GENI and the Challenges of Network Science

Dr. Will E. Leland
wel@research.telcordia.com
4 March 2008

GLOBAL ENVIRONMENT FOR NETWORK INNOVATIONS

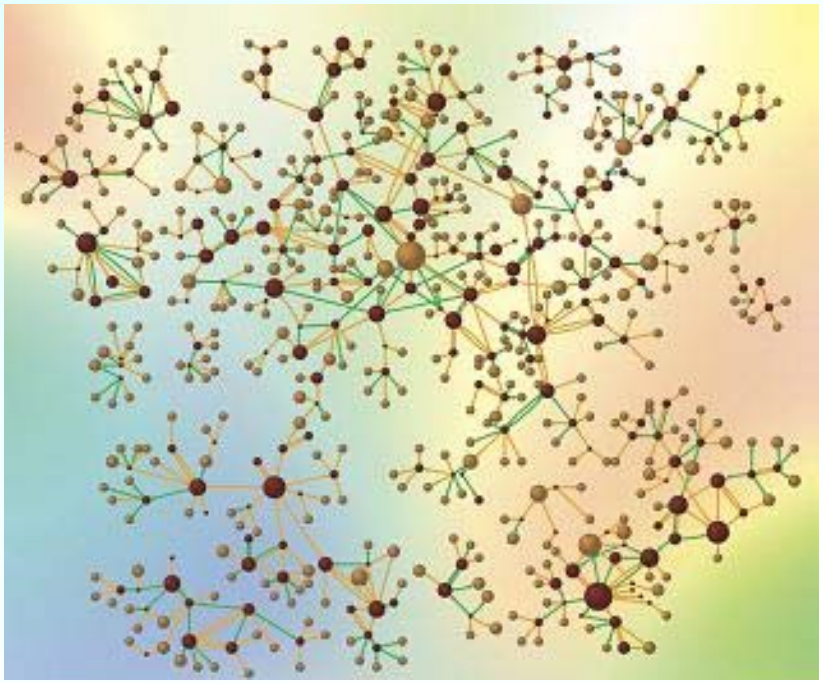
Telcordia®

GENI and Network Science
Propositions of This Talk

- Network science exists *(almost true)*
- GENI can contribute to Network Science
- Network Science can contribute to GENI
- Science and society can benefit from both

GENI and Network Science
Talk Outline

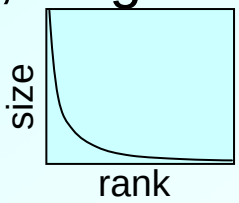
- "Network Science" and "Computer-Related Networks"
- Challenges for Network Science
- Opportunities for GENI
- Implications for GENI

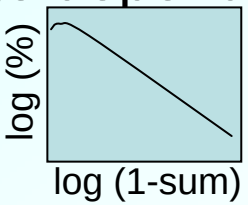


Telcordia

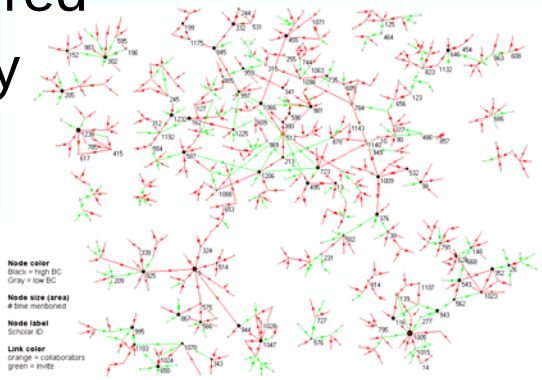
"Network Science"
All Kinds of Networks

- The study of common properties and mechanisms that hold over all "networks"
  - There are robust empirical laws for networks
    - Heavy-tailed distributions, long-range dependence
    - Self-similarity
    - Small-world phenomena
    - Pareto distribution of applications, communities





  - Disparate *kinds* of networks have deep relations
    - Biological, physical, social, engineered
    - Layers of abstraction & dependency
  - Emerging discipline: not proven out



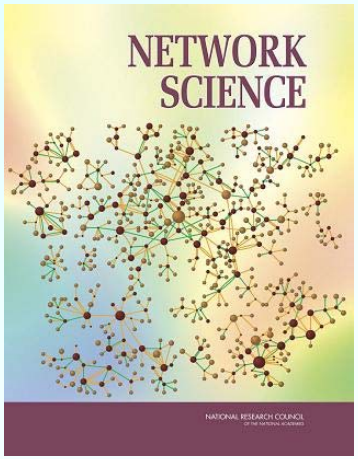
Computer-related networks are central

Telcordia

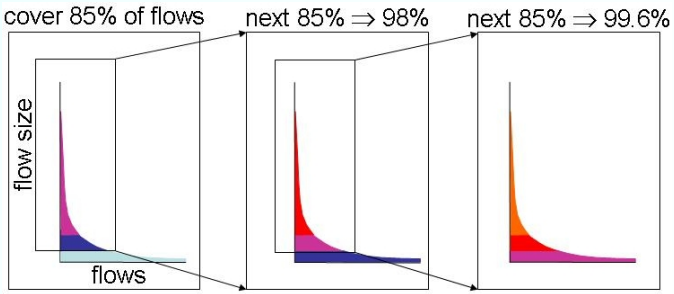
"Computer-Related Networks" (CRNs)

- GENI is a testbed for more than "computer networks"
- I use "computer-related networks" (CRNs) to emphasize that GENI research includes
  - Communicating devices (varying intelligence)
  - Communicating applications and services
  - Communicating infrastructure
    - Naming, routing, discovery, authentication, security, robustness, maintenance, reconfiguration, policy, …
  - Communicating *humans* using these device and services
    - Researchers [distinguished class of GENI users]
    - End users
    - Service & data creators and suppliers
    - Operators
  - Not assuming existing IP technology, WWW, or packets

A Broader Research Opportunity: Network Science & GENI



- What is a network? The 3 “CEL” attributes:
  - **Connectivity**: Nodes with finite links between them
  - **Exchange**: Exchanging resources takes time
  - **Locality**: Nodes only interact through links
- Common research themes:
  - Dynamics, resilience, evolution, analysis, synthesis, visualization
  - Network interactions, layers, abstraction, representation
- Enrich CRN research with NetSci perspective
  - Broad insights
  - Challenging hypotheses & examples



- Enrich network science with CRN perspective
  - Varied, well-instrumented, well-studied, multi-layer networks

Challenges For Network Science

- NetSci hypotheses claim **universality**: must be tested across ensembles of different networks
  - Topological properties (small-world, heavy-tails,…)
  - Evolutionary trajectories (emergent phenomena, …)
  - Dynamic behavior (phase transitions, …)
- NetSci hypotheses propose abstract **mechanisms**: must be mapped to real networks
  - Do these mechanisms really describe what happens in well-instrumented networks?
  - Do they have the effects predicted (transient, steady-state)?
- **Do we learn something new?**

GENI Can Be a Unique Facility
NetSci ↔ Computer Science

- Network Science needs a facility for research on
  - Ensembles of highly varied, well-instrumented, multi-scale, multi-layer networks
  - With known, controllable cross-network interactions
  - Including both emergent and engineered networks
- Such facilities do not now exist
- GENI is uniquely situated for
  - Testing the hypotheses of Network Science
  - Bringing Network Science to the benefit of research on computer-related networks
  - Bringing CRN research to the benefit of Network Science

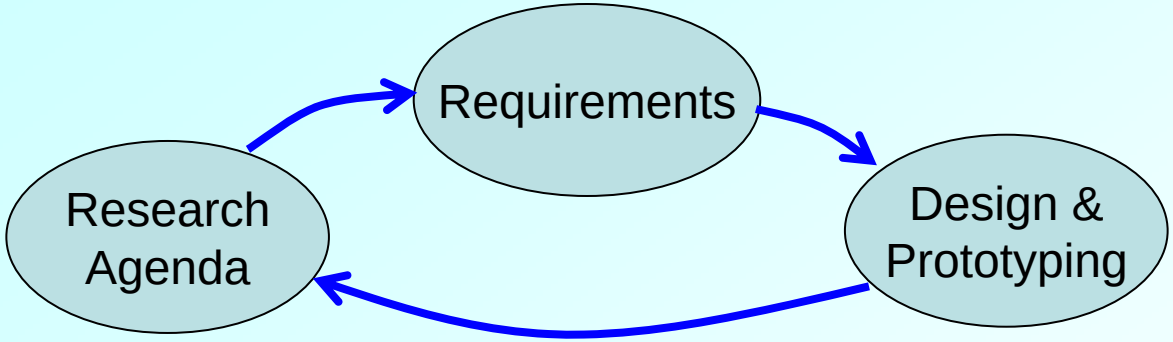
Opportunities For GENI Offered by Network Science (1)

- A source of strong scientific hypotheses to test
  - Proposed network evolution mechanisms
    - Drivers of evolution: percolation, attachment preferences, highly optimized tolerance, …
    - Barriers to evolution: centrality, Nash equilibria, …
    - Evolutionary consequences for structure and behavior
  - Scaling laws:
    - Locality of interaction, small-world networks, self-similarity for size distributions (node degrees, communities, frequency of use, …)
  - Behavioral phenomena
    - Phase transitions, emergent behavior, resilience, …

Opportunities For GENI Offered by Network Science (2)

- A source of ideas
  - Unfamiliar network structures and mechanisms
    - Economic networks based on potlatch, ecological networks driven by mimetic phenomena (warning, crypsis, Mullerian & Batesian mimicry), kinship networks based on fraternal polyandry, ….
  - Cross-network mechanisms
    - Resilience by social network instead of computer net?
    - Efficient support for economic or social networks?
    - Damping epidemics by improving remote interactions?
  - Insight into CRN structures and mechanisms
    - What would we change to speed or slow evolution?
    - Mutual evolution of overlay networks

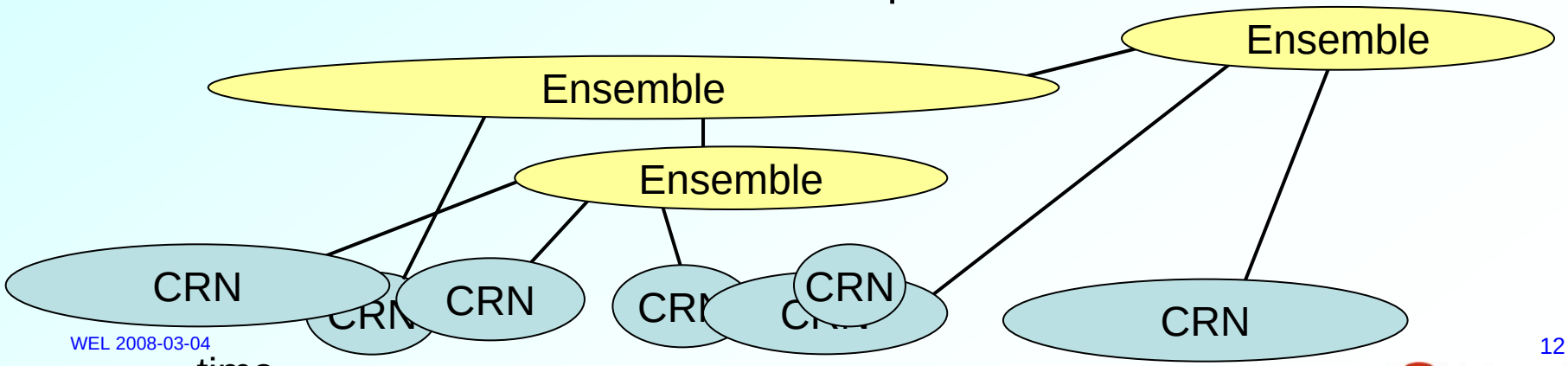
Exploiting the Opportunities



- Add this context to our research agenda
  - Our research community, NetSEC, other NetSci communities
- Develop requirements that support NetSci studies on ensembles of CRN experiments
- Design, prototype, experiment
  - Mechanisms, impacts, operations, measurements, legal, …
- Inform and evolve the research agenda
  - New possibilities
  - Necessary trade-offs to be resolved in supporting the agenda

Network Science Studies on GENI
Spanning Multiple GENI CRN Experiments

- Possible NetSci studies: relation to experiments studied
  - Pure observation of CRN experiments
  - Mutual influence over time between study and CRN experiments
  - Embedded NetSci plug-ins in CRN experiments
  - (Partial) control of CRN experiment parameters or environment
- Ensembles: multi-experiment collections
  - Active and default opt-in of CRN experiments
  - Completed and current CRN experiments
  - Used in CRN and NetSci multi-experiment studies



Implications for GENI
Many Issues to Address (Affect All WGs)

- Policy, technical, operational, legal, …
- What NetSci studies should GENI address?
- What measurements should GENI experiments take so (other) researchers could study NetSci issues? Defaults, plug-ins, scrubbing, timeliness, data ownership, retrospective studies, repeatability/replayability, specs & ontologies, …
- How do experiments opt into or out of NetSci studies? What is the default? Experiment specs?
- How do NetSci studies recruit specific GENI CRN experiments & other NetSci ensembles?
- How do end-users opt in and out? Do they?

The Grand Challenge
The Grand Opportunity

Understanding Complex Networks

Approaches:

- Theory
- Modeling and simulation
- Experimentation
- Real-world application

Results:

- Prediction
- Design & synthesis
- Control
- Directed evolution

of all the networks that matter to society

Thank you!