DARPA Director’s Vision of Communications Technology Evolution

Key to Infrastructureless Comm

Self-Forming
Small Unit Operations-Situational Awareness System Program – SUO SAS

Packet Radios
Global Mobile Program - GLOMO

Dynamic Spectrum
Next Generation Comms Program - XG

Mobile
Mobile Networked MIMO Program – MNM
Future Combat System – Comms Program - FCS-C
Disruption Tolerant Networking - DTN

Future Network(s)
Wireless Network after Next Program - WNAN

Network Adaptation & Optimization
Control-Based Mobile Ad-Hoc Networking Program – CBMANET
Connectionless Networking - CN

Information Protection
Dynamic Quarantine of Computer Based Worm Attacks Program – DQW
Defense Against Cyber Attack in MANETs Program – DCMANET
Intrinsically Assurable MANET – IA MANET

MEMS/NEMS
Analog Spectral Processors - ASP
WNaN Radio

- Single RF Processing Slice Replicated to form 4 Transceiver Voice/Data Radios
- Early Hardware and Networking Capability to Enable Experimentation, TTP Development by Services
- Low Technical and Cost Risk Hardware to Maximize Transition Success
- Built in Dynamic Spectrum Capability
  - No Frequency or Network Planning Required

WNaN Radio Goals:
• 4-Transceiver Node @ $500 in Lots of 100K
• Spectrally Adaptive
• MIMO in Urban and Tight Spectrum Environments
• Member of Four Simultaneous Subnetworks
Multiple Input and Multiple Output Communications (MIMO)

Reliable and Assured Communications

“The growing reliance of the U.S. military on "information superiority" underscores the need to address problems of military communication in urban areas.”


MIMO will provide a communication link that is...

- reliable
- adaptable
- morphable

Distribution Statement “A” (Approved for Public Release, Distribution Unlimited)
DARPA MIMO Vision

Communicate Where Today’s Radios Fail

Challenge: Urban warfare communications
- Traditional communication platforms are unable to operate in urban environments where US forces are increasingly engaged

Solution: MIMO Technology
- High bandwidth and adaptable communications allow the message to get through regardless of the surrounding environment
- Harnesses the surrounding landscape to provide a highly reliable, adaptable and morphable communication link
- MIMO thrives in multi-path environment that is detrimental to current radios
- MIMO offers the network a spatial resource

Commercial MIMO has limitations
- Poor performance in interference
- Fragile networking
- Mobility implementations basic and limited
- Data rate and low cost are higher priorities than link robustness

MIMO Allows Urban NLOS Communications Where Current Radios Fail
Issues with Commercial MIMO Applied to Military Systems

- Commercial MIMO is fragile
  - Poor performance in interference
  - Weak coding
  - Lossy receiver algorithms
  - Fragile synchronization
  - Fragile networking
  - Limited delay spread compensation

- Data rate and cost higher priorities than link robustness

- Limited by computations and standards

---

**Commercial MIMO Hardware**

**IEEE 802.11N MIMO WiFi**

**Performance Comparison**

10 dB SNR

**Fraction of Optimal Capacity**

**Interference (dB)**

- MI - Minimum Interference
- MMSE - Minimum Mean Squared Error

**Estimate Interference**

**Blind to Interference**

Data rate and cost higher priorities than link robustness

- Limited by computations and standards
Military Network Performance Improvements Leveraging MIMO

- Strong potential for military network improvements using antenna arrays and MIMO techniques
- In order to take full advantage of array and MIMO technology, customized PHY, MAC and Network protocol designs are required
  - Signal separation improves frequency re-use
  - Improved link reliability softens acknowledgment overhead
  - Longer hops lighten scheduling overhead
System Description:
- Detection: Single airborne receiver or multiple terrestrial receivers (w/ GPS) to provide location and tracking information for SAR Operations
- Localization w/o GPS at tag accuracy < 70’ and processing speed < 30 sec
- Demo’d LOS range = 82 miles
- Cost < $100 per tag (in quantities)
Prototype Receiver System

**IFPS Equipment**

**Tag**

- Tag completely inert until activated
- Lifetime limited by battery shelf life
- Activated lifetime: Days to week
- 40% reduction in size for next phase

**System includes Tag Docking Station (not shown)**

- Programs Tag transmission codes
- Recharges Tag batteries

Distribution Statement “A” (Approved for Public Release, Distribution Unlimited)
Consistently Detect Individuals in Multi-path, Urban Environment

- Conducted 4 field experiments and several airborne experiments
  - Camp Pendleton II MEU Test Results-Jun 07:
    - Stationary and moving vehicles and Marines
    - 100% tag activation and identification
    - Geolocation to within meters
    - LPI/LPD proven – not detected by RAD BN
    - Classified after action report on SIPR
  - Quantico Airborne Experiments 28-29 Aug 07:
    - IFPS standalone equipment easily setup on CH-53
  - JPRA is assisting with TTP development and tactical employment lessons learned to mitigate any concerns

Marines operate system, experiment w/ CONOP

Distribution Statement “A” (Approved for Public Release, Distribution Unlimited)
Typical Tag Experiments

- Inside vest
- Attached to belt under clothing
- Inside Wet Shirt sleeve pocket
- Inside variant of LAV
The Concept: Overcome bad links using a vastly improved version of “20 Questions”

**Why does this overcome the bad link?**

\[ SNR \text{ Increase (dB)} = 10 \log (T_{1\text{bit}} \times R_b) \]

Example: 1 Mbps using conventional comm, 1 bit over 1 sec using 1-bit comm

60 dB SNR Increase

**Drop “1-Bit Data Rate” to Lowest Possible Level to Boost SNR**

The views, opinions, and/or findings contained in this article/presentation are those of the author/presenter and should not be interpreted as representing the official views or policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the Department of Defense.

Distribution Statement “A” (Approved for Public Release, Distribution Unlimited)
High Level Architecture

Mission-Specific Memory Module

General Purpose Processor (GPP)

Data Storage

Sensors, Devices

Information Accuracy
- Low False Alarm
- High Probability of Success

"1-Bit" Signaling
- How do you cope with "lies?"
- How do you "encrypt" one-bit?

Frequent Reconfiguration
- On-the-fly use of new algorithms
- Hardware implements only the mode needed NOW, NOT all possible modes

Three Key Technical Challenges

The views, opinions, and/or findings contained in this article/presentation are those of the author/presenter and should not be interpreted as representing the official views or policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the Department of Defense

Distribution Statement "A" (Approved for Public Release, Distribution Unlimited)
This framework allocates a sandbox region in which modules from a library are flexibly placed and interconnected while continuously running (no reboot).

An algorithm can be incorporated in 10 ms without resetting FPGA.

State of Practice Digital Radio Restart Times
- MNM radio: 20 sec to 1 min
- Cell Phone: 10 sec
- Blackberry: 7 sec to 2 min
- Single FPGA Reset: 250 ms
Communicate using a predefined "Dialog", a decision tree whose nodes are "20-Q Games", each of which is also a decision tree.

- Questions can be binary (yes/no) or m-ary (Multiple Choice)
- The answers may sometime be "lies" due to channel corruption
- Questioner learns the answer before asking the next question

The views, opinions, and/or findings contained in this article/presentation are those of the author/presenter and should not be interpreted as representing the official views or policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the Department of Defense.

Distribution Statement “A” (Approved for Public Release, Distribution Unlimited)
Mission Benefits

**Mission Benefits**

**Achieves Mission Objectives**

**Fact:** Objective is often not to “see video”, but to generate actionable information

- **Approach:** Define overarching mission objectives, and carefully define when the link interactivity is “done”

**Enables missions that are currently not possible**

**Fact:** Some scenarios had many decades of additional path loss or interference that make traditional communication intractable

- **Approach:** Drop the required data rate from the disadvantaged size of a two-way asymmetric link to one bit per unit time to increase SNR

**Extends utility of long lifetime “No-data” Tag, RFID and Tripwire sensor systems**

**Fact:** Communications throughput and energy constrains many “one-bit” devices and limits their utility

- **Approach:** By shifting the burden to the advantaged side of the link, valuable information can be gained from these devices

**Technical Benefits**

**Transmitting One-Bit Signals will Increase Detectability**

**Fact:** Energy per symbol for a given interference and noise channel limits range

- **Approach:** Extend the symbol duration by many orders of magnitude
  (ex/ 1 nanosecond to 1 second yields 90 dB of SNR benefit)

**Interactivity**

**Fact:** A highly interactive dialogue between two nodes can optimize mutual information from a single symbol

- **Approach:** Develop methods for forming good questions and efficient answers (dialog)

**Asymmetry**

**Fact:** Often, one can overpower the link in one direction

- **Approach:** Leverage ability to communicate “real data” to give disadvantaged node special abilities that enable the transfer of information

---

The views, opinions, and/or findings contained in this article/presentation are those of the author/presenter and should not be interpreted as representing the official views or policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the Department of Defense.

Distribution Statement “A” (Approved for Public Release, Distribution Unlimited)
Military Utility

Ship Boarding
- Below Deck
- Ship-to-Ship
- Very high interference

Robotic Warfare
- Dynamic environment
- Real time Video
- Command and control from around corners

Urban Warfare
- Reliable mobile communications throughout the labyrinth of buildings and streets

Subterranean Warfare
- High risk, difficult communications environment

Allows Successful Military Operations