Modeling the UnderWater Acoustic (UWA) channel for simulation studies

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Motivation

Channel modeling is important for

- Evaluation and comparison of communication techniques and networking protocols
- Design and optimization of cross-layer communications and networking techniques

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Simulations are

- Cheaper than experiments
- Based on channel models which represent statistics both in time and in space
- Reliable only if models are sufficiently accurate and representative
- Therefore, accuracy vs computational complexity

Long-term scientific objectives

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- Key features of channel that most significantly affect the performance of communication systems
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- Key features of channel that most significantly affect the performance of communication systems
- Key features of channel that most significantly affect the performance of networking protocols
- Paradigms for modeling the channel that are most suitable for simulation studies and evaluations

Scientific and technical approaches

- Data analysis
  - Time-varying channel conditions: types of dynamics, stationarity, predictability
  - Relationship between environment and channel quality dynamics

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  - Hybrid sparse/diffuse channel model
  - Markov models for channel and protocol evaluations

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  - Relationship between environment and channel quality dynamics
- Analytical derivations and model validation through data
  - Hybrid sparse/diffuse channel model
  - Markov models for channel and protocol evaluations
- Tools and resources
  - Ray-tracer included in Network Simulator 2 (NS2): WOSS
  - DESERT: an NS-Miracle extension to DEsign, Simulate, Emulate and Realize Test-beds for Underwater network protocols
  - Making data availability to the community through a website

Key features of the UWA channel

- Statistics representing both temporal and spatial variations
  - First order statistics and their temporal variations
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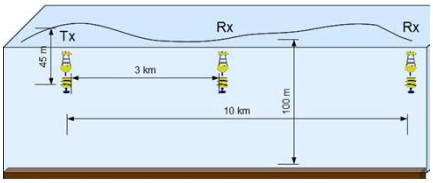
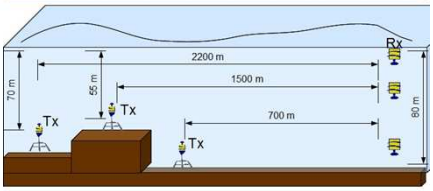
Data analysis

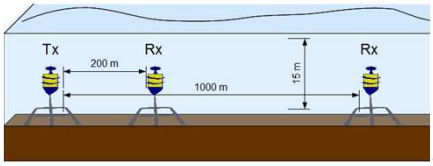
Experimental data sets



KAM 11, Kauai (HI)
June-July 2011



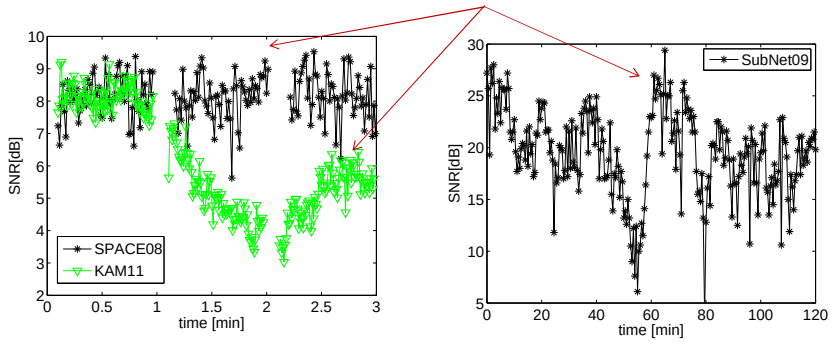
SubNet09, Pianosa (IT)
May-September 2009



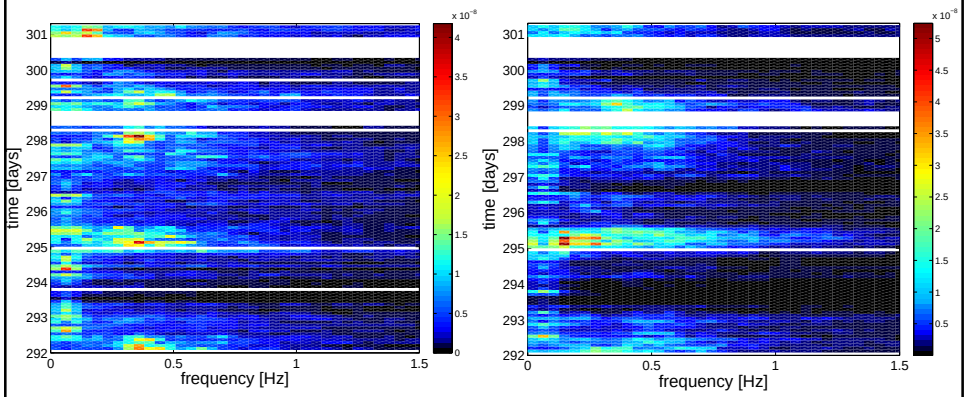
SPACE08, Martha's Vineyard (MA), October 2008

Time-varying channel conditions

Different SNR dynamics depend on scenario and environmental conditions dominating propagation (KAM11 and SubNet09 water depth ~100 m -> ssp, SPACE08 water depth~15 m -> surface)



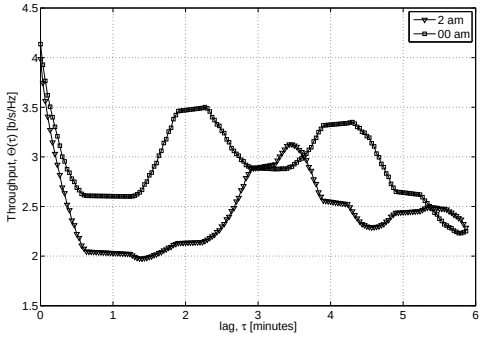
Wide-sense stationarity of the channel quality



Time series of Power Spectral Density (PSD) of received energy at link Tx-S3

Time series of Power Spectral Density (PSD) of received energy at link Tx-S4

Adaptation and predictability



Throughput as a function of feedback delay in a variable-rate communication scheme.

- Time-correlated dynamics enable predictability of the channel quality
- Long propagation delays make the Channel State Information (CSI) outdated
- Therefore adaptive techniques should include a learning phase and prediction

Channel dynamics and environmental conditions

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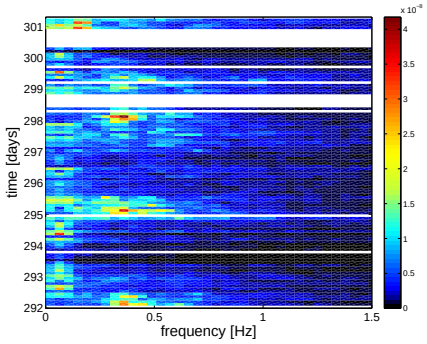

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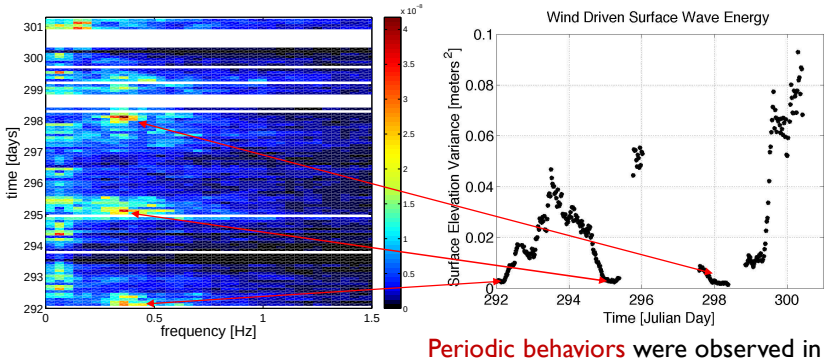


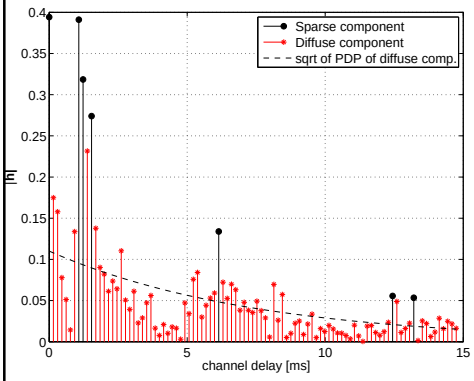
Periodic behaviors were observed in correspondence of low wind driven surface energy during SPACE08

Open issues

- Relate typical environmental conditions and channel quality dynamics
- Model the channel dynamics
- Evaluate predictive techniques with limited observability
- Identify channel dynamics that most affect coherent and non-coherent communications techniques
- Evaluate communications and networking techniques for the modeled channel dynamics

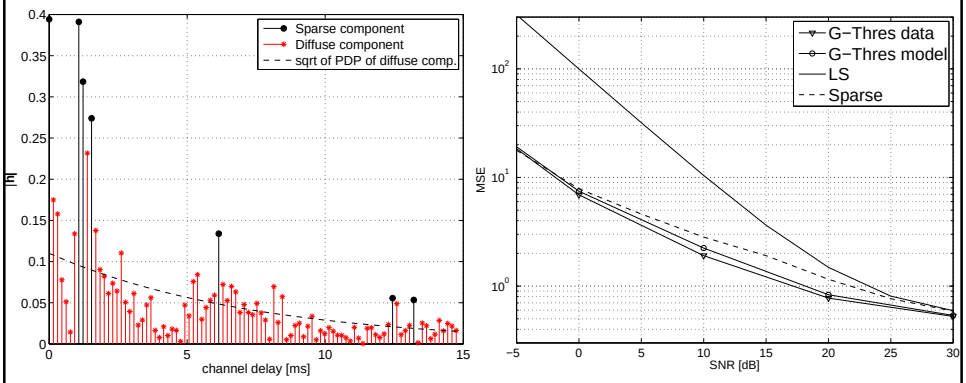
Analytical derivations and model validation

Hybrid sparse-diffuse channel model



Channel model for UWA communications via an Ultra-Wideband channel. Sparse channels have been proposed so far, however, a hybrid channel (both sparse and diffuse) is more accurate.

Hybrid sparse-diffuse channel model



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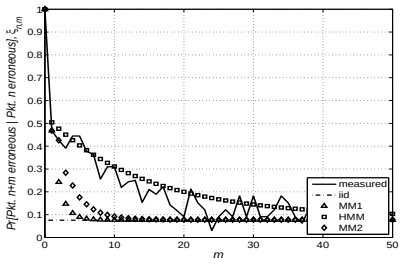
Markov and time-correlated models for UWA channels



- Validated Markov and hidden Markov model to accurately represent the packet error process at the physical layer

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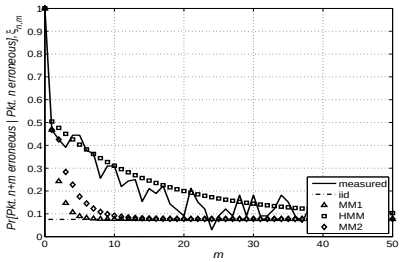

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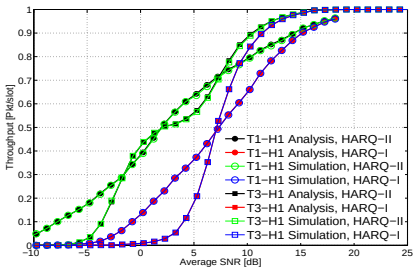


- Validated Markov model to be sufficiently accurate for representing the performance of Hybrid Automatic Repeat reQuest techniques

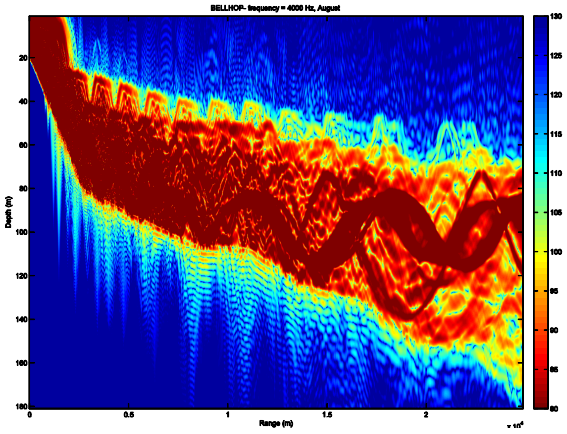
Open issues

- Parametric models can be used to fit the different channel dynamics and conditions measured throughout different experiments
- Model validation through experimental data may not be conclusive, but current evidence is favorable
- The gap on the relationship between environmental and channel conditions limits the generalization of such results

Tools and resources

From simulation toward experiments

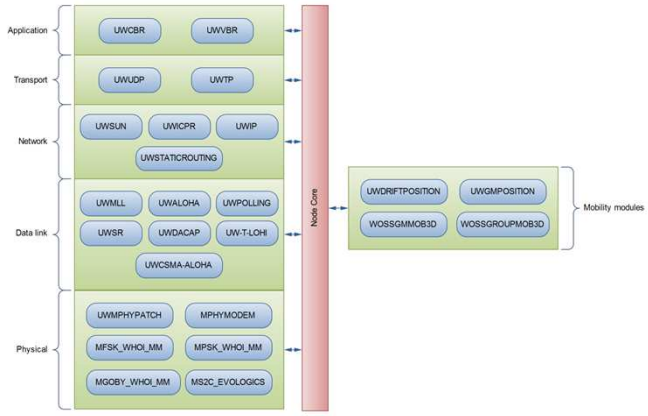
World Ocean Simulator System (WOSS)



- Ray-tracer (Bellhop) has been included in NS2, in order to get more accurate evaluations of the performance of networking protocols.

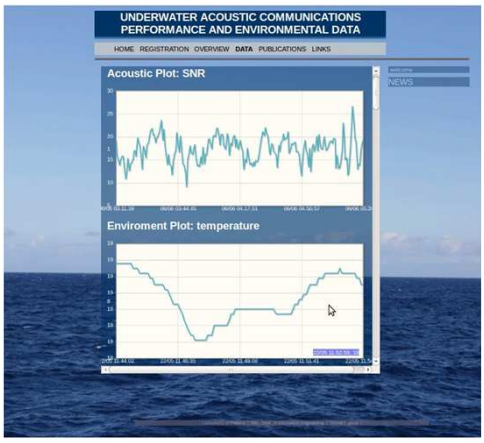
http://telecom.dei.unipd.it/ns/woss/

DESERT: DEsign, Simulate, Emulate and Realize Test-beds



http://nautilus.dei.unipd.it/desert-underwater

Controlled data access via website



- Experimental time series of both channel qualities and communication performance belonging to the 3 data sets are going to be public and downloadable through a login and password procedure

https://telecom.dei.unipd.it/uns/php/data.php

Open issues

- Time-varying channel conditions are not included in WOSS and are cumbersome to be recreated through a ray-tracer
- Lack of modeling able to represent how statistics of environmental conditions reflect into statistics of channel conditions (both in time and space)

Conclusions

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Contributions

- Identified the most important characteristics of the channel to be included in simulators: temporal and spatial dynamics
- Made progress towards understanding the limitations in generalizing the results derived from data analysis
- Highlighted the important missing measurements and characterizations for effective simulation studies
- Provided important and useful instruments (WOSS, DESERT, and a website) to the community

Conclusions

- Time- and space-varying behaviors are observed in UW channels
- Dealing with them is important and challenging
- The UW channel is very difficult to characterize, but recent results show some patterns (at least from a networking perspective)
- Understanding these effects and their relationship with environmental parameters is an emerging topic
- How to use this information will involve a mixture of adaptation, prediction, and learning
- Availability of open-source tools a key enabler for many groups

Thanks to…

- The US Office of Naval Research and ONR-Global

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Thanks to…

- The US Office of Naval Research and ONR-Global
- And to…
- The Italian Institute of Technology
- The European Commission
- The NATO Undersea Research Centre (now CMRE)
- The US National Science Foundation

Further reading on our web site

- http://telecom.dei.unipd.it/underwater
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