Modelling and analysis of a mobility-based information network

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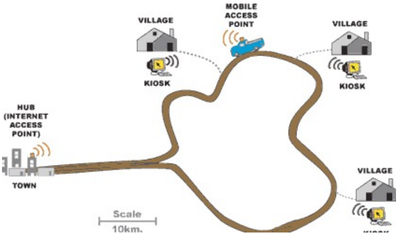
Executive Summary

- We focus on a delay-tolerant, "intermittently connected" information network in which a terminal communicates only when it is near another
- Far from an impairment or even a secondary assistant, mobility is indispensable
- Store-carry-and-forward relaying provides the essential mean of data transfer
- As an abstraction, we study a simple model in which "random walkers" exchange information when they meet
- We identify an interesting network architecture, and an available enabling technology
- Our ongoing study has led to many important questions, and to a few answers
- In a low-node-density scenario, a mobility-based network is feasible provided that the terminals move over at most 2 dimensions, because then each pair meets infinitely often
- Many important questions remain unanswered

Mobility-based information network

- In the typical communication network, any pair of "nodes" can talk to each other at any time, at least with the help of intermediate nodes (relaying).
- Permanent connectivity is not always practical or possible.
- When the application is delay-tolerant, and (some of) the nodes are mobile, an "intermittently connected" network may be practical.
- Here, a terminal communicates only when it is near another; mobility is indispensable
- Sample applications
  - wildlife monitoring (TurtleNet, ZebraNet) [1]
  - livestock monitoring
  - delay-tolerant human communication (e-mail, messages, etc) as in Student-Net
  - asynchronous Internet service as in India's Daknet [2]

Store-carry-forward relaying



- store-carry-and-forward (SCF) relaying is indispensable
- A sends a packet to B, B stores, carries and forwards it to C when B and C are sufficiently close
- Special-purpose nodes may help:
    - “data mules” may randomly move and collect data from sensors
    - a “normal” vehicle (such as a taxi or bus) may be a “data mule”
    - simple static “throw boxes” in strategic locations may enable information exchanges

Candidate enabling technology: UWB

- Ultra-wide-band (UWB) technology has been recently approved for communication applications around the world
- UWB has many advantages:
  - produces noise-like signalling
  - enables transceivers of low cost and complexity
  - can coexist with other technologies over same spectrum
- Present regulations make negligible the effect of UWB devices on incumbent networks.
- But approved UWB devices are severely range-limited, which limits their usefulness
- Applications often targeted include “cable-replacement”, sensor networks, and location/tracking
- UWB could also support communication among cooperative nodes in a mobility-based network

Plausible high-density network architecture

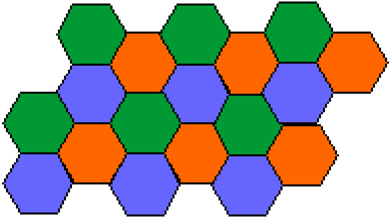


Figure: Small base-station-less “cells” for interference-control in a high-node-density scenario. For information to travel from a cell to another, at least some terminals must be mobile, and perform relaying

Random walkers analytical model

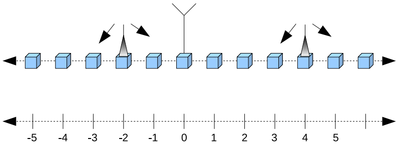


Figure: A triangle denotes a mobile terminal; “Y” represents a fixed node (for data collection, and/or a relay-assistance).

- A simple random-walkers model is a useful abstraction (more involved relevant models have been studied [3])
- A walker hops left or right with equal probability.
- When walkers “meet” they may communicate
- Static “walkers” may collect and/or help transfer data
- Model appropriate if terminals do *not* adjust mobility to facilitate (or frustrate) communication.

Critical low-density question

- Since terminals need to meet in order to communicate, and obvious concern is:
  will they meet “often enough” when terminals are “few” (for example, if there are only 2 “walkers”)?
- Since data is generated at perpetuity, they must meet infinitely often
- Worst case scenario: Do 2 random walkers in a “large” area meet infinitely often?
- Answer: YES, if they “walk” over a 1- or 2-dimensional region. Otherwise, they may never meet (possibly after a finite number of meetings)
- Many application scenarios can be reasonably modelled as 2D or even 1D (corridor, highway, etc).
- But WARNING: a dimension need not be spatial (for example, consider a frequency-hopping system)

More questions than answers

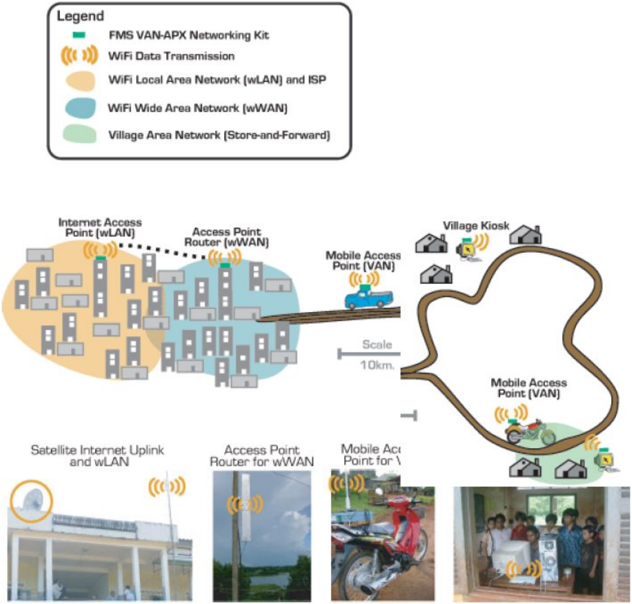
Many important questions remain unanswered. For instance:

- even with only 3 “walkers”:
  - If A has information for B but meets C instead, how much information should A transferred to C for C to carry and forward to B (especially if relaying is costly)?
  - By how much does relaying increases “capacity”?
  - If all 3 meet, how should the channel be allocated? Should “broadcasting” be used, and if so, which “gain” would result?
- With additional terminals, 2 pairs may meet near each other:
  - which measures to take to mitigate interference?
  - In particular, how high must walker density be to justify channelisation?

Recapitulation

- When the underlying application is delay-tolerant, and (some of) the nodes are mobile, an “intermittently connected” network may be practical
- Several interesting application has been mentioned
- A candidate network architecture and present-day enabling technology has been discussed
- A simple random-walkers model is being studied
- Study has led to a critical question and its answer: A mobility-based network is feasible even with very few terminals (2) provided their random movement occurs over at most 2 dimensions
- Many other important questions have been stated, but not answered

Daknet: the electro-mechanical Internet



TurtleNet

- deployed in USA by Univ. of Massachusetts
- turtles fitted with GPS, solar panel, radio and battery within weight/size limits
- location, body temp periodically recorded
- when two are within 150m apart, devices swap data
- data relaying ends at a single base station
- device dynamically adapts to energy status

ZebraNet

- power/location-aware ad-hoc sensor net implemented in Kenya by Princeton Univ.
- selected zebras fitted with a sensing/transmitting collar
- integrates computing, radio, non-volatile storage, sensors
- no centralised data collection: while travelling, researchers radio-receive recorded data from zebras
- enables novel studies of animal migrations and inter-species interactions

Throwbox in DieselNet: simple static node can aid data exchange

Radio-tagged whale

Further Reading I

- Z. J. Haas and T. Small, "A new networking model for biological applications of ad hoc sensor networks," *IEEE/ACM Trans. Netw.*, vol. 14, no. 1, pp. 27–40, 2006.
- A. Pentland, R. Fletcher, and A. Hasson, "Daknet: rethinking connectivity in developing nations," *Computer*, vol. 37, pp. 78–83, Jan. 2004.
- Y. Wang, H. Dang, and H. Wu, "A survey on analytic studies of delay-tolerant mobile sensor networks," *Wireless Communications and Mobile Computing*, vol. 7, no. 10, 2007.