Fundamental Understanding and Theory of Network Systems

Resiliency, Performance, and Usability

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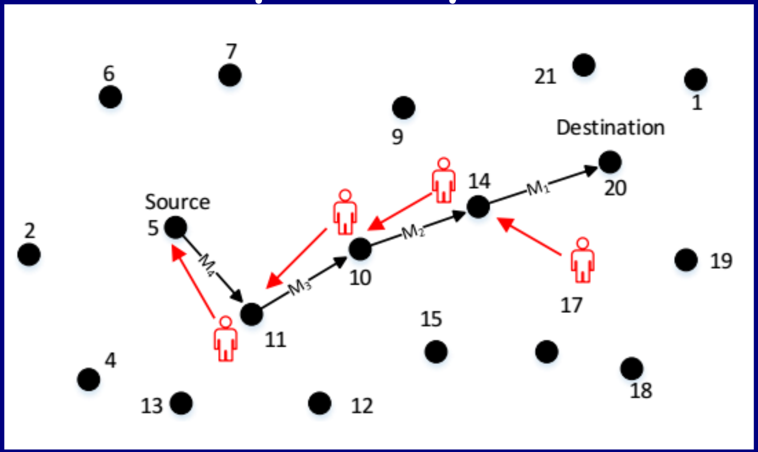
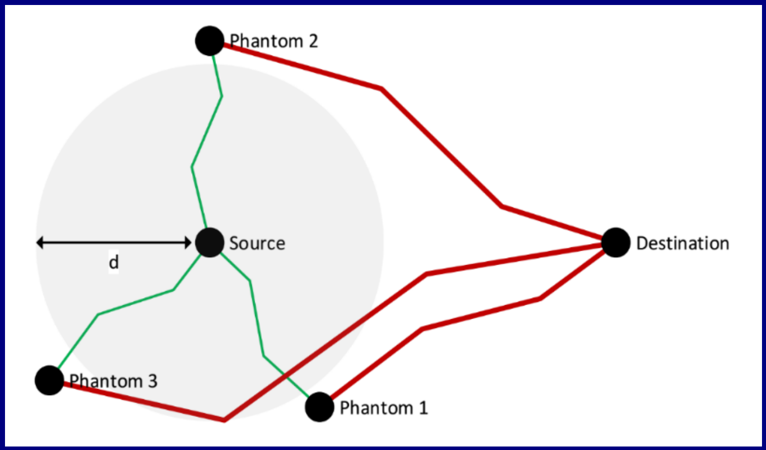
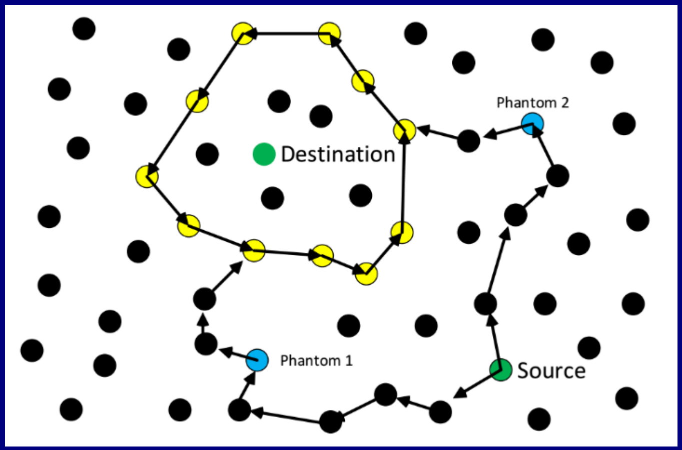
Intractability

- Source and destination location privacy (Panda-hunter game)

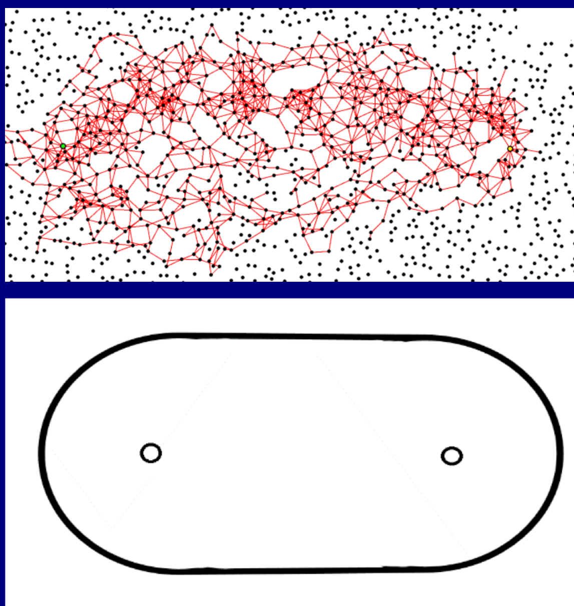


- Phantom/Circular Ring Routing



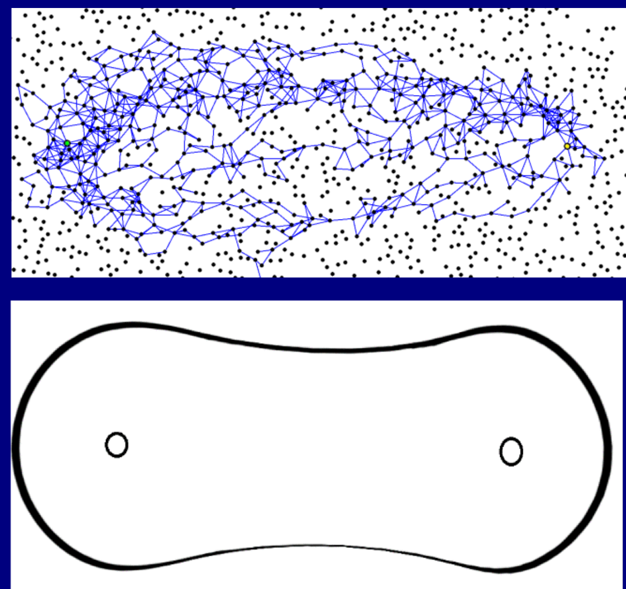


Probabilistic/Controlled Random



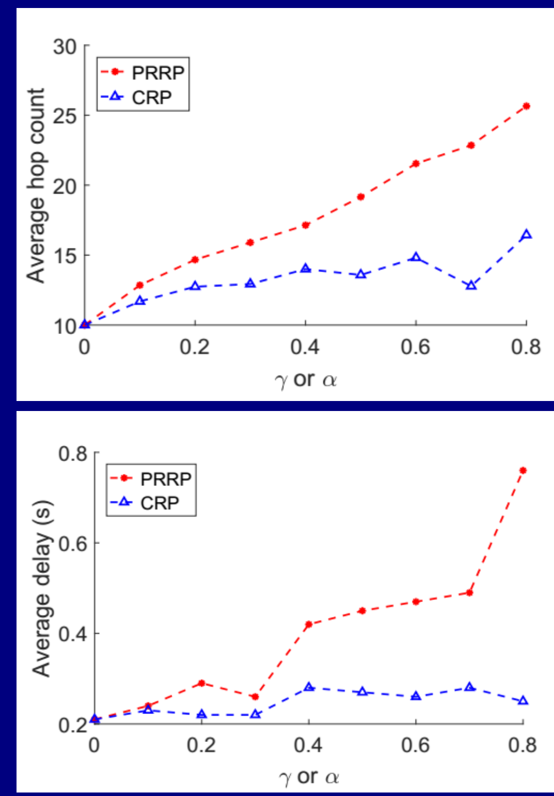
Probabilistic Random Routing (PRRP)

- More spread out packets
- Higher hop count and delay



Controlled Random Routing (CRP)

- Less spread in the middle
- Lower hop count and delay



NS3 Simulation

Adversary Model

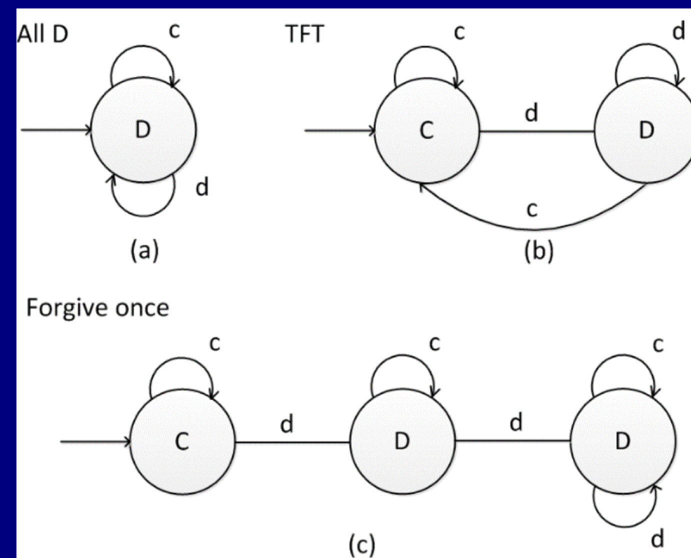
- Kerckhoffs's principle: system is public knowledge
- It is unclear how smart an adversary can be
- Traffic analysis challenge: algorithm + big data
  - An adversary can use a sophisticated ML method
  - An adversary can use compressive traffic analysis (CCS 2017)

    Perform traffic analysis on compressed features instead of raw data

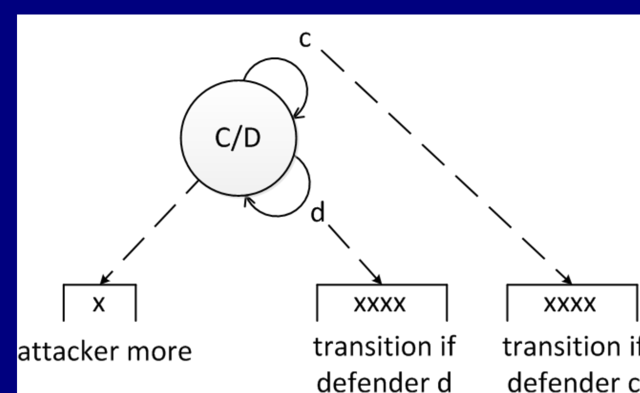
Adaptive Strategic Learning

- Repeated prisoner's dilemma
  - Cooperate (C) or Defecting (D)
  - Payoff metrics between 1 and 2

$$\begin{array}{c} \\ C_1 \\ D_1 \end{array} \begin{array}{c} \begin{array}{cc} C_2 & D_2 \end{array} \\ \begin{pmatrix} 3,3 & 0,5 \\ 5,0 & 1,1 \end{pmatrix} \end{array}$$

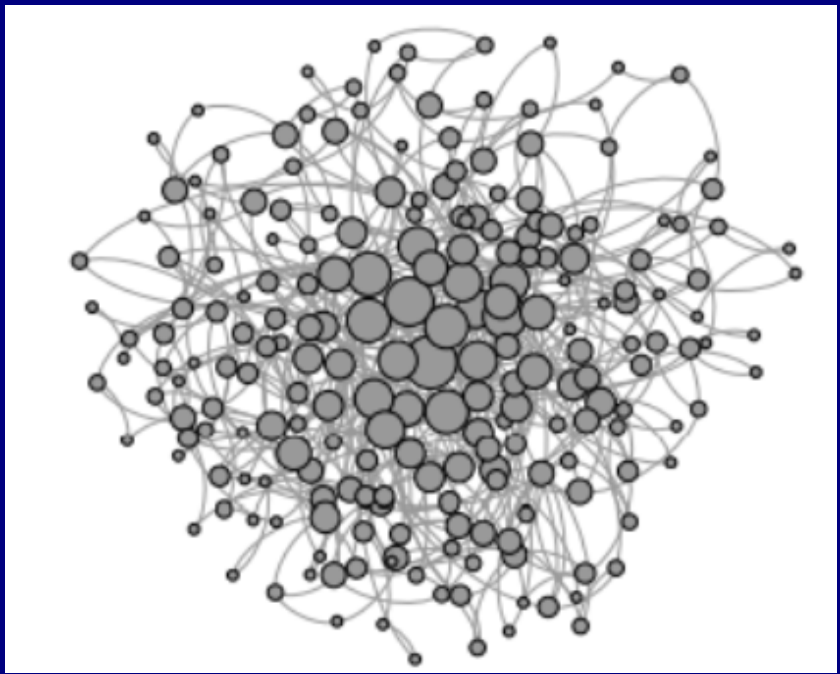


- Genetic algorithm: mutation and crossover
  - 148 bits with 16 recent states: chromosomes
- From Moore machine to timed automata
  - *Adversary's learning through timing analysis*
  - Fitness levels with imperfect information



Adaptive Changes in Structure Hierarchy

- Hierarchical military command chains
- Network hierarchy
  - SDN controllers: load balance and fault tolerance



Self-Organized Systems

Theory community

- Dijkstra's self-stabilizing system (Dijkstra, 1974)
  - An illegitimate state (caused by some *perturbations*) can be changed back to a legitimate state in a finite number of steps

- *How can we handle the long convergence time that usually occurs in dynamic labeling in a distributed solution?* (ICDCS 2017)

J. Wu, "Uncovering the Useful Structures of Complex Networks in Socially-Rich and Dynamic Environments" Proc. of IEEE ICDCS, 2017.

Self-Organizing Solutions

Local decision

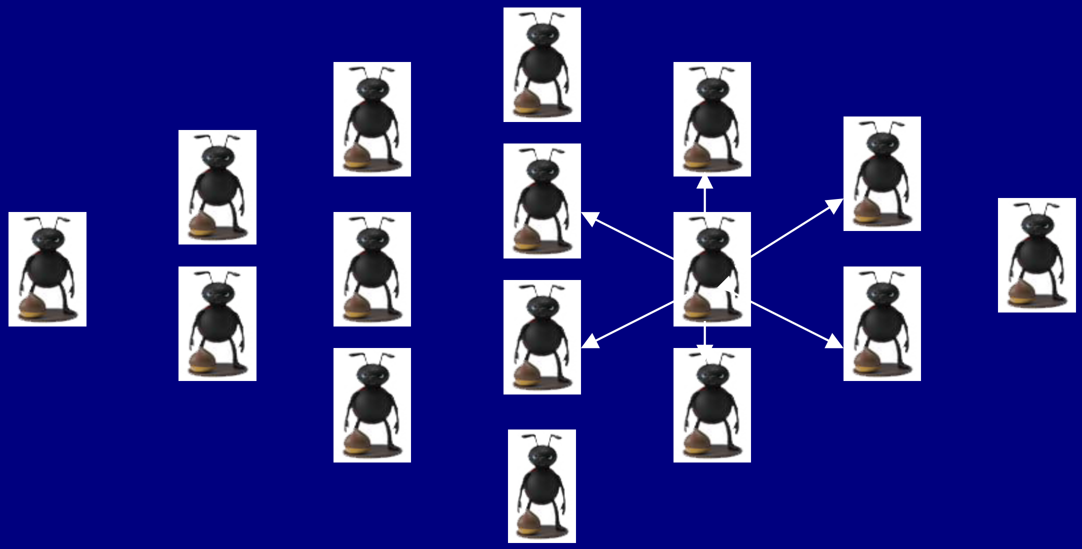
- P2P and simple interaction (mostly local and without sequential propagation)

Global functionality

- Adaptive, robust, and scalable

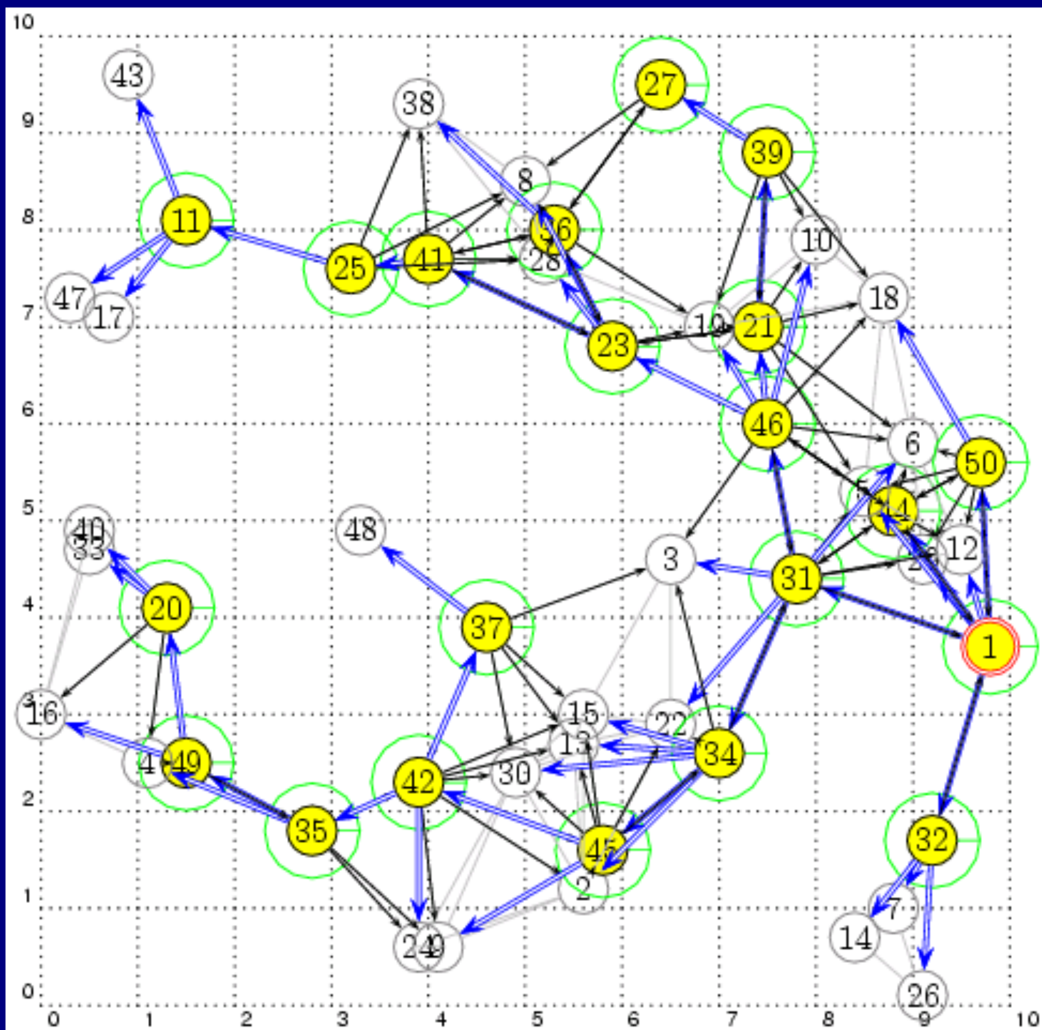
Principle

- P_1: Local interactions with global properties (scalability)
- P_2: Minimization of maintained state (usability)
- P_3: Adaptive to changes (self-healing)
- P_4: Implicit coordination (efficiency)



Agility

Broadcasting



Local decision:

backbone nodes

based on node priority (ID, degree, energy)

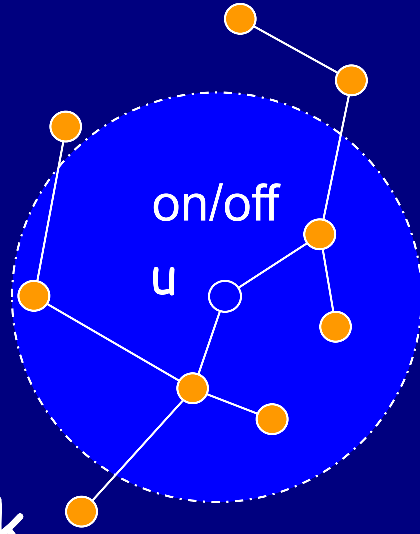
Global properties:

Connectivity

Coverage

Self-Healing

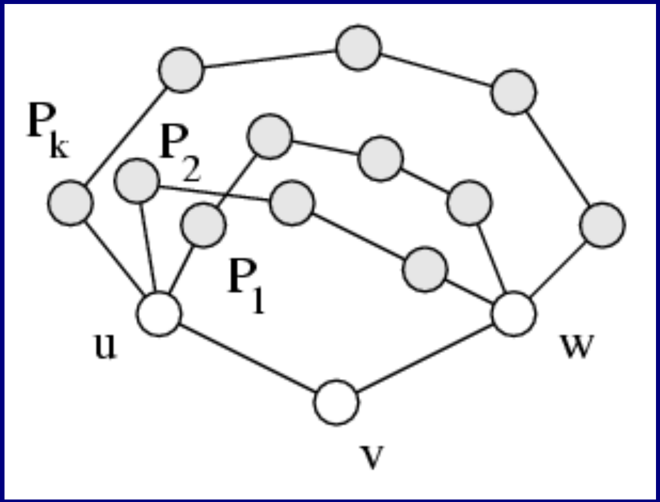
- *How can we deal with the complexity of building a structure along with a change of topology?* (ICDCS 2017)

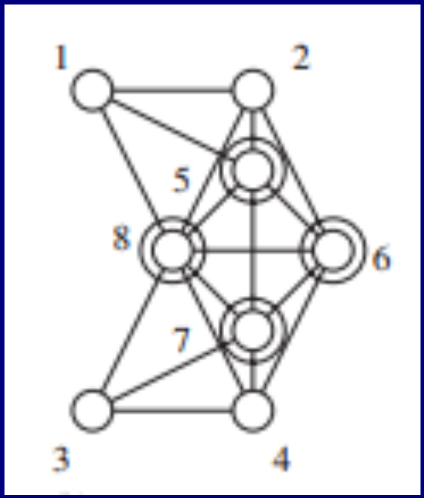


- Switched-on/off nodes
  - Status changes in 1-hop/2-hop neighbors only
- Seamless integration in a dynamic network
  - Iterative application of a local solution

Resiliency

- Exploiting redundancy: *K-connected & K-dominated*
  - Non-backbone node: if any pair of its neighbors are connected by a path of higher priority nodes
  - Non-backbone node: K node-disjointed paths for any neighbor pairs





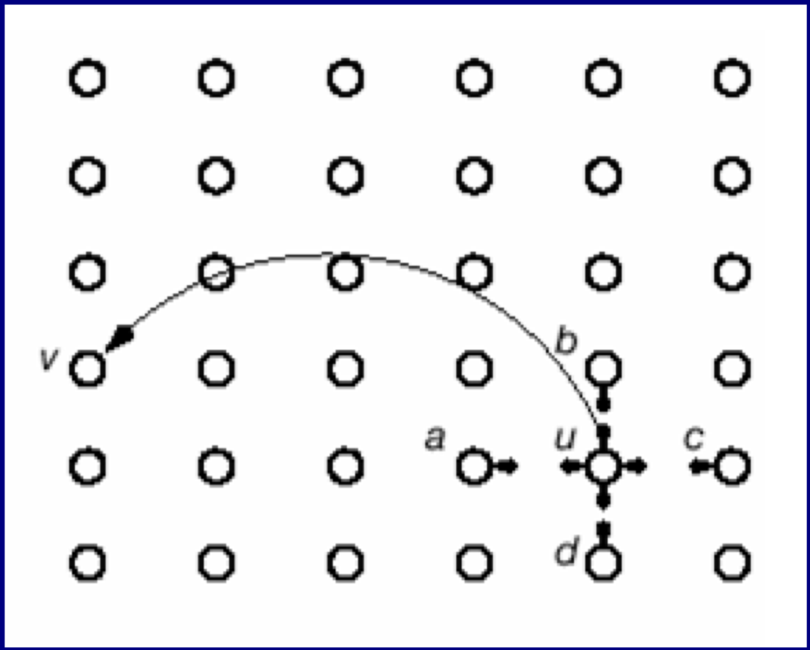
  - Moving target defense: IP mutation

Extensions

- Backbone marking works well in small-world networks
- In addition to geometric graphs

P	*CC*	*l*	*Backbone*
0.01	0.96	0.82	1.05
0.02	0.95	0.75	1.08
0.03	0.91	0.7	1.1

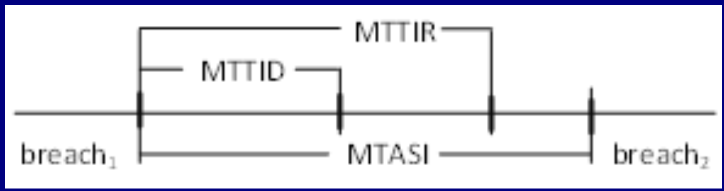
- *P*: percentage rewiring
- *l*: average path length
- *CC*: clustering coefficient



Performance-Security Tradeoff

Dependability includes security

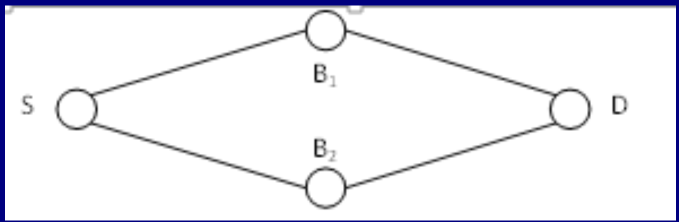
- Mean time between security incidents (MTBSI)
- Mean time to incident discovery (MTTID)
- Mean time to incident recovery (MTTIR)



Performability: work completed before the next security breach

Degradation

- B_1: Level 1 breach, 1,000 hrs
- B_2: Level 4 breach, 5 hrs



Human factor in discovery and recovery

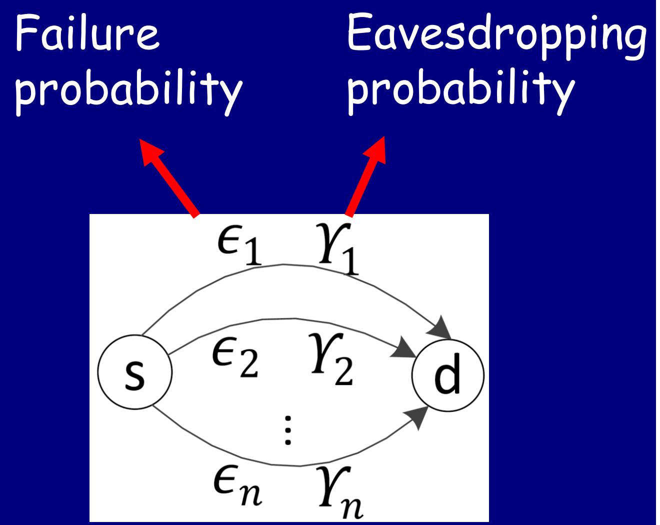
Conclusions

- Importance of intractability
  - Capability of an adversary
- Importance of self-organized design
  - Basic principles and challenges
- Future
  - A better (graph) model for dynamic networks
    - Intersection graphs and time-evolving graphs
  - Science of security (S & P 2017)
    - Induction and deduction

Network Coding

- Linear combinations of packets

$$
\begin{cases}
q_1 = \alpha_{1,1}p_1 + \alpha_{1,2}p_2 + \alpha_{1,3}p_3 \\
q_2 = \alpha_{2,1}p_1 + \alpha_{2,2}p_2 + \alpha_{2,3}p_3 \\
\vdots \\
q_k = \alpha_{k,1}p_1 + \alpha_{k,2}p_2 + \alpha_{k,3}p_3
\end{cases}
$$

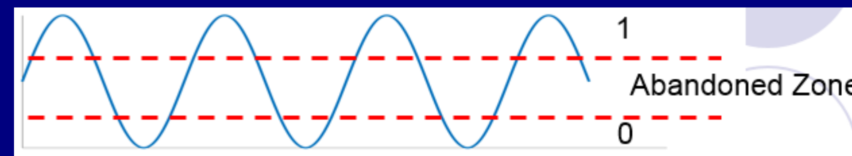


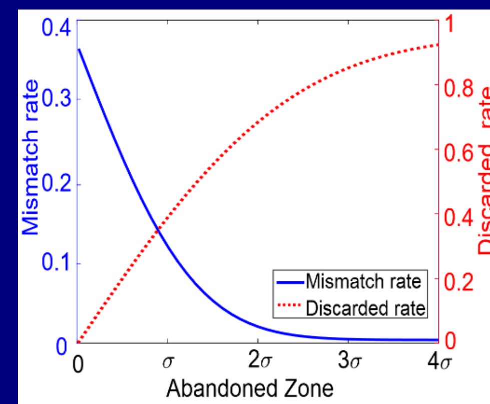
- Trade-off: security and fault tolerance (ICCCN 2017)
  - Active vs. passive: Byzantine vs. eavesdropping
  - More transmission: more robust, but more vulnerable
  - Low-complexity cryptography: encrypts coefficients only
- Inter-layer coding: efficiency/reliability trade-off (ToN 2016)

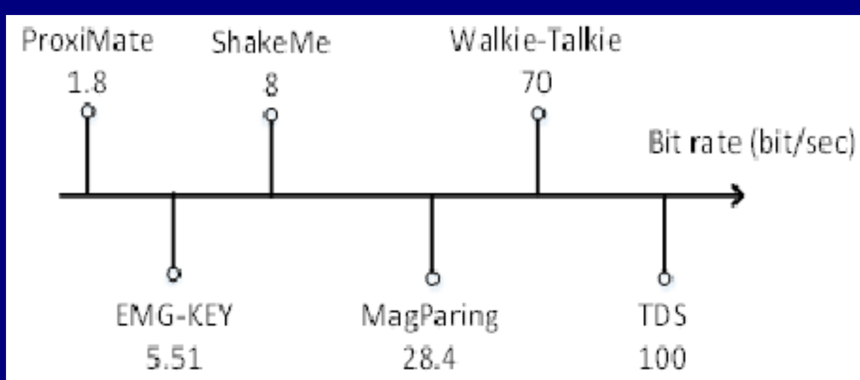
$\alpha_{1,1}p_1 + \alpha_{1,2}p_2 + \alpha_{1,3}p_3$	$\alpha_{1,1}p_1$
$\alpha_{2,1}p_1 + \alpha_{2,2}p_2 + \alpha_{2,3}p_3$	$\alpha_{2,1}p_1 + \alpha_{2,2}p_2$
$\alpha_{3,1}p_1 + \alpha_{3,2}p_2 + \alpha_{3,3}p_3$	$\alpha_{3,1}p_1 + \alpha_{3,2}p_2 + \alpha_{3,3}p_3$

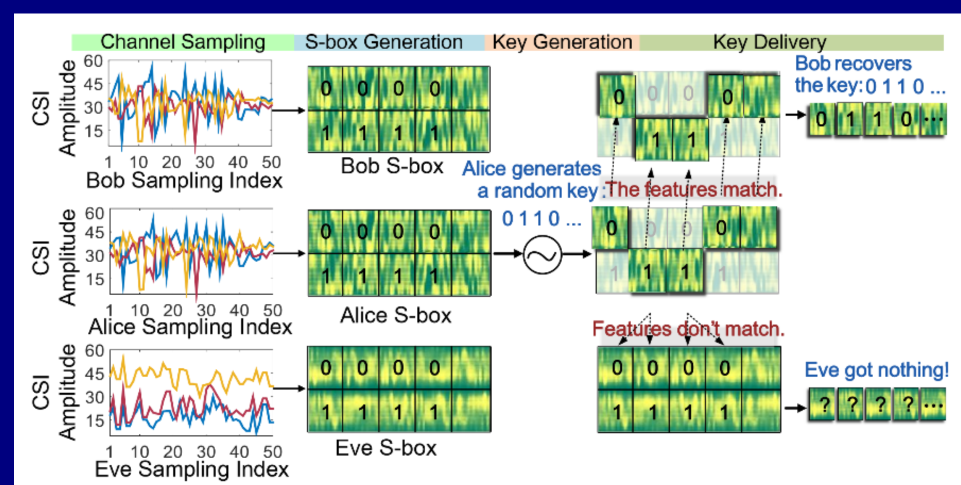
Key Generation

- Random signals (which signal?)
  - Shaking trajectory (ShakeMe, IUCC 2015)
  - Gait (Walkie-Talkie, IPSN 2016)
  - Magnetic signals (MagParing, TIFS 2016)
  - Electromyography (EMG-KEY, Sensys 2016)
  - Ambient wireless signals (ProxiMate, Mobisys 2011)
  - Channel state information (TDS, CCS 2016)
- Quantization
  - Performance and security trade-offs
  - Usability

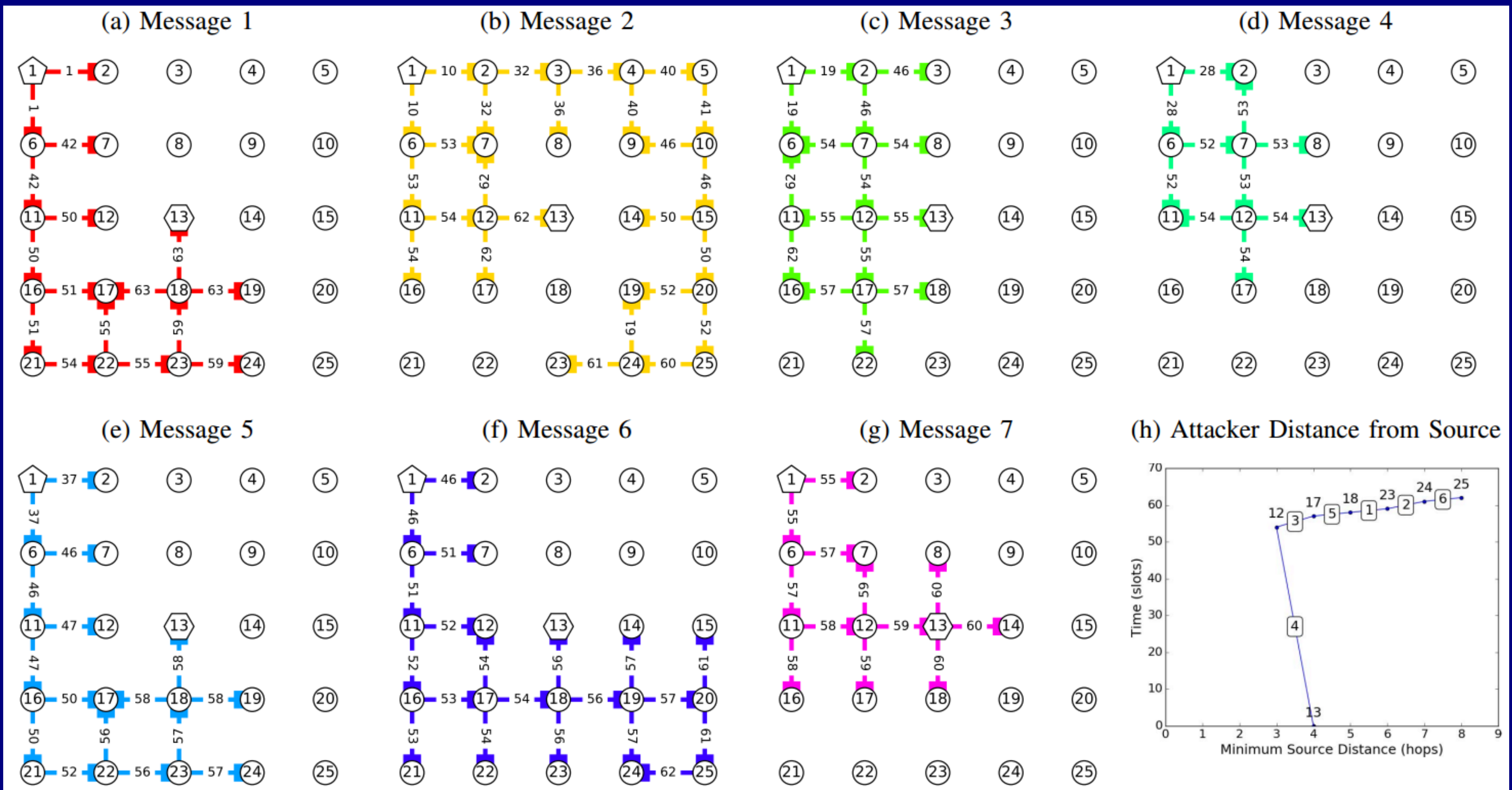








Near-Optimal ILP (Trustcom 2017)



Backbone Local Marking

Marking a backbone locally in MANETs

- A node is a backbone node if it has two unconnected neighbors
- Non-backbone node: if its neighbor set is covered by several connected and higher priority nodes