Mobility in Wireless Networks: Friend or Foe?

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Overview

1. Introduction
   - Professional Activities
   - Current State
2. Mobility as a Foe
   - Recovery Scheme
   - Tolerant Scheme
3. Mobility as a Friend
   - Random Movement
   - Controlled Movement
4. Future of Networking
   - Network Science: Hype or Reality?

Professional Activities

MANETs/Sensor Nets

- Edtior: IEEE TMC
- General Chair: MASS and DCOSS
- Program Chair: INFOCOM and MASS
- Panel Chair: INFOCOM and MobiCom
- Committee: INFOCOM, MobiHoc, and ICNP

Distributed Systems

- Chairman: IEEE TC on Distributed Processing (TCDP)
- Executive Program Vice Chair: ICDCS
- Committee: ICDCS, HPCA, and SRDS

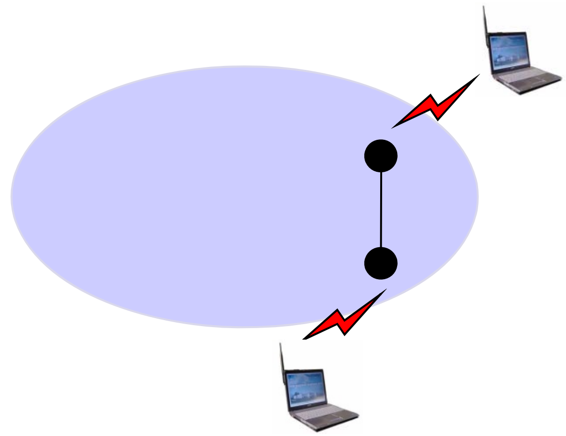
Parallel Processing

- Former Editor: IEEE TPDS
- General Chair: IPDPS
- Committee: IPDPS and ICPP

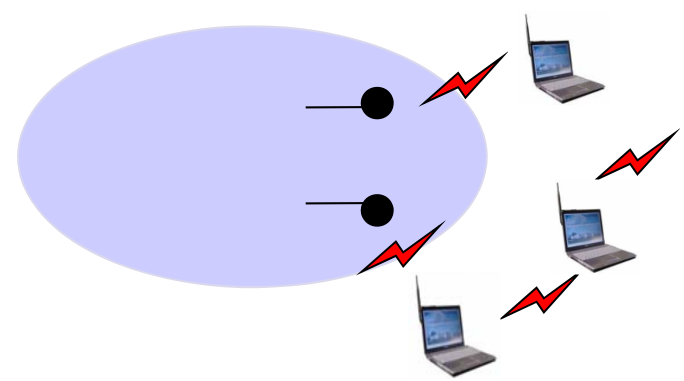
Current State: Wireless and Mobile

- Current
  - Different types: PDA, BlackBerry, Laptop
  - Internet connections: more and more wireless
  - Node mobility
- (Near) future
  - 1 billion vehicles
  - 5 billion RFID
  - 10-15 billion sensor/embedded devices
- Future: anytime, anywhere

(a) Edge of the Internet

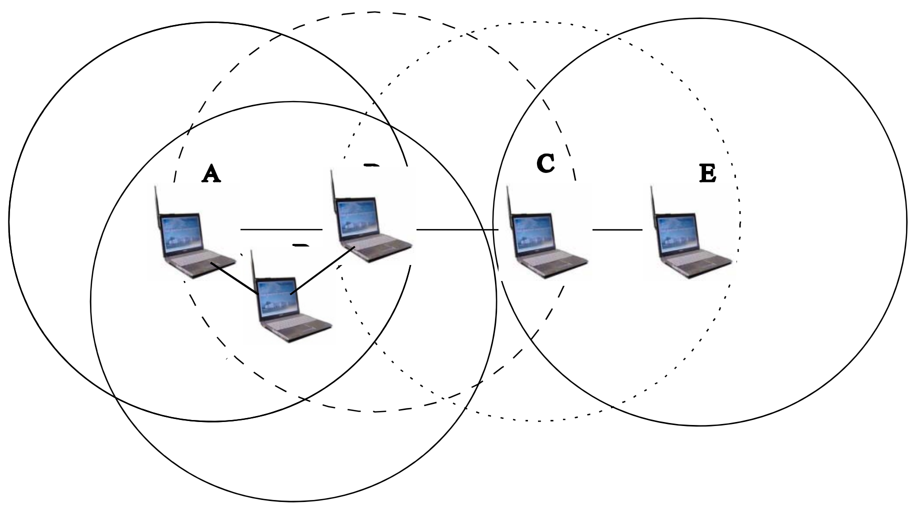


(b) General way of data transmission



2. Mobility as a Foe

- Node mobility is considered to be undesirable in MANETs using a connection-based model
- Recovers from and tolerates "bad" effects caused by mobility
- Nodes are assumed to be relatively stable



Two Schemes

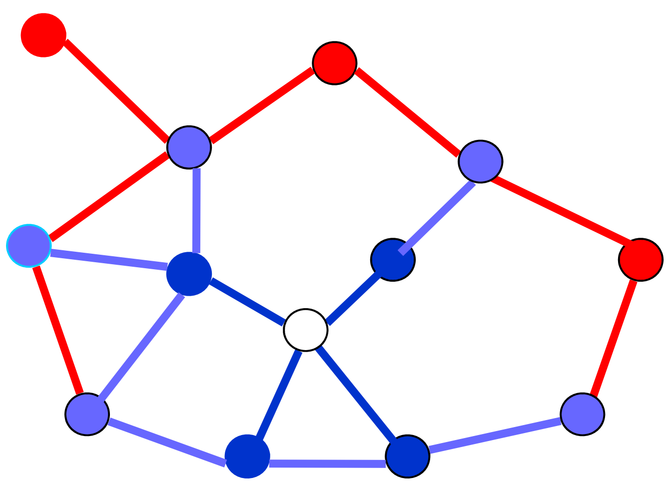
- Recovery Scheme
  - If a routing path is disrupted by node mobility, it can be repaired quickly
  - E.g., route discovery and route repair
- Tolerant Scheme
  - Masks the bad effects caused by node mobility
  - E.g., transmission buffer zone and view consistency

Mobility as a Serious Threat

- Mobility threatens localized protocols that use local information to achieve certain global objectives
- "Bad" decisions occur because of
  - Asynchronous sampling of local information
  - Delays at various stages of handshake
  - Mobile node movement

Local Information

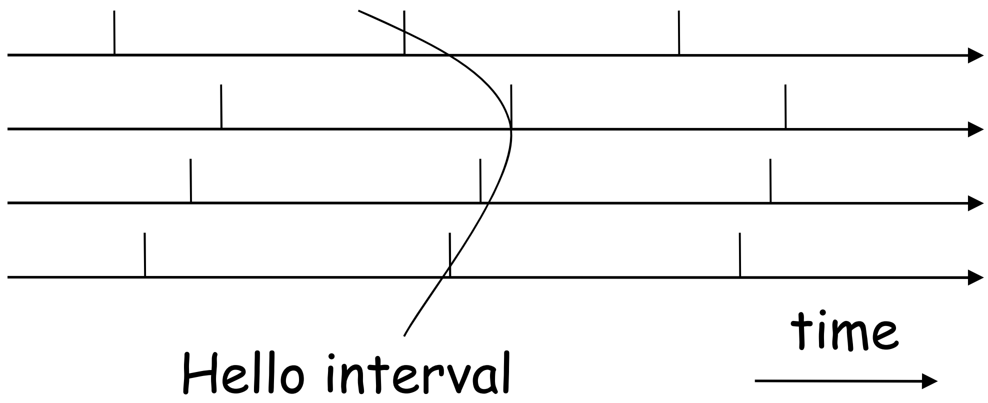
- 1-hop information
- 2-hop information
- 3-hop information



- *k*-hop information
  - Discovered via *k* rounds of Hello exchanges
  - Usually *k* = 1, 2, or 3
- Neighborhood vs. location information

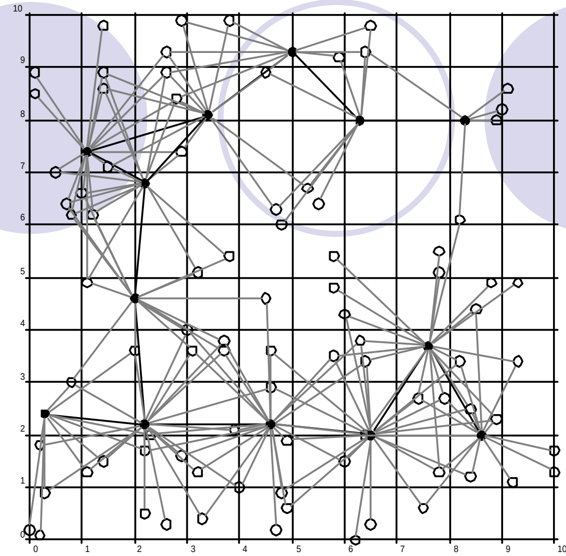
Time-Space View

- Snapshot: a global state in time-space view

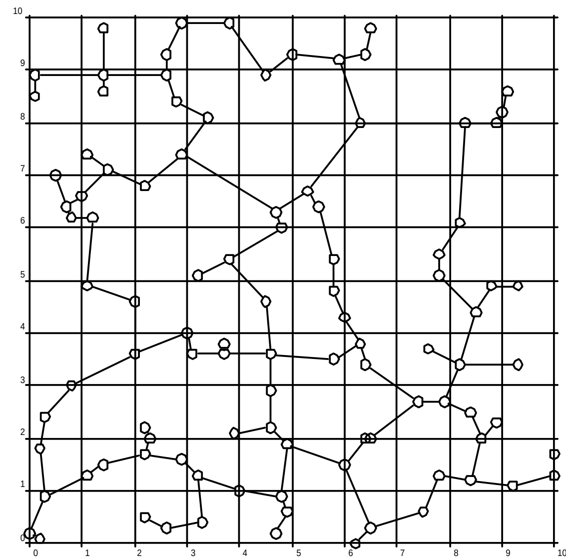


Applications

- Energy saving:
  - Sleep mode
    - Connected dominating set (CDS)
    - Wu and Li's 2-hop neighborhood solution
  - Adjustable transmission range
    - Topology control (TC)
    - Li, Hou, Sha's 1-hop location solution



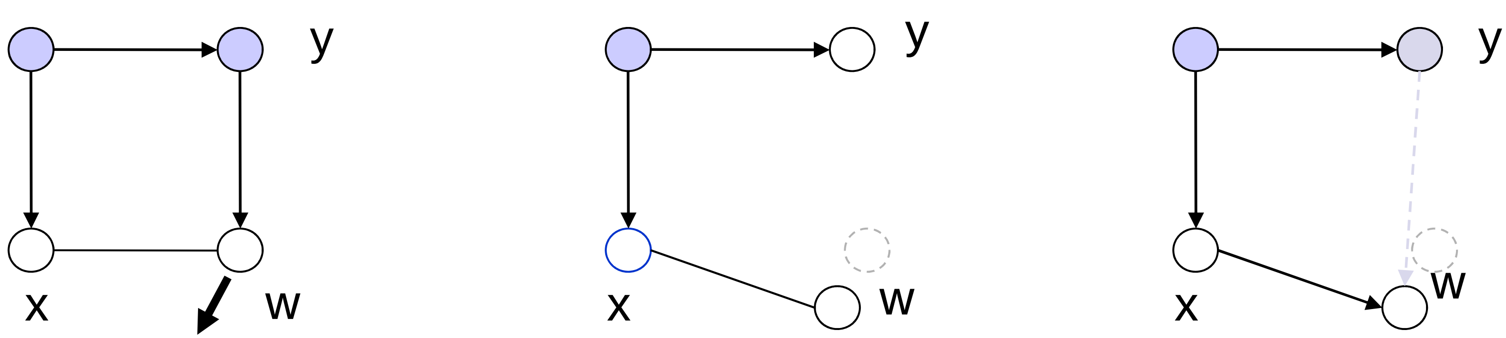
Virtual backbone (CDS)



Topology control (TC)

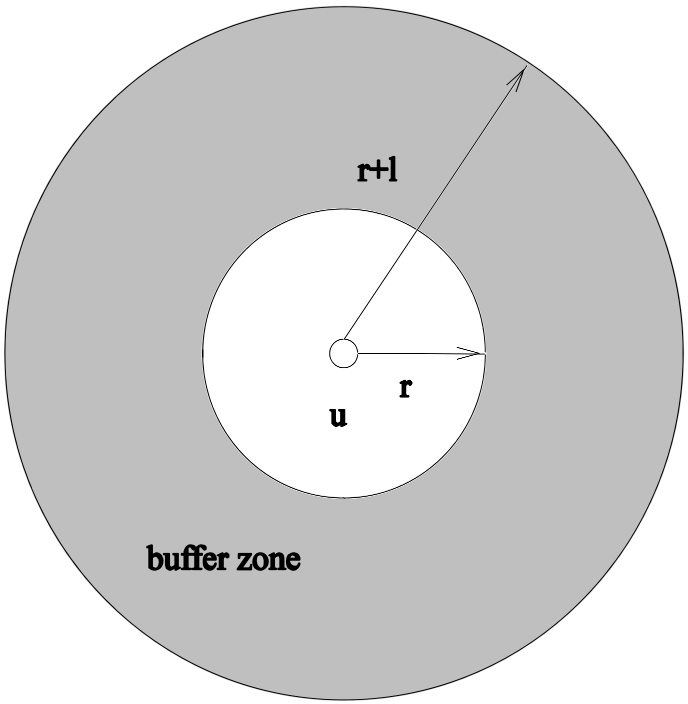
Two Technical Issues

- Link Availability
  - How protocols deal with imprecise neighborhood information caused by node mobility and delays
- Inconsistent Local Views
  - How each node collects and uses local information in a consistent way



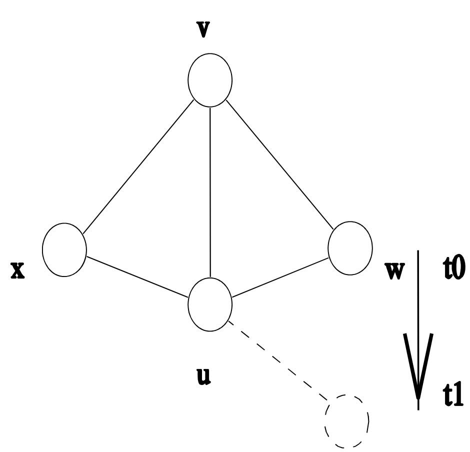
Tolerant Scheme I (link availability)

- A buffer zone is used in existing protocols without having to redesign them.

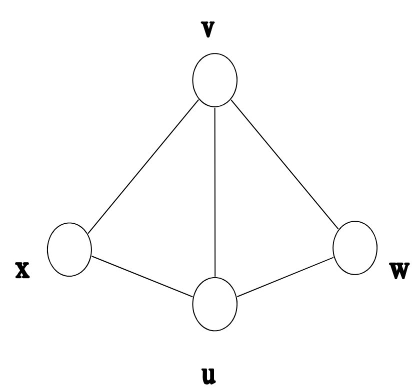


Sample I (inconsistent local view)

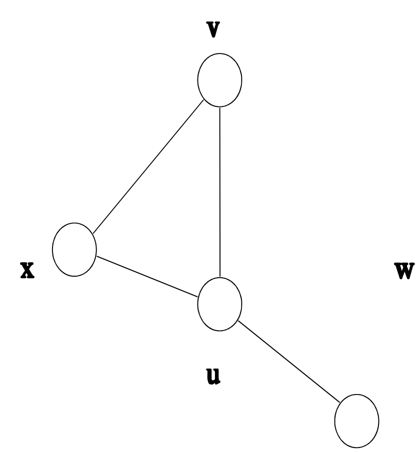
- Wu and Li's marking process (for CDS construction)
  - Node *u* is marked if there are two unconnected neighbors
  - Node *u* is unmarked if its neighbor set is covered by several connected marked nodes with higher IDs



(a) w's position at t0 and t1



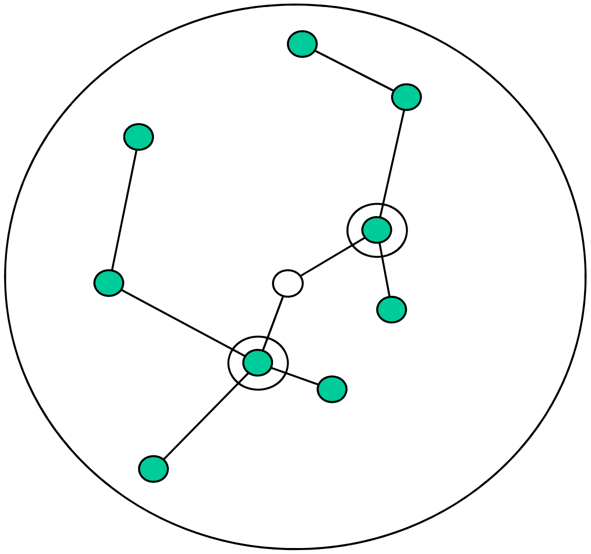
(a) u's decision as an unmarked node at t1

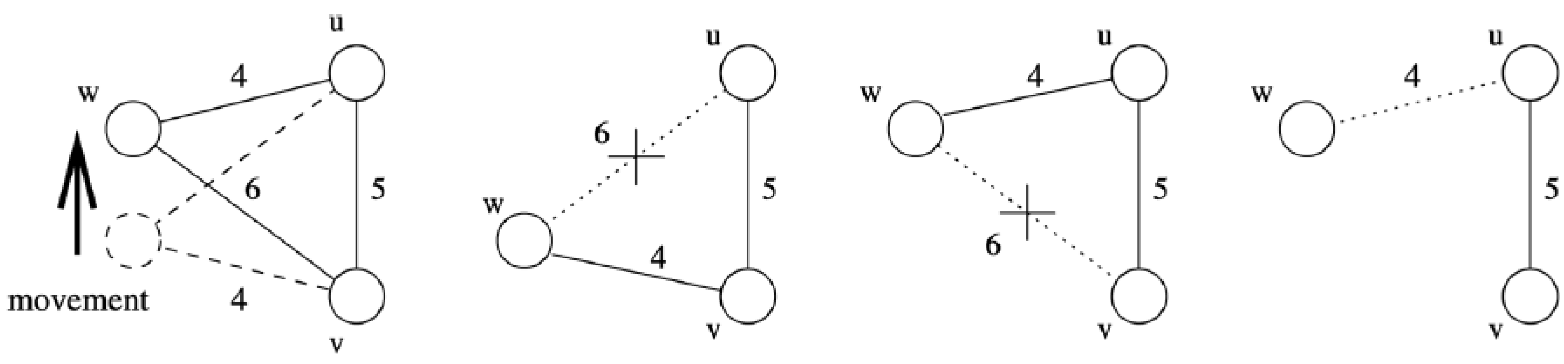


(a) v's decision as an unmarked node at t1

Sample II (inconsistent local view)

- Topology Control (Li, Hou, and Sha, INFOCOM 2003)
  - Network connectivity: if each node connects to its neighbors in the local MST (LMST)





(a) (b) (c) (d)

Tolerant Scheme II (inconsistent local view)

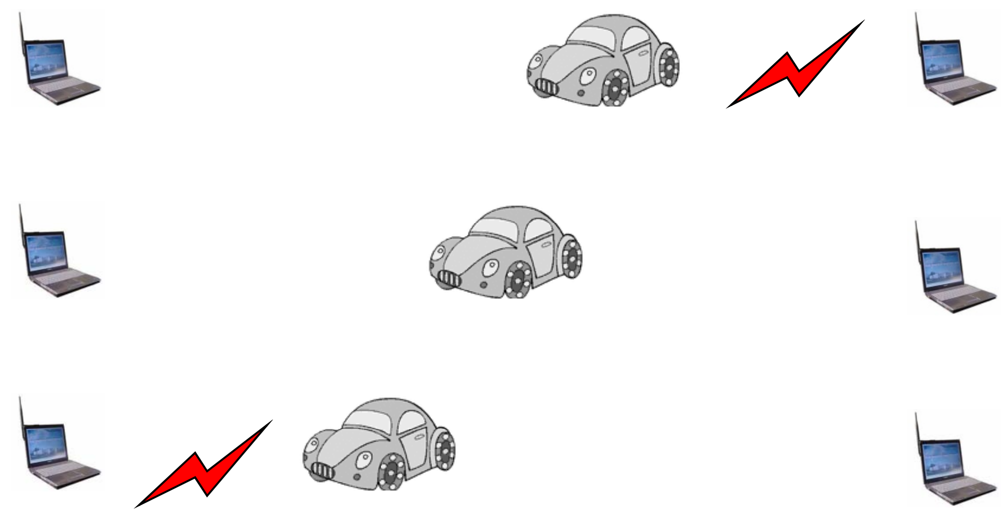
- Consistent Local View
  - Each view keeps a version by using a timestamp
- Conservative Local View
  - Maintaining a window of multiple views
  - New-view(i)= F(view(i), view(i-1), …view(i-k))

    where F: {union, max, min, …}

(More information on tolerant schemes: Wu and Dai, IEEE IPDPS 2004, IEEE INFOCOM 2004, IEEE TMC 2005, IEEE TPDS 2006)

3. Mobility as a Friend

- Movement-Assisted Routing
  - Views node movement as a desirable feature
  - Store
  - Carry
  - Forward



Challenged Networks

- Assumptions in the TCP/IP Model are Violated
  - Limited End-to-End Connectivity
    - Due to mobility, power saving, or unreliable networks
  - DTN
    - Delay-Tolerant Networks
    - Disruption-Tolerant Networks
  - Activities
    - IRTF's DTRNRG (Delay Tolerant Net. Research Group)
    - EU's Haggle project

Two Paradigms

- Random Mobility
  - E.g., epidemic routing
  - Sightseeing cars (random movement)
- Controlled Mobility
  - E.g., message ferrying
  - Taxi (destination-oriented)
  - Public transportation (fixed route)

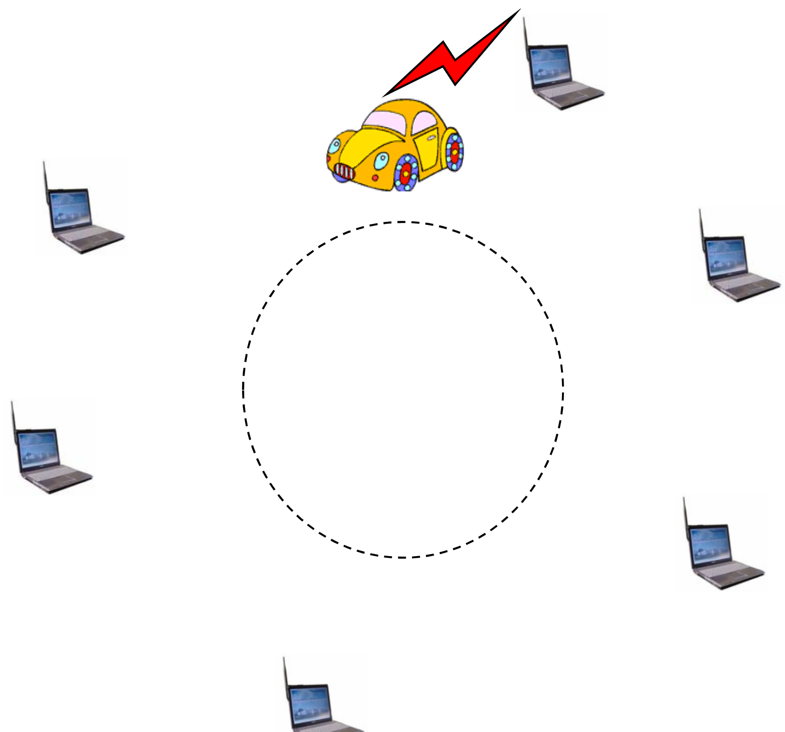
Mobility pattern affects the spread of information

Epidemic Routing (Vahdat & Becker 00)

- Nodes store data and exchange them when they meet
- Data is replicated throughout the network through a random talk

Message Ferrying (Zhao & Ammar 03)

- Special nodes (ferries) have completely predictable routes through the geographic area



Mobility-Assisted Routing

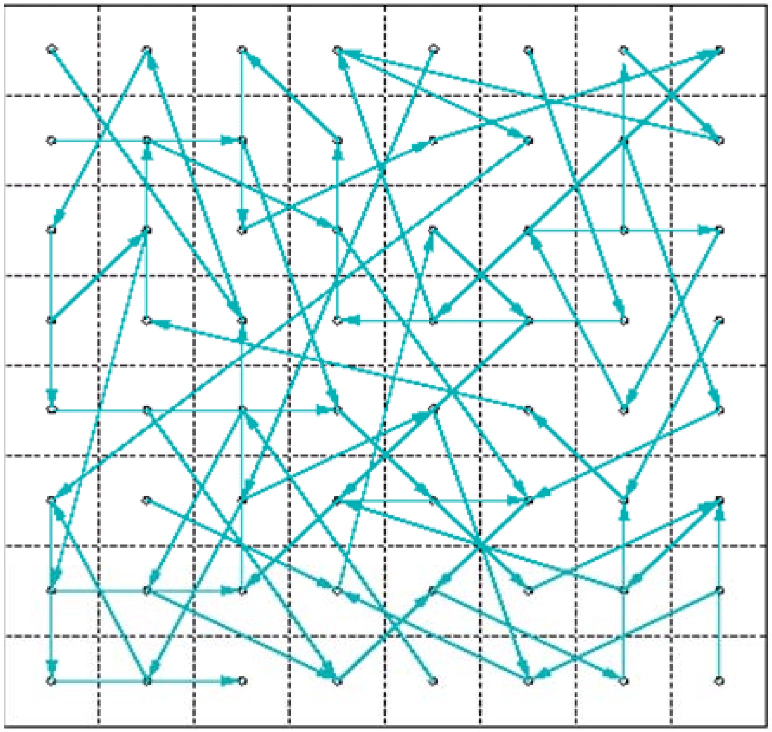
- Replication
  - Single copy vs. multiple copy
  - E.g., spray-and-wait and spray-and-focus
- Knowledge
  - Global vs. local information
  - Deterministic vs. probabilistic information
  - E.g., MaxProp

(Predict-and-relay: Quan, Cardei, and Wu, ACM MobiHoc 2009)

Mobility-Assisted Routing (cont'd)

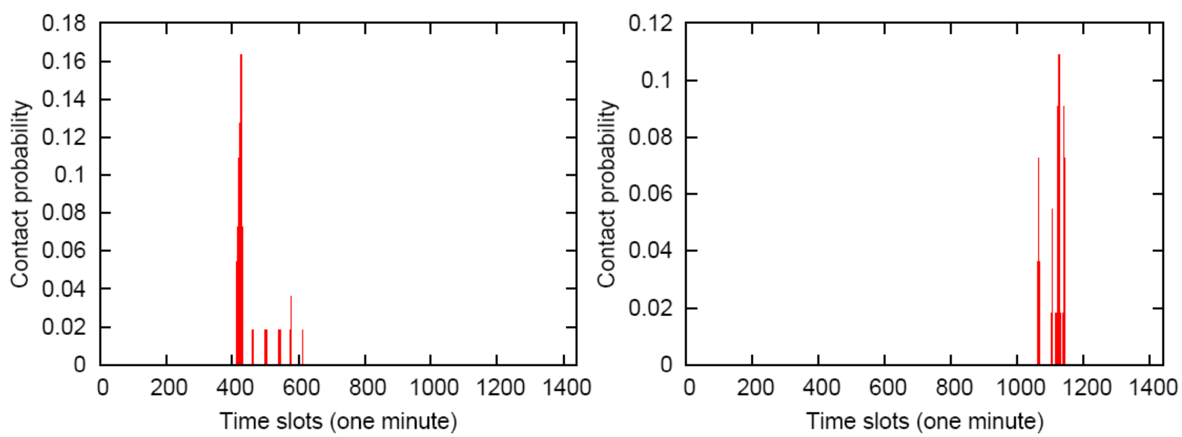
- Closeness (to dest.)
  - Location information (of contacts and dest.)
  - Similarity (between intermediate nodes and dest.)
  - E.g., logarithmic (and polylogarithmic) contacts
- Mobility
  - Random vs. control
  - Predictable
    - E.g., cyclic MobiSpace

(More information: Wu and Yang: IEEE MASS 2007 and IEEE TPDS 2007; Liu and Wu: ACM MobiHoc 2007 and 2008)



Routing in a Cyclic MobiSpace

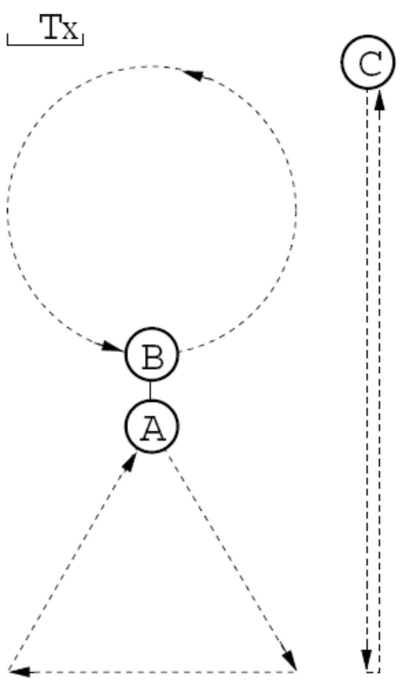
- Challenges
  - How to perform efficient routing in probabilistic time-space graphs
- Definition (t_i, p)
  - **p** is the contact probability of two nodes in t_i.

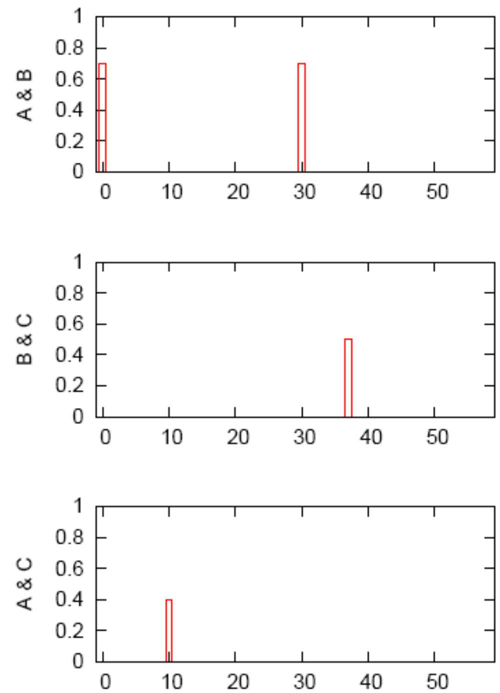


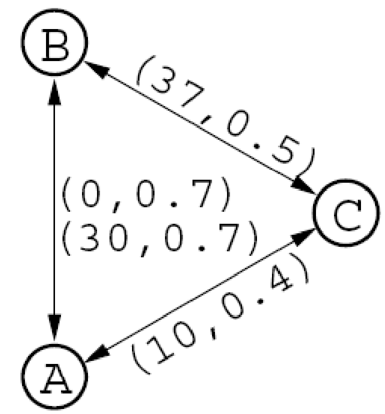
(a) Shifts 01/AM & 03/AM (b) Shifts 32/PM & 21/EVE

Probabilistic Time-Space Graph

- A common motion cycle **T** (=60)

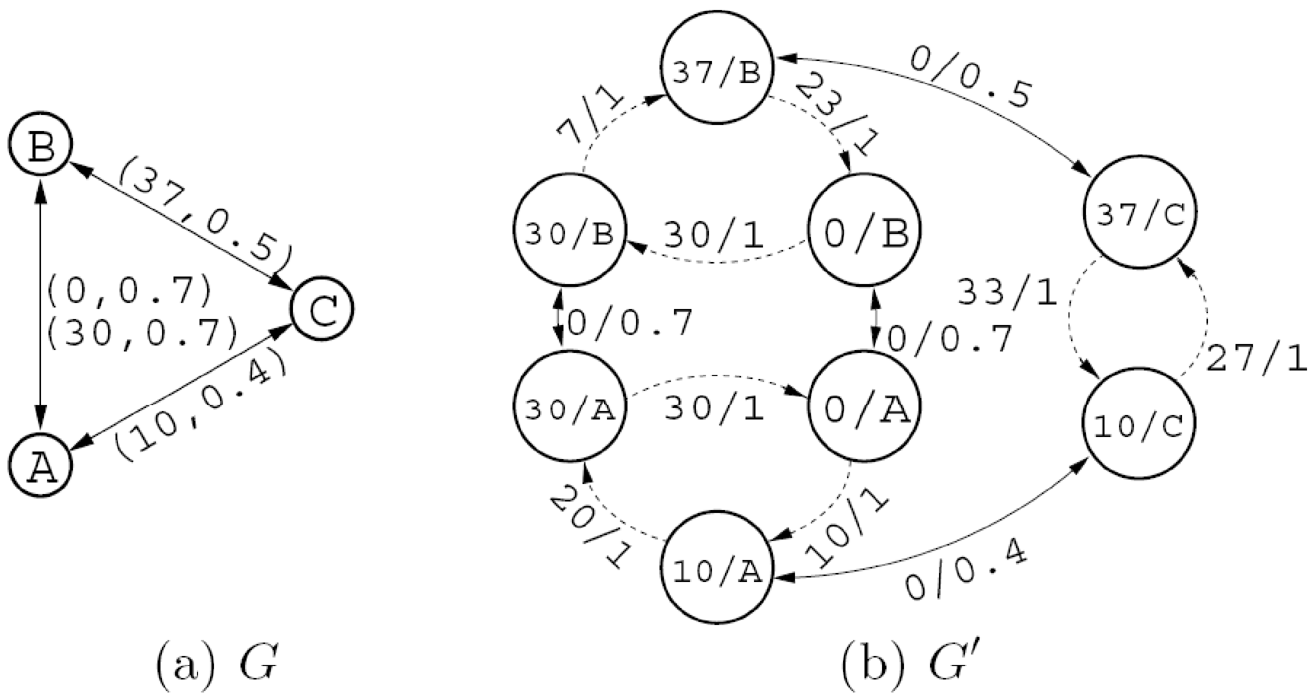






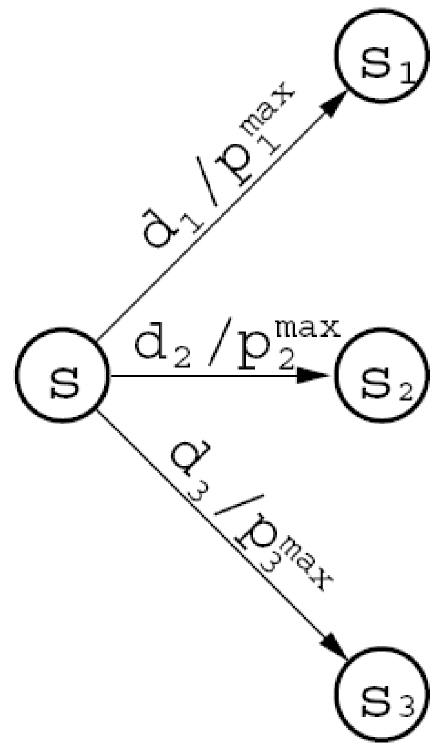
Probabilistic state-space graph

- Remove time dimension
- Links are labeled: **d / p^{max}** (delay/max transition probability)



Iterative Process

- Iterative steps
  - Step t+1 based on step t
  - Ordering of neighbors

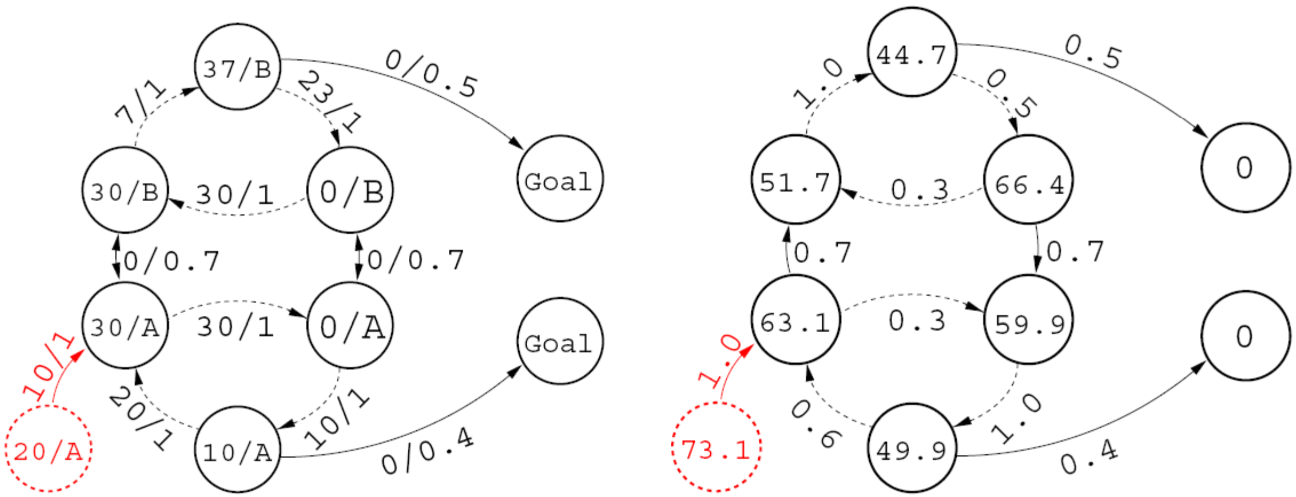


$p_i \le p_i^{max}$ and $\sum_i p_i = 1$

$$v_s^{t+1} \leftarrow \min_{p_1, p_2, p_3 \ldots} \{p_1 \times (d_1 + v_{s_1}^t) + p_2 \times (d_2 + v_{s_2}^t) + p_3 \times (d_3 + v_{s_3}^t) + \ldots\}$$

Expected Minimum Delay (EMD)

- Using EMD as the delivery probability metrics
  - Optimal single-copy forwarding: Liu and Wu MobiHoc 2008



- Optimal prob. forwarding with hop constraints
  - Single copy: Liu and Wu MobiHoc 2009
  - Multiple copy: Liu and Wu MASS 2009

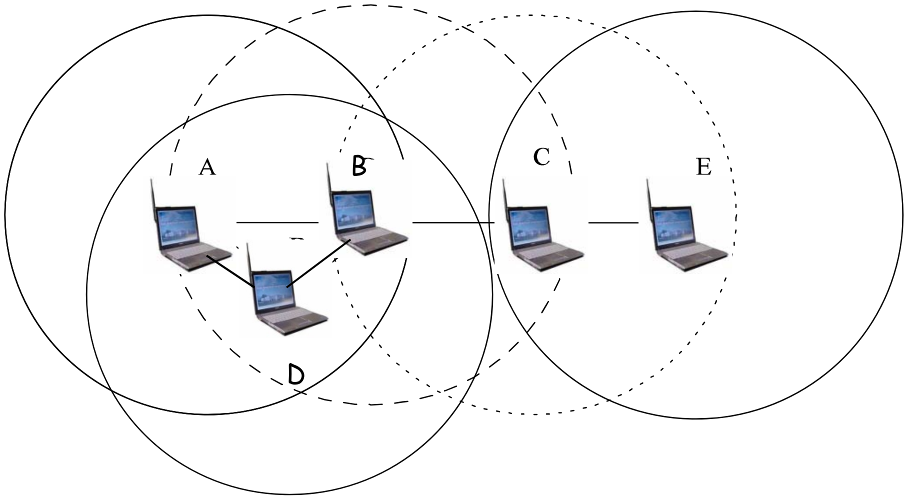
Simulation

- Real traces
  - NUS student contact trace
  - UMassDieselNet trace (sub-shift based)
- Synthetic bus trace
  - Miami
  - Madrid

Other Challenges

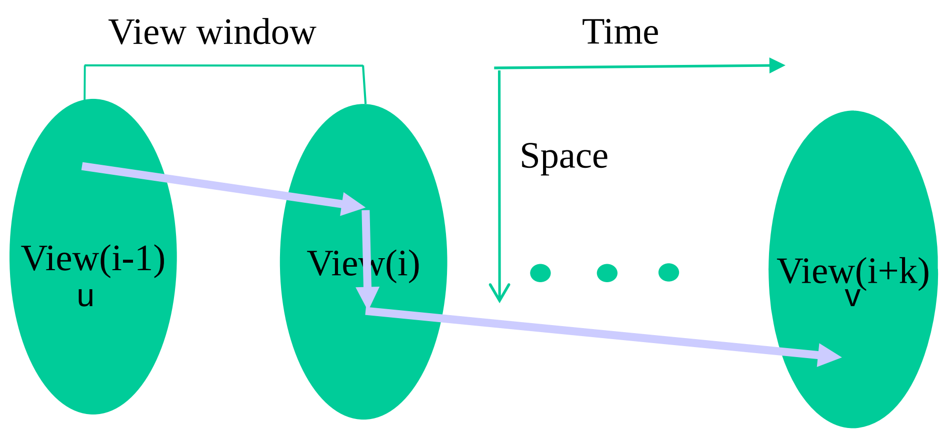
- Mobility
- Connectivity
- Complexity
- Bandwidth
- Latency
- Robustness
- Storage
- Security

- Intermittent connectivity
  - Node mobility
  - Unstable wireless links
  - Scheduled on/off sensor nodes



Connectivity

- (u,v) - connectivity under time-space view
  - Exist i, (u(i), v(i))
  - All i, (u(i), v(i))
  - Exist i, j, (u(i), v(j))
  - All i, j, (u(i), v(j))



Complexity

Managing complexity of time-space graphs

- Lossless translation method
  - Time-space to state-space (state explosion issue)
- Lossy comprehension method
  - Removing time using averaging in hierarchical routing
  - E.g. contact information compression

(Liu & Wu: Scalable Routing in Delay Tolerant Networks, ACM MobiHoc 2007)

Opportunities

- Increasing system performance
  - Routing capability
  - Network capacity
  - Security
  - Sensor coverage
  - Information dissemination (mobile pub/sub)
  - Reducing uncertainty in reputation systems

  (Li and Wu, IEEE INFOCOM 2007)

4. Future of Networking

Multi-disciplinary

Data Management

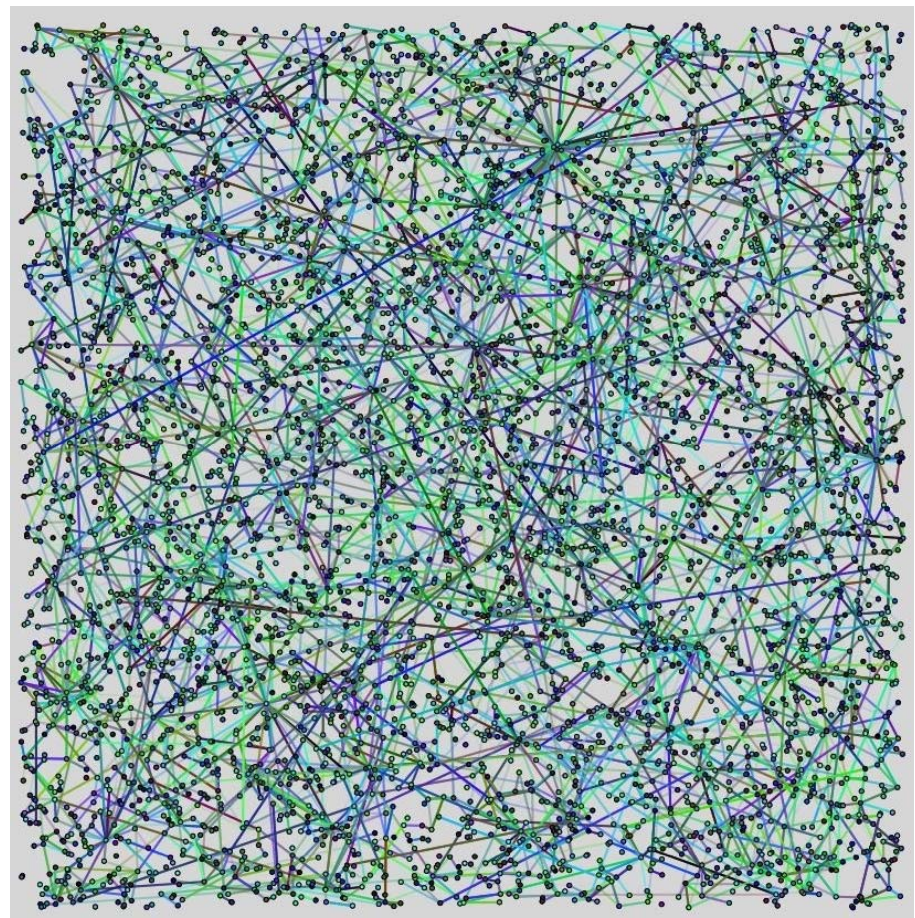
- In-network processing
- Tradeoffs among communication, computation, and storage

Theory

- Rigorous model and scaling properties
- Swarm intelligence

Social Networks

- Small-world (six degrees of separation)
- Scale-free networks (power-law)



Network Science: Hype or Reality?

- Moderator at ACM MobiCom'09
  - Jie Wu (Temple U., USA)
- Panelists
  - Anthony Ephremides (U. of Maryland, College Park, USA)

    Chuanxiong Guo (Microsoft Research-Asia, China)

    Peter Steenkiste (Carnegie Mellon U., USA)

    Taieb Znati (NSF, USA)

Network Science (NS)

A brief history

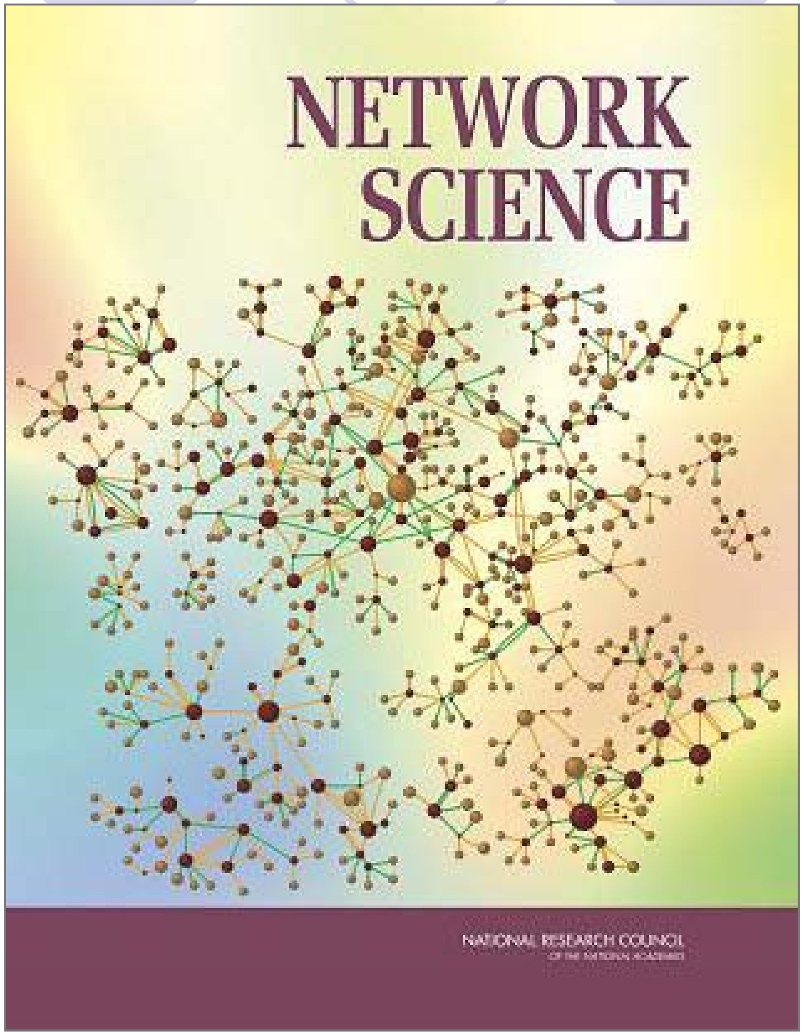
- Graph theory (Euler) and prob. theory (Erdos): random graph
- Social networks: exponential random graph, small-world
- DOD initiative: Network Science (2005)
- NSF NetSE program (2008)

NS: the study of network representations of physical, biological, and social phenomena leading to predictive models

Scope: technological (electronic data), natural (biological, cognitive), and social (social networks)

DoD Network Science Report

- Society depends on a diversity of complex networks
- Global communication and transportation networks
  - provide advanced technological implementations, however
  - behavior under stress still cannot be predicted reliably
- Biological and social networks
  - We do not fully understand these networks, nor the manner with which they operate



NSF NetSE Program

- Network Science and Engineering (NetSE)
  - Develop the science and engineering of global socio-technical networks
  - Yield new scientific understanding about network complexity and inform future network design

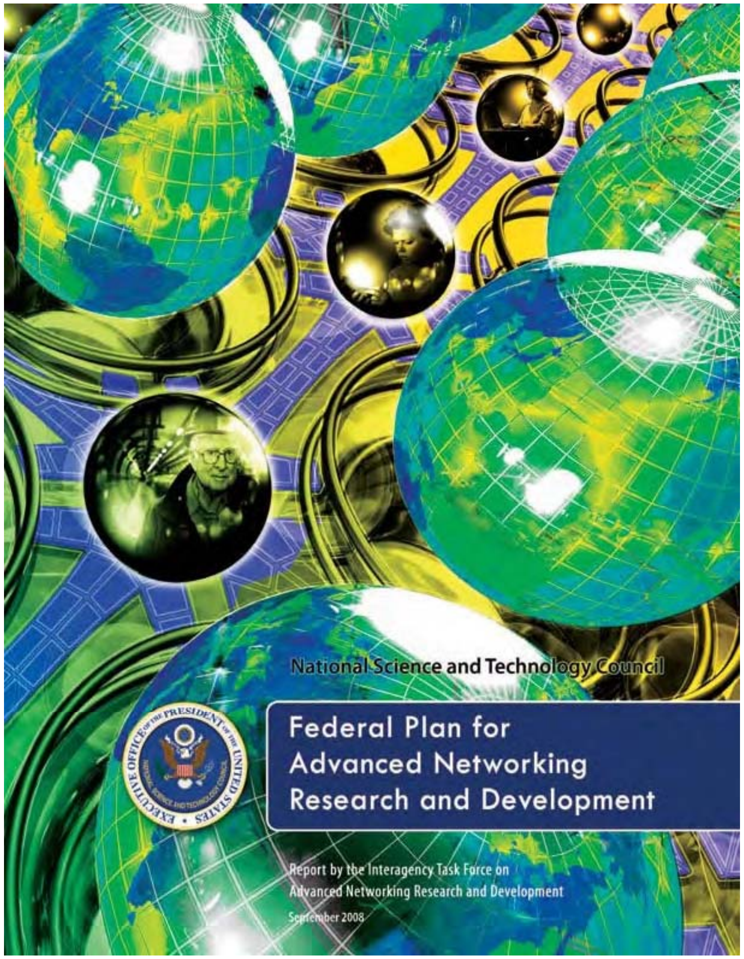
- Extending
  - Future INternet Design (FIND)
  - Science for the Internet Next Generation (SING)
  - Next-Generation Information Systems (NGNI)

More NetSE-related Activities

- GENI
  - NetSE council
  - NetSE research agenda (Sept. 2009)
  - Calling for "theory of networked computing"
- NCO NITRD
  - NITRD workshop on research challenges for 2015 global network (May 2009 report)
  - NetSE recommendations

NCO NITRD Report (Aug. 2008)

- Provide secure network services anytime, anywhere.
- Make secure global federated networks possible.
- Manage network complexity and heterogeneity.
- Foster innovation among the federal, research, commercial, and other sectors through development of advanced network systems and technologies.



Questions to Panelists

- Network science (NS): hype or reality?
- What should be the appropriate funding model/level for NS?
- What should be the right scope for NS research?
- What have we done right and wrong?

Questions to Panelists (cont'd)

- Which communities should be involved and how?
- What role can the wireless network and mobile computing community play?
- How does the future of NS stand and what are the remaining challenges?

Questions