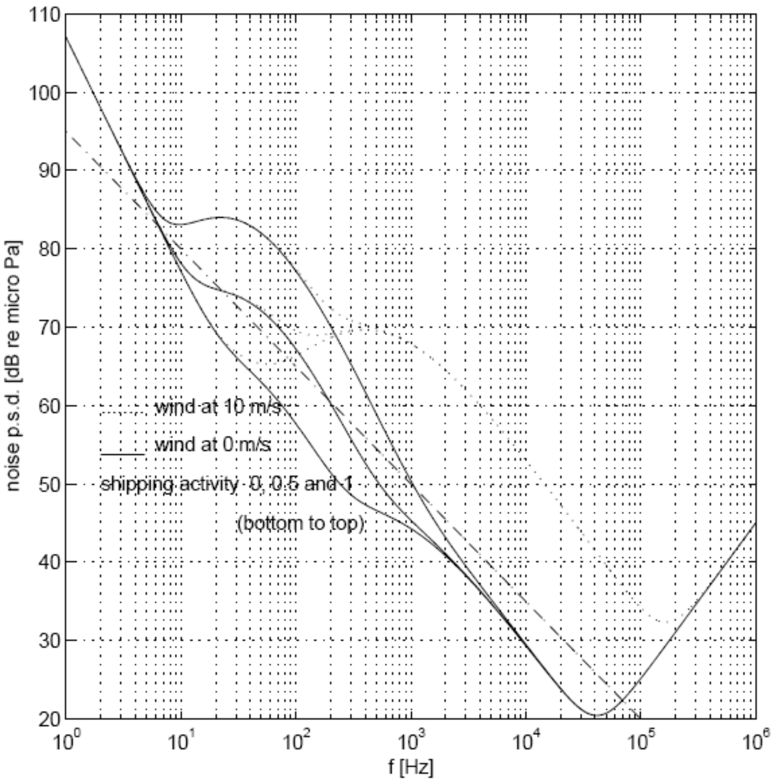
- Sum of four components:

$$N(f) = N_t(f) + N_s(f) + N_w(f) + N_{th}(f)$$

Noise sources:
turbulence, shipping, wind, thermal noise

- where:

$$10 \log N_t(f) = 17 - 30 \log f$$
$$10 \log N_s(f) = 40 + 20(s - 0.5) + 26 \log f - 60 \log(f + 0.03)$$
$$10 \log N_w(f) = 50 + 7.5 w^{1/2} + 20 \log f - 40 \log(f + 0.4)$$
$$10 \log N_{th}(f) = -15 + 20 \log f,$$



(adapted from Stojanovic)

uwphysical and noise time variability

- Uses shipping factor (faraway ships) and wind speed (m/s) to compute the colored noise in the desired bandwidth
- Check test_uwtdma.tcl as an example
  - MPropagation/Underwater set windspeed_ 10
  - MPropagation/Underwater set shipping_   1
- These parameters can be changed upon tcl event, with ns at <time> <event>

ns at 1000 “$phy(1) set windspeed 20”

Windspeed realistic values

Beafort Scale	Description	Wind speed (w)
0	Calm	< 0.3 m/s (2 km/h)
1	Light air	0.3 m/s (2 km/h) <= w < 1.6 m/s (6 km/h)
2	Light breeze	1.6 m/s (6 km/h) <= w < 3.4 (12 km/h)
3	Gentle breeze	3.4 (12 km/h) <= w < 5.5 m/s (20 km/h)
4	Moderate breeze	5.5 m/s (20 km/h) <= w < 8 m/s (29 km/h)
5	Fresh breeze	8 m/s (29 km/h) <= w < 10.8 m/s (39 km/h)
6	Strong breeze	10.8 m/s (39 km/h) <= w < 13.9 m/s (50 km/h)
7	High wind	13.9 m/s (50 km/h) <= w < 17.2 m/s (62 km/h)
8	Gale	17.2 m/s (62 km/h) <= w < 20.8 m/s (75 km/h)
9	Strong gale	20.8 m/s (75 km/h) <= w < 24.5 m/s (89 km/h)
10	Storm	24.5 m/s (89 km/h) <= w < 28.5 m/s (103 km/h)
11	Violent storm	28.5 m/s (103 km/h) <= w < 32.7 m/s (118 km/h)
12	Hurricane	>= 32.7 m/s (118 km/h)

DESERT Standard PER

- Two interference models available
  - MEANPOWER
  - CHUNK
- Compute SNR, SINR and
  - Given the modulation we get the BER from standard formula of BER vs S(I)NR
  - Given the packet size in bits we get the PER:

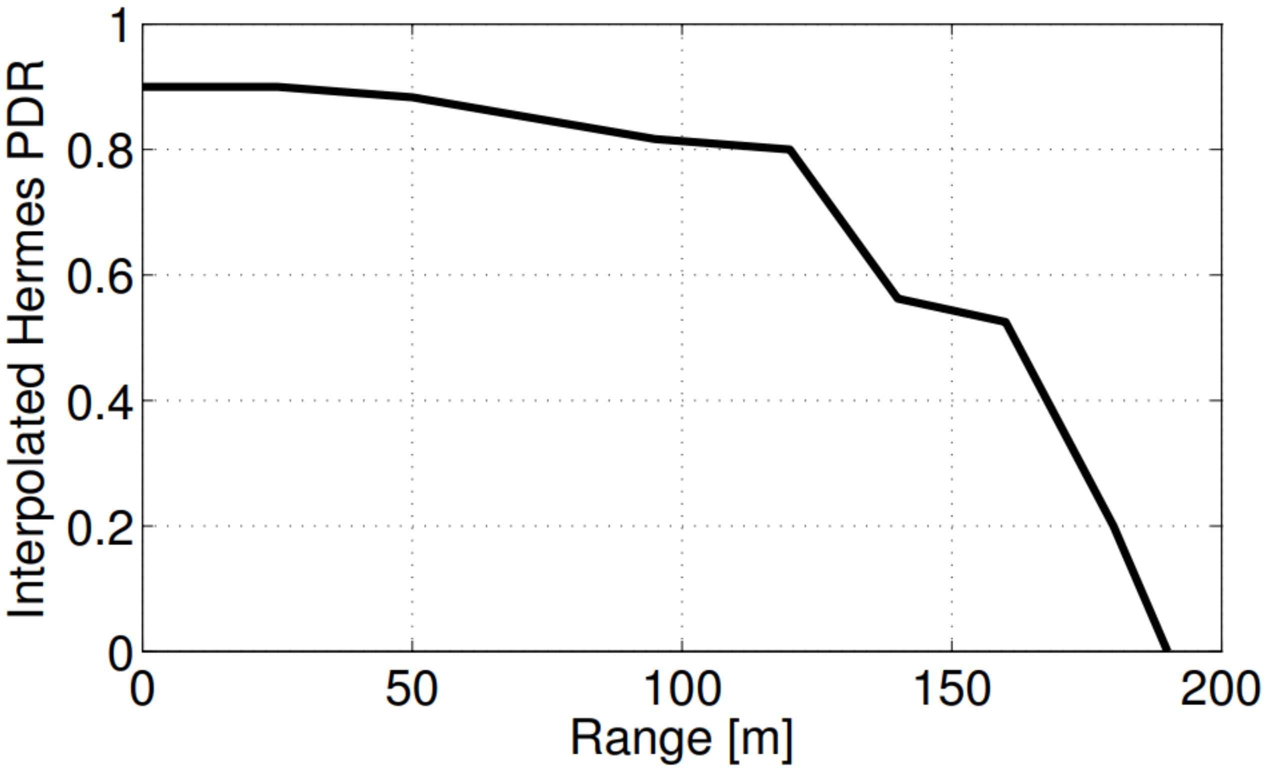
$$PDR = (1\text{-}BER)^{\wedge size}$$

PER: modem performance figure (static)

Modem performance figures

- Figures of performance included as lookup tables (LUTs)
- PDR vs range LUT
- PDR vs SIR LUT
  - Considered as an added degradation of PDR
- Assumes channel to be not time-varying
- OK to test the network in a certain channel condition

Hermes modem performance



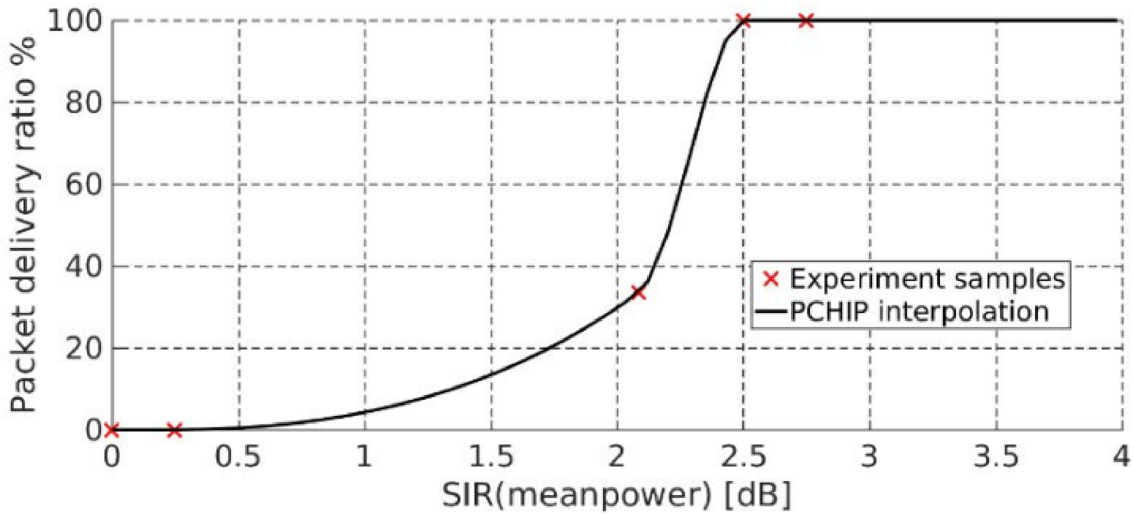
Model presented in
F. Campagnaro, F. Favaro, F. Guerra, V. Sanjuan Calzado, M. Zorzi, P. Casari, Simulation of Multimodal Optical and Acoustic Communications in Underwater Networks, IEEE/OES Oceans 2015 Genova

- Hermes modem developed from FAU, 87.7 kbps @ 150 m

P.-P. Beaujean, J. Spruance, E. A. Carlson, and D. Kriel, “HERMES - A high-speed acoustic modem for real-time transmission of uncompressed image and status transmission in port environment and very shallow water,” in Proc. MTS/IEEE Oceans, Qu´ebec City, Canada, Sep. 2008

Ahoi modem performance

Size [Bytes]	*PDR@12 m*	*PDR@24 m*	*PDR@46 m*	*PDR@99 m*	*PDR@152 m*
16	96.5%	75.0%	89.5%	88.0%	84.5%
32	95.0%	70.0%	88.5%	99.0%	51.5%
96	77.0%	92.0%	83.0%	100.0%	n.a.



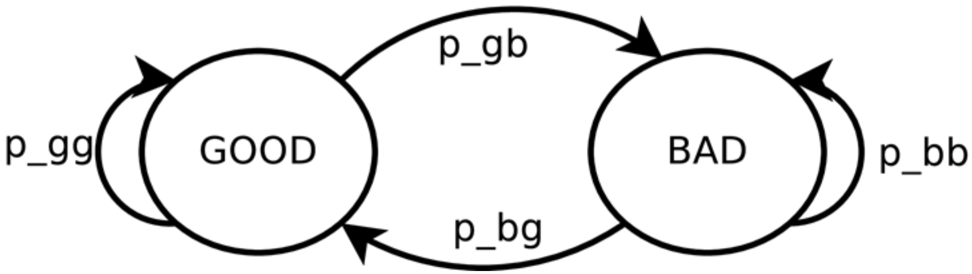
Model presented in F. Campagnaro, F. Steinmetz, A. Signori, D. Zordan, B.-C. Renner, M. Zorzi, Data Collection in Shallow Fresh Water Scenarios with Low-Cost Underwater Acoustic Modems, UACE 2019 Crete

- Low cost *ahoi* modem, 200 bps @ 200 m

C. Renner and A. J. Golkowski, “Acoustic Modem for Micro AUVs: Design and Practical Evaluation,” in Proc. of the 11th ACM International Conf. on Underwater Networks & Systems (WUWNet), Shanghai, China, Oct. 2016

PER: time varying links: a statistical model from sea trials

Hidden Markov Model

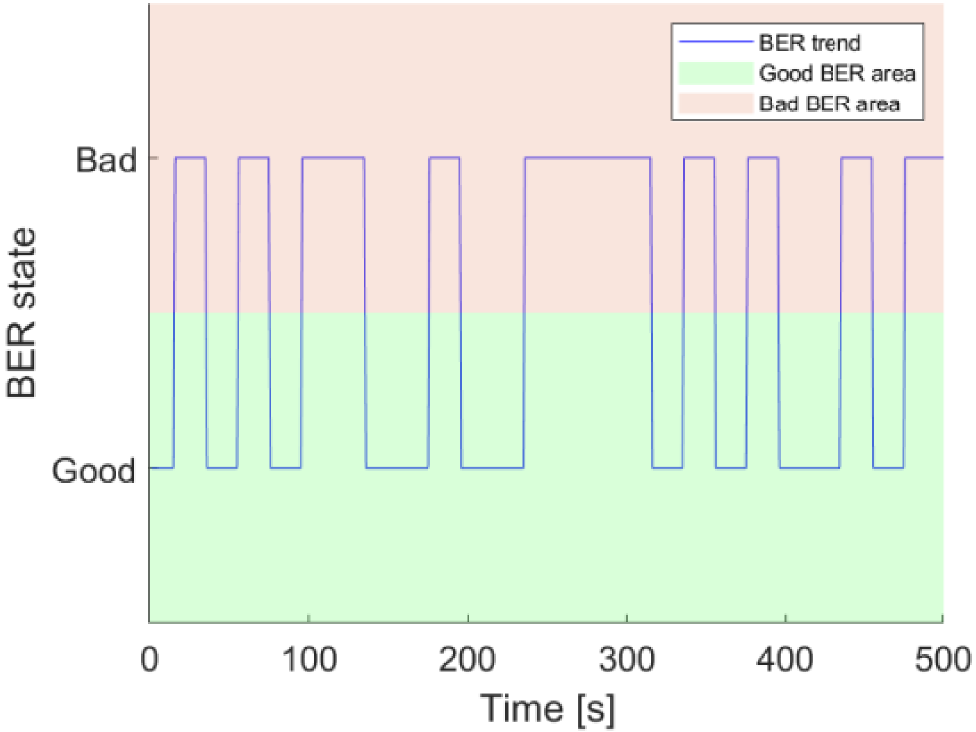


2-state HMM
3-state HMM also available

- Analyzing sea trial data, we can observe the acoustic channel to be time-varying
  - When it is in good state, it will stay in good state for a while: same for bad state
- PER in good and bad state con be inferred from sea trial data. Same for transition probabilities

B. Tomasi, J. Preisig, and M. Zorzi, "On the predictability of underwater acoustic communications performance: The KAM11 data set as a case study," in Proc. International Conference on Underwater Networks & Systems (WUWNet), Seattle, WA, US, December 2011.

BER time variability link 4→2



Topology2, Link 4→2	**Good**	**Bad**
Good	0.947	0.053
Bad	0.192	0.808

https://sites.google.com/marsci.haifa.ac.il/asuna

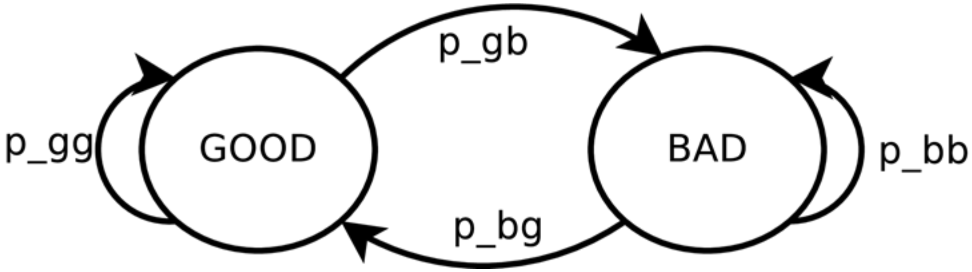
P. Casari, F. Campagnaro, E. Dubrovinskaya, R. Francescon, A. Dagan, S. Dahan, M. Zorzi, R. Diamant, ASUNA: A Topology Dataset for Underwater Network Emulation, IEEE Journal of Oceanic Engineering 2021

- BER good = 0.005
- BER bad = 0.019

N. Toffolo, A. Montanari, F. Campagnaro, M. Zorzi, Modeling acoustic channel variability in underwater network simulators from real field experimental data, MTS/IEEE Oceans 2022 Hampton Roads – US

F. Campagnaro, N. Toffolo, M. Zorzi, Modeling acoustic channel variability in underwater network simulators from real field experiment data, MDPI Electronics 2022

Transition probabilities - n step



2-state HMM
3-state HMM also available

- $P = \begin{pmatrix} p_{gg} & p_{gb} \\ p_{bg} & p_{bg} \end{pmatrix}$ transition matrix 1 step
- P^n transition matrix at n step, computed in general (for > 3 states) as matrix exponentiation (complexity **O(n)**)
- For two states it can be computed with **O(1)** as:

$$P^n = \frac{1}{p_{gb'} + p_{b'g}} \begin{pmatrix} p_{b'g} & p_{gb'} \\ p_{b'g} & p_{gb'} \end{pmatrix} + \frac{(1 - p_{gb'} - p_{b'g})^n}{p_{gb'} + p_{b'g}} \begin{pmatrix} p_{gb'} & -p_{gb'} \\ -p_{b'g} & p_{b'g} \end{pmatrix}$$

PER: time varying links and ray tracing

Bellhop ray-tracer

- Multipath is a key component of performance degradation
- More on this when talking about WOSS

References

- F. Campagnaro, F. Steinmetz, A. Signori, D. Zordan, B.-C. Renner, M. Zorzi, Data Collection in Shallow Fresh Water Scenarios with Low-Cost Underwater Acoustic Modems, UACE 2019 Crete
- C. Renner and A. J. Golkowski, “Acoustic Modem for Micro AUVs: Design and Practical Evaluation,” in Proc. ACM WUWNet, Shanghai, China, Oct. 2016
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