# Herbivore: An Anonymous Information Sharing System

Emin Gün Sirer

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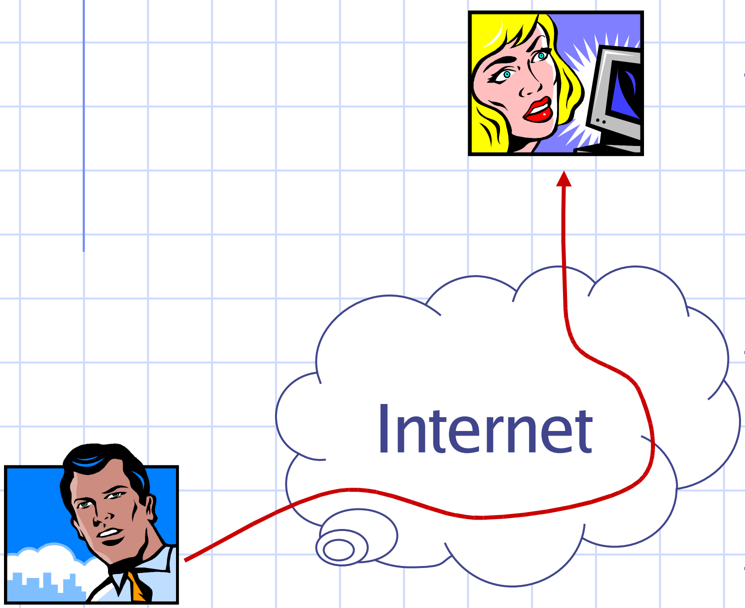
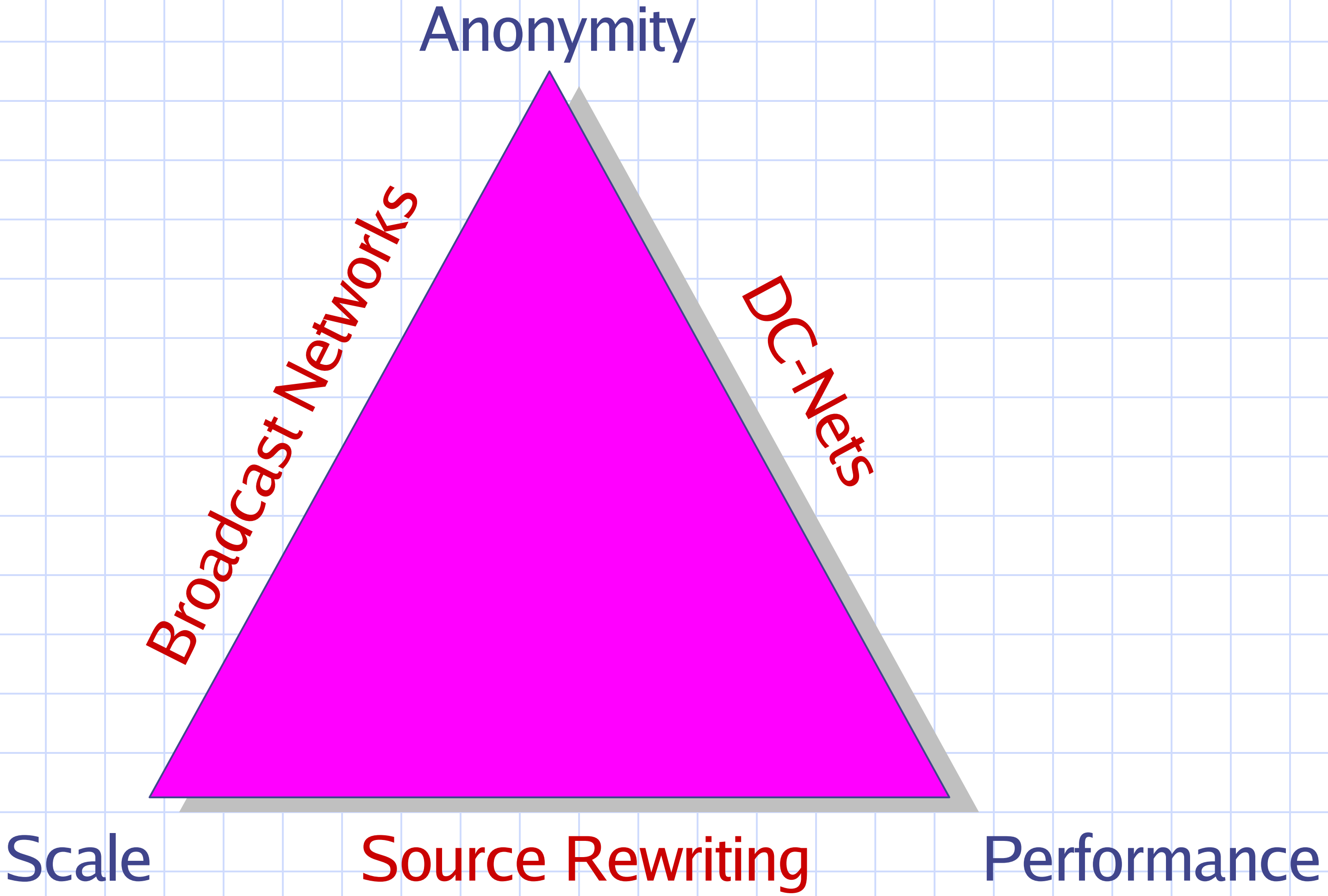
# Need Anonymity Online

- Current networking protocols expose the identity of communication endpoints

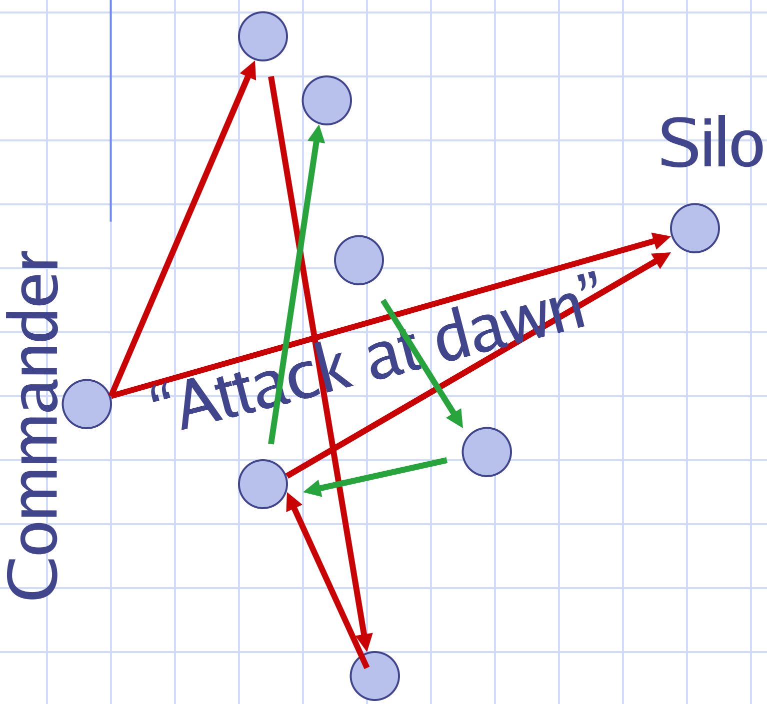



- Anyone with access to backbone Internet traffic can determine communication patterns
- Encryption helps conceal content, but not identity
- Constitutes a military vulnerability
  - Easy to determine C&C centers
- Opportunities for industrial espionage

# Goals

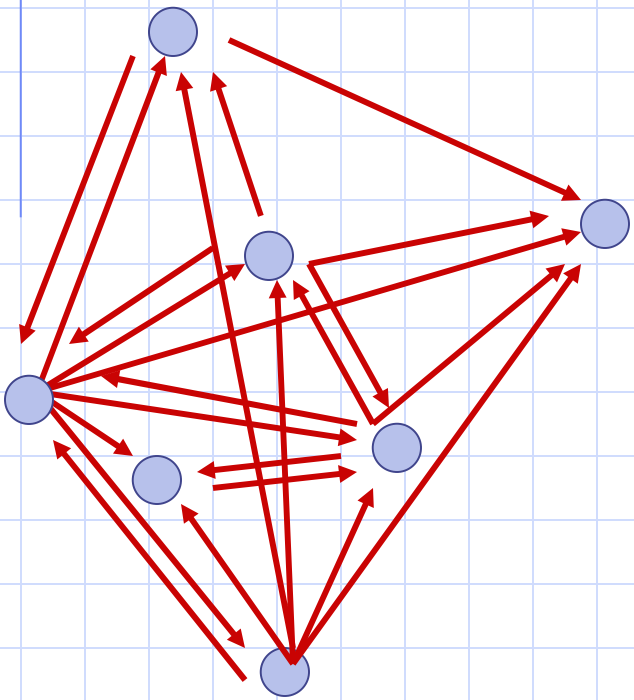

Anonymity
Broadcast Networks
DC-Nets
Scale
Source Rewriting
Performance

# Source Rewriting




- Packets sent through an intermediary to mask origin
  - E.g. MIXes, Crowds, Onion Routing, Tarzan, AP3B
- ☺ Long paths and time delays make it difficult to trace back
- ☺ Practical, implemented
- ☹ High latency
- ☹ A powerful adversary, through observations,

# Broadcast Networks

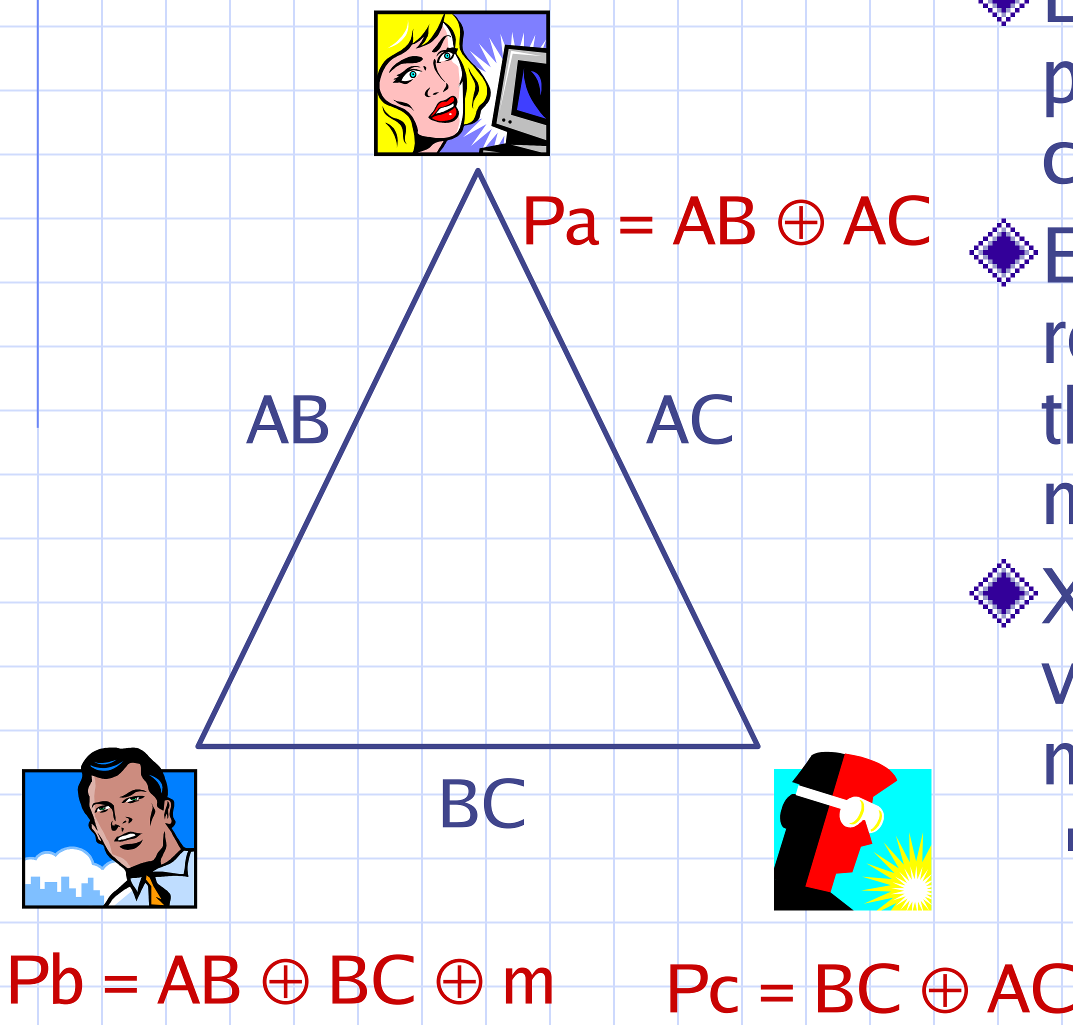


- Every node sends to every other node all the time
  - E.g. P5
- ☺ Strong anonymity: cannot tell who or when
- ☹ Must constantly send at peak bandwidth
- ☹ Low throughput
- ☹ High network load
- ☹ Never implemented

# Herbivore Overview

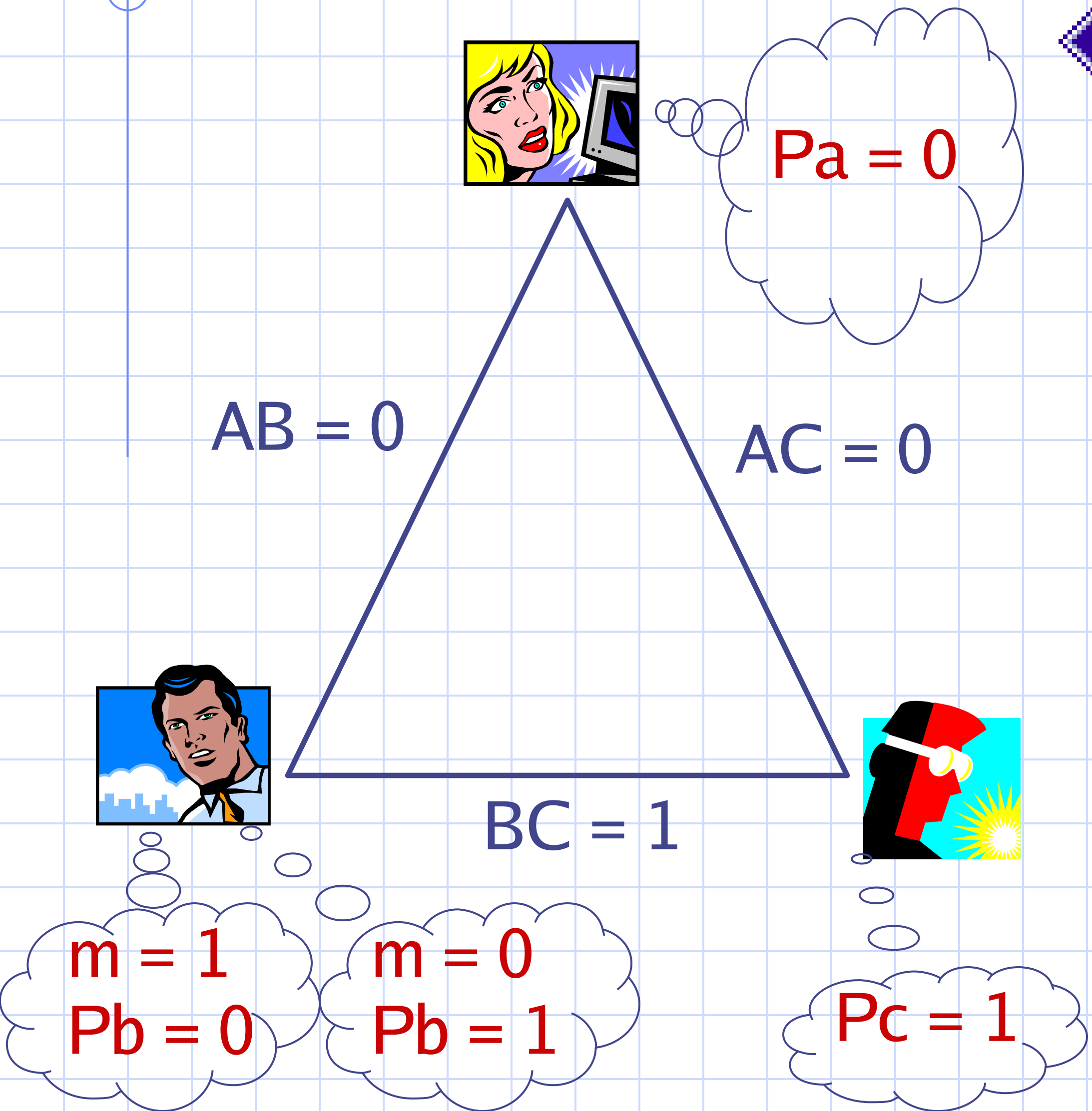
- Herbivore builds on dining cryptographer networks (DC-Nets)
  - Elegant scheme for anonymous communication [Chaum 1981]
- Strong anonymity guarantee
  - Even an adversary that has tapped the entire network and observed every packet cannot determine packet origin
- Herbivore makes DC-Nets practical
  - Efficient and scalable, with the same strong anonymity guarantee

# DC-Net Operation




- Every pair of participants tosses a coin in secret
- Every participant reports the XOR of all their coins and messages
- XORing all reported values reveals message
  - XOR of all messages if more than one transmitter

# DC-Net Example




- $Pa \oplus Pb \oplus Pc =$

  $(AB \oplus AC) \oplus$
  $(AB \oplus BC \oplus m) \oplus$
  $(BC \oplus AC) =$

  $\cancel{AB} \oplus \cancel{AB} \oplus \cancel{AC} \oplus \cancel{AC} \cancel{\oplus}$
  $\cancel{BC} \oplus BC \oplus m = m$

  $0 \oplus 0 \oplus 1 = 1$

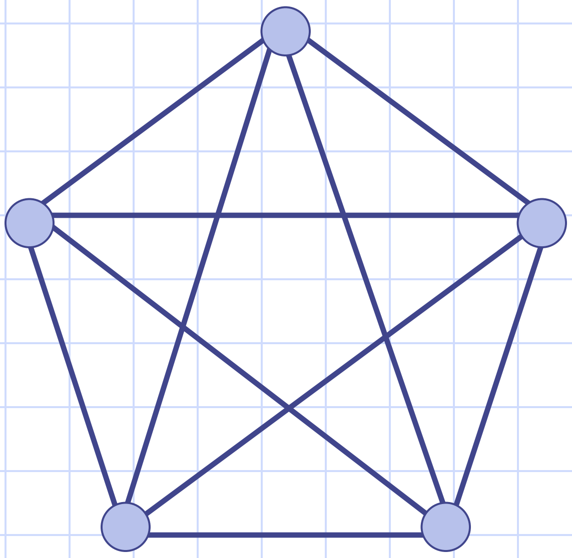
  $0 \oplus 1 \oplus 1 = 0$

# DC-Net Properties

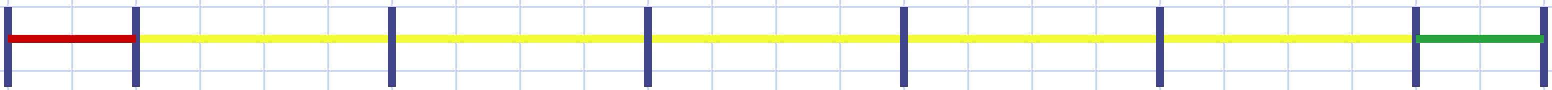
- Why does it work ?
  - All nodes participate in the computation of the packet
  - All nodes equally culpable
  - Information theoretic guarantee
- Shared anonymous broadcast channel
  - Like Ethernet, but virtual
- As described so far, it is not a practical system
  - Lacks protocol, scale and performance

# Herbivore DC-Net Protocol

- Use PRNG instead of coins
  - Derive stream of coin tosses efficiently
- Fully-connected key graph
  - Every pair has a unique key, no weak points
- Communication occurs in rounds, of three phases
  - Reservation
  - Transmission
  - Voting



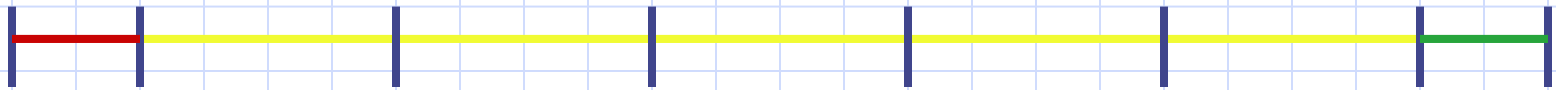
# Herbivore Reservation Phase



- Goal: anonymously acquire exclusive access to the channel
- Divide time into transmission slots
  - A node with a message to send
    - selects a transmission slot, i, at random
    - broadcasts a bit vector, with 0's everywhere and a 1 for the ith bit
    - everyone receives XOR of all reservations
    - transmits in reserved slot, if succeeded
- Collisions trigger Ethernet-like backoff

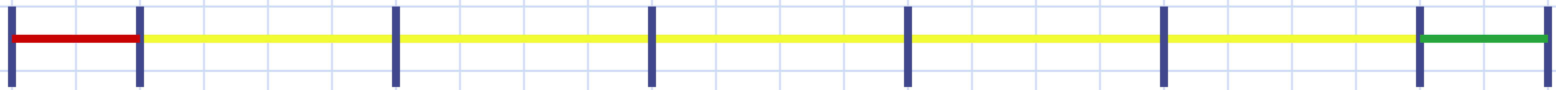
A: 00001000
B: 00010000
C: 00000010
---------------
00011010

# Herbivore Transmission Phase



- A node transmits its message in the slot it has reserved
  - Unreserved slots are skipped
- Collisions may occur during the transmission phase
  - If an odd number of nodes select the same slot, or if there is a malicious node
  - Every packet carries data and hash
  - Provides collision detection & ensures packet integrity
- Multiple rounds in parallel

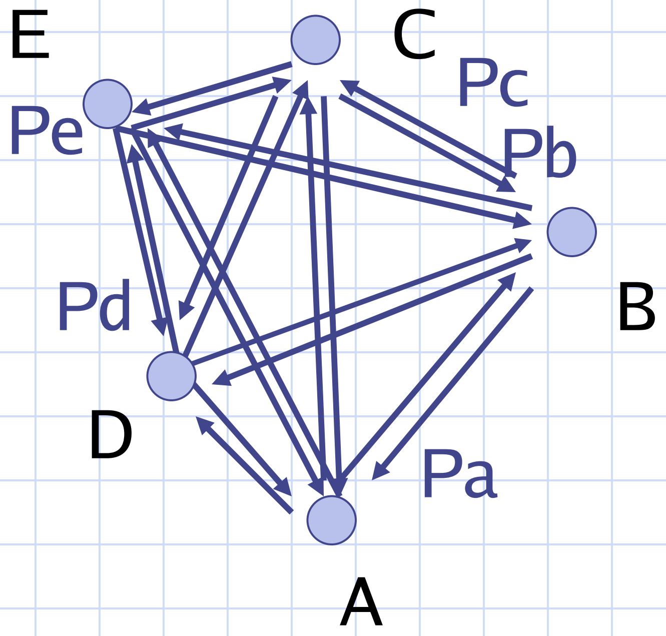
# Herbivore Voting Phase



- Goal: signal to other nodes that a node is in the middle of a long transaction
- Delay departure until transaction is completed, if possible
- Herbivore voting is bandwidth efficient (2 bytes)
  - Special case for anonymous 1-bit voting

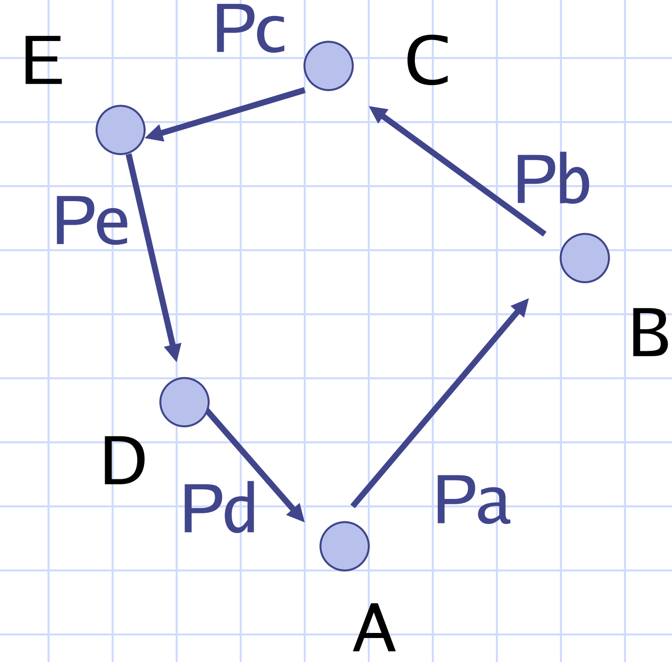
# Herbivore Overlay Topology

- Chaumian DC-Nets use a Fully-Connected Graph
  - O(1) latency, O($N^2$) load

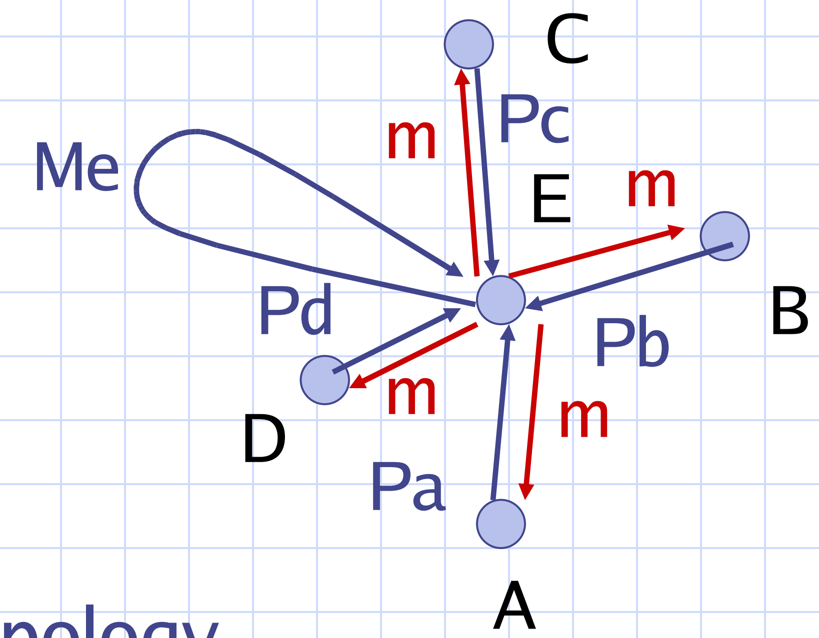


# Herbivore Overlay Topology

- Chaumian DC-Nets use a Fully-Connected Graph
  - O(1) latency, O($N^2$) load
- Or Ring
  - O(N) latency, O(N) load



# Herbivore Overlay Topology




- Chaumian DC-Nets use a Fully-Connected Graph
  - O(1) latency, O($N^2$) load
- Or Ring
  - O(N) latency, O(N) load
- Herbivore uses a Star topology
  - All nodes send their packets to a “center” node in each round
  - Center duties rotate deterministically at each round
  - O(1) latency, O(N) load

# Herbivore Protocol Efficiency

- Topology
  - Low latency, low load overlay organization
- Reservation
  - We derive and use optimal vector size
- Transmission
  - We run multiple transmission rounds concurrently
- Voting
  - We extend system lifetime with efficient 1-bit voting

# Herbivore Scale

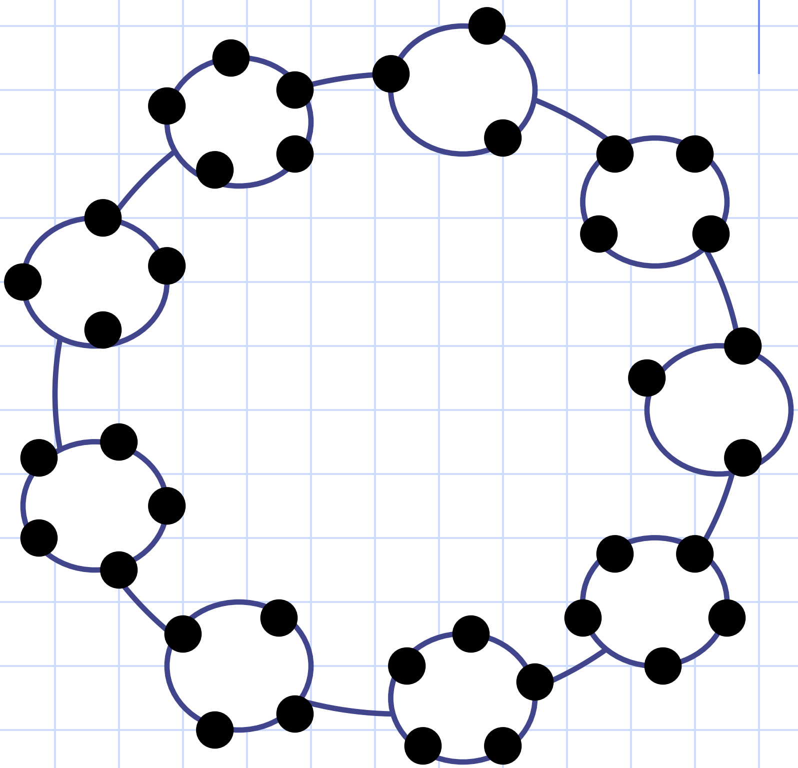
- Traditional DC-Nets do not scale
  - Protocol is too heavy-weight for use at planetary scale
- Divide and conquer!
  - Self-organize the network into cliques of k-nodes
  - Use the relatively heavy-weight protocol in small cliques
- Decouple protocol cost from system size

# Herbivore Clique Management

- Use a P2P overlay to organize N participants into cliques of minimum size k
  - Clique size ranges from k to 3k, for k = 20 or so
- Every node solves a crypto-puzzle to obtain a node-id and join the system
  - Puzzle solution randomizes entry into cliques
  - Nodes demonstrate solution of the puzzle to each preexisting clique member
  - No central authority is involved
- Use Pastry to map nodes to clique

# Herbivore Cliques

- A clique of more than 3k nodes is split into 2 cliques
- When nodes depart and clique size drops below k, the nodes depart and join closest existing cliques



# Interclique Operation

- Within a clique, all communication is anonymous
  - Uses the Herbivore DC-Net protocol
- Between cliques, packets are forwarded via randomly selected proxies
- Interfacing with the outside world also occurs through randomly selected proxies

# DC-Net Filesharing

- Naïve solution is simple
  - Every node has a list of files it offers for downloads
  - Queries are broadcast from clique to clique
  - Files are transferred back if query hit
- Naïve solution is open to intersection attacks
  - RIAA queries for "Metallica", examines clique membership of all cliques that respond, takes the intersection over time
  - Whoever remains is guilty of placing Metallica songs online

# Herbivore Filesharing

- Batch download system with a simple user interface
  - List of files to publish
  - List of files to acquire
- Every node has two file stores
  - A-list: files available to others but not yet disseminated to anyone
  - B-list: LRU cache of files recently sent in response to queries

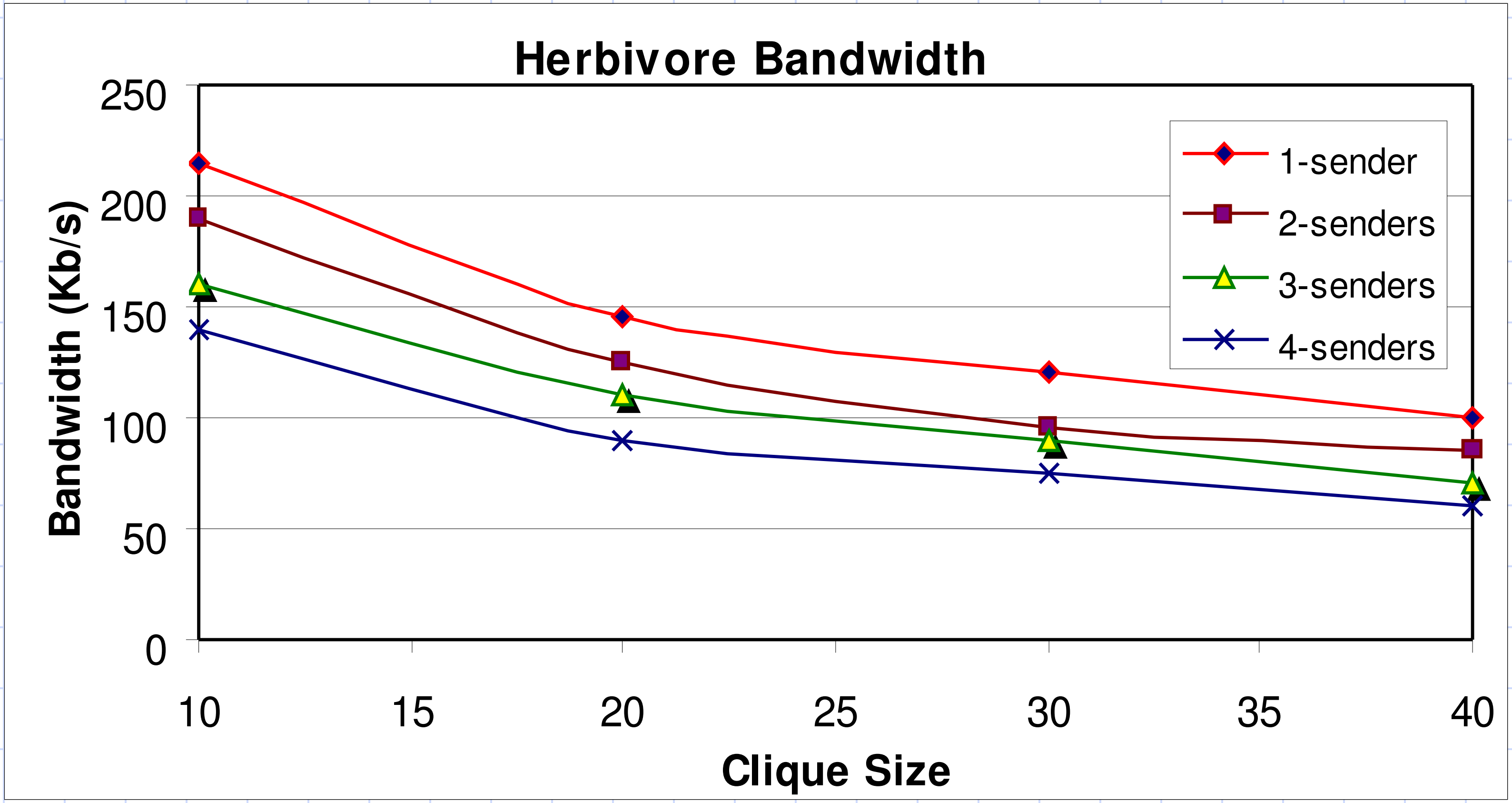
# Herbivore Filesharing

- When a query arrives for a file held in the A or B-list, the node responds with the file
  - If on A-list, the file is transferred to the B-list
- When a file is overheard on the broadcast channel, it is placed on the B-list
  - Hence, all nodes in the clique have state identical to the originator
  - Can be done probabilistically, with $p < 0.5$
- No way to determine the originator, despite use of small anonymization groups!
  - Can search or sue everyone in the clique (not under US law)
  - Published files may get dropped for lack of interest

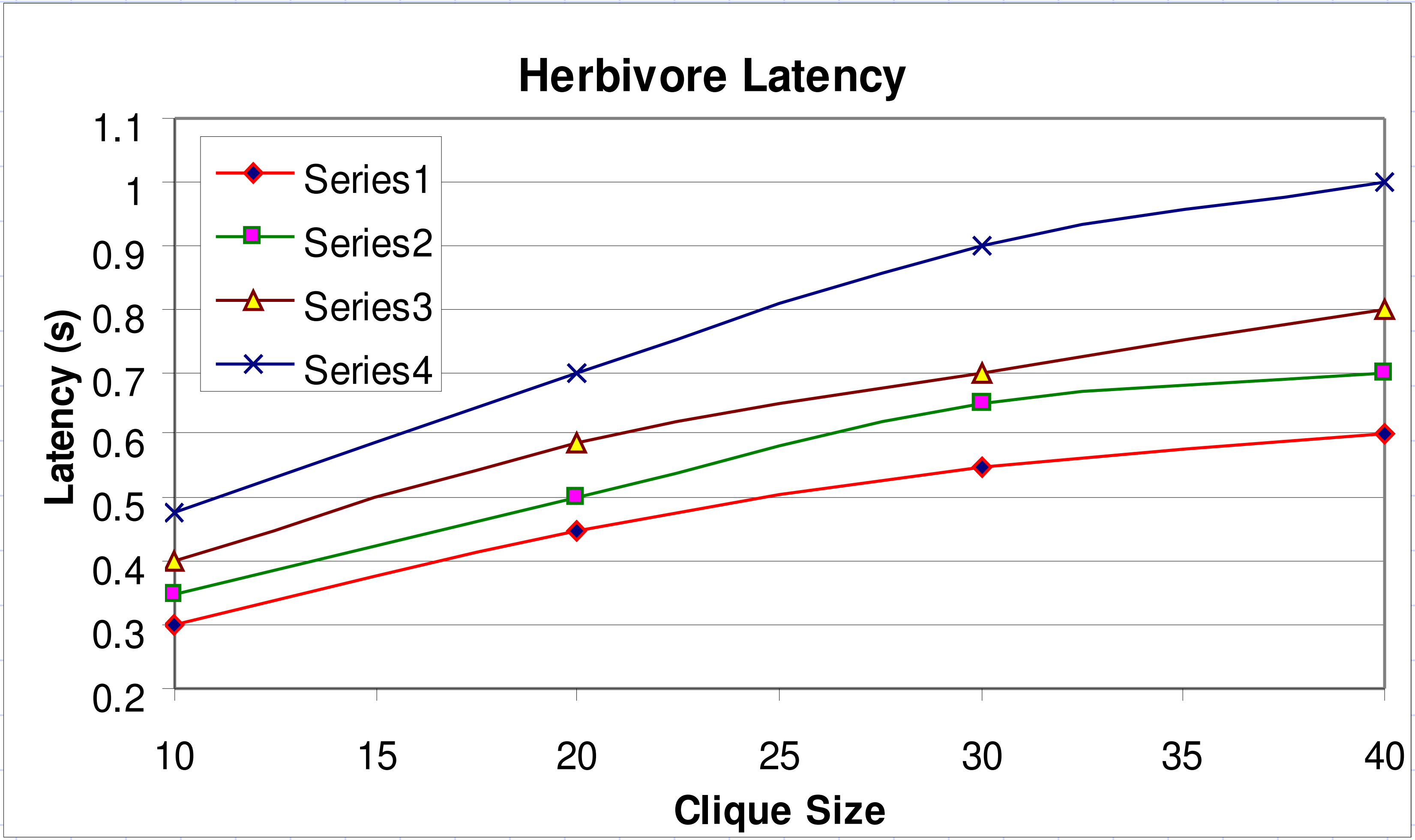
# Herbivore Status

- Implemented the system
  - Anonymous filesharing, instant messaging and web browsing
  - YIM-like interface for FS and IM + web proxy
  - ~27,000 lines of code
- Deployed on Planetlab
- The system is practical
  - First known deployment of DC-Nets
  - Scales well, efficient protocol

# Herbivore Bandwidth



# Herbivore Latency



# Summary

- Herbivore provides strong anonymity, scalability and performance
  - DC-Nets are practical!
- Enables participants to share information anonymously, even in the presence of omnipotent adversaries

# Further Information

- E. Gün Sirer
- egs@cs.cornell.edu
- http://www.cs.cornell.edu/People/egs/herbivore/

# Attacks and Defenses

- Sybil: use cryptopuzzles
- Jamming: use commitment and trap
- Intersection: use A and B-lists
- Statistical: DC-Nets
- Sloth: accrues strikes
- Center: accrues a fractional strike
- Eclipse: check adjacent clique members on clique creation
- Abuse: selective revocation with secret sharing

# Anonymity and Abuse

- What if someone uses the system to perform nefarious activities ?
  - E.g. plot a terrorist attack
- Serious problem
  - But not new, police have mechanisms for tracking down criminals with similar anonymous channels in the real world
- Technical solution
  - Share secret keys using (n, k)-secret sharing
  - Revoke anonymity when k out of n participants agree