Control-Based Mobile Ad-Hoc Networking (CBMANET) Program Motivation & Overview

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August 30, 2005

CBMANET questions to BAA05-42@darpa.mil

Caveats

- I have no authority to bind the government

- In the event of any discrepancies between material here and material on FedBizOps, the FedBizOps material takes precedence

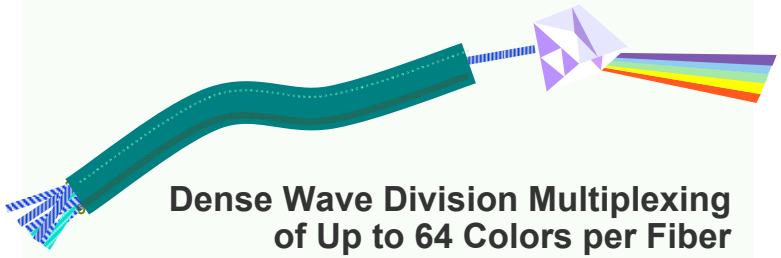
Outline

- **Motivation**
  - Spectrum is a scarce resource
  - Networks do not use spectrum efficiently
- **Programmatic details**
  - Timeline
  - What you need to build
  - How it will be evaluated
  - Who will evaluate it and how they will help you
- **Big picture issues & risks**

DO NOT MISINTERPRET ANYTHING I SAY AS SPECIFYING A TECHNICAL APPROACH. I ONLY MEAN TO SHOW OPPORTUNITIES.

Wireless Communication Is Inherently Limited

FIBER:
Bandwidth is PLENTIFUL
Inefficiency Not Noticed

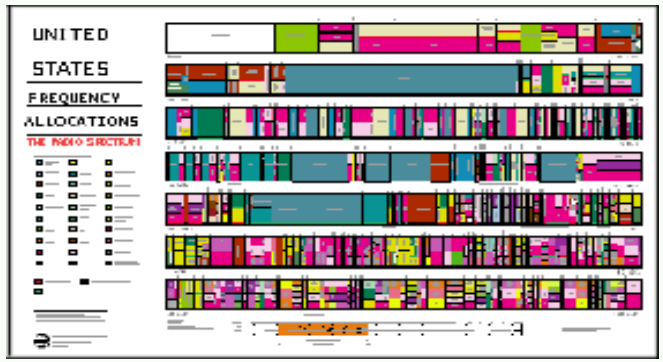


Dense Wave Division Multiplexing of Up to 64 Colors per Fiber – with 20 Fibers per Bundle

Each Color = **10 GHz**

ONE BUNDLE= **12,800 GHz**

WIRELESS:
Bandwidth is SCARCE
Overhead Limits Applications



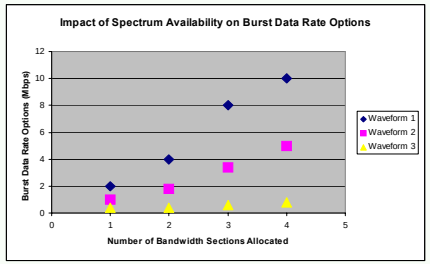
Each spectrum region has different properties & "owner"

USEABLE MOBILE= **3 GHz**

Technologies developed for bandwidth-rich Internet may not work with limited wireless spectrum

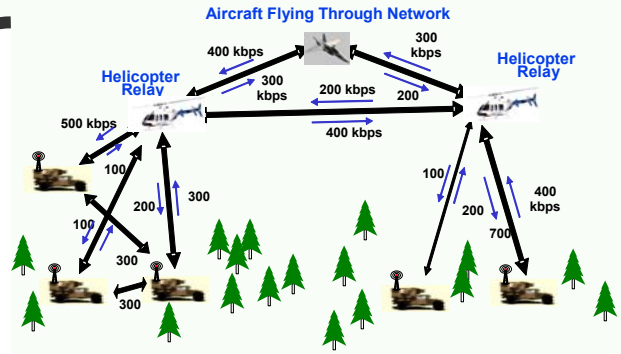
Throughput of Mobile, Ad Hoc, NETworks (MANETs)

Maximum MANET throughput…



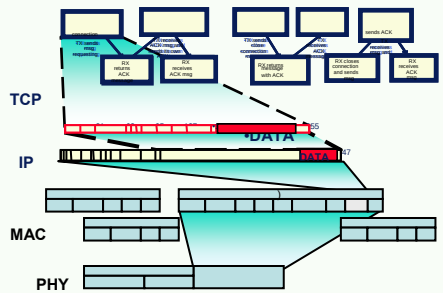
The advertised network throughput of many MANETs is often given as the maximum burst rate on a single link

…is shared across many links



However, the burst rate figure is misleading because it represents capacity that must be shared by other network users, not the capacity that each user can expect. Individual users generally obtain only a fraction of the maximum burst rate.

…and largely wasted by overhead and inefficiency

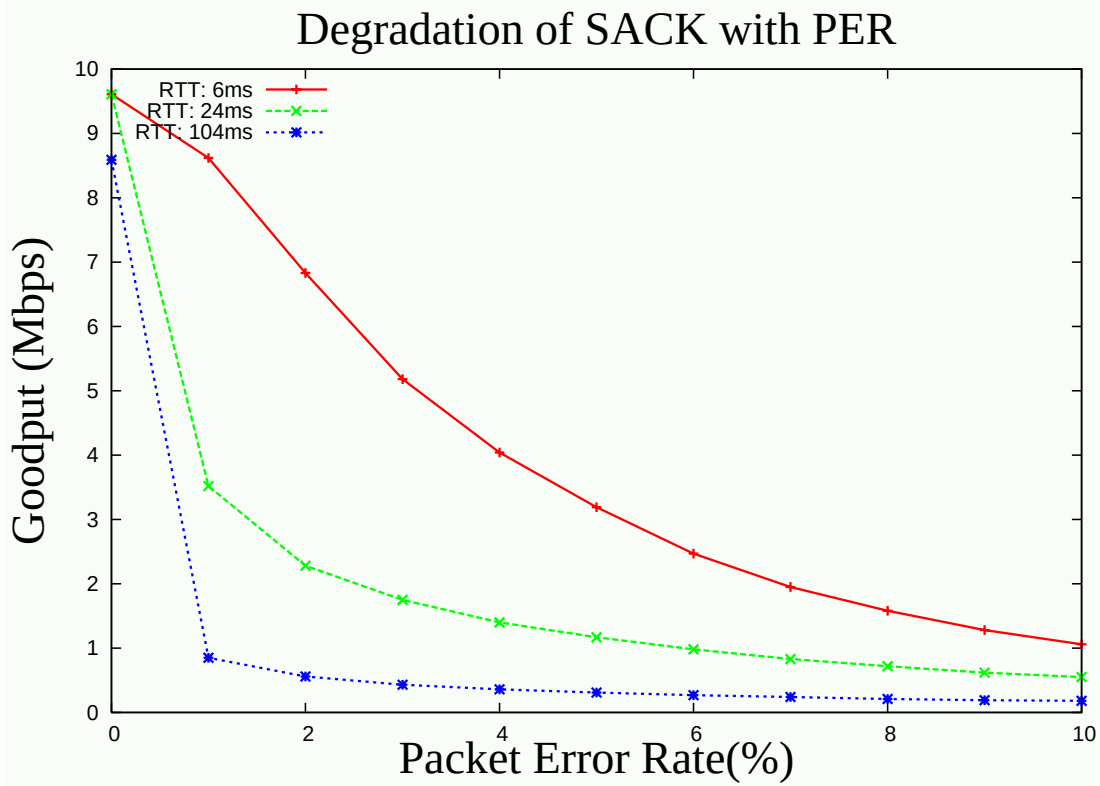


Also, the burst rate does not reflect data transfer efficiency, which may be low because of large protocol overhead per frame, limited cross-layer coordination, the absence of network resource management, etc.

Risk: Military Network demands may not be met by current commercial MANETs

Existing Protocols Are Not Designed for Wireless Environments

EXAMPLE #1: TCP – Designed for Stable, High-Quality, Low-Latency Links



Source: Robust TCP for Large-Bandwidth Delay, Packet Erasure and Multi-Path Environments. Shivkumar Kalyanaraman (RPI), K.K. Ramakrishnan (AT&T Labs Research)

TCP/SACK:

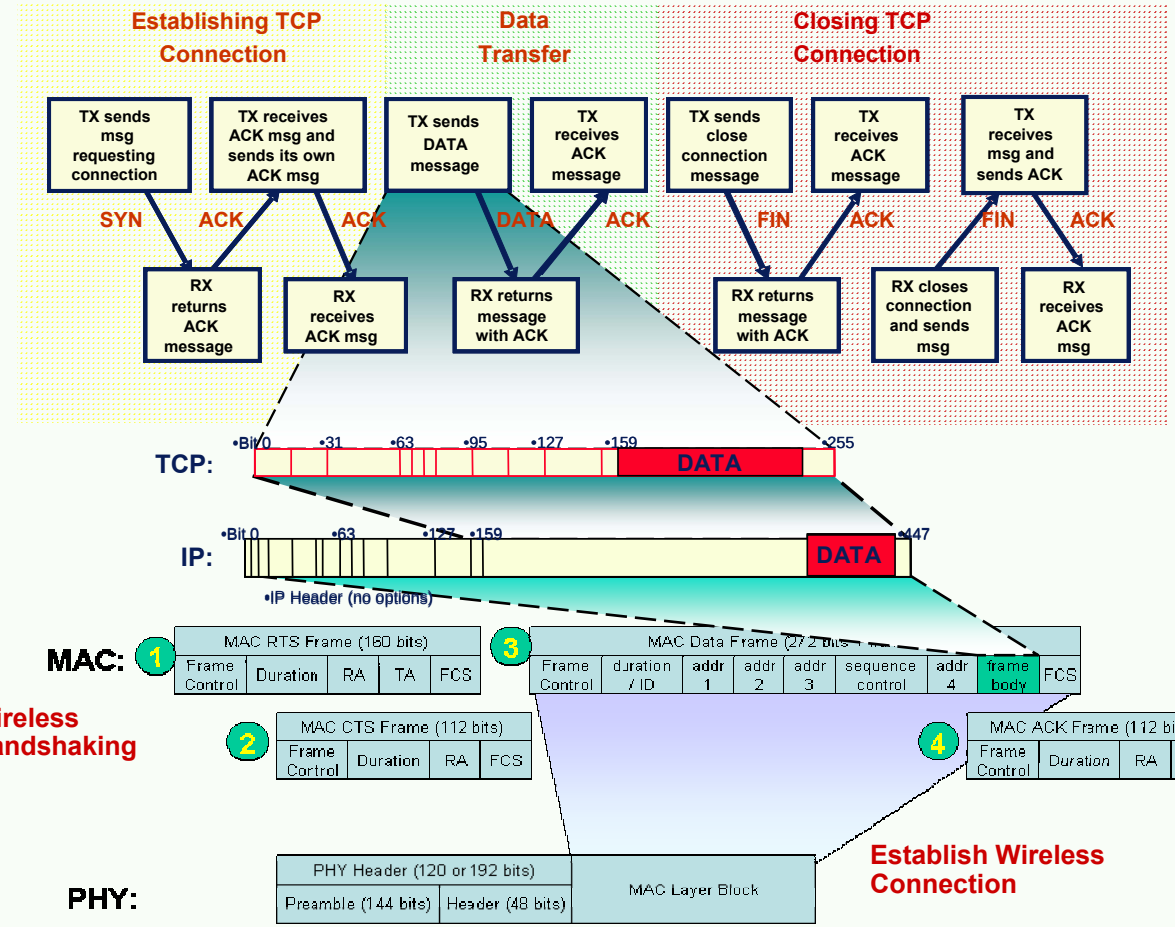
Packet Error Rate: 10%

% Effective: <11 %

It is possible that we need to completely rethink wireless network protocols

Existing Network Protocols Are Not Always Efficient

EXAMPLE #1 (Cont'd): TCP/IP/RTS-CTS – Transfer Inefficiencies, Excessive Overhead, Single 80-bit Payload



TCP/IP Protocols:

Payload: 80 Bits
Total Sent: 2,000 Bits
Transmissions: 6*

% Effective: 4 %

*could be 7 if receiver is not ready to close the connection

Wireless Protocols:

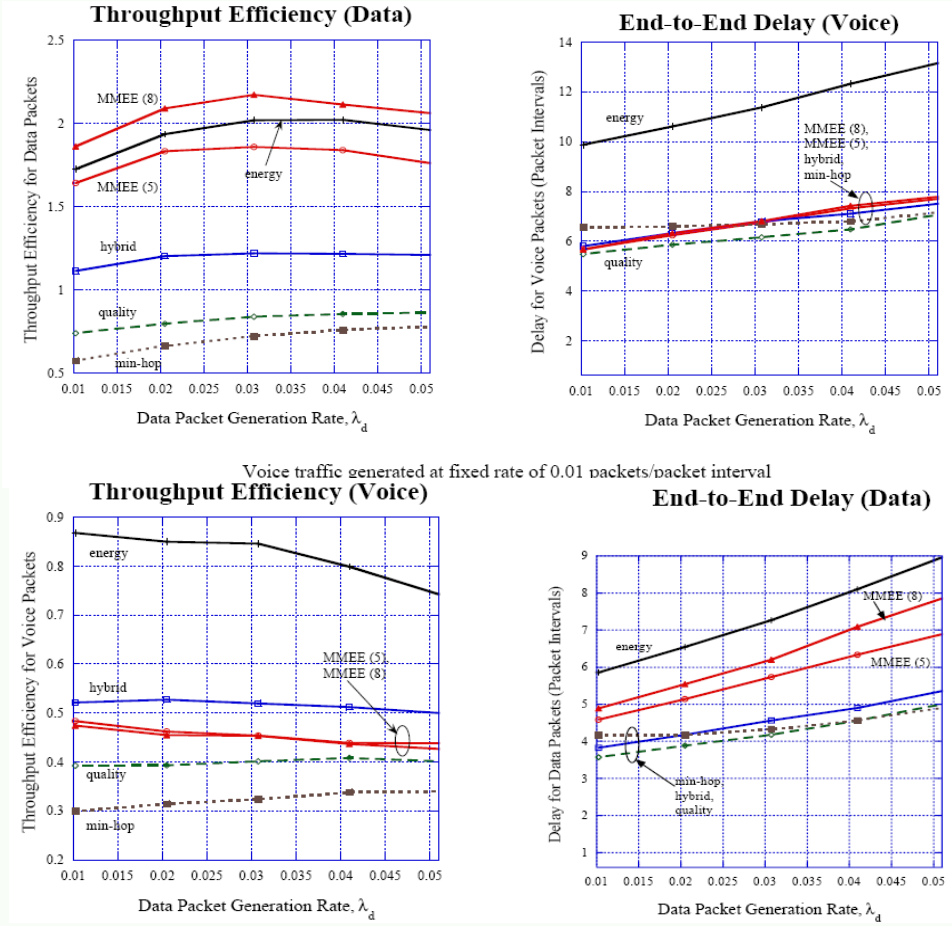
(802.11b)
Wireless Sent: 10,554 Bits
Transmissions 24

BW Efficiency: 0.75 %

It is possible that we need to completely rethink wireless network protocols

Existing Network Protocols Are Purpose-Built

EXAMPLE #2: Existing Protocols – One-Size-Does-Not-Fit-All



Existing Network Protocols:

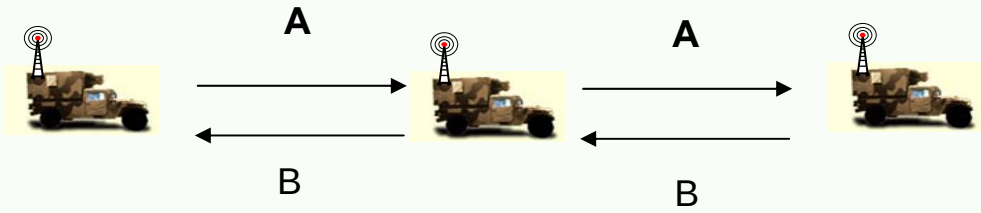
Wireless networks can trade throughput vs. latency (delay) vs. power. Protocols are often hard-wired to favor one choice (this example concerns routing protocols)

Source: Pursley '02

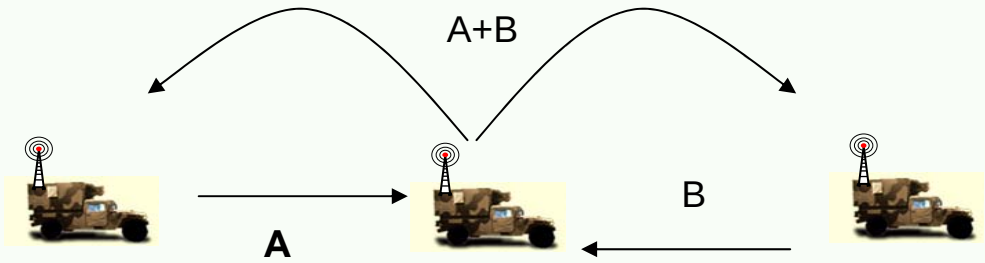
It is possible that we ought to completely rethink wireless protocols

Wireless Network Protocols Offer Unique Opportunities and Drawbacks

EXAMPLE #3: Network Coding and Multicast



TODAY: Four transmissions needed to exchange packets via relay



TOMORROW: 3 transmissions needed to exchange packets?

Network Coding and Multicast:

Tactical networks rely heavily on multicast!

It is possible that we can get a lot out of completely rethinking wireless protocols

Wireless Network Protocols Offer Unique Opportunities and Drawbacks

EXAMPLE #4: Multiuser diversity could be exploited

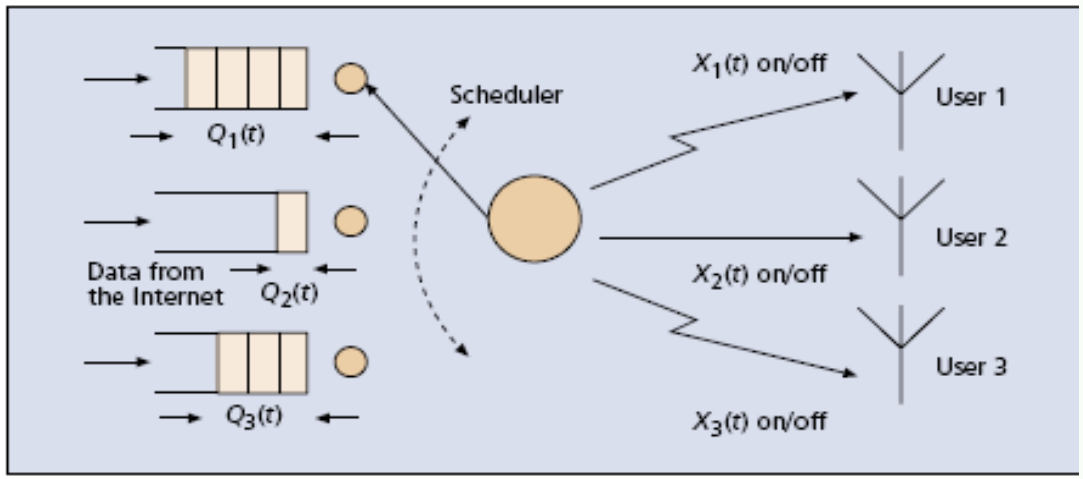


Figure 1. *Packet data flows arrive from the Internet to the base station. The data is destined to mobile users and are temporarily buffered at the base station. At each time* t, *the scheduler transmits to one of the mobile users based on the channel state* $(X_1(t)X_2(t)X_3(t))$, *with each component taking one of two values: ON or OFF.*

Packet Scheduling:

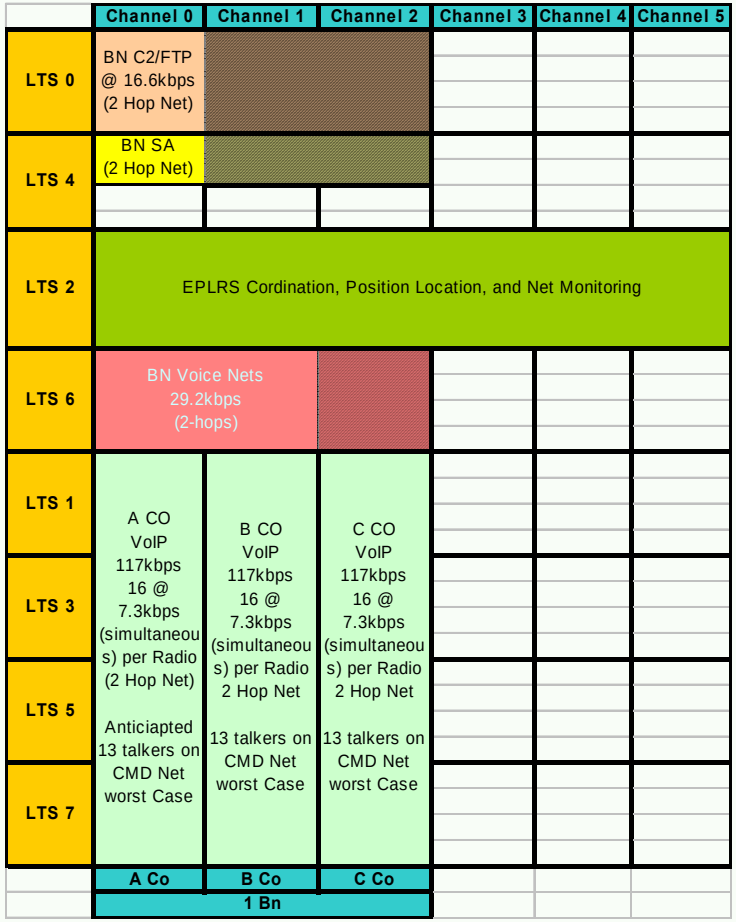
Round-robin wastes capacity if links are unavailable, as they often are in wireless

Source: Shakkottai '03

It is possible that we can get a lot out of completely rethinking wireless protocols

Manual Configuration Restricts Flexibility

EXAMPLE #5: Military Manual Network Planning



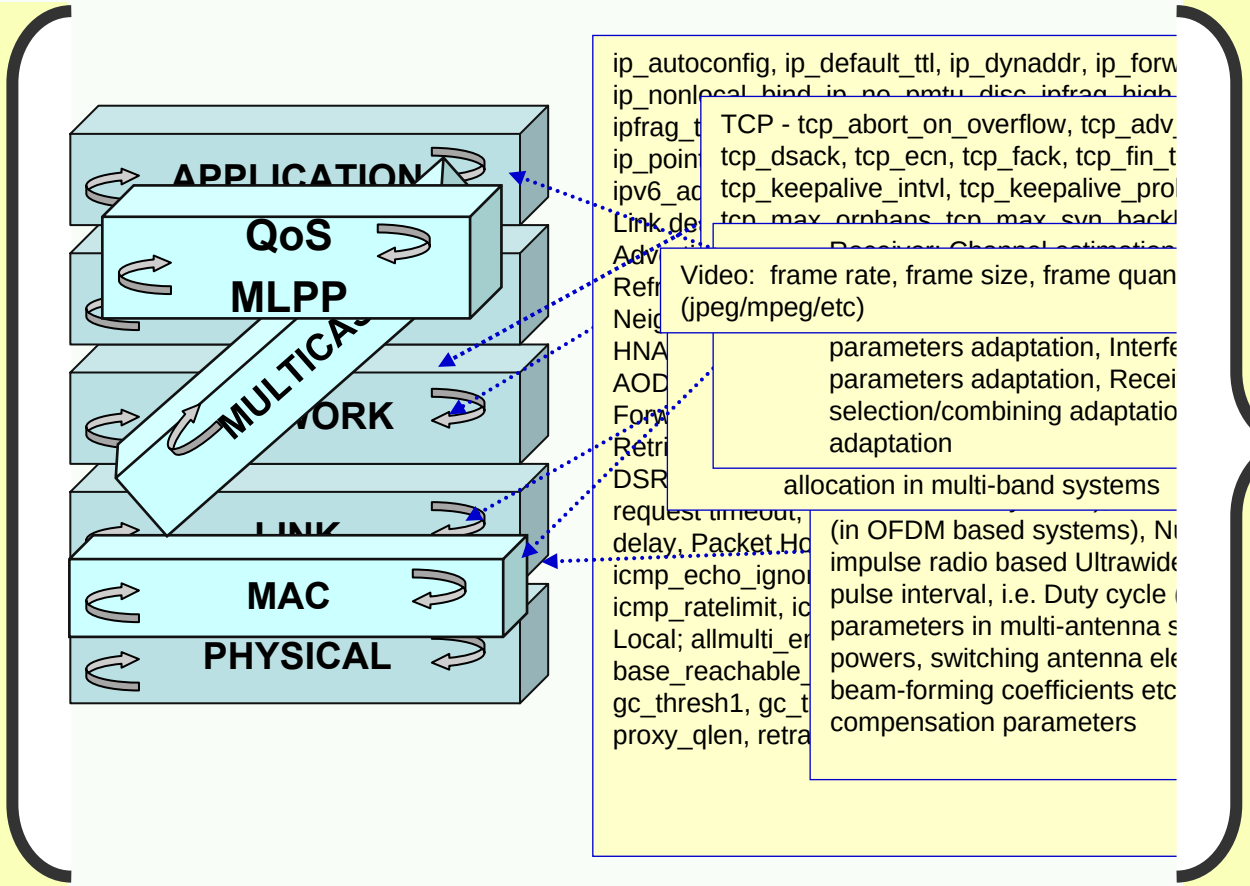
EPLRS System:

Manual methods of resource allocation are "reliable" (predictable) yet inflexible and can lead to underutilized resources

MANET resource allocation should reliable *and* flexible

Configuration Complexity Is Hard to Overcome

EXAMPLE #6: Knob and Dial Tuning



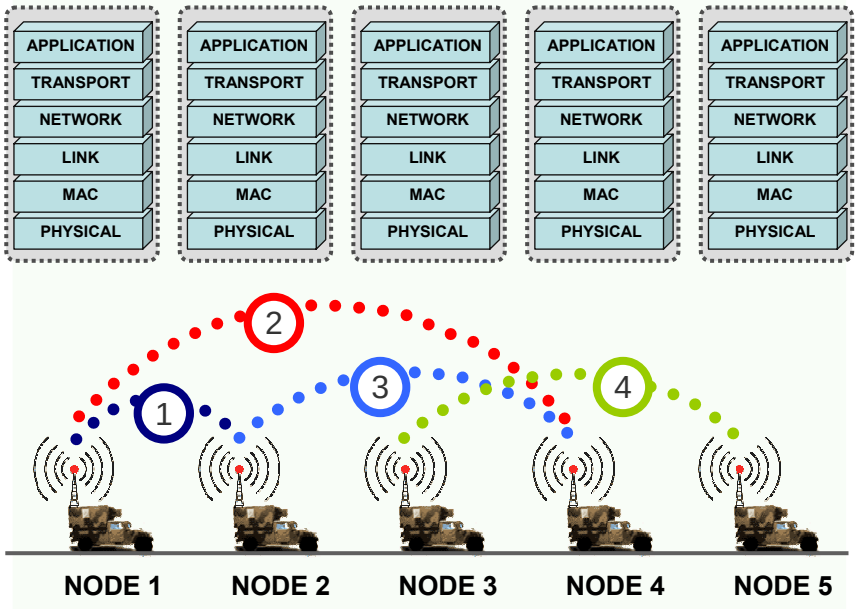
Manual, static methods of configuration often lead to suboptimal capacity or latency

The sheer number and complexity of network "knobs and dials" are overwhelming for human network managers. Poor configurations underperform.

Layers Act Independently, Without Coordination

Example #7: Uncoordinated Layering

*A wireless multi-hop network with **FIVE nodes** and **FOUR competing transport sessions.** Suppose that **SESSION 2** is experiencing congestion: Each Network layer recognizes situation and offers focus solution for their part. Who decides which one(s) to implement as best?*



Layer/ Mechanism	Contention Mechanism	Potential Downside
Application	**Increase compression?**	**Processor Cycles**
QoS	**Eject a lower-priority session?**	**Other users affected**
Transport	**Reduce TCP Window Size?**	**Download takes longer**
Network/Routing	**Find an alternative route?**	**Other routes may be even worse**
MAC	**Allocate extra time slots; change channels?**	**Other users affected**
Physical	**Modify waveform parameters to increase capacity?**	**Interference with other users; LPD**

Why Resource Management?

In today's layered, unmanaged wireless networks, there is no basis for deciding which layer should take action to eliminate cited congestion. Chaos and inefficiency result.

We need to develop a resource management capability for DoD MANETs

Resource Allocation Usually Requires Trades

MISSION TRADEOFFS

Individual vs Mission:
Individuals look for high QoS, but LPI/LPD requirements may require minimal RF footprint

TECHNICAL TRADEOFFS

Layer 2 vs Layer 3:
Slot assignment at layer 2 should be coordinated with DIFFSERV allocations at layer 3

Routing vs Error recovery
UAV relay placement competes with OSPF area redesign as a solution to minimizing inter-area traffic

Individual vs Individual:
Some nodes may choose to operate as relays on behalf of others with less battery life

Node vs Node:
Spectrum Management and Power Control can prevent denial of service from "friendly interference"

Application vs Physics:
High data rate applications must make tradeoffs for lower frequency RF propagation in Urban environments.

SOCIAL TRADEOFFS

Individual vs Individual:
[General vs 1st LT and MLPP]
Seniority and the need for time-critical information, dictate network resource allocation

Military networks must manage trade-offs in a self-organizing and adaptive fashion

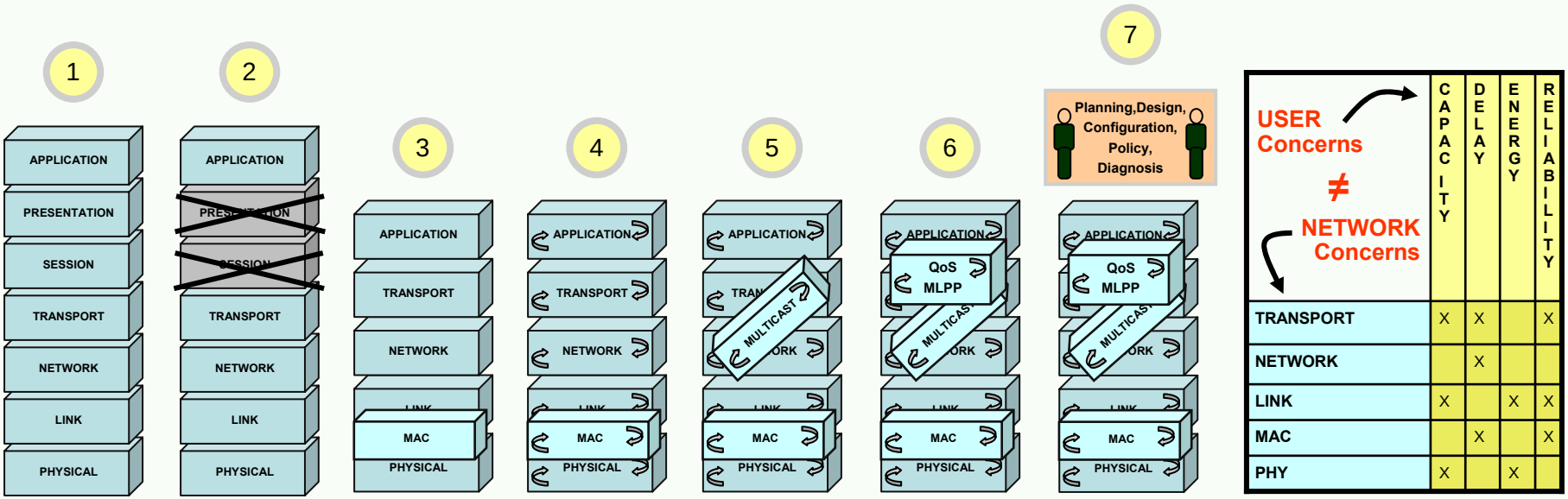
PHYSICAL TRADEOFFS

Environment vs Physics:
Terrain, weather, and environment limit allowable frequency bands due to terrain limitations, LOS, weather

We need to develop adaptive management technology that supports relevant DoD trades, or resources will be misallocated and user needs will not be met

OSI Model Did Not Anticipate DoD MANETs

How did we get into this situation – and what do we need to do:



Abstract OSI network protocol model	**As used in practice**	**As used in wireless networks**	**Tactical mobility requires adaptation at all layers**	**In contrast to Internet, multicast is the rule, not the exception**	**Scarce spectrum and military emphasis on reliability force MLPP, QoS**	**Putting it all together requires lots of manual labor**

USER Concerns ≠ NETWORK Concerns	CAPACITY	DELAY	ENERGY	RELIABILITY
TRANSPORT	X	X		X
NETWORK		X		
LINK	X		X	X
MAC		X		X
PHY	X		X	

BOTTOM LINE:
It isn't clear why we went down this path in the first place, because the OSI layering doesn't modularize what the user cares about

We need a tabula-rasa rethinking of the network stack for DoD MANETs from the management and user perspectives

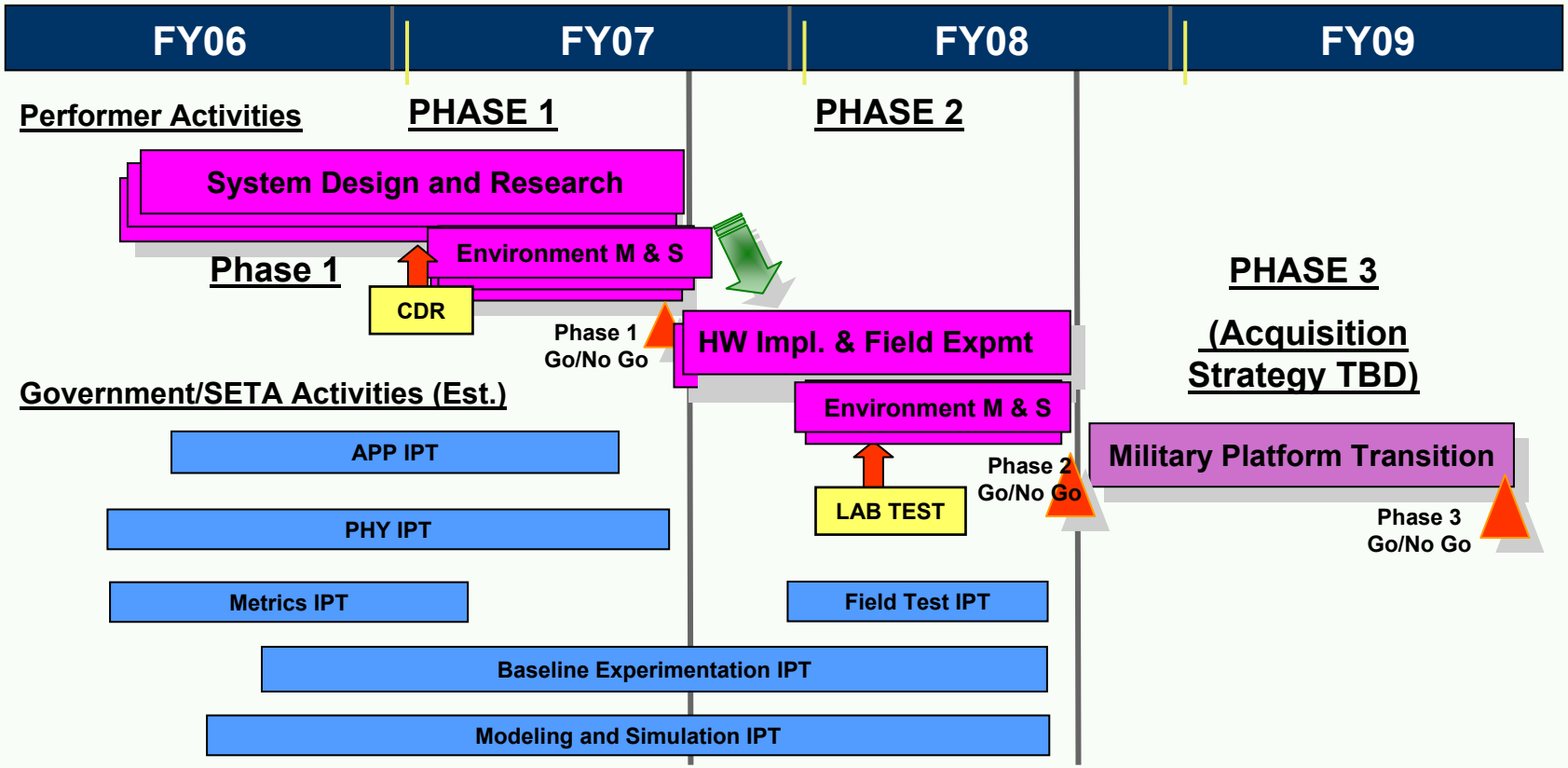
Therefore: Control Based Tactical Networking

- **Why?**
  - Spectrum is a scarce resource
  - Viability of historical & TCP/IP based approaches to tactical MANETworking are increasingly questioned
- **What & How?**
  - Radical rethinking of the network stack based on { INSERT YOUR IDEA HERE }
- **Why now?**
  - Cross-layer design, distributed resource allocation, information theoretic breakthroughs, etc are emerging hot topics with powerful but scattered results, but nobody has ever put all the pieces together to see if they really work
- **Why DARPA?**
  - DARPA is interested in seeing if these high-risk/high-payoff ideas can be coherently assembled into a ***working system***

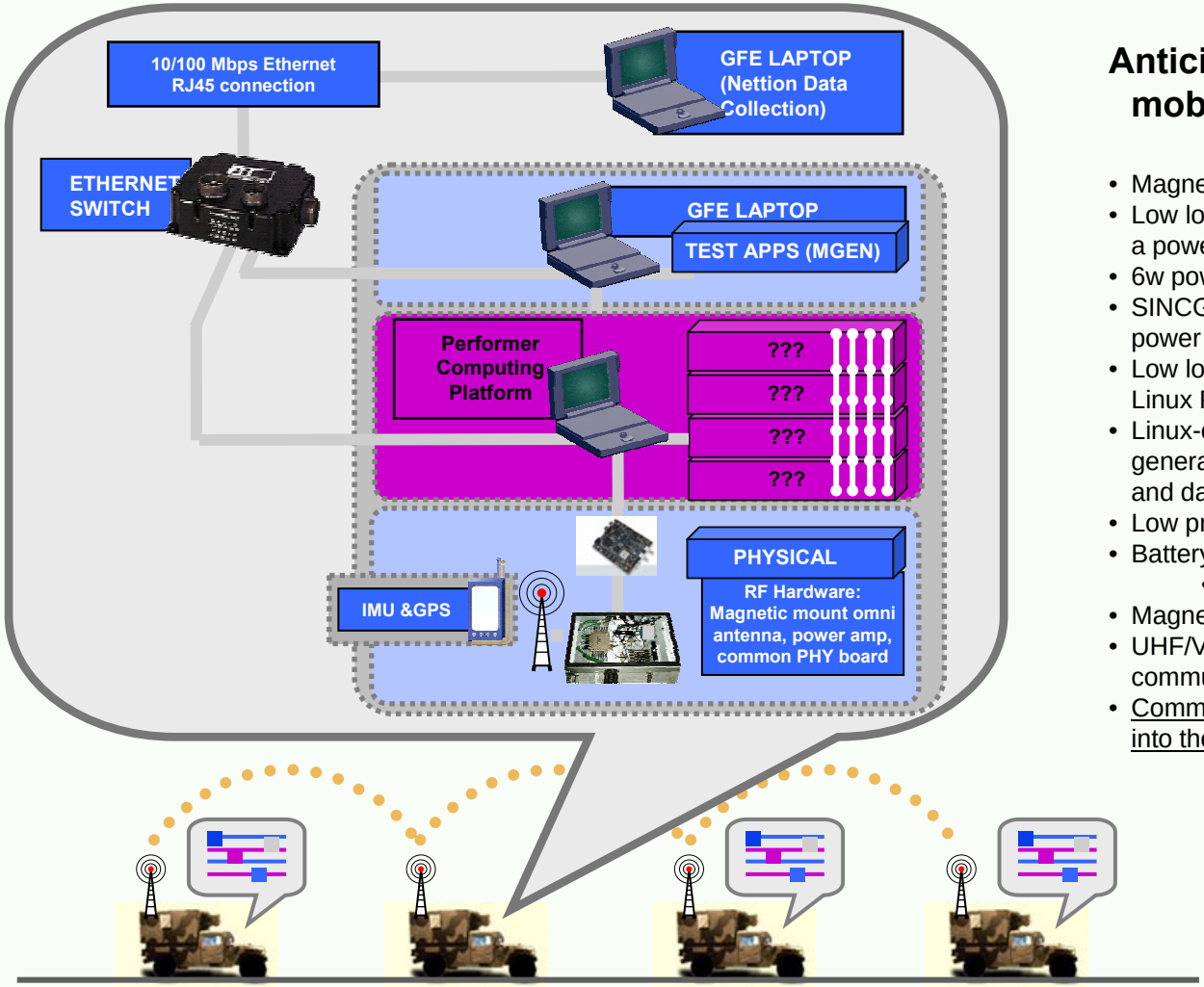
Programmatics

Acquisition Strategy

- 18 Month Phase 1 (Base)
- 12 Month Phase 2 (Option)
- Release BAA Aug 30
- Proposals Due Nov 2
- Anticipate March start



Candidate Field Test Node Configuration



Government to provide mobile node platform (SUV) with power, weather protection, etc.

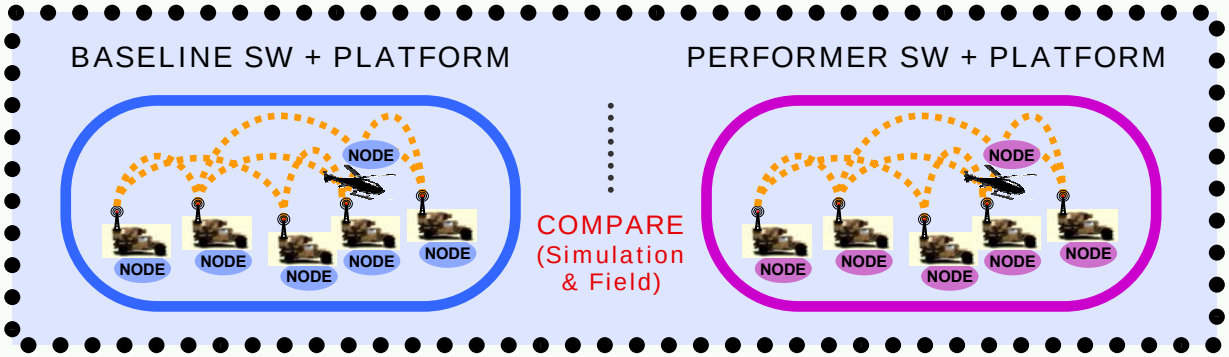
Anticipated configuration of GFE mobile platform

- Magnetic mount with a 9dBi omni antenna
- Low loss RF cable to connect the 9dB antenna to a power amp
- 6w power amp located inside the POV
- SINCGARS (or equivalent) battery to power the power amp
- Low loss cable connecting the power amp to a Linux PC
- Linux-equipped PC containing software for generating application traffic (e.g. RAPR, MGEN) and data collection (e.g. Nettion)
- Low profile magnetic mount GPS antenna
- Battery powered GPS unit inside the vehicle
  - With RS-232 connection into Linux PC
- Magnetic mount UHF/VHF voice antenna
- UHF/VHF voice transceiver for orderwire communications
- Common PHY board that performer will integrate into the Performer Computing Platform

Performer-provided solution
GFE
Ethernet or Low Loss RF cable

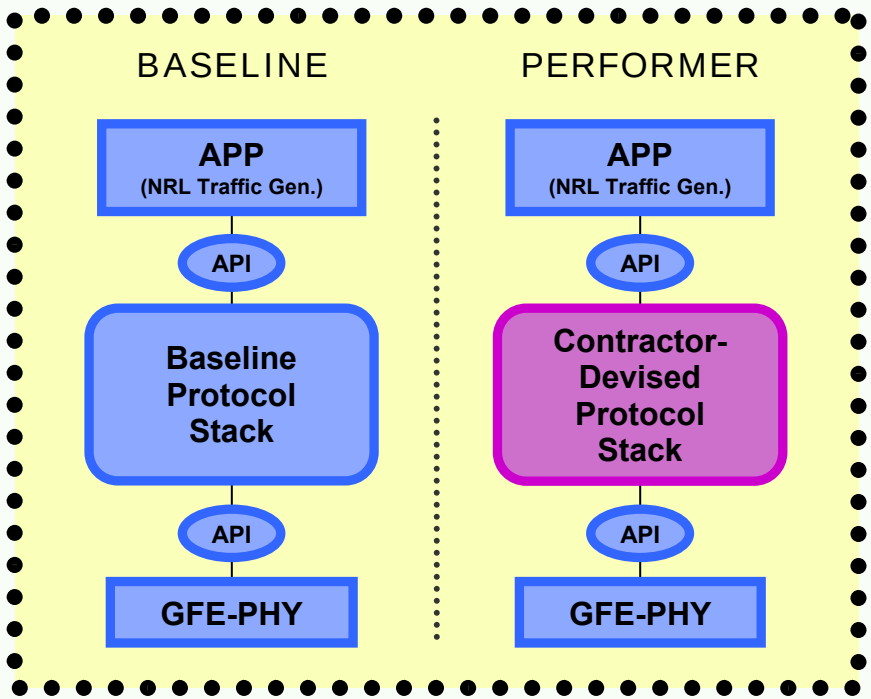
Performers are ultimately responsible for system integration BUT we will do everything we can to make it easy

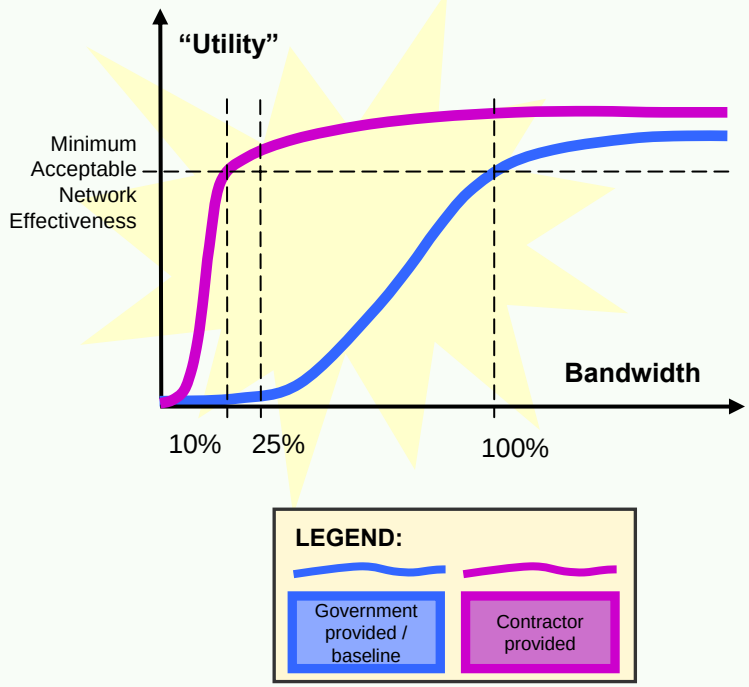
Independent Test & Evaluation Strategy



Test & Evaluation Strategy Overview:

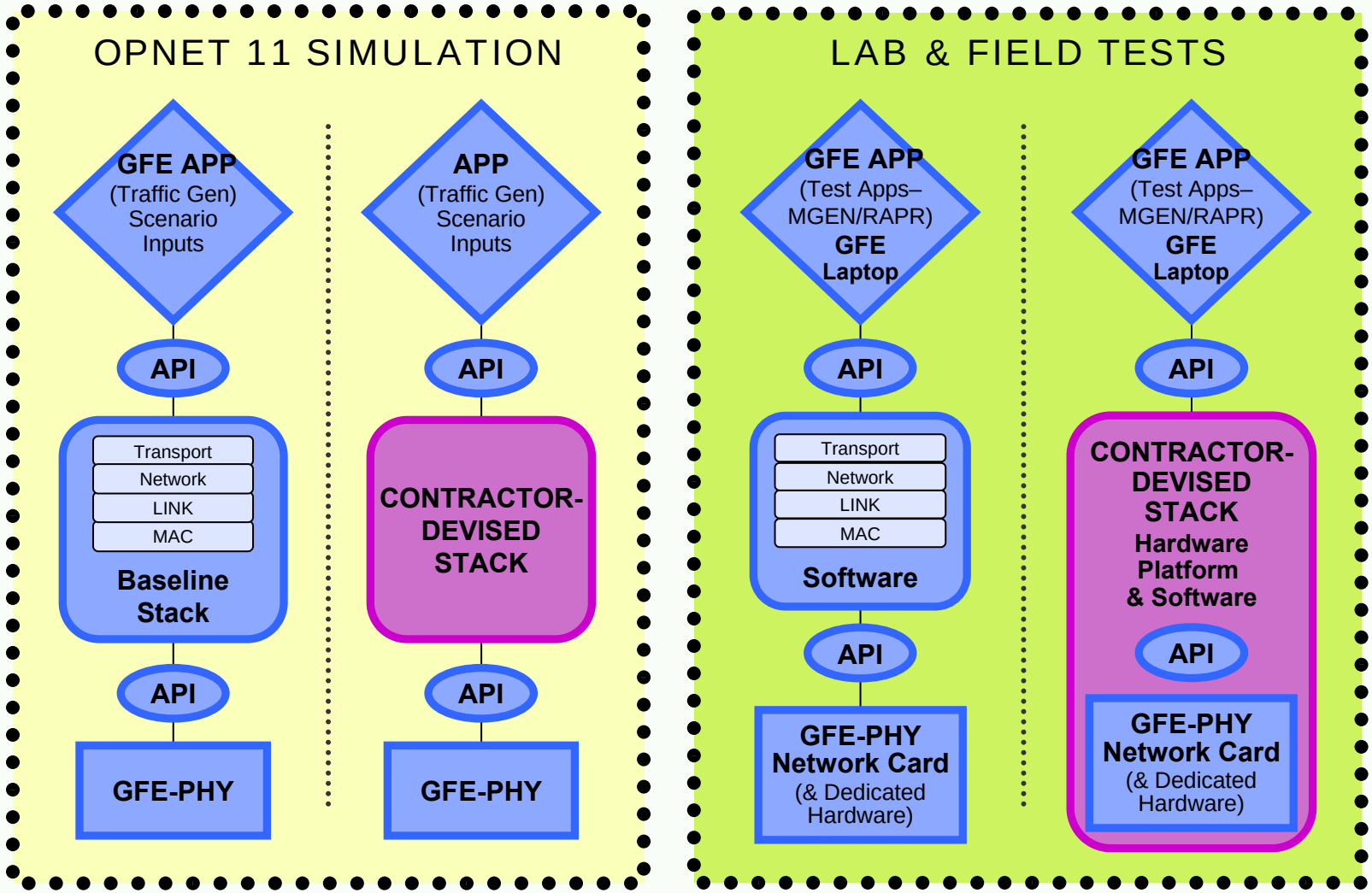
Contractor stack is expected to be as effective as the baseline even though it only uses a fraction of the bandwidth





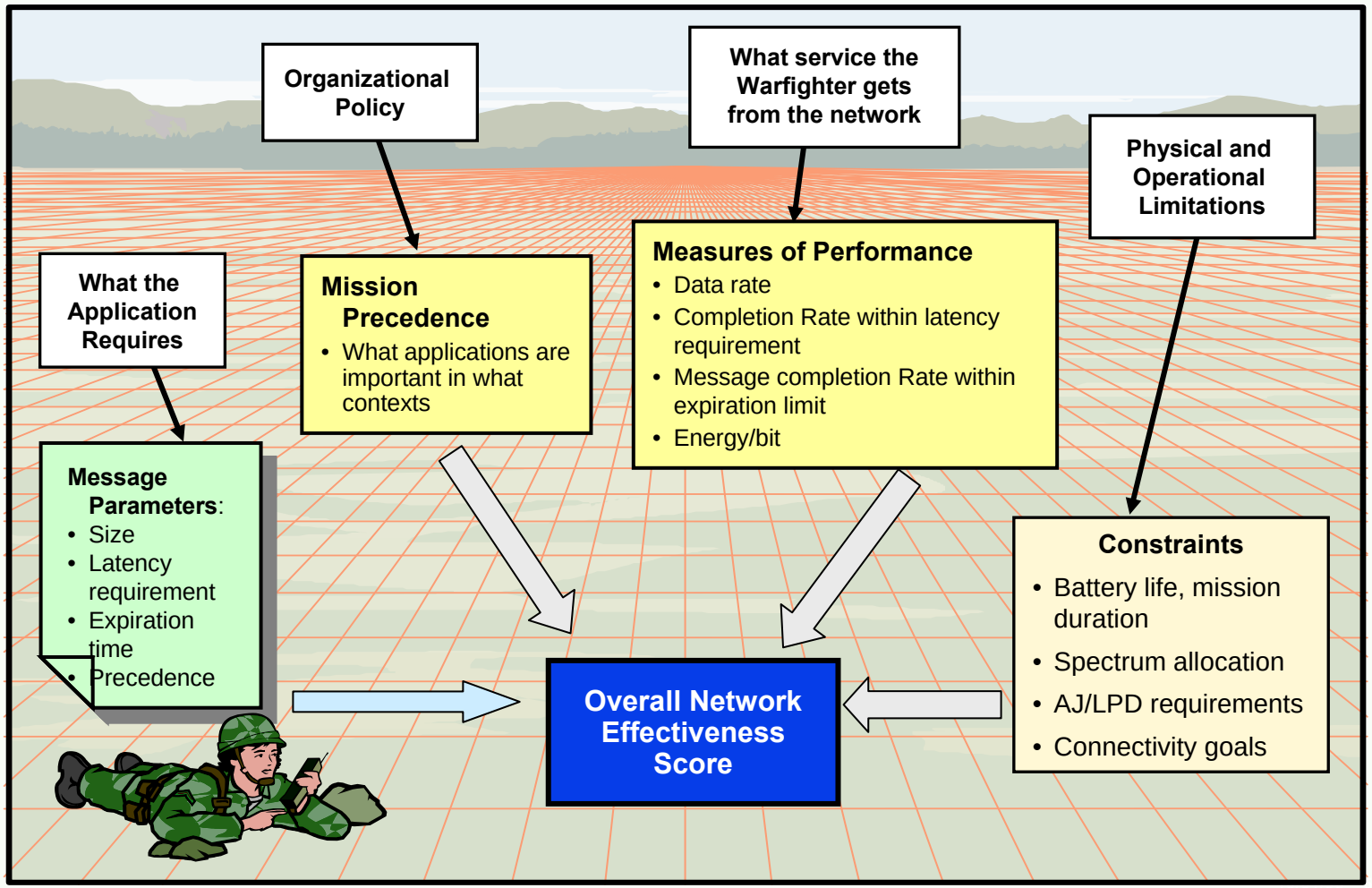
Goal: equivalent network effectiveness using a fraction of the bandwidth (holding PHY, APP, and scenarios constant)

Phase 1 vs. Phase 2 Deliverable Solution



Performers must have breakthrough ideas AND implement them in a working hardware-based system by the end of Phase 2

Elements of a Network Effectiveness Metric



CBMANET will attempt to discover a measure of network effectiveness, rather than rely on mere measures of performance

Notional Traffic Load / Mixture / End-to-End Characteristics Table

unicast

multicast

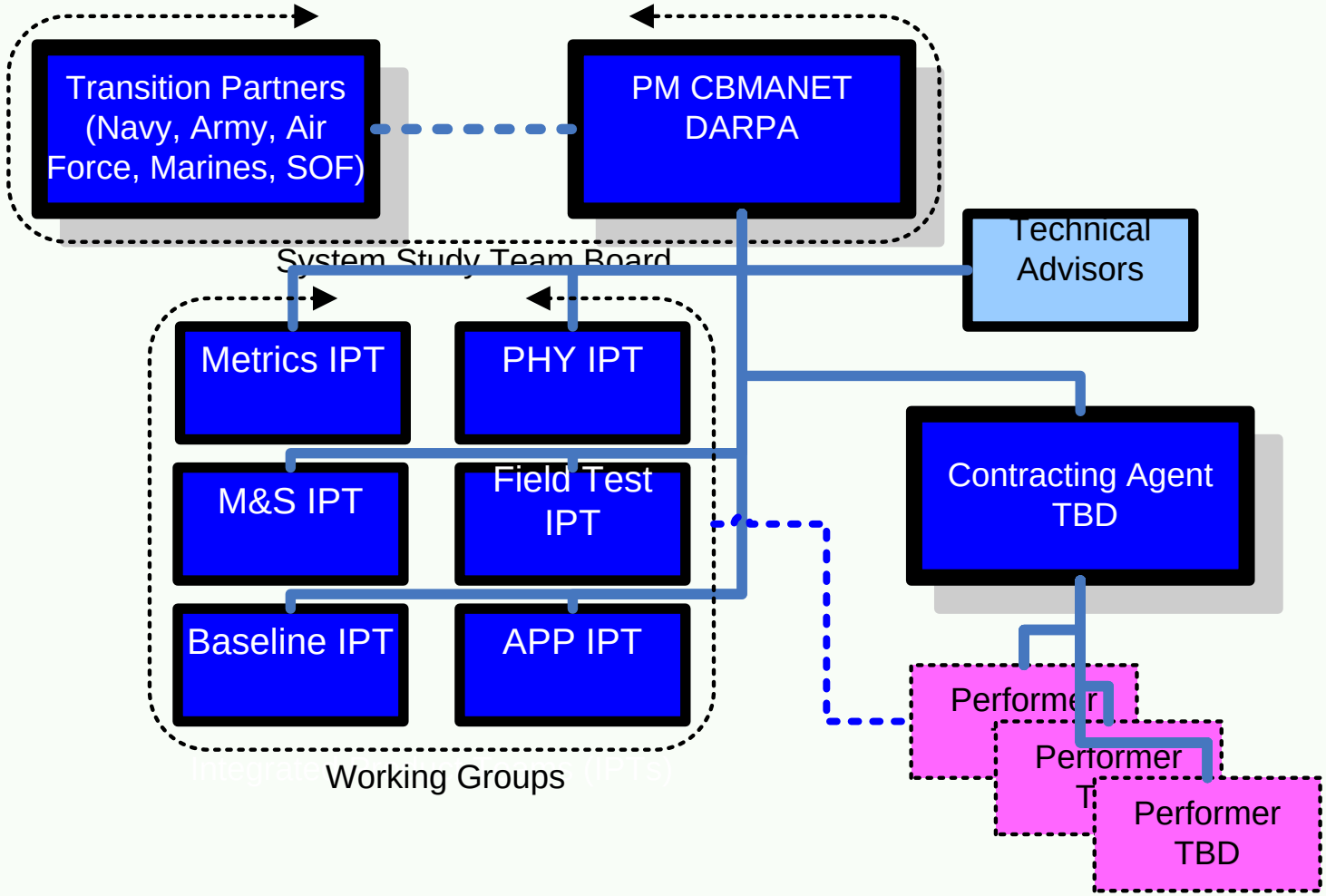
IER Type	Current or Expected Capacity	Latency Sensitivity	Jitter Sensitivity	Lost Data Sensitivity	Message Completion	Start Test (Staging)	Mid Test (Shaping)	End of Test (Engagement)
C2 High Priority (Fire, Medic)	29.2 kbps (14.6 if 2 hops)	High	Low/Medium	Medium	< 0.5 sec	52036 msgs (10.84 msg/sec)	49293 msgs (10.27 msg/sec)	43833 msgs (9.13 msgs/sec)
Unicast C2 Routine	29.2 kbps (14.6 @ 2 hops)	Low/Medium	Low/Medium	Medium	< 1 sec			
Voice	7.3kbps	High	High	Medium	<0.5 sec			
SA	7.3 kbps	Low/Medium	Low	Medium	<12 sec			
Video Feed	8 kbps 32 kbps	High	High	Medium/High	< 1 sec	2.667 msg/sec, 8 kbps	2.52 msg/sec, 8kbps	1.3 msg/sec
File Transfer	7.3kbps	Medium	Low	Medium	N/A			
Live Imagery*	128 kbps	High	High	Medium	< 12sec (map)	10.8 msg/min, 128 kbps	9.5 msg/min, 128 kbps	9.075 msg/min
C2 High Priority (Fire, Medic)	29.2 kbps (14.6 if 2 hops)	High	Low/Medium	Medium	< 0.5 sec	301106msgs (62.73 msg/sec)	289364 msgs (60.28 msg/sec)	272896 msgs (56.85/sec)
C2 Routine Priority	29.2 kbps (14.6 if 2 hops)	Low/Medium	Low/Medium	Medium	< 1 sec			
Multicast Voice	7.3 kbps	High	High	Medium	<0.5 sec			
Multicast SA	7.3 kbps	Low/Medium	Low	Medium	<12 sec			
Video	8 kbps	High	High	Medium/High	< 1 sec	12791 msgs 2.66msg/sec	10377 msgs 2.16 msg/sec	5675 msgs 1.18 msg/sec
Live Imagery*	128 kbps	Medium	Low	Medium	< 12 sec (map)	4061msgs 50.7msg/min	3170 msgs, 39.63msg/min	3156 msgs, 39.45 msg/min

CBMANET Program Metrics

Program Metrics	Baseline	Phase 1 (Month 18) Go / No-Go Criteria (Threshold)	Phase 2 (Month 30) Go / No-Go Criteria (Threshold)
Principal Metric: Minimum bandwidth required by the CBMANET as a percentage of what was required by the baseline network.	100%	40% (Simulation Threshold) + analysis showing how any unfulfilled Phase 2 performance improvements are expected to be achieved	10% (Simulation and Field Test)
Conditioned on: Comparable network effectiveness	Network meets requirements of the offered load and/or the network supports the network load as effectively as the baseline using a comparative utility-based methodology		
Number of network nodes	30	30 (Simulation)	30 (Hardware) 30/50/130 (Simulation)
Interoperability with legacy networks demonstrated	Yes	No	Yes
Network is robust to the addition of a new application	Yes	Yes	Yes
Network initialization time	<6 min.	<6 min.	<3 min.
Node entry time	<30 sec.	<30 sec.	<15 sec.
Detect node exit time	<10 sec.	<10 sec.	<10 sec.

Results that exceed the program metrics are highly desirable. Other criteria are also important; these metrics merely bound the problem.

Program Team Structure

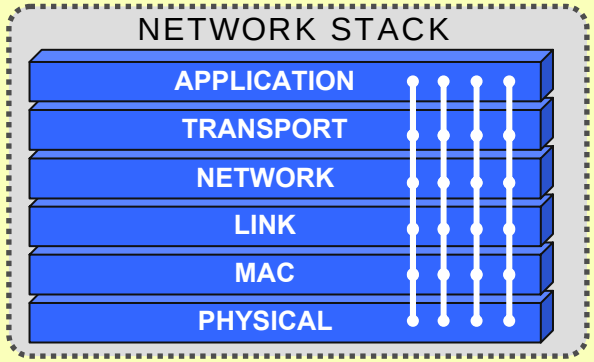


Government responsibilities will be executed by IPTs reporting to PM CBMANET

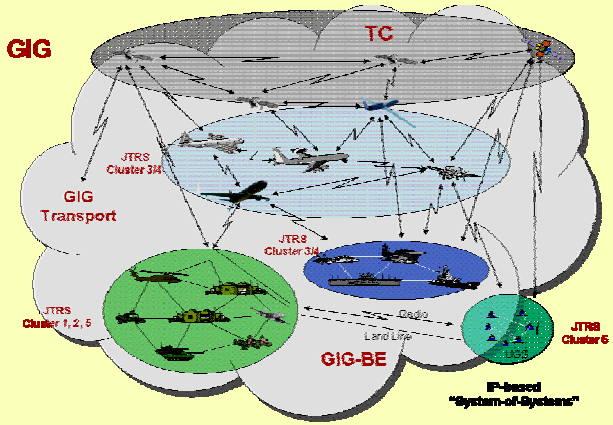
Some Big-Picture CBMANET Research Issues

$$\begin{aligned} \text{maximize} \quad & \sum_{i} U_i(x_i, P_{c,i}) + \sum_{j} V_j(w_j) \\ \text{subject to} \quad & \mathbf{Rx} \preceq \mathbf{c}(\mathbf{w}, \mathbf{P}_c), \\ & \mathbf{x} \in \mathcal{C}_1(\mathbf{P}_c) \bigcap \mathcal{C}_2(\mathbf{F}), \\ & \mathbf{R} \in \mathcal{R}, \quad \mathbf{F} \in \mathcal{F}, \quad \mathbf{w} \in \mathcal{W}. \end{aligned}$$

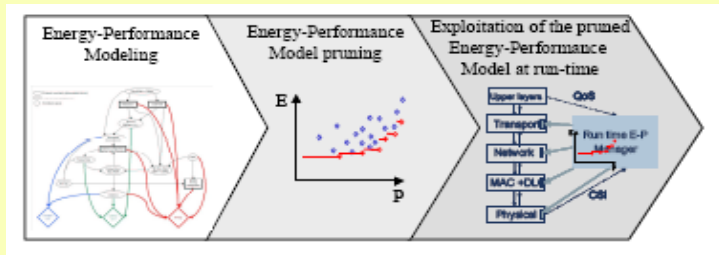
1 **What is the proper metric/objective function for a general-purpose network?**



2 **What is the right layering? Can cross-layer optimizations be generalized without destroying the benefits of a layered architecture?**



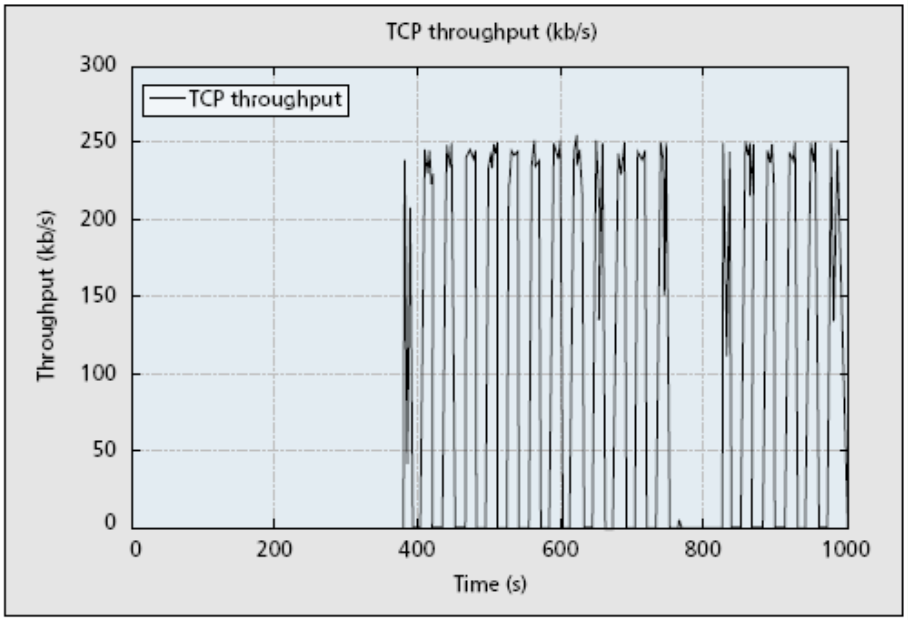
3 **Are cross-layer approaches only good for optimizing "stovepipe" networks – or can they support general-purpose networks with widely varied applications?**



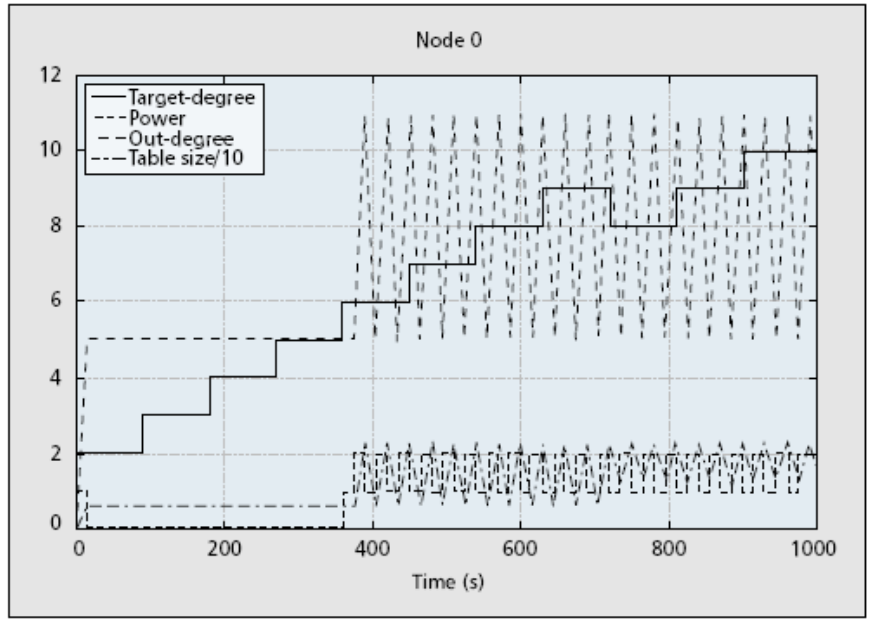
4 **Can that objective function and network be tuned by a designer *at runtime* to effect trades in e.g. energy, capacity, delay? How much overhead exist and do the algorithms scale?**

CBMANET Will Develop a Network "Designed for Manageability"

Risk illustrations



TCP Throughput in the presence of an unfortunate routing adaptation



Control parameter fluctuations at node 0

Source: A CAUTIONARY PERSPECTIVE ON CROSS-LAYER DESIGN
Kawadia & Kumar IEEE Wireless Communications, Feb 2005

There are many traps and pitfalls

Proposal Technical Evaluation Criteria

#1: Innovative Technical Approach

#2: System Architecture

#3: Security and Survivability

#4: Management Approach and Past Experience

#5: Potential Contribution and Relevance to the DARPA Mission

#6: Cost Realism

For the purpose of award under this BAA, the technical evaluation criteria are more important than cost

Questions?

- Contribute questions on 3x5 cards
- Q&A panel after lunch
- Additional questions to BAA05-42@darpa.mil
- Please check the CBMANET website for answers and updates (updated periodically)

http://www.darpa.mil/ato/solicit/CBMANET/index.htm