From Self Forming Mobile Networks to Self-Forming Content Services

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Roadmap

• **Review Some of the Objectives of Cognitive Networking**
  – Infrastructure Free Operation
  – Lower Cost through Environmental Adaptation

• **Present Recent Work Funded By DARPA**
  – Why We Believe Cognitive Radio Networks are Imminent

• **What’s Next: Content-Based Networking**
  – Transition from Packet to Content Metaphors
  – Use Cases

• **Some Needed Research**
What Does it Take to Make Wireless Networks Practical As a Service?

Some of the Major Impediments

1. How to Provide Access to Content
   - Without Infrastructure and Backhaul to Reach it

2. How to Be Affordable?
   - WiFi is not Enough, and Next Step is Costly

3. How to Get Spectrum
   - All Prime Real Estate Gone!

4. How to Scale to High Density
   - Interference Issues of Gupta-Kumar

5. How to Make Management Load Not Scale with Size
   - Not to Be the Radio Engineers “Full Employment Act”

All Challenges Must Be Met to Be Useful
Network Infrastructure: More than Just the Radio

- Cell Towers
- Finite Energy
- Frequency & Network Planning
- Unknown Topology
- Index Services
- Fiber & Wire Backhaul
- Cache Servers
- Central Servers
- XYZ.COM

Distribution Statement A – Approved for Public Release – Distribution Unlimited
Network Architectures

Plain Old Telephone Service Era (POTS)
Everyone Talks Thru a Switch

Internet Age
Everyone Can Exchange Data with Anyone Else

Internet Services Over Internet
DNS, Web, Index, VoIP, Email, Chat
## Infrastructureless Operation

<table>
<thead>
<tr>
<th>Function</th>
<th>Infrastructureless Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Planning</td>
<td>DSA using common policies in devices to avoid pre-planning frequencies, resolve interference, and manage spectral energy</td>
</tr>
<tr>
<td>Network Planning &amp; Topology</td>
<td>DSA to match spectrum availability and RF propagation with density and topology needs dynamically. Late binding to avoid maintaining IP addressing in dynamic regions.</td>
</tr>
<tr>
<td>Index Services</td>
<td>Content metadata advertised locally, and routable metadata descriptions.</td>
</tr>
<tr>
<td>Cache Services</td>
<td>All nodes cache content. Content metadata can enable access without full address or URL description.</td>
</tr>
<tr>
<td>Information Servers</td>
<td>Any node can store, advertise, and serve metadata defined content</td>
</tr>
<tr>
<td>Name/List Servers</td>
<td>“Late binding” of delivery addresses to address messages and content without knowledge of the destination.</td>
</tr>
<tr>
<td>Cell Towers and Land Lines</td>
<td>Maximize reliance on lower cost and expendable nodes to enable density, and create connectivity.</td>
</tr>
</tbody>
</table>
Wireless & the Core

What works in the core doesn’t work in wireless

• Core
  – Fast, Well-connected, Reliable

• Wireless – *not so much!*
  – Connections to the Core (Backhaul) limited by Spectrum and Shannon
    (“Maxwell’s not making any more of it’’)
  – Connections limited by range or LOS (& power)
  – Connections frequently disrupted
    • By mobility, terrain, lack of infrastructure, damage to infrastructure
    • Standard end-to-end protocols don’t deal well with disruption
    • Standard end-to-end protocols *can’t* deal with partitioned networks
  – Correlated User Behaviors

• Wireless Disruption Affects More than Connections
  – Affects IP “Protocol Infrastructure” Behind the Scenes (e.g. DNS)
  – Can Deplete Scarce Resources (retransmission over thin pipes)
  – Chatty Protocols Suffer from Product Probabilities – may *never* complete a transfer
    • *Fifty-five (55!)* network traversals before FTP transfers 1st data byte
Is Cognitive Radio as a Path to Affordable Wireless Networks?

• Assume that Interference Is a Prime Driver of Performance and Interference Avoidance is to Cost
  – Costs of Radios Driven by Ability to Avoid In-Channel and Adjacent Channel Energy

• General Argument has been that Cognitive Radio can Create Improvements in Radio Performance (Line A)

• Perhaps Even More Important is that Cognitive Radio Can Reduce the Component Requirements (Cost) to Achieve the Same Performance Points (Line B)

• How Much can Cognitive Adaption Reduce Cost?
RF Environment Energy Management Key to Robust Operation and Affordability

- Even Open Frequencies Not Usable in High-Energy RF Environments, ex. CREW
  - Frequencies can be “Perfectly Assigned”, but RF Cannot Deal with Energy Density
  - Even Ultra-High Quality Front Ends, Experience 20 dB (100 Times) Increase in Noise due to Inter-Modulation
- “Better” Frequency Management not an Answer
  - Intractable Problem for Centralized Management
- “Better” Technology not an Answer
  - Can Not Throw Linearity at the Problem
  - Energy Costs of High Linearity Unacceptable in Battery Devices

Non-Linear Effects (Co-Site) Make Frequency Management Impractical in Future Military Systems, Also Drive Cost of Military Radios

Results Shown for 10w, 10dB Gain, IIP3 = 50dBm (Ultra High Quality) LNA
Dynamic Spectrum Access Supports Operation in Dense RF Environments

- DSA-Enabled Radios Achieve 100% Unaffected Link Availability within 10 dB of Noise Floor
- Radios without Dynamic Spectrum Capability (XG) only Achieve < 50% Link Availability Due to Co-Channel and Intermodulation Distortion

Assumptions
- 2 km x 2 km Area with:
  - Ten 250 W Non-Cooperative Emitters
  - 250 Pairs of WNaN Radios
- 225 – 525 MHz
- -90 dBm Threshold
- OIP3 Varies from 0 to -20 dBm
- Filter BW at 20%

Analysis Based on WNaN RF Front End Filter Design
Critical Technologies Recently Developed or Under Development

- **Dynamic Spectrum Access**
  - Offers a way out of the Gupta-Kumar straitjacket that limits wireless node density

- **Disruption Tolerant Networking**
  - Creates a reliable network from unreliable network links
  - Provides a framework for distributed network services

- **Affordable Cognitive Radio Nodes**
  - If you can afford only one radio, you will have a very small network
  - If you can afford a million radios, you can build very different wireless network architectures

- **Adaptive Networking**
  - Tens of thousands of mobile radios cannot be managed by an operator
  - Adaptation thru machine cognition & policy control will be essential
DARPA XG Program Investments

**XG Prototype & Demonstration**

- **Spectrum Awareness**
  - Sensor Technology
  - Signal Processing Algorithms
  - Distributed Sensing Algorithms
  - Interference Effects Assessment

- **Behavior**
  - Policy Reasoning
  - Policy Language
  - Enforcement Implementation
  - Engineering Basis
  - Framework & Semantics
  - Methodology

- **Optimizing Strategies**
  - Tactics
  - Adaptive Network Operation
  - Non-Interfering Operation
  - Spectrum Adaptive Networking

- **Spectrum Measurements**
  - Capability and Affordability
  - Dynamics

- **IEEE SCC 64**
  - Performance Experiments
  - Assessments
2006 -- DARPA XG Demonstrated that Dynamic Spectrum is Possible Now!

• Conducted at AP Hill Drop Zone
  – OSD NII Provided Test Criteria
  – Two+ Month Evaluation Effort Culminating in Live Field Demos in August 2006
  – Demonstrated XG Benefits to Key Stakeholders Including NTIA/FCC
  – Collected Data for Comprehensive Performance Analyses

• 6 Mobile XG Radios in “Fully-Assigned” Spectrum Environment (“Electromagnetic Obstacle Course”)
  – Services Provided Current DoD Tactical Communications Environment
  – Adaptive Coexistence with Military and Civil Radios in Mobile Environment
  – Operation in Presence of XG, non-XG, and Malicious Interferers

Core XG Technologies Demonstrated Reliable Networking Without Harmful Interference Legacy Nodes In in Stressed Operationally Relevant Context

<table>
<thead>
<tr>
<th>Metric</th>
<th>NII Threshold</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show: XG Causes No Harm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abandon Time</td>
<td>500 msec</td>
<td>100% in 465 msec</td>
</tr>
<tr>
<td>Interference Limit</td>
<td>3 dB</td>
<td>Mean: 0.16dB, Max: 0.49dB</td>
</tr>
<tr>
<td>Show: XG Works</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Formation</td>
<td>30 sec w/ 6 Nodes</td>
<td>90%: 3.6s; 100%: 8.68s</td>
</tr>
<tr>
<td>Net Join</td>
<td>5 sec</td>
<td>90%: 2.07s; 100%: 4.36s</td>
</tr>
<tr>
<td>Net Re-Establish</td>
<td>500 msec</td>
<td>100%: 165msec</td>
</tr>
<tr>
<td>Show: XG Adds Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectrum Occupancy</td>
<td>60% w/ 6 Nodes</td>
<td>85% Occupancy at 83% Confidence</td>
</tr>
</tbody>
</table>
Cognitive Radio Adaptation to Avoid Front End Overload in Typical Spectrum

Non-Cognitive Radios Have High Probability of Overload at Reasonable IIP3

Cognitive Radio Adaptation Provides Higher Performance AND at Lower Component Performance Levels

Wireless Network after Next (WNaN) Program
A Networked Radio for Every Person!

Program Concept: Develop an Intelligent, Adaptive, Affordable Network that Changes Design Focus from Individual Radio Performance to Densely Deployed Network Performance

- Radio Design Leverages High Volume, Low Cost COTS Components to Enable $500 Unit Cost in Lots of 100K
- Network Adaptation Mechanisms Address Analog Weaknesses and Enable Low-Cost Design

Early Radio Availability Provides Opportunity for Experimentation and Use Case Development
WNaN Radio

- Single RF Processing Slice Replicated to form 4 Transceiver Voice/Data Radios
- Early Hardware and Networking Capability to Enable Experimentation, TTP Development by Services
- Low Technical and Cost Risk Hardware to Maximize Transition Success
- Built in Dynamic Spectrum Capability
  - No Frequency or Network Planning Required

WNaN Radio Goals:
- 4-Transceiver Node @ $500 in Lots of 100K
- Spectrally Adaptive
- MIMO for High Capacity in Urban Environments
- Member of Four Simultaneous Subnetworks

Each (of 4) Channel:

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>900 MHz to 6 GHz Continuous</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Power</td>
<td>1 Watt/ Transceiver, 4 Watts Total</td>
</tr>
<tr>
<td>Data Rate</td>
<td>16KBPS to 10 MBPS</td>
</tr>
<tr>
<td>Range</td>
<td>Up to 3 KM</td>
</tr>
<tr>
<td>Filter Q</td>
<td>Q &gt; 150</td>
</tr>
<tr>
<td>Modulation</td>
<td>OFDM, QPSK, BPSK, QAM</td>
</tr>
<tr>
<td>MIMO</td>
<td>2x2, 3x3, 4x4</td>
</tr>
<tr>
<td>Frequency Selection</td>
<td>DARPA XG Dynamic Spectrum Sensing and Assignment</td>
</tr>
<tr>
<td>RF Environment</td>
<td>&lt; 0.01% Chance of RF Overload in Dense Environments</td>
</tr>
<tr>
<td>Battery Life</td>
<td>• Early Product: 8.8 hrs</td>
</tr>
<tr>
<td></td>
<td>• Final Product: 12.8 hrs</td>
</tr>
<tr>
<td>Form Factor</td>
<td>Handheld or Wearable</td>
</tr>
<tr>
<td></td>
<td>2.6” x 1.8” x 6.5”</td>
</tr>
</tbody>
</table>
WNaN Reliability and Scaling through Diverse Paths and Frequencies

Today’s Mesh or MANET

- Low Reliability Due to Single Link Routes
- Bandwidth Drops as More Radios Added to Network
- Bandwidth Constrained by Mutual Interference – More Nodes do Not Create More Capacity
- Large Number of Nodes on Single Frequencies

WNaN

- Multiple Links and Routes Provide High Reliability
- Bandwidth Increases as More Radios Added to Network
- Diversity in Frequency Avoids Interference
- Dynamic Spectrum Can Use Network to “Make Before Break” For Dependable Operation

WNaN Architecture Addresses Known Weaknesses of Current MANET Technology
## Roles of Layers in Unified Interference Process

<table>
<thead>
<tr>
<th>Functional Element</th>
<th>Responsibility within an Unified Interference Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Spectrum Planning</td>
<td>Provide isolation of interference tolerant and non-interference tolerant systems so devices can make assumptions about the degree of interference that is permissible to be caused to other users of the same spectrum band. Instead of “protecting” individual users, the spectrum planning process protects classes of users.</td>
</tr>
<tr>
<td>Dynamic Spectrum Access</td>
<td>The DSA functionality determines the probability that a given frequency selection will, receive both in-channel and adjacent channel interference events, or cause them to others. Depending on the frequency, the tolerance to causing interference is driven by the policy established through the manual spectrum planning process. DSA provides the flexibility so that networks can limit the amount of interference to a given amount.</td>
</tr>
<tr>
<td>MIMO (if Present)*</td>
<td>As an alternative to time and frequency separation, exploit spatial dimensions to isolate signals, either to receive multiple simultaneous information streams, or to isolate a signal in the presence of interference that would otherwise preclude successful demodulation.</td>
</tr>
<tr>
<td>Media Access Layer</td>
<td>Provide temporal separation of signals in a common signaling channel, through shared protocols or channel access procedures and allocations.</td>
</tr>
</tbody>
</table>


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

*Radios Do More Than Host the Network They Should Change it!*
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

Radios Do More than Host the Network
They Should Change it!
Dynamic Spectrum Too Tight

Dynamic Spectrum Key to Adaptive Networking

Relocate Around Spur

Device Spurs, ...

Move to New Preselector Band

Strong Neighbor Signal

MIMO

No Good MIMO Paths

Need More Range

Unavoidable Strong Signal

Nulling

Beam Forming

Each Technology Can Throw “Tough” Situations to other More Suitable Technologies without Impact on User QOS
Disruption Tolerant Networking (DTN)

- DTN Technology Provides Network Services in Intermittent & Disrupted Networks
  - Edge Units Continue to Operate with Only Limited Access to Servers
  - Store and Forward Reduces Back Haul Traffic

- DTN Demonstrated Three Value Propositions:
  - High Reliability: Achieves More Reliable Message Delivery than IP in Disrupted Environments
  - Better Performance: Performs Better than End-to-End IP Given the Same Resources
  - Lower Resources: Uses Less Resources (e.g. Bandwidth) while Maintaining or Improving Information Delivery

Current Network (CONDOR) Demo: EPLRS Equipped Convoys Communicate w/in Convoy and via CONDOR to HQ and other Convoys using DTN

Future Network Demo: Mix of Mobile (5) and Fixed Nodes (15) Use 802.11 and EPLRS to Send Messages to Night Vision Lab using DTN
**Disruption Tolerant Networking (DTN)**

**DTN Serves Four Critical Roles in Wireless Networking Concept:**

1. **DTN** deals with the reality that mobile edge networks may not have complete source-to-destination paths
   - DTN Uses Opportunistic Links, Drop Boxes, Data “Mules”

2. **DTN** Allows Each Hop in the Network to Be Optimized Uniquely and Individually, vs. End to End
   - Deal with Latency, Congestion, and Loss Locally, Bilaterally
   - Content Cached at Each Hop (Encrypted or “Clear”)

3. **DTN Bundle** is an Information (vs. Packet) Interface
   - Any (Predicate Calculus) Description of a Node is An Address
   - Nodes Supply to and Request Content from Network Using Same Structure – Network is Aware of Information, Not Just Addresses
   - Cognitive Management Decides on Data Storage, Replication, …

4. **DTN Hides Internal Network Details (Protocols, Routing, Name Services**
   - Allow non-IP networks, Avoid OSPF Flooding, DNS Dependence, Unstable Routes, …
Knowledge of Information Flows Provides Ability to Adapt Network to Meet Actual Needs Consistent with Physical Environment.

Dynamic Spectrum Key to Adaptive Networking.

Network-Wide

Network Planning

Re-plan Network

Spectrum Planning

Re-plan Across Network

Spectrum Too Tight

MIMO

No Good MIMO Paths

Need More Range

Unavoidable Strong Signal

Radio Device

Relocate Around Spur

Move to New Preselector Band

Dynamic Spectrum

Device Spurs, ...

Strong Neighbor Signal

Strong Signal

Beam Forming

Nulling

Dynamic Spectrum

Link

Re-plan Network

Move to New Preselector Band

Dynamic Knowledge of Information Flows Provides Ability to Adapt Network to Meet Actual Needs Consistent with Physical Environment.

Knowledge of Information Flows Provides Ability to Adapt Network to Meet Actual Needs Consistent with Physical Environment.
From DTN to Content Networking

• Started as Reliability Services as Key Objective
• Then We Wanted “Late Binding” to Allow Meta Data Description of Nodes, without connectivity to Core Name Services (DNS, Email …)
• Then Same Mechanism Could Provide Cache for Content as It Moved through Wireless Networks, or was Overheard
  ‒ Required New Cryptography for Protecting meta data separately from Payload
• Then ,Why not Let Cache be a Server, and Leverage the High Local Bandwidth of Wireless Networks
• Topology and Service Positioning now Interactive within a Unified Network Control Process

All Enabled by DTN’s Bundle Interface, Which Describes Content, not Packets
Why Content-Based Networking is Important at the Edge

- Edge Connectivity Often Disrupted
  - Access to Core for Named Network Services Wastes Link Opportunities & Incurs Delays (DNS, Databases, Key Servers..)

- The Association of Content with a Server Depends on Manual Planning & Access to the Internet
  - Increases Time-to-Deploy

- Backhaul Bandwidth is Expensive, Can’t Be Scaled, May Not Even Be Available (3rd World, Disaster Areas)
  - Communication between Edge and Core May Overwhelm Limited Backhaul Systems

- Applications at Edge Tend to Have Correlated Content
  - Content Sharing at Edge Can Reduce Backhaul Demands
  - Client-Server Data Sharing Doesn’t Work with Mobility
  - P2P Architecture Allows Dynamic Data Sharing if We Can Disseminate Knowledge of Available Content & Unit Characteristics

- CBN a Good Match to Dynamic Deployments
  - Provides Network with Control over Content Placement
  - Enables a Fit to Available Resources
  - Allows Ad Hoc & Autonomous Access to Content & Units

Content-Based Networking is **Necessary** for Mobile Ad Hoc Networks
Content Based Networking Built on Adaptation Mechanisms

- Content Topology
- Topology and Service Location are Interactive

Network-Wide
- Re-plan Across Network

Packet focused
- Topology Planning
- Spectrum Planning

Re-plan

Content focused
- Topology Too Tight
- No Good MIMO Paths

Link focused
- Dynamic Spectrum
- Re-plan

Relocate
- Around Spur

Move to New Preselector Band
- Strong Neighbor Signal

Device Spurs, ...
- MIMO
- Need More Range

Unavoidable Strong Signal
- Beam Forming
- Nulling

Distribution Statement A – Approved for Public Release – Distribution Unlimited
Why Thinking of Content and Wireless is Such an Opportunity

The Popular Conception of Bandwidth vs. Distance: A Slow Wireless Edge

In Fact, the Wireless Edge is Much More Capable than Currently Exploited

Backhaul is the Bottleneck!
Wireless Needs CBN
Wireless an Opportunity for CBN

Wireless Has Advantages that Match CBN

- **Wireless Networking is Physically Local (Range, LOS)**
- **Desired Content Often Local ⇒ Correlation**
  - Maps
  - Incidents
  - Situation Reports
- **User Interest Often Local ⇒ Correlation**
  - 3rd World
  - First Responder / Emergency Response
  - Military Tactical Networks
- **Wireless Networks are:**
  - Ad hoc
  - Self-organizing
  - Necessarily adaptive because no infrastructure
- **Wireless Networks tend to be:**
  - Well-connected over short ranges
  - Can be Moderately Fast (1-50 Megabits) over Short Ranges
Wireless & Content-Based Networking

• **CBN can use Wireless Communities of Interest & Correlations of Interest & Content**
  - Characterize content via metadata
  - Publish content characterization (metadata)
  - Units express interest in types of (meta-)data
  - Locality of interest/content ⇒ data can be disseminated at the edge without resort to (constrained) backhaul

• **Caching!**
  - Leverages correlation
  - Reduces Backhaul Traffic
  - Reduces Latency
First Responder Use Case

Disaster Relief Effort in 3rd World

• Devices Shipped as 1 CONEX from
  – NGO Aid Agency
  – No Support Personnel Available
  – Limited or Non-Existent Backhaul
  – Pre-Planned Policies for Spectrum, Routing, Security Developed for the Relief Effort are common across all Devices

• Devices Unpacked and Distributed to Users on-site
  – User Identity Imprinted at Issue
  – Devices Locate Available Spectrum, Form ad-hoc Networks and Locate any Available Backhaul

• Users Execute Relief Mission
  – No IT, Spectrum, Networking, or Human Contact Configuration or Management throughout Recovery Effort
    • No Need to Pre-configure Servers/Services
    • No Need to Pre-configure Spectrum
    • No Need to Pre-configure IP Address
    • No Need to Pre-configure Keys
    • No Need to Pre-configure Routing
  – Inquiries Locate Appropriate Content and Source/Destination Units
  – Content Dumped into Network Automatically as Possible

• Best “Available” Information Accessible at All Times
Users describe what they want, not where it is stored – DTN moves information where it is needed, *when it is needed*.

Low-latency access to requested information without access to remote servers, if the content is at the edge.

Reduced demand on long-haul thin pipes through distributed caching and local retrieval from cache.

DTN supports push and pull; appropriate third-party can direct content flow.

DTN Distributes Content at the Edge, Without Servers, When & Where it’s Needed.
Experiment: Caching & Content-Based Access
Field Demonstration

- Demonstrates caching & long-haul bandwidth reduction at the local end of the thin pipe
- Mix of radios in convoy
  - Lead element has EPLRS for comms to Ops
  - Others have short-range 802.11, so communicate to Ops by routing thru EPLRS vehicle
- Each element of the convoy requests imagery of the region when it enters the region
  - e2e IP: 5 end-to-end transactions with the image server at Ops
  - DTN: 1 end-to-end transaction to the Ops server, 4 queries short-stopped by cache

- Backhaul is expensive: $14/min SATCOM or $100K LOS radios
- Local bandwidth is cheap & available

Information caching at the edge enables independent edge ops
Experiment: Caching & Content-Based Access

- Area is gridded
- Vehicle entering a grid request imagery for the grid; a green question mark appears in the corresponding grid in the display
- When the imagery is received, it is copied into the grid
- If the request expires (5 minutes), a red cross is displayed in the grid

E2E IP vs. DTN

- Delivery latency
- Delivery ratio v. time
- Long-haul Bandwidth Usage (EPLRS) v. time
• Intentional Naming is Not as Compelling in the core network, because IN primarily useful for:
  – Communities of interest
  – Correlation between locality & interest
  – Dynamic Networks
  – Uncertainty about network composition (units, position, equipment)

Core Network is quasi-static; locality & interest generally uncorrelated; uncertainty can be resolved by query and/or enumeration

Wireless has localized Communities of Interest & Correlations between Content / Interest / Locale

Wireless is dynamic

Wireless disruption makes perfect knowledge impossible
  – Enumeration of units / position / equipment requires knowledge of who is in the network, or access to someone who does.
Content Description & Intentional Naming Usages

“I want maps for my area”, not “I want to ftp to 192.168.4.17”
“Give me a map of the relief area with evacuee aggregation points”
“Send this information to any unit w/i 200m of any bridge over the river”
“Send this information to police units w/i a kilometer of me”
“Acquire and report back to me sensor data w/i a kilometer of my current position”
“Monitor and report to me information as it becomes available about traffic on the road to the airport”

Enable any two connected edge nodes to exchange mission data without core mediation

Don’t describe addresses, describe content.
Access data by content description.
Create Ad Hoc Network Groups by Reference to Relevant Characteristics

Every Node Provides Content to Any Other Node

Distribute Content at the Edge by the Description of the Content or Need
Users *describe* the destinations; the network chooses paths across heterogeneous networks to deliver to nodes with those characteristics.

Delivery is *persistent*: delivery will be made to nodes that satisfy the description *during the lifetime of the information, even if the node does not yet satisfy the description*.

- Content from Ops sent to any nodes that match the description, e.g.: “all drivers within 1 km of a specified location”
- Content delivered efficiently using geographic routing to geo region, then local dissemination w/i the region
- Mobile nodes that match the role receive the content *when* they enter the specified region
- Content persists for its TTL and can be delivered at any time during that TTL
- Content is delivered dynamically to any node when the node’s role changes to match the description
  - any entering a region receives traffic reports for that region

**Scenario Description:**
1. Persistent Content Sent from Ops indicating Delivery to Geo Region (large shaded disc)
2. Convoy returns towards Ops from end of zone
3. As matching nodes enter geo region, the open circles are colored to indicate message delivery to matching nodes

*Persistent delivery to a geo-location can be a transformational capability*
Challenges - How Do We:

• Integrate Dynamics from Layer 1 to 7?
  – Cognitive Radio Only First Step to Cognitive Information Networks

• Leverage Inherent Correlation in Wireless Information Access and Locality
  – Information Often Generated and Consumed within Local Regions

• Networking that Adapts the Network to the Demand
  – Don’t Shape the Traffic – Shape the Network

• Investigate Viability of Alternative Models of Wireless Service Delivery (Infrastructureless?)
  – Military Has Clear Need
  – 3rd World, Disaster Recovery (Tsunami, Katrina, Typhoon), First Responders - All Have Similar Needs

• Question that Networks Must be Based on “Dumb” Node Principles
  – Appropriate in X-25, NCP, Early IP Eras
  – Same Argument as Once Used for Timesharing
  – Most Users Use Content Addressed Network via Search Engines
Fundamental Research Challenges

• **Scaling**
  – Density of Not Just People, but Things (Sensors, Vehicles, Robots. …)

• **Stability without Constraining Abstractions**
  – Prove (not Just Demonstrate) Stability with Millions of Nodes Interacting at all Layers
  – Performance May Have to Take a Backseat to Provable Transient Behaviors

• **Expressions of Logic and Reasoning**
  – Few IA Researchers Have Approached IA Tools as a “Process Control”
  – Wireless Could be the “Killer App”
  – Let’s Not Create another Pile of Code no One Can Understand!

• **Cognitive Radio Environmental Assumptions**
  – How do we “Prove” Performance without Being Specific to Millions of MATLAB© Data Points?
Fundamental Research Challenges (cont’d)

• A Generalized Decision Theory on Channel and Environmental Awareness
  – What is the Benefit of Resolving Uncertainty of the Channel and Environment vs. the Benefit?
  – Transition from Overhead %, to Relative Utility/Benefit

• Extending Machine Cognition Technologies
  – How to Create Ontologies from Service Descriptions
  – Better / Faster / More Robust Knowledge Base Technology

• Expand Network Capacity Models to Reflect Content, not Packets
  – How does Correlation impact Capacity
  – Unified Interference Model that Reflects Adaptation, MIMO, …
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Thank You!

Questions?

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