Future Internet Resilience

Summary of Networking Research at The University of Kansas ITTC

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ITTC Networking Research

Major Themes

- Major related research themes
  - future Internet architecture and infrastructure
  - resilient and survivable networks
  - information assurance and security
  - disruptive and novel communication paradigms

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ITTC Networking Research
Collaborators and Funding

- Collaborators
  - regional: K-State, UMKC, UNL, …
  - national: Rutgers, Penn State, CMU, ORNL, …
  - international: U. Lancaster UK, ETH Zürich, TU-Munich, …
- Funding
  - NSF FIND, GENI, …
  - DoD DARPA, CTEIP, …
  - EU FP6 SAC, FP7 FIRE
  - Industry: Sprint, …

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Resilient Networks
Motivation

- Increasing reliance on network infrastructure

⇒ Increasingly severe consequences of disruption

⇒ Increasing attractiveness as target from bad guys

- Internet is *critical infrastructure*
  - interdependent with other CI, e.g. power grid

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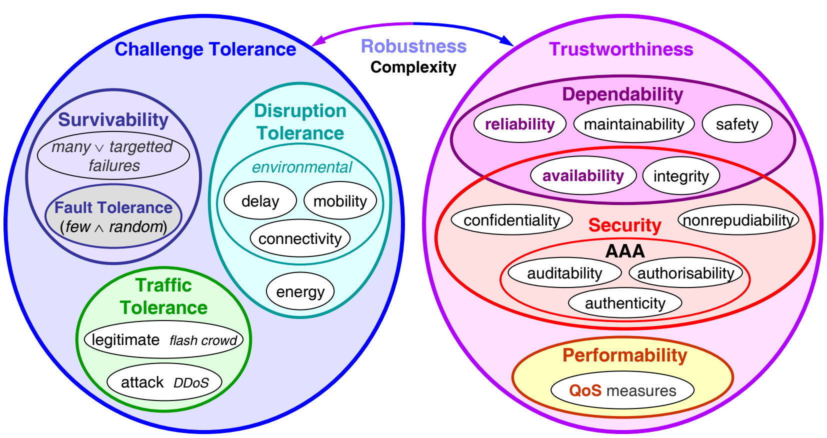
Resilient Networks
Resilience Definition

- Resilience
  - provide and maintain acceptable service
  - in the face of faults and challenges to normal operation
- Challenges
  - faults
  - unintentional misconfiguration or operational mistakes
  - large scale disasters (natural and human-made)
  - malicious attacks from intelligent adversaries
  - environmental challenges (wireless, mobility, delay)
  - unusual but legitimate traffic
  - service failure at a lower level

Resilience Scope
Relationship to Other Disciplines



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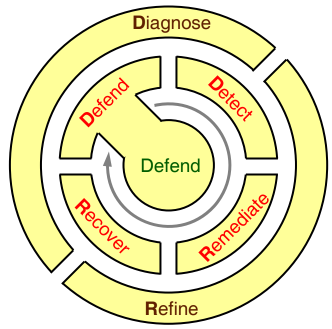
Resilience Architecture

ResiliNets Strategy: D^2R^2 + DR

- Real time control loop: D^2R^2
  - defend
    - passive
    - active
  - detect
  - remediate
  - recover
- Background loop: DR
  - diagnose
  - refine



[ComNet 2010]

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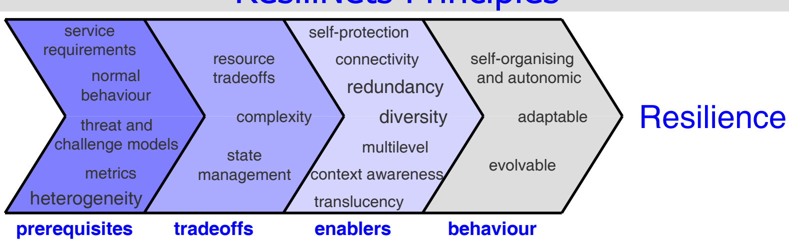
Resilience Architecture

ResiliNets Principles



- Prerequisites: to understand and define resilience
- Tradeoffs: recognise and organise complexity
- Enablers: architecture and mechanisms for resilience
- Behaviour: require significant complexity to operate

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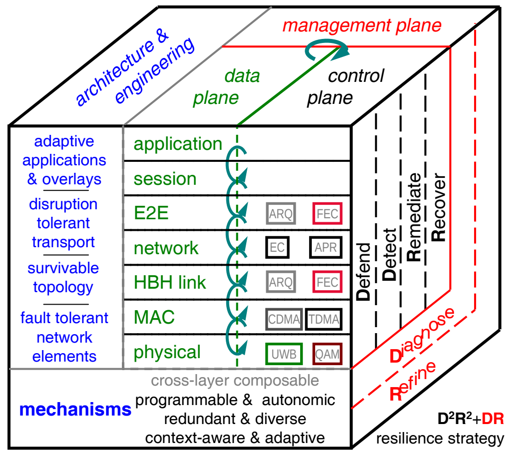
Resilience Architecture

Multilevel Resilience and Cross-Layering

- ResiliNets Cube
  - multilevel
    - protocol layers
    - planes
    - mechanisms
- D^2R^2+DR strategy
  - D^2R^2 control plane
  - DR mgt. plane
- Cross-layering
  - knobs and dials are metrics
  - $\mathbb{K},\mathbb{D} \subseteq \mathbb{N} \cup \mathbb{P}$



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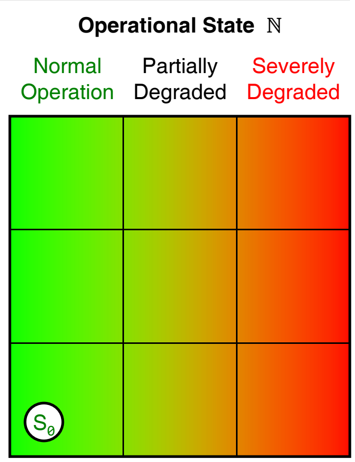
Resilience Quantification

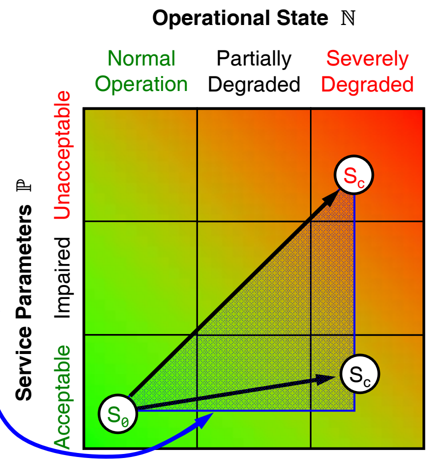
State Space: Operational Resilience

- Operational resilience
  - minimal degradation
  - in the face of challenges
- Resilience state
  - remains in normal operation



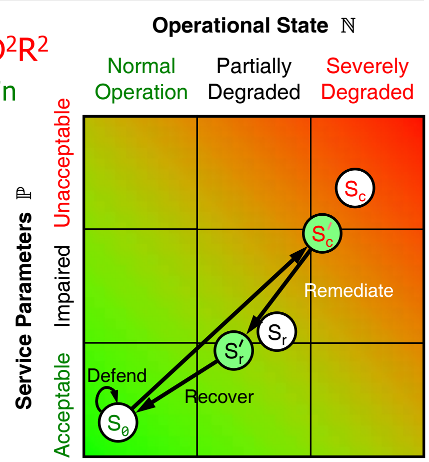
Resilience Quantification
State Space: Service Resilience

- Service resilience
  - acceptable service
  - given degraded operation
- Resilience state
  - remains in acceptable service
- Resilience
  - ℝ = area under trajectory
  - for particular scenario
  - resilience ℜ over all scenarios



Resilience Quantification
D^2R^2 + DR Relationship to State Space

- Real time control loop: D^2R^2
  - defend keeps toward origin
    - passive
    - active
  - detect when leaves
  - remediate pushes back
  - recover back to origin
- Background loop: DR
  - diagnose
  - refine tightens trajectory



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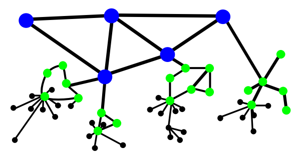
Resilience Evaluation
Topology Generation: KU-LoCGen



- Generation of realistic topologies
- Multilevel hierarchy
  - level 1: represents (tier 1) backbone
  - level 2: represents access networks around a backbone PoP
  - level 3: represents subscriber nodes
- Constrained generation
  - geographic node location (infrastructure or population)
  - constrained link location (based on exiting fiber runs)
  - constrained cost (fixed + variable cost)
  - graph-theoretic constraints for resilient diversity

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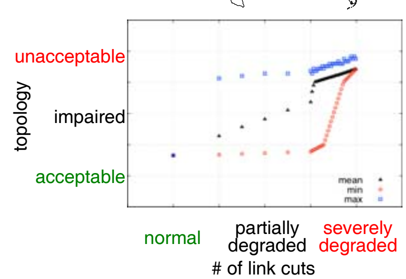
Resilience Evaluation
Evaluating Challenges in State Space

- Topology generation
  - use KU-LoCGen
- Challenge simulation
  - random failures
  - intelligent attacks
    - degree, betweeness, etc.
  - large scale disasters
    - hurricanes, blackouts
- Example
  - resilience of alternatives based on Sprint PoPs



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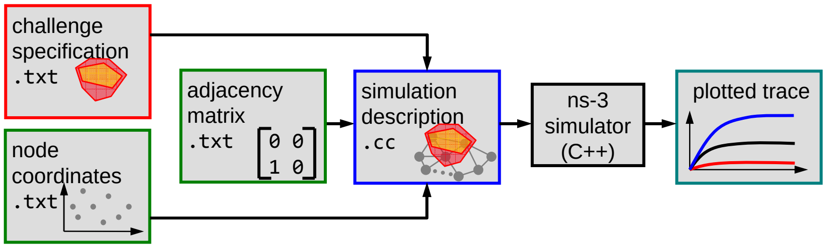
Resilience Evaluation

KU-CSM Challenge Simulation



- KU-CSM Challenge Simulation Module
  - challenge specification describes challenge scenario
  - network coordinates provide node geo-locations } KU-LoCGen
  - adjacency matrix specifies link connectivity } KU-LoCGen
  - input to conventional ns-3 simulation run
  - generates trace to plot results

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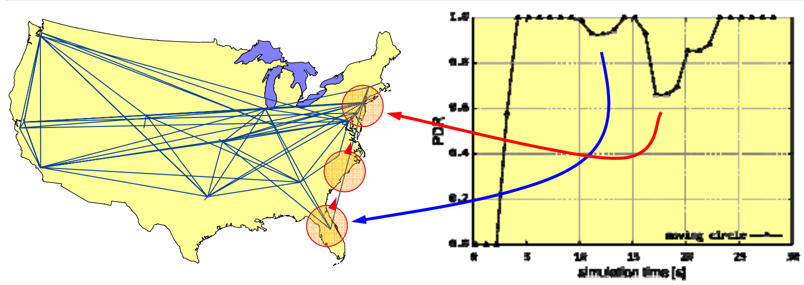
Resilience Evaluation

KU-CSM Challenge Simulation



- Example: evolving area-based challenge example
  - circle moving from Orlando to NY
- Performability analysis: packet delivery ratio
  - PDR varies with # links nodes down

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Enabling Future Internet Research
GpENI Overview

- Great Plains Environment for Network Innovation
  - part of NSF GENI program
  - affiliated with EU FP7 FIRE programme / ResumeNet project
- Programmable network infrastructure (L1–7)
  - Midwest US optical backbone
  - International testbed
- Conduct experiments in:
  - future Internet architectures
  - resilience and survivability
  - cross-evaluation with analytical- and simulation-based eval.

	GpENI Layer	Programmability
	experiment	Gush, Raven
7	application	PlanetLab
4	end-to-end	PlanetLab
3	router	Quagga, XORP, Click
	topology	VINI
2	VLAN	DCN
	lightpath	DCN
1	RF,photonics	site-specific

[TridentCom 2010]

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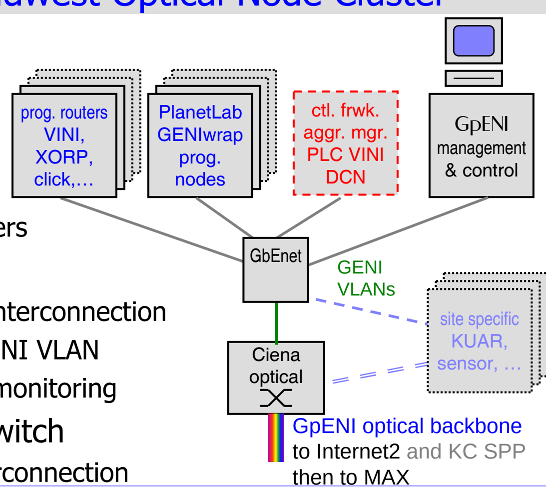
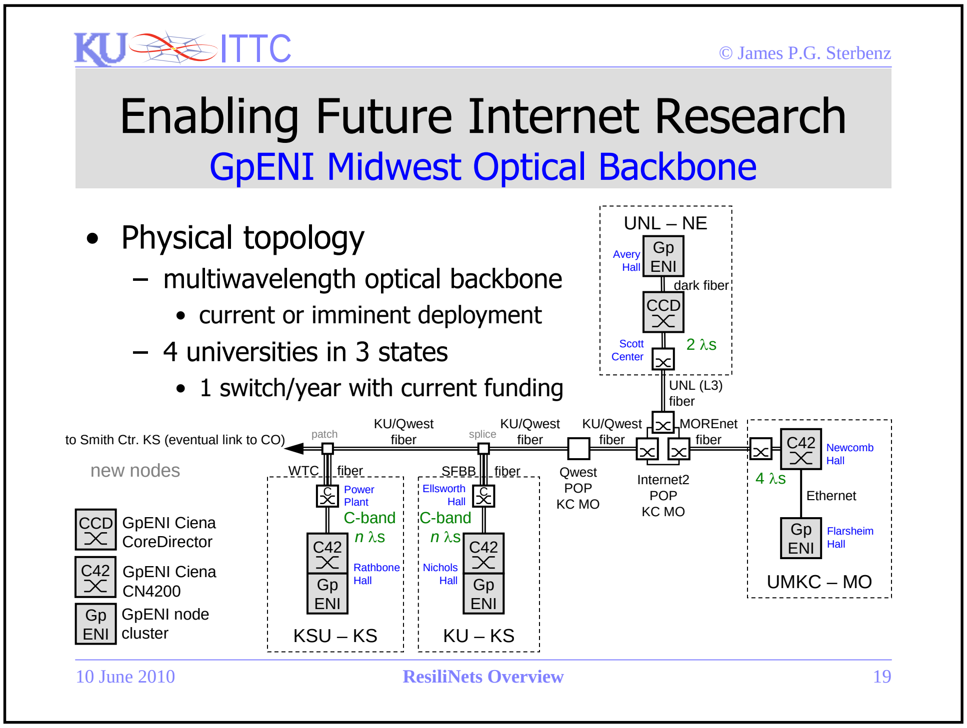
Enabling Future Internet Research
GpENI Midwest Optical Node Cluster

- GpENI cluster
- 5–10 PCs
  - GpENI mgt.
  - L4: PlanetLab
  - L3: prog. routers
- GbE switch
  - arbitrary site interconnection
  - L2: GpENI/GENI VLAN
  - SNMP cluster monitoring
- Ciena optical switch
  - L1 GpENI interconnection

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Enabling Future Internet Research
GpENI Midwest Optical Backbone
• Physical topology
– multiwavelength optical backbone
• current or imminent deployment
– 4 universities in 3 states
• 1 switch/year with current funding
UNL – NE
Avery Hall
Gp ENI
dark fiber
CCD
Scott Center
2 λs
UNL (L3) fiber
to Smith Ctr. KS (eventual link to CO)
patch
KU/Qwest fiber
splice
KU/Qwest fiber
KU/Qwest fiber
MOREnet fiber
Qwest POP KC MO
Internet2 POP KC MO
new nodes
WTC fiber
SFBB fiber
Power Plant
Ellsworth Hall
C-band
n λs
C42
Gp ENI
Rathbone Hall
Nichols Hall
KSU – KS
KU – KS
C42
Newcomb Hall
4 λs
Ethernet
Gp ENI
Flarsheim Hall
UMKC – MO
CCD GpENI Ciena CoreDirector
C42 GpENI Ciena CN4200
Gp ENI GpENI node cluster
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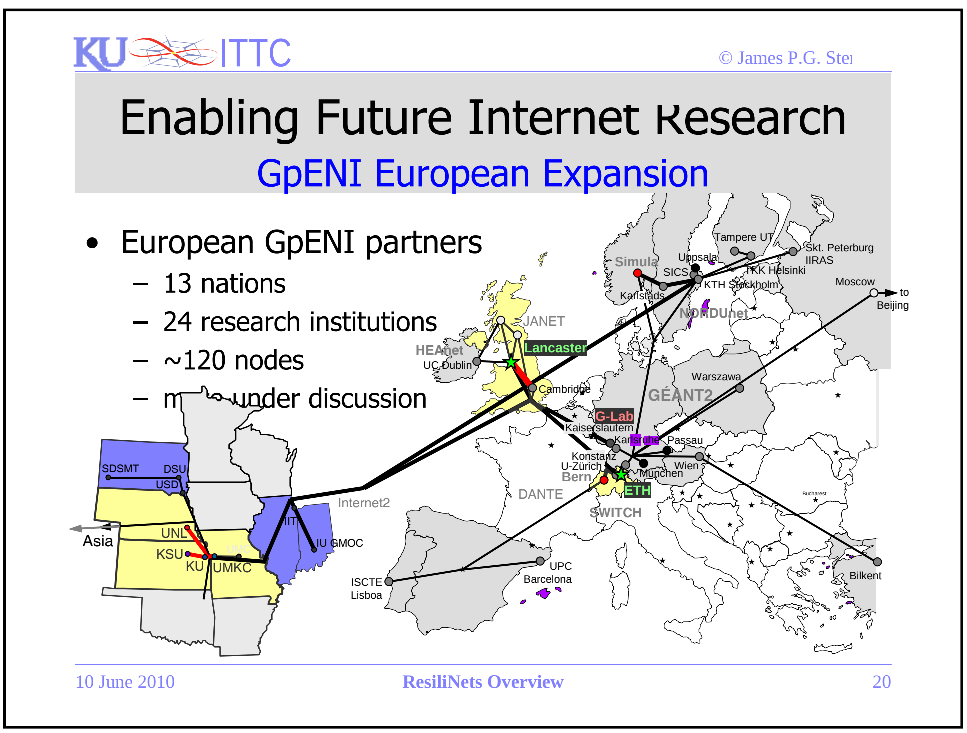
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Enabling Future Internet Research
GpENI European Expansion
• European GpENI partners
– 13 nations
– 24 research institutions
– ~120 nodes
– under discussion
Tampere UT
Skt. Peterburg IIRAS
Simula
Uppsala
SICS
TKK Helsinki
Karlstads
KTH Stockholm
Moscow
to Beijing
JANET
NORDUnet
HEAnet
Lancaster
UC Dublin
Cambridge
Warszawa
GÉANT2
G-Lab
Kaiserslautern
Karlsruhe
Passau
Konstanz
U-Zürich
Bern
München
Wien
ETH
DANTE
SWITCH
Internet2
SDSMT
DSU
USD
Asia
UNL
KSU
KU
UMKC
IIT
IU GMOC
ISCTE Lisboa
UPC Barcelona
Bilkent
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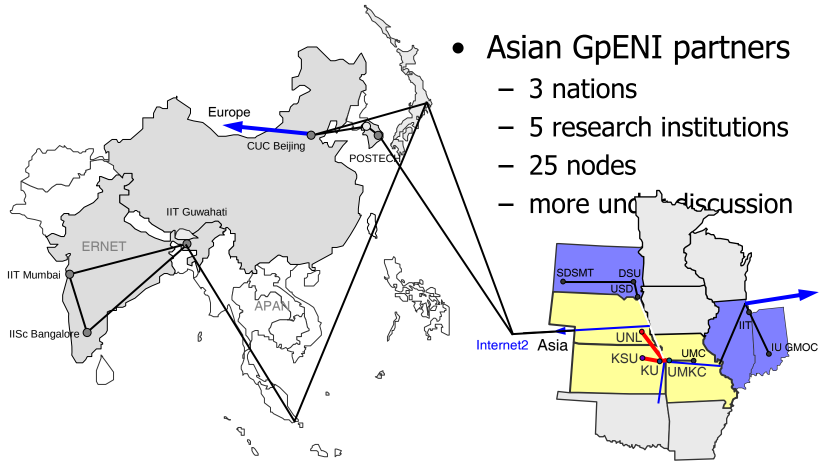
Enabling Future Internet Research
GpENI Asian Expansion

- Asian GpENI partners
  - 3 nations
  - 5 research institutions
  - 25 nodes
  - more under discussion



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ITTC Networking Research
Selected Project Examples

- Weather disruption-tolerant networking (Sterbenz)
- Highly-dynamic airborne networking (Sterbenz)
- Information security and privacy (Luo)
- SDRs and cognitive networking (Minden, Evans)
- Sensor networking (Frost)

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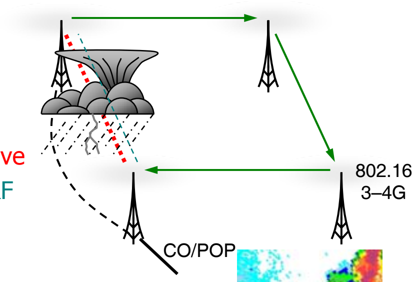
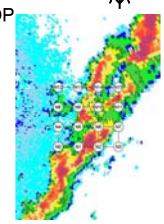
WDTN Project
Overview

- Mesh architecture
  - high degree of connectivity
  - alternate diverse paths
    - severely attenuated mm wave
    - alternate mm, lower-freq. RF
    - fiber bypass (competitor)

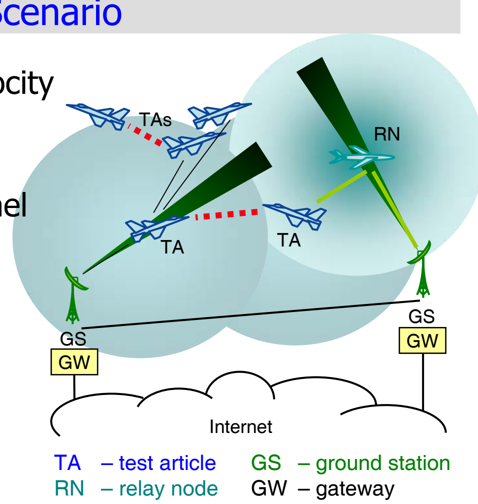


- Solution [INFOCOM 2009]
  - reroute *before* link failures they occur
  - P-WARP predictive routing
    - image radar to predict weather
  - XL-OSPF instantaneously reactive routing
    - cross-layered with BER estimation



Airborne Networking Project
Scenario

- Very high relative velocity
  - Mach 7 ≈ 10 s contact
  - dynamic topology
- Communication channel
  - limited spectrum
  - asymmetric links
    - data down omni
    - C&C up directional
- Multihop
  - among TAs
  - through relay nodes



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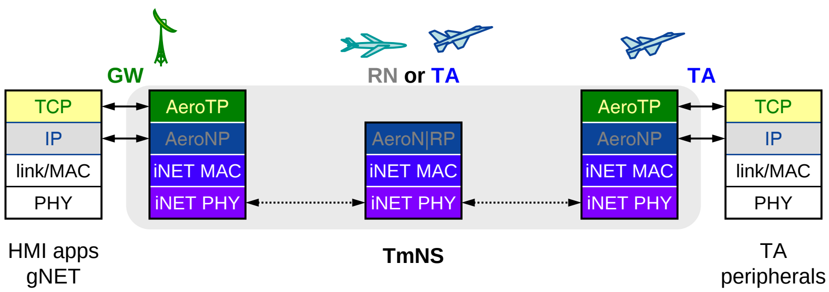
Airborne Network Project

Protocol Stack and Interoperability



- AeroTP: TCP-friendly transport
- AeroNP: IP-compatible forwarding
- AeroRP: routing [MILCOM 2008]

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InfoSec and Privacy Projects

[Bo Luo PI]

- CAT: A node-failure-resilient anonymous communication protocol through commutative path hopping [INFOCOM 2010]
  - protect the identity/privacy of communication participants
  - group-based path probing & commutative path hopping: resilient to relay node failures
- Secure in-network operations for smart grids
  - in-network operations: distribute operations (e.g. aggregation) into smart meters
  - Secure operations: perform operations without revealing the data, using applied crypto methods

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SDR and Cognitive Radio Projects

[Gary Minden and Joseph Evans PIs]

- KUAR: KU agile radio
  - experimental system: wireless networking & radio research
  - 5.8 GHz UNII band; independent 30MHZ tx/rx signal paths,
  - signal processing is entirely in an FPGA and GPU
- Application
  - sharing radio frequency spectrum with multiple users
  - configure radio software for specific missions
  - adaptation to dynamic RF environment and other users
  - radio network control and resource management
- Cognitive networking
  - new dynamic routing algorithms exploiting SDR technologies

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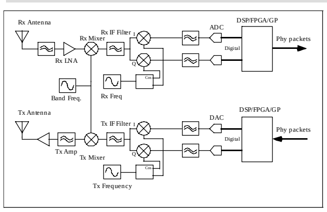
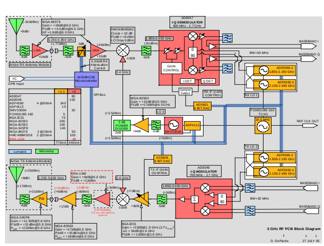
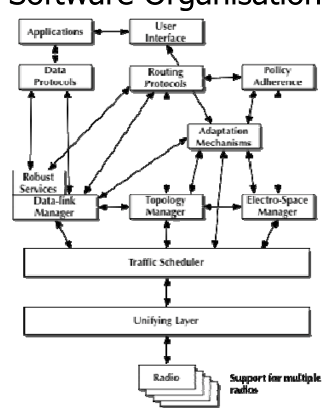
SDR and Cognitive Radio Projects

KUAR Diagrams





Software Organisation



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Transportation Security SensorNet
[Victor Frost PI]

- Objective and problem
  - KC SmartPort is encouraging development
  - transport systems require
    - visibility, accountability, efficiency, security
- Transportation security approach
  - sensing, communications, and information integration
  - integrate sensor information and real-time tracking with… trade data documents to correlate
  - expand the ORNL SensorNet technologies
    - to mobile rail network environment

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End

Questions?

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