Mobile Social Networks

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Systems Research Group
University of Cambridge Computer Laboratory
I. Spread of Infectious Diseases

- Thread to public health: e.g., swine flu, SARS, AIDS
- Current understanding of disease spread dynamics
  - Epidemiology: Small scale empirical work
  - Physics/Math: Mostly large scale abstract/simplified models
- Real-world networks are far more complex
  - Advantage of real world data
  - Emergence of wireless technology for proximity data
    (tiny wireless sensors, mobile phones...)
  - Post-facto analysis and modelling yield insight into human interactions
- Model realistic infectious disease epidemics and predictions
Susceptible, Infected, Recovered: the SIR Model of an Epidemic
What is a Mathematical Model?

a mathematical description of a scenario or situation from the real-world

focuses on specific quantitative features of the scenario, ignores others

a simplification, abstraction, “cartoon”

involves hypotheses that can be tested against real data and refined if desired

one purpose is improved understanding of real-world scenario

e.g. celestial motion, chemical kinetics
The SIR Epidemic Model

First studied, Kermack & McKendrick, 1927.

Consider a disease spread by contact with infected individuals.

Individuals recover from the disease and gain further immunity from it.

\[ S = \text{fraction of susceptibles in a population} \]

\[ I = \text{fraction of infecteds in a population} \]

\[ R = \text{fraction of recovereds in a population} \]

\[ S + I + R = 1 \]
The SIR Epidemic Model (Cont’d)

• Differential equations (involving the variables $S$, $I$, and $R$ and their rates of change with respect to time $t$) are

$$\frac{dS}{dt} = -\rho SI, \quad \frac{dI}{dt} = \rho SI - \alpha I, \quad \frac{dR}{dt} = \alpha I$$

• An equivalent compartment diagram is
Parameters of the Model

- $\rho$ = the infection rate
- $\alpha$ = the removal rate

The basic reproduction number is obtained from these parameters:

$$N_R = \frac{\rho}{\alpha}$$

- This number represents the average number of infections caused by one infective in a totally susceptible population. As such, an epidemic can occur only if $N_R > 1$. 
Vaccination and Herd Immunity

If only a fraction $S_0$ of the population is susceptible, the reproduction number is $N_R S_0$, and an epidemic can occur only if this number exceeds 1.

Suppose a fraction $V$ of the population is vaccinated against the disease. In this case, $S_0 = 1 - V$ and no epidemic can occur if

$$V > 1 - 1/N_R$$

The basic reproduction number $N_R$ can vary from 3 to 5 for smallpox, 16 to 18 for measles, and over 100 for malaria [Keeling, 2001].
Fig. 19.3. Influenza epidemic data (●) for a boys boarding school as reported in British Medical Journal, 4th March 1978. The continuous curves for the infectives (I) and susceptibles (S) were obtained from a best fit numerical solution of the SIR system (19.1)–(19.3): parameter values $N = 763$, $S_0 = 762$, $I_0 = 1$, $\rho = 202$, $r = 2.18 \times 10^{-3}$/day. The conditions for an epidemic to occur, namely $S_0 > \rho$ is clearly satisfied and the epidemic is severe since $R/\rho$ is not small.
Boarding School Flu (Cont’d)

• In this case, time is measured in days, $\rho = 1.66$, $\alpha = 0.44$, and $R_N = 3.8$. 

![Graphs](image-url)
In this case, new susceptibles are arriving and those of all classes are leaving.

\[
\frac{dS}{dt} = \beta - \rho SI - \lambda S, \quad \frac{dI}{dt} = \rho SI - \alpha I - \lambda I, \quad \frac{dR}{dt} = \alpha I - \lambda R
\]
Flu at Hypothetical Hospital (Cont’d)

- Parameters $\rho$ and $\alpha$ are as before. New parameters $\beta = \lambda = 1/14$, representing an average turnover time of 14 days. The disease becomes endemic.
Case Study: Bombay Plague, 1905-6

• The *R* in SIR often means *removed* (due to death, quarantine, etc.), not *recovered*.

**Fig. 19.2.** Bombay plague epidemic of 1905–6. Comparison between the data (●) and theory (○) from the (small) epidemic model and where the number of deaths is approximately $dR/dt$ given by (19.16). (After Kermack and McKendrick 1927)
Eyam Plague, 1665-66

Raggett (1982) applied the SIR model to the famous Eyam Plague of 1665-66.

http://www.warwick.ac.uk/statsdept/staff/WSK/Courses/ST333/eyam.html

It began when some cloth infested with infected fleas arrived from London. George Vicars, the village tailor, was the first to die.

Of the 350 inhabitants of the village, all but 83 of them died from September 1665 to November 1666.

Rev. Wm. Mompesson, the village parson, convinced the villagers to essentially quarantine themselves to prevent the spread of the epidemic to neighboring villages, e.g. Sheffield.
In this case, a rough fit of the data to the SIR model yields a basic reproduction number of $R_N = \ldots$
Enhancing the SIR Model

Can consider additional populations of disease vectors (e.g. fleas, rats).

Can consider an exposed (but not yet infected) class, the SEIR model.

SIRS, SIS, and double (gendered) models are sometimes used for sexually transmitted diseases.

Can consider biased mixing, age differences, multiple types of transmission, geographic spread, etc.

Enhancements often require more compartments.
Geo-mapping,, Snow’s Ghost Map
We *meet, we connect, we communicate*

We *meet* in real life in the real world

We use text *messages*, phones, IM

We make *friends* on facebook, Second Life

How are these *related*?

How do they *affect* each other?

How do they *change* with new technology?
Give it to me, I have 1G bytes phone flash.

I have 100M bytes of data, who can carry for me?

Reach an access point.

Thank you but you are in the opposite direction!

I can also carry for you!

Don't give to me! I am running out of storage.

There is one in my pocket...

Search La Bonheme.mp3 for me

Finally, it arrive…

Internet
My facebook friends wheel
My email statistics!
Cliques and Communities

$k=3$

$k=4$

$k=5$

$k=10$
We are still learning about this!

There are big problems understanding this

Data?

Privacy?

Usefulness?
Spread of Infectious Diseases

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  - Epidemiology: Small scale empirical work
  - Physics/Math: Mostly large scale abstract/simplified models
- Real-world networks are far more complex
  - Advantage of real world data
  - Emergence of wireless technology for proximity data
    (tiny wireless sensors, mobile phones...)
  - Post-facto analysis and modelling yield insight into human interactions
- **Model realistic infectious disease epidemics and predictions**
The FluPhone Project

- Understanding behavioural responses to infectious disease outbreaks
- Proximity data collection using mobile phone from general public in Cambridge

https://www.fluphone.org

FluPhone Study

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This study will record how often different people (who may not know each other) come close to one another, as part of their everyday lives. To do this, we will ask volunteers to install a small piece of software (called FluPhone) on their mobile phones and to carry their phones with them during their normal day-to-day activities. The software will look for other nearby phones, periodically using Bluetooth, record this information and send it back to the research team via the cellular phone data service. This information will give us a much better understanding of how often people congregate into small groups or crowds, such as when commuting or through work or leisure activities. Also, by knowing which phones come close to one another, we will be able to work out how far apart people actually are, and how fast diseases could spread within communities. We are also asking participants to inform us of any influenza-like symptoms they may experience during the study period, so that we can match the spread of flu to the underlying social network of encounters made.

If you wish to take part in this study, please read the study information below, and then click here to start the registration process.

News:
- The pilot study within the university will start on the April 1st, 2010
- The webpage is up!
Various Data Collection

- Flu-like symptoms
- Proximity detection by Bluetooth
- Environmental information (e.g. in train, on road)
- Feedback to users
  - (e.g. How many contacts past hours/days)
- Towards potential health-care app
- Extending Android/iPhone platforms

iMote

FluPhone
Sensor Board or Phone or ...

- iMote needs disposable battery
  - Expensive
  - Third world experiment
- Mobile phone
  - Rechargeable
  - Additional functions (messaging, tracing)
  - Smart phone: location assist applications

- Provide device or software
Phone Price vs Functionality

- ~<20 GBP range
  - Single task (no phone call when application is running)

- ~>100 GBP
  - GPS capability
  - Multiple tasks – run application as a background job

- Challenge to provide software for every operation system of mobile phone

- FluPhone
  - Mid range Java capable phones (w/ Blutooth JSR82 –Nokia)
  - Not yet supported (iPhone, Android, Blackberry)
Experiment Parameters vs Data Quality

- Battery life vs Granularity of detection interval
- Duration of experiments
  - Day, week, month, or year?
  - Data rate
- Data Storage
  - Contact /GPS data <50K per device per day (in compressed format)
  - Server data storage for receiving data from devices
  - Extend storage by larger memory card
- Collected data using different parameters or methods → aggregated?
Proximity Detection by Bluetooth

- Only \( \sim 15\% \) of devices Bluetooth on
- Scanning Interval
  - 5 mins phone (one day battery life)
- Bluetooth inquiry (e.g. 5.12 seconds) gives >90% chance of finding device
- Complex discovery protocol
  - Two modes: discovery and being discovered

Make sure to produce reliable data!
Data Retrieval Methods

- Retrieving collected data:
  - Tracking station
  - Online (3G, SMS)
  - Uploading via Web
  - via memory card

- Incentive for participating experiments

- Collection cycle: real-time, day, or week?
FluPhone Server

- Via GPRS/3G FluPhone server collects data
Security and Privacy

- Current method: Basic anonymisation of identities (MAC address)
- FluPhone server – use of HTTPS for data transmission via GPRS/3G

- Anonymising identities may not be enough?
  - Simple anonymisation does not prevent to be found the social graph

- Ethic approval tough!
  - ~40 pages of study protocol document for FluPhone project – took several months to get approval
Currently No Location Data

- **Location data necessary?**
  - Ethic approval gets tougher
  - Use of WiFi Access Points or Cell Towers
  - Use of GPS but not inside of buildings

- **Infer location using various information**
  - Online Data (Social Network Services, Google)
  - Use of limited location information – Post localisation

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**Bluetooth Big Brother uses mobiles and laptops to track thousands of Britons**

By DAVID DERBISHIRE

Last updated at 9:15 am on 23rd July 2010

A Big Brother network of hidden scanners is monitoring hundreds of thousands of Britons without their knowledge, it emerged yesterday.

Scientists track people walking around cities, using the Bluetooth signals from their mobiles, laptops and handheld computers.

Scanners in bars, offices and universities register nearby Bluetooth devices and send the information to a central database.

---

Scanner Location in Bath
Consent

This page asks for you to agree to be a participant in the study. It is important that you understand and agree with the consent and study information.

See here for information about this study.

You must read this software disclaimer.

If you are under 16 years old, we require that your parent or carer provide their consent for you to take part in this study. You must be over 12 years old to take part in this study.

To participate in this study, you must:

- have read, understand and agree with the consent and study information;
- have access to a compatible mobile phone;
- have read, understand and agree with the Fluphone software disclaimer;
- agree to download and run the Fluphone software application on your mobile phone;
- agree for the Fluphone application to use the Bluetooth function of your mobile phone;
- agree for the Fluphone application to send the data it collects to the study team via your network connection, and that this may incur a cost to the billpayer of the phone;
- be willing to allow your data and the information that the Fluphone software collects on your phone to be used for scientific research by the study team.

Please note: You have to fill in all fields.

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<td>[ ] I am under 16 years old, but over 12 years old, and have parental or carer consent for me to take part in this study.</td>
<td></td>
</tr>
<tr>
<td>[ ] I am over 16 years old and wish to take part in this study.</td>
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</table>

<table>
<thead>
<tr>
<th>2. Please click the appropriate one.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ] I have the permission of the bill payer to use this mobile in the study.</td>
<td></td>
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Submit
Study Status

- Pilot study (April 21 ~ May 15)
  - Computer Laboratory
  - Very few participants – people do not worry flu in summer

- University scale study (May 15 ~ June 30)
  - Advertisement (all departments, 35 colleges, student union, industry support club, Twitter, Facebook...)
  - Employees of University of Cambridge, their families, and any residents or people who work in Cambridge

- Issues
  - Limited phone models are supported
  - Slightly complex installation process
  - Motivation to participate...
Encountered Bluetooth Devices

- A FluPhone Participant Encountering History
Existing Human Connectivity Traces

- Existing traces of contact networks
- ...thus far not a large scale

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<th>Experimental data set</th>
<th>MIT</th>
<th>UCSD</th>
<th>CAM</th>
<th>INFC06</th>
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<td>iMote</td>
<td>iMote</td>
<td>PC</td>
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<td>Network type</td>
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<td>Bluetooth</td>
<td>Bluetooth</td>
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<tr>
<td>Duration (days)</td>
<td>246</td>
<td>77</td>
<td>11</td>
<td>3</td>
<td>5.5</td>
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<tr>
<td>Granularity (seconds)</td>
<td>300</td>
<td>600</td>
<td>120</td>
<td>120</td>
<td>Continuous</td>
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<tr>
<td>Number of Experimental Devices</td>
<td>97</td>
<td>274</td>
<td>36</td>
<td>78</td>
<td>7431</td>
</tr>
</tbody>
</table>

- Let’s use Cambridge trace data to demonstrate what we can do with FluPhone data...
Analyse Network Structure and Model

- Network structure of social systems to model dynamics
- Parameterise with interaction patterns, modularity, and details of time-dependent activity
  - Weighted networks
  - Modularity
  - Centrality (e.g. Degree)
  - Community evolution
  - Network measurement metrics
  - Patterns of interactions

Publications at:
http://www.haggleproject.org
http://www.social-nets.eu/
Regularity of Network Activity

- Cambridge Data (11 days by undergraduate students in Cambridge): Size of largest fragment shows network dynamics
Uncovering Community

- Contact trace in form of weighted (multi) graphs
  - Contact Frequency and Duration

- Use community detection algorithms from complex network studies
  - K-clique, Weighted network analysis, Betweenness, Modularity, Fiedler Clustering etc.
Simulation of Disease – SEIR Model

Four states on each node:

\[ \text{SUSCEPTIBLE} \rightarrow \text{EXPOSED} \rightarrow \text{INFECTED} \rightarrow \text{RECOVERED} \]

Parameters

- \( p \): exposure probability
- \( a \): exposed time (incubation period)
- \( t \): infected time

Diseases

- \( D_1 \) (SARS): \( p=0.8, \ a=24\text{H}, \ t=30\text{H} \)
- \( D_2 \) (FLU): \( p=0.4, \ a=48\text{H}, \ t=60\text{H} \)
- \( D_3 \) (COLD): \( p=0.2, \ a=72\text{H}, \ t=120\text{H} \)

Seed nodes

Random selection of 20% of nodes (=7) among 36 nodes
**SARS**

- Exposure probability = 0.8
- Exposed time = 24H (average)
- Infected time = 30H (average)
Flu

- Exposure probability = 0.4
- Exposed time = 48H (average)
- Infected time = 60H (average)
Time to Exposure vs # of Meetings

- Distribution of time to infection (black line) is strongly influenced by the time dependent adjacency matrices of meetings.
**D0: Simple Epidemic (3 Stages)**

- First Rapid Increase: Propagation within Cluster
- Second Slow Climbing
- Reach Upper Limit of Infection

![Graph showing number of infected nodes over time with different stages of infection indicated by lines of different colors. The graph spans from 0 to 35 infected nodes along the y-axis and from 0 to 25 CAM time units (300 seconds) along the x-axis. A horizontal arrow indicates a 5-day period.]
Virtual Disease Experiment

- Spread virtual disease via Bluetooth communication in proximity radio range
- Integrate SAR, FLU, and COLD in SIER model
- Provide additional information (e.g. Infection status, news) to observe behavioural change
The FluPhone Project

http://www.cl.cam.ac.uk/research/srg/netos/fluphone/
https://www.fluphone.org
Email: flu-phone@cl.cam.ac.uk

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**ErdOS**
*Enabling opportunistic resources sharing in mobile Operating Systems*

Narseo Vallina-Rodríguez

Jon Crowcroft

University of Cambridge

MUM 2010, Cyprus
Motivation

- WiFi
- Bluetooth
- GSM/GPRS/3G
- Camera
- Accelerometer
- GPS
- CPU (1 GHz)
- Storage (>2 GB)

Page dimensions: 595.0x842.0
“Energy is still the main limitation in mobile systems”
Motivation

Para ver esta película, debe disponer de QuickTime™ y de un compresor.
Motivation

- GPS
- CPU
- 3G
Motivation

Network Type

Operator 1

Operator 2

Signal Strength

-103 dBm
-101 dBm to -91 dBm
-99 dBm to -78 dBm
-77 dBm to -57 dBm
-55 dBm to -55 dBm
> -53 dBm

GPRS
EDGE
LMTS
Motivation

Why not sharing mobile resources opportunistically with other users?
II. ErdOS
ErdOS

Social energy-aware OS

Access co-located resources opportunistically

Customised proactive resources management

Social connections provide access control
Dataset Description

18 Android OS users

1-2 weeks

Resources Tracker

“Exhausting battery statistics”. Mobiheld 2010
Dataset Description

Battery Statistics
- Current Voltage
- Remaining Capacity
- Temperature
- Charging Status

O.S. Info
- CPU
- Process
- Memory

Network & Telephony
- Airplane Mode
- Telephony State
- Cellular Network Type
- Cellular Network State
- WiFi State
- Bluetooth State
- GPS State
- Traffic

Contextual
- Time
- Location (Cell ID)
- Roaming
- Screen State
Usage Analysis Tools

Principal Component Analysis (PCA):

Transforms a number of possibly correlated variables into a smaller number of uncorrelated ones called Principal Components.
Principal Component Analysis

![Graph showing variance explained by principal components](image-url)
Principal Component Analysis
Context importance

Percentage of total time per user spent at the most popular 3 cells

- 1st Pop.
- 2nd Pop.
- 3rd Pop.
- No signal

User ID

Percentage of time at cell

0 10 20 30 40 50 60 70 80 90 100

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
**Spatial context:** Screen usage

![Graph showing screen usage with data points labeled U1 to U18. The graph is divided into two regions: Low Predictability (U15, U16, U2) and High Predictability (U11, U17, U18).](image-url)
Spatial context: Cellular traffic

- Mean (%)
- Std dev (%)
- U1, U2, U3, U4, U5, U6, U7, U8, U9, U10, U11, U12, U13, U14, U15, 16, U17, U18
- Low Predictability
- High Predictability

Graph showing the relationship between mean and standard deviation for different cellular traffic indicators.
Temporal context: Daily usage
Resources Allocations: Activities

Users' Activities → 2nd Level Activities

Users' Actions → Social Actions

Users' Apps → Remote Act.

System Act.
Forecasting Resources Demands

Average Tx-Traffic Forecasting Error

Error

User 1  User 2  User 3  User 6  User 13

1m  5m  15m  30m  1h  2h  6h  12h  1d  2d  7d
Forecasting Resources State

Average Network Type Forecasting Error

- User 1
- User 2
- User 3
- User 6
- User 13
Access Control

Social links facilitate access control and security

- Unix-like permissions are made automatically based on users’ social networks
- Proximity reduces privacy and security issues
- OSNs can help to exchange public keys
Architecture

USER SPACE

ANDROID APPLICATION FRAMEWORK

APPLICATIONS

ErdOS MANAGERS
- CONTEXT MGR
- ACTIVITIES MGR
- NAME MGR
- DISCOVERY MGR

Android Libraries

Activity Events

Android Runtime

Social Cloud Manager

Remote Allocation

KERNEL

WiFi Driver
Camera Driver
Camera Driver
Flash Mem. Driver
Flash Mem. Driver
Binder (IPC) Driver

Display Driver
Keypad Driver
Audio Driver
Power Managemnt.

HARDWARE
Related work

- **Resource allocation and energy-aware OS**
  - **ECOSystem.** Zeng et al. ACM ASPLOS, 2002
  - **Quanto.** Stoica et al. USENIX 2008
  - **CinderOS.** Rumble et al. MOBIHELD 2009

- **Mobile usage and energy demand**
  - Falaki et al. ACM Mobisys 2010
  - Oliver, ACM HotPlanet 2010
  - Balasubramanian et al. ACM IMC 2010
  - Rice et al. ACM PerCOM 2010
Conclusions

Energy is a primary target for optimization in mobile handsets

- Benefits in QoS and energy savings by accessing resources opportunistically
- Social links can be used for access control policies

Applications and users’ behavior generate complex dynamics and interdependencies among resources

- Energy allocation and resources control must be customized to each user and handset
- Pro-active resources management aided by contextual information
Future Work

Finishing implementation as an Android OS extension
   Performance/Scalability evaluation

Demonstrate benefits of sharing different resources (Cellular Nets, GPS, CPU)

Resources Discovery Protocols

Research on lighter forecasting techniques
   Cloud Computing?

Security evaluation

Incentive schemes?
III

Droplets: - Condensing the Cloud

http://www.cl.cam.ac.uk/~jac22
From the Cloud...

The cloud has its risks...
Centralisation of PII

What if
   Provider goes broke
   Lose all your family photos
   Assets sold to another (unknown) provider

In a large organisation,
   There will always be someone bad
   Who can datamine
   Identity theft
   And worse
To Droplets

At the other extreme...
A fully decentralised approach...

Can obviate cloud risks
  But introduces complexity
  Management overhead (p2p/manet/dtn)
  Availability/resilience
  Total data loss if device stolen

Can we compromise
  Between extreme centralisation…
  And extreme decentralisation?
Via extraction

Firstly, we need to pull/push data

From/to the cloud…
...and condensation
Replication/Decentralisation are necessary, but not sufficient...

Need to encrypt data
  Both in Cloud
  And in Mist

The mist is a collection of droplets -
  small objects with key/capability
  and auditor

What about cloud business models?
  Use privacy preserving advertising (MPI)
  Use k-anonymity and threshold security
  Use differential privacy for market research
## Implementation Details

<table>
<thead>
<tr>
<th>Platform</th>
<th>Google AppEngine</th>
<th>VM (e.g., on EC2)</th>
<th>Home Computer</th>
<th>Mobile Phone</th>
</tr>
</thead>
<tbody>
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<td>high</td>
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<td>Cost</td>
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<tr>
<td>Reliability</td>
<td>high</td>
<td>high</td>
<td>medium (failure)</td>
<td>low (loss)</td>
</tr>
</tbody>
</table>
To Conclude...

Use contributed resources are fine
   Home hub, phone, etc

But need to unify with cloud
   Do so at API level

Have *both* decentralised and central

Advantages of both
   Low latency access to home/pocket
   High resilience in cloud
   No loss of privacy if bad cloud/pick pocket