A Commentary on Reconfigurable Communications Systems in Support of NASA Mission

Dr. Félix A. Miranda  
Deputy Chief, Communications and Intelligent Systems Division  
NASA Glenn Research Center, Cleveland, OH  44135

Felix.A.Miranda@nasa.gov  
Tel: 216.433.6589

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and  
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and Deployable Multifunctional Antennas

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What is a reconfigurable?

Definition of reconfigure –

- To rearrange the elements or settings of something…
- To change the shape of something …
- To reorder, realign, reshape..

What is a reconfigurable antenna?

A reconfigurable antenna is an antenna whose physical or electromagnetic distinctive/fundamental parameters (i.e., size, frequency, radiation pattern, and polarization) could be altered in a controlled manner. Such reconfiguration could be either in response to human commands/inputs, e.g., via Software Defined Radio (SDR), or autonomously as induced via a cognitive/intelligent agent. More on this later in the talk…
Why Reconfigurable Communications Systems?

**Traditional Satellite Communications Assets:**

- Designed following very stringent specifications dictated by intended functionality, orbital placement, frequency of operation, power consumption, expected lifetime, etc.
- Lack flexibility…
- Upgrading in satellite series typically requires upgrade/advances in hardware with its concomitant high cost and development time implications, among others.

**Reconfigurable Communication Systems:**

- Can respond according to specific needs hence increasing versatility and usability of the asset.
- Potentially lower cost since reconfiguration is attained via waveforms inputs (e.g., software defined radio) as opposed to hardware changes.
- NASA GRC is at the vanguard of reconfigurable communication systems via Software Define Radio (SDR) and Cognitive Systems for Space Communications.
In today’s communication systems, many functions including Coding and Modulation are implemented using Software Defined Radios (SDRs).

With SDRs, functionality can be changed with updates to application software (“Waveforms”) instead of hardware replacements. Fixed hardware is replaced with reprogrammable hardware such as Field Programmable Gate Arrays (FPGAs) and Processors.

SDRs enable increased capability with reduced Size, Weight, Power and Cost (SWaP-C).

GRC has played a strong role in advancing the SOA in SDR technology.

Software Defined Radios-STRS Architectures

2010 – SCaN Testbed Flight Radios Developed by General Dynamics, Harris Corp., JPL

The Space Communications and Navigation (SCaN) Testbed (STB), established to perform system prototype demonstration in relevant environment (TRL-7). The STB was launched on July 12, 2012 to the ISS.

Development of design tools and validation test beds. Development of design reference implementations and waveform components. Establish SDR Technology Validation Laboratory at GRC. NASA/Industry Workshops conducted

Develop common, open standard architecture for space-based software defined radio (SDR) known as Space Telecommunications Radio Architecture (STRS). Allow reconfigurable communication and navigation functions implemented in software to provide capability to change radio use during mission or after launch. NASA Multi-Center SDR Architecture Team formed.
Advancing the SOA in Software Defined Radios

GRC developed the **Scan Testbed (STB)** - launched to the ISS 2012

- Technology Demonstration Mission to mature Communication, Navigation, & Networking technologies for application in space
- Highly modular software enabling in-orbit reconfiguration and multi-waveform operation
- Coding and modulation can be varied based on link conditions resulting in improved performance and efficiency.
- To date over 20 Consultative Committee for Space Data Systems (CCSDS) Protocols including IP over CCSDS, Delay Tolerant Networking & Digital Video Broadcasting - Satellite - Second Generation (DVB-S2) have been implemented.

Since 2002, GRC has led development of the Space Telecommunications Radio System (STRS) architecture standard for SDRs. Standard allows waveforms to be reused for different applications and on platforms developed by different vendors.
**Roadmap to Cognitive Communications**

**Goal:** Leverage STB and develop next generation cognitive technologies for communications to increase mission science return and improve resource efficiencies.

SCaN Test Bed is an early proving ground for experiments in cognitive communications

- Performed experiments in VCM and ACM
- Moving toward cognitive communications
  - More efficient use of spectrum, power and network resource management

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<th>SDR</th>
<th>Variable Coding &amp; Modulation (VCM)</th>
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<td>Configurable Properties</td>
<td>Reconfigure system based on predictions</td>
<td>Dynamic reconfiguration based on feedback</td>
<td>Adapting and learning to form intelligent systems: cognitive radios, intelligent networking, user initiated services</td>
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Automatic compensation for dynamic link environment
SCaN Next Generation Architecture

Optical & Ka-Band
Disaggregated
Software Defined
Multi Node
Networked
Delay/Disruption Tolerant
Autonomous
Interoperable
Affordable
Extensible

Wideband Ka-band

Breaking Ka Band Interoperability Barriers

Hybrid Radiofrequency Optical Technology – Under Development

SCaN Interplanetary Network

Integrated Radio and Optical Communications (ROC)

Combined Ka-band RF and 1550 nanometer optical capability

Technology Under Development

- Integrate 3 meter Ka-band reflector with 12.2 meter telescope operating at 1550 nanometers – “Teletenna” concept
- Reconfigurable software defined radio with PSK (OP) and PPM (option)
- Re-acquisition pointing system based on fusion of radar sensors

User Spacecraft 3 meter Teletenna
- Wide Ka-band antenna
- Mechanically scanned optical system
- Telescope contributes to RF aperture gain

Ref: Mr. Badri Younes, Deputy Associate Administrator for Space Communications and Navigation (SCaN).
Adaptive coding and modulation with cognitive engines
- Choose optimal settings by predicting channel conditions
- Eliminate the need for calculating precise link budgets

Radio Frequency (RF) interference mitigation
- Automatically sense and avoid spectrum interference by changing frequency, bandwidth, and data rate
- Cognitive engines to identify and remove interference

Self-configuration of radio by modulation recognition of signal
- Perform signal recognition that allows self-configuration and link acquisition even with noise or weak signal

Cognitive compensation for propagation and nonlinear channel effects
- Classify overall channel degradation by its component effects and mitigate each one appropriately
- Learned communication channel optimization (DeepSig)

Optimal hand-off between Free Space Optical and RF links
- Integrate FSO and RF seamlessly to form a unified transport

Ref. Dr. Janette Briones (janette.c.briones@nasa.gov) SCaN Cognitive Communications
**Cross-layer optimization and discovery of network devices**
- Autonomously assign Quality of Service metrics to user data
- Discover capabilities of user radios on SCaN network

**Drop user spacecraft data at any space or ground asset**
- Improve network management and responsiveness
- Eliminate the need for reserving specific assets for customers

**Delay and disruption tolerance (DTN) over multiple hops**
- Apply CE to determine the optimal route through a space network with infrequent or distant nodes

**Network security for integration of commercial providers**
- To protect user data and provide flexibility when using third-party transport services

Ref. Dr. Janette Briones
(janette.c.briones@nasa.gov) SCaN
Cognitive Communications
Determine optimum link configuration
- Configuration to target link, network performance, past performance, priority, & data urgency.

Enable user spacecraft to request high-rate data services...to allow SCaN services to be scheduled in near real-time

Automate Quality of Service metrics and collect network data
- to identify degradation within SCaN assets and customer spacecraft

Distributed Cognition
- Network configurations based on priority, throughput, asset availability, schedule, and performance

Ref. Dr. Janette Briones
(janette.c.briones@nasa.gov) SCaN Cognitive Communications
To fully exploit the advantages of Cognitive Communications Systems the hardware should not be the communications bottleneck…

…Hence the reconfigurable antennas!!
Challenges of Antenna Reconfiguration

- Multiple functions within one radiating aperture; this can be achieved via,
  - Frequency Selective Surface – fulfill operations at a variety of frequencies
  - Ultra-Wide Band Antennas – communication and sensing; radar/radiometry
  - Phased Array Feed Antennas (PAFA) – Multiple Beams, Multiple frequency antennas

- All along while maintaining quality of operation upon multiple reconfigurations, scanning, etc.
  - Impedance Matching
  - Gain/Directivity
  - Efficiency
  - Others

- Burden/requirements on Materials/components
  - Resiliency (e.g., Rad hard; no hysteresis; long MTBF)
  - Power handling capabilities (particularly for Tx arrays)

Reconfigurable Antennas
Example of Potential Reconfigurable and UWB Antennas

Potential Functions

- Ultra Wide Band
- Multi-Band
- Multi-function (Sensing and Communications)
- Beam shaping
- Beam steering

References:

The central frequency in a stacked square patch can be reconfigured by as much as 100MHz (Shifted from 8.1017 to 8.2017 GHz)

Polarization Reconfiguration – CP Square Patch

- Polarization Reconfiguration:
  - Demonstration of semiconductor control component integration with printed circuit antenna elements
  - Switching is performed by PIN diodes
  - Ability to reconfigure between LHCP or RHCP

Corner Truncated Square Patch

Conformal Lightweight Antenna Structures For Aeronautical Communications Technologies (CLAS-ACT)

This project is to develop antennas which enable beyond line of sight (BLOS) command and control for UAVs. We will take advantage of newly assigned provisional Ku-bands for UAVs and use unique antenna designs to avoid interference with ground. This will involve designing antennas with high effective radiated power (EIRP) and ultra-low sidelobes. The antennas will be made with polymer aerogel as a substrate to both reduce weight and improve performance.

POCs: Dr. Mary Ann Meador (maryann.meador@nasa.gov); Dr. James Downey; Mr. Bryan Schoenholz; Ms. Marie Piasecki
CLAS-ACT Antenna Design

Circular Patch Element

Triangular Lattice Sub-Array

Conformal Prototype Array for Flight Test

POCs: Dr. Mary Ann Meador (maryann.meador@nasa.gov); Dr. James Downey; Mr. Bryan Schoenholz; Ms. Marie Piasecki
Simulated performance of 64 element sub-array
- Conformed to 16” radius
- Antenna-aircraft coupling effects
- Beam synthesis (alternating projections with quantization) and null steering methods to meet ITU mask

POCs: Dr. Mary Ann Meador (maryann.meador@nasa.gov); Dr. James Downey; Mr. Bryan Schoenholz; Ms. Marie Piasecki
THE MULTIPLE ACCESS TESTBED FOR RESEARCH IN INNOVATIVE COMMUNICATIONS SYSTEMS (MATRICS)

GRC Test Bed to Evaluate Antenna Performance in a Controlled Emulated Environment

**TDRSS Ka Forward Service**

- **EIRP**: 63 dBW
- **Free Space Loss**: ~210 dB
- **Bandwidth**: 50 MHz
- **Modulation**: BPSK/UQPSK
- **Data Rate**: 300 kbps – 25 Mbps
- **Max. User Rx Power (before antenna)**: -117 dBm

**TDRSS Ka Return Service**

- **G/T**: 26.5 dB/K
- **Free Space Loss**: ~210 dB
- **Bandwidth**: 225 - 650 MHz
- **Modulation**: BPSK/UQPSK
- **Data Rate**: 300 Mbps

**Approach:** Scale LEO-GEO relay links into a controlled, emulated environment to perform CONOPS, architecture trades, and technology assessments for various relay/user terminal technologies.

- Flexible platform to test/demonstrate various relay and user terminal technologies and CONOPS

GRC POC: Dr. James Nessel (james.a.nessel@nasa.gov)
The MATRICS
Dynamic Phased Array Testing

MATRICS Test Parameters
• ISS LEO orbit configuration
• Anokiwave 64-element COTS phased array
• 26 GHz return service link
• Characterize EVM through entire LEO-GEO link pass

GRC POC: Dr. James Nessel (james.a.nessel@nasa.gov)
Summary and Conclusions

- Reconfiguration of communication systems is critical to maximize the performance of communication assets particularly those in aerospace applications where,
  - Assets are difficult to reach for replacement and/or maintenance (i.e., space)
  - Assets as limited to small form factors and conformal surface (e.g., Space CubeSats and aerospace platforms such as UAVs, sUAS, and HALE among others).

- System reconfiguration has been demonstrated in space via Software Define Radio (SDR). GRC has led numerous experiments since 2012 up to present using the Space Communications and Navigation (SCaN) Test bed in the International Space Station.

- Yet, SDR reconfiguration is based on-command based (i.e., Human-Machine interface which becomes more challenging for Deep Space Communications.

- Cognitive Communications Systems could potentially address autonomous reconfiguration on demand.

- Accordingly, hardware that is reconfigurable is required to fully exploit the potential of cognitive communications systems.

- Reconfigurable antennas and cognitive antennas are then critical technologies highly desired for the next generation of aerospace communications architecture.