Directionality for Acoustic Communications

2018 NSF Workshop on Underwater Wireless Communications and Networking March 19 – 20, 2018

Arthur B. Baggeroer
Massachusetts Institute of Technology
Cambridge, MA 02139

Milica Stojanovic
Northeastern University
Boston, MA 02115

Outline

- **Motivate directionality for acomms**
- **Comparisons to RF**
- **Past / current directional acomms systems**
- **Acomms environments**
  - **Shallow vs deep**
  - **Frequency and directionality**
  - **Noise**
- **Challenges (unique to directionality)**
  - **Channel acquisition**
  - **Tracking**
- **Summary**

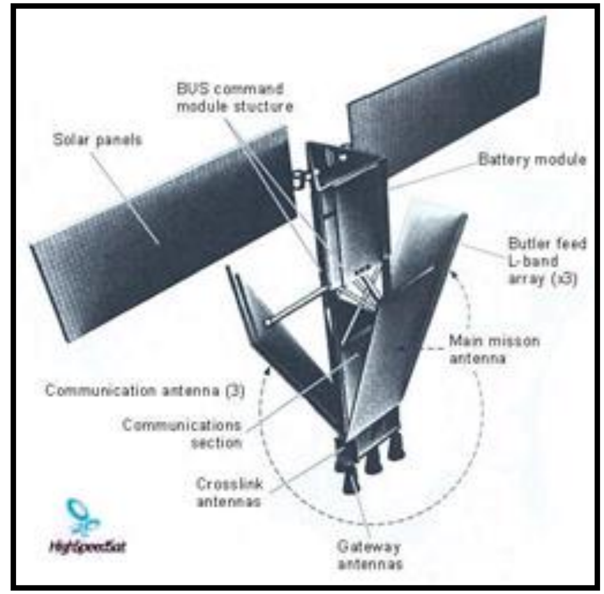
Motivation (I)

- Can improvements for the physical layer of acomms systems be achieved?
  - Introducing directionality suggest YES!
  - Note designs of most RF duplex systems
- Advantages
  - @ XMTR
    - Transmit array gains => higher SNR
    - Spurious multipath not excited
  - @ RCVR
    - Receive array gains => lower ambient noise
    - Multichannel adaptive equalizers => lower ISI

Motivation (II)

- **LPI/LPD =>**
  - Do not transmit to the whole wide world
  - Do not listen to the whole wide world
- **Deconfliction for networks**
  - Network nodes saturate the available time-bandwidth-space dimensions regardless of modulation method
  - Not enough distance for absorption to deconflict
  - => Links should occupy only their paths!!
  - The lightning bolts on the network diagrams in all papers to date are fictitious!!

RF Directionality



ATT Microwave circa 1962

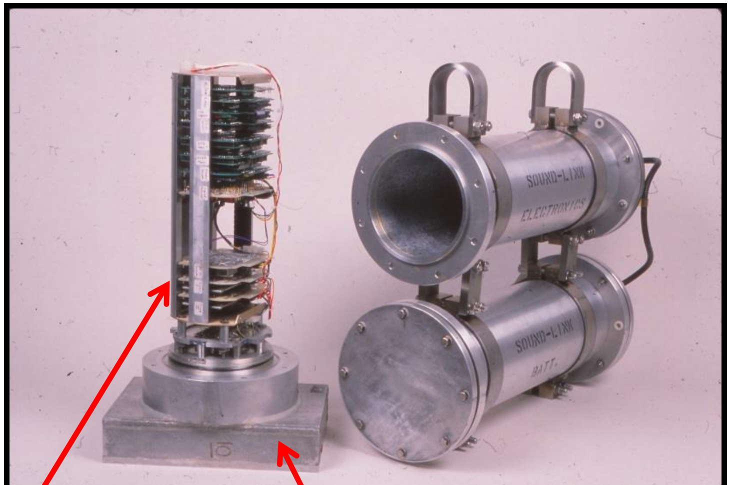
- 62 m$ = .51 b$ today
- 11 – 43 GHz (λ = 2.7 - .7 cm)
- fixed / fixed angles
- Troposphere channel

Iridium circa 2009

- 5 b$ = 8.3b$ (Motorola bankrupt)
- 10 mHz @ ~1.62 GHz (λ = 18 cm)
- 3 dB gain on hand set telephone
- fixed / fixed angles steered w/ gateway

Acomms Directionality
Two Systems w/ Directionality

Digital Acoustic Telemetry System (MIT/WHOI) circa 1982



Electronics XMTR array

10 kHz @ 50 kHz
4 x 8 array (30 x 15 deg)
Steered w/ CCD's

Digital Acomms System circa 2010

1 kHz @ 3.5 kHz
Bow ~10 m
Legacy to WHOI

MIT Acoustics

Acomms Experiements w/ Arrays

- **KAM 08 (Kauai Acomms MURI). Preisig, et al, WHOI**
- **Time Reversal methods, Song, et al, Scripps**
- **LRAC (Long Range Acomms), Song, et al Scripps**

Directionality and the Platform

- **Array beamwidths**

$$\Delta\phi \text{ (radians) } = 1/(L/\lambda) \text{ (broadside)}$$

$$\Delta\phi \text{ (radians) } = 1/\sqrt{2L/\lambda)} \text{ (endfire)}$$

- **UUV examples**
  - **REMUS 100 (~ 1m) @ broadside & 30 kHz**

$$\Delta\phi = 3^\circ$$

  - **REMUS 600 & LDUUV (~ 3m) @ broadside & 15 kHz**

$$\Delta\phi = 2^\circ$$

  - **Boeing XLDUUV (~15 m) @ broadside @ 1.5 kHz**

$$\Lambda\phi = 4^\circ$$

- **Narrow beamwidths attainable @ useful frequencies**

Directionality
Steering the beams issues

- **Link acquisition**
  - Beam pointing – needs duplex comms for feedback
    - Wide beams to narrow beams
  - Time and frequency w/ Doppler handshaking
    - Establish frame synchronization and Doppler track
  - Wide proportional bandwidth to carrier issues
  - Speed of sound vs. vehicle motion
- **Tracking algorithms**
  - M seqs/LFMs and residual carrier for time domain
  - Angle tracking – split beam correlator algorithm? Or?
- **Rapid and covert link reacquisition**
- **These are the most difficult issues!!!**

Summary

- **Arrays and directionality can increase the performance of digital acoustic comms substantially!**
- **Narrowbeams for useful CONOPs (concepts of operation) available on Existing UUV platforms.**
- **The challenging issues are**
  - **Link acquisition**
  - **Tracking**
  - **Rapid reacqustion**
  - **Spatial processing for comms**