Pervasive Systems

Ioannis Chatzigiannakis

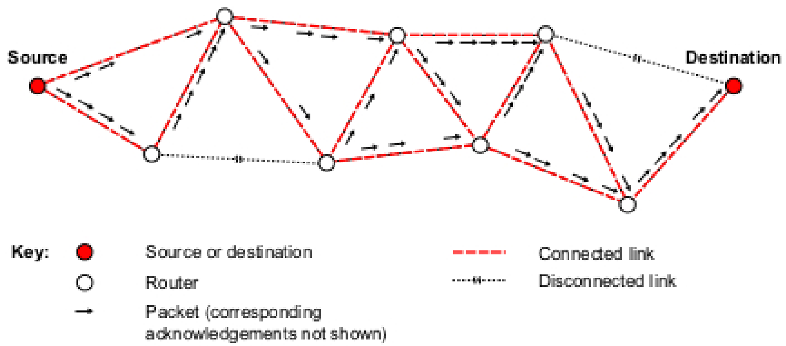
Sapienza University of Rome
Department of Computer, Control, and Management Engineering (DIAG)

Lecture 3:
Delay-Tolerant Networking

IP-based Network Assumptions

- End-to-end RTT is not terribly large.
  - A few seconds at the very most – typically less than 500ms,
  - window-based flow/congestion control works.
- Some path exists between endpoints.
  - Routing finds single "best" existing route.
- E2E Reliability using ARQ works well.
  - True for low loss rates (under 2% or so).
- Packet switching is the right abstraction.
  - Internet/IP makes packet switching interoperable.

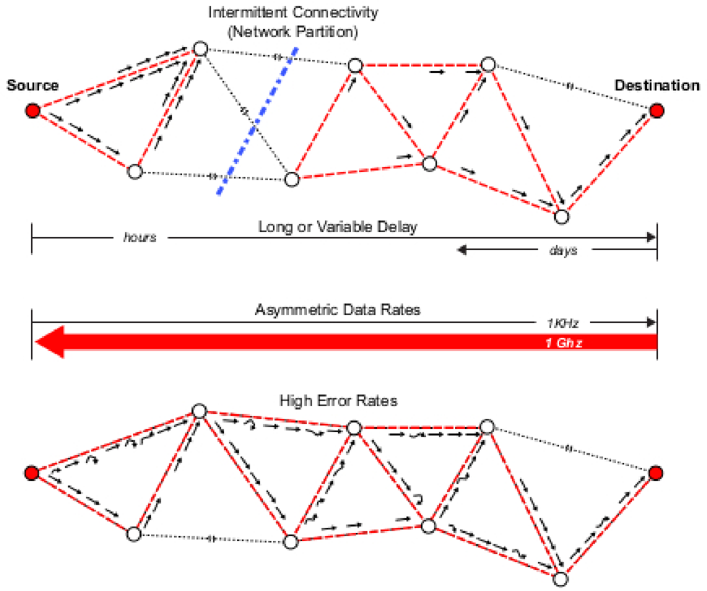
Typical IP-based Network E2E Path



Non-IP-based Networks

- Stochastic mobility
  - Military/tactical networks
  - Mobile routers w/disconnection (e.g. ZebraNet)
- Periodic/predictable mobility
  - Spacecraft communications
  - Busses, mail trucks, police cars, etc. (InfoStations)
- "Exotic" links
  - Deep space [40+ min RTT; episodic connectivity
  - Underwater [acoustics: low capacity, high error rates & latencies]

Delay-Tolerant Network E2E Path



New Challenges

- Very Large Delays
  - Natural delay could be seconds to minutes
  - If disconnected, may be (effectively) much longer
- Intermittent/Scheduled/Opportunistic Links
  - Scheduled transfers can save power and help congestion; scheduling common for esoteric links
- High Link Error Rates / Low Capacity
  - RF noise, light or acoustic interference
- Different Network Architectures
  - Many specialized networks won't/can't ever run IP

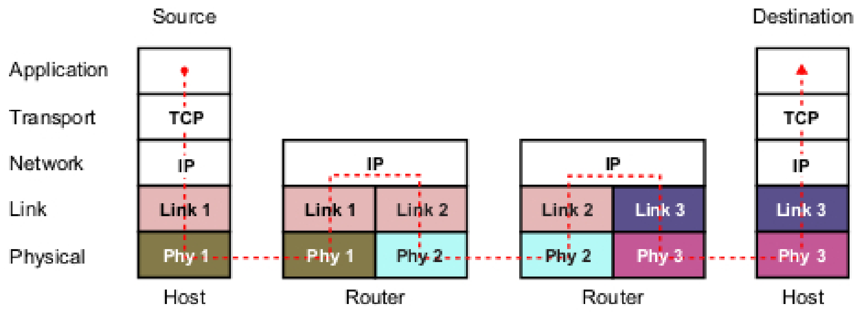
How to Address these issues?

- Some problems surmountable using Internet/IP
  - "cover up" the link problems using PEPs
  - Mostly used at "edges", not so much for transit
- Performance Enhancing Proxies (PEPs):
  - Do "something" in the data stream causing endpoint (TCP/IP) systems to not notice there are problems
  - Lots of issues with transparency security, operation with asymmetric routing, etc.
- Some environments never have an E2E path
  - Consider an approach tolerating disconnection, etc...

Delay and Disruption Tolerant Networking (DTN)

- Support interoperability across radically heterogeneous networks
- Acceptable performance in high loss/delay/error/disconnected environments
- Decent performance for low loss/delay/errors
- Environments without continuous network connectivity.
- For challenged environments: remote sensors in Antarctica, a spacecraft in deep space, submersible vessels etc.
- For communication during Disasters and Emergency.
- Communication is asynchronous by nature.

Delay-Tolerant Network Store & Forward Approach

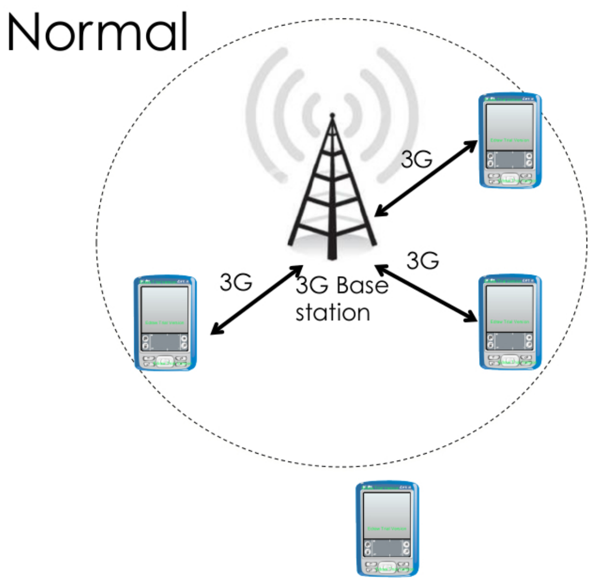



Terrorist Attack

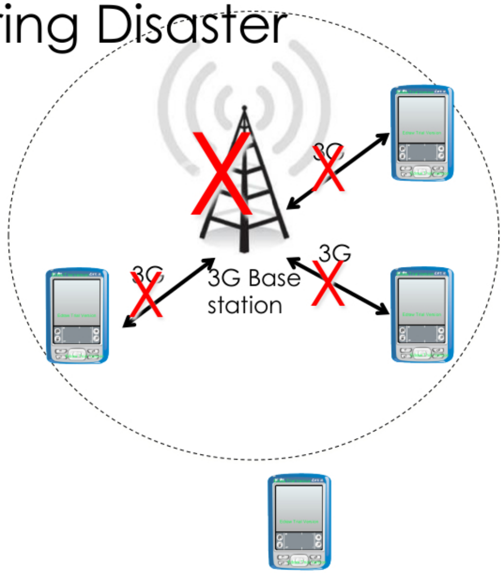

Hurricane


Tsunami

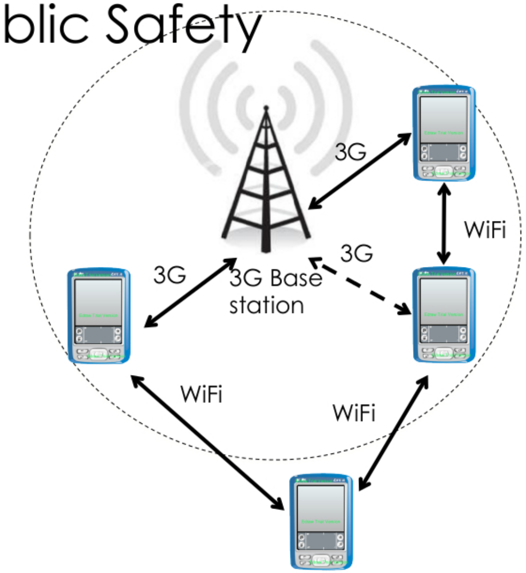

Earthquake



During Disaster

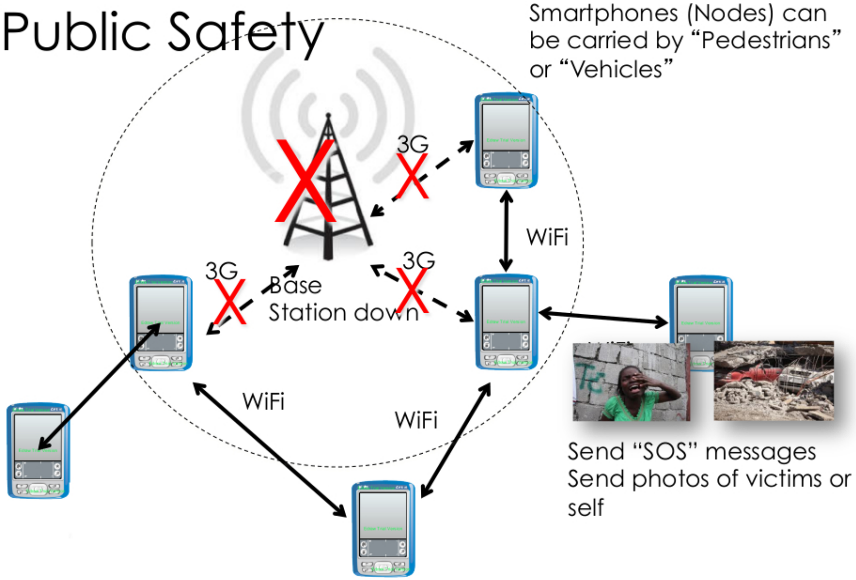


Public Safety



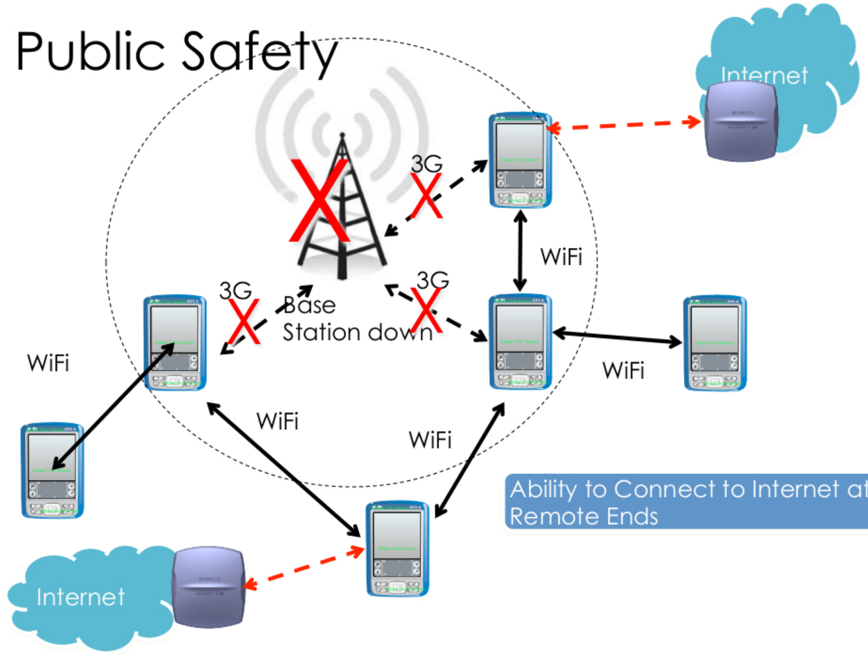
Public Safety

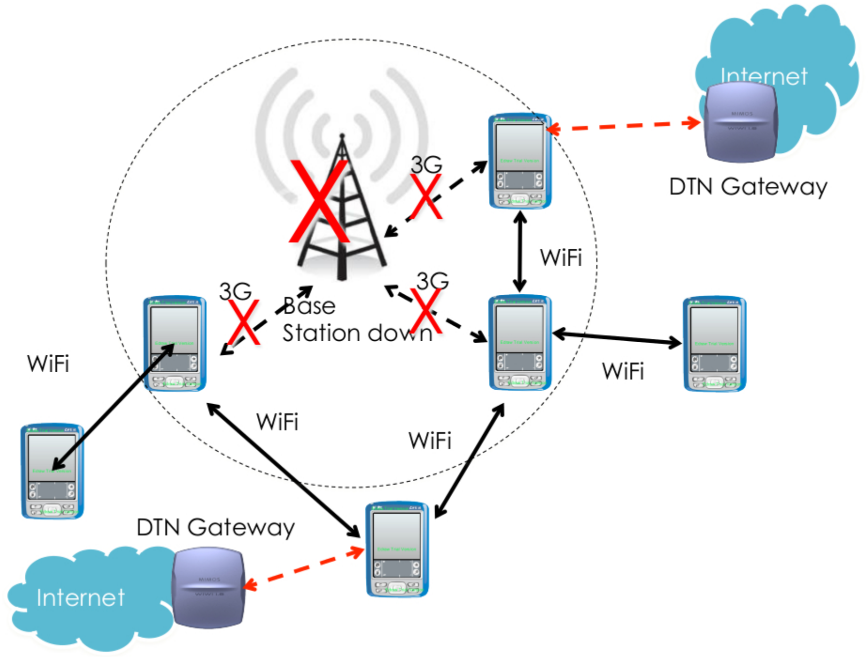
Smartphones (Nodes) can be carried by "Pedestrians" or "Vehicles"



Send "SOS" messages
Send photos of victims or self

Public Safety





Message Overlay Abstraction

- Message exchanges are called *bundles*.
  - "postal-like" message delivery over regional transports with coarse-grained CoS [4 classes]
  - Options: return receipt, "traceroute"-like function, alternative reply-to field, custody transfer
  - Supportable on nearly any type of network
- Bundles are routed in a store and forward manner.
  - "Application data units" of possibly-large size
  - May require framing above some transport protocols
  - API supports response processing long after request was sent (application re-animation)

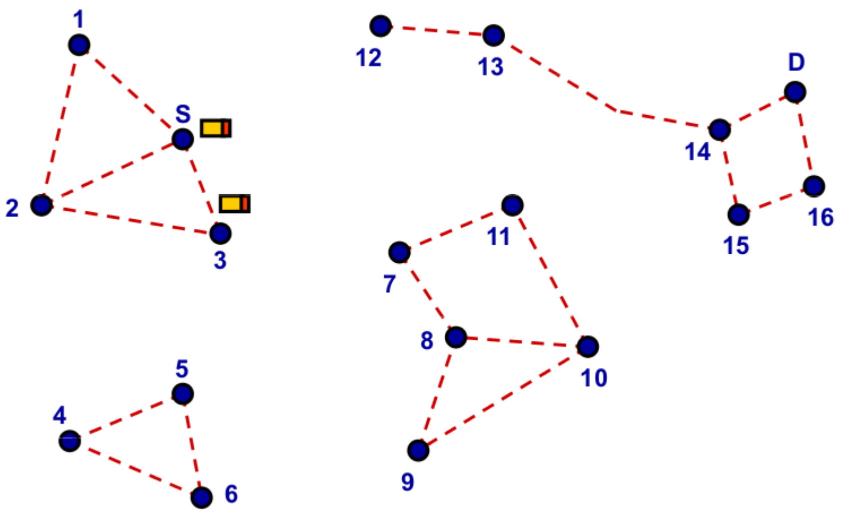
Is it an e-mail like communication scheme?

- Many similarities to (abstract) e-mail service
- Primary difference involves routing and API
- E-mail depends on an underlying layers 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

Store, Carry and Forward Scheme for Routing

- A node stores a message until an appropriate communication opportunity arises.
- A series of independent forwarding decisions.
- Eventually bring the packet to its destination.
- Key decisions in forwarding packets:
  1. What to send (own packet or a relayed packet ?)
  2. To whom (to a relay or the destination ?)
  3. When to do so (will suffer collisions, or cause interference ?)
- Simple (and efficient) approach: Randomize on
  1. Whom to send,
  2. When to send.

Store, Carry and Forward



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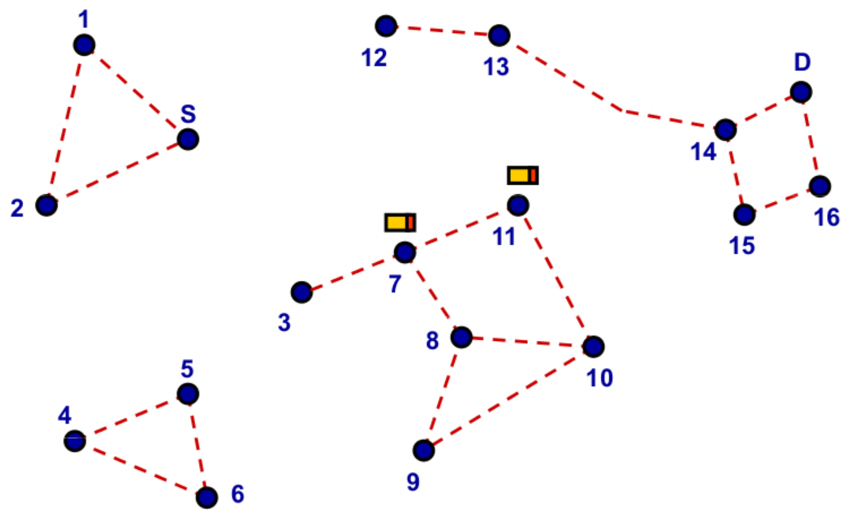
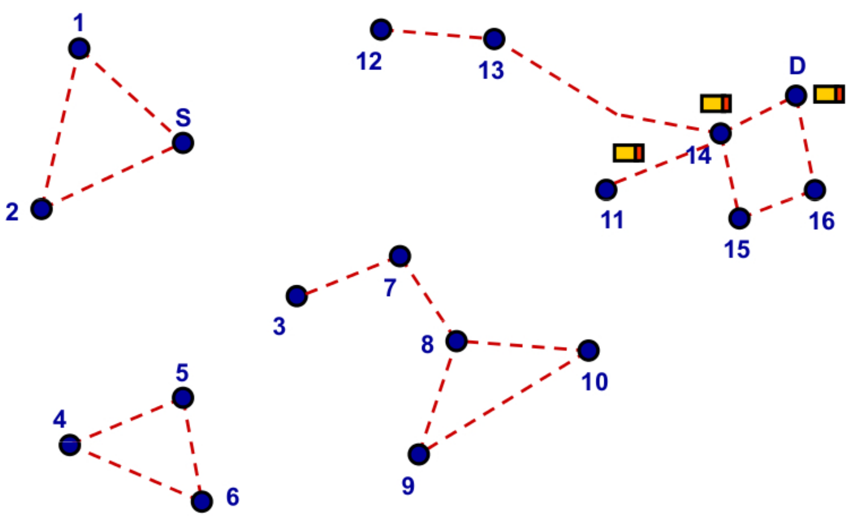


Store, Carry and Forward



Strategies

- Single-Copy: only a single copy of each message exists in the network at any time.
  - lower number of transmission,
  - lower contention for shared resources.
- Multiple-Copy: multiple copies of a message may exist concurrently in the network.
  - lower delivery delay,
  - higher robustness.

Single-Copy Strategy

- Direct transmission – Source only forwards message to destination.
- First Contact – Node A forwards message to the first encounters.
- Randomized routing – Node A forwards message to node B with probability p.

Multi-Copy Strategy

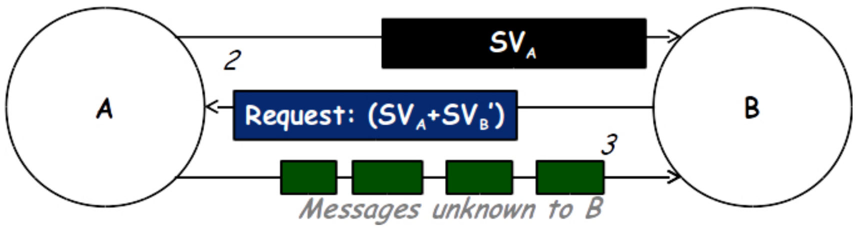
- Epidemic routing
  - Spread of “disease”.
  - Whenever “infected” node meets “susceptible” node, a copy is forwarded.
- Utility-based routing:
  - Node A forwards a message to node D to node B iff $U_A(D) < U_B(D)$

Basic Idea of Epidemic Routing

- Bio-inspired: packets are considered to infect nodes (Vahdat & Becker, 2000)
- Nodes are randomly mobile & have ordered identifiers.
- Resources sufficiency (battery / buffers).
- Forwarding Decision: fixed – flooding
- Buffers: FIFO
- Buffer (hashed) “index”: Summary Vector (SV)
- Reliability: acks

Main Mechanism

- Upon meeting a newly identified neighbor node
  1. Exchange SVs,
  2. Exchange unknown messages.
- For protocol sake the process is initiated by the node with the smaller identifier.
- Per-host queuing.
- New messages given preference over old ones in terms of buffer availability.



Main Concepts of PRoPHET Protocol

- PRoPHET: Probabilistic Routing Protocol using History of Encounters and Transitivi (Lindgren, et al. 2003)
- Users move in a “not so random”, predictable fashion.
- Forwarding decision: by Delivery Predictability $P(M, D)$ set up at every node M for each known destination D.
- Epidemic Routing SVs are used here too to exchange.

Protocol Details

- When the node Mencounters another node N, the predictability for$N$ increases a

$$P(M, N)_{new} = P(M, N)_{old} + (1 - P(M, N)_{old}) \times L_{enc}$$

  where L_{enc} is an initialization constant.
- The predictabilities for all destinations D other than N suffer ageing:

$$P(M, D)_{new} = P(M, D)_{old} \times \gamma \times K$$

  where γ is an aging constant, and K is a time factor.

Protocol Details

- Transitive property updates the predictability of destination D for which N has a $P(N, D)$ value:

$$P(M, D)_{new} = P(M, D)_{old} + (1 - P(M, D)_{old}) \times P(M, E) \times P(E, D) \times \beta$$

  where β is a scaling factor.
- The assumption here is that M is likely to meet N again.

Main concepts of MAXPROP

- Motivated by pedestrian mobility and city vehicles (busses) (Burgess, et al. 2006)
- Addressed resources issues considering vehicles.
  - Bulky equipment,
  - Energy.
- Maintains ordered destination based queues.
  - Addresses on top of PRoPHET.
  - QoS,
  - Stale data.
- Assumes:
  - Unlimited buffer for own messages per node,
  - Fixed size buffer for relaying messages,
  - No topology knowledge/control.

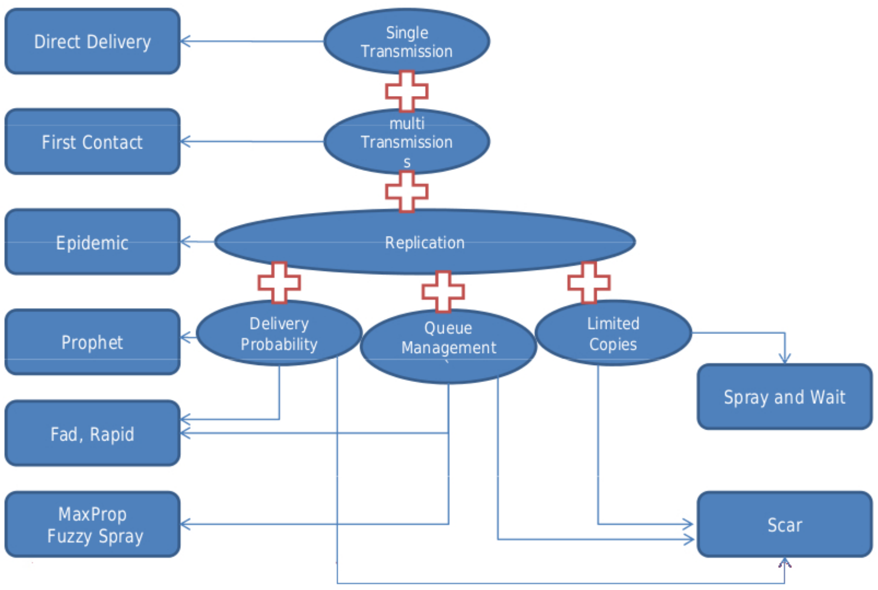
Communication steps of MAXPROP

- Neighbor Discovery.
  - no knowledge of when the next opportunity to communicate will be.
- Data Transfer.
  1. Transfer packets destined for neighbor peer,
  2. Transfer routing information,
  3. Acknowledge any delivered data,
  4. Prioritize "young" relayed packets,
  5. Send un-transmitted packets by estimated delivery likelihood,
  6. Ensure only new packets are sent.
- Storage Management.
  - Expunge packets to accommodate the relay buffers.

Which Routing Schemes is more suitable?

- Design space is LARGE
- Many different protocols have been proposed in the literature

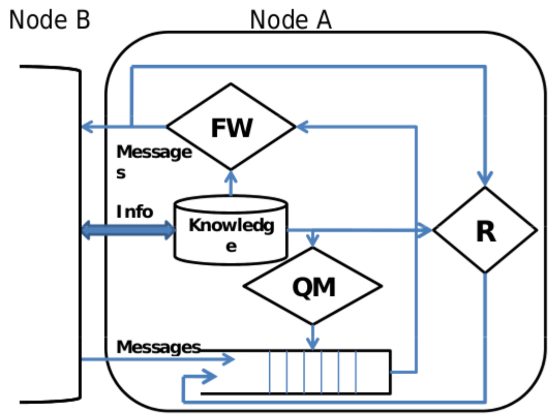
Diverse Features



An DTN Protocol Architecture

A DTN protocol scheme is made of the combination of three basic techniques:

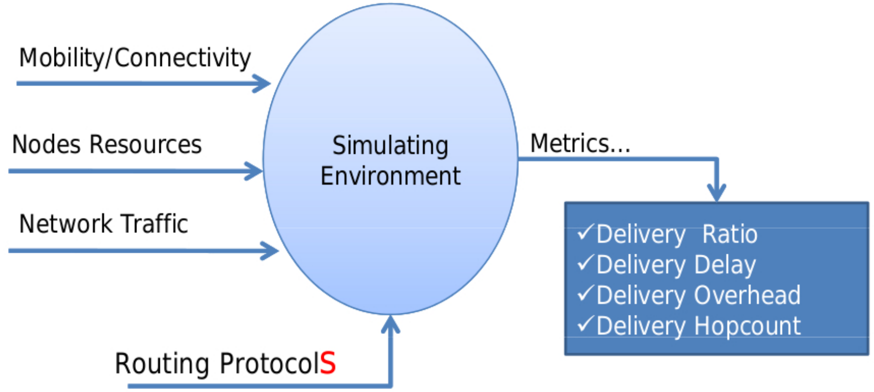
- Queue management (QM)
- Replication(R)
- Forwarding(FW)



How to Evaluate Routing Schemes?

- Many factors affect performance
  1. Mobility of nodes,
  2. Size of area covered by nodes,
  3. Available Resources,
  4. Network Traffic.

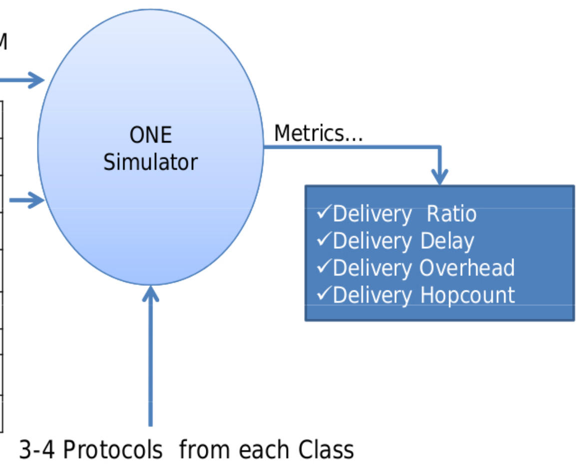
Quantitative Evaluation using Simulation



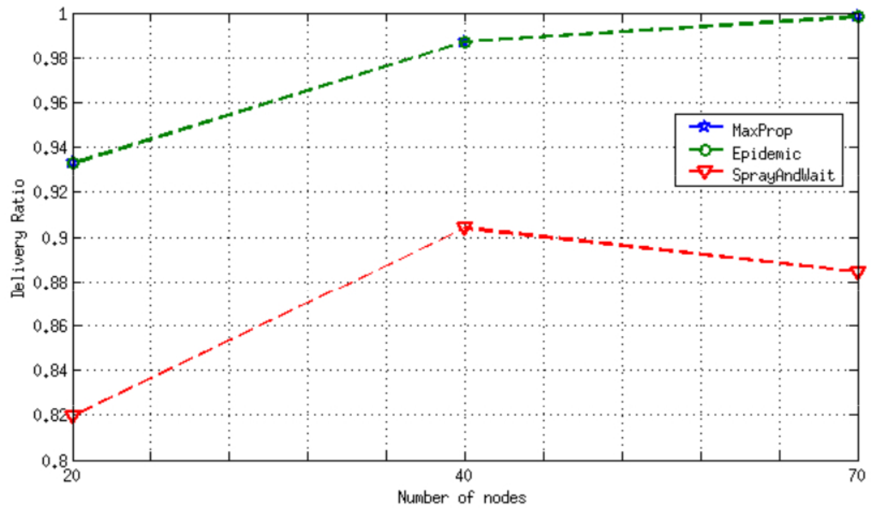
Software Simulation Parameters

4-Mobility models:
RWP, RW, LW and CM

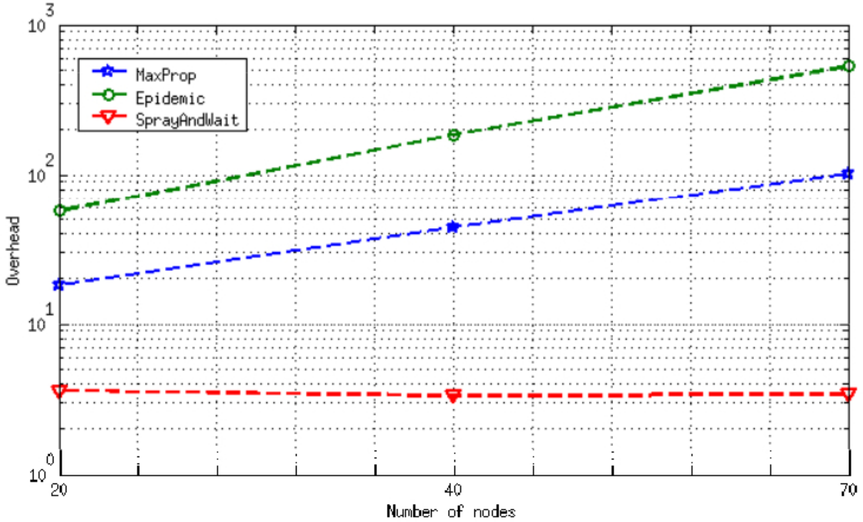
Simulation Time	**12 hours**
World Size	**400X200 m**
Number of Nodes	**10,20,40,70**
Message Size	**100B-200B**
Message Creation Interval	**[60 - 180]s**
Transmission speed	**25kBps**
Transmission range	**10m**
Node speed	**0.8-2.0 m/s**
Buffer Size	**10KB, 100KB**



Evaluation Result: Delivery Ratio



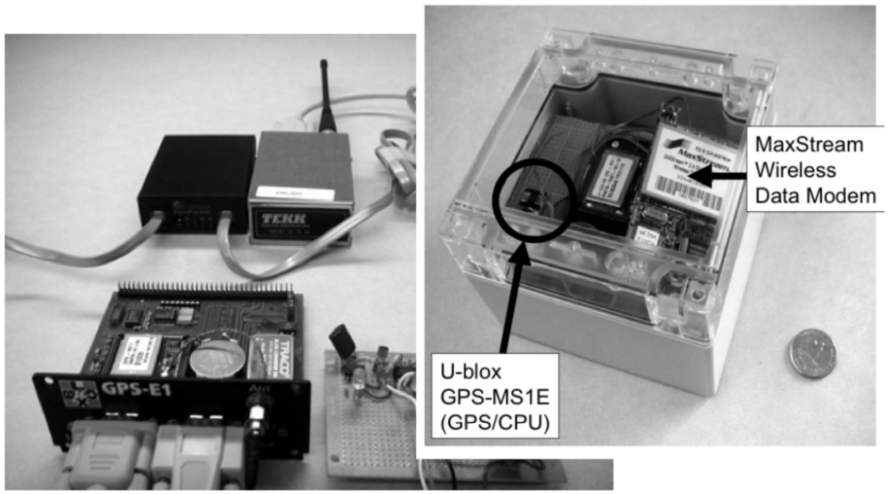
Evaluation Result: Overhead



Wildlife Monitoring

- The users are the biologists.
- Track position of zebras in wildlife.
- Special colars with GPS are attached to zebras.
- Tracking data is replicated when animals are in reach of each other.
- Tracking data gathered daily or weekly using a base station in a car or plane (called a "message ferry").
- Project did not use the term "DTN".

Prototype Hardware



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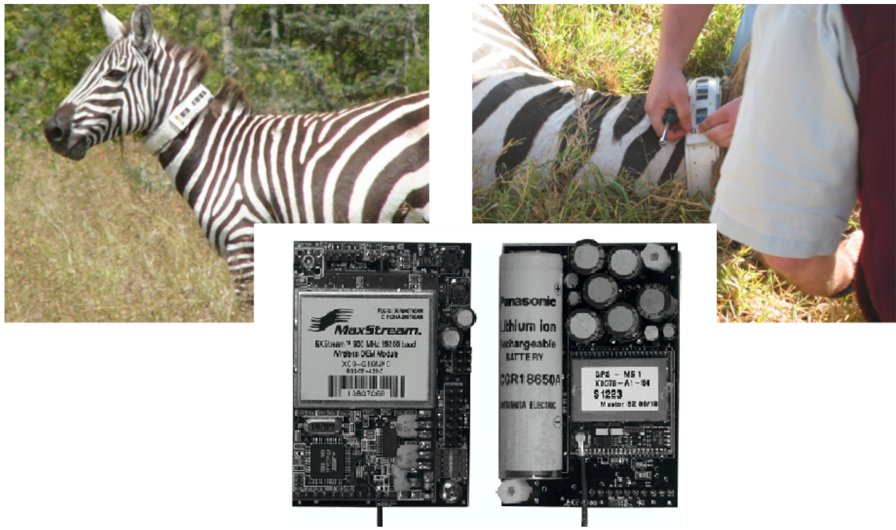


Prototype Hardware

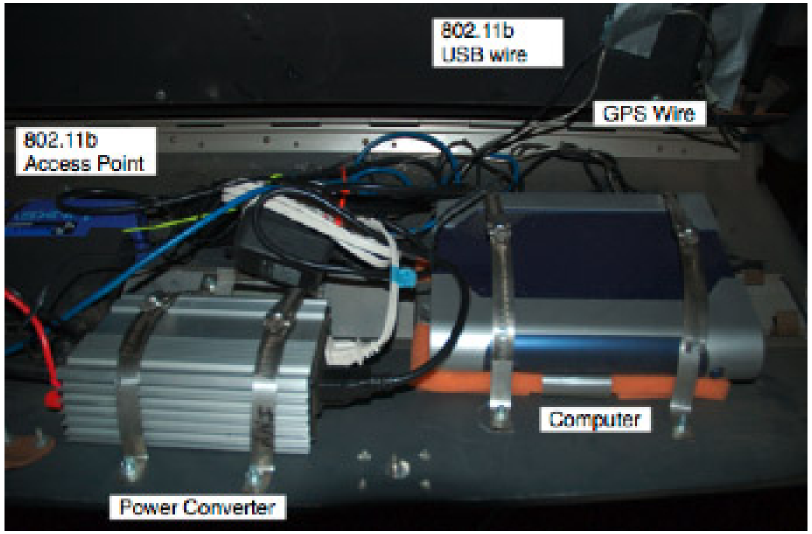
Technical Considerations

- Track animals long term and over long distances.
- All sensing nodes are mobile.
- Large area: 100s . . . 1000s sq kilometers.
- "Coarse-Grained" nodes.
- GPS on-board.
- Long-running and autonomous.

Public Transportation Network

- A DTN over public transportation busses.
- Deployed in Amherst and surrounding county.
- Includes 40 busses.
- Network inaccessibility corresponds to physical inaccessibility.
  - DTN administration difficult,
  - DTN system administration must be accomplished in a disruption-tolerant manner.
- DTN solution handles configuration of IP, Link, and physical network.
- Buses transfer data as they pass by each other and via available hot spots.

The OpenBrick Hardware



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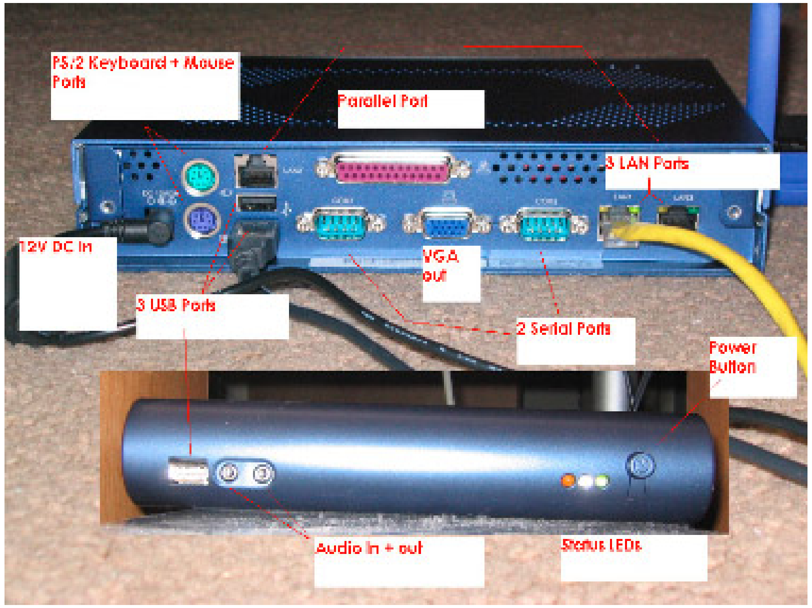

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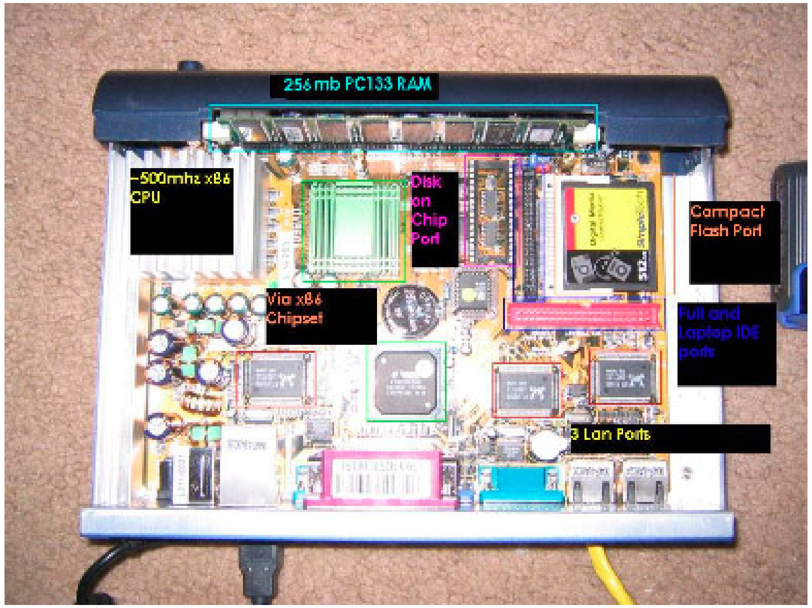

The OpenBrick Hardware

The OpenBrick Hardware

The OpenBrick Hardware

Software Considerations

- Autonomous operation and "shutdown".
- Maximal failure tolerance.
  - No remote administrator login or local terminal.
  - Physical inaccessibility during operation (6am - 1am).
  - Nodes versus support staff.
- Handle network interface configurations.
  - Support IP programs.
- Handle bundle routing.
  - Support DTN programs.

Software Components

1. Init and Restore
   - Perl and Python
2. Auto update
   - Python
3. Live IP
   - Java 1.4
4. GPS update
   - Python
5. DTN daemon
   - Java 1.4 and linux-only Java 1.3

Connection Events

- Red dots indicate bus-to-bus transfers (1 month)
- Measurement of real TCP throughput.
- Traces collected everyday.