Which “Network” Company to Invest in?

Network Going Postal

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Which “Network” Company to Invest in?
• Start with a conventional home DSL router
• Users oblivious of “routers”
• Routers are general and transparent

• At the end of the day, it spits out a DVD

• Picked up by a postman
What Is A Postmanet Router?

- The postman may also drop off an incoming DVD

A Postmanet Router

- Basic idea of using DVDs not new
- What is new: general and transparent
  - General:
    - Support for multiple applications
    - Generic infrastructure (public transit system)
    - 2-way communication
    - Multiplexing/demultiplexing onto/from minimum disks
  - Transparent:
    - No manual inspection of DVD content
    - No manual staging, copying
    - No manual handling of acks, losses, duplicates, …
    - Just insert/remove DVDs from the box

Shared Postmanet Routers

- Not necessary: dedicated per-desktop or per-house Postmanet routers
- Technology reality: short fat wires, long thin wires, big disks
  - How do you build systems out of these components?

Outline

- What is Postmanet?
- What is it good for?
- Routing
- End point support
- Conclusions
Advantages

- Wide reach: a truly global “network”
- Great bandwidth potential, technology trends:
  - “Sneaker nets” becoming more powerful
  - Storage density growth > Moore’s Law
  - Wide area bandwidth growth bound by digging ditches, launching satellites, erecting WiMax towers…
- Low cost
- Incremental deployment:
  - Classic chicken & egg problem: infrastructure, applications, users
- Good scalability

Academic Computers

in 1983 and 2003

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<td>3Ghz</td>
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<tr>
<td>$/machine</td>
<td>$80k</td>
<td>$800</td>
<td>100:1</td>
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<tr>
<td>DRAM</td>
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<td>256M</td>
<td>1:1000</td>
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<tr>
<td>Disk</td>
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<td>200GB</td>
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<td>10Mbits/sec</td>
<td>1GBits/sec</td>
<td>1:100</td>
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<tr>
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<td>32-64</td>
<td>1:2</td>
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<tr>
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<td>&gt; 10:1</td>
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<td>&lt; $800/1000</td>
<td>100,000+:1</td>
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Exponential Growth

(Courtesy J. Gray)

- Performance/Price doubles every 18 months
- 100x per decade
- Progress in next 18 months = ALL previous progress
  - New storage = sum of all old storage (ever)
  - New processing = sum of all old processing

DVD Capacity

- HD-DVD: 15-20GB per layer, maximum of 40GB dual-layer discs
- Blu-Ray: 27GB per layer, 54GB dual-layer discs
- Sony plans to commercialize 4-layer 100GB Blu-Ray discs in 2007
- Sony has demonstrated 8-layer 200GB Blu-Ray discs in October of 2004
- Torok of Imperial College London
  - Asymmetric pits encode more than one bit per pit
  - Expects 4-layer 1TB discs 2010-2015

Scientific American, February 2005.
**Advantages**

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**Goals**

- Non-goal: compete against existing alternatives
- For the “have-not’s”: give high b/w connectivity to places that have none
- For the “have-little’s”: complement existing low-bandwidth connections
- For the “will-have’s”: foster the development of b/w-hungry applications and users

**The Uganda Case**

- Short fat wire:
  - Makerere University: 2 Gb/s campus-wide fiber
- Long thin wire
  - Satellite gateway to Internet: total bandwidth of Uganda: 25Mb/s
- No optical fiber links to east Africa
  - Each country: an island in the global Internet
- No optical fiber links across country
  - Each city: an island in the global Internet

<table>
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<th>MUK</th>
<th>MIT</th>
<th>MUK/MIT ratio</th>
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<td>campus gateway (Mb/s)</td>
<td>2.5</td>
<td>~2,300</td>
<td>~10^3</td>
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<tr>
<td>gateway cost ($ per month)</td>
<td>$28K</td>
<td>~$80K</td>
<td>~1/3</td>
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<tr>
<td>GDP per capita</td>
<td>$1.2K</td>
<td>$36K</td>
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<tr>
<td>bandwidth cost relative to per capita GDP</td>
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ET Write Home: Extreme Bandwidth/Latency Tradeoff

Radio wave messages across the stars
- Need tremendous energy
- Need an antenna the size of earth
- 10 billion billion nano-bits, all of earth’s current info within a gram of matter

Suggestion: mine ET letters in “resting points” near earth

Goals

Latency and Bandwidth

- Latency: amount of time to send a byte
- Bandwidth: bytes per second when trying to send a large amount of data

LAN

Latency and Bandwidth

WAN

Internet

“Sequential”: Extending the Internet

“Parallel”: Complementing weak links

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Complementing Weak Connectivity

- Postman: high-latency high-bandwidth (HLHB)
- A modem: low-latency low-bandwidth (LLLB)
- How to combine the two to get the advantages of both?

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Example Applications

- Themes
  - Bandwidth-intensive
  - Simultaneous exploitation of LLLB and HLHB links
- Applications
  - Email with large attachments (e.g., home movies)
  - Web embedded with large objects
  - Remote file system mirroring for sharing/backup
  - Peer-to-peer file sharing
  - Video “almost on-demand”
  - Certain Grid applications?
  - Distance learning (especially for disadvantaged areas)
- Infinite bandwidth: what would you do with it?
Old Netflix

- Problem: no instant gratification

Old Netflix

- Problem: no instant gratification

Old Netflix

- Problem: no instant gratification

“New Netflix”

- Encrypted content pushed via Postman
"New Netflix"

- Large home library accumulated

"New Netflix"

- User wants to see a movie

"New Netflix"

- Purchase decryption key with modem
  - (DRM needed)

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“New Netflix”

- Purchase decryption key with modem
- (DRM needed)
- Instant gratification (almost)

“Video Almost On-Demand”

- The point:
  - Simultaneous exploitation of LLLB and HLHB links
  - Liberal “wastage” of capacity for gaining other advantages
- Recurring central themes
  - For all applications
  - At both application- and various system-levels

Peer-to-Peer File Sharing

- LLLB: Small messages associated with search requests or content announcements
- HLHB: bulk media
- Liberal wastage of capacity: may request same data from multiple senders
- How might a peer-to-peer Netflix work?
- Would I have to send or receive 1000 disks per day?
Internet Storage

• Only half of consumers have thought about reliability of their digital photos *
• Shutterfly: order prints online, but can do more…
• Organize, backup, share, access from anywhere…
• Message: centralized storage has many advantages


Internet Storage

• Why stop at photos?
  – Music, movies, documents, emails, …
  – Organize, backup, share, access from anywhere, index, search, cross reference, “content distribution” management, …
  – All the benefits of the web: a new web!

• The problem: not enough bandwidth

Internet Storage

• Postmanet solves the bandwidth gap
• Turn home storage into a “mirror” or a “cache”

A Postmanet-Based “Public Transit” System

• Emails with home movie attachments
• Web embedded with rich media
• Remote file system mirroring/sharing
• TV/radio
• Magazines, newspapers, store catalogues (with rich media), softwares and updates

• What can you do with practically infinite bandwidth into each household?!
• Implication on ways of doing business and ways of getting information
Outline

• What is Postmanet?
• What is it good for?
  • Routing
  • End point support
  • Conclusions

(a) Centralized Routing

• Lots of obvious disadvantages
• Big advantage: one incoming disk and one outgoing disk per postman visit per site
• Minimize manual labor: assembly-line handling of DVDs
• Today: robotic arm-operated DVD readers/writers

(b) Direct Peer-to-Peer Routing

• “Opposite” of (a)
• Zero demand on an infrastructure
• Risk: too many disks sent/received per site per postman visit

(c) Multiple Data Distribution Centers

• Some amount of geography-awareness
• Limits the number of disks handled per site per postman visit
• Still need an infrastructure
An indirect Peer-to-Peer Routing system works as follows:

- A disk that lands at your house may contain data destined for others.
- You need to forward the data.
- But to whom?

- Disks = buses, messages = passengers.
- Passengers need to get on and off buses to get to their destinations...
- Potentially need to switch buses.

- How do you deal with misbehaving participants?
  - Existing Byzantine-tolerant routing protocols apply.
  - Netflix-like model of throttling service to "lazy" members.
  - Proactive replication on multiple routes.
- Misbehavior less a problem in cooperative groups.
Desired Routing Characteristics

- Small number of disks handled per site: a unique metric in Postmanet
- Small end-to-end latency
- Does not require an expensive infrastructure
- Does not burden sites with unbalanced data copying duties
- Robust when some Postmanet users misbehave
- These are conflicting goals

Which Option?

(a) is a special case of (c)
(b) is a special case of (d)

• (b,d) best if:
  - We want quick/incremental deployment…
  - Without investing in an infrastructure
  - Under light traffic
  - Inside cooperative groups
(c) and (d) can coexist:
- (d) could get things started
- (c) can be added to (d) to gradually improve service

Static Routing Topologies

- Number of disks handled per site: node degree
- End-to-end latency: graph diameter
- Best you can do: $O(1)$ degree, $O(\log N)$ hops
  - E.g., de Bruijn graphs
- Qualitative goal not new, but the quantitative tradeoffs are

Dynamic Routing

- Bus schedule problem
  - Disks=buses, messages=passengers
  - Given traffic pattern, devise bus schedule dynamically
  - Unique Postmanet metric: limit buses per bus station
- Take short cuts in a static graph when possible

The Relationship Between Static and Dynamic Routing Graphs

- Under light traffic: can achieve single-hop latencies
- Under heavy traffic
  - Few opportunities for short cuts
  - Dynamic routes degenerate to static routes
  - So static routes give latency bounds
The Relationship Between Static and Dynamic Routing Graphs

- To compute bus routes and passenger choices:
  - Need “progress metric” of passengers
  - Use “closeness” of passengers to their destinations in the underlying static graph
- Current solution: maximum weight matching on an underlying de Bruijn graph

Recurring Theme 1:
Simultaneous exploitation of LLLB and HLHB links

- LLLB:
  - traffic pattern gathered during the day
  - routes computed at centralized site
  - routes disseminated to users
  - postal labels generated by users
- HLHB:
  - bulk data picked up by postmen

Recurring Theme 2:
Liberal “wastage” of capacity

- Replicate data on disks destined for multiple paths
- Replicas can be had for “free”
- Let the buses race against each other
- Can “shoot down” passengers in transit
- Shoot-downs can also occur at app-level and end point system-level
- Shoot-downs uniquely useful in Postmanet

Outline

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Characteristics Unique to Postmanet

- Bursty arrival of large amounts of data
- Postal system: classic case of datagram service
- Two networks
- Delayed action and “shoot-downs”
- Storage media as wires

Recurring Theme 1:
Simultaneous exploitation of LLLB and HLHB links

- Transport- and application-level control messages travel on LLLB links
  - ACKs, NACKs, retransmission requests, shoot-downs
- Data message: choose between the LLLB/HLHB links depending on size and delivery deadline
- May send variations of a single message on both links
- May view an LLLB link as a “cache” of an HLHB link

Recurring Theme 2:
Liberal “wastage” of capacity

- Liberal and proactive replication of data on subsequent days
- Speculative transmission of anything that might get used

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Shoot-down
Recurring Theme 2: Liberal “wastage” of capacity

- Liberal and proactive replication of data on subsequent days
- Speculative transmission of anything that *might* get used

Related Work

- Delay-Tolerant Networks (DTNs)
  - Buses equipped with 802.11 and disks
  - Zebras gathering and exchanging migration logs with each other
  - Communicating with LEOs
  - Directional 802.11 routers running out of power
- Postmanet
  - An example of DTN, so share commonalities, e.g.: asynchronous communication
  - Different from other DTNs

Related Work

- DTNs vs. Postmanet:
  - Local vs. global
  - DTNs: ad hoc networking a key issue, Postmanet: different routing issues
  - DTNs: “challenged networks”, Postmanet: dormant in transit, abundant resources (and efficient) when connected
  - Postmanet: two networks

Related Work

- Jim Gray ships entire NFS servers filled with astronomy data
  - Need “system support” at transport and application levels
- Rover: wireless app toolkit---asynchronous API
  - Different network characteristics
- Mobile storage systems
  - Different abstractions a key
Conclusions

• The postal system has many attractive characteristics as a digital communication mechanism
• To fully realize these potentials, we need to turn it into a truly generic and transparent “network”
• Two recurring themes: exploiting two networks simultaneously and “wasting” storage to gain other advantages
• What would you do with infinite bandwidth?
• Key applications for the developing world