Delay Tolerant Networks (and email)

COS 461: Computer Networks
Spring 2009 (MW 1:30-2:50 in COS 105)

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http://www.cs.princeton.edu/courses/archive/spring09/cos461/

Drawing on slides by Kevin Fall and Michael Demmer

Goals of Today's Lecture

- Underlying assumptions of the Internet
  - And how they are cooked into the protocols
- Challenging network environments
  - Example networking scenarios
  - Delay-Tolerant Networking architecture
- E-mail as a example of disruption tolerance
  - Mail servers and user agents
  - Simple Mail Transfer Protocol (SMTP)
  - Retrieving e-mail from a mail server
- E-mail message format (if time allows)

Assumptions Underlying the Internet Protocols

Best-Effort Packet Delivery

- Abstract IP datagram
  - Sending a portion of a message in each packet
  - *Assumption: end hosts provide message abstraction*
- No application or transport-level state
  - Routers do not maintain state across a connection
  - *Assumption: communicating hosts can store this state*
- Best-effort delivery
  - Drop packets during times of overload
  - *Assumption: retransmission by end hosts is sufficient*

Stationary Hosts and Stable Topology

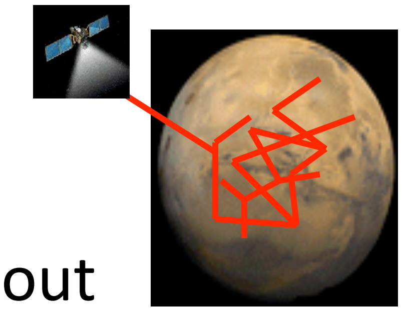
- Addressing
  - Hierarchical 32-bit IP addresses
  - *Assumption: end hosts are largely stationary*
- Routing
  - Discover network topology and compute "best" path
  - *Assumption: topology is relatively stable over time*
- Drop on failure
  - Drop packets when no route currently exists
  - *Assumption: communicating hosts usually connected*

End-to-End Argument

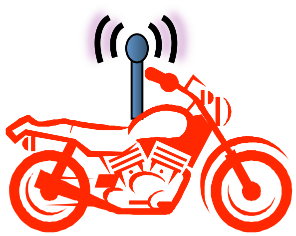
- Link properties
  - Links exist and are generally reliable
  - *Assumption: loss rates typically less than 1%*
- Flow control and congestion control
  - React to flow control on a half round-trip time
  - React to congestion on a full round-trip time
  - *Assumption: end-to-end path has reasonably small RTT*
- Router storage
  - Short-term queuing of a few packets
  - *Assumption: no long-term storage of data in the network*

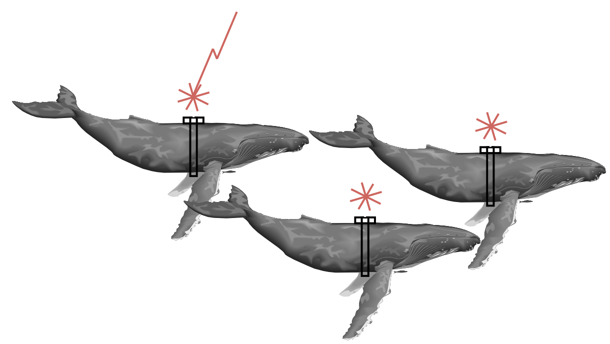
Challenging Network Environments

What are Challenged Networks?



- Unusual
  - Contain features or reqs that a network designer would find difficult to reason about
- Challenged
  - Operating environment makes communications difficult
- Examples: mobile, power-limited, far-away nodes communicating over poorly or intermittently-available links



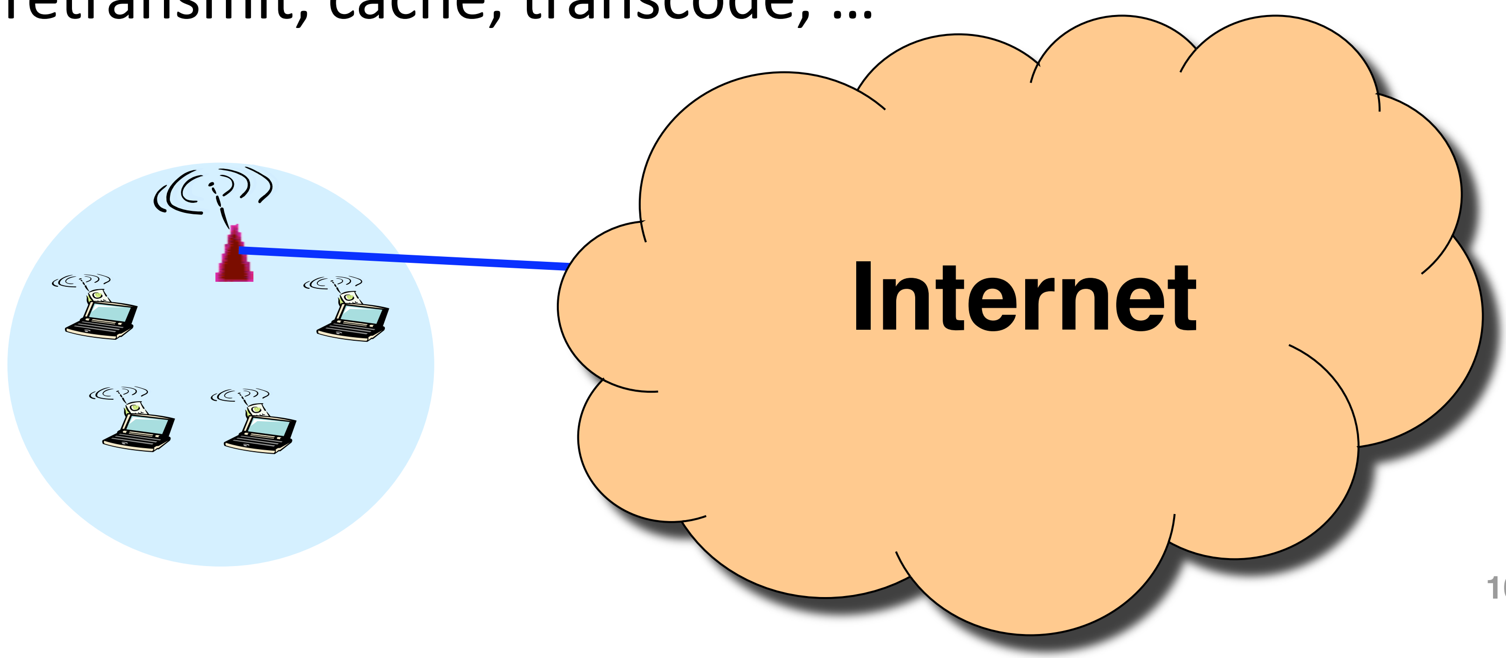


Challenging Environments

- Random or predictable node mobility
  - Military/tactical networks (clusters meet clusters)
  - Mobile routers with disconnection (e.g., ZebraNet)
  - Daily schedule for a bus passing by a village
- Periods of complete disconnection
  - E.g., the bus is out of range
- Big delays and low bandwidth (high cost)
  - Satellites (GEO, LEO / polar)
  - Exotic links (e.g., deep space or underwater acoustics)
- Big delays and high bandwidth
  - Busses, mail trucks, delivery trucks, etc.

Limp Along With Internet Protocols?

- Run existing Internet protocols
  - And endure the poor performance and poor reliability
  - … and the risk that communication *never* succeeds
- Deploy proxies at the boundary points
  - E.g., at the wireless/wired boundary
  - To retransmit, cache, transcode, …



Design New Protocols?

- Revisit the assumptions underlying the Internet
  - Create new assumptions tailored to the environment
  - Design new protocols based on those assumptions
- Advantages
  - More efficient, reliable, and better-performing network
  - Especially for extremely challenging environments
- Disadvantages
  - Additional protocols and complexity, and perhaps cost
  - Significant risk of incompatibility with the Internet

Example Projects

- Digital Gangetic Plains
  - Low-cost networking in rural India
  - Outdoor long-distance directional links using 802.11
  - http://www.cse.iitk.ac.in/users/braman/dgp.html
- Sami Network Connectivity Project
  - Internet connectivity for nomadic reindeer herders
  - E-mail, cached Web access, & reindeer herd telemetry
  - Opportunistic relaying of data through gateways
  - http://www.snc.sapmi.net/
- ZebraNet
  - Study animal migration and inter-species interaction
  - Tracking collars, P2P communication, and base stations
  - http://www.princeton.edu/~mrm/zebranet.html

Delay / Disruption Tolerant Networking

DTN Architecture

- Goals
  - Interop. across ‘radically heterogeneous’ networks
  - Tolerate delay and disruption
    - Acceptable performance in high loss/delay/error environs
    - Decent performance for low loss/delay/error environments
- Components
  - Flexible naming scheme
  - Message abstraction and API
  - Extensible Store-and-Forward Overlay Routing
  - Per-(overlay)-hop reliability and authentication

Naming

- Support 'radical heterogeneity' using URI's:
  - {scheme ID (allocated), scheme-specific-part}
  - Associative or location-based names/addresses optional
  - Variable-length, can accommodate "any" net's names and addresses
- Endpoint IDs (EIDs)
  - Multicast to send to multiple recipients
  - Anycast to send to one of many possible recipients
  - Unicast to send to one specific recipient
- Late binding of EID permits naming flexibility:
  - EID "looked up" only when necessary during delivery
  - Contrast with Internet lookup-before-use DNS/IP

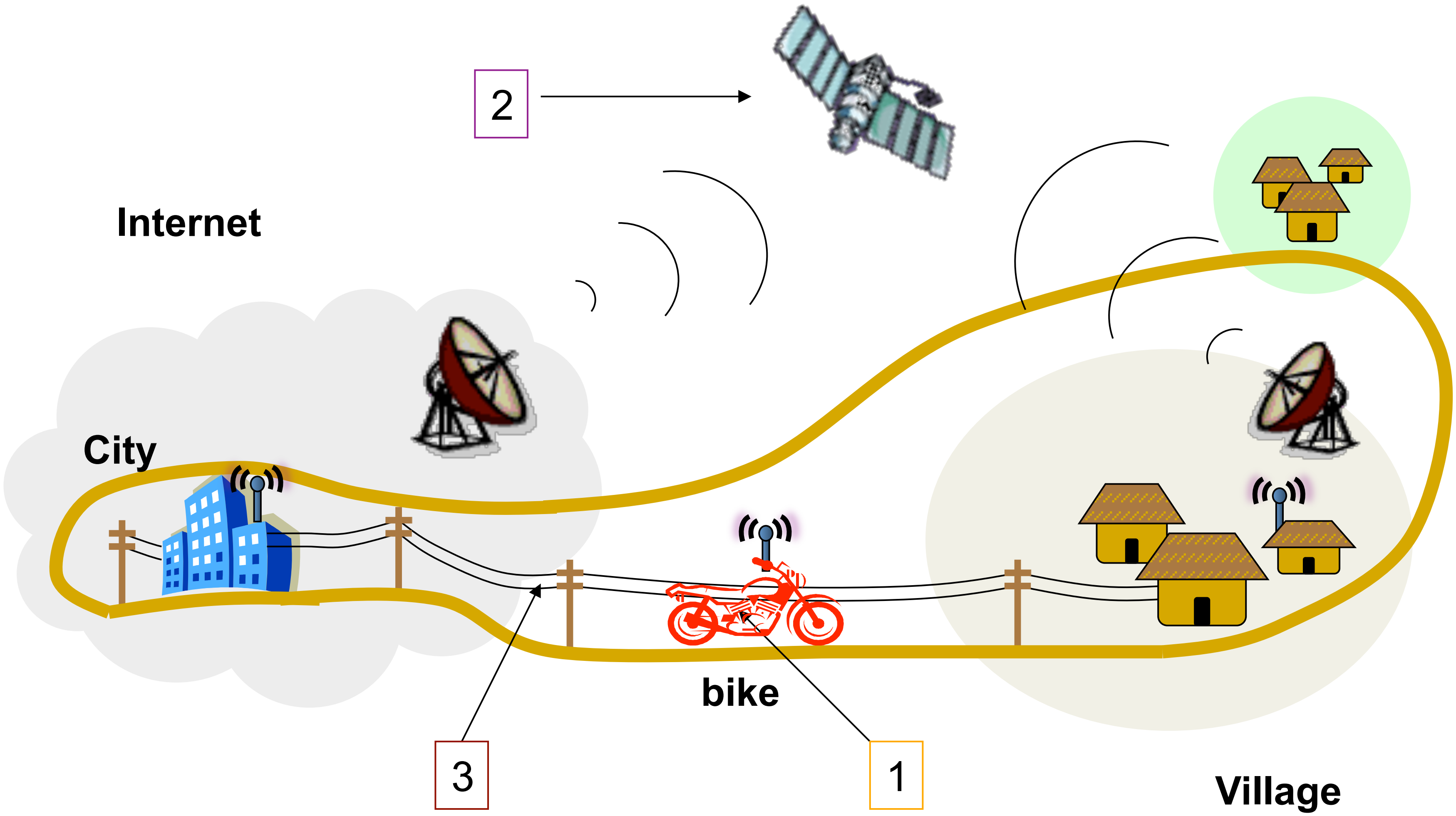
Message Abstraction

- Network protocol data unit: bundles
  - "Postal-like" message delivery
  - Coarse-grained CoS (4 classes)
  - Origination and useful life time
  - Source, destination, and respond-to EIDs
  - Options: return receipt, "traceroute"-like function, alternative reply-to field, custody transfer
  - Fragmentation capability
  - Overlay atop TCP/IP or other (link) layers (layer 'agnostic')
- Applications send and receive messages
  - "Application data units" (ADUs) of possibly-large size
  - Adaptation to underlying protocols via 'convergence layer'
  - API includes persistent registrations

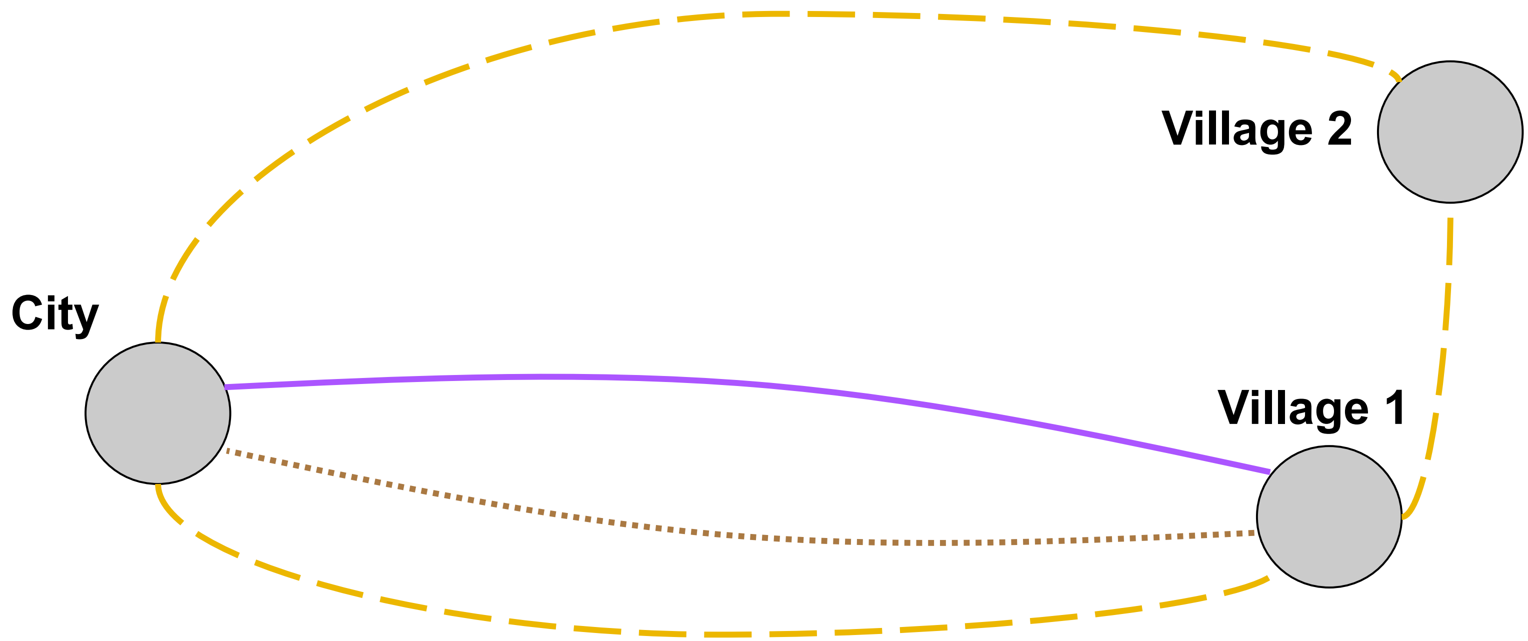
DTN Routing

- DTN Routers form an overlay network
  - Only selected/configured nodes participate
  - Nodes have persistent storage
- DTN routing topology is a time-varying multigraph
  - Links come and go, sometimes predictably
  - Use any/all links that can possibly help
  - Scheduled, Predicted, or Unscheduled Links
    - May be direction specific
    - May learn from history to predict schedule
- Messages fragmented based on dynamics
  - Proactive fragmentation: optimize contact volume
  - Reactive fragmentation: resume where you failed

Example Routing Problem



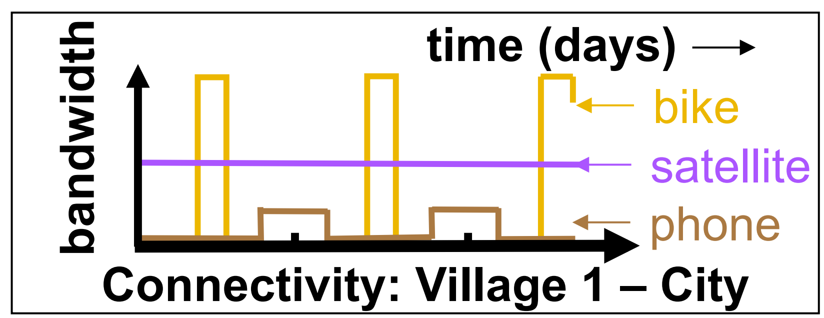
Example Graph Abstraction



bike (data mule)
intermittent high capacity

Geo satellite
medium/low capacity

dial-up link
low capacity



The DTN Routing Problem

- Goal: satisfy message demand matrix
- Vertices have buffer limits
- Edge is possible chance to communicate:
  - One-way: (S, D, c(t), d(t))
  - (S, D): source/destination ordered pair of contact
  - c(t): capacity (rate); d(t): delay
  - A Contact is when c(t) > 0 for some period [ik,ik+1]
- Problem: optimize some metric of delivery
  - What metric to optimize? Efficiency? Cost?

So, is This Just E-mail?

	naming/ late binding	routing	flow contrl	multi-app	security	reliable delivery	priority
e-mail	Y	N (static)	N(Y)	N(Y)	opt	Y	N(Y)
DTN	Y	Y (exten)	Y	Y	opt	opt	Y

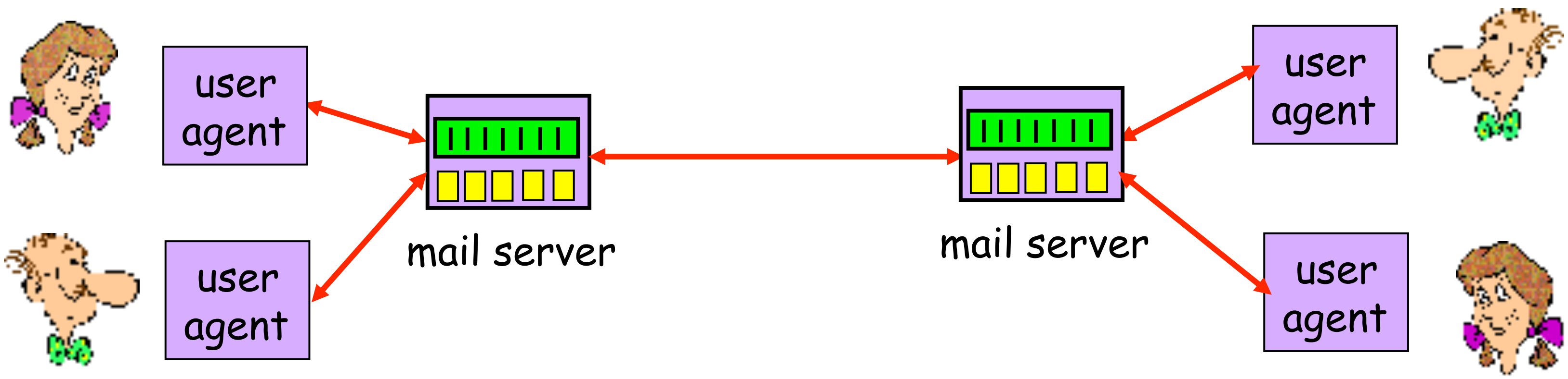
- Many similarities to (abstract) e-mail service
- Primary difference involves routing, reliability and security
- E-mail depends on an underlying layer's routing
  - Cannot generally move messages 'closer' to their destinations in a partitioned network
  - E-mail protocols are not disconnection-tolerant or efficient for long RTTs due to "chattiness"
- E-mail security authenticates only user-to-user
- Still, e-mail has some properties that are useful…

Delivering E-Mail

E-Mail Must Tolerate Disruptions

- Message abstraction
  - Sending a (potentially large) message
  - From one user to another user
  - Okay if there is some delay in delivering the message
- Users may not be online together
  - Receiver may be offline when the sender sends
  - Sender may be offline when the receiver receives
  - Cannot afford to wait until they are both online
- Users may connect from different places
  - Home, work, airport, hotel room, …
  - Cannot assume a single IP address, or single host

Mail Servers and User Agents



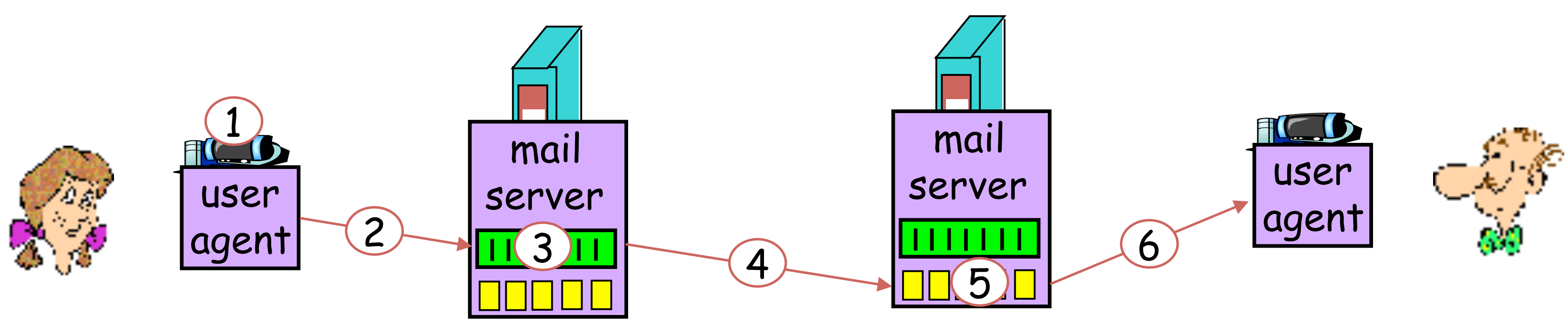
- Mail servers
  - Always on and always accessible
  - Transferring e-mail to and from other servers
- User agents
  - Sometimes on and sometimes accessible
  - Intuitive interface for the user

Store-and-Forward Model

- Messages sent through a series of servers
  - A server stores incoming messages in a queue
  - … to await attempts to transmit them to the next hop
- If the next hop is not reachable
  - The server stores the message and tries again later
- Each server adds a Received header
  - To aid in diagnosis of problems

Scenario: Alice Sends Message to Bob

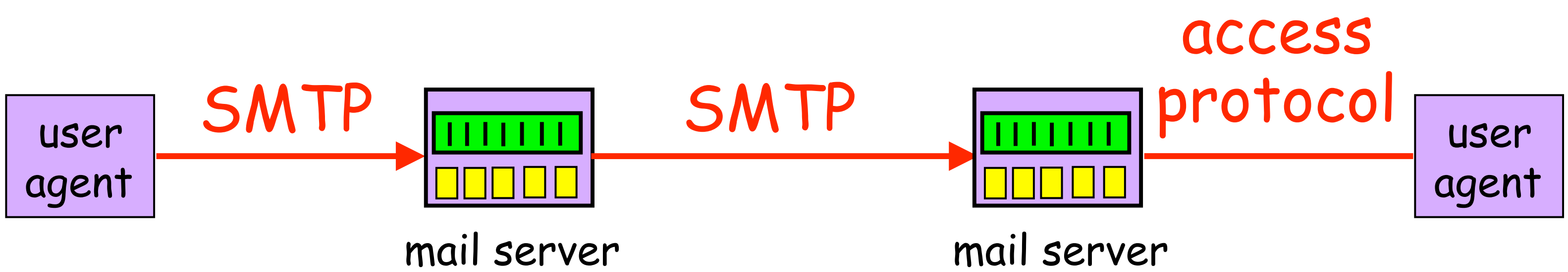
1) Alice uses UA to compose message "to" `bob@someschool.edu`
2) Alice's UA sends message to her mail server; message placed in message queue
3) Alice's mail server opens TCP connection with Bob's mail server
4) Alice's mail server sends Alice's message over the TCP connection
5) Bob's mail server places the message in Bob's mailbox
6) Bob invokes his user agent to read message



Identifying the Mail Server

- Alice identifying her mail server
  - Explicit config of her user agent (e.g., smtp.cs.princeton.edu)
- Alice's mail server identifying Bob's mail server
  - From domain name in Bob's e-mail address (e.g., mit.edu)
- Domain name is not necessarily the mail server
  - Mail server may have longer/cryptic name
    - E.g., cs.princeton.edu vs. mail.cs.princeton.edu
  - Multiple servers may exist to tolerate failures
    - E.g., cnn.com vs. atlmail3.turner.com and nycmail2.turner.com
- Identifying the mail server for a domain
  - DNS query asking for MX records (Mail eXchange)
    - E.g., nslookup –q=mx yale.edu
  - Then, a regular DNS query to learn the IP address

Simple Mail Transfer Protocol



- Client-server protocol
  - Client is the sending mail server
  - Server is the receiving mail server
- Reliable data transfer
  - Built on top of TCP (on port 25)
- Push protocol
  - Sending server pushes the file to the receiving server
  - … rather than waiting for the receiver to request it

Sample SMTP interaction

```
S: 220 hamburger.edu
C: HELO crepes.fr
S: 250  Hello crepes.fr, pleased to meet you
C: MAIL FROM: <alice@crepes.fr>
S: 250 alice@crepes.fr... Sender ok
C: RCPT TO: <bob@hamburger.edu>
S: 250 bob@hamburger.edu ... Recipient ok
C: DATA
S: 354 Enter mail, end with "." on a line by itself
C: Do you like ketchup?
C: How about pickles?
C: .
S: 250 Message accepted for delivery
C: QUIT
S: 221 hamburger.edu closing connection
```

Try SMTP For Yourself

- Running SMTP
  - Run “telnet servername 25” at UNIX prompt
  - See 220 reply from server
  - Enter HELO, MAIL FROM, RCPT TO, DATA commands
- Thinking about spoofing?
  - Very easy
  - Just forge the argument of the “FROM” command
  - … leading to all sorts of problems with spam
- Spammers can be even more clever
  - E.g., using open SMTP servers to send e-mail
  - E.g., forging the “Received” header

Multiple Server Hops

- Typically at least two mail servers
  - Sending and receiving sides
- May be more
  - Separate servers for key functions
    - Spam filtering
    - Virus scanning
  - Servers that redirect the message
    - mfreed (@) princeton.edu to mfreed (@) cs.princeton.edu
    - Messages to princeton.edu go through extra hops
  - Electronic mailing lists
    - Mail delivered to the mailing list's server
    - … and then the list is expanded to each recipient

Example With Received Header

Return-Path: <casado@cs.stanford.edu>
Received: from ribavirin.CS.Princeton.EDU (ribavirin.CS.Princeton.EDU [128.112.136.44])
by newark.CS.Princeton.EDU (8.12.11/8.12.11) with SMTP id k04M5R7Y023164
for <jrex@newark.CS.Princeton.EDU>; Wed, 4 Jan 2006 17:05:37 -0500 (EST)
Received: from bluebox.CS.Princeton.EDU ([128.112.136.38])
by ribavirin.CS.Princeton.EDU (SMSSMTP 4.1.0.19) with SMTP id M20060104170536O7946
for <jrex@newark.CS.Princeton.EDU>; Wed, 04 Jan 2006 17:05:36 -0500
Received: from smtp-roam.Stanford.EDU (smtp-roam.Stanford.EDU [171.64.10.152])
by bluebox.CS.Princeton.EDU (8.12.11/8.12.11) with ESMTP id k04M5XNQ005204
for <jrex@cs.princeton.edu>; Wed, 4 Jan 2006 17:05:35 -0500 (EST)
Received: from [192.168.1.101] (adsl-69-107-78-147.dsl.pltn13.pacbell.net [69.107.78.147])
(authenticated bits=0)
by smtp-roam.Stanford.EDU (8.12.11/8.12.11) with ESMTP id k04M5W92018875
(version=TLSv1/SSLv3 cipher=DHE-RSA-AES256-SHA bits=256 verify=NOT);
Wed, 4 Jan 2006 14:05:32 -0800
Message-ID: <43BC46AF.3030306@cs.stanford.edu>
Date: Wed, 04 Jan 2006 14:05:35 -0800
From: Martin Casado <casado@cs.stanford.edu>
User-Agent: Mozilla Thunderbird 1.0 (Windows/20041206)
MIME-Version: 1.0
To: jrex@CS.Princeton.EDU
CC: Martin Casado <casado@cs.stanford.edu>
Subject: Using VNS in Class
Content-Type: text/plain; charset=ISO-8859-1; format=flowed
Content-Transfer-Encoding: 7bit

Retrieving E-Mail From the Server

- Server stores incoming e-mail by mailbox
  - Based on the “From” field in the message
- Users need to retrieve e-mail
  - Asynchronous from when the message was sent
  - With a way to view the message and reply
  - With a way to organize and store the messages
- In the olden days…
  - User logged on to the machine where mail was delivered
  - Users received e-mail on their main work machine
- Now, user agent typically on a separate machine
  - And sometimes on more than one such machine

Influence of PCs on E-Mail Retrieval

- Separate machine for personal use
  - Users did not want to log in to remote machines
- Resource limitations
  - Most PCs did not have enough resources to act as a full-fledged e-mail server
- Intermittent connectivity
  - PCs only sporadically connected to the network
  - … due to dial-up connections, and shutting down of PC
  - Too unwieldy to have sending server keep trying
- Led to the creation of new e-mail agents
  - POP, IMAP, and Web-based e-mail

Post Office Protocol (POP)

- POP goals
  - Support users with intermittent network connectivity
  - Allow them to retrieve e-mail messages when connected
  - … and view/manipulate messages when disconnected
- Typical user-agent interaction with a POP server
  - Connect to the server
  - Retrieve all e-mail messages
  - Store messages on the user's PCs as new messages
  - Delete the messages from the server
  - Disconnect from the server

Limitations of POP

- Does not handle multiple mailboxes easily
  - Designed to put user's incoming e-mail in one folder
- Not designed to keep messages on the server
  - Instead, designed to download messages to the client
- Poor handling of multiple-client access to mailbox
  - Increasingly important as users have home PC, work PC, laptop, cyber café computer, PDA, etc.
- High network bandwidth overhead
  - Transfers all of the e-mail messages, often well before they are read (and they might not be read at all!)

Interactive Mail Access Protocol (IMAP)

- Supports connected and disconnected operation
  - Users can download message contents on demand
- Multiple clients can connect to mailbox at once
  - Detects changes made to the mailbox by other clients
  - Server keeps state about message (e.g., read, replied to)
- Access to parts of messages and partial fetch
  - Clients can retrieve individual parts separately
  - E.g., text of a msg without downloading attachments
- Multiple mailboxes on the server
  - Client can create, rename, and delete mailboxes
  - Client can move messages from one folder to another
- Server-side searches
  - Search on server before downloading messages

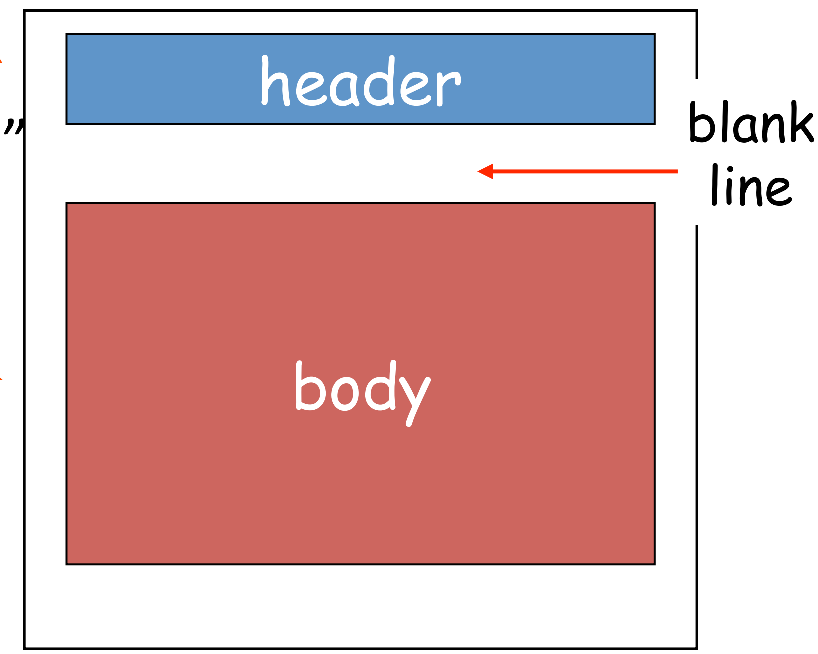
Web-Based E-Mail

- User agent is an ordinary Web browser
  - User communicates with server via HTTP
  - E.g., Gmail, Yahoo mail, and Hotmail
- Reading e-mail
  - Web pages display the contents of folders
  - … and allow users to download and view messages
  - “GET” request to retrieve the various Web pages
- Sending e-mail
  - User types the text into a form and submits to the server
  - “POST” request to upload data to the server
  - Server uses SMTP to deliver message to other servers

E-Mail Messages
(Backup Material)

E-Mail Message

- E-mail messages have two parts
  - A header, in 7-bit U.S. ASCII text
  - A body, also represented in 7-bit U.S. ASCII text
- Header
  - Lines with “type: value”
  - “To: mfreed (@) princeton.edu”
  - “Subject: Go Tigers!”
- Body
  - The text message
  - No particular structure or meaning



E-Mail Message Format (RFC 822)

- E-mail messages have two parts
  - A header, in 7-bit U.S. ASCII text
  - A body, also represented in 7-bit U.S. ASCII text
- Header
  - Series of lines ending in carriage return and line feed
  - Each line contains a type and value, separated by ":"
  - E.g., "To: jrex@princeton.edu" and "Subject: Go Tigers"
  - Additional blank line before the body begins
- Body
  - Series of text lines with no additional structure/meaning
  - Conventions arose over time (e.g., e-mail signatures)

Limitation: Sending Non-Text Data

- E-mail body is 7-bit U.S. ASCII
  - What about non-English text?
  - What about binary files (e.g., images and executables)?
- Solution: convert non-ASCII data to ASCII
  - Base64 encoding: Map each group of 3B into four printable U.S.-ASCII characters
  - uuencode (Unix-to-Unix Encoding) was widely used

```
begin 644 cat.txt
#0V%T
`
end
```

  - Limitation: filename is the only cue to the data type

Limitation: Sending Multiple Items

- Users often want to send multiple pieces of data
  - Multiple images, powerpoint files, or e-mail messages
  - Yet, e-mail body is a single, uninterpreted data chunk
- Example: e-mail digests
  - Encapsulating several e-mail messages into one aggregate messages (i.e., a digest)
  - Commonly used on high-volume mailing lists
- Conventions arose for how to delimit the parts
  - E.g., well-known separator strings between the parts
  - Yet, having a standard way to handle this is better

Multipurpose Internet Mail Extensions

- Additional headers to describe the message body
  – MIME-Version: the version of MIME being used
  – Content-Type: the type of data contained in the message
  – Content-Transfer-Encoding: how the data are encoded
- Definitions for a set of content types and subtypes
  – E.g., image with subtypes gif and jpeg
  – E.g., text with subtypes plain, html, and richtext
  – E.g., application with subtypes postscript and msword
  – E.g., multipart for messages with multiple data types
- A way to encode the data in ASCII format
  – Base64 encoding, as in uuencode/uudecode

Example: E-Mail Message Using MIME

MIME version

method used to encode data

type and subtype

encoded data

```
From:  mfreed (@) cs.princeton.edu
To: jrex (@) cs.princeton.edu
Subject: picture of Thomas Sweet
MIME-Version: 1.0
Content-Transfer-Encoding: base64
Content-Type: image/jpeg

base64 encoded data .....
.........................
......base64 encoded data
```

Thomas Sweet ICE CREAM & CHOCOLATE

Distribution of Content Types

- Content types in e-mail archive
  - Searched on "Content-Type", not case sensitive
  - Extracted the value field, and counted unique types
  - At UNIX command line:

```
grep -i Content-Type * | cut -d" " -f2 | sort | uniq -c | sort -nr
```

- Out of 44343 matches
  - 25531: text/plain
  - 7470: multipart to send attachments
  - 4230: text/html
  - 759: application/pdf
  - 680: application/msword
  - 479: application/octet-stream
  - 292: image (mostly jpeg, and some gif, tiff, and bmp)

Electronic Mailing Lists

- Community of users reachable by one address
  - Allows groups of people to receive the messages
- Exploders
  - Explode a single e-mail message into multiple messages
  - One copy of the message per recipient
- Handling bounced messages
  - Mail may bounce for several reasons
  - E.g., recipient mailbox does not exist; resource limits
- E-mail digests
  - Sending a group of mailing-list messages at once
  - Messages delimited by boundary strings
  - … or transmitted using multiple/digest format

Conclusions

- New challenges in data networking
  - Sensors, intermittent connectivity, long-delay links, …
  - Require revisiting traditional assumptions
- Disruption Tolerant Networking (DTN)
  - Relatively new area of research and standards
  - Many application scenarios with unique properties
- Electronic mail as an example
  - Sporadic end-host connectivity
  - Resource constraints on the end host
  - User connecting from different hosts and locations
  - While still relying on the underlying Internet infrastructure