Exploring Cognition using Software Defined Radios for NASA Missions

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Future Space Communications

- Communications across solar system
- International interoperability – cooperation with other space agencies
Steps and Objectives for NASA Cognitive Communication Systems

1. Software Defined Radios
   - Flexible technology for communications and navigation

2. Variable Coding & Modulation
   - Improves point-to-point data throughput and efficiency over fixed mode for deterministic environment changes.

3. Adaptive Coding & Modulation
   - Improves point-to-point data throughput, reliability, and efficiency over VCM for non-deterministic environment changes.

4. Cognitive Applications
   - Maximizes data throughput, communications efficiency (BW, power, etc.), interference and other mitigations.

5. Intelligent Network Automation
   - Reduces operations complexity and cost.
A cognitive system makes the most sense when all dimensions are considered.
Adaptive/cognitive applications

• Node-to-node communications (local knowledge)
• Cognitive & adaptive techniques to better use link resources (margin/power/spectrum) for data transfer (e.g. large volume)
• Self aware, able to respond to surroundings and link conditions

System wide knowledge and automation

• Ground control manages/monitors system assets for dynamic reconfiguration
• Architecture considerations for changing space system – inform network ops & MOC
• Automated service requests and usage, location sensitive information
• Event Manager grants requests according to other requests and priorities (hours, not weeks)
• Seamless connectivity among satellite relays and ground stations – use any available link

Internetworking (reliable data transport)

• Disruptive tolerant networking (DTN) overlay of adaptive/cognitive system
• DTN protocol changes to accommodate data rate and link changes (multi-node)
• Anytime, anywhere, any network connectivity
Distance Matters

Real-time feedback control from Earth on actual link.

Use of uplink metrics to control downlink mode.
Transmit waveform targeted for S-band SDR

- Compatible with the DVB-S2 standard V1.3.1
- Operates up to 6.16 Msym/s
- Up to 27.3 Mbps user data
- Direct-to-earth link band limited to 5 MHz (4.55 Msym/s, 20 Mbps)

**Transmit Filters:** SRRC, $\alpha = 0.2, 0.25, 0.35$, span = 12 symbols

**Framing:** CCSDS AOS

**Utilization:** 50% of Virtex-2 XC2V3000
Dynamic link difficult to model completely — appropriate scenario for automated adaptive approach.
DVB-S2 Direct-to-Earth VCM Testing Results

VCM yields significant increase in user data throughput over constant modulation and coding.

ACM will improve performance further towards capacity.

<table>
<thead>
<tr>
<th>User Data Throughput</th>
<th>Gain/Loss</th>
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</thead>
<tbody>
<tr>
<td>VCM actual vs NASA Legacy</td>
<td>3.71 dB</td>
</tr>
<tr>
<td>Prediction</td>
<td>-0.59 dB</td>
</tr>
<tr>
<td>Capacity</td>
<td>-0.80 dB</td>
</tr>
</tbody>
</table>
16-APSK and LDPC (1/2, 2/3, 7/8) FEC transmit waveform on Ka-band flight SDR.

Non-linear digital pre-distortion used to compensate for Travelling Wave Tube Amplifier effects.

Commercial receiver on the ground.

Achieved 433 Mbps user data rate over 225 MHz Channel.
Point-to-Point Optimization Example
Digital Pre-distortion Results

DPD off EVM = 34%
DPD on EVM = 14%

- 16-APSK digital pre-distortion module: gain and phase adjustment of inner and outer rings to account for non-linearity
- Enables operation near saturation point of amplifier, and improves BER performance
- Plans to make this a dynamic adaptation with full duplex feedback
Virginia Tech - *Adaptive Modulation*

- Applying to direct-to-earth S-band uplink
- Using six PSK and QAM modulation schemes
- New waveform apps for SCaN Testbed; USRP development for ground systems
- Simulations show when shadowing from solar panels occur

*Worcester Polytechnic* and *Penn State* - *Adaptive Link Layer Protocol*

**Atmospheric & Space Weather Impairments Research**

- Time/temperature varying effects of ionosphere at Ka/S-band
- Multipath propagation of scintillated signals
- Mapping of effects into distinct states

**Cognitive algorithms**

- Machine learning: Neural networks, Reinforcement learning
SCaN Testbed Ground Network

**Flight System on ISS**
- 3 Relay Satellite Paths w/ IP
- On-Orbit Flight Computer
- VCM or other Experiment Laptop
- IP over CCSDS Gateway

**Ground Testbed at GRC**
- GRC Ground Station Path
- Direct to Ground Path
- 3 Relay Satellite Paths
- GRC Front End Processor
- RS-422 Serial
- SLE / DTN Gateway
- GRC External Services Network (ESN)
- IP over CCSDS Ground Network
- Internet
- VN or other Experiment Laptop
- GRC Ground Station or Test Gateway
- High-Bay Network (Ground Station and Ground Test Network )
- Other space agencies
- JPL Ground Station or Test Radio
- GD Ground Station or Test Radio
- Ground Testbed Flight Computer
- ABC Company
- GD Company
- JPL

**Other Space Agencies**
- IP over CCSDS
- Ground Station
- Test Gateway
Evolution to Intelligent Routing

Internet Protocol (IP) over CCSDS
Space Link Extension (SLE) Gateway
Delay Tolerant Networking (DTN)
Secure DTN
Launch Waveforms

Cross-layer Cognition (Sensing, Learning, Adapting)

End-to-end Data Exchange is:
Adaptive, Autonomous, Cross-layer Connecting, Secure, Scalable.
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visit SCaN Testbed on-line:
http://spaceflightsystems.grc.nasa.gov/SOPO/SCO/SCaNTestbed