Theme 2
Establishment of Networked Symbiosis Environment Architecture

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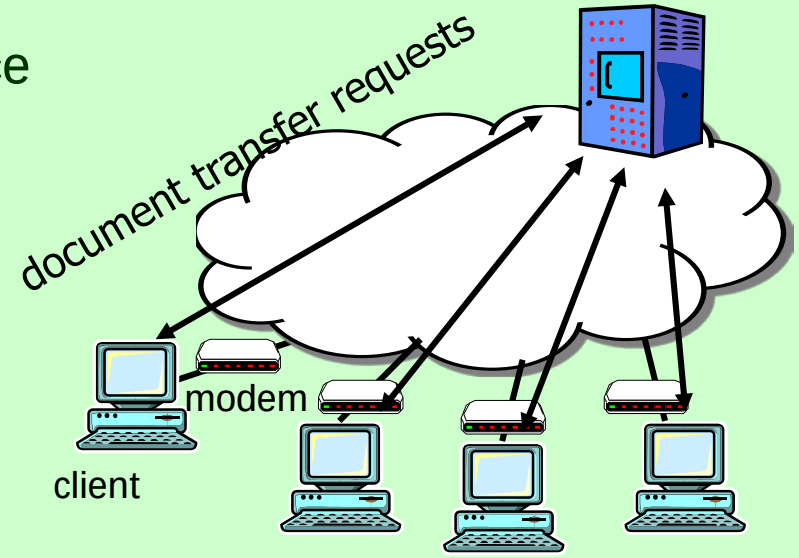
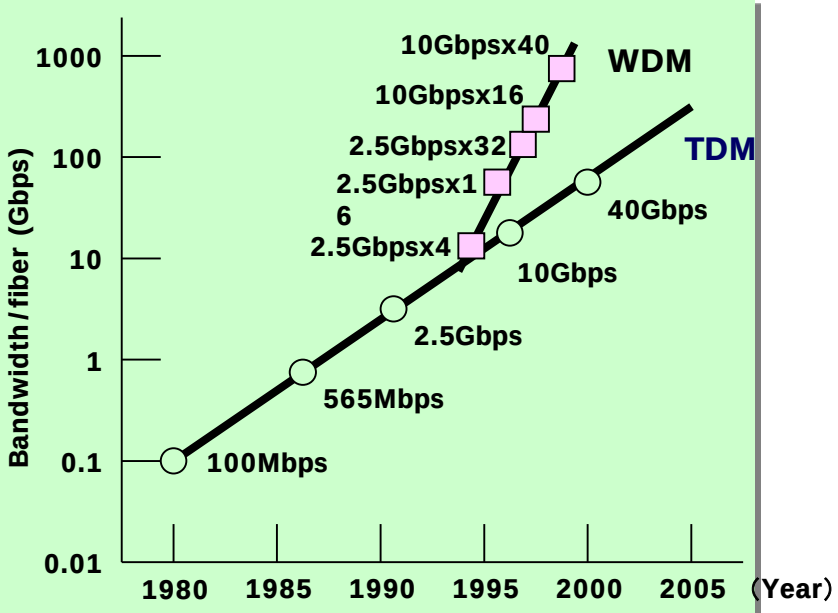
Traditional Network is ...

- Network resource management assumes existence of network resources permanently (or, at least during the connection)
  - IntServ offers a fixed amount of resources (bandwidth) between source/destination pair
  - DiffServ offers the relative resources to active users
  - Route must be fixed during the connection
- The Web server at the far end provides the service to the users (server/client model)

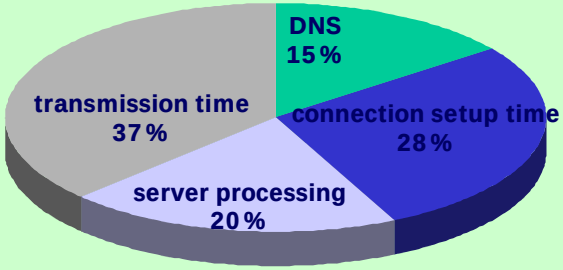


Problems of Web-based Computing Paradigm

- Excessive load at Web servers
  - fixed roles of servers and clients
    - the clients connect to ISP via modems when necessary
  - server bottleneck (CPU, memory and link)
  - proxy cache and server parallelization may alleviate the problem, but the effect is limited
- Possibility of new computing paradigm
  - broadband access via ADSL/FTTH
    - Total resources in the world: 10 billion MHz, 10Pbytes (assuming 1 million computers)
  - explosive growth of bandwidths
  - bottleneck is increasingly moving to end hosts



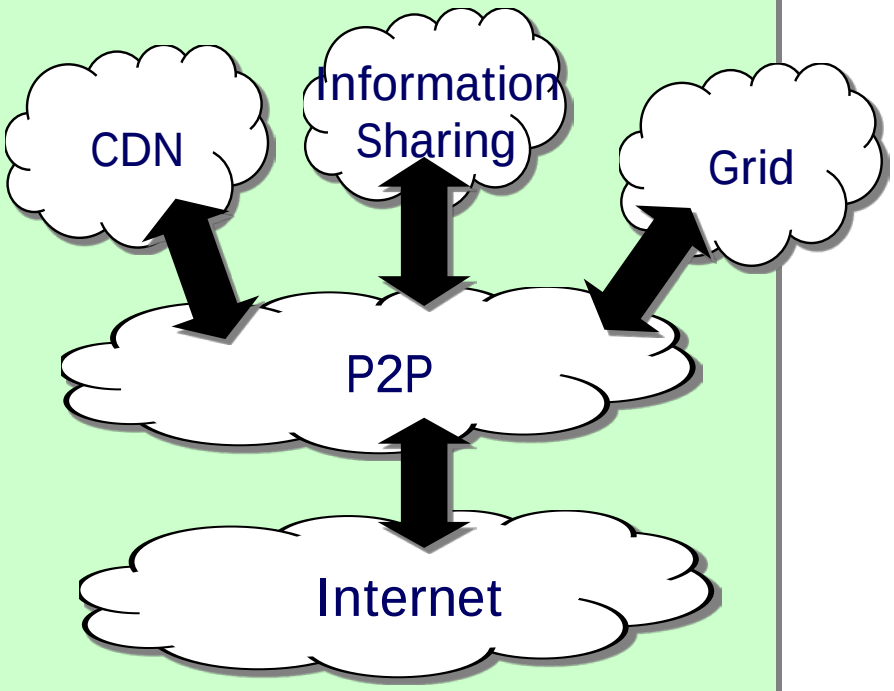
Expenditure of typical document transfer time



Produced from ftp://www.telcordia.com/pub/huitema/stats

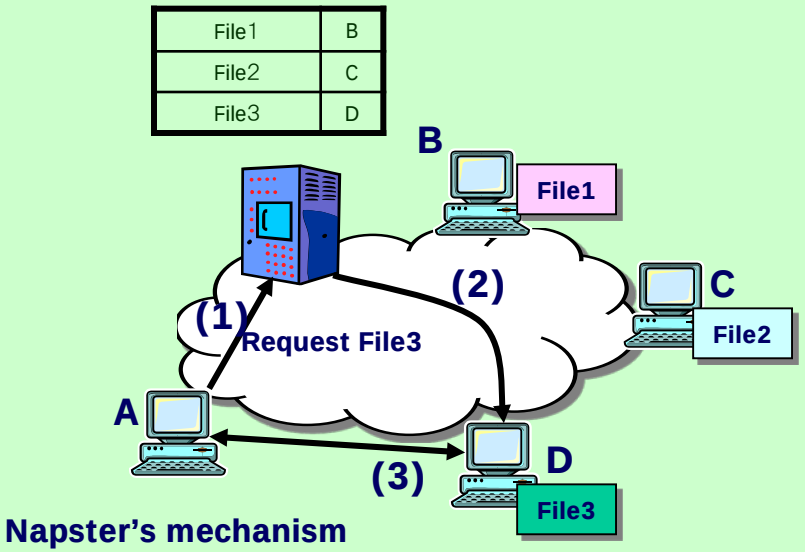
P2P as Networking Infrastructure

- Shares CPU and storage in a distributed environment
  - Grid Computing
- Shares devices and sensors
  - Sensor Network
- Direct communication between users
  - Ad hoc Network
- Information sharing
  - P2P itself
- Realizes information infrastructure and application platform by P2P networking architecture; P2P acts as an overlay network for resource findings

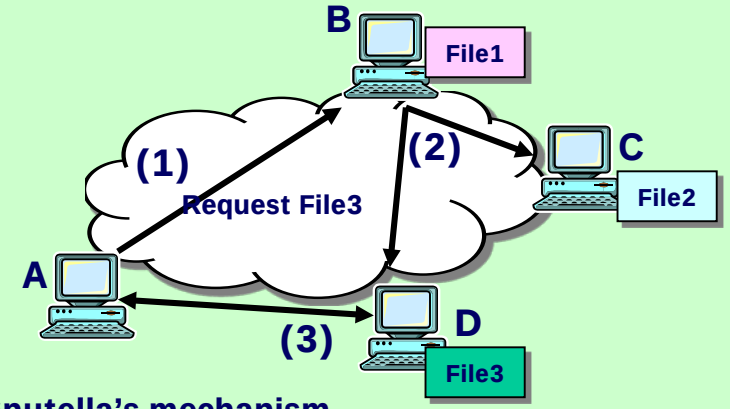


Information Findings in P2P

- Hybrid P2P
  - Information on peers (meta information) is maintained at the server
  - Advantages
    - fast search
    - stores search/information retrieval for next use
  - Disadvantages
    - load increasing at servers
    - robustness is weak
- Pure (Unstructured) P2P
  - Advantages
    - no servers
    - robust
    - anonymity (?)
  - Disadvantages
    - scalability: 6^{10} query messages for nodes with six degrees (in average) if TTL=10



Napster's mechanism



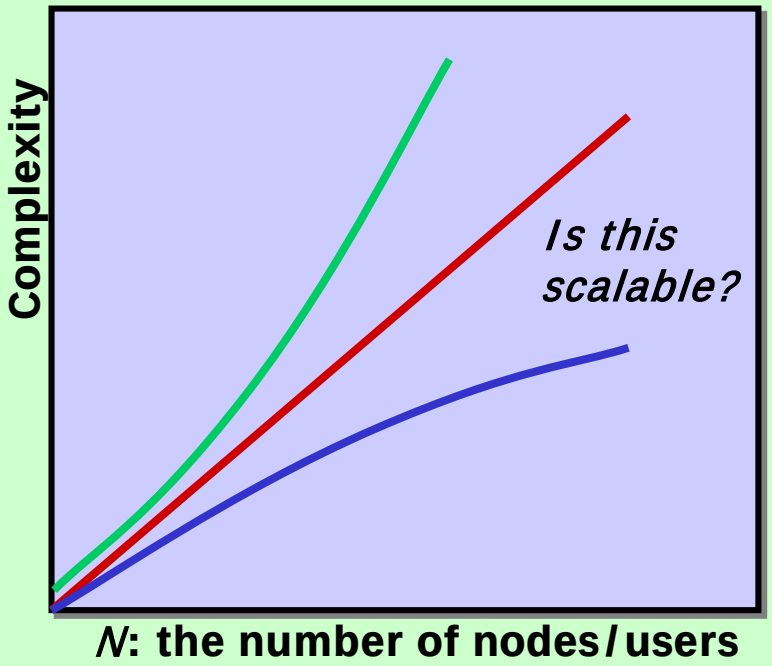
Gnutella's mechanism

Three Targets of New Network Architecture

- Scalability
  - to allow an explosive increase of network users, client devices, and network nodes (routers)
- Variety
  - to get along with varying networking technologies from still narrow wireless network to over 10Gbps high-speed backbone network, and changing nature of traffic (in volume and time-dependent behavior) that we cannot anticipate
- Mobility
  - to react to physical movement of users, and to allow frequent changes of available network resources
- A key technology is ADAPTABILITY of end hosts (not network). Network should provide mechanisms to support the adaptability.

What is Scalability?

- The network control of O(N) is scalable?
  - If N represents the # of nodes, the answer could be yes
  - But, the answer is probably "no" if N does the number of users
  - For the end-to-end communications, O($\sqrt{N}$) is desirable

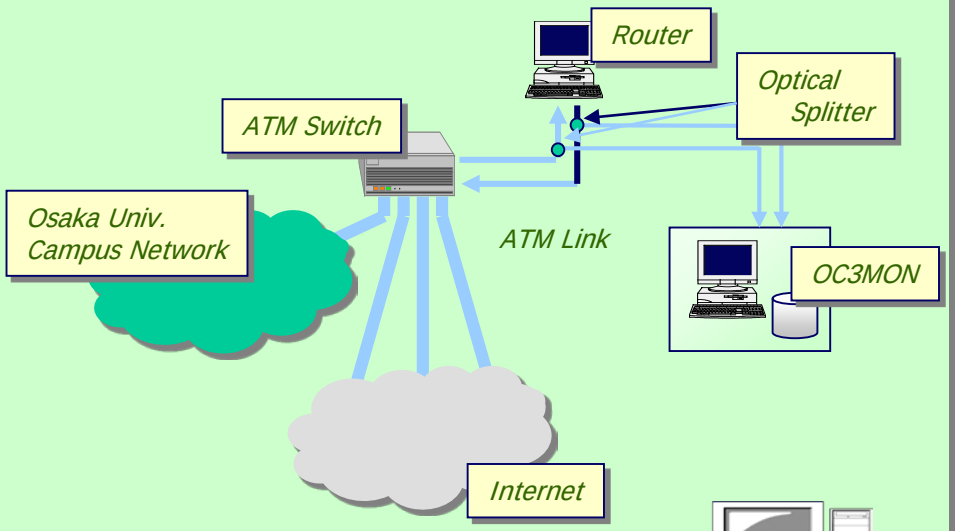


End-to-End Argument is still Important

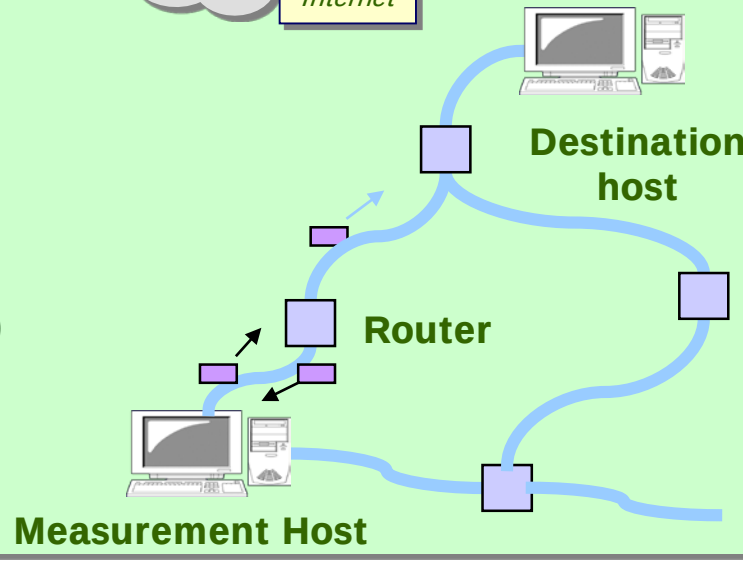
- We should go back to the early principle of the Internet: *End-to-end arguments*
  - The network provides the best-effort service for the end-to-end connectivity
  - The user (end hosts) should be equipped with a capability of having an adaptability to the current status of the network, including
    - topology, traffic load, etc.
- A new technology is traffic measurement for end hosts to acquire the current status of the network
  - RTT & packet loss probability
  - available bandwidth

Traffic Measurement Approaches

- Passive measurement
  - observe the traffic flow
  - point estimation



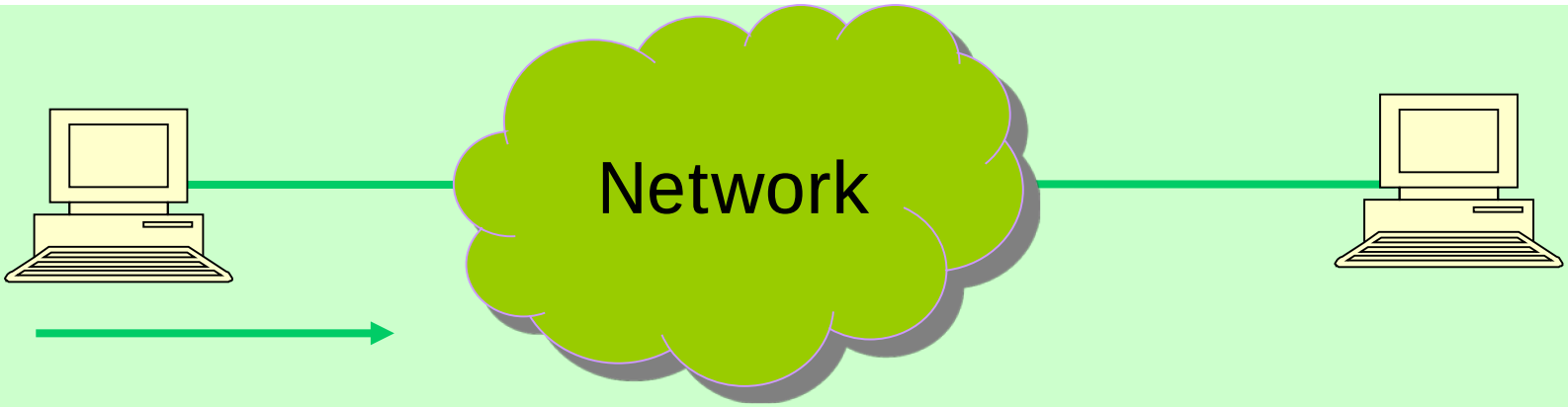
- Active measurement
  - exchanges packets between source/destination host pair
  - sends packets repeatedly for statistical guarantees
  - estimates the capacity (pathchar) or available bandwidth (cprobe) on each link



Ongoing Researches (1)

- Inline Network Measurement
  - Passive measurement: point estimation
  - Active measurement: wastes the bandwidth
  - Inline measurement investigates the network status during the data transmission by TCP, which can be used for later transmission or background traffic
- Control Theoretic Analysis of TCP Network
  - Classical approach is queueing theory/queueing network theory, that treat feed-forward systems
  - TCP is essentially closed loop, i.e., feedback system
    - Interaction between network and TCP connection?
    - Routers behavior?
- Incremental Network Dimensioning for Unpredicted Traffic Growth
  - Currently, we apply it to IP over WDM (GMPLS)

Mechanism of Inline Network Measurement



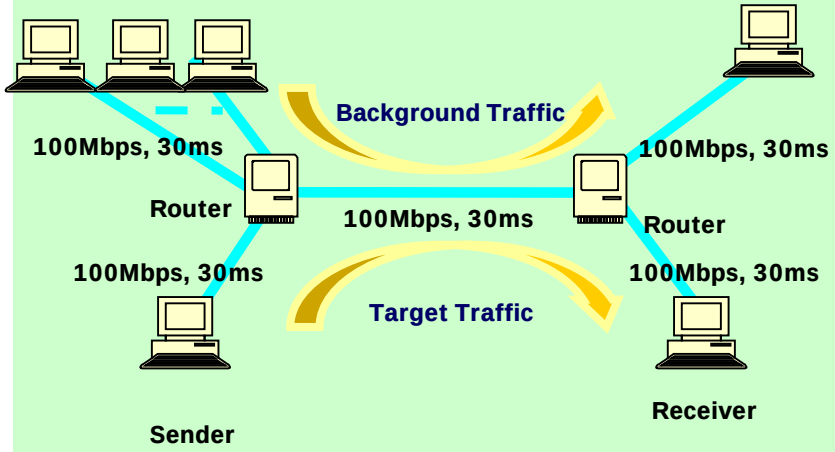
1. Transmits a small bunch of packets

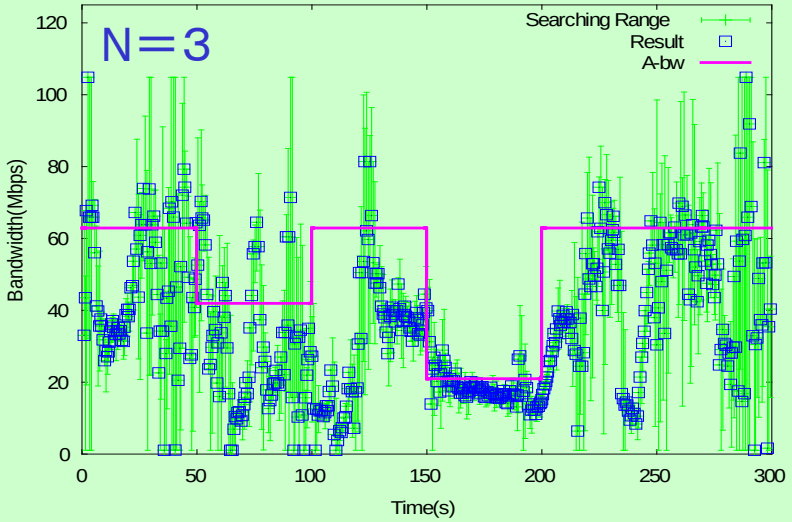
2. Returns ACK for each packet

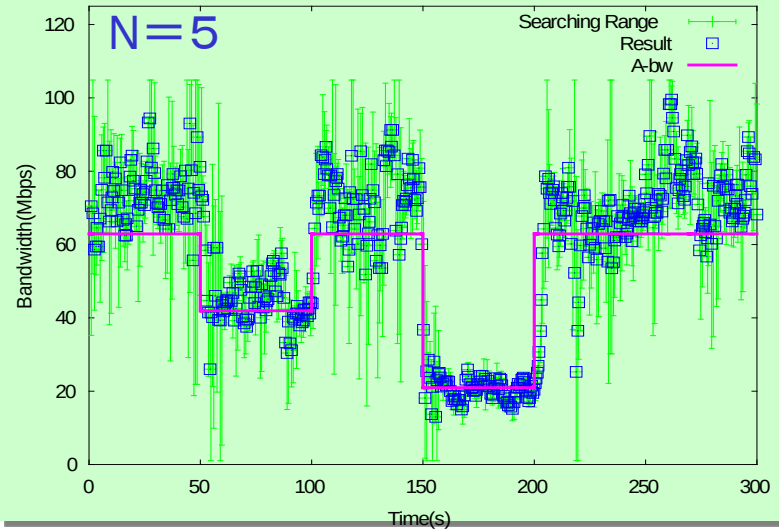
3. Estimates the available bandwidth by utilizing returned ACK

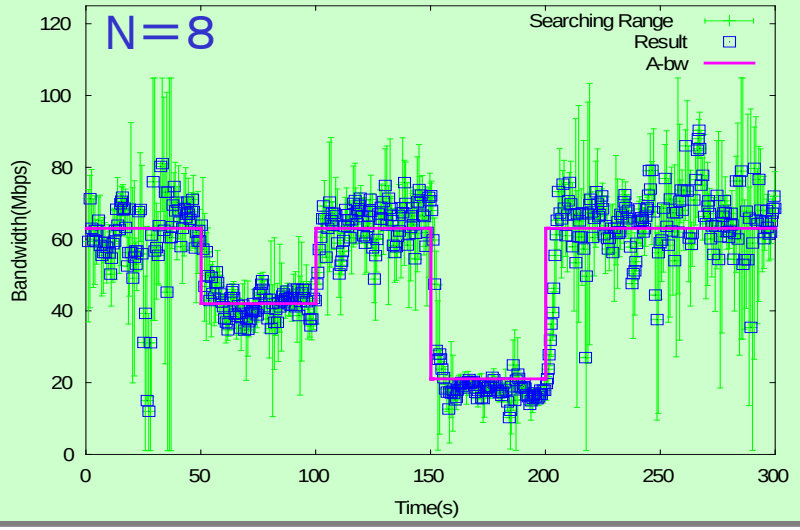
Can be integrated into TCP since it tends to transmit packets bursty within the window

Simulation Experiments



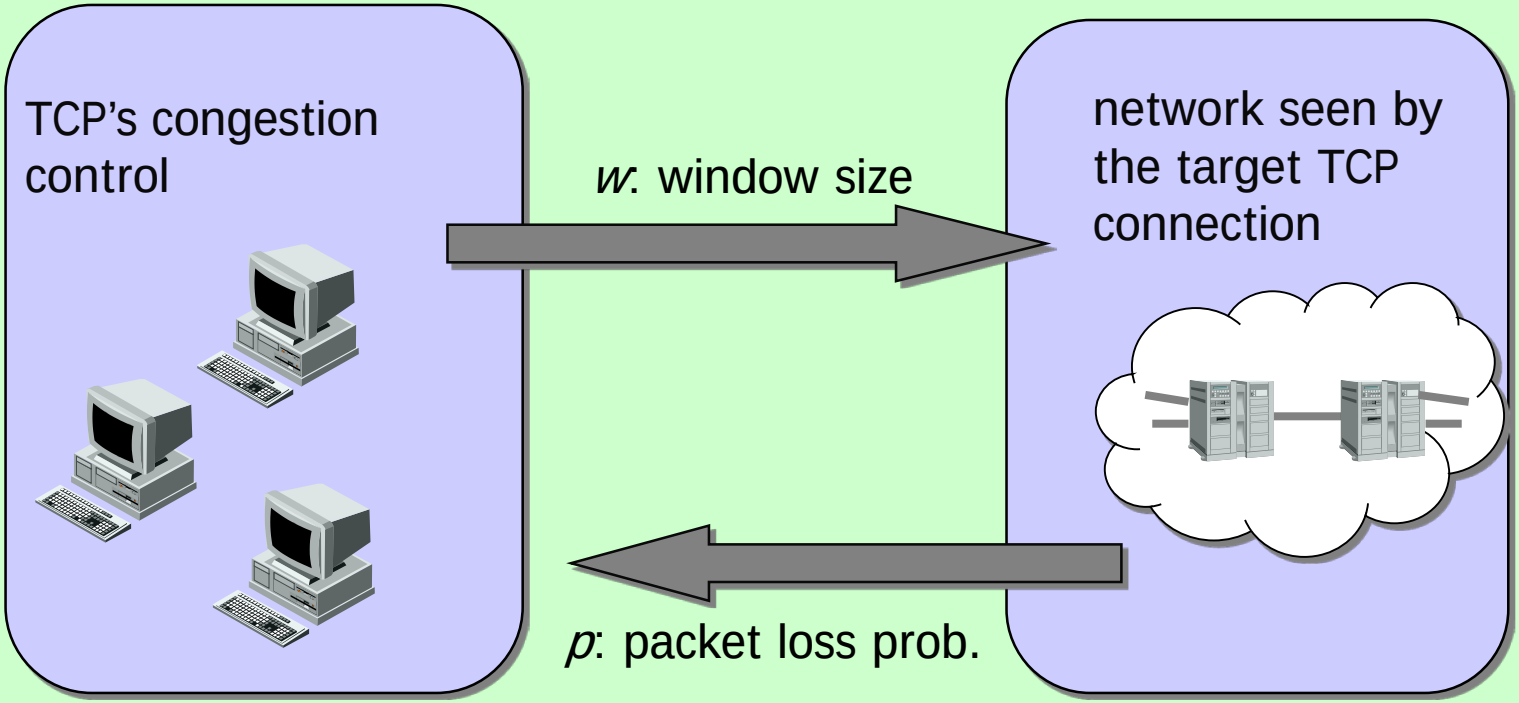






Control Theoretic Approach for the Internet

- Models Interaction between TCP connections and the network as a feedback system
  - Window-based congestion control for TCP is a feedback system



Transient Performance of Feedback System

- Relations between window size and packet loss probability

$$w(k+1) = f(p(k)), p(p+1) = g(w(k))$$

- We get eigenvalues of the state transition matrix A, which determines the system stability and transient characteristics:

$$x(k) = \begin{bmatrix} w(k) - W^* \\ p(k) - p^* \end{bmatrix} \quad \text{and} \quad x(k+1) = \mathrm{A}\, x(k)$$

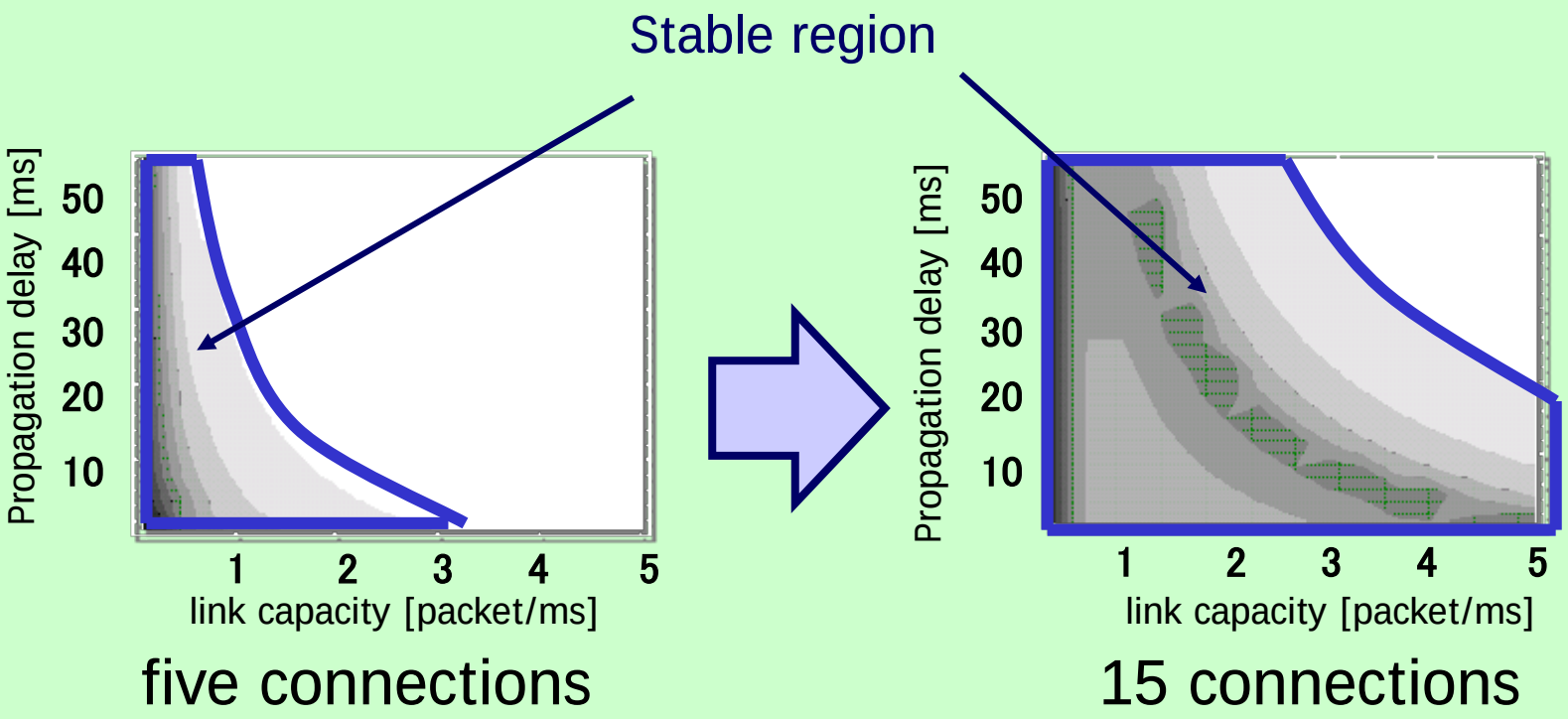
where w* and k* are equilibrium values

- Let s be the maximum modulus of eigenvalues.

$$s = \max_i(|s_i|)$$

- Then we have
  - $s < 1$: stable, $s > 1$: unstable
  - Transient performance becomes better by smaller s

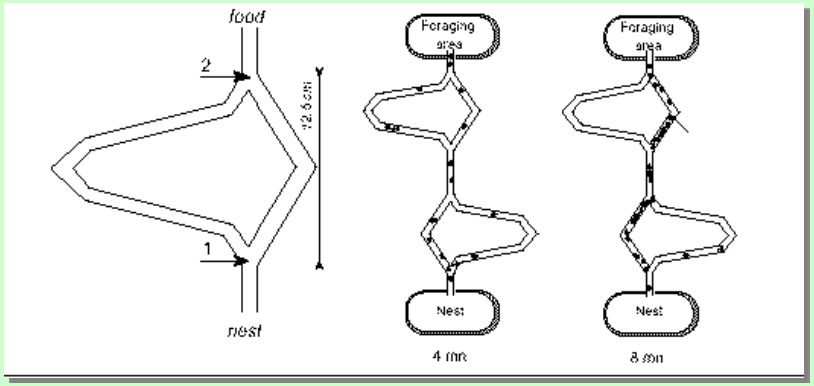
System Stability



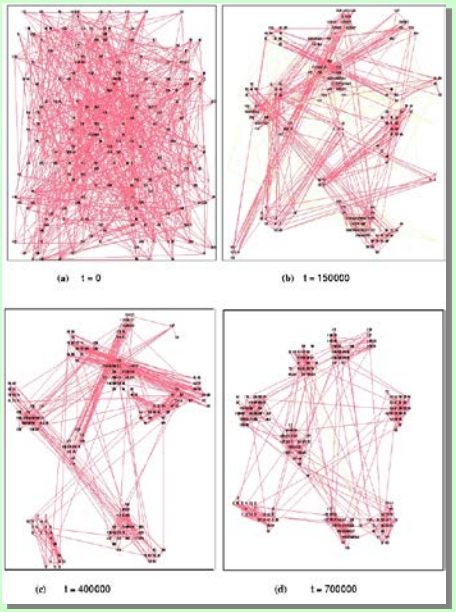
Stable region is increased

What Can We Learn from Ants?

- Three behaviors that we can learn from ants
  - foraging
    - Dorigo & Di Caro (2003)
    - can be applied to optimization problems;
  - division of labor
  - clustering
    - Kunts, Layzell & Snyers (1997)
    - seems to be able to be applied to self-organization



- To apply to the routing algorithm, we have two problems
  - blocking problem; how fast can we act against tear down of links
  - short-cut problem; how do we solve when new link is established?
  - Many solution approaches do exist, but those are ad-hoc. How do the ants solve the problems in actual?
- The other and more difficult problem is how we can determine the parameters
  - velocity of ants, vanishing speed of pheromone, probability that the ants choose the other longer path, etc.
- Adaptability cannot be obtained by ants behavior(?)



What Can We Learn from Biology?

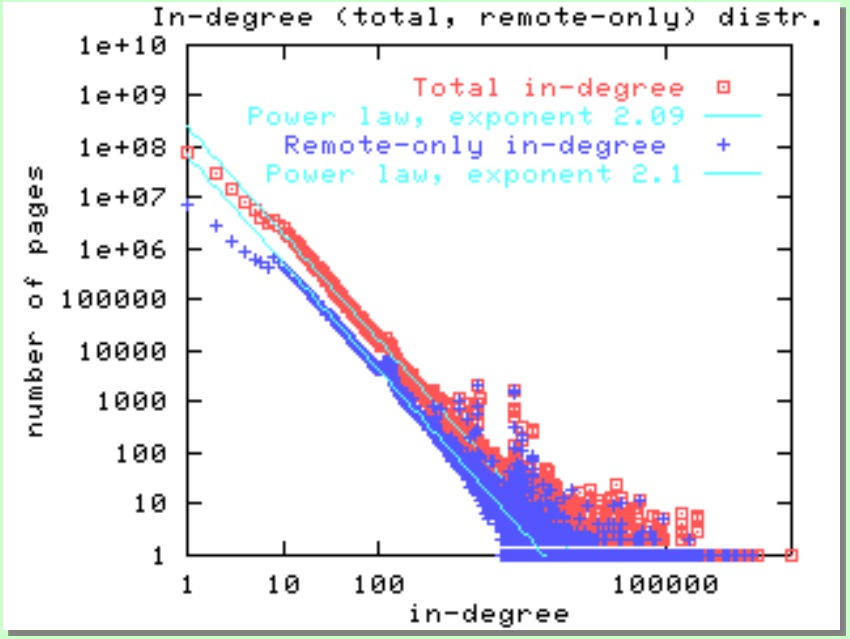
- Several Problems
  - It may not be best for solving optimization problems
  - Just an analogy to explain the procedure for seeking the solution or for control?
  - We need trial and error to find out an appropriate parameter set
    - just same as a genetic algorithm
- Why can ants do the things well?
  - It does not provide the best solution in terms of optimality and computational time
  - It means that it is not best in getting “adaptability”
  - Seems best for establishing robustness/fault tolerance against failure/fluctuation
  - We need to consider evolution when it is applied to a real world

Research Items

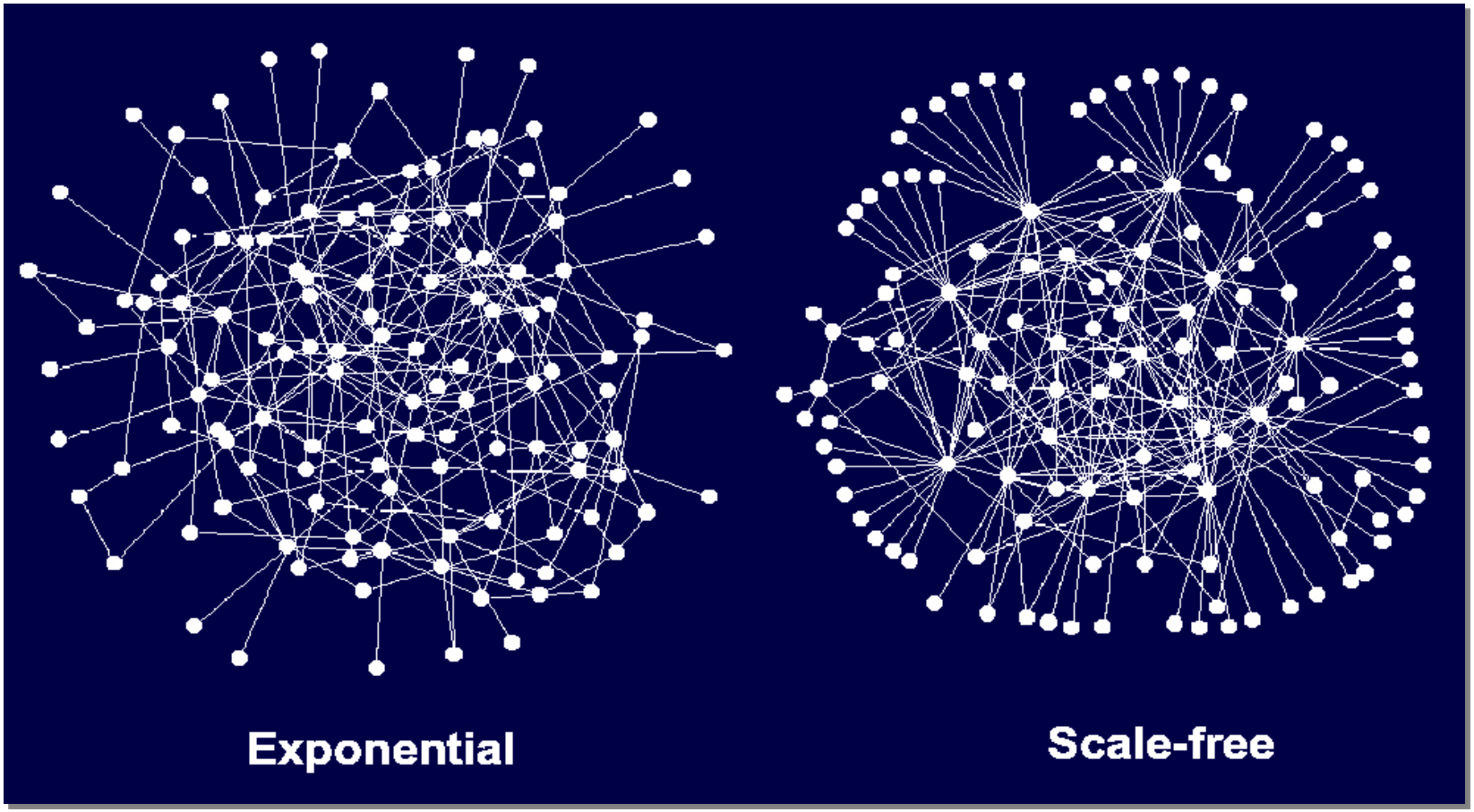
- Solves scalability problems in P2P and ad-hoc networks
  - Introducing hierarchical structure is one promising approach
  - We may use an analogy of ants for self-organizing hierarchy
  - Use local knowledge
- Power-saving in sensor networks
  - The approaches must be different by objectives of sensors
    - All devices should keep alive
    - Only a part of devices alive is sufficient
  - We may again use an analogy of self-organization mechanism in biology
- The Internet as a complex system
  - Metcalf's law again
    - The value of a network increases exponentially with the number of nodes.": $V(N) \sim N^2$, assuming combinatorial graph
    - Web created imbalance between clients/servers
    - End-to-end arguments and P2P again bring a combinatorial problem
  - Self-similarity and power-law have been "found." What is a cause of such a phenomenon?
  - Relation between optimality/convergence speed and robustness/tolerance?

P2P as Power Law Network

- Power Law Distribution
  - Probability density of event X: $P[X=x]=x^{-k}$
- Many observed examples
  - Human community (small world)
  - Citations of papers
  - The number of links connected to AS-level routers
  - The number of links included in Web pages

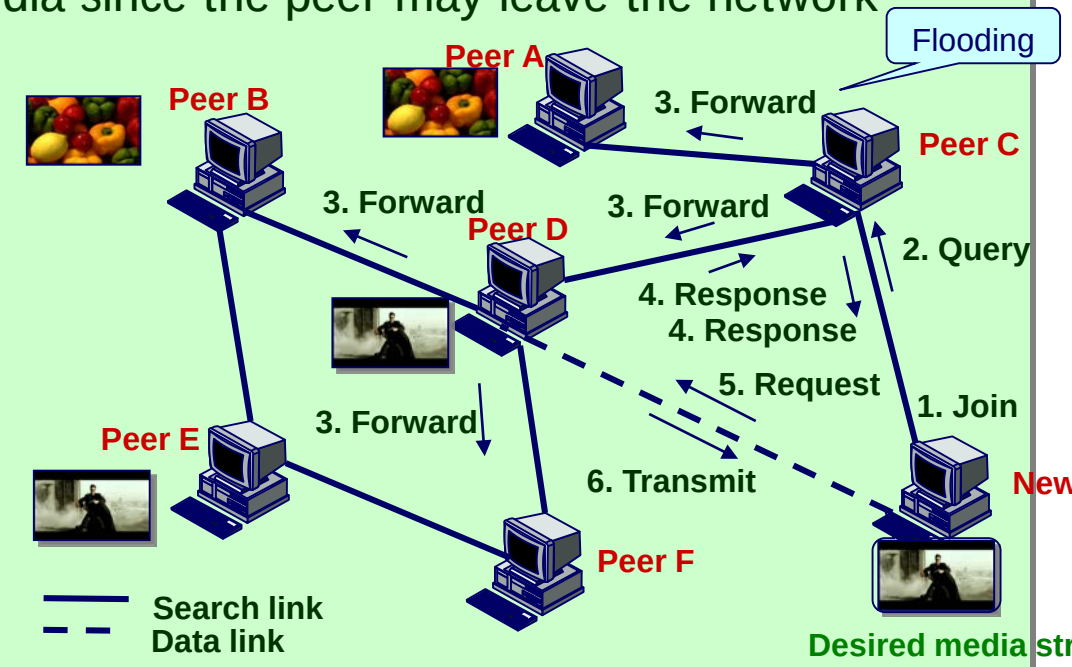


Visual Representation of Power Law Network



Ongoing Researches (2)

- Search Mechanism in P2P that follows Power-Law Property
  - In P2P environment, peers connects/disconnects very frequently
  - Cache mechanism is important, but its capacity is limited. Search mechanism taking into account the power law property is essential
- Scalable and Continuous Media Streaming on P2P Networks
  - Segmentation of media since the peer may leave the network during the playout
  - Cache mechanism can allow changing the search range, which resolves the scalability to some extent



Ongoing Researches (3)

- Mobile Agent System with Location Transparency
  - Distributed location management
  - Multi-plain logical network for various applications
  - Agent authentication for secure communications