Opportunistic Mobile Networks

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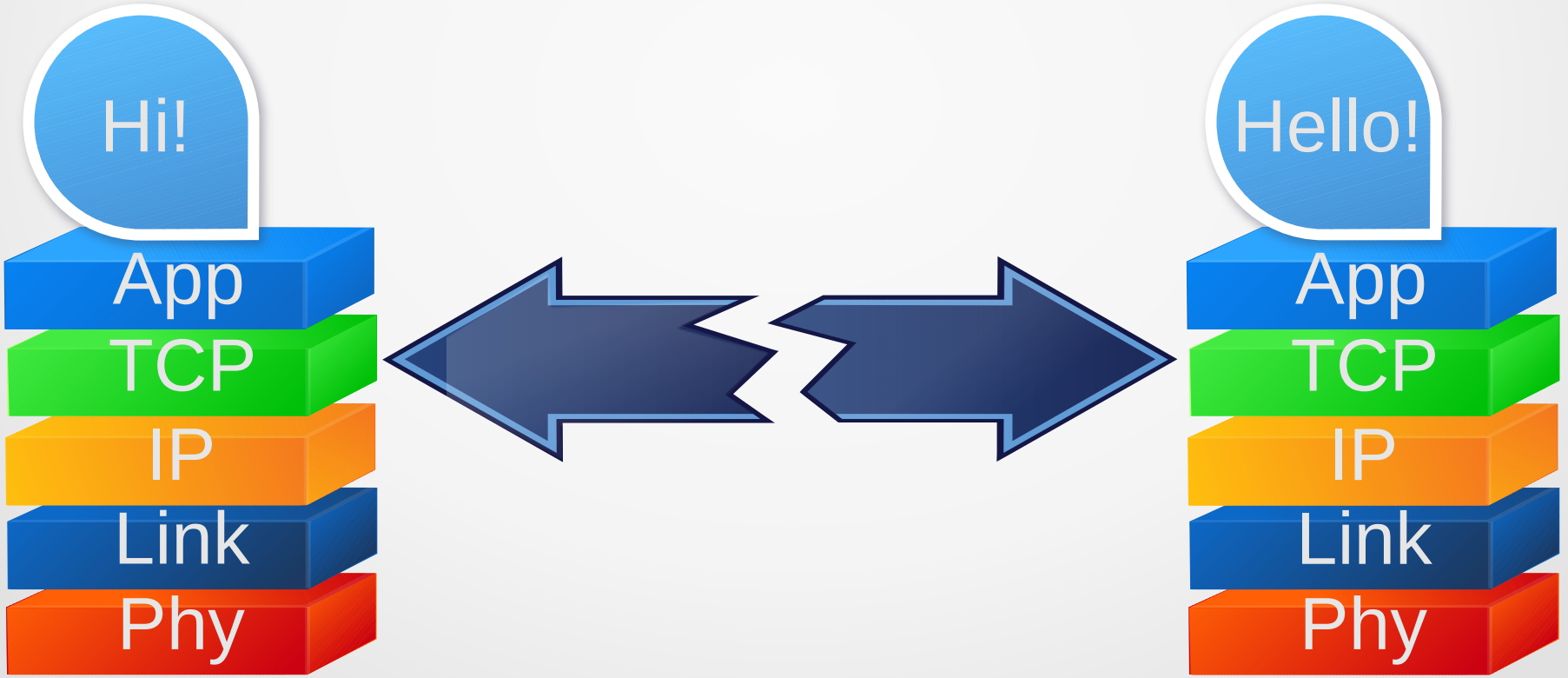
Why the Internet Model Fails?

- Try loading a web page over an unstable connection
  - Timeout



Why the Internet Model Fails?

- TCP:
  - Connection oriented
  - End-to-end communication path
- Support or reject the claim:
  - Since TCP is connection oriented, if we replace TCP with UDP, we would not require OMNs.

OMNs: Characteristics

- Hop-by-hop message transfer
- Store-carry-and-forward
- Message replication, not forwarding
- Optimal decision based on locally available information
- Delivery latency: In the order of hours

Epidemic Routing

- Summary vectors
  - Probabilistic set query using Bloom filters
- Immune:
  - Maintain a list
- Vaccine:
  - Let others know
- Sequence diagrams
  - Insightful for implementation

Epidemic Routing: Quiz

- **A**: `{m1, m4}` **B**: `{m7, m8, m12}` **C**: `{m3}`
- Destination of `m4` is B
- Nodes A and B meet
- Nodes A and C meet
- C generates `m15`
- Messages with C?

Epidemic Routing: Solution

- **A**: {m1, m4} **B**: {m7, m8, m12} **C**: {m3}
- Destination of m4 is B
- Nodes A and B meet **A** = {m1, m7, m8, m12}
- Nodes A and C meet **C** = {m1, m3, m7, m8, m12}
- C generates m15
- Messages with C? **C** = {m1, m3, m7, m8, m12, m15}

Spray-and-Wait

- Message replication limit, L
- Binary and non-binary modes

SnW: Quiz

- **A**: `{m1, m4}` **B**: `{m7, m8, m12}` **C**: `{m3}`
- All messages have L = 2 copies
- Destination of `m4` is B
- Nodes A and B meet
- A generates `m14`
- Nodes A and C meet
- C generates `m15`
- Messages with C?

SnW: Solution

- **A**: `{m1, m4}` **B**: `{m7, m8, m12}` **C**: `{m3}`
- All messages have L = 2 copies
- Destination of `m4` is B
- Nodes A and B meet **A**: `{m1, m7, m8, m12}`
- A generates `m14`
- Nodes A and C meet **A**: `{m1, m3, m7, m8, m12, m14}`
- C generates `m15`
- Messages with C? **C**: `{m3, m14, m15}`

PRoPHET

- Delivery predictability – likelihood of meeting a node
- Transitivity:
  - “Chinese whisper”
    - John meets with Paul
    - Paul meets with Henry
    - Pass a message from John to Henry

Comparison

	Epidemic	SnW	PRoPHET
Intelligence			
# of replications	Unlimited	L	Unlimited
Overhead	High	Low	High

Inter-contact Time

- Contact
- Inter-contact time (ICT):
  - Aggregate
  - Pairwaise
    - Friends vs. familiar strangers
- Power law paradox

Inter-contact Time: Quiz

- Process X follows exponential distribution
- Process Y follows Pareto (Power law) distribution
- Given two set of sample data from both the processes
- (Pictorially) Guess which sample is from which process

Inter-contact Time: Solution

- CCDF: P(X > x)
- Exponential distribution:
  - Semi-log plot would be a straight line
- Power law distribution:
  - Log-log plot would give a straight line
- Caution: Straight line CCDF in a log-log plot does not necessarily mean power law!

Human Mobility

- Truncated Levy Walk:
  - Flight length, L
  - Direction, a
  - Flight time, t
  - Pause time, p
- L and p follow Levy distribution (Power law)
  - Results in heavy-tailed ICTs
- We are not alone:
  - Monkeys and other animals do so too!

Let's Play a Game

- Select an option
- Option A:
  - Win $1,000 with a 50% chance
  - Win nothing with a 50% chance
- Option B:
  - Win $450 for sure!

Let's Play a Game (Again)

- Select an option
- Option C:
  - Lose $1,000 with a 50% chance
  - Lose nothing with a 50% chance
- Option D:
  - Lose $450 for sure!

Experimental Outcomes

- Expected payoffs:
  - Option A: $500
  - Option B: $450
  - About 82% people chose **B**
- Expected loss:
  - Option C: $500
  - Option D: $450
  - About 82% people chose **C**

Prospect Theory

- Developed by Tversky and Kahneman
  - Kahneman later proposed cumulative prospect theory
  - Won Nobel prize in economics
- Expected Utility Theory:
  - Rational choices
- Human decision making is far from rational!
  - Risk averse in the domain of gains
  - Risk seeking in the domain of loss
- Objective vs. subjective probabilities

TLW + Exploration = TLWE

- **B. K. Saha**, S. Misra, and S. Pal, “Utility-based Exploration for Performance Enhancement in Opportunistic Mobile Networks,” *IEEE Transactions on Computers*, DOI: 10.1109/TC.2015.2441700, March 2015.
- Points of Interest (PoI)
- PoI discovery; explore to PoI probabilistically
- PT-based utilities for exploration
- Better performance than TLW

OOP/Java

- Class:
  - `public class A {}`
- Inheritance:
  - `public class A extends B {}`
- Override methods

Network Simulation

- Simulation vs. real life
- Your toolkit:
  - Java (JDK & JRE) – preferably version 6
  - The ONE simulator
  - [Optional] NetBeans / Eclipse
  - [Optional] Python or other scripts
  - Gnuplot => EPS figures
  - Latex
  - [Optional] Git
- "*One script to rule them all*" [With apologies to JRR Tolkien]

Opportunistic Network Environment

- ONE:
  - Modules
  - External events
  - Reports
  - Unit tests
- The DTN Blog:
  - http://delay-tolerant-networks.blogspot.in/
- The ONE Knowledge Base:
  - http://theonekb-barunsaha.rhcloud.com/

Setting Up a Scenario

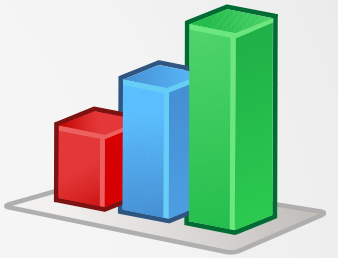
- # of groups, nodes
- Transmission speed, range
- Terrain size
- Mobility / connection patterns
  - Real life traces available at CRAWDAD
- Traffic, TTL, buffer size
- Routing protocol
- Simulation duration

Multiple Scenarios

- Parametrized simulations
- # of parameter values = Relative prime numbers
  - GCD(`i`, `j`) = 1

Performance Evaluation

- Why?
- Typical metrics:
  - Delivery ratio of messages
  - Average delivery latency
  - Overhead ratio
- Confidence intervals



Develop a Routing Protocol

- SnW with utility (SnWU)
- Utility, U(`i`, `j`) = total # of contacts `i` had with `j`
- Node `i` has a message `m`; comes in contact with `j`
- Classical SnW:
  - Replicate to `j`: L(`m`) > 1
- SnWU:
  - Replicate to `j`: L(`m`) > 1 and U(`j`, `d`) > U(`i`, `d`)
    - `d` is the destination of `m`

Hands-on Session

Heterogeneity in OMNs

- **B. K. Saha** and S. Misra, “Effects of Heterogeneity on the Performance of Pocket Switched Networks,” *IET Networks*, vol. 3, no. 2, pp. 110–118, June 2014.
- Harware and software
- Diverse routing protocols
  - Protocol Translation Units

The Big Picture

- OMNs: Hop-by-hop message forwarding
- Intelligent routing (overhead?)
- Mobility pattern => ICT
  - Real-life traces
  - TLW, TLWE
- Human decision making
- The ONE simulator

Thank you!