15-744: Computer Networking

L-20 Data Oriented Networking

Outline

- Data-oriented Networking
- DTNs

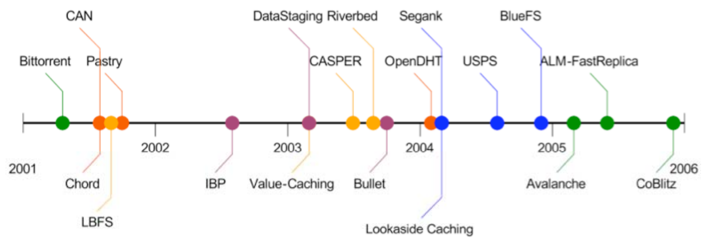
Data-Oriented Networking Overview

- In the beginning...
  - First applications strictly focused on host-to-host interprocess communication:
    - Remote login, file transfer, ...
  - Internet was built around this host-to-host model.
  - Architecture is well-suited for communication between pairs of stationary hosts.
- ... while today
  - Vast majority of Internet usage is data retrieval and service access.
  - Users care about the content and are oblivious to location. They are often oblivious as to delivery time:
    - Fetching headlines from CNN, videos from YouTube, TV from Tivo
    - Accessing a bank account at “www.bank.com”.

To the beginning...

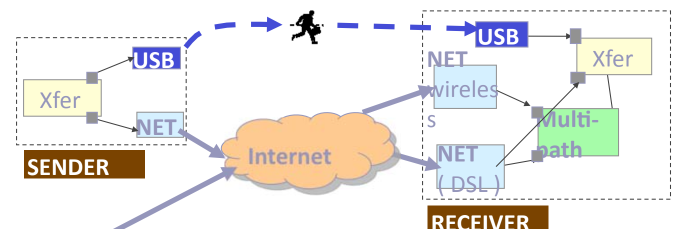
- What if you could re-architect the way “bulk” data transfer applications worked
  - HTTP
  - FTP
  - Email
  - etc.
- ... knowing what we know now?

Innovation in Data Transfer is Hard



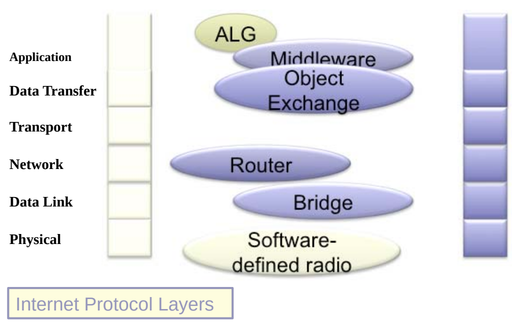
- Imagine: You have a novel data transfer technique
- How do you deploy?
  - Update HTTP. Talk to IETF. Modify Apache, IIS, Firefox, Netscape, Opera, IE, Lynx, Wget, …
  - Update SMTP. Talk to IETF. Modify Sendmail, Postfix, Outlook…
  - Give up in frustration

Data-Oriented Network Design

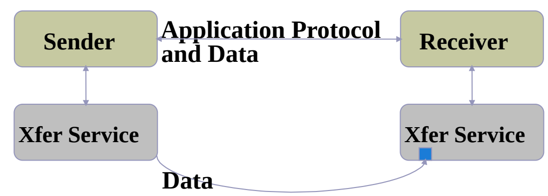


Features
- ✓ Multipath and Mirror support
- ✓ Store-carry-forward

New Approach: Adding to the Protocol Stack



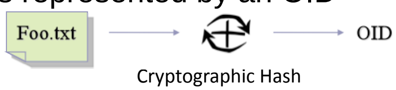
Data Transfer Service



- Transfer Service responsible for finding/transferring data
  - Transfer Service is shared by applications
- How are users, hosts, services, and data named?
- How is data secured and delivered reliably?
- How are legacy systems incorporated?

Naming Data (DOT)

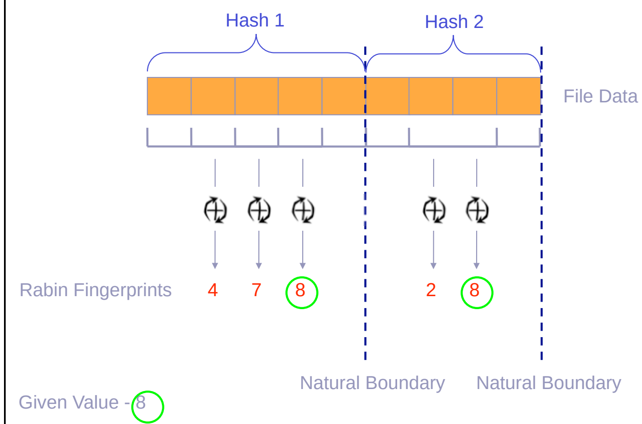
- Application defined names are not portable
- Use content-naming for globally unique names
- Objects represented by an OID



- Objects are further sub-divided into “chunks”

- Secure and scalable!

Similar Files: Rabin Fingerprinting



Naming Data (DOT)

- All objects are named based only on their data
- Objects are divided into chunks based only on their data

- Object “A” is named the same
  - Regardless of who sends it
  - Regardless of what application deals with it

- Similar parts of different objects likely to be named the same
  - e.g., PPT slides v1, PPT slides v1 + extra slides
  - First chunks of these objects are same

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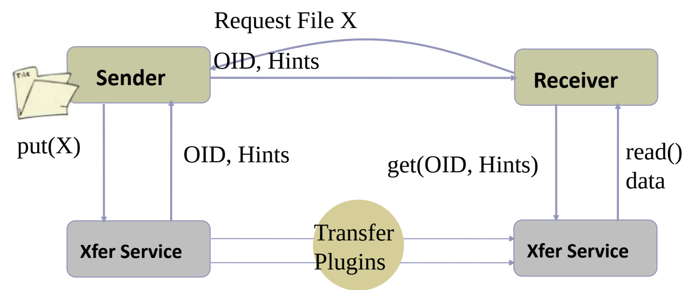
Naming Data (DONA)

- Names organized around principals.
- Names are of the form P : L.
  - P is cryptographic hash of principal’s public key, and
  - L is a unique label chosen by the principal.
- Granularity of naming left up to principals.
- Names are “flat”.

Self-certifying Names

- A piece of data comes with a public key and a signature.
- Client can verify the data did come from the principal by
  - Checking the public key hashes into P, and
  - Validating that the signature corresponds to the public key.
- Challenge is to resolve the flat names into a location.

Locating Data (DOT)



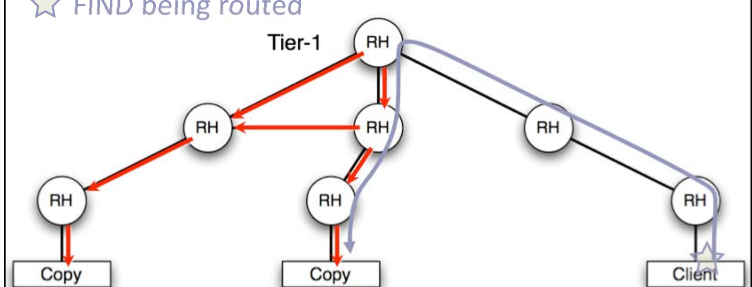
Name Resolution (DONA)

- Resolution infrastructure consists of Resolution Handlers.
  - Each domain will have one logical RH.
- Two primitives FIND(P:L) and REGISTER(P:L).
  - FIND(P:L) locates the object named P:L.
  - REGISTER messages set up the state necessary for the RHs to route FINDs effectively.

Locating Data (DONA)

REGISTER state

FIND being routed



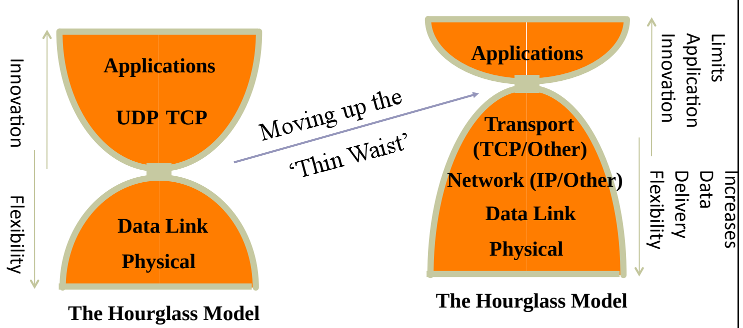
Establishing REGISTER state

- Any machine authorized to serve a datum or service with name P:L sends a REGISTER(P:L) to its first-hop RH
- RHs maintain a registration table that maps a name to both next-hop RH and distance (in some metric)
- REGISTERs are forwarded according to interdomain policies.
  - REGISTERs from customers to both peers and providers.
  - REGISTERs from peers optionally to providers/peers.

Forwarding FIND(P:L)

- When FIND(P:L) arrives to a RH:
  - If there's an entry in the registration table, the FIND is sent to the next-hop RH.
  - If there's no entry, the RH forwards the FIND towards to its provider.
- In case of multiple equal choices, the RH uses its local policy to choose among them.

Interoperability: New Tradeoffs



Interoperability: Datagrams vs. Data Blocks

	Datagrams	Data Blocks
What must be standardized?	IP Addresses Name→Address translation (DNS)	Data Labels Name → Label translation (Google?)
Application Support	Exposes much of underlying network's capability	Practice has shown that this is what applications need
Lower Layer Support	Supports arbitrary links Requires end-to-end connectivity	Supports arbitrary links Supports arbitrary transport Support storage (both in-network and for transport)

Outline

- Data-oriented Networking
- DTNs

Unstated Internet Assumptions

- Some path exists between endpoints
  - Routing finds (single) “best” existing route
- E2E RTT is not very large
  - Max of few seconds
  - Window-based flow/cong ctl. work well
- E2E reliability works well
  - Requires low loss rates
- Packets are the right abstraction
  - Routers don’t modify packets much
  - Basic IP processing

New Challenges

- Very large E2E delay
  - Propagation delay = seconds to minutes
  - Disconnected situations can make delay worse
- Intermittent and scheduled links
  - Disconnection may not be due to failure (e.g. LEO satellite)
  - Retransmission may be expensive
- Many specialized networks won’t/can’t run IP

IP Not Always a Good Fit

- Networks with very small frames, that are connection-oriented, or have very poor reliability do not match IP very well
  - Sensor nets, ATM, ISDN, wireless, etc
- IP Basic header – 20 bytes
  - Bigger with IPv6
- Fragmentation function:
  - Round to nearest 8 byte boundary
  - Whole datagram lost if any fragment lost
  - Fragments time-out if not delivered (sort of) quickly

IP Routing May Not Work

- End-to-end path may not exist
  - Lack of many redundant links [there are exceptions]
  - Path may not be discoverable [e.g. fast oscillations]
  - Traditional routing assumes at least one path exists, fails otherwise
- Insufficient resources
  - Routing table size in sensor networks
  - Topology discovery dominates capacity
- Routing algorithm solves wrong problem
  - Wireless broadcast media is not an edge in a graph
  - Objective function does not match requirements
    - Different traffic types wish to optimize different criteria
    - Physical properties may be relevant (e.g. power)

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What about TCP?

- Reliable in-order delivery streams
- Delay sensitive [6 timers]:
  - connection establishment, retransmit, persist, delayed-ACK, FIN-WAIT, (keep-alive)
- Three control loops:
  - Flow and congestion control, loss recovery
- Requires duplex-capable environment
  - Connection establishment and tear-down

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Performance Enhancing Proxies

- Perhaps the bad links can be 'patched up'
  - If so, then TCP/IP might run ok
  - Use a specialized middle-box (PEP)
- Types of PEPs [RFC3135]
  - Layers: mostly transport or application
  - Distribution
  - Symmetry
  - Transparency

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TCP PEPs

- Modify the ACK stream
  - Smooth/pace ACKS → avoids TCP bursts
  - Drop ACKs → avoids congesting return channel
  - Local ACKs → go faster, goodbye e2e reliability
  - Local retransmission (snoop)
  - Fabricate zero-window during short-term disruption
- Manipulate the data stream
  - Compression, tunneling, prioritization

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Architecture Implications of PEPs

- End-to-end "ness"
  - Many PEPs move the 'final decision' to the PEP rather than the endpoint
  - May break e2e argument [may be ok]
- Security
  - Tunneling may render PEP useless
  - Can give PEP your key, but do you really want to?
- Fate Sharing
  - Now the PEP is a critical component
- Failure diagnostics are difficult to interpret

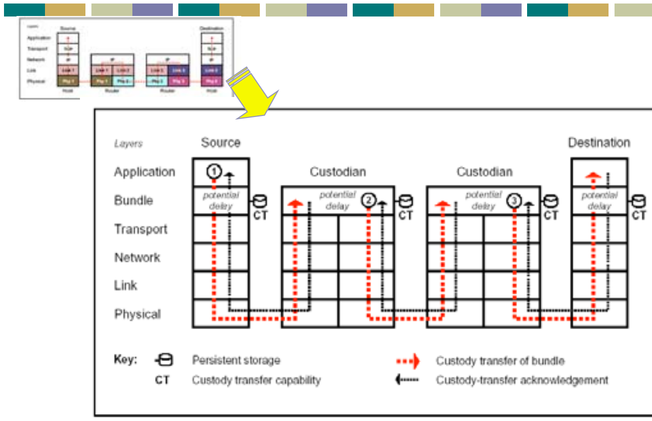
Architecture Implications of PEPs [2]

- Routing asymmetry
  - Stateful PEPs generally require symmetry
  - Spacers and ACK killers don't
- Mobility
  - Correctness depends on type of state
  - (similar to routing asymmetry issue)

Delay-Tolerant Networking Architecture

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

Disruption Tolerant Networks



Disruption Tolerant Networks

Naming Data (DTN)

- Endpoint IDs are processed as names
  - refer to one or more DTN nodes
  - expressed as Internet URI, matched as strings
- URIs
  - Internet standard naming scheme [RFC3986]
  - Format: <scheme> : <SSP>
- SSP can be arbitrary, based on (various) *schemes*
- More flexible than DOT/DONA design but less secure/scalable

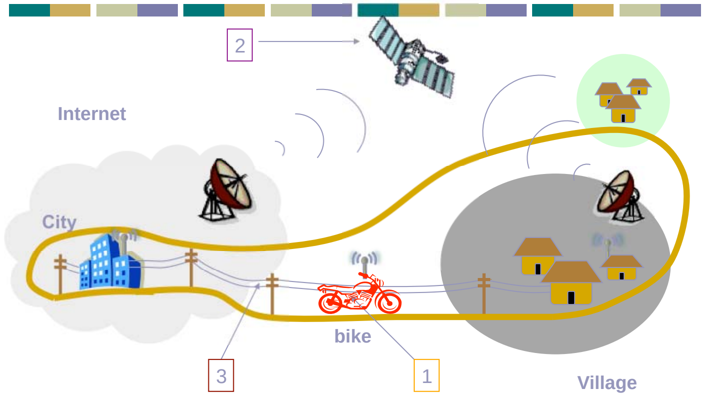
Message Abstraction

- Network protocol data unit: <u>bundles</u>
  - "postal-like" message delivery
  - coarse-grained CoS [4 classes]
  - origination and useful life time [assumes sync'd clocks]
  - 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/receive <u>messages</u>
  - "Application data units" (<u>**ADUs**</u>) of possibly-large size
  - Adaptation to underlying protocols via 'convergence layer'
  - API includes persistent registrations

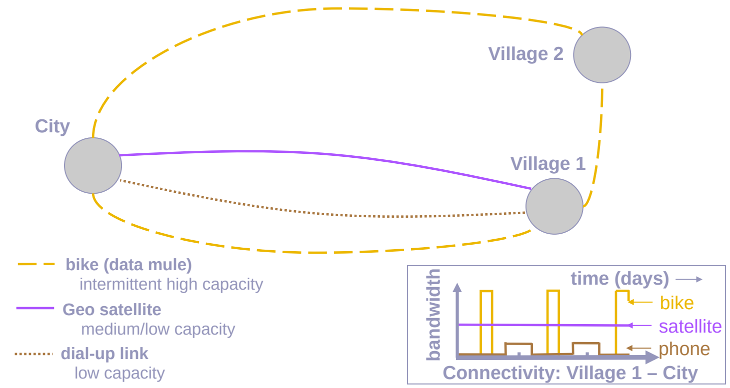
DTN Routing

- DTN Routers form an overlay network
  - only selected/configured nodes participate
  - nodes have persistent storage
- DTN routing topology is a <u>**time-varying**</u> multigraph
  - Links come and go, sometimes predictably
  - Use any/all links that can possibly help (multi)
  - Scheduled, Predicted, or Unscheduled Links
    - May be direction specific [e.g. ISP dialup]
    - 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



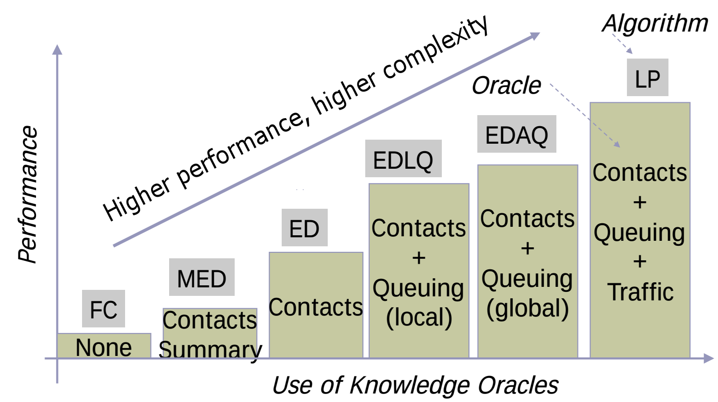
Example Graph Abstraction



The DTN Routing Problem

- *Inputs*: topology (multi)graph, vertex buffer limits, contact set, message demand matrix (w/priorities)
- An ***edge*** is a possible opportunity 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 $[i_k, i_{k+1}]$
- Vertices have buffer limits; edges in graph if ever in any contact, multigraph for multiple physical connections
- *Problem*: optimize some metric of delivery on this structure
  - Sub-questions: what metric to optimize?, efficiency?

Knowledge-Performance Tradeoff



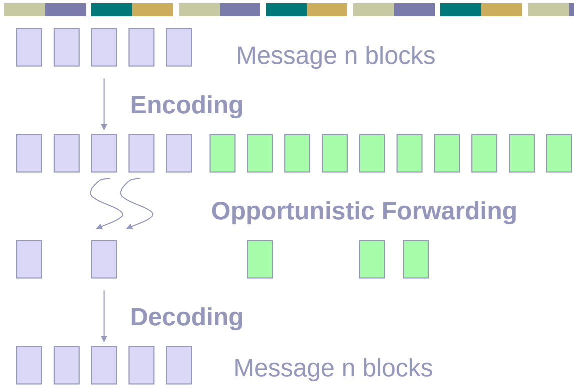
Routing Solutions - Replication

- "Intelligently" distribute identical data copies to contacts to increase chances of delivery
  - Flooding (unlimited contacts)
  - Heuristics: random forwarding, history-based forwarding, predication-based forwarding, etc. (limited contacts)
- Given "replication budget", this is difficult
  - Using simple replication, only finite number of copies in the network [Juang02, Grossglauser02, Jain04, Chaintreau05]
  - Routing performance (delivery rate, latency, etc.) heavily dependent on *"deliverability" of these contacts* (or *predictability of heuristics)*
  - No single heuristic works for all scenarios!

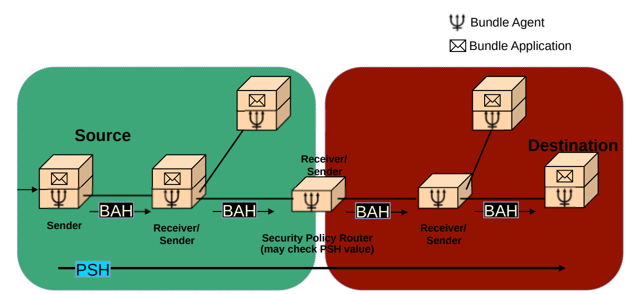
Using Erasure Codes

- Rather than seeking particular "good" contacts, "split" messages and distribute to more contacts to increase chance of delivery
  - Same number of bytes flowing in the network, now in the form of coded blocks
  - Partial data arrival can be used to reconstruct the original message
    - Given a replication factor of *r,* (in theory) any *1/r* code blocks received can be used to reconstruct original data
  - Potentially leverage more contacts opportunity that result in lowest worse-case latency
- Intuition:
  - Reduces "risk" due to outlier bad contacts

Erasure Codes



DTN Security



- Payload Security Header (PSH) end-to-end security header
- Bundle Authentication Header (BAH) hop-by-hop security header

credit: MITRE

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
  - In the Internet (SMTP) case, not disconnection-tolerant or efficient for long RTTs due to "chattiness"
- E-mail security authenticates only user-to-user

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