

Multiuser MIMO as a multiaccess technique for mobile underwater acoustic networks

P.-J. Bouvet, A. Pottier and B. Tomasi



Outlines

- 1 Introduction
- 2 MU-MIMO
- 3 Results
- 4 Conclusion

Outlines

- 1 Introduction
 - Underwater wireless communications
 - Mobile underwater acoustic networks
 - Multiple access techniques [OAC⁺12]

2 MU-MIMO

3 Results

4 Conclusion

Introduction

Underwater wireless communications

- Subsea to surface communications
 - Submarines
 - Gather data from fixed instruments
 - ...



Introduction

Underwater wireless communications

- Subsea to surface communications
 - Submarines
 - Gather data from fixed instruments
 - ...
- Communication between subsea systems
 - AUV coordination
 - Divers
 - ...



Introduction

Underwater wireless communications

- Subsea to surface communications
 - Submarines
 - Gather data from fixed instruments
 - ...
- Communication between subsea systems
 - AUV coordination
 - Divers
 - ...
- Many applications
 - Ocean monitoring (climate, pollution, ...)
 - Industry (oil, fisheries, ...)
 - Underwater exploration (marine archeology, natural resources, ..)
 - Search and survey (shipwrecks, mines, ...)



Introduction

Underwater wireless communications

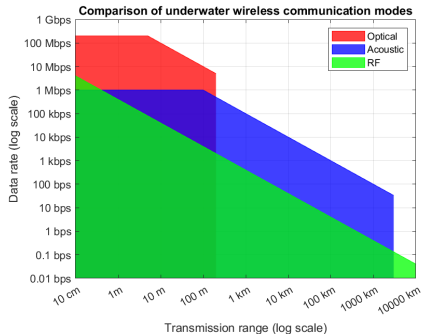


Figure 1 – from [FvTS20]

Introduction

Underwater wireless communications

- Electromagnetic radio
 - ✓ High bandwidth at very low range
 - ✓ Non line-of-sight
 - ✗ Large antenna and high power for longer range

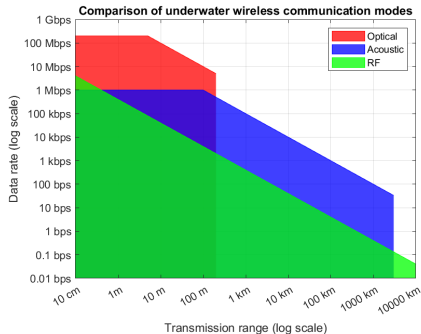


Figure 1 – from [FvTS20]

Introduction

Underwater wireless communications

- Electromagnetic radio
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- Optical
 - ✓ Ultra high bandwidth at low range
 - ✗ Ambient light and turbidity affects data rate
 - ✗ Line of sight required

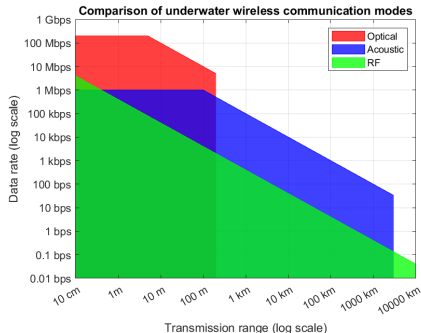


Figure 1 – from [FvTS20]

Introduction

Underwater wireless communications

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- Optical
 - ✓ Ultra high bandwidth at low range
 - ✗ Ambient light and turbidity affects data rate
 - ✗ Line of sight required
- Acoustics
 - ✓ Long range, moderate bandwidth
 - ✓ Non line-of-sight
 - ✗ Noise / channel dependent
 - ✗ Latency ($\simeq 1500$ m/s)

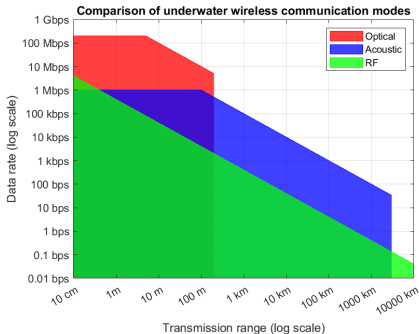
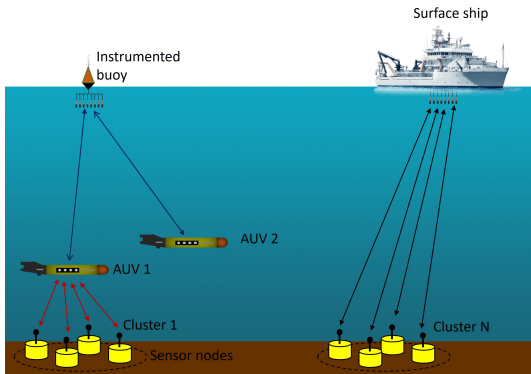


Figure 1 – from [FvTS20]

Introduction

Mobile underwater acoustic networks



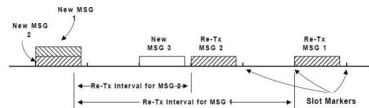
Open issue

Efficient acoustic spectrum sharing between static and mobile nodes

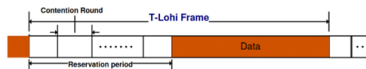
Introduction

Multiple access techniques [OAC⁺12]

- Contention-based protocols (random)
 - ALOHA
 - CSMA and variants
 - CSMA
 - FAMA
 - T-Lohi
 - ...



Slotted ALOHA Protocol

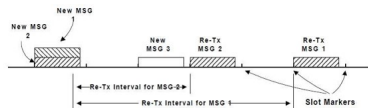


Introduction

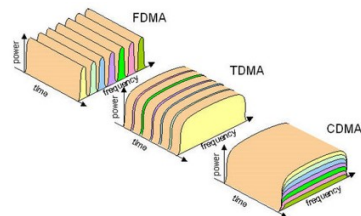
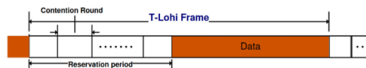
Multiple access techniques [OAC⁺12]

- Contention-based protocols (random)
 - ALOHA
 - CSMA and variants
 - CSMA
 - FAMA
 - T-Lohi
 - ...

- Contention-free protocols (deterministic)
 - Orthogonal
 - TDMA [MMZ18]
 - CDMA
 - FDMA
 - Non-Orthogonal
 - **MU-MIMO** [GKH⁺07, PBF21]



Slotted ALOHA Protocol



Outlines

① Introduction

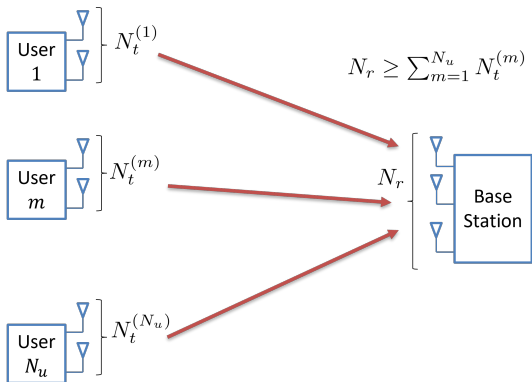
② MU-MIMO
Principle (uplink)
System model
Transmitter
Receiver

③ Results

④ Conclusion

MU-MIMO

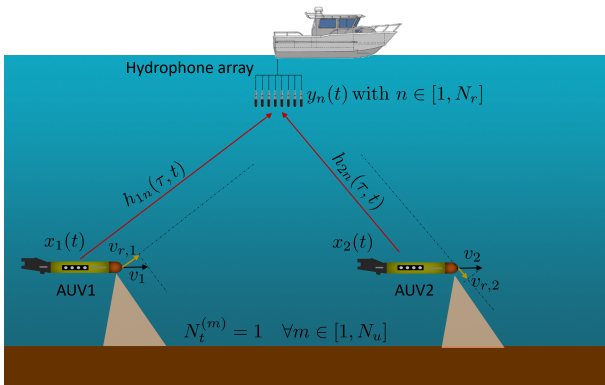
Principle (uplink)



- Simultaneous data transmission within the same spectrum
- Successive Interference Cancellation (SIC) at the receive side

MU-MIMO

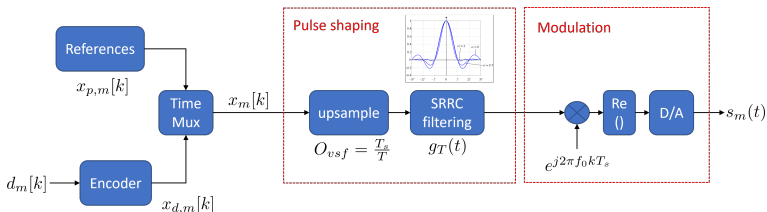
System model



$$y_n(t) = \sum_{m=1}^{N_u} \int_{-\infty}^{+\infty} h_{mn}(\tau, t) x_m \left(\left(1 - \frac{v_{r,m}}{c_w}\right) t - \tau \right) e^{-j2\pi f_0 \frac{v_{r,m}}{c_w} t} d\tau + w_n(t)$$

MU-MIMO

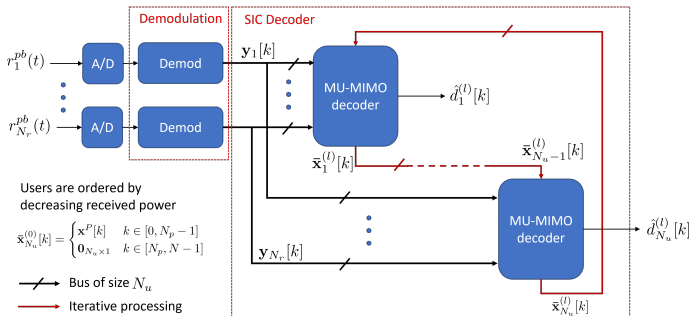
Transmitter



$$\begin{aligned}
 s_m(t) &= \Re \left(x_m(t) e^{j2\pi f_0 t} \right) \\
 &= \Re \left(\sum_{m=-\infty}^{+\infty} x_m[k] g_T(t - kT) e^{j2\pi f_0 t} \right)
 \end{aligned}$$

MU-MIMO

Receiver



Main features

- Multiuser channel equalization based on ordered SIC algorithm
- Differential Doppler compensation

Outlines

① Introduction

② MU-MIMO

③ Results

Model parameters

Simulation

Experiments

④ Conclusion

Results

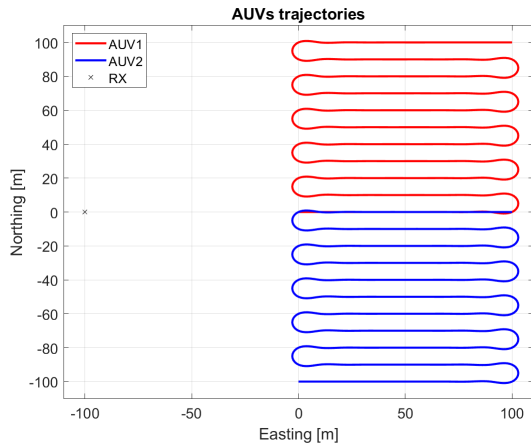
Model parameters

Notation	Meaning	TDMA	MU-MIMO
N_u	Number of users		2
N_r	Number of receive hydrophones		4
f_0	Center frequency		23 kHz
B	Signal bandwidth		8.4 kHz
M	Modulation order		4 (QPSK)
N_p	Number of pilots symbols per frame	253	509
N_d	Number of data symbols		1030
gc	Convolutional code generator		(133, 171) _o
R_C	Convolutional code rate		1/2
D_b	Maximum data rate	2.41 kbit/s	4.02 kbits/s
c_w	Wave celerity		1500 m/s
z_w	Water depth		110 m
d_{mn}	Transmission range		$\in [97, 224]$ m
$v_{r,m}$	Relative speed		$\in [-2, 2]$ m/s
TL(d)	Transmission loss		$17 \log_{10}(d) + 4.02 \cdot d/1000$ dB
NL	Noise level		79.6 dB re 1 μ Pa
SL	Signal Level		$\text{SNR}_{\min} + \text{NL} + \text{TL}(\max(d_{mn}))$

$$D_e = D_b(1 - \text{FER})$$

Results

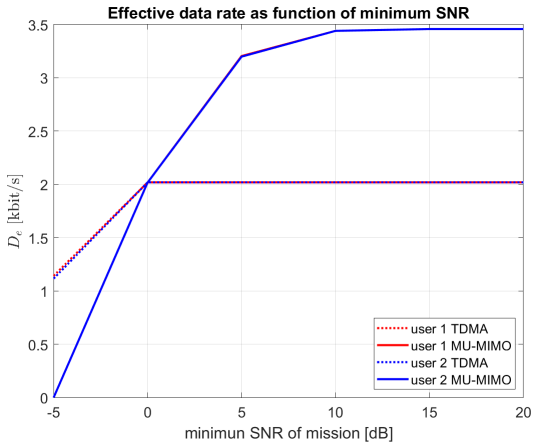
Simulation



- Boustrophedon navigation path
- 100 m × 100 m area for each drone
- $v_1 \simeq v_2 \simeq 2$ m/s
- Acoustic comm. channel model [QS13]

Results

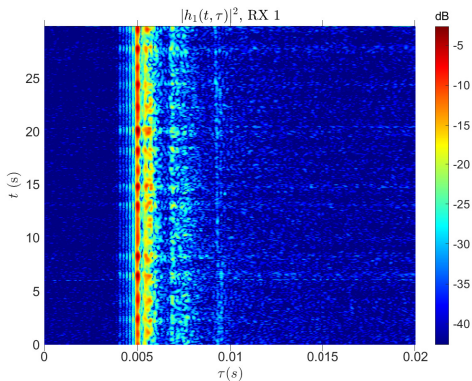
Simulation



- Effective data rate as function of minimum SNR received during mission
- MU-MIMO provides $\simeq +70\%$ data rate gain against TDMA
- Better robustness of TDMA at very low SNR

Results

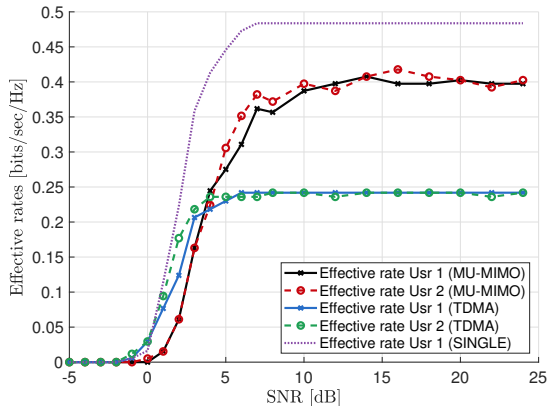
Experiments



- UWA channels sounded using MLS sequence at $\simeq 300$ m range
- Recorded using IROM-LMAIR system in Lanveoc, Bay of Brest, June 2019

Results

Experiments



- Multiuser channel replay [VWSOJ17]
- Static scenario
- MU-MIMO provides +67% data rate gain against TDMA

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Synthesis

Conclusion

Synthesis

- Study of MU-MIMO access technique as an alternative to TDMA
 - ✓ Deterministic protocol
 - ✓ Better channel capacity exploitation than orthogonal multiple access
 - ✓ Effective data rate gain vs TDMA $\simeq 70\%$
 - ✓ No complexity added on transmit side
 - ✗ Requires (rough) synchronization protocol (as TDMA)
 - ✗ Less robust than TDMA at very low SNR
 - ✗ Sensitive to near-far effect (> 1000 m)
 - ✗ Requires advanced decoding scheme
- Future works
 - Comparison of SIC algorithms with single user and multiuser channel estimation
 - Asynchronous streams decoding

Do you have any questions?

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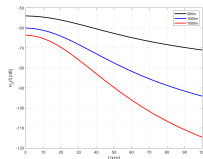
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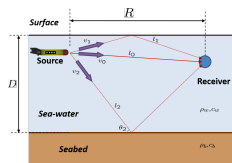
Backup

Underwater acoustic communications

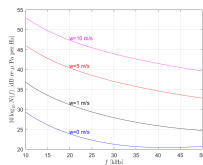
- Low wave celerity
 - $\simeq 1500$ m/s
- Frequency attenuation
- Frequency selectivity
 - Multipaths.
- Noise :
 - Natural
 - Artificial
- Temporal selectivity
 - Motion induced Doppler
 - Scattering effect



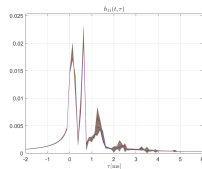
(a) Attenuation



(b) Multipaths



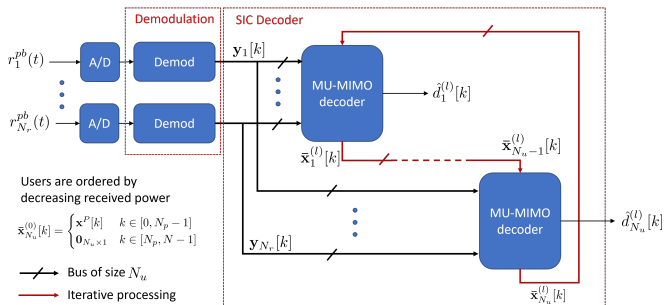
(c) Noise



(d) CIR

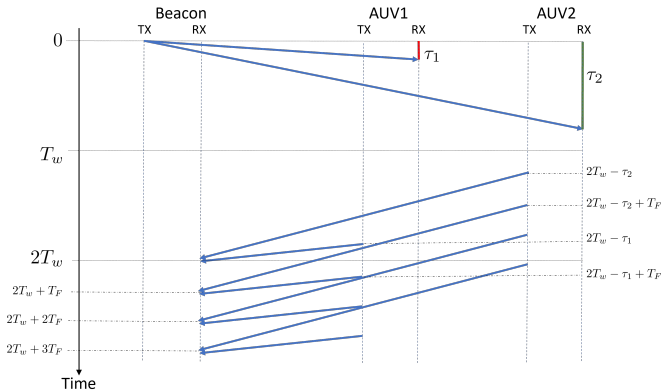
Backup

MU-MIMO decoder



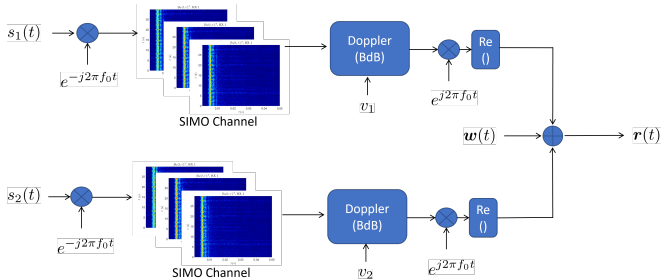
Backup

Synchronization protocol



Backup

Multiuser channel replay



Backup

Achievable rates

