DESIGNING RESILIENCE IN TRANSPORT PROTOCOLS

PROPOSAL FOR PH.D. DISSERTATION RESEARCH
Overview

- Introduction and Motivation
- Related Work
- Proposed Research
- Preliminary Results
Overview

- Introduction and Motivation
  - Communication Networks & Challenges
  - Related Disciplines
  - Cross-Layering
  - ResiliNets Architecture
  - PoMo Architecture

- Related Work

- Proposed Research

- Preliminary Results
Communication Networks

- Are pervasive in our society
- Used for daily communication
- Trusted with livelihoods, finances, and health
- Control essential services: power grid, EMS
- An increasingly attractive target for attacks
Challenges

- Unusual but legitimate traffic
- Wireless channel conditions
  - Bit errors
  - Intermittent & episodic connectivity
- Resource limitations of mobile nodes
- Attacks
- Misconfiguration
- Natural Faults
Disciplines

- Fault Tolerance (few, random)
- Survivability (many, intelligent)
- Dependability
  - Availability (instantaneous)
  - Reliability (long-term)
- Disruption Tolerance (interrupted connectivity)
Resilience

- Defined as: “The ability of the network to provide and maintain an acceptable level of service in the face of various faults and challenges to normal operation.”

- By implication, Resilience is a superset of FT, Survivability, Dependability, and Disruption Tolerance
Scope of Resilience

Faults and Challenges

- **Survivability**: many \( \vee \) targeted
- **Fault Tolerance**: (few \( \wedge \) random)
- **Traffic Tolerance**: legitimate, flash crowd, attack, DDoS
- **Disruption Tolerance**: environmental, delay, mobility, connectivity, energy

Robustness

- **Reliability**
- **Maintainability**
- **Safety**
- **Availability**
- **Integrity**
- **Confidentiality**
- **Auditability**
- **Authorisability**
- **Authenticity**
- **Nonrepudiability**

Measurement and Metrics

- **Security**
- **AAA**
- **Trustworthiness**
- **Dependability**
- **Performability**

Credit: [ResiliNets Group]
Cross-Layering 1

- Needed to support resilience
- Knobs influence behavior (e.g. FEC)
- Dials expose characteristics (e.g. BER)
- In band (header fields)
- Out of band (explicit signaling)
- NOT saying to throw away layering
  - Translucency principle
Cross-Layering 2

- Explicitly avoided in current Internet
- Implicitly essential to TCP
  - TCP infers congestion based on packet loss
  - RED based on this
- Implicit cross-layering insufficient
  - TCP assumes congestion for any loss event
  - Results in poor performance and inefficiency
ResiliNets Architecture

- Architecture for designing resilient networks
  - Motivational
  - Guides design
- Four Axioms
- Six-step Strategy $D^2R^2+DR$
- 18 Principles
ResiliNets Architecture

- Four Axioms
  - Inevitability of Faults
  - Understand Normal Operations
  - Expect Adverse Events and Conditions
  - Respond to Adverse Events and Conditions

- Six-step Strategy D²R²+DR

- 18 Principles
ResiliNets Architecture

- **Four Axioms**
- **Six-step Strategy D²R²+DR**
  - Real-time
    - Defend
    - Detect
    - Remediate
    - Recover
  - Background
    - Diagnose
    - Refine
- **18 Principles**
ResiliNets Architecture

- Four Axioms
- Six-step Strategy
- 18 Principles

service requirements
normal behavior
threat and challenge models
metrics
heterogeneity

resource tradeoffs
complexity
state management

self-protection
connectivity
redundancy
diversity
multilevel
context awareness
translucency

self-organising and autonomic
adaptable
evolvable

behavior

Credit: [ResiliNets Group]
PoMo Architecture

- Needs/enables x-layer transport layer
- PoMo: Postmodern Internetwork Architecture
- Funded by NSF under FIND program
- Thin internetwork layer (3.5)
- Enables heterogeneous internetworking
- Uses knobs and dials for cross-layering
PoMo Model
end-to-end communication with resilience as an inherent design property is necessary to meet specified service requirements in the face of various attacks and challenges.
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  - Disruption Tolerant Networking
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Related Work

- Transport Protocols
  - 4th layer of OSI model
  - Lowest level of end-to-end communication
  - Ideal service:
    - Zero delay
    - Zero errors
    - Infinite bit rate
  - Still working on achieving ideal service
Related Work

- **Transport Protocols**
  - General purpose
    - UDP
    - ISO-TP (TP0-TP4)
  - Application specific
    - RTP
    - NETBLT
    - TP++
  - TCP and derivatives
- **Disruption Tolerant Networking**
Related Work

- **Transport Protocols**
  - Flexible and composable, e.g. TP++
    - 3 traffic classes
    - ARQ for bit errors & congestion loss
    - FEC for congestion loss
  - TCP and derivatives, e.g. SCPS-TP
    - Error notification
    - Outage notification
    - Rate based flow control
Related Work

- Transport Protocols
- **Disruption Tolerant Networking**
  - Challenged network types
    - Terrestrial Mobile Networks
    - Exotic Media Networks: satellite, acoustic, LOS
    - MANET & Military Ad-Hoc
    - Sensor Networks
  - TCP for Space
  - Bundling protocols
Related Work

- Transport Protocols
- Disruption Tolerant Networking
  - Challenged network types
  - TCP for Space
    - TCPSat
    - SCPS-TP
  - Bundling protocols
    - IPN
    - DTN RG
Problem Statement

- Resilience not explicitly addressed in TP design
- Fixed error control mechanisms
- Minimal adaptability
- Connection state too fragile
- Limited or no explicit cross-layering
- No support for multipath
Overview

- Introduction and Motivation
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- Proposed Research
  - Architecture and Design
  - 4-phase research plan
- Preliminary Results
Proposed Research

- Protocol Architecture and Design
  - Resilience Measures
  - Cross-Layering
  - Operational Modes (continuous or discrete)
- Research Plan
  - Resilience Principle Application
  - Algorithm Development
  - Simulation
  - Implementation
Proposed Research

- Protocol Architecture and Design
  - Resilience Measures
    - Metrics to characterize resilience of system
    - Work in progress by Abdul Jabbar
  - Cross-Layering
    - Knobs influence operation of lower layers
    - Dials pass info to higher layers
  - Operational Modes (continuous or discrete)
    - Multidimensional map accounting for network state and application needs
Proposed Research

Operational Modes

Requirement > Path capability
Path capability > Requirement

Can trade abundant resource for scarce (e.g. sacrifice bandwidth to reduce bit errors with FEC)
Proposed Research: Error Control Mechanism Tradeoffs

- Error Detection alone
  - Trades bandwidth for error detection
  - Open Loop

- FEC
  - Trades bandwidth for error correction
  - Open loop

- ARQ
  - Trades latency for error correction
  - Closed loop
Proposed Research: Error Control

- Error Control Example
- Alternatives
  - N: none
  - O: open loop (FEC)
  - C: closed loop (ARQ)
    - S&W, GB-N, SelRep
- Location
  - HBH
  - E2E
- App requirements
  - unreliable
  - quasi-reliable
  - reliable

Credit: [James P.G. Sterbenz & David Hutchison]
Proposed Research: Mechanisms

- **Error Control**
  - FEC and/or ARQ
    - E2E or HBH?
  - Explicit Congestion Notification (ECN)
  - Explicit Corruption Notification
    - Recoverable
    - Unrecoverable (ELN)
  - Explicit Outage Notification (EON)
  - Explicit Delay Notification (EDN)
Proposed Research: Mechanisms

- Multipath
  - Present given resilient topology (≥bi-connected)
  - Requires multipath routing
  - What to do and where to do it?
    - Transport layer or Network layer?
  - Aggregate bandwidth
  - Erasure Coding

- Geographic Diversity
  - Benefits of multipath + survivability
Proposed Research

- **Research Plan**
  - **Phase 1: Resilience Principles**
    - Service requirements, threat and challenge models, context aware, multilevel resilience, redundancy and diversity, resource tradeoffs
  - **Phase 2: Algorithm Development**
    - Explore interactions and tradeoffs of mechanisms
    - ECN, ELN, EON, EDN
    - Open and closed loop flow control
Proposed Research

- Research Plan
  - Phase 3: Resilient Transport Simulation
    - ns-2: open source, widely used
    - Experiment with mechanisms from phase 2
    - Challenge scenarios
    - Wired, MANET, and sensor realms
  - Phase 4: Resilient Transport Implementation
    - Validate simulation models from phase 3
    - Analyze real-word effects
    - Wired, MANET, & sensor realms
Research Contributions

- Theory
  - Service Requirement to Path State relationship
    - How do knobs and dials relate in multidimensional space?
    - How does this relate to metrics space?
  - Tradeoffs
    - Between layers
    - Within E2E layer

- Functional
  - Simulation models
  - Transport protocol implementation
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  - Packet size adaptation
  - Cross-layer ns-2 architecture
  - PoMo E2E cross-layer framework
Preliminary Work

- Packet Size Adaptation
  - Simulation code to verify mathematical model
- Cross-layer Architecture for Simulation
  - Data structure in ns-2
- PoMo E2E Cross-Layering Framework
Preliminary Work

- Packet Size Adaptation
  - Selects optimal packet size given header length and BER
  - 4 fixed-size curves
  - Adaptive curve forms envelope of fixed-size curves

Credit: [Sarvesh Varatharajan]
Preliminary Work

- Packet Size Adaptation
- Cross-layer Architecture for Simulation
  - No packet content in ns-2 simulations
  - Need data structure to store knobs/dials
- PoMo E2E Cross-Layering Framework
**Preliminary Work**

PoMo E2E Cross-Layering Framework
Realms communicate via PoMo layer
Provides standardized cross-layering interface

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**PoMo Layering**

Realm A (MANET) -> Realm B (IP) -> Realm C (Native PoMo)

Transport -> Internet

Network -> Link

Source -> Router -> PoMo Gateway

E2E Context

Realm Context

HBH Context

Destination
## Timeline and Milestones

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Questions