Strategic Technology Office

Wireless Network after Next (WNaN)

"Making Network Centric Accessible for the Warfighter"

WNaN Adaptive Network Development (WAND)
BAA 07-07
Proposers' Day

Preston Marshall

27 February 2007

Defense Advanced Research Projects Agency
Strategic Technology Office

WNaN Overview

Preston Marshall
DARPA Program Manager (STO)

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DARPA Director's Vision of Communications Technology Evolution

Key to Infrastructureless Comm

MEMS/NEMS

Self-Forming

Small Unit Operations-Situational Awareness System Program– SUO SAS

Mobile

Mobile Networked MIMO Program – MNM
Future Combat System – Comms Program - FCS-C

Packet Radios

Global Mobile Program - GLOMO

Dynamic Spectrum

Next Generation Comms Program - XG

Future Network(s)

Wireless Network after Next Program - WNAN

Network Adaptation & Optimization

Control-Based Mobile Ad-Hoc Networking Program - CBMANET

Cognitive Technology

Information Protection

Dynamic Quarantine of Computer Based Worm Attacks Program – DQW
Defense Against Cyber Attack in MANETs Program – DCMANET

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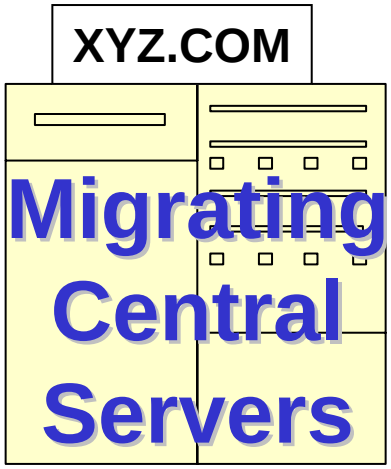
Future Wireless Program is Attacking All Aspects of Networking

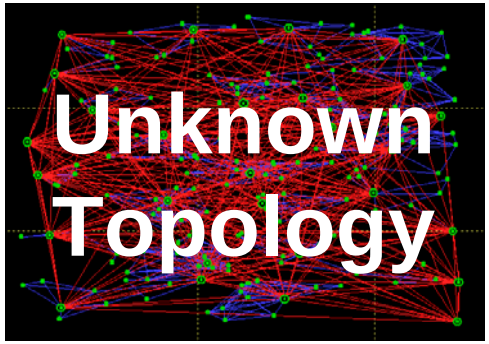
No Cell Towers

Finite Energy



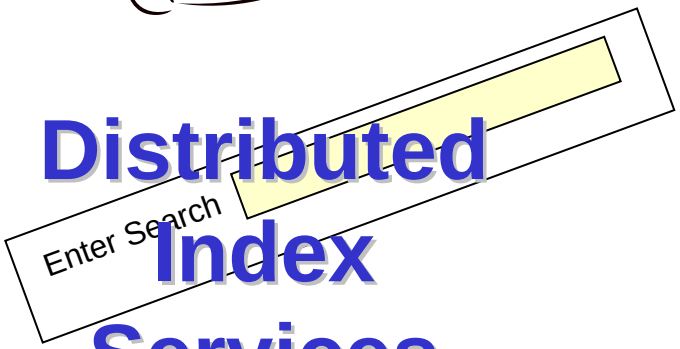
Migrating Central Servers

No Frequency & Network Planning

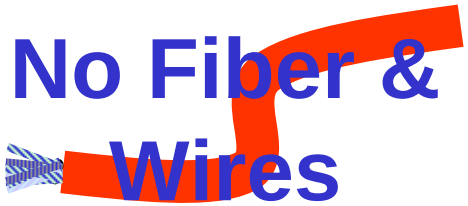


Unknown Topology

Distributing Cache Servers



Distributed Index Services



No Fiber & Wires

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Technology Implications

Current	(Possible) Future
▪ Extensive Pre-Planning	▪ Self Monitoring and Adaptation
▪ Fixed Network Structure	▪ Self Forming
▪ Asymmetric, Hub-Spoke (ex. Cellular, VOIP)	▪ Peer to Peer
▪ Separate Network and User Equipment	▪ User Equipment the Network
▪ Security at the Perimeter	▪ Distributed Security
▪ Services and Info at Core	▪ Info at Edge

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Overall WNaN Program Objectives

- Purpose-Built Military Networking Radio Using Commercial Parts, Lines, and Processes
  - *Usable Radio Early in Program*
- Network Capability that will Adapt to:
  - Characteristics of Environments
  - Hardware Capabilities
  - Essential Military Applications
- Network Capability that Integrates Up to 100K Radios into an Effective and Efficient Network
- Adaptation Mechanism to Leverage Successful Elements of DARPA Programs
  - *XG, DTN, MnM, and CBMANET*
- Brigade-Sized Demonstration with Functionality of, and Interoperability (via IP) with Legacy Systems

More Capable, 99% Cost and SWAP Reduction …, Connect Every Soldier to Any Place

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Wireless Network after Next (WNaN) Program
(as Approved by DIRO)

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- Program Concept: Develop a High Speed, Affordable Battlefield Network that Changes Design Focus from Individual Radio Performance to High Density Network Performance
  - Network Adaptation Mechanisms to Address Analog Weaknesses
  - Use High Volume, Low Cost Components (Radio Node)
- Program Structure: Two Complementary, Parallel Efforts

Future Networks:
***Wireless Network after Next* (WNaN)**

Wireless Adaptable Network Node (WANN)

Development and Demonstration of a Mass Produced Adaptable Wireless Node with $500 Unit Cost in Lots of 100K

WNaN Adaptive Network Development (WAND)

Developing and Designing Network Technologies that can Scale from Two of Radio Nodes to Tens of Thousands of Radio Nodes

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Related Wireless Networking Research Programs at DARPA

- neXt Generation Communications (XG)
  - *Program Goal:* Develop Technology to Sense and Situationally Adapt Spectrum Usage for a 10 Times Increase in Spectrum Access
  - *Potential WNaN Application:* Spectrum Survey, Interference / Spur Avoidance, and Sensor Algorithms
- Disruption Tolerant Networking
  - *Program Goal:* Extend the Network Framework to Leverage Available Connectivity and Include Storage and Delivery for Episodic Networks
  - *Potential WNaN Application:* Hop-by-Hop, Store-and-Forward, Security, Routing Algorithms
- MnM Mobile MIMO
  - *Program Goal:* Robust Interference-Mitigated, Multi-Antenna Node Operation in Complex RF Environment
  - *Potential WNaN Application:* Spatial Diversity and Beam-Forming Algorithms for use in Spectrum Limited Environment
- CB MANET
  - *Program Goal:* Develop New and Efficient Inter-Layer Protocols for Mobile Ad-hoc Network
  - *Potential WNaN Application:* Algorithms / Processes / Protocols for Cross-Layer Adaptive Resource Allocation Management

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WNAN –
A Unified Approach to Interference

- Much of What We do in Radios and Networking Addresses Interference at Different Layers
  - Spectrum Management and XG
  - Multiple Input/Multiple Output (MIMO) Eigen Separation
  - MAC Layer Protocols
  - Minimizing non-Linear Responses (IIP3, Co-Site, Adjacent Channel, Near/Far, …)
  - Partitioning Ad-hoc Networks to Avoid Interference Scaling
- There is Massive Synergy Between these –
  - If I have MIMO, I can Back off on Interference Thresholds and Allow Massive Channel Reuse?
  - If I have MIMO, I can Eliminate Much of the MAC Layer Chatter?
  - If I have XG-like Sensing, I can Eliminate Some MAC Traffic?
  - If I can Better Manage Co-Channel, does that Enable Better Management of Adjacent Channel?
- How Do We Put all These Technologies Together into one Dynamic Trade Space?

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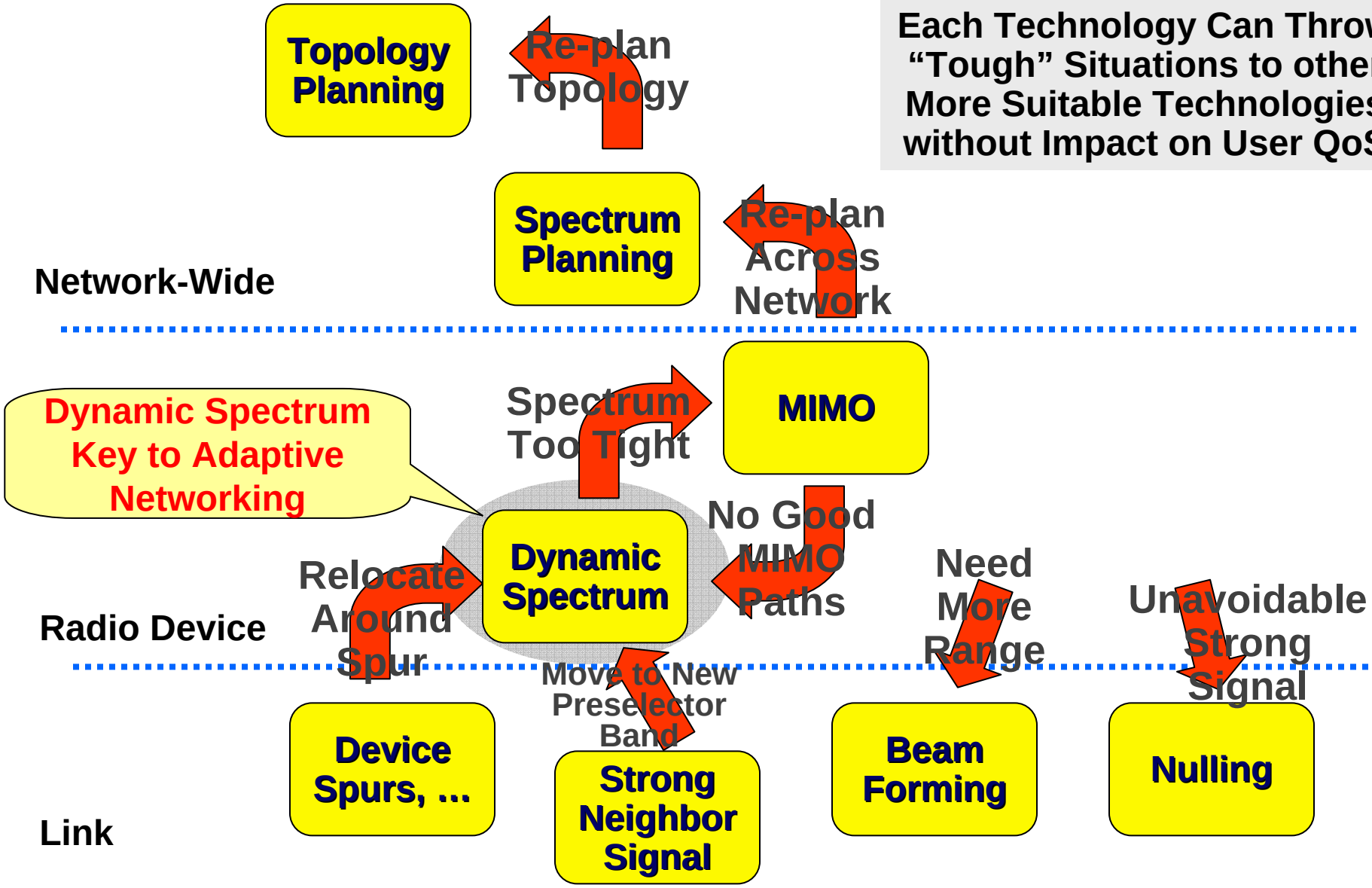
WNaN Adaptive Radio Uses Multiple Technologies to Resolve Issues

Each Technology Can Throw "Tough" Situations to other More Suitable Technologies without Impact on User QoS



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Key to Low Cost / High QoS is Interactive Layers

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Adaptive Network Topology

- Fixed
- Adaptive Topology

Adaptive Network Techniques

- Internet Protocol Ver 6
- Internet Protocol Ver 4
- High QoS Streaming
- Disruption Tolerant

Adaptive Physical Layer Techniques

- Fixed
- MIMO
- Dynamic Spectrum

Affordable, Replicated Hardware Implementation

- Spur Limited Ranges
- Spur Free Ranges
- High Multipath Regions
- Low Multipath Regions

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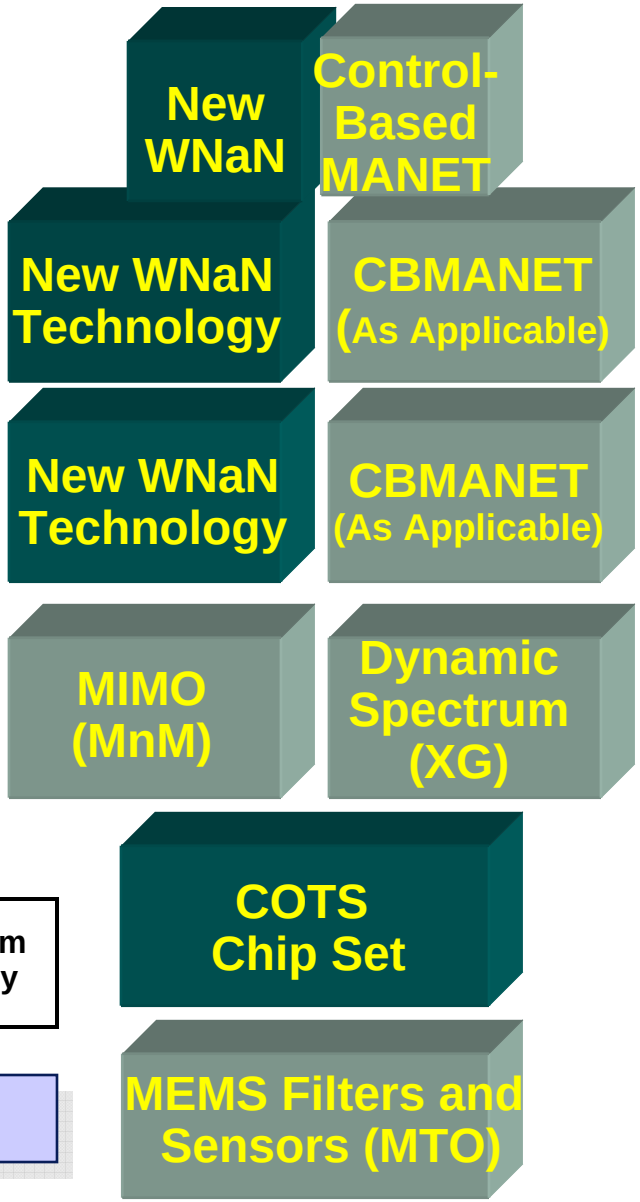
The DARPA WNaN Network & Radio

- Optimizing Layer
  - "Looks Through" Lower Layers to Make Globally Optimizing Decisions
- Topology Layer
  - Makes the Network Topology Achievable by the Radios. Plans Network Around Spectrum, Power, Channel, …
- Network Layer
  - Multiple, Unique Networks Optimized for Stream (Voice and Video), Broadcast (GBS-Like) and Packet Services
- MAC Layer
  - Adaptive Spectrum, MIMO, and Beamforming Modes
- PHY Layer
  - Commercial Component-Based
  - Mitigated H/W Weaknesses
  - Standard RF Slice Widely Replicated



Existing Program Technology | New Program Technology

Optimize the Network, Not the Radio

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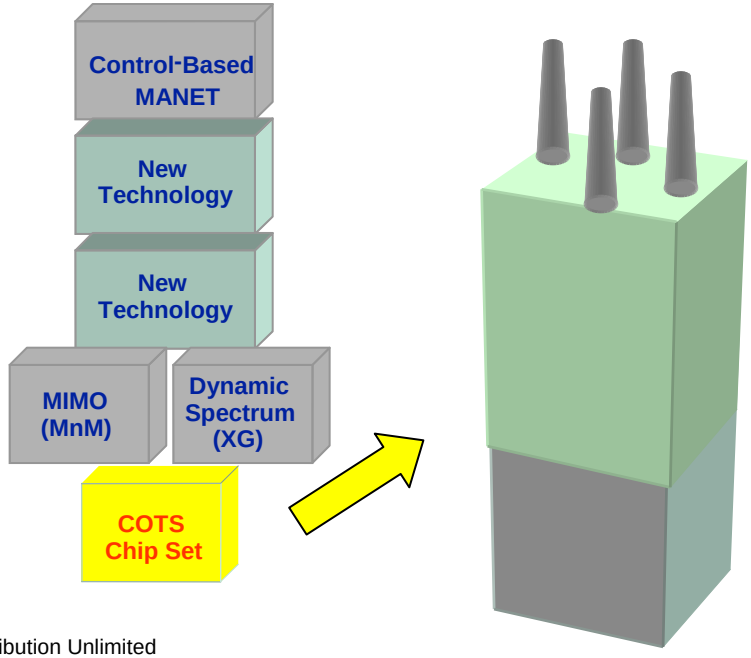
Adaptive Radio Hardware Platform (WANN)

- Single RF Processing Slice Replicated to form 1, 2 and 4 channel MIMO/XG/ Beamforming Capable Radios
- Reverse of Standard STO Approach
  - Build Early H/W and Incrementally Add Network Capability
  - Have Early Demonstration of DARPA Philosophy and Technology
- Approach:
  - Develop Early Wireless Node By Leveraging Available Commercial Chips
- Contribution from MTO New Analog Signal Processing (MEMs Filter Program) Essential

Frequency	900 MHz to 6 GHz
Power	36 dBm
SFDR	60 dB
IP3	What it is!
Peak	10 Mbps

WANN Goals:
- **$ 500 per 4 Channel Node**
- **Spectrally Adaptive**
- **MIMO & Beamforming**
- **Member of Four Simultaneous Subnetworks**
- **Ultra Low Latency**



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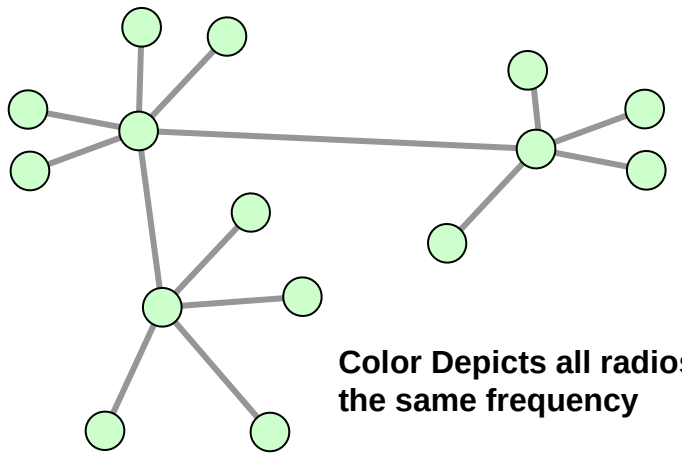
WNaN MANETS Achieve Reliability through Diverse Paths and Frequencies

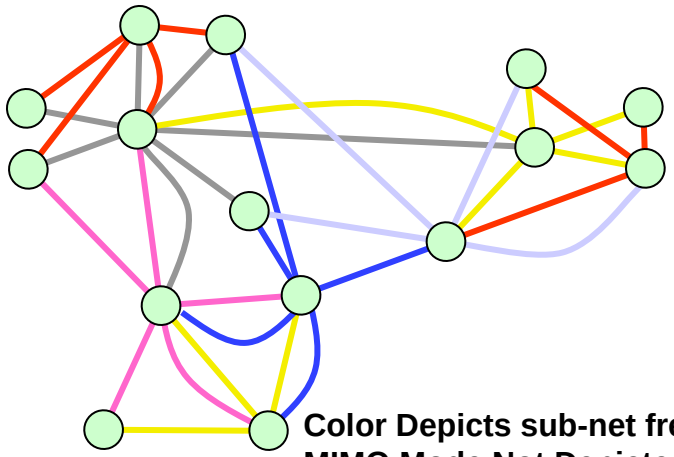
Mesh or MANET



Color Depicts all radios on the same frequency

- Limited Scalability
- Bandwidth Constrained by Mutual Interference – More Nodes do Not Create More Capacity
- Low Reliability Due to Single Link Routes
- Large Number of Nodes on Single Frequencies

WNaN



Color Depicts sub-net frequencies
MIMO Mode Not Depicted

- Unconstrained Scalability
- Additional Nodes Create Additional Networks – Enabling More Capacity
- Diversity in Frequency Avoids Interference
- Multiple Routes Reduce Link Dependency
- Dynamic Spectrum Can Use Network to "Make Before Break"

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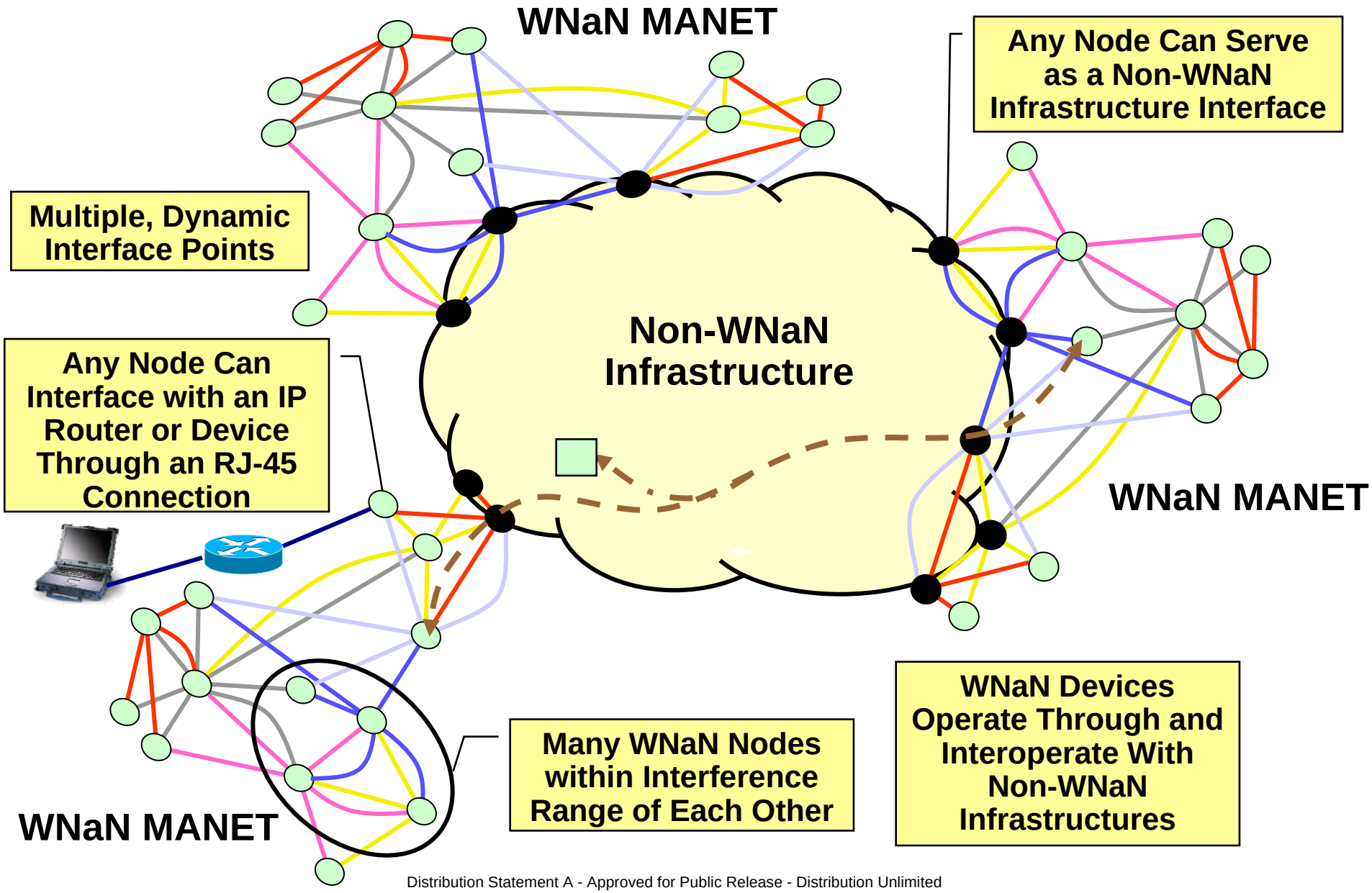
Linkage of Interleaved WNaN by and between Non-WNaN Infrastructures



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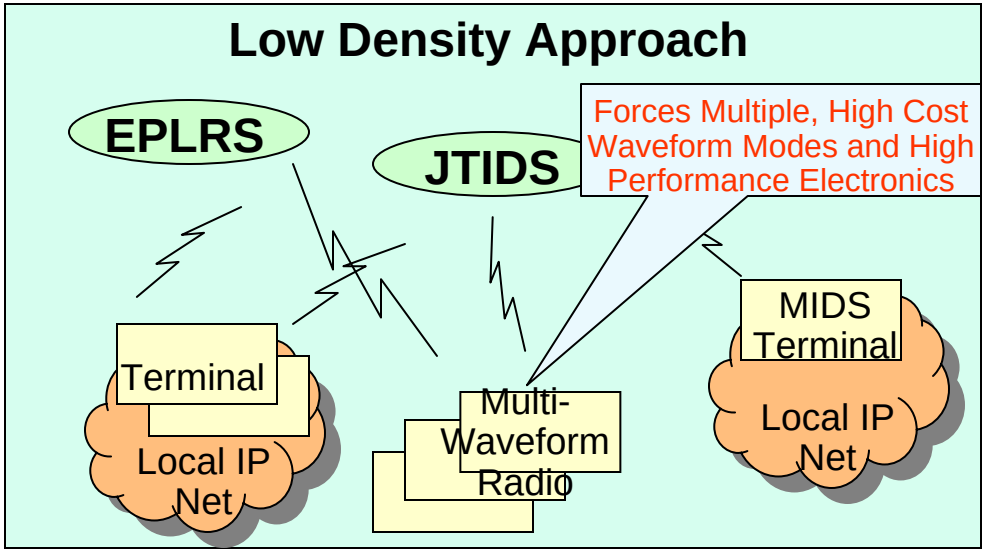
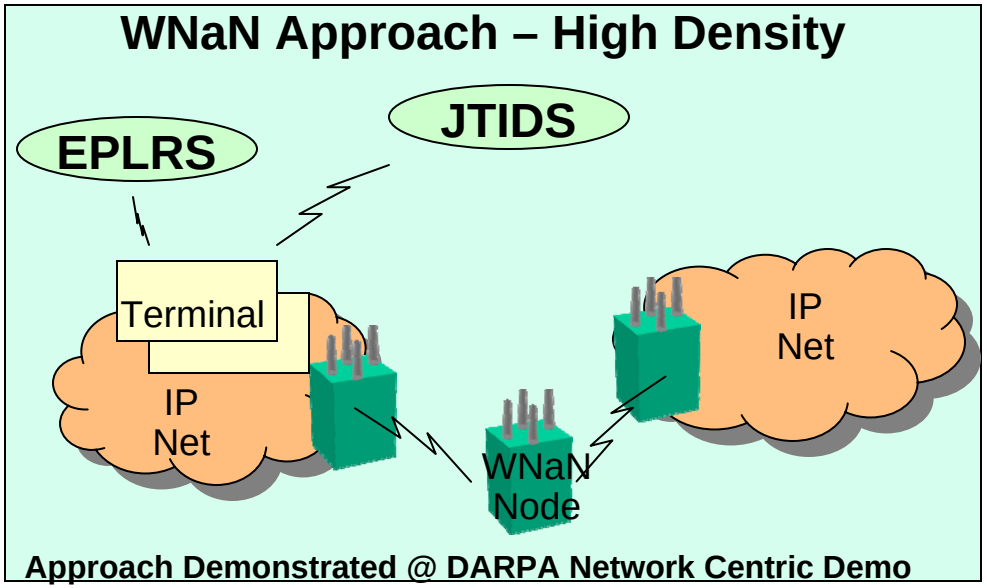
Philosophic Transition to Density Rather than Range

- Transition from End-to-End to Meshed Network Connectivity
  - Network Takes Responsibility for Delivery
- Use IP Linkage to Avoid Need for All Nodes to Reach All Platforms
  - Network Provides Range and Reliability
- Interoperate at Network (At IP, Not Physical) Layer with JTIDS, SINCGARS, EPLRS, …
- Use Global Network to Resolve Local Shortcomings
- Not Your Grandfather's NxN Gateway – Everyone to IP

DARPA Network Centric Demonstration Instantiates





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The 11 Theses for DARPA's Wireless Network after Next

1. The Network Will Adapt to the Mission and Organize Itself Responsively to Traffic Flow and QoS Across the Entire Range of Tactical Dynamics, Network Size, and Network Density
2. The Architecture Will *Create the Best Mission Topology* Rather than Passively Accepting *Network Topology* and Routing, as Given
3. The MANET Will Interconnect with Fixed Infrastructure at Multiple, Dynamic Points of Presence Rather than at a Single, Fixed Point of Presence
4. The Network Will Create a Distributed Computing Environment where the Applications and Services are Populated/Migrated onto Nodes According to Traffic Flows and Resource Availability
5. The Network Will Have Intelligent Multicast Protocols and Caching Mechanisms to Use Scarce Wireless Bandwidth Efficiently
6. The Network Will Have Cross-Layer Adaptation Mechanisms that Work Together to Optimize Network Performance and Reduce Stress on Inexpensive Physical Layer Devices
7. The Network Will Use Policy to Drive Topology and Load Sharing in the Network
8. The Architecture Will Provide Persistent Caching and Content-Based Access of Information Within the Network
9. The Network Will Support Multiple Network Structures and Multiple Network Frameworks for Delivering High Speed / Low Latency Streaming / Data Services
10. Disruptive Tolerant Networking (DTN) Will be a Native Mode of the Network rather than an Overlay
11. New Policies and Policy Controlled Functions can be Introduced Asynchronously, without code changes, and linked symbolically through an extensible semantic structure

Optimize the Network, Not the Radio

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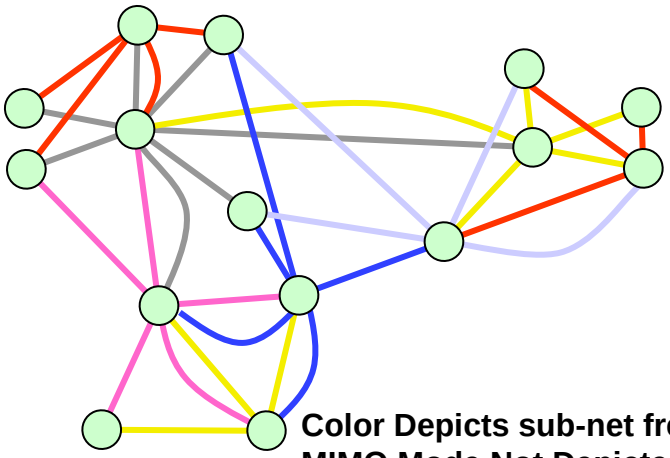
Adapt to Mission & Environment, Identify the Best Mission Topology and Interconnect with Non-WNaN Infrastructures



Color Depicts sub-net frequencies
MIMO Mode Not Depicted

1. The WNaN network should be aware of, and have the ability to adapt to, the mission and the environment, and be able to organize topologies in response to traffic flow and QoS across the entire range of tactical dynamics, network size, and network density. WNaN network should also be able to identify and create a unified /coordinated approach to interference management by exploiting technologies as trades at multiple layers to maximize performance within spectrum management, network layer and physical layer constraints.

2. The WNaN network should be able to identify and instantiate the “Best Mission Topology” rather than passively accepting network topology and routing as given. WNaN network should create topology by allocating/modifying resources such as spectrum, interference, routing responsibility, battery power, MIMO, etc.

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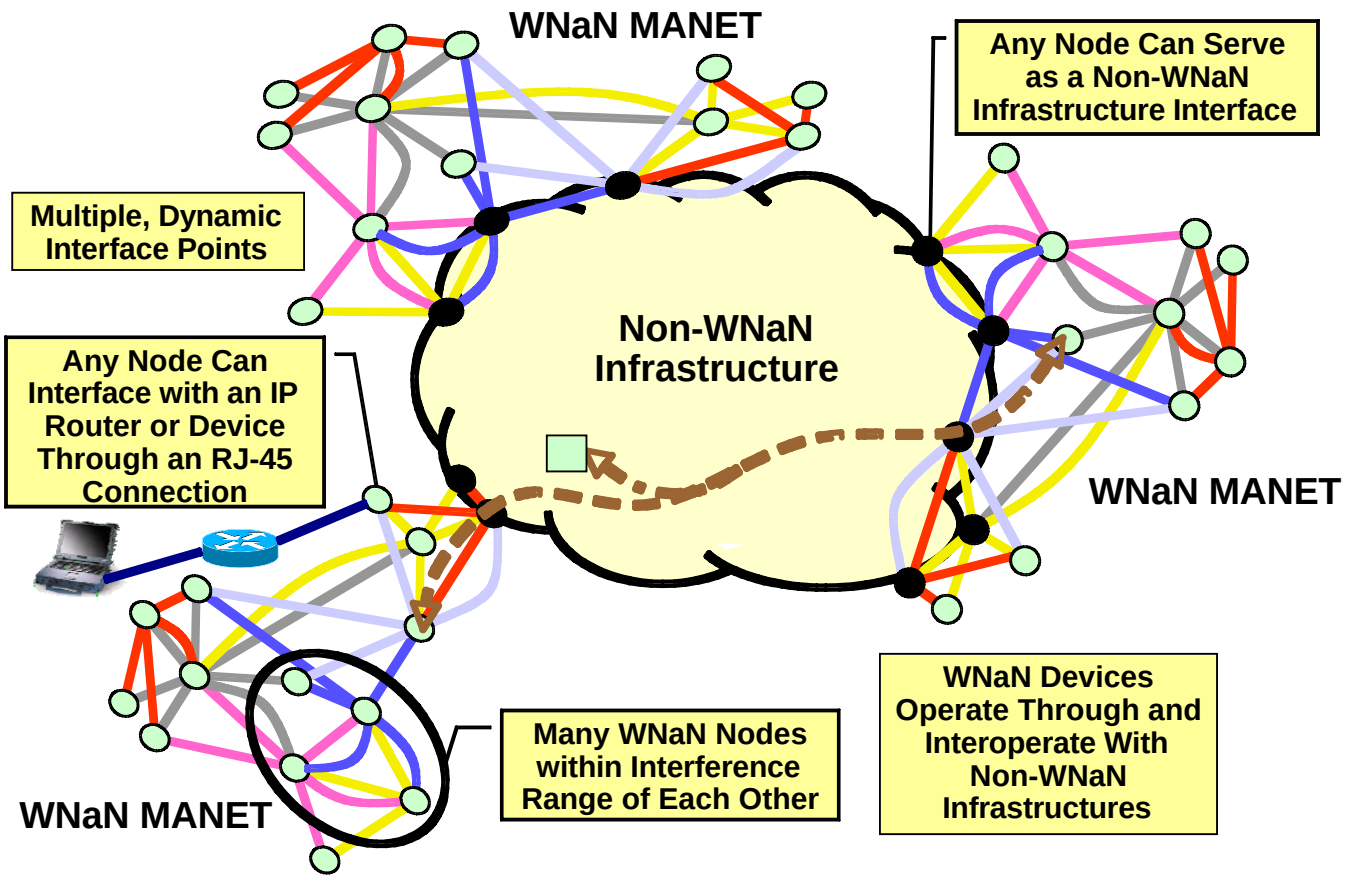
Linkage of Interleaved WNaN by and between Non-WNaN Infrastructures

3. The WNaN network should be able to interconnect with non-WNaN infrastructures at multiple, dynamic points of presence – wherever and whenever a connection to the infrastructure can be created - rather than at a single, fixed point of presence.



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Create Distributed Network / Computing Environment

4. The WNaN network should provide the ability to create distributed computing environments where the applications and services are populated / migrated onto nodes according to demand, traffic flows, network congestion and resource availability.
   - Develop a Service Network Technology that Allows Composition of Services and Applications
   - Develop a Model for Distributing Applications and Services Within the Network According to Demand, Bandwidth, Network Congestion, and Resource Availability
   - Develop a Model that Acts in Response to Changing Conditions in the Network by Migrating Processes / Agents to Where they are Needed
   - Replicate Critical Processes for Backup Operation

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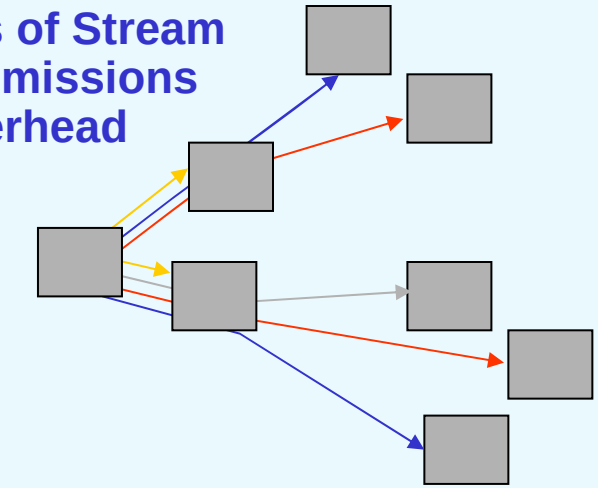
Multicast Protocols and Caching Mechanisms

5. The WNaN network should be able to implement intelligent multicast protocols and caching mechanisms as appropriate to optimize streaming services, intelligent multicast, predictable performance, bandwidth reservation and end-to-end congestion control.

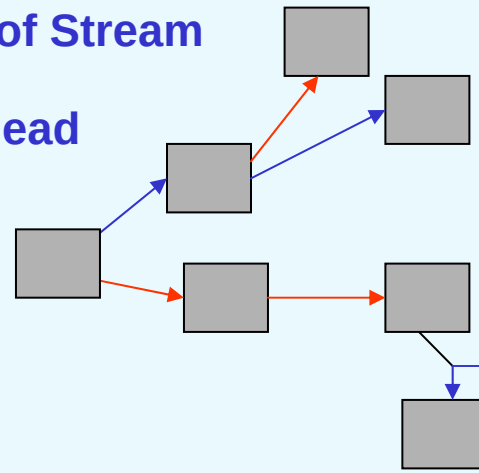
Internet VOIP Model

- 7 Copies of Stream
- 12 Transmissions
- 25% Overhead



WNaN Model

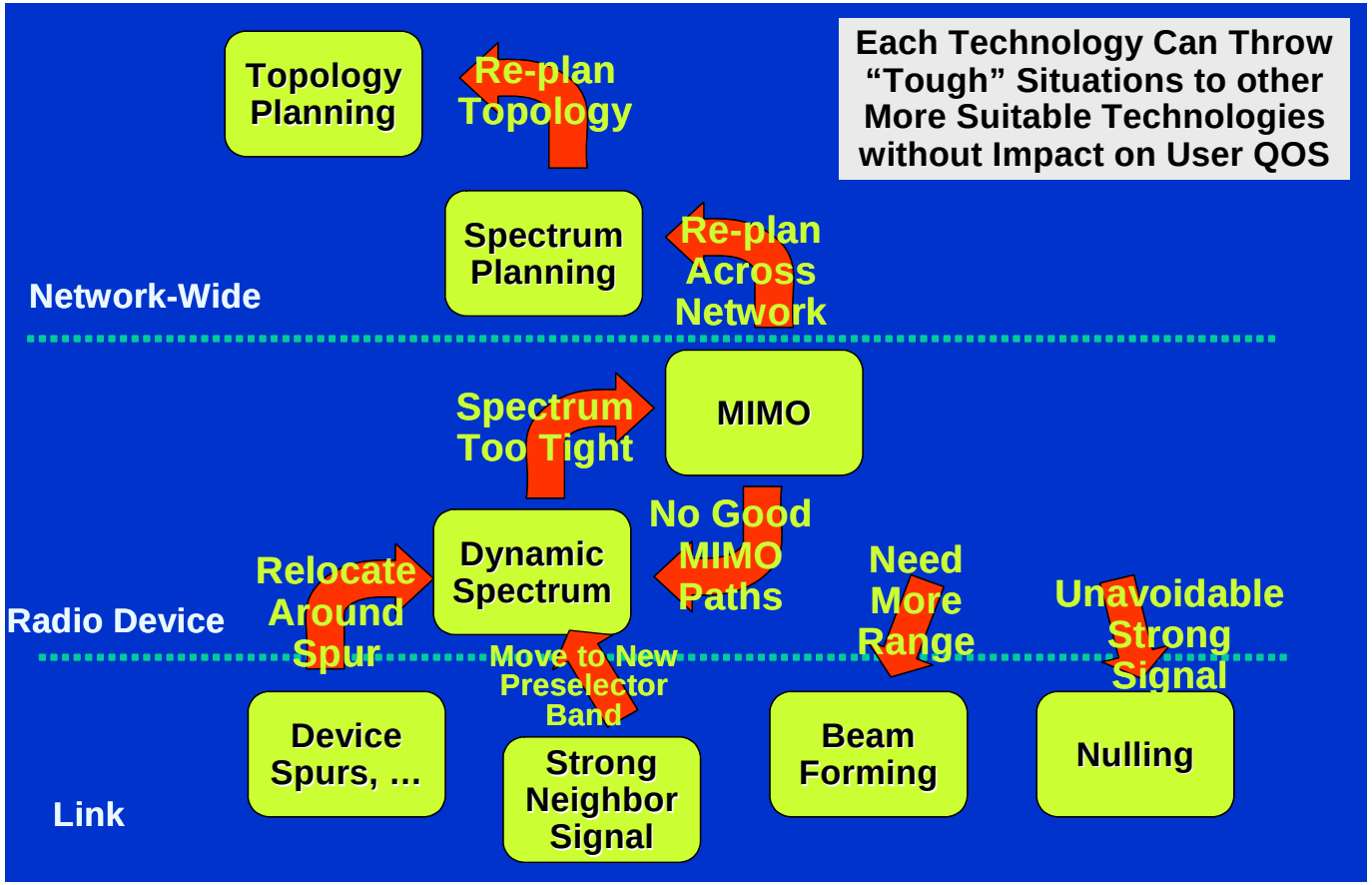
- 2 Copies of Stream
- 6 “Hops”
- 3% Overhead



Both Radios Receive the Same Transmissions

Cross-Layer Adaptation

6. The WNaN network should be able to support, as appropriate, cross-layer adaptation mechanisms that work together to optimize network performance and reduce stress on inexpensive physical layer devices.



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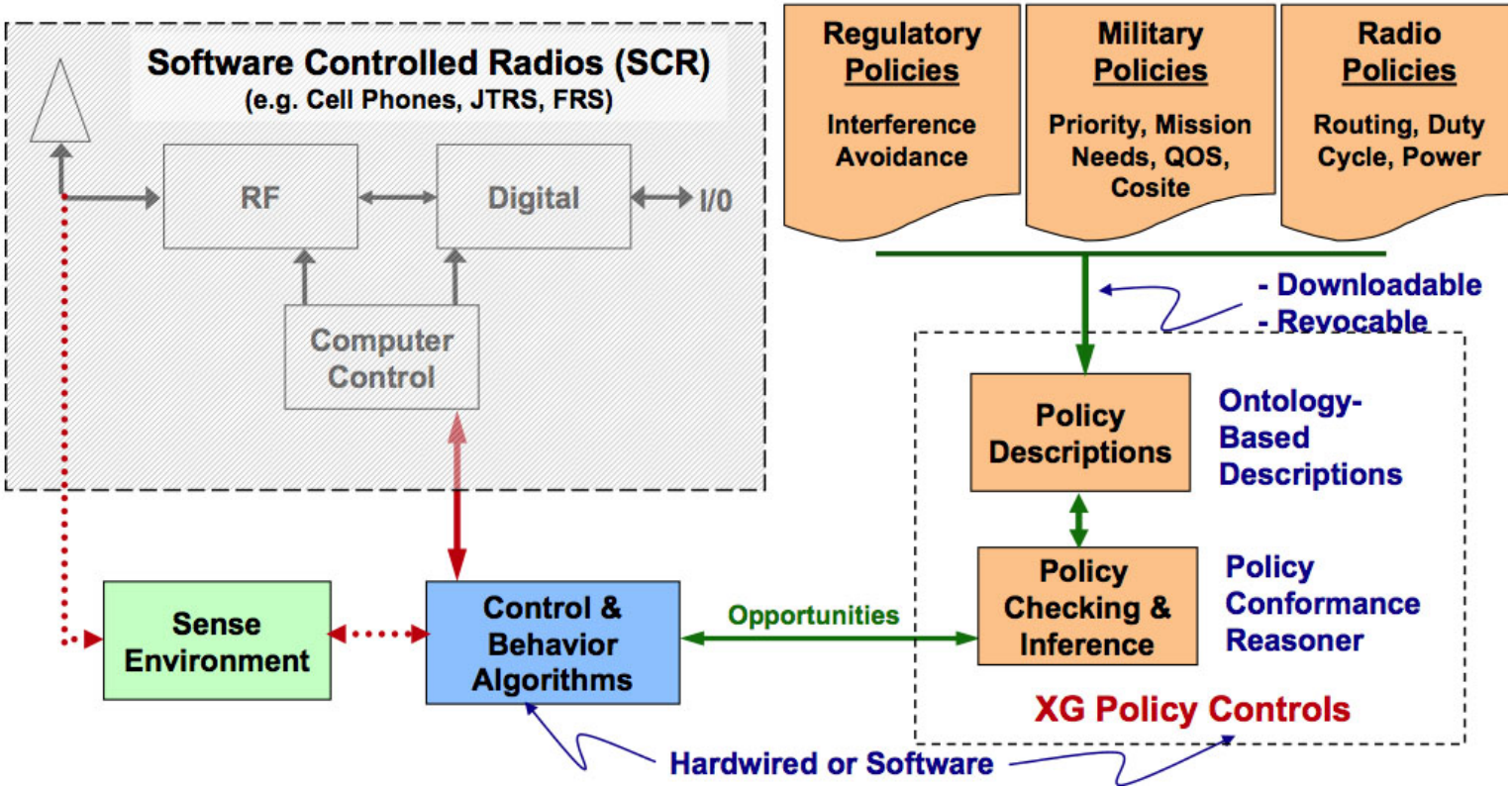
Policy Driven Topology and Load Sharing

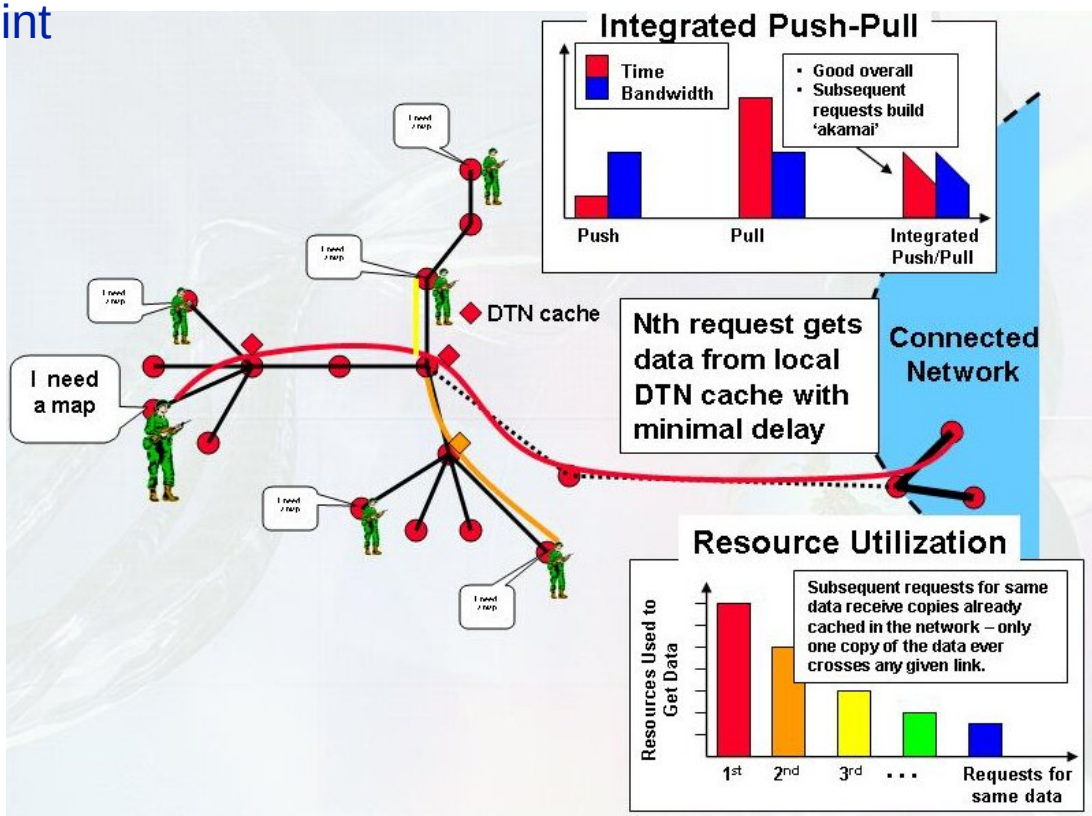
7. The WNaN network should be able to use policy and reasoning techniques to drive topology formation and load sharing.



Persistent Caching and Content-Based Access

8. The WNaN network should be capable of supporting persistent caching and content-based access of information within the network. The objective is to retrieve once and then be able to provide to local users as requested.

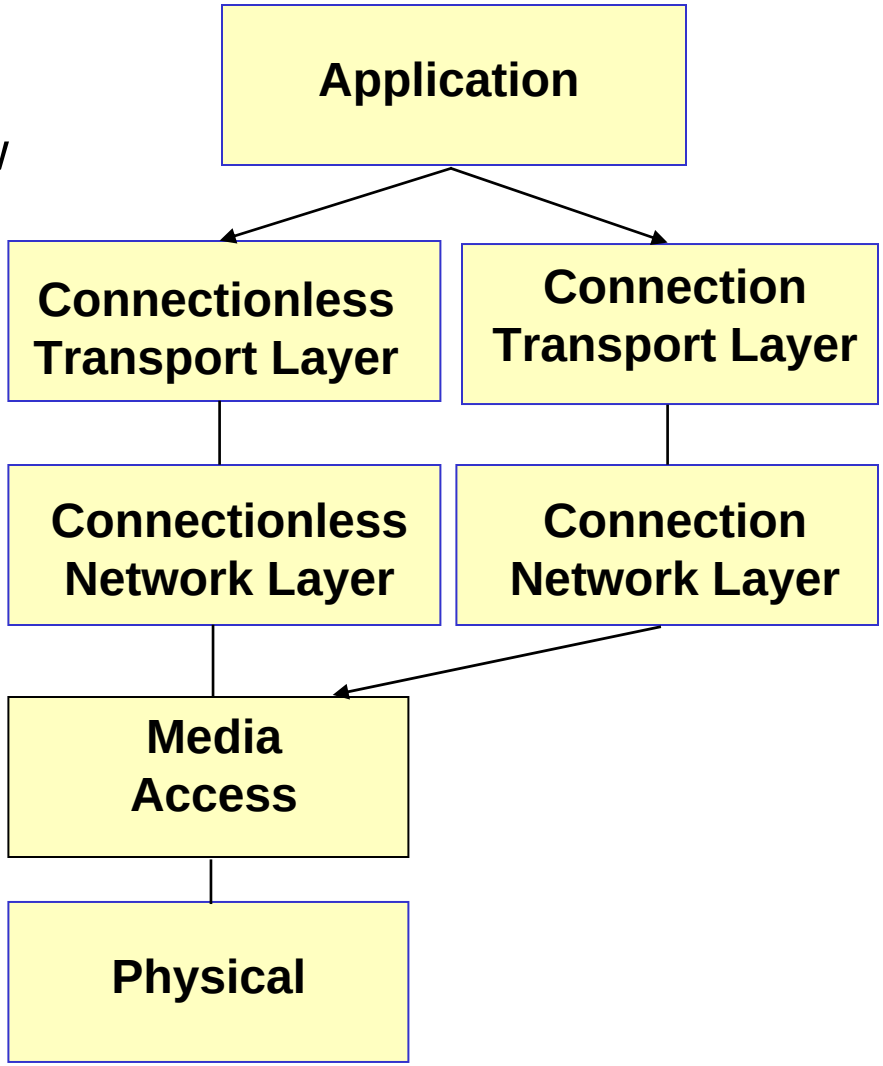
- Each Node is Capable of Dynamically Self-Forming Akamai-Like Caching / Content-Based Point
- Retrieve Once, Provide to Local Users as Requested
- Use Node Storage to Create Persistence within Tactical Nets



Multiple Network Structures and Frameworks

9. The WNaN network should be able to support multiple network structures and multiple network frameworks to optimize delivery of high speed / low latency streaming / data services. The network should provide both Connectionless and Connection-Oriented Services as appropriate.

Example



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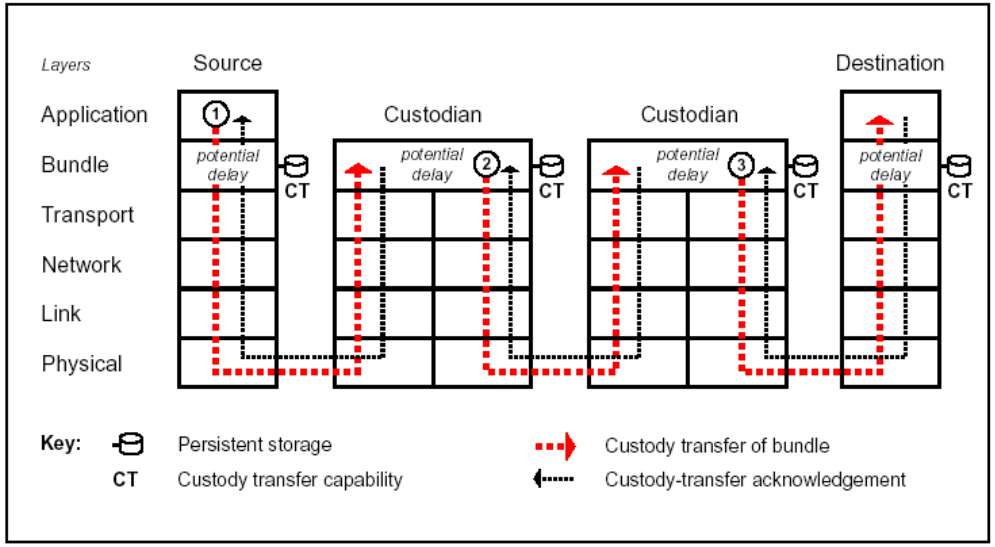
Operating under Episodic Connectivity Effectively

10. When the network experiences delays and disruptions, the WNaN network should be able to sense the impairment and to mitigate the effect of these impairments using techniques such as Disruption Tolerant Networking (DTN) to knit together heterogeneous network fabrics and to operate with episodic connectivity effectively.

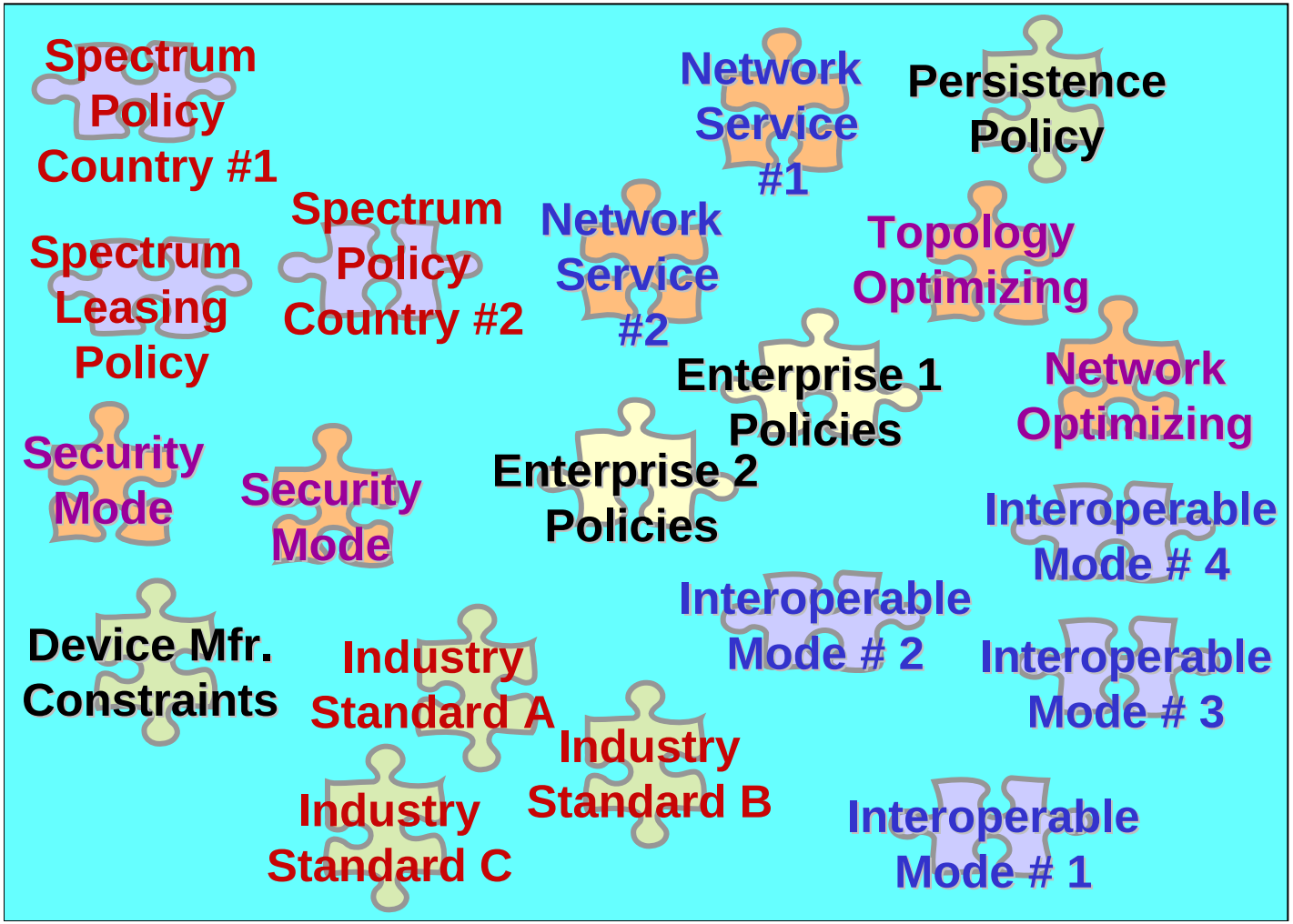
- Provide Hop-by-Hop Oriented Behavior, along with End-to-End
- Enables WNaN Network to Take Responsibility for Information Delivery, rather than Burdening Node Applications with that Responsibility
- Use DTN to Provide Incremental Data Delivery Over Unreliable / Disrupted Networks, Rather than End-to-End IP Connections (Which Cannot Tolerate Even Short Disruptions)
- Implement DTN Directly Above Those Link Layers that Support Reliable Transport
- Fit Critical Applications to DTN Bundle Interfaces, not IP
- Use DTN Gateways to Provide Backhaul an Interface Between Networks with Heterogeneous Hardware

DTN



Future Cognitive Components Will Not Come From Just One Source

11. The WNaN network should be able to asynchronously introduce new policies and policy controlled functions without code changes. Policies and policy controlled functions could be linked symbolically through an extensible semantic structure.



Multiple Dynamically Interacting Cognitive Processes

If Your Team Can Do All These, You Probably are What We're Looking for!