Resilient Networked Distributed Mosaic Communications (RN DMC)

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Assured long range communications through distributed element mosaic antennas

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Program Overview
Challenge: Long Range Tactical Communications - Today

- Large size, weight, power, and cost (SWAP-C)
- Large visual and Radio Frequency (RF) signatures
- Single points of failure
- Vulnerable to jamming
What if antennas could be autonomously formed from individual low-cost transceiver elements with little restriction on where the elements are placed?

- Size, weight, and power can be distributed
- More robust against failure/attack and more difficult to detect and locate
- If done correctly, lower cost (target $1000 dollars each or less) and expendable
- Leverage existing tactical radios and waveform

**Big Idea: Antenna Tile Mosaic**

Transceiver elements are ‘tiles’ in a self forming, self healing mosaic antenna.
Squad leader to squad leader communications

- Tactical Radio using tactical waveform
- Tactical Radio using RN-DMC
- Peer-state adversary detection, location, and jamming capabilities

RN-DMC enables squad-to-squad communications in a challenging threat environment.
1. Interface (gold) transceiver receives signal from radio
2. Gold transceiver augments signal (may add preamble, co-channel underlay, subcarriers or even completely transform the signal digitally to support distributed coherent transmission and additional networking and/or telemetry data)
3. Every blue transceiver in the mosaic ‘hears’ the gold transceiver
4. Blue transceivers measure channels and compute phase offsets then retransmit with appropriate phase adjustment to form directional beam towards remote receiver
5. Gold transceivers extract tactical radio waveform from augmented signal and provide to tactical radio
6. Low data rate links between nodes support computation of relative node positions

Transceivers work together to provide distributed coherent gain
Signal Injection Chain

- **Receive**
  - Tactical Signal $f_1$
  - Analog to Digital
  - Processor: *Inject chain processing may augment digitized signal to support DCT*
  - Digital to Analog
  - Telemetry link

- **Transmit**
  - Digital to Analog
  - Analog to Digital
  - Gain + downconversion
  - upconversion + gain

Signal Recovery Chain

- **Receive**
  - Augmented Tactical Signal
  - Digital to Analog
  - Gain + downconversion
  - Upconversion + gain
  - Telemetry link

- **Transmit**
  - Analog to Digital
  - Digital to Analog
  - Gain + downconversion
  - Upconversion + gain

**Blue mosaic transceivers**
(block diagramed on next slide)

- Telemetry link: Times of arrival from blue transceivers and routing information. Telemetry/networking channel is distinct from tactical comms

This is a notional architecture for an interface between the tactical radio and the blue tiles. The design is up to the performers.
Blue Transceivers – Functional Block Diagram (Notional)

- Communications signals transmitted to and received from either
  - Gold interface transceiver
  - Remote mosaic antenna

- Nodes also send telemetry messages within the mosaic (illustrated by interconnecting lines)

- Design objectives (quantified in metrics)
  - Minimize inter-transceiver communication
  - Minimize bandwidth (BW) of augmented tactical signal relative to non-augmented tactical signal

![Diagram showing block diagram of Blue Transceivers](image)

- Tactical signal BW
- Augmented Tactical Signal BW

- Processing: Compute channel estimate; add variable delay, measure RF phase (of jamming signal, compute time of arrival)
- Times of arrival, routing data, computed carrier phase battery power; transceiver health
- Telemetry link

- Analog to Digital
- Digital to Analog
- Tactical signal BW
- Augmented Tactical Signal BW

Distribution Statement A: Approved for Public Release, Distribution Unlimited, Case 33086
Notional Approach: Sounding the Channel

N Transmitters

$B_{N1}$

$B_{N2}$

$B_{N3}$

Sounding Beacon

$d_1$

$d_2$

$d_3$

M Receivers

$B_{N1}$ Channel Est.

$B_{N2}$ Channel Est.

$B_{N3}$ Channel Est.

$B_{N4}$

$B_{N2}$ Channel Est.

$B_{N3}$ Channel Est.

$d_1$

$d_2$

$d_3$
Notional Approach: Sounding the Channel

N Transmitters

BNN1
BNN2
BNN3

M Receivers

BNM1
BNM2
BNM3
BNM4

D_N
D_M

DN
DN
Align Transmissions

\[ A = M^*N^*\sqrt{P_o} + \sum_{i=1}^{M} \sigma \]

\[ A = N^*\sqrt{P_o} + \sigma \]

\[ SNR = \left( \frac{M^*N^*\sqrt{P_o}}{\sigma^2 M} \right)^2 = \frac{P_o N^2 M}{\sigma^2} \]
Notional Approach to Computing Relative Position of Transceiver Tiles

- In addition to gain through coherent combining, signaling between transceivers allows their relative positions to be computed.
- This will enable unit commanders to visualize the locations of their soldiers or marines, even in GPS denied environments.
- Relative position estimates can be computed from time difference of arrival (TDOA) measurements.

**Step 1:** Gold transceiver initiates TDOA.

**Step 2:** Each transceiver in turn transmits with a unique transceiver identifier. Each transceiver receives signals from other transceiver and logs time of arrival ($t_{mn}$).

**Step 3:** TOA's from transceiver 1, 2 and 3 sent back to transceiver 0.

**Step 4:** Relative position estimates computed using TDOA's and displayed on ATAK or similar visualization tool.

TDOA's:
- $t_{01} - t_{21}$, $t_{01} - t_{31}$, $t_{21} - t_{31}$
- $t_{02} - t_{12}$, $t_{02} - t_{32}$, $t_{12} - t_{32}$
- $t_{03} - t_{23}$, $t_{03} - t_{13}$, $t_{13} - t_{23}$
Telemetry channel security
• Minimal impact: loss of node produces graceful degradation of transmission
• Telemetry compromise poses no risk to mission data
• Worst case scenario is DDOS-like attack by attack large percentage of telemetry links (same as a jammer with conventional comms)

Telemetry security approach within the distributed antenna array (Blue nodes)
• Telemetry link – commercial encryption
• Intrusion detection – physical layer measurements made by other blue nodes
• Anomaly detection – inconsistent behaviors given the antenna array geometry
• Response – disable/ignore compromised nodes

Security from the far end (Gold nodes)
• Detection – identify degraded performance caused by a transmit node
• Response – warn all nodes on the transmit side

Notional RN DMC Security Approach

COMSEC addressed by legacy tactical radios (RN DMC is a “colorless core”)
• Standard crypto and red/black separation as exists on legacy radios
• Encrypted data passed over RN DMC distributed antenna array same as free space
• Risk to mission data confidentiality and integrity no different than legacy over-the-air transmission
RN DMC Key Technology Enablers

- RN DMC will leverage unmodified tactical radios in concert with mosaic antennas to demonstrate antenna array to antenna array communications

- Advanced signal processing in small, low-cost packages
  - Small form factor software defined radios (SDRs)
  - Radio Frequency Systems on a Chip (RFSoCs)

- Feasibility of basic Distributed Coherent Transmission (DCT) validated under earlier R&D efforts
  - DARPA CLASS, ReACT, PrEW
  - Projects tested comms from a distributed cluster to a point receiver, employing custom hardware and waveforms

- Low-cost, expendable platforms for airborne/space mosaics
  - High altitude balloons (good option for program demo)
  - Drones
  - Micro/Nanosats

Powerful signal processing in a small, inexpensive form factor is the key enabling mosaic antenna technology
• The RN DMC program will include three focus areas:
  1. System Design (performer focus)
  2. Experimental Performance Validation (performer focus)
  3. Operational Architecture Definition (Government team focus with performer collaboration)
• Design milestones and key test events are interleaved, similar to a ‘spiral’ development approach
• Three phase, 45 month program
  • Prototypes tiles in Phase 1
  • Field demonstration at end of each phase with performance validation against metrics
  • Memorandum of Agreement with one or more services (completed during Phase 2) required to proceed to transition focused Phase 3
Phase 1 (18 Months) Design, Prototype and Test

Objectives
- Develop design to support multi-hop distributed to distributed communications
- Many to one Long-Link Test to validate RN DMC concept demonstrated with tactical radio/waveforms (e.g., TSM-X, Link 16, ANW2, HNW, PTW, UHF SATCOM)

Key Events
- System Design Review (SDR) #1 – Month 4
- SDR #2 – Month 10
- Long Link Test – Month 14
- SDR #3 - Month 18

Long Link Test details
- Minimum 10 mosaic tiles, two tactical waveforms
- Represents ground to air use case
- At least 2 ground waveforms and 1 SATCOM waveform
- Both static and moving use cases for ground based tiles
- Interference nulling

Options for airborne platform
- Performer assumes responsibility for flight platform and all aspects of test
- Performers integrate with government platform

Long-reach communications with interference nulling using a single antenna array
Phase 2 (15 Months) Distributed to Distributed Coherent Communications

Objectives:
• Refine and update design
• Two distributed to distributed tests (Terrestrial Test and Relay Field Test)
• Relative positioning

Key Events
• SDR #4 – Month 4
• Terrestrial Test – Month 11
• Relay Field Test – Month 14

Terrestrial Test details
• 20 mosaic tiles
• Represents squad to squad use case
• Line of sight and obstructed paths between squads
• Static and moving user tests
• Distributed coherent communications and beam nulling

First test of distributed to distributed coherent communications
Relay Field Test details

- Two ground mosaics (at least 10 tiles each)
- Airborne mosaic (at least 10 tiles)
- Represents long range comms in a contested, SATCOM denied environment
- Performers responsible for airborne platforms
- Distributed coherent communications, and beam nulling
- Relative positioning
- Moving and static test for ground users
- Terrestrial and SATCOM waveforms
Phase 3 (12 Months) Service Implementation

Objective:
- Cost share with Services to develop a transition ready capability that meets their specific needs

Key events – proposer plans should include
- SDR #5 – Month 4
- User Field Exercise – Month 10

Phase 3 is contingent on formal transition partnership between DARPA and one or more military services

Phase 3 adapts RN DMC to service specific needs
<table>
<thead>
<tr>
<th>FY20</th>
<th>FY21</th>
<th>FY22</th>
<th>FY23</th>
<th>FY24</th>
<th>FY25</th>
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**Design & Prototype**

- BAA

**System Demonstration**

- Phase 1 Base (18 Months)
  - System Design Review (SDR) 1
  - SDR2
  - Long Link Demo
  - SDR3

- Phase 2 Option (15 Months)
  - SDR4
  - Terrestrial Test
  - Relay Field Exercise

- Phase 3 Option (12 Months)
  - User Field Exercise
  - SDR5
  - MOAs

**Service Implementation**

**Government Support**

**RN DMC Program Schedule**

<table>
<thead>
<tr>
<th>Design &amp; Prototype</th>
<th>System Demonstration</th>
<th>Service Implementation</th>
<th>Government Support</th>
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</thead>
<tbody>
<tr>
<td>BAA</td>
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<tr>
<td>FY20</td>
<td>FY21</td>
<td>FY22</td>
<td>FY23</td>
</tr>
<tr>
<td>FY24</td>
<td>FY25</td>
<td>Q1</td>
<td>Q2</td>
</tr>
</tbody>
</table>

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Proposal Expectations

BAA (page 6) includes detailed list of specific proposal expectations – partial list below

- Describe the tactical radios and operational waveforms that will be demonstrated
- Include a system-level illustration of the proposed RN DMC approach
- Describe the tactical radios and operational waveforms that will be demonstrated
- Describe the components represented by the ‘blue’ transceiver tiles…
- Describe the tactical radio/RN DMC components represented by the ‘gold’ transceiver tiles…
- Describe in detail how both distributed coherent transmission (DCT) and distributed coherent reception (DCR) will be achieved without GPS
- Describe an approach that maximizes both information security and physical security, while allowing the blue tiles to remain unclassified and attritable
- Present a realistic roadmap leading to production of the tiles 18 months or less after program completion
- Describe any airborne platforms used for tests and demonstrations…

Proposals should provide convincing evidence of capability to build and test RN DMC
### RN DMC Metrics – Technical Performance

- Three categories of metrics: Technical Performance, System Level and Manufacturability
- Table below shows Technical Performance Metrics
- BAA (page 33) contains instructions for obtaining the FOUO Addendum which has the values for the final four metrics in the table

#### Table: RN DMC Metrics – Technical Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Threshold (Objective)</th>
<th>Validation Method</th>
<th>Validation Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal to noise ratio enhancement</td>
<td>50% (75%) of ideal performance</td>
<td>Test</td>
<td>End of phase 1 (M=1); End of Phase 2 (M&gt;1)</td>
</tr>
<tr>
<td>Interference suppression</td>
<td>20 (30) dB for M-1 spatially distributed interferers where M is the number of mosaic transceivers</td>
<td>Test</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td>Mean side lobe suppression</td>
<td>-10Log(N) (-20Log(N))</td>
<td>Test</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td>Relative position measurement accuracy</td>
<td>20m RMS across 5 or more transceivers in &lt;60 seconds</td>
<td>Test</td>
<td>End of Phase 2</td>
</tr>
<tr>
<td>LPD</td>
<td>See FOUO Addendum</td>
<td>Modelling/Analysis</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td>Range Ratio (ground to ground)</td>
<td>See FOUO Addendum</td>
<td>Modelling/Analysis</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td>Range Ratio (ground to air)</td>
<td>See FOUO Addendum</td>
<td>Modelling/Analysis</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td>LPE</td>
<td>See FOUO Addendum</td>
<td>Modelling/Analysis</td>
<td>End of Phase 1</td>
</tr>
</tbody>
</table>
• Note emphasis on minimizing bandwidth expansion and inter-tile communications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Threshold (Objective)</th>
<th>Validation Method</th>
<th>Validation Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency extent</td>
<td>&gt;3GHz (&gt;10GHz)</td>
<td>Test</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td>Number of operational tactical waveforms demonstrated (ground/terrestrial)</td>
<td>2 (4)</td>
<td>Test</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td>Number of operational tactical operational waveforms demonstrated (SATCOM)</td>
<td>1 (2)</td>
<td>Test</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td>Maximum capacity of communications links between local mosaic transceivers (which are distinct from the communications which originate from tactical radios)</td>
<td>10 Kbit/sec (0)</td>
<td>Test</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td>Maximum ratio of instantaneous BW of augmented or transformed tactical signal to BW of non-augmented tactical signal</td>
<td>3 or less (1)</td>
<td>Test</td>
<td>End of Phase 1</td>
</tr>
</tbody>
</table>
Proposers must show a convincing path to meeting the production SWaP-C targets at quantity.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Threshold (Objective)</th>
<th>Validation Method</th>
<th>Validation Point</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SWaP of prototype transceiver</strong></td>
<td>Volume: 20 in³</td>
<td>Inspection</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td></td>
<td>Weight: 1 lb</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effective Isotropic Radiated Power: 1 W</td>
<td>Inspection</td>
<td>End of Phase 1</td>
</tr>
<tr>
<td><strong>SWaP-C of production transceiver at quantity</strong></td>
<td>Volume: 6 in³</td>
<td>Design analysis</td>
<td>End of Phase 2</td>
</tr>
<tr>
<td></td>
<td>Weight: 0.5 lb</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effective Isotropic Radiated Power: 1 W</td>
<td>Design analysis</td>
<td>End of Phase 2</td>
</tr>
<tr>
<td><strong>Mission duration under normal mission comms load</strong></td>
<td>72 (96) hours</td>
<td>Design analysis</td>
<td>End of Phase 2</td>
</tr>
</tbody>
</table>
• Program is **UNCLASSIFIED**
• Tactical radio and/or waveform information required in the development of RN DMC will be classified in accordance with the specific tactical radio/waveform Security Classification Guide (SCG)
• Proposers must request a specific DARPA SCG per the BAA instructions

RN DMC will produce unclassified, expendable hardware and software