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.
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-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
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.
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.

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

Legend
- FMS VAN-APX Networking Kit
- WiFi Data Transmission
- WiFi Local Area Network (wLAN) and ISP
- WiFi Wide Area Network (wWAN)
- Village Area Network (Store-and-Forward)
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
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
