Exploring the Potential in Practice for Opportunistic Networks amongst Smart Mobile Devices

Shu Liu, Aaron Striegel

Department of Computer Science and Engineering
Wireless Institute
University of Notre Dame
Setting the Stage

Wireless Data Tsunami

1000x data growth over next 10 years

Opportunistic Networking
Opportunistic Communication

Opportunistic Relaying
Opportunistic Collaboration

**Large** volume of work on opportunistic networking


8172 citations – Google Scholar
Theory vs. Practice

Hard to measure in practice

Scale – Time, Users
Accurate Proximity
Expensive

Synthetic dataset is the norm
What if We Could Measure It?

<table>
<thead>
<tr>
<th>Prevalence</th>
<th>How often do we see nodes in close proximity?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability</td>
<td>How stable are the relationships when we see them?</td>
</tr>
<tr>
<td>Reciprocity</td>
<td>How reciprocal are the relationships?</td>
</tr>
</tbody>
</table>

This is what our paper sets out to do. Measuring potential on a live network over 15 months.
Data Source – NetSense Study

Provided 200 smart devices to incoming freshmen at Notre Dame (Aug 2011)

200x Nexus S 4G
200 anytime mins
Unlimited data, text

Location, Environment (WiFi, Cell)
User proximity (Bluetooth)
Phone state (Screen, Battery)
Phone usage (data / app tonnage)

User level agent
(1-3 min intervals)
Step 1: Prevalence

How often do we see nearby nodes?

Bluetooth Perspective

WiFi Perspective

Comparison – WiFi vs. Bluetooth

Combined Perspective

Is there enough proximity to make it worthwhile?
Prevalence (Bluetooth)

- **Raw** = All B/T Disc. Devices
- **Good RSSI** = RSSI $\geq -80$
- **In Project** = Only NetSense Devices
- 25% of time off campus
Prevalence (Bluetooth) - Diurnal

Is the proximity real?
Is most of it at night (incidental) or is it useful?

Day \sim\approx Sleep
Prevalence (WiFi)

WiFi Proximity

>= 2 Same APs

Only NetSense participants (189)
WiFi Proximity Accuracy

Only NetSense participants (189)

**False Negative**
- WiFi No, Bluetooth Yes

**False Positive**
- WiFi Yes, Bluetooth No

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**Apr12 False Positive**
- Black triangles

**Apr12 False Negative**
- Black line

**Nov11 False Positive**
- Red crosses

**Nov11 False Negative**
- Red line

Days vs. Percentage (%)
Combined Proximity

Only NetSense participants (189)
Bluetooth + WiFi
FP = True
Perspective
200 Phones
2000 (Class)
8000 (UGrads)
Prevalence = Yes
Step 2: Stability

Are those relationships stable enough?

Contact Duration

Node Strength

Is it stable enough to amortize the cost of exchanging?
Stability

- 25% between 10 to 45 minutes
- Average is roughly 6 minutes
- Filter the long tail
  Must see it more than once per day on average
Stability – Node Strength

Node Strength is the number of observed proximity aspects.

Filter: More than 500 meetings, all months.

Biometric?

Stable = Yes

6 nodes see frequently, average of 4500 observations.
Step 3: Reciprocity

How reciprocal are the relationships?

Simple case

Node has traffic, bad / no WiFi
Looking for node with Good WiFi

Impact of Energy

Do I benefit as much as I give?
Step 3: Reciprocity

- Bad or non-existent WiFi with traffic need, % of total day
- Relay detection
  - Good WiFi Detected as Relay % of Day
  - Low Energy is a subset of Detected As Relay
- Battery has a role < 10% of relay time
Step 3: Reciprocity Ratio

One week period
November 2012

Can only serve if detected, good WiFi

Target is a ratio of 1

Altruistic

Selfish

Reciprocal = Yes
Conclusions

Prevalence

Yes, 60%+ for all devices
30% in the “wild”

Stability

50% of the common nodes
exhibit 6+ mins proximity

Reciprocity

Battery is usually not a problem
Slight tilt towards selfishness

Framework with metrics for comparison
Future Work

Beyond the campus environment
Location and cohort

Diversity of devices and radio
Different handsets, tablets, laptops, LTE

Impact of longer range (*Direct)
Floor versus ceiling

Social / content interplay
Sneakernet
Questions?

striegel@nd.edu

Support

Grant IIS-0968529

Sprint

Alcatel-Lucent

COLLEGE of ENGINEERING

UNIVERSITY of NOTRE DAME
Visualization – Short Range (24 hour period, < -65 dB)

NetSense Pair–Wise Visualization

Minute by Minute View of Changes for a 24 hour period
Collaborating

Can I get access to your data?

Yes* Depending on what data you want

Can I run experiments on your phones?

SUNY PhoneLab

Probably not Singapore LiveLabs Urban Lifestyle Innovation Program

Cohort through May 2015
Cohort of +500 in August 2015*
How many relay choices?

April 2012,
In Project

Greatest diversity in daytime
Prevalence - Effective Utility

Is it useful for relaying and collaboration when we see it?

In Project Only

Nearly all of the time we see a relay, we are likely to have traffic

Prevalence = Yes
Stability - Streakiness

- **Probability**
- **# of Days**

- **Total Appearances**
- **Continuous Appearances**
Comparison with other datasets

<table>
<thead>
<tr>
<th>Traces</th>
<th>Our Dataset</th>
<th>MIT Reality</th>
<th>UCSD</th>
<th>Dartmouth</th>
<th>Infocom</th>
<th>Nokia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device</td>
<td>Smartphone</td>
<td>Cell Phone</td>
<td>PDA</td>
<td>Laptop PDA</td>
<td>iMote</td>
<td>Smartphone</td>
</tr>
<tr>
<td># of Devices</td>
<td>189</td>
<td>97</td>
<td>275</td>
<td>6,648</td>
<td>41</td>
<td>185</td>
</tr>
<tr>
<td>Network Type</td>
<td>Bluetooth/WiFi</td>
<td>Bluetooth</td>
<td>WiFi</td>
<td>WiFi</td>
<td>Bluetooth</td>
<td>Bluetooth/WiFi</td>
</tr>
<tr>
<td>Contact Type</td>
<td>Direct/AP-based</td>
<td>Direct</td>
<td>AP-based</td>
<td>AP-based</td>
<td>Direct</td>
<td>Direct/AP-based</td>
</tr>
<tr>
<td>Duration (days)</td>
<td>458</td>
<td>246</td>
<td>77</td>
<td>114</td>
<td>4</td>
<td>210</td>
</tr>
<tr>
<td>Granularity (seconds)</td>
<td>60/300</td>
<td>300</td>
<td>120</td>
<td>300</td>
<td>120</td>
<td>N/A</td>
</tr>
<tr>
<td># of internal contacts</td>
<td>3,616,184</td>
<td>54,667</td>
<td>195,364</td>
<td>4,058,284</td>
<td>22,459</td>
<td>N/A</td>
</tr>
<tr>
<td>Internal pairwise contact/day</td>
<td>0.221</td>
<td>0.022</td>
<td>0.034</td>
<td>0.008</td>
<td>3.4</td>
<td>N/A</td>
</tr>
<tr>
<td>Other proximity related data</td>
<td>Cell, Traffic, etc.</td>
<td>Cell</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Cell, etc.</td>
</tr>
</tbody>
</table>

- 41 million Bluetooth records
- 50 million WiFi scans
- 1 million SMS messages.
Prevalence

- Good RSSI
• Inter-contact Time
Symmetry

![Graph showing percentage variations over months with and without symmetry consideration.](image-url)
Diversity