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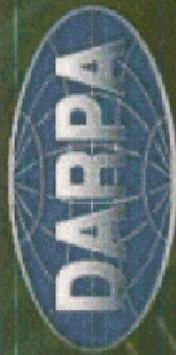
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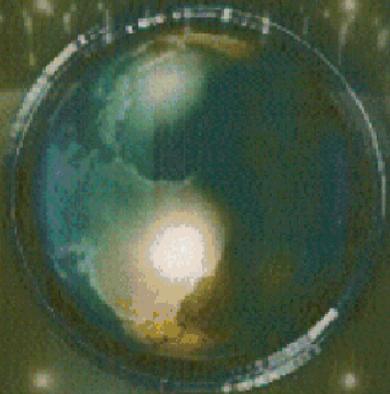
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*Beyond the Outer Limits*

**XG**

*Next Generation Communications*



**Presented by  
Preston Marshall**

**FCC Cognitive Radio Conference  
19 May 2003**





## Today's Topics



- **DARPA XG Program**
- **Future Spectrum Utilization**
- **How Policy, Technology and Radio Waveform Interact**
- **Cognitive Radio Opportunities**

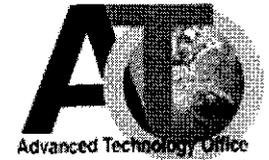
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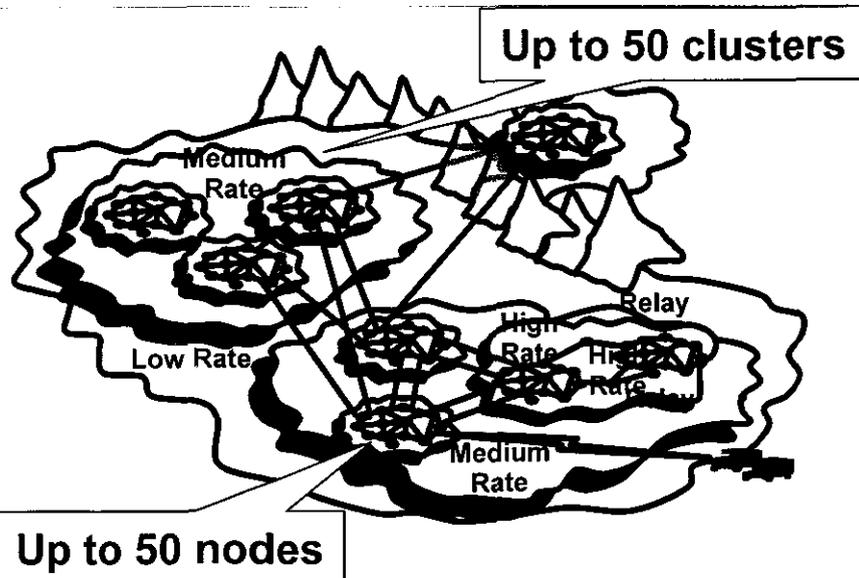
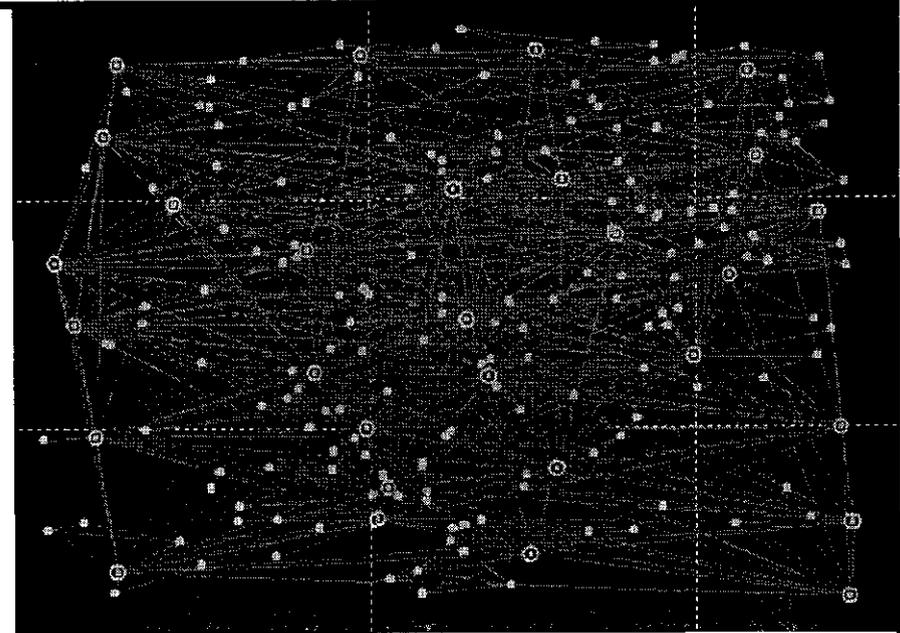
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# A New Way to Manage Spectrum Is Necessary



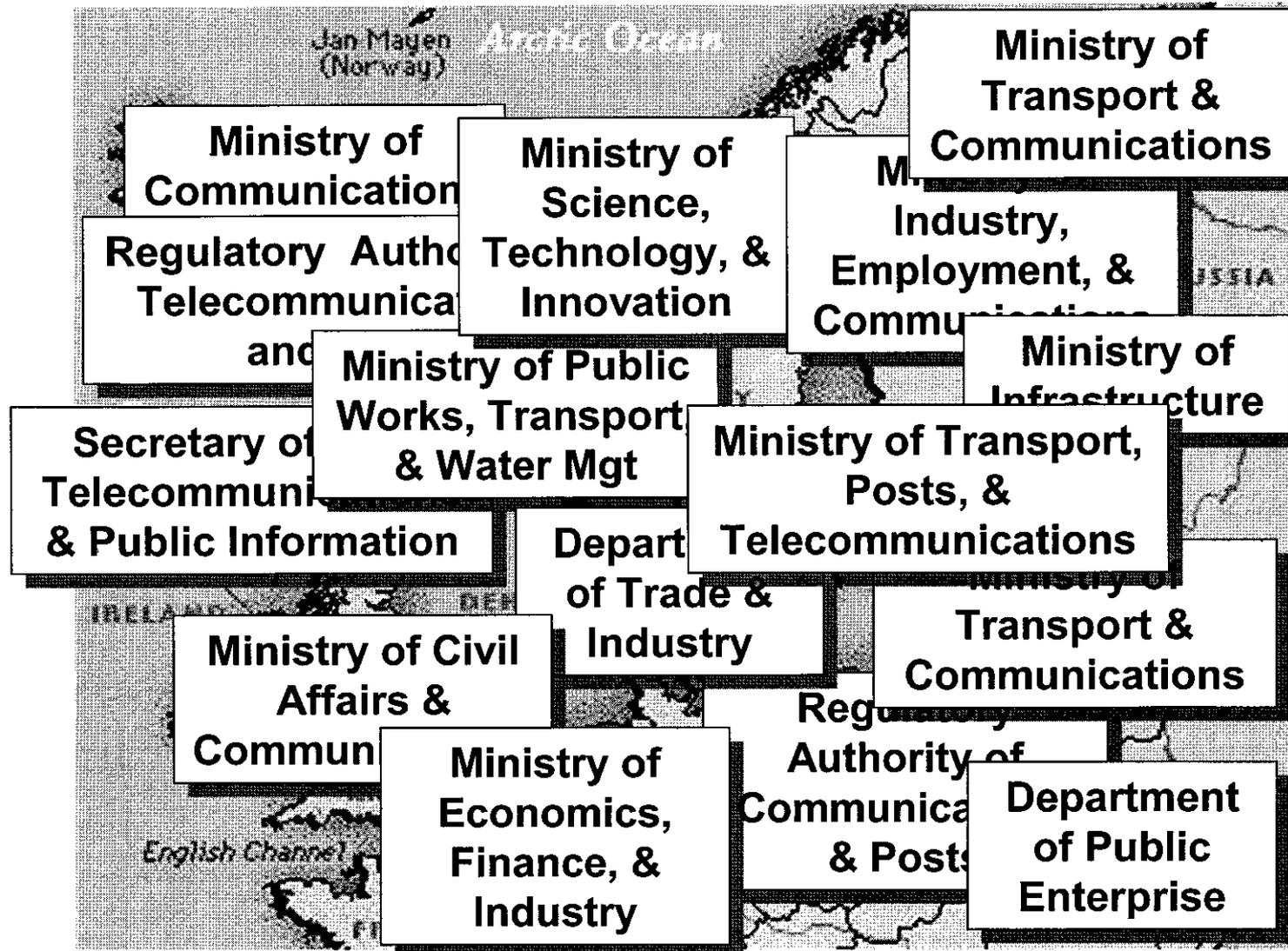
- **Large-Scale Ad Hoc Network Complexity is Beyond Human Planning**
  - Ever Changing Membership, Extent, Topology, Routing, ...
  - Varying Demand, Multiple QOS Require Adaptive Solutions
- **Planning is at least  $N^2$**



- **Conventional Static Frequency Planning Process Not Possible**
  - Not Enough Spectrum to Provide for All Possibilities
  - NW Topology Dynamic- Unknown at Onset
  - Only Net Members Know Actual Link Conditions



# Spectrum Access is Not Just A US Issue! What DoD Faces Overseas!





# XG Program Components



## Measurements

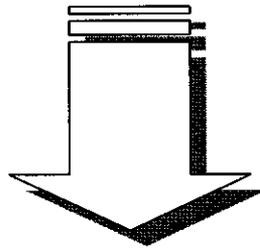
Temporal, Spectral,  
Dimensional, Energy  
Characteristics

## Policy-Based Controls

Control of Features,  
Priorities, Allocations,  
Exclusions,...

**XG Products**

**XG Protocol Set**



**Initial XG Implementation**

**Military & Civil  
Communications and  
Sensor Applications**

**Transition to  
Military Use**

**The Primary Product XG Program is Not a New Radio, but a Set of  
Advanced Technologies for Dynamic Spectrum Access**



# XG Key Principles



- **Create Set of Abstract Behaviors**
  - Manage Communications Network Spectrum Access
  - Coordinate Other Spectrum Users (Radars,...)
  - Not Specific to Any One Physical or Link Layer
  - Implementation and Application (Military/Civil) Independent
- **Suitable for Range of Architectural Implementations**
  - From Stand-alone to Fully-cooperative
  - Extensible Set of Control Protocols
  - Enable P3I Into Existing Programs
- **Protocol Developed & Managed Via Request For Comment (RFC)**
  - Modeled After Internet Development Process
  - DARPA-Run and Managed, but Open to Public for Comment/input
- **Identify “*Interference-Preserving*” Core Set**
  - Similar to Security-Preserving Frameworks
    - Red/Black Separation, Labeling, TCB, ...
  - Allow for XG Extension Outside of Core Set Boundary



# XG Policy-Based Controls



- **XG Being Developed In Advance of Policy Framework**
  - Implementations Must Fit With National And International Regulations
  - Algorithms Must be Adaptable
    - Regional and operational situations
    - Evolving policies
- **Policy-Based “Metalanguage”**
  - Translates Policy Rules Into Radio Behavior Controls
  - Decouples XG Technology From Regulatory Process
  - Control Operating Rules Based on Policies and Situations

**Policy-Based Controls Will Draw on Practices & Methodologies Currently Employed Manually by Spectrum Managers**

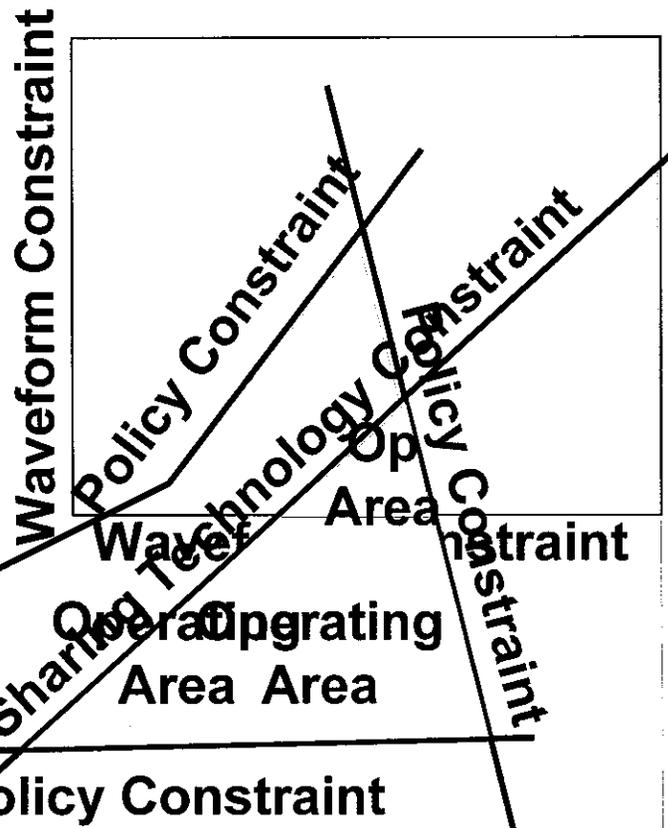


# Policy, Technology, and Design



Dimensions Could be Frequency, Time to Vacate, Maximum Power, Maximum Xmit Time, ...

**Dimension 2**



Limit Potential Operating Rules by Imposing Policy on All Users

Spectrum Sharing Has Only Limited Capability to Manage Spectrum Use, and Further Constrains Capability

Radio Standards (Waveform, MAC, Bandwidth) Have Minimum Requirements

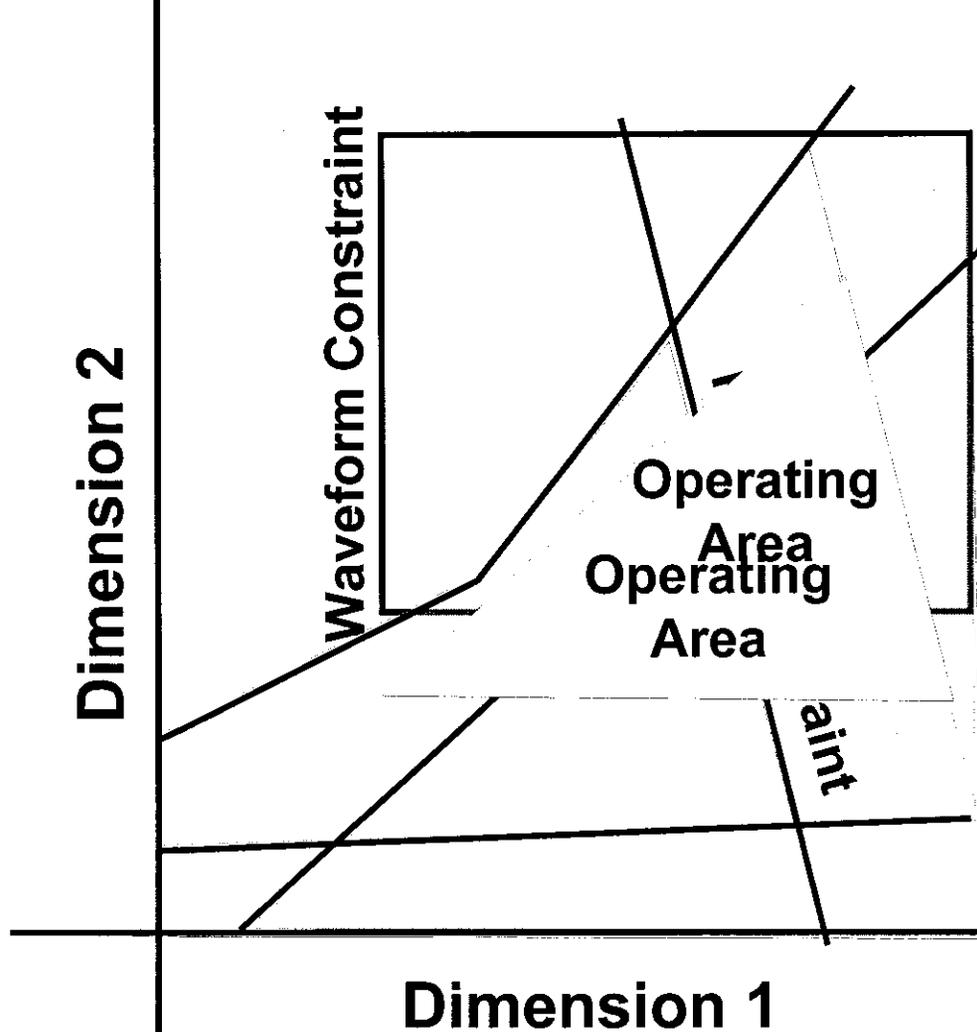
**Dimension 1**



# How to Technology and Policy Can Maximize Access



## Three Ways to Make Opportunistic Sharing More Effective



1. Enhance Policy Flexibility by Opening Up the Envelope
2. Increase Capability to Dynamically Sense and Adapt  
  - Accept and Manage More Risk
  - Faster Spectrum Analyzers, More Instantaneous Bandwidth
3. Develop Radios & Waveform Standards that Can Adapt to Meet Sharing Requirements  
  - Wider Coverage, Better Antennas, Adaptive Waveforms



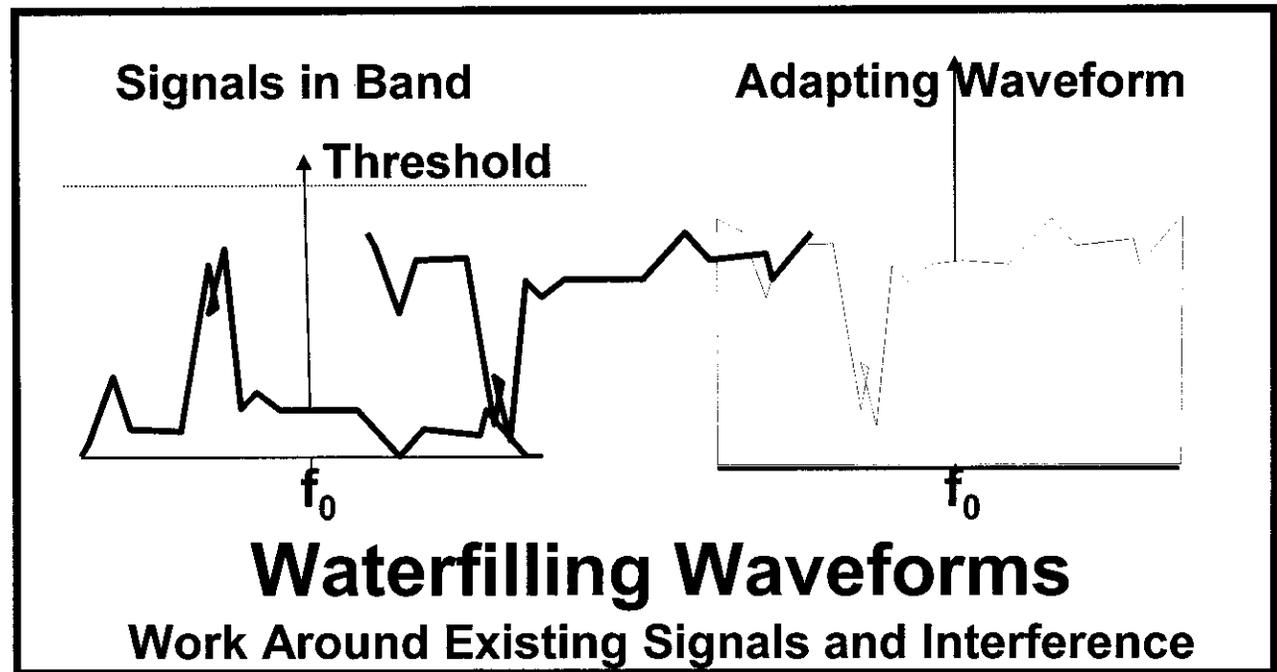
# Where is the Opportunity?



- **As We Implement New Spectrum Practices, We Will Learn What Are the Impediments**
  - Clear a New Generation of Physical and MAC layers are Appropriate
  - Opportunistic Spectrum Has Unique Challenges from What We Used to Build
- **Some Physical Layer Challenges/Opportunities**
  - How to Use Any Piece of Available Spectrum
  - How to Use a Collection of Pieces of Spectrum
  - How to “Squeeze” onto Currently Used Spectrum Without Causing Interference
- **Enabled by Transition to Software/Cognitive/Networked Radios**



# Where is the Opportunity?





# The Future



- **Automated Spectrum Access Will Happen**
  - FCC Spectrum Task Force Recommendations on Enabling Adaptive Spectrum Access Technologies
  - Existing 802.11a Protocols
    - Sensing of holes and cooperative spectrum sharing
  - 4G Spectrum Management Technologies
- **Immediate Needs**
  - Policy to Allow Initial Development and Usage
    - This Process, Task Force, ...
  - Spectrum Sensing and Adaptation Technology
    - DARPA XG, ?
- **Far Term**
  - Radio Designs that Are Specific to the Adaptive Policies and Technology