Integrity ★ Service ★ Excellence

Complex Information Systems

8 Dec 2012

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Goals:

- Preserve critical information structure and minimize latency over a heterogeneous distributed network and system
- Ensure network and system robustness and stability under a diverse set of resource constraints and manage not assuming static models
- Find invariant properties for a given network and system from a distributed set of observations and predict network behavior
- Develop unifying mathematical approach to discovering fundamental principles of networks and system and use them in network and system design

Payoffs:

- Preserve information structures in a network rather than just delivering packets or bits
- Quantify likelihood of a given network management policy to support critical mission functions
- Predict and manage network and system failure comprehensively
Foundations of Information Systems

Program Objectives

- **Model** heterogeneous distributed systems using unified mathematical framework *through previous measurement* and validate

- Verify the properties of a given system application *through measurement* of a limited set of system parameters and assess mission risk

- Define general architectural principles of **design** through unified assessment of system operating properties

- Generalize design properties to universal system architectural principles

Payoff

- Assess and verify properties of a distributed heterogeneous system where there is limited access to its elements

- Assess dynamic Air Force system mission performance and assess risk of failure
Complex networks and systems uses measured information to assure, manage, predict, and design distributed networks, systems, and architectures.
Local Network/System Research: Preserving Information Content

- Statistical geometric coding structures are used to transport diverse sets of information in a network and system and preserve its critical structure.
The state of information transfer on a network changes with network and system management policy and protocol
– Particularly important to the Air Force given its unique heterogeneous mobile infrastructure

**Network/System Management Research: Guaranteeing Information Transfer**

- **Less:** Information Loss With Disruption
- **More:** Latency, Difficult to Control

<table>
<thead>
<tr>
<th>Information Sources</th>
<th>Protocol/Policy Information Distribution</th>
<th>Protocol/Policy Information Loss With Interference</th>
<th>Protocol/Policy Information Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δt ~ groups of packets, subroutine, virtual mem.</td>
<td>Random Protocol (ex: Flooding)</td>
<td>Information Loss Distributed</td>
<td>Recover With Redundancy</td>
</tr>
<tr>
<td>Source 1</td>
<td>Hybrid Routing (ex: OLSR)</td>
<td>Information Loss Measurable</td>
<td>Recover With Redundancy and Retransmit</td>
</tr>
<tr>
<td>Source 2</td>
<td>Deterministic Routing (ex: OSPF)</td>
<td>Information Loss Significant</td>
<td>Recover With Retransmission</td>
</tr>
<tr>
<td>Source 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Message 1:** Recovered Information

**Message 2:**

**Message 3:**

**Less:** Latency
**More:** Information Loss With Disruption, Controllable
We wish to develop information invariants that can be used to assess network/system performance.

Information Sources
- Source 1
- Source 2
- Source 3

Information Timescale $\Delta t$ ~ blocks of information, program, virtual memory

- Random Network (ex: Mobile Ad Hoc)
- Hybrid Network (Mesh)
- Deterministic Routing (ex: Core/Backbone)

Architecture Information Distribution

- Information Loss Distributed
- Information Measurable
- Information Significant

Architecture Information Loss With Interference

- Change Information Distribution
- Reroute and Change Distribution
- Reroute Information

Architecture Information Recovery

Less: Information Loss Under Disruption
More: Latency, Resource Intensive

Less: Latency/Disruption Tolerant
More: Controllable
Example: Unified Mission Assured Architecture

- Current networks are managed with multiple protocols depending on their taxonomy
- Air Force networks, particularly Airborne Networks are heterogeneous
- A unified network approach should adapt to the conditions and provide design principles

![Diagram showing current and future networks with design principles and constraints.]

- Less: Disruption Tolerant, Latency
  - More: Information Loss Under Interference, Observable/Controllable
- More: Disruption Tolerant, Latency
  - Less: Information Loss Under Interference, Observable/Controllable

Unified Strategy
- Design Principles According To Constraints
- Adapt According To Measurements
Foundations of Information Systems

Measure and verify information system properties among various system constraints

**Measured Performance Regions**

- **Deterministic Content**
- **Hybrid Content**
- **Random Content**

**Network States**
- packets, packet blocks, packet groups

**Software States**
- variable, subroutine, program

**Hardware States**
- register, ram, virt. mem

**System Measurements**

**Global Properties**
- Unstable/Un-resourced Insecure

**Statistical Properties**
- Stable/Resourced Secure

**Less:** Information Loss Under Disruption/Live
**More:** Latency, Resource Intensive/Safe

**Less:** Latency/Disruption Tolerant/Safe
**More:** Controllable/Live

**Heterogeneous Information**

(timescale/level of abstraction)
Measuring Information Systems Fundamental Properties

Units of information translate across heterogeneous domains and can be used to measure and quantify system performance.

- Taking this approach can lead to a unified systems and security strategy.

**Basic Information Unit Scales**

- **Data Network**: Wireless, Network, Hardware/Software
- **Packet**: Modulation Unit, Register/Variable, Words, DNA
- **Packet Groups**: Waveform, Ram/Subroutine, Phrases, Protein Synth.
- **Packet Blocks**: Signal Array, Virtual Mem./Program, News Reports/Blogs, Cell Function

**Frequency**

(1/information timescale)

**Content**

(1/local)

**System Policy/Protocol**

(management)

**System Structure**

(global)

**Deterministic**

**Heterogeneous**

**Random**

**Time Evolution**

(Global Properties)

**Measured System Properties**

- Design Excluded Properties
- Not Resourced, Not Stable, Not Secure
- Resourced, Stable, Secure, (Safe)

**Design Included Properties**
• If we would like to estimate, detect, control, or predict networks, there are many algorithms that have been adapted to the relevant network conditions
• We would like new classes of integrated algorithms that can adapt across many dynamic network conditions
Comprehensive Systems Modeling

- Model heterogeneous distributed systems using unified, modular, composable and scalable mathematical framework from previous measurement and system specification
  - Use new statistical, algebraic, and geometric representations and theory for modularized representations and composable into a modeling framework
Measurement-Based System Verification

- Verify the properties of a given unified system through measurement of a limited set of parameters and calculate system risk of not meeting mission requirements.
  - Assess risk by distance between properties of desired representation (model) and measured properties.
  - Incorporate risk of sparse measurement.

Desirable Properties:
(Example) Robustness to Disruption

Undesirable Properties:
(Examples) Latency, Interference, Computational Overhead

Mission Requirements
Desired Properties
Performance Verification

Measurement
Risk Assessment

Measured Properties
Low Mission Risk
Medium Mission Risk
High Mission Risk

Desirable Properties:
(Example) Robustness to Disruption

Undesirable Properties:
(Examples) Latency, Interference, Computational Overhead
- Define general application architectural and policy *validation* principles through unified assessment of system operating risk
  - Apply to existing architectures through policy implementation

*System Operating Trade-space*

*Architecturally Excluded Modalities (high mission risk)*

*Architecturally Validated Modalities (low mission risk)*