



XG Communications Program Overview

27 February 2007

Preston Marshall

DARPA XG PM

Preston.Marshall@darpa.mil

Todd Martin

Science & Technology Associates

DARPA XG SETA

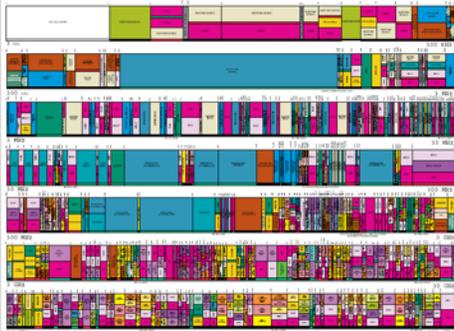
tmartin@stassociates.com



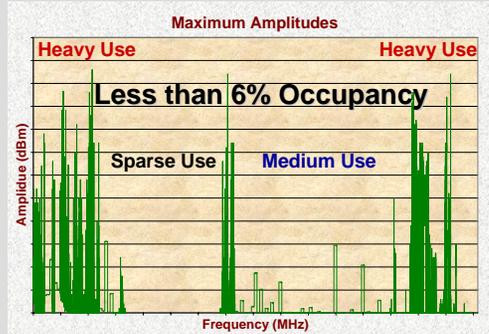
XG Program - Concept



All Spectrum May Be Assigned, But...

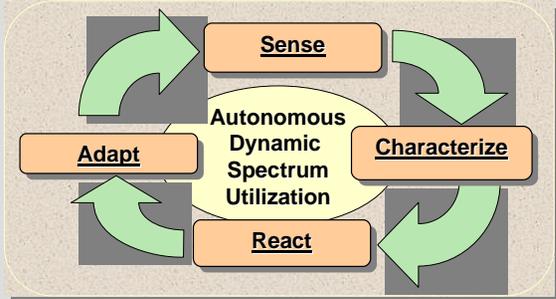
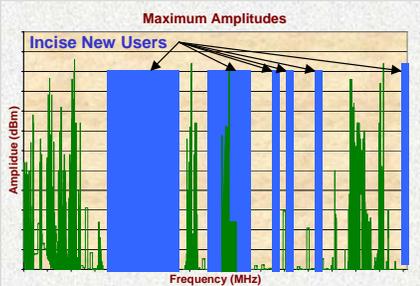


...Most Spectrum Is Unused!



XG Provides Spectrum Access... Worldwide.

Dynamically Locate Spectrum, Organize Networks, and Implement Policies to Ensure No Interference.



Develop the Technology to Dynamically Use Unoccupied Spectrum Without Interference to Other Spectrum Users

Achieve 10 Times Increase in DoD Spectrum Access

Technical Challenges:

- High-Speed, Wideband Sensing
- Adaptive Protocols and Networking
- System Performance and Scalability
- Non-Interference Operations

Near-Term Impact:

- Increased Operational Capability (Simultaneous Assets and Missions) and Tempo
- Increased Communications and RF System Capacity
- Increased Communications Reliability

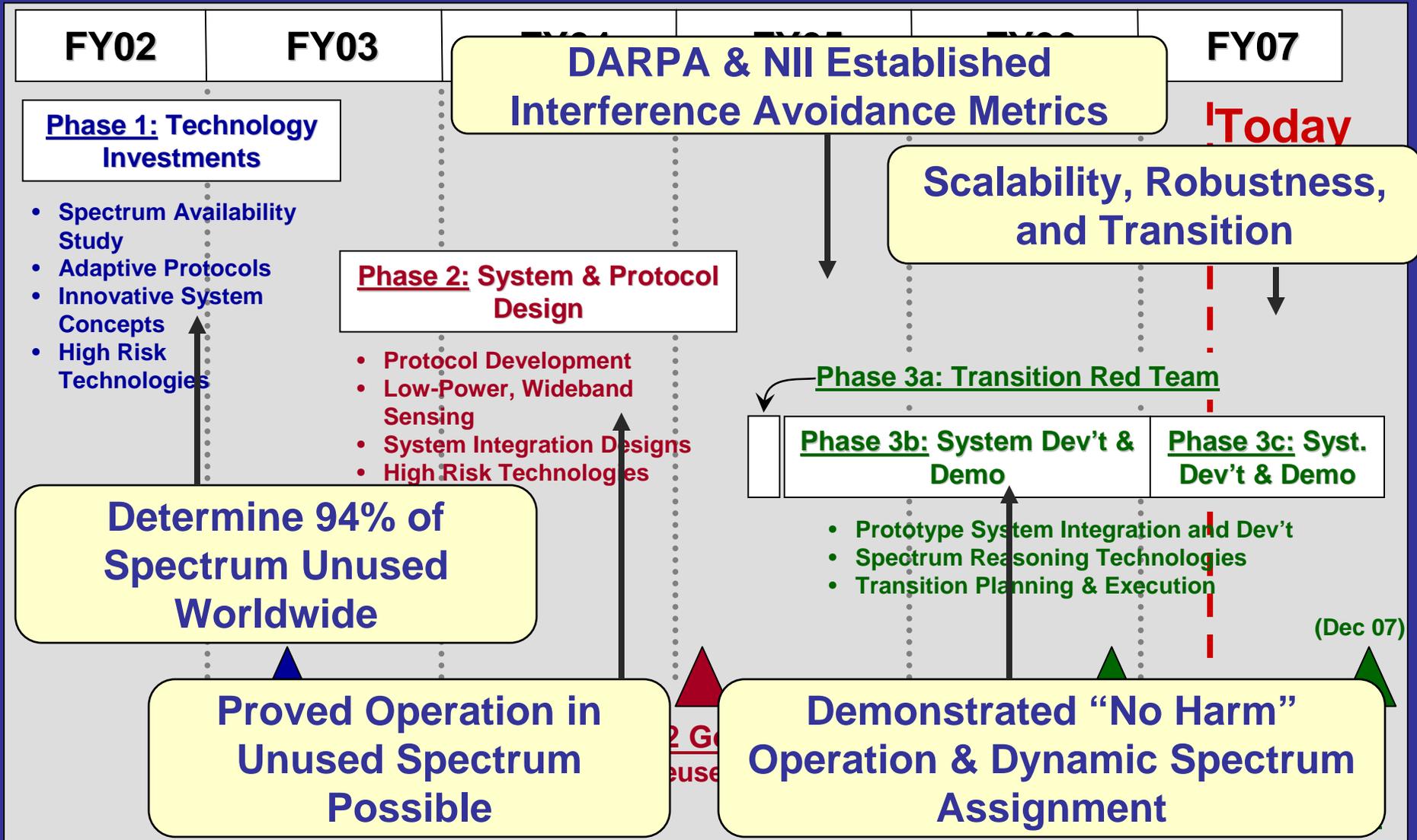
Future Impact:

- Key to Dynamic Topology, Bandwidth and Resource Management in Wireless Networks (WNaN, etc.)

XG is Not a New Radio Program, but the Technologies and System Concepts for Dynamic Spectrum Use and Factor of 10 Increased Spectrum Access for Any Networked Radio



XG Program Schedule





XG Key Principles

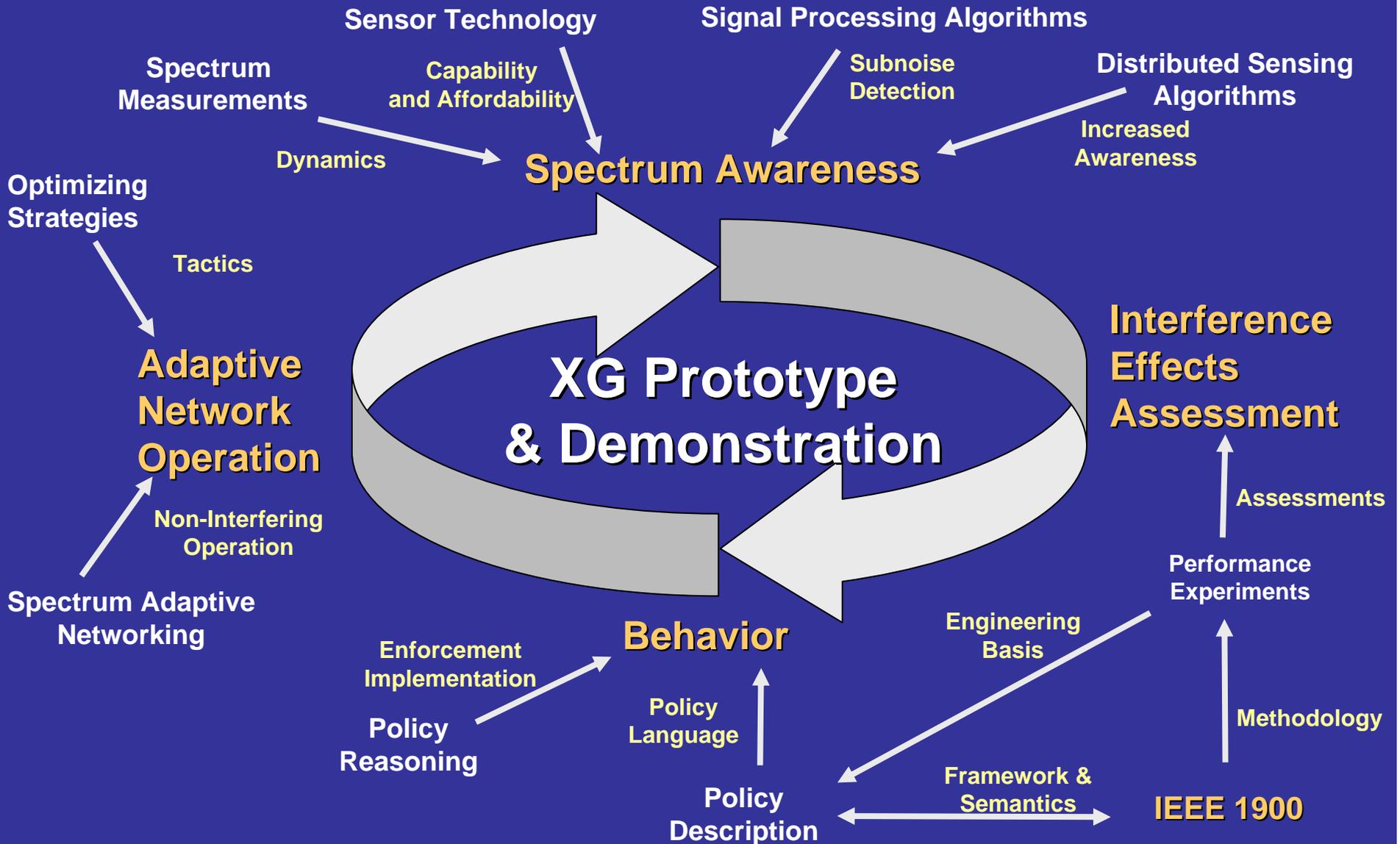


- **Suitable for Range of Architectural Implementations**
 - Enable Centralized And Decentralized Architectures
 - Develop Technologies, System Design Principles, and Adaptation Behaviors, Not A Specific Radio Architecture
- **Identify “Interference-Preventing” Core Set**
 - Develop the Fundamental Capabilities for Dynamic Spectrum Access while Preventing Harmful Interference
 - Flexible with Respect to Interference Avoidance Mechanisms
 - Extensible To Other Features (Subleasing, Microcharging,...)
- **Separate Policies From Engineering**
 - Policies Define Common Approaches & Etiquettes that Can be Adopted Widely But Change Over Time and Geography
 - Allow For Diversity of Policy Sources (Peer-Peer, Hierarchical,...)
 - Engineering Approaches Can be Implemented in Many Ways to Develop Unique Products & Capabilities
 - Enable Extension To “Cognitive” Optimizing Logic

Develop Technologies in a Flexible Framework that Enables Implementations to Evolve With Engineering & Policy Changes



DARPA XG Program Investments





XG Policy Compliant Behavior



Rejected Notion that General Solution to Adaptive Radio Could be "Just Code"

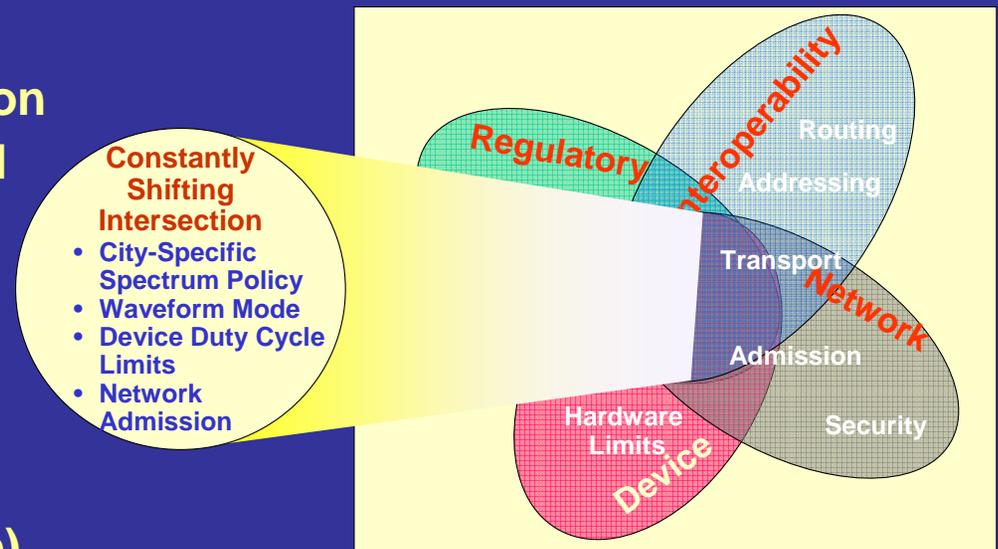
- Almost 200 Sovereignties
- Thousands of Bands
- Emerging Technologies

Investing in Computer Science Structure for Policy Reasoning

- Reasoning Technologies to Control Real-Time Process
- Declarative Language Expression
- Provable Policy Expression and Implementation

Partitioned Policies into Two Categories

- Policy Enforcement (Permitted Operation)
- Optimizing (Network and Above)





XG Policy Language Features



- **Resolve Multiple Policy Sources Without Causing Failure**
 - **Allows for Multiple Uncoordinated Sources of Policy**
- **Approachable Implementation**
 - **Growing Community Of Policy Language Users, Features and Authoring Tools**
- **Class Extensible**
 - **Maximizes Generality and Reduces Complexity**
 - **Everyone Can Extend Policies To Their Needs**
 - **Rapid Adoption Of New Policy Concepts And Technologies**
- **Provable Structure**
 - **Set Theory, Logical Reasoning And Theorem Proving**
- **Host Implementation Independent**
 - **All Policies Can Run On Any Compliant Device**

Transition from Describing *Self-Operation* to Defining *Effects on Others*



Example Spectrum Rules of Engagement

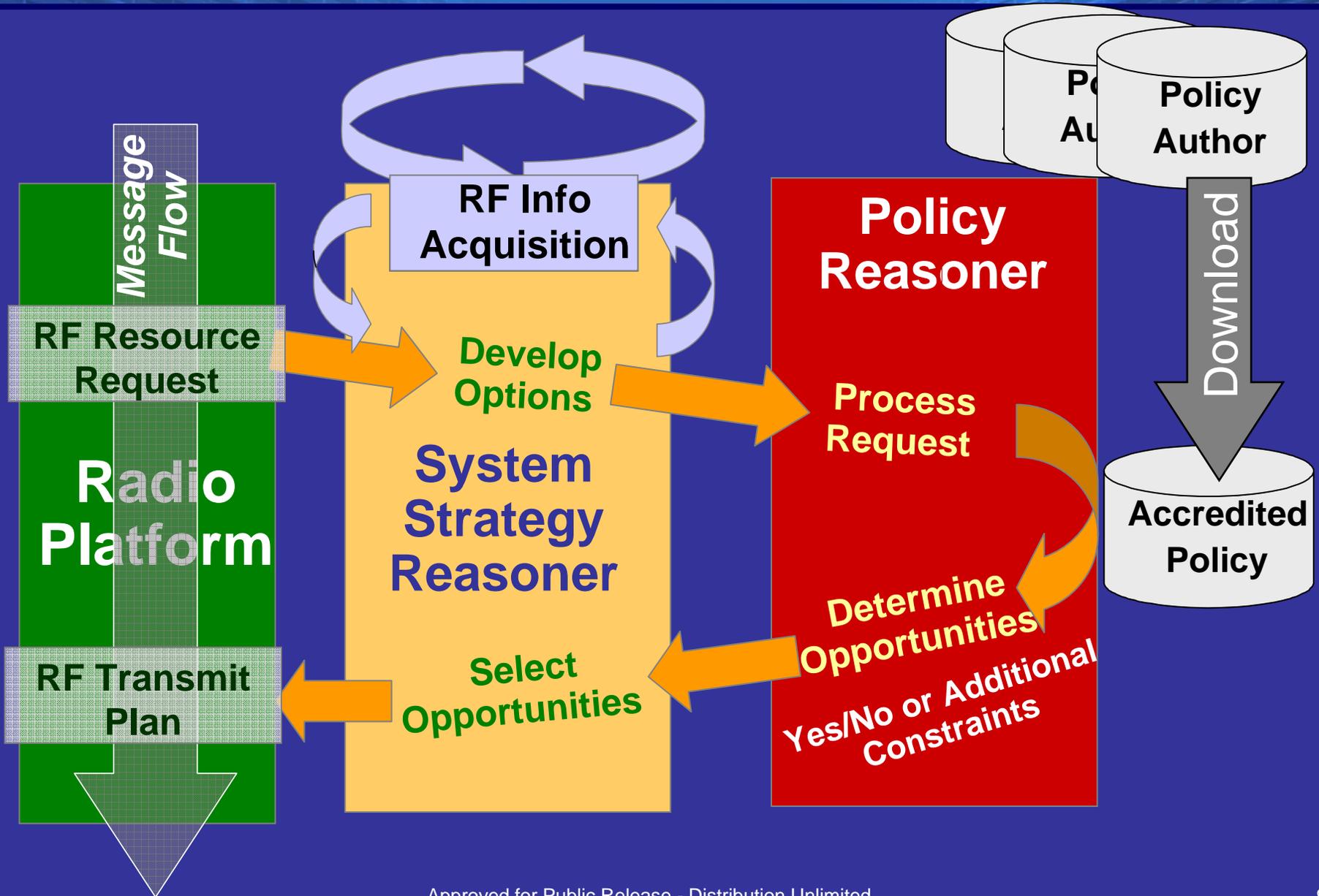


Phases Users	Shape, Deter	Seize Initiative	Dominate	Stabilize, Enable Civil Authority
Military (Blue, Red)	Protect	Available	Available	Avoid causing interference
Allies, HNs (Civil, Military)	Protect, Avoid causing interference	Available	Available	Protect, Avoid causing interference
Civil Cellular	Protect	Available	Available	Avoid causing interference
Navigation, Safety of Flight	Protect, Avoid causing interference	Avoid causing interference	Avoid causing interference	Protect, Avoid causing interference
Commercial Satellite	Protect	Avoid causing interference	Available	Protect, Avoid
Regional Broadcast	Protect	Available	Available	Protect, Avoid
NGO	Avoid causing interference	Available	Available	Avoid causing interference

Policy Flexibility Provides Commanders With Ability to Shape System Access Behaviors to Mission Needs



XG Operational Concept





Phase 3b Go/No-Go Metrics



- **No Harm**
 - Detects Other Emitters Before Causing Harmful Interference
 - Disseminates Spectrum Awareness In Network
 - Incorporates Automated Spectrum Rule Enforcement Algorithms
- **XG Works**
 - Demonstrates Automated Rendezvous and Frequency Selection
 - Conducts Operations With Multiple Cooperative and Non-Cooperative networks
- **Adds Value**
 - Increases Spectrum Access and Communications Capacity
 - Enables EMI Tolerant Networks

Demonstrate Fundamental Building Blocks Of Dynamic Spectrum Systems Upon Which to Build Needed Performance and Scalability

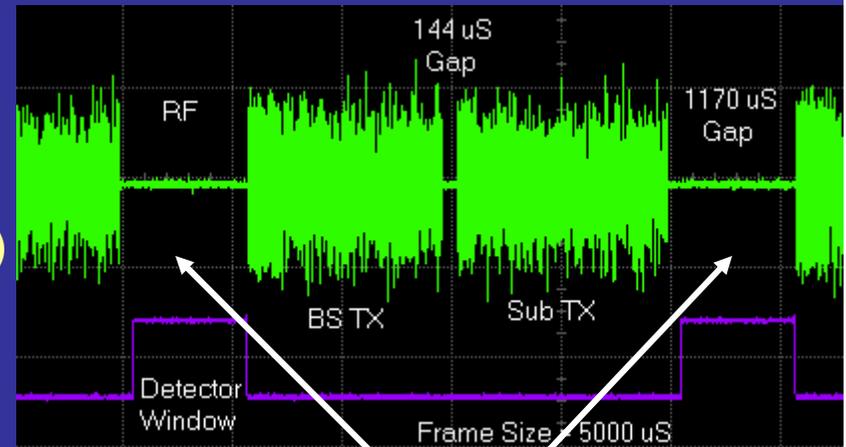


XG Phase 3b Prototype



Phase 3b Prototypes Incorporate a Subset of Final XG Capability

- **WNW-Like Capabilities (COTS)**
 - Modified 802.16 (WiMAX) Networking Waveform
 - 225-600 MHz Band (Tactical Comms)
- **Dynamic PHY With Modified but Static MAC & NET**
 - Variable Bandwidth (1.75 & 3.5 MHz)
 - Networking Topologies and Sizes Defined via Software at Scenario Start
- **Basic Spectrum Access Logic and Algorithms**
 - Based on Conditions of Go/No-Go Criteria
 - Scaling, Complexity, and Performance Developed to Meet GNG Metrics and Enable Long Term Fielding Needs
- **Single Wideband Sensor**
 - Sensing Fully-Integrated into MAC for High Detection Confidence
 - Sufficient for Phase 3b Density and Dynamic Range



Look-Through Gap
Created for Sensing

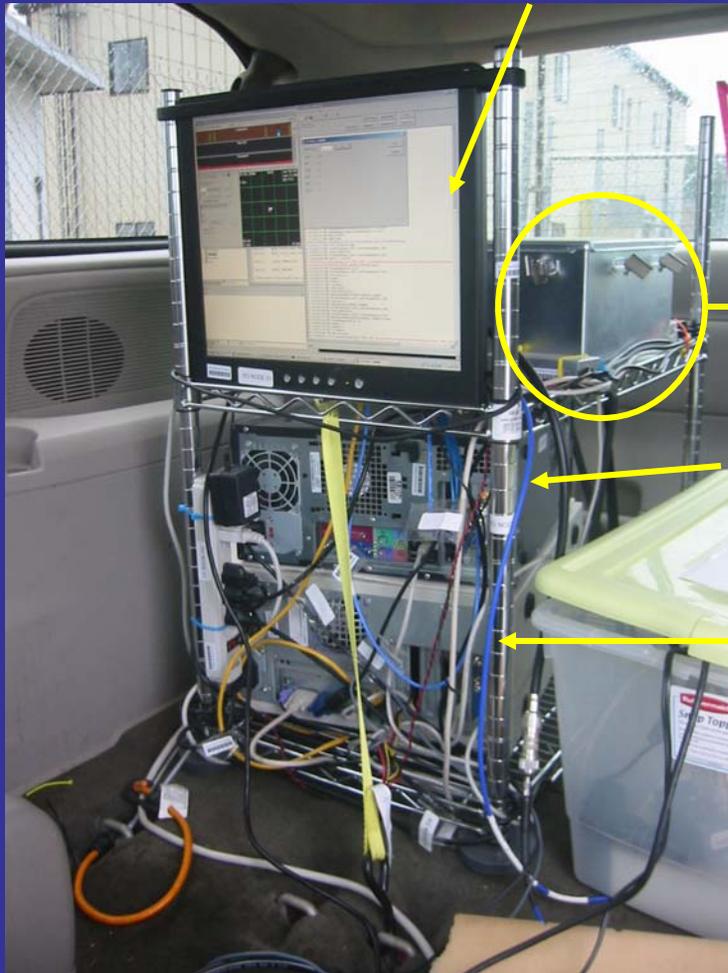
**Core Dynamic Spectrum Technologies Forming Phase 3b Prototypes
Serve as Proven Foundation for Needed Performance and Scalability**



XG Phase 3b Prototype Radio



Display showing XG operational state



Rockwell Sensor

RF Power Amp

RF Enclosure



GPP with 802.16 modem

GPP with XG algorithms

225-600 MHz RF Transceiver (located under shelf)

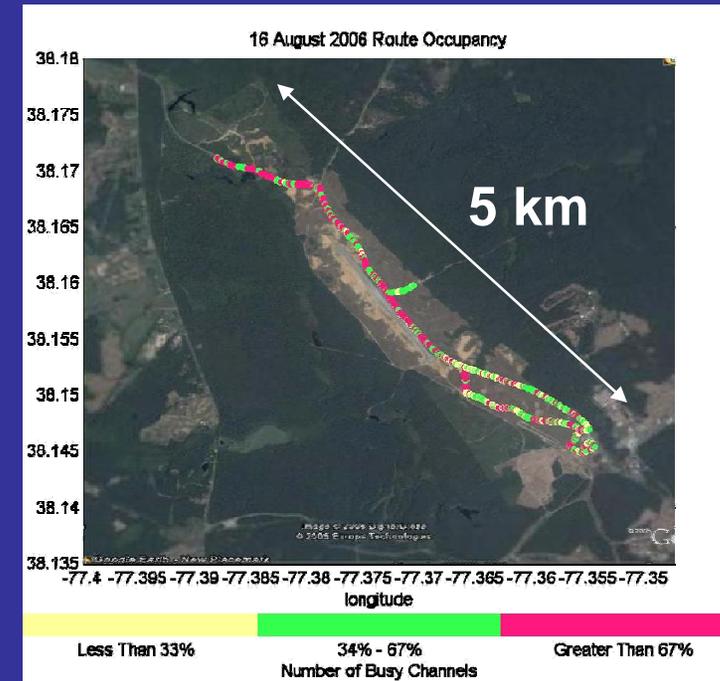




XG Demonstrations & Evaluations



- **Conducted at AP Hill Drop Zone**
 - Two+ Month Evaluation Effort Culminating in Live Field Demos on 15-17 August
 - Demonstrated XG Benefits to Key Stakeholder Representatives
 - Collected Data for Comprehensive Go/No-Go Analyses
- **Two Scenarios of 6 Mobile XG Radios in “Electromagnetic Obstacle Course”**
 - “Fully-Assigned” Spectrum
 - Adaptive Spectrum Reuse of Military and Civil Radio Frequencies in Mobile Environment
 - Intrinsic Ability to Simultaneous Operate in Presence of XG, non-XG, and Malicious Interferers
 - Blue-Blue EMI is an Emergent Issue in Current Operations
 - Some Regions Had No Spectrum Available for Multiple XG Nets



Phase 3b Demonstrated Initial Technical Capability and Operational Relevancy in Dense RF Environment



Legacy Radios



Legacy DoD
Radio (fixed)

XG Radios
(mobile)



PRC-117



Microlight



Legacy DoD Radio/Test Equipment



PSC-5

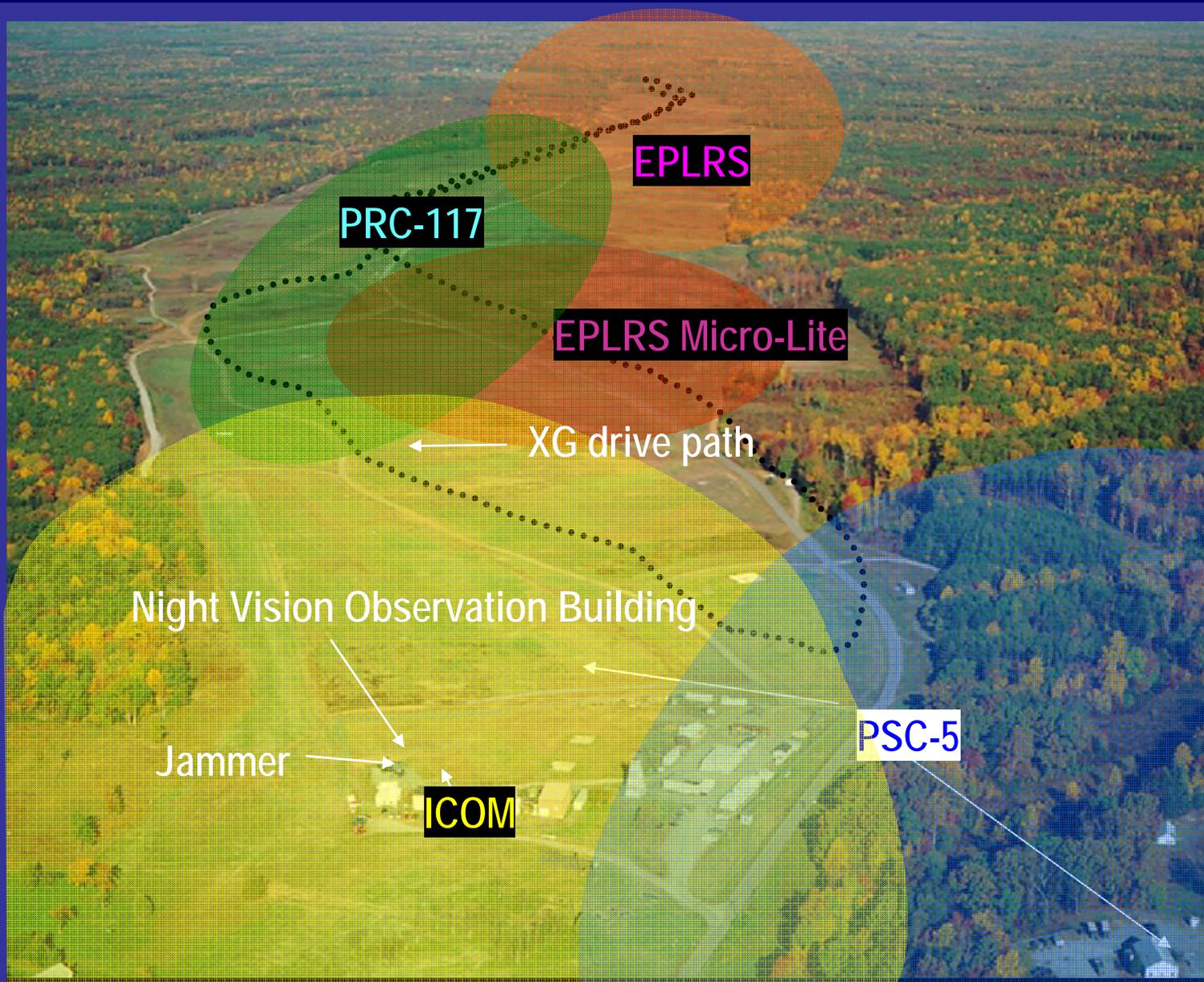


Legacy Radios

- PRC-117: Frequency Hopping to Force Dynamics
- PSC-5: Narrowband Voice
- EPLRS: DoD Networking Radio
- Micro-Lite: DoD Networking Radio
- ICOM F561: Widely Used in Public Safety



The XG "Electromagnetic Obstacle Course"

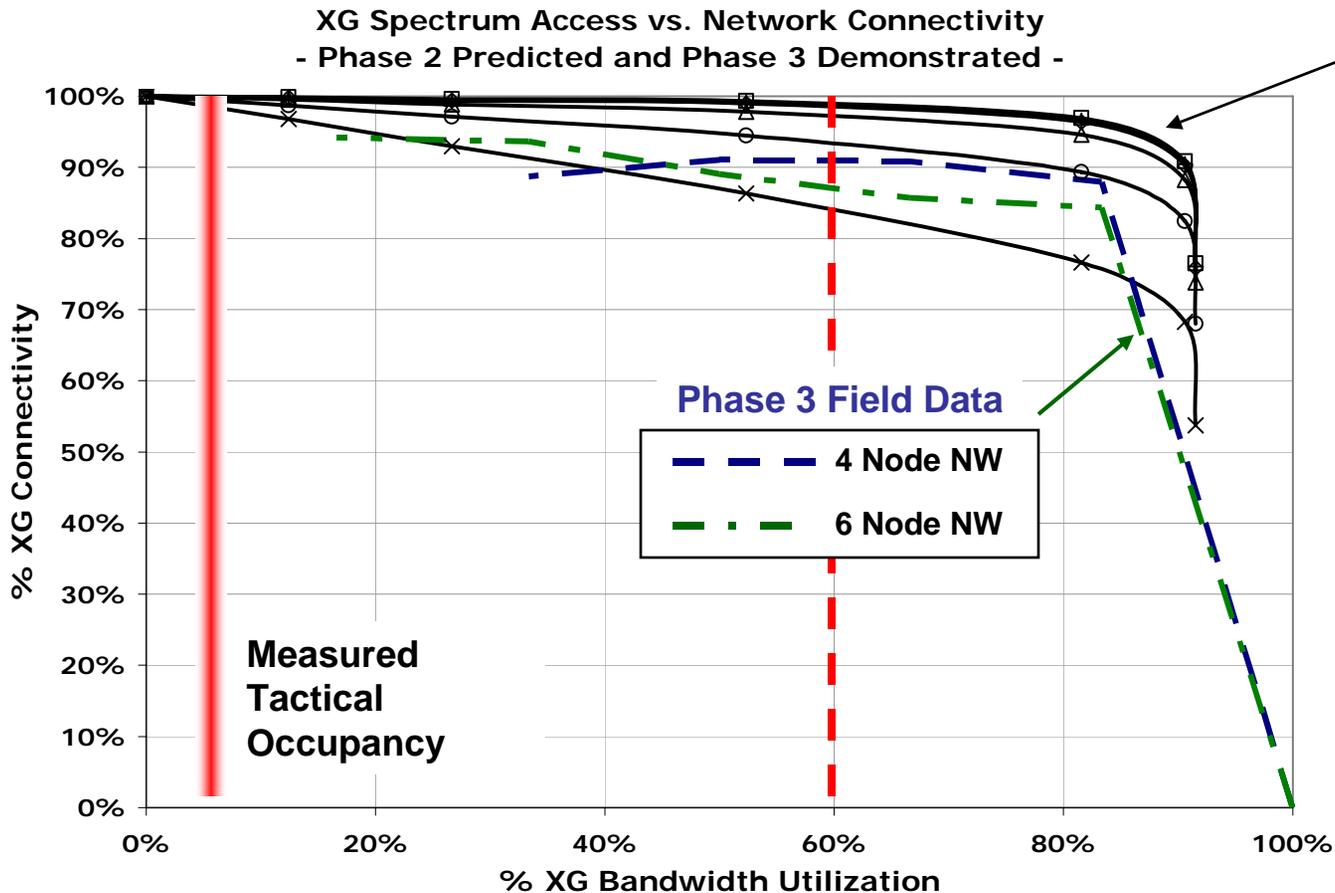




Adds Value: Spectrum Occupancy



Phase 2 Simulations



- 25-500 kHz Mix
- 50 kHz - 1 MHz Mix
- 100 kHz - 2 MHz Mix
- 150 kHz - 3 MHz Mix
- 200 kHz - 4 MHz Mix
- 300 kHz - 6 MHz Mix

**XG Achieved > 60% Spectrum Occupancy for Networks of 6 Nodes
And 85% Access Confidence at 83% Occupancy**



XG Program Next Steps



- **Integrate XG into Network Technology**
 - **Enable Variable Network Topologies**
 - **Establish Load Balancing to Assure High Confidence**
- **Develop and Demonstrate Scalability**
 - **Increased DoD Radio Applications up to 2.5 GHz**
 - **Greater XG-XG Network Size, Density, and Interaction**
- **Address Broader Class of Signals**
 - **Sub-noise Detection and Wideband Signals**
 - **Data Fusion for False Alarm and Detection Confidence**
- **Extend Spectrum Access Logic and Algorithms to Cover the Range and Complexity of DoD Operational Needs**
 - **Investigate Operational Benefits in a Complex EMI Environment**
 - **Investigate Immediate Transition into an Existing Military Network Radio**

Phase 3b Investments Provide Cornerstone for Phase 3c Development of Field-Ready Technologies



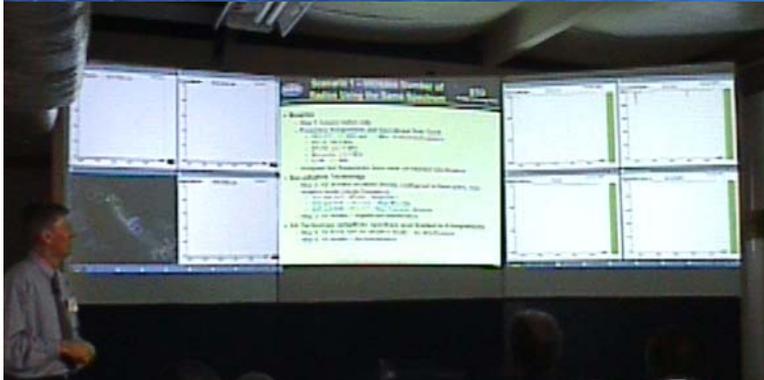
XG Technology Fielding



- Anticipate Incremental Adoption on a Not to Interfere Basis (NIB)
 - Military on Military (10x Greater Packing of Radios)
 - Coordinated Sharing (Military with Coordinated Users)
 - Opportunistic (Widespread NIB Operation)
- Incremental Rollout Enables Near-Term Deployment as Appliqué Into Existing Systems
 - Add Protocols and Adaptation Software to Digital Networking Radios
 - Add Spectrum Sensing Algorithms



Incremental Rollout Enables Near-Term DoD Implementation Prior to New Regulatory Frameworks





Phase 3 Metrics & Results Summary



<u>Metric</u>	<u>Threshold</u>	<u>Results</u>
<u>XG Causes No Harm</u>		
Abandon Time	500 msec	100% in 465 msec
Interference Limit	3 dB	Mean: 0.16dB, Max: 0.49dB
<u>XG Works</u>		
Net Formation	30 sec w/ 6 Nodes	90%: 3.6s; 100%: 8.68s
Net Join	5 sec	90%: 2.07s; 100%: 4.36s
Net Re-Establish	500 msec	100%: 165msec
<u>XG Adds Value</u>		
Spectrum Occupancy	60% w/ 6 Nodes	85% Occupancy at 83% Confidence

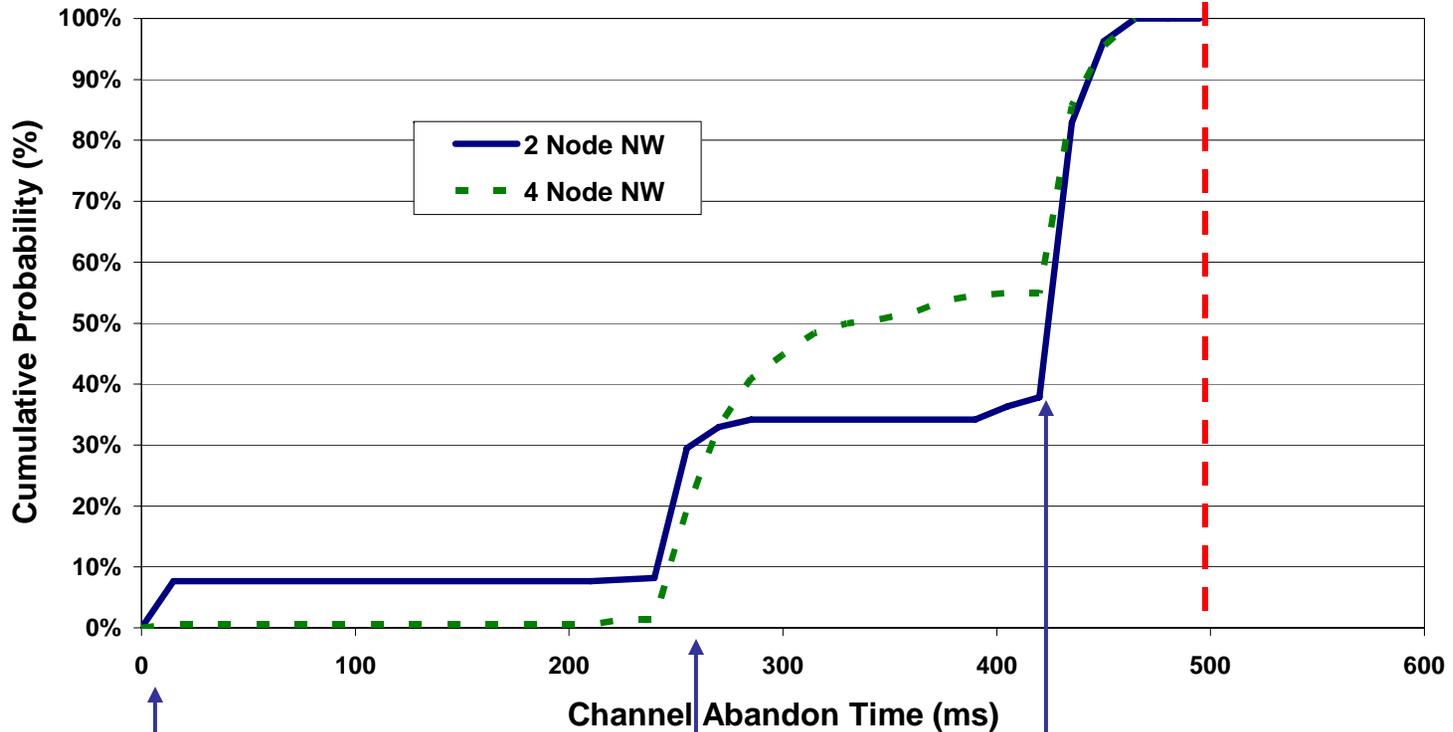
XG Demonstrated Reliable Networking Without Harming Legacy Nodes In Dense Spectrum Environments



No Harm: XG Abandonment Time



Channel Abandonment Time



Detections by Net Master, but No Other Frequencies Available

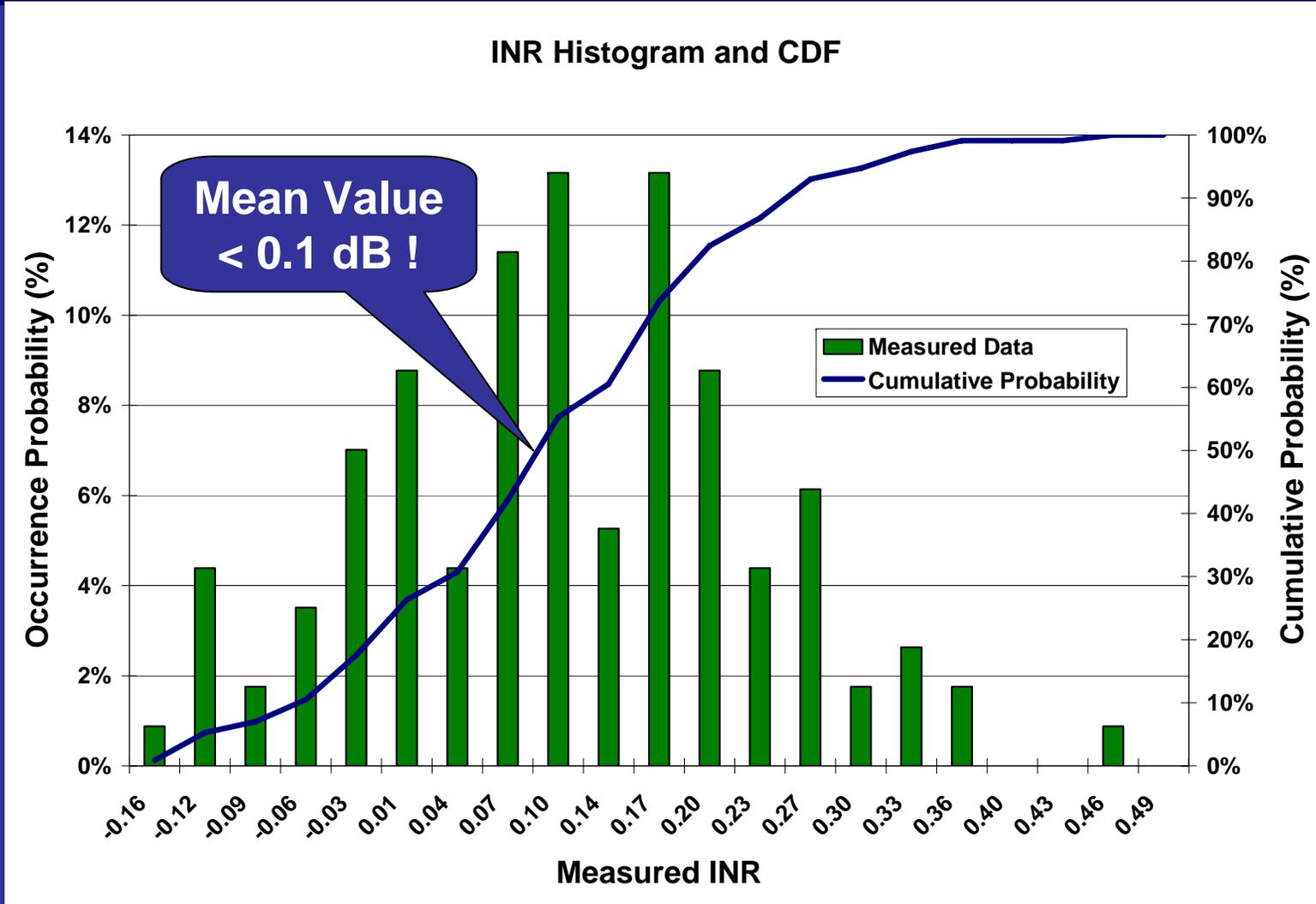
Detections by Master Node & Negotiation for New Frequency

Non-Master Node Detects and Alerts Master Node

XG Abandoned Frequencies In < 500ms



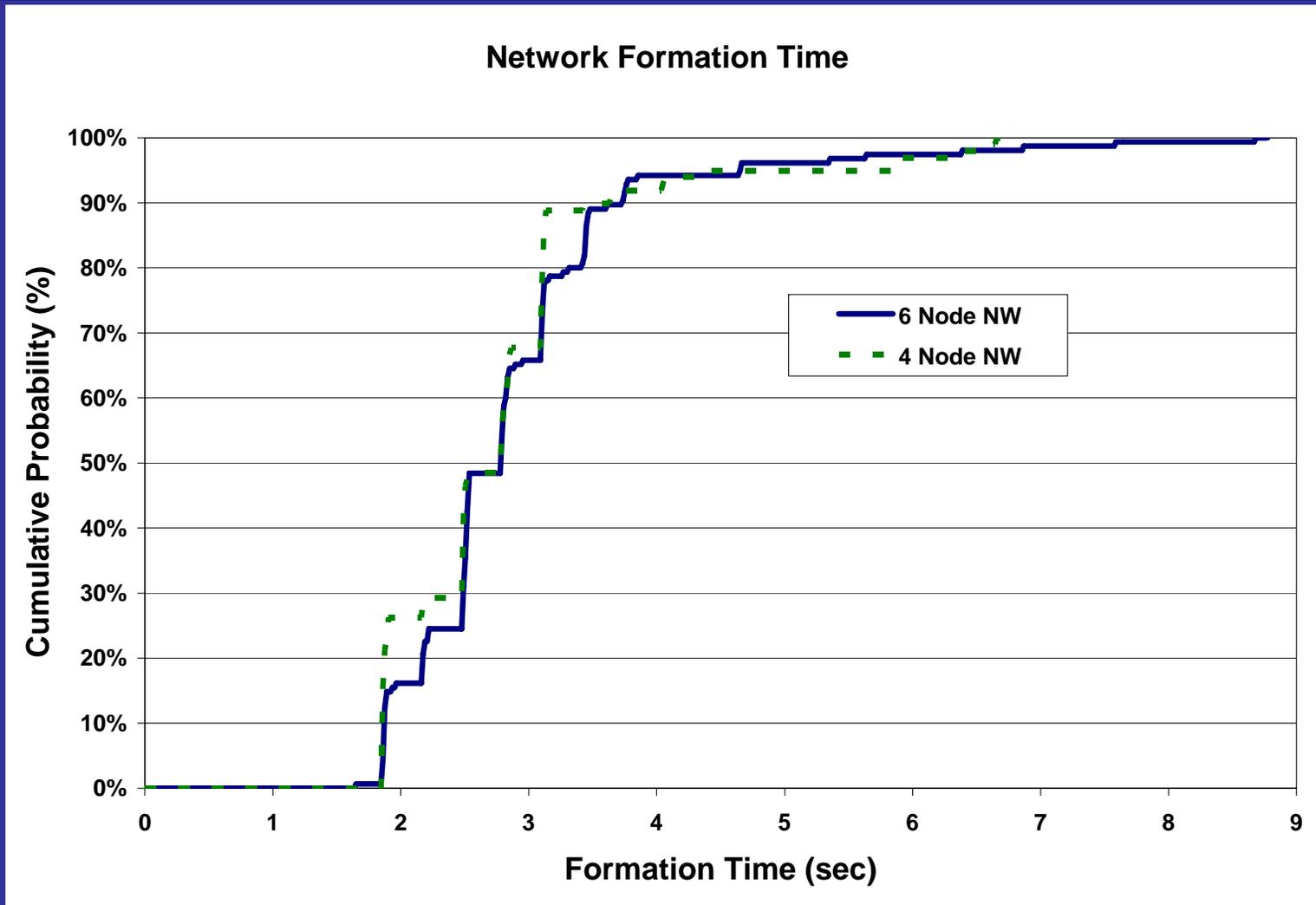
No Harm: XG INR at Non-XG Radios



XG Produced Marginal INR at Non-XG Radios



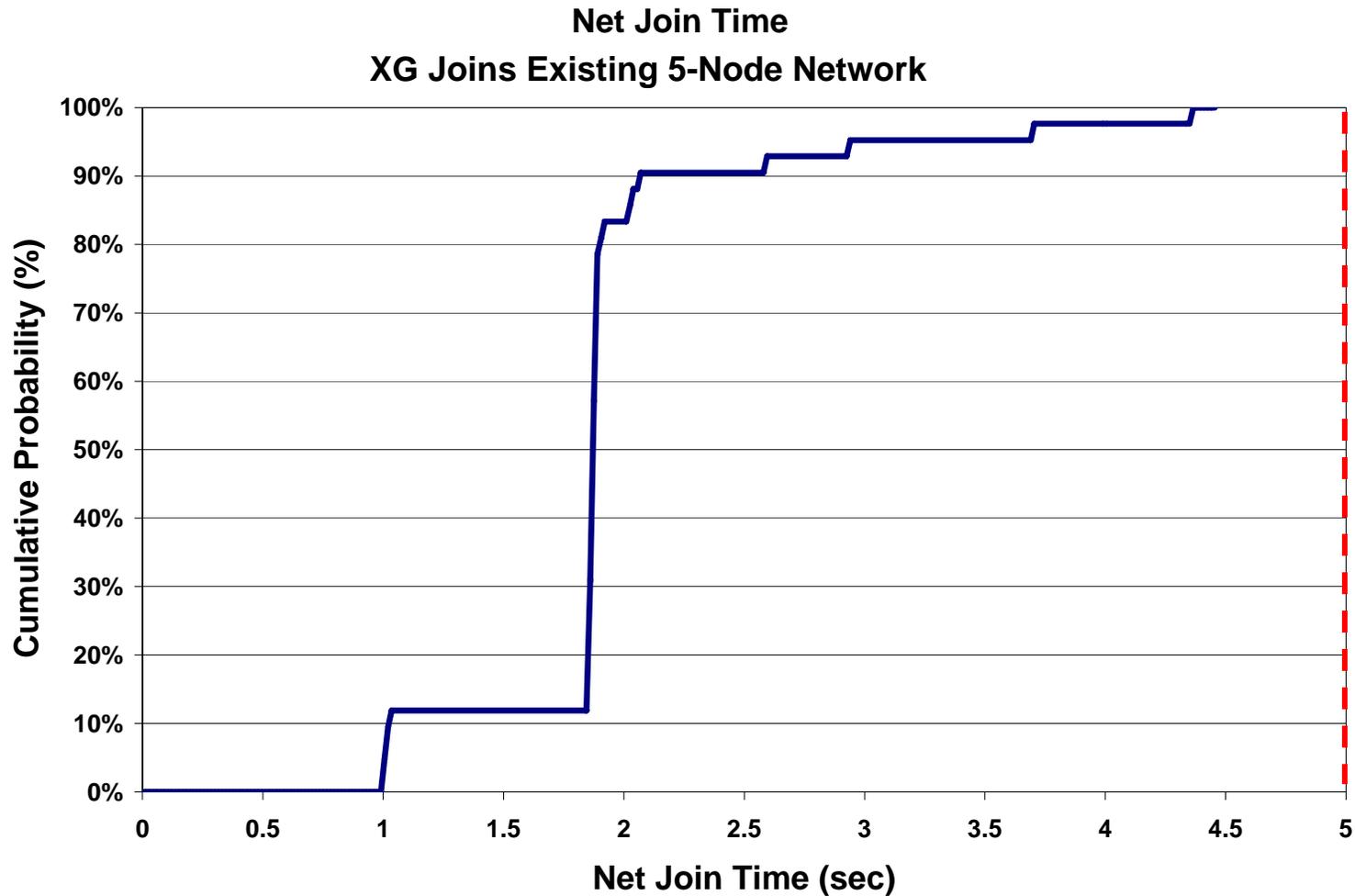
XG Works: Rendezvous/Net Formation



XG Established 6 Node Networks in < 30 sec.



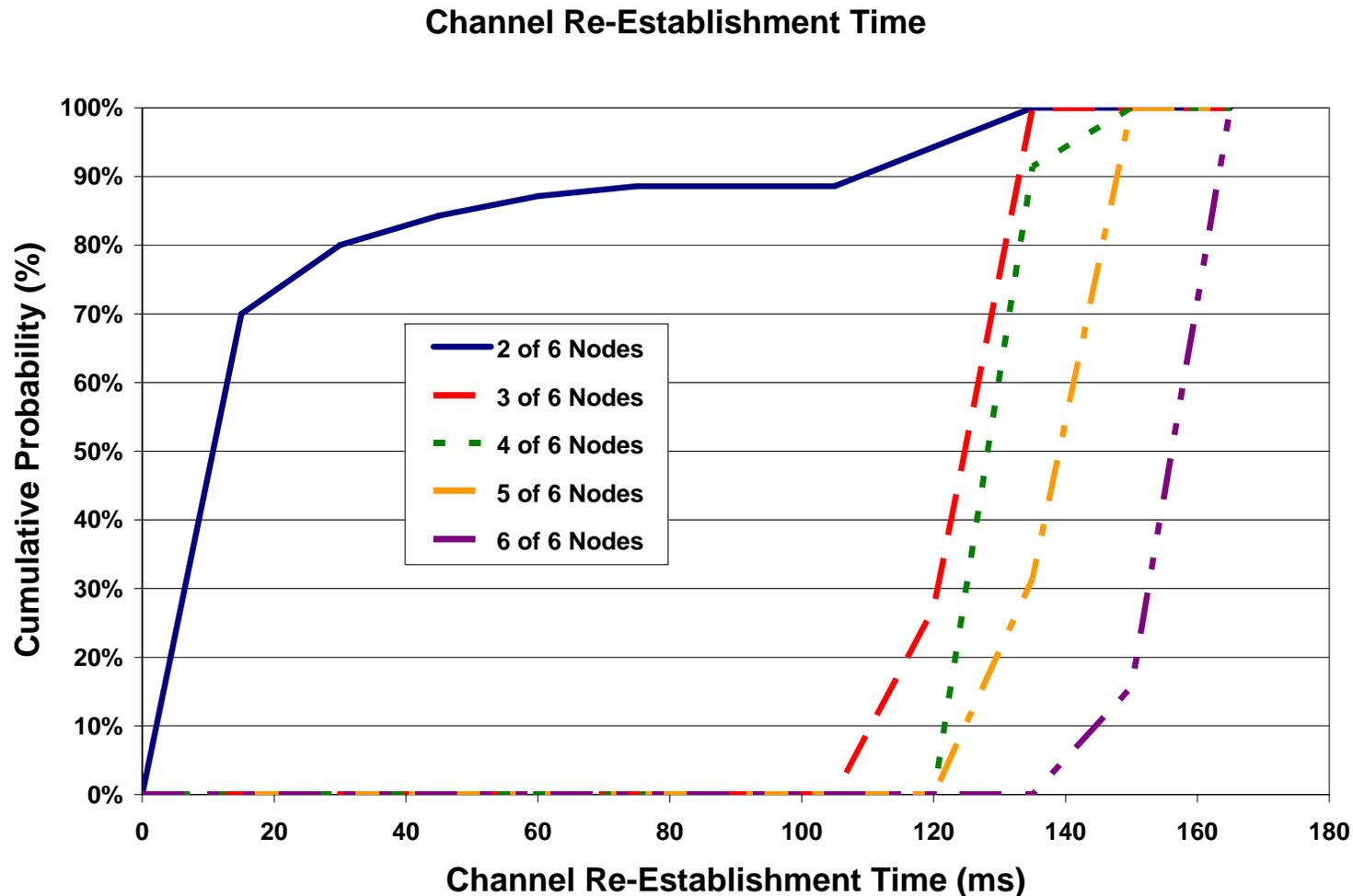
XG Works: Net Join Time



XG Nodes Joined Networks in < 5 sec.



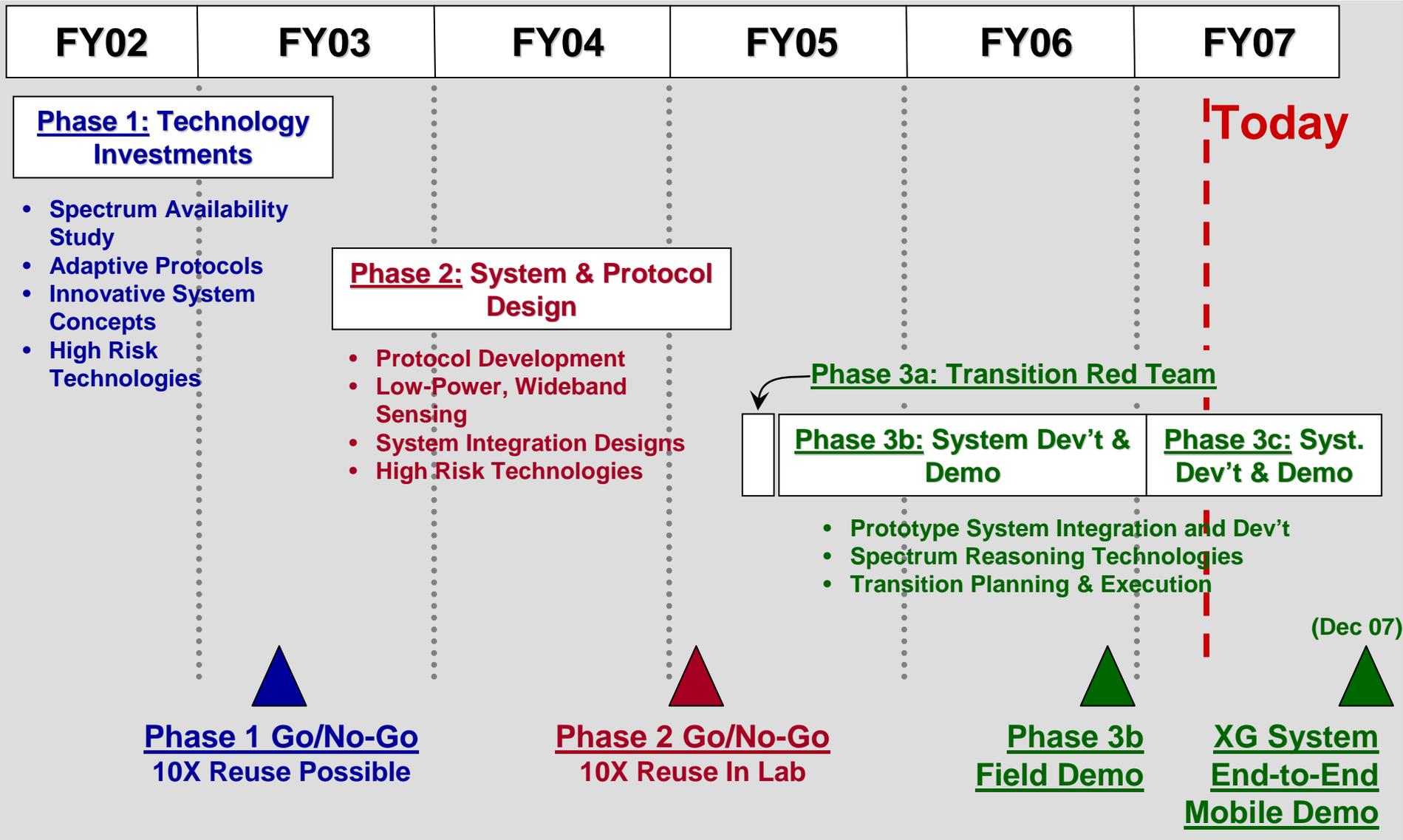
XG Works: Re-Establish Time



XG Re-Established Networks in < 500 msec.



XG Program Schedule



Today