

# Delay Tolerant Networks and Spatially Detailed Human Mobility

Position Paper

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E-DTN at ICUMT, St. Petersburg, Oct 2009



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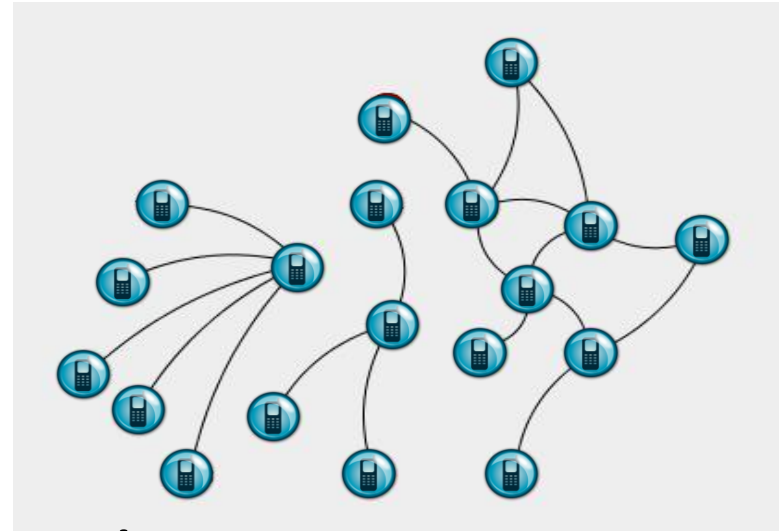
# Problem

## Information dissemination without infrastructure

- Environmental (Participatory) Sensing
- Failed/No Infrastructure
  - Large communities without infrastructure (3<sup>rd</sup> World)
  - Disaster situations where infrastructure failed

# Future of mobile devices

- Powerful
- Information rich
- Indispensable
- Autonomous communication using
  - Social Networks
  - Human Proximity Networks
- Exploit Properties of Human interaction networks

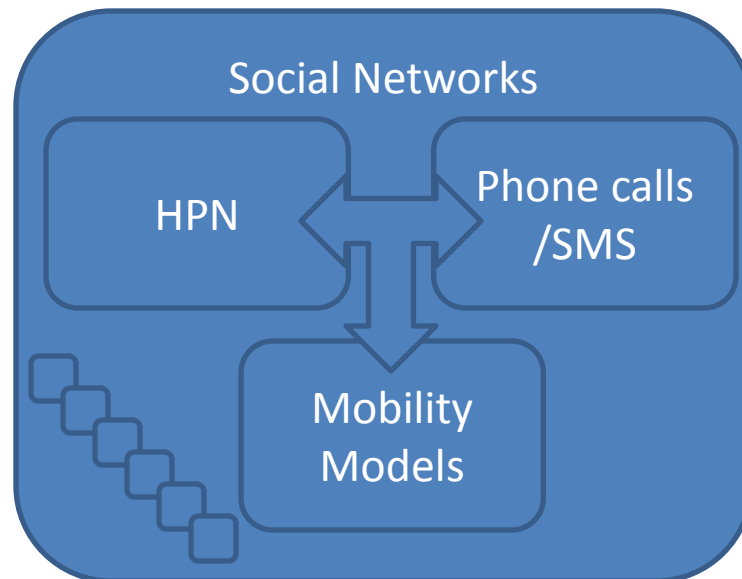


# Fixed vs. Dynamic Networks

- Fixed networks are already well researched
- More recently dynamic networks
  - Social Networks
  - Protein interaction networks
  - MANETs etc.
  - etc.

# Human Interaction / Social Networks\*

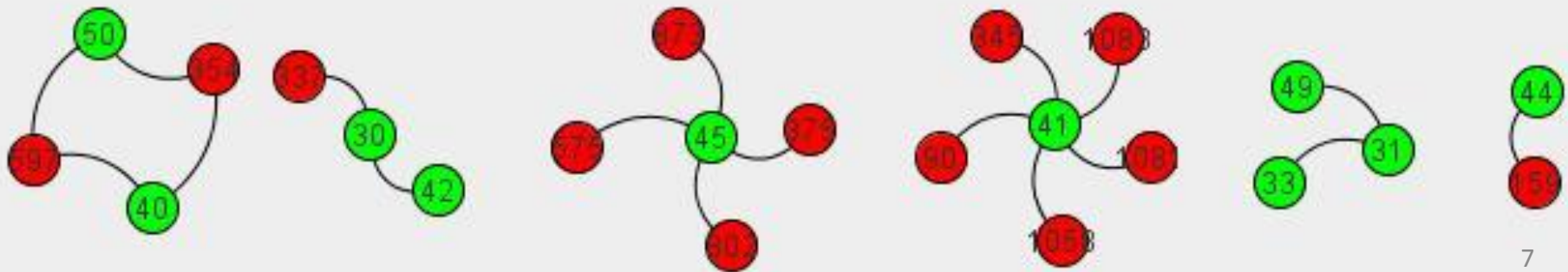
- Phone calls / SMS graphs
- Spatial Location
- Human Proximity Networks (HPN)



\* not Facebook

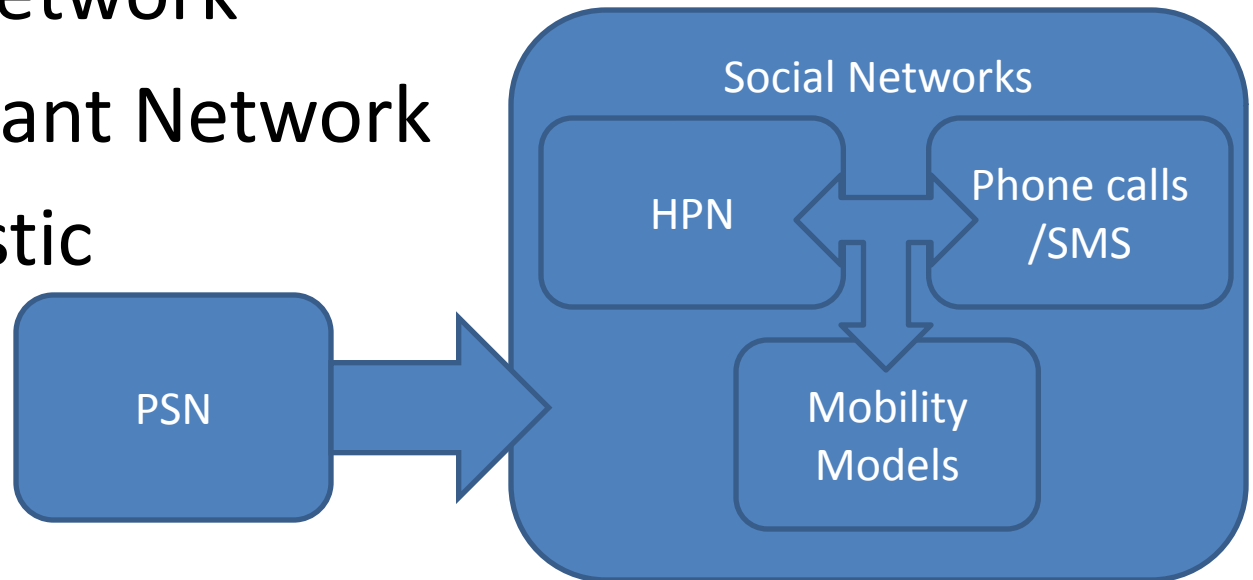
# Human Proximity Networks (HPN)

- Dynamic Networks
  - Nodes Move
  - Edges Come and Go
- If two individuals are close they have an edge
- Form communities (as this is a social network)
- *May* be sparse



# Pocket Switched Networks (PSN)

- Devices carried by Humans
- Transmit data across Human Proximity Networks
- Dynamic Network
- Delay Tolerant Network
- Opportunistic



# Data Dissemination (1)

- Algorithm designed for battlefield communications (Li & Rus 2000)
- Epidemic-like dissemination schemes. (Vahdat & Becker, 2000)

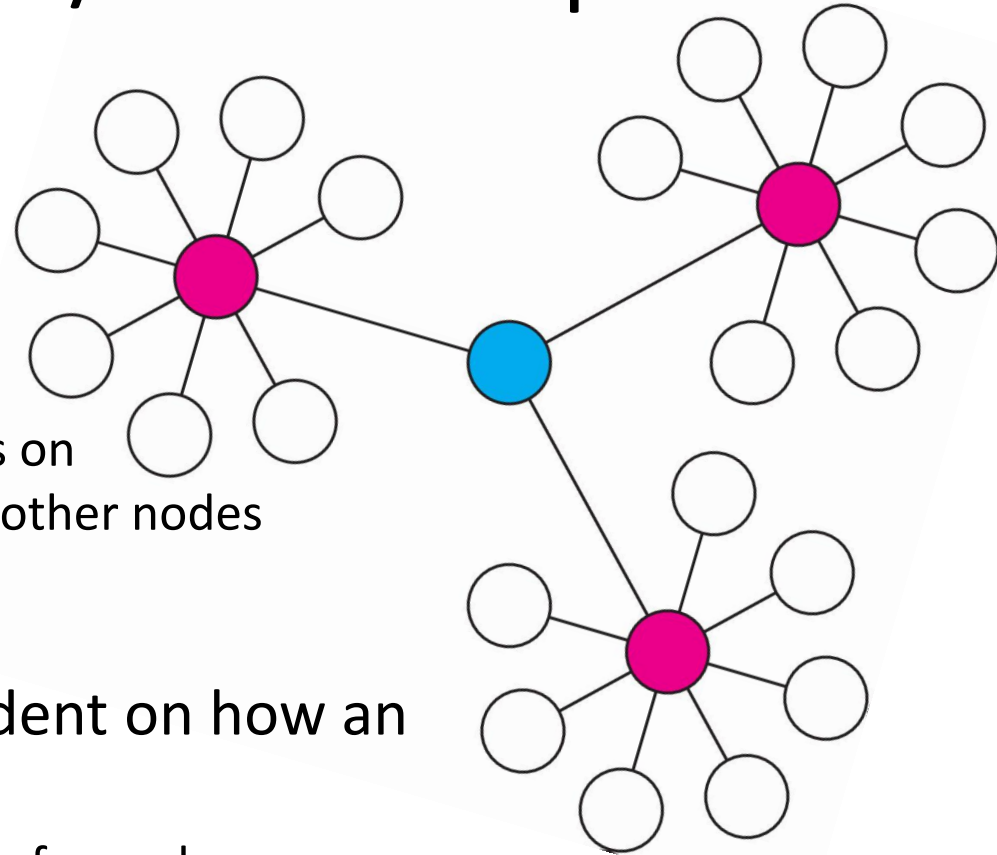
# Related Experiments include:

- **ZebraNet** - (*Juang et al, 2002*)
- **HAGGLE** - (*Scott et al, 2005*)
- **Reality Mining Project** - (*Eagle & Pentland, 2006*)
- **Seal2Seal** - (*Lindgren et al, 2008*)
- **CAR** - (*Musolesi and Mascolo, 2009*)
- **CABSPOTTING** (analysis of) – (*Piorkowski et al 2009*)

All reveal/use some properties of the network to decide how to route messages

# Importance of Local/Global Properties

- Node Degree (local)
  - Number of edges a node has
  - **Easy to detect**
- Node Centrality (global)
  - The number of times a node is on the shortest path between all other nodes
  - Cannot be calculated locally
  - Shortest path routing
- Dynamic Networks: Dependent on how an edge is defined
  - How quickly should an edge be formed
  - How long does an edge last
  - How many edges should be formed



Nodes do not know about global properties and must rely on local information

# Data Dissemination (2)

BUBBLE Rap (Hui, Crowcroft & Yoneki, 2008)

Routing based on:

- Community
- Degree of node

Results

- A local property (6 hours degree) as a good routing metric
- No need for a global property (centrality)

**Why 6 Hours?**

# Related work

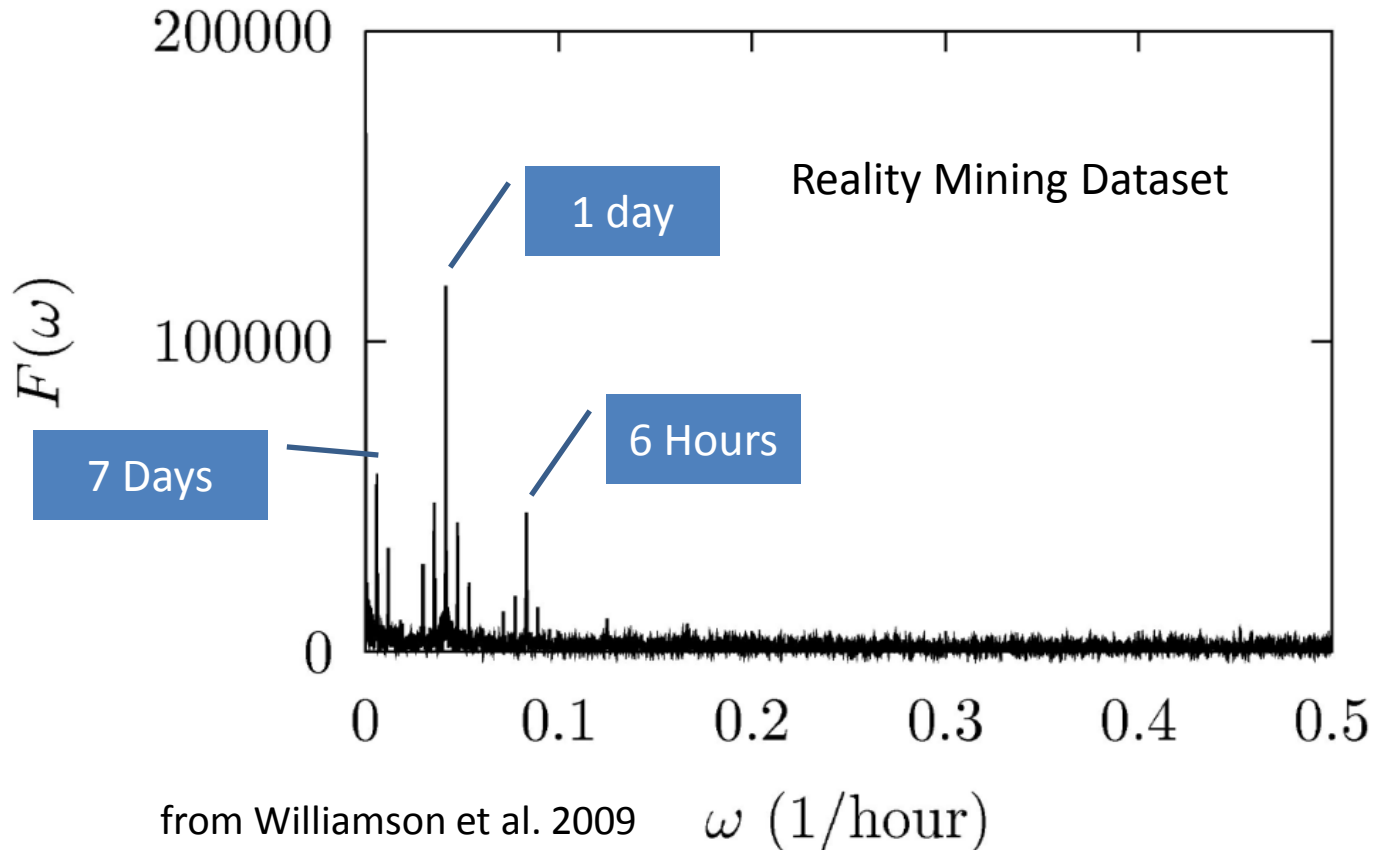
- Williamson et. al. 2009
  - Examined two datasets (Reality Mining and CABSPOTTING)
  - Discovered the importance of periods of time between encounters (periodicity)
    - Used to regulate degree calculations
    - Best local property for routing
  - Routing Scheme based on adaptive calculation
    - Automatically calculate period
    - Adapts over time to account for change in network structure

# What is Periodicity

- The notion of the amount of time between regularly occurring proximity events
  - Meeting others for mealtimes / meetings (~6hrs)
  - Come into work most days (~1 day)
  - Meet to play football once a week (~7 days)

# Calculating Periodicity

Correlation between the number of connections and time, (in one hour periods) showed three distinct peaks



from Williamson et al. 2009

$\omega$  (1/hour)

*Fourier transform of the time evolution of the number of connections, defined on time slots of 1 hour. The frequency  $\omega$  has been normalized, so that a peak in  $\omega$  corresponds to a period  $T = 1/\omega$ .*

# Our Position

- Data collection experiment to capture
  - Proximity, Location, Communications
- Investigate correlations
  - Proximity / Centrality (Who is near me, am I a hub)
  - Location / Centrality (where I am, am I a hub)
  - Call records / Location (Who calls me, where I am)
  - Location / Time (where am I, at certain times)
- Causality
  - Who am I calling, where am I going
  - Who is near me, where am I going

# Prototype Implementation

- Nokia N95
  - Campaignr (CENS/UCLA)
    - GPS, Bluetooth, WiFi, Cell-id, Battery Level
  - Custom Python Application (PyS60)
    - Call Logs, SMS Logs, Status
- Server
  - Apache + MySQL + PHP

# Dataset

- Highly detailed data
  - GPS Location
  - WiFi / Bluetooth/ Cell Proximity
  - Call / SMS Records
  - Battery Level and Phone Status
- Record data every 30 seconds
- Post-Processing
  - WiFi triangulation – (see [placelab.org](http://placelab.org))
  - Increase fidelity (roughly) over time
- Anonymity

# Sample Data



User data for matt

[Previous 150](#) [Next 150](#)  
[# Records 10 | 50 | 100 | 200 | 300 | 400 | 500](#)  
[Clear](#)

150 records (2200 to 2350)  
From Wed 16:18 26-Aug-2009 to Wed

16:18 26 Aug 2009 to 17:52 26 A

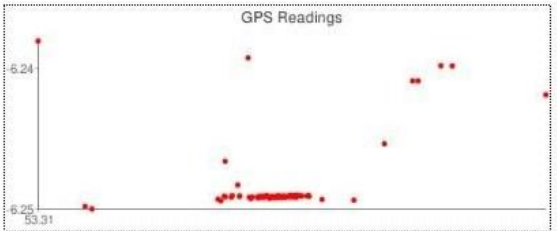
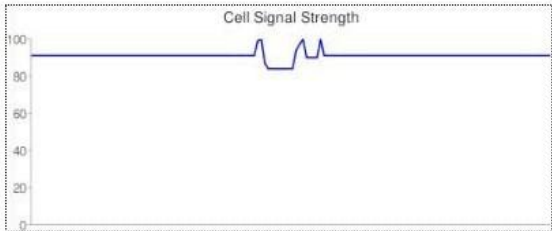
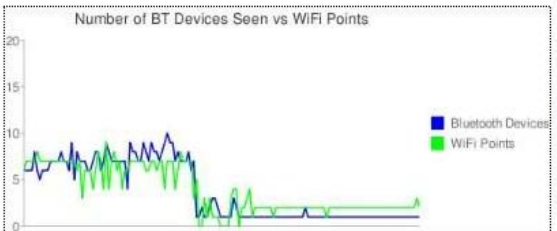
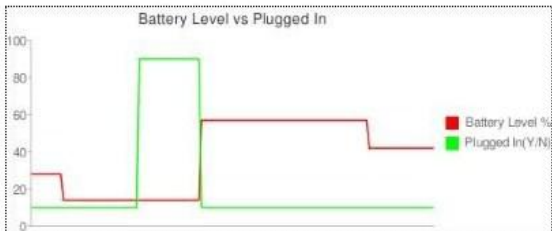
Set Timescale hh:mm dd mmm yy

Today

WiFi Mac	Occurrences	Avg. Signal Strength	AP Names
00192F3291E0	100	51.7	CSI-WLAN
00192F3291E1	100	51.8	WaveLAN Network
00192F3291E2	100	52.2	eduroam
001FF3C3FFE5	92	50.1	SRG
001C2E69910C	21	83.5	EWA@ECN
001C2E69910D	20	86.1	EWA@GUEST
			WaveLAN

Cell ID	Occurrences	Avg. Signal Strength
667578	99	90.8282828283
0	1	94

BT Mac	Occurrences	BT Names
001f00b1ed0a	98	
001f00b1573f	29	
0017f29dd199	67	
001ff3aec7b6	8	
001f00b1ed18	24	
001ff3ab7073	90	



# Experimental Setup

- Approx 30 participants
  - Primarily computer scientists (post-grads/academics) at UCD
  - Existing Hardware Available to Lab
  - Plus a request for handset owners to participate
- 1 week initial trial of prototype
  - 5 people
  - Bug finding
  - Examine data

# Future

- New routing metrics
  - E.g. competition between location and centrality
- Detect Causality
- Spot common patterns
- Application to larger datasets
- Simulation (and synthesis)

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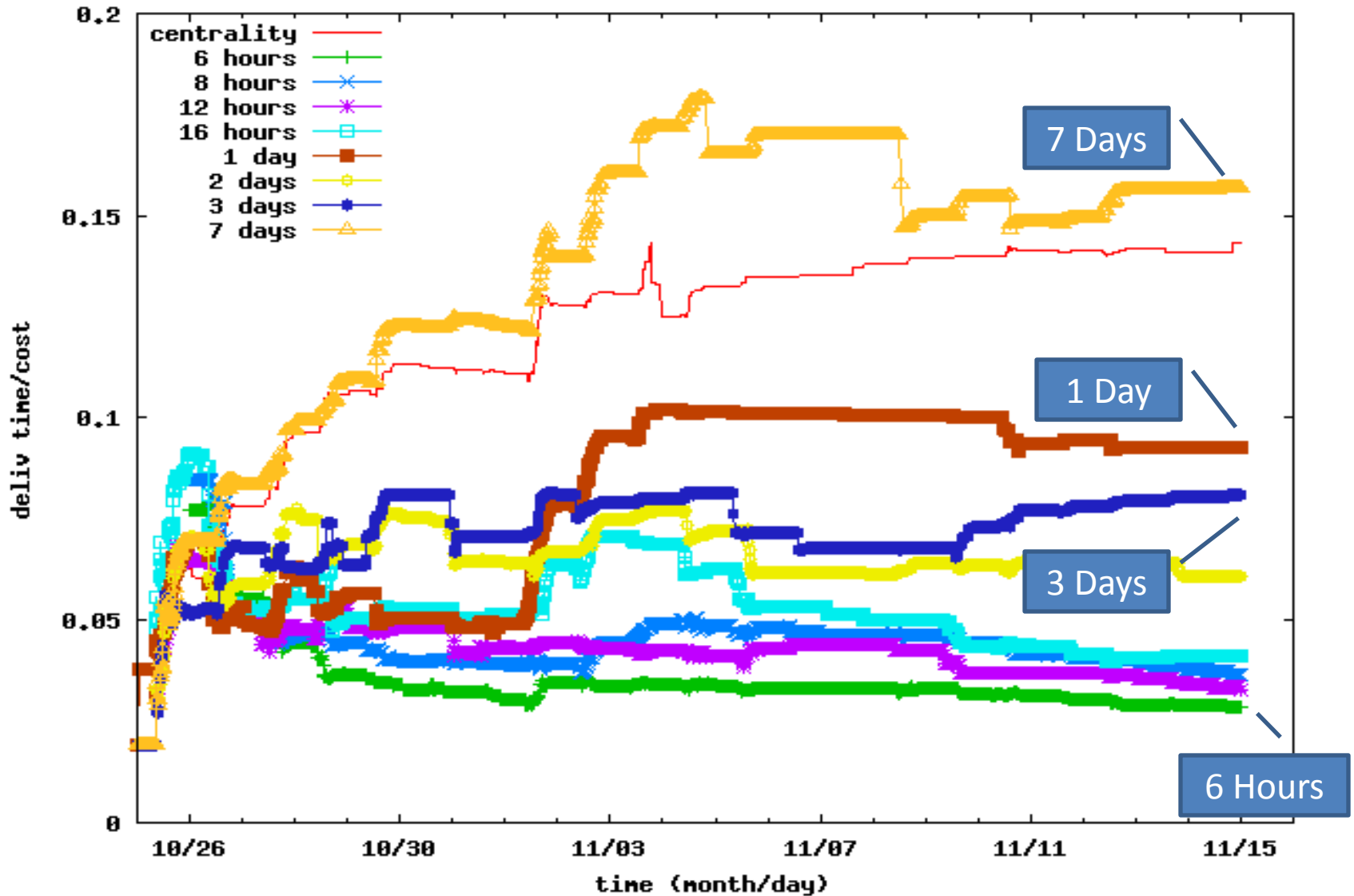


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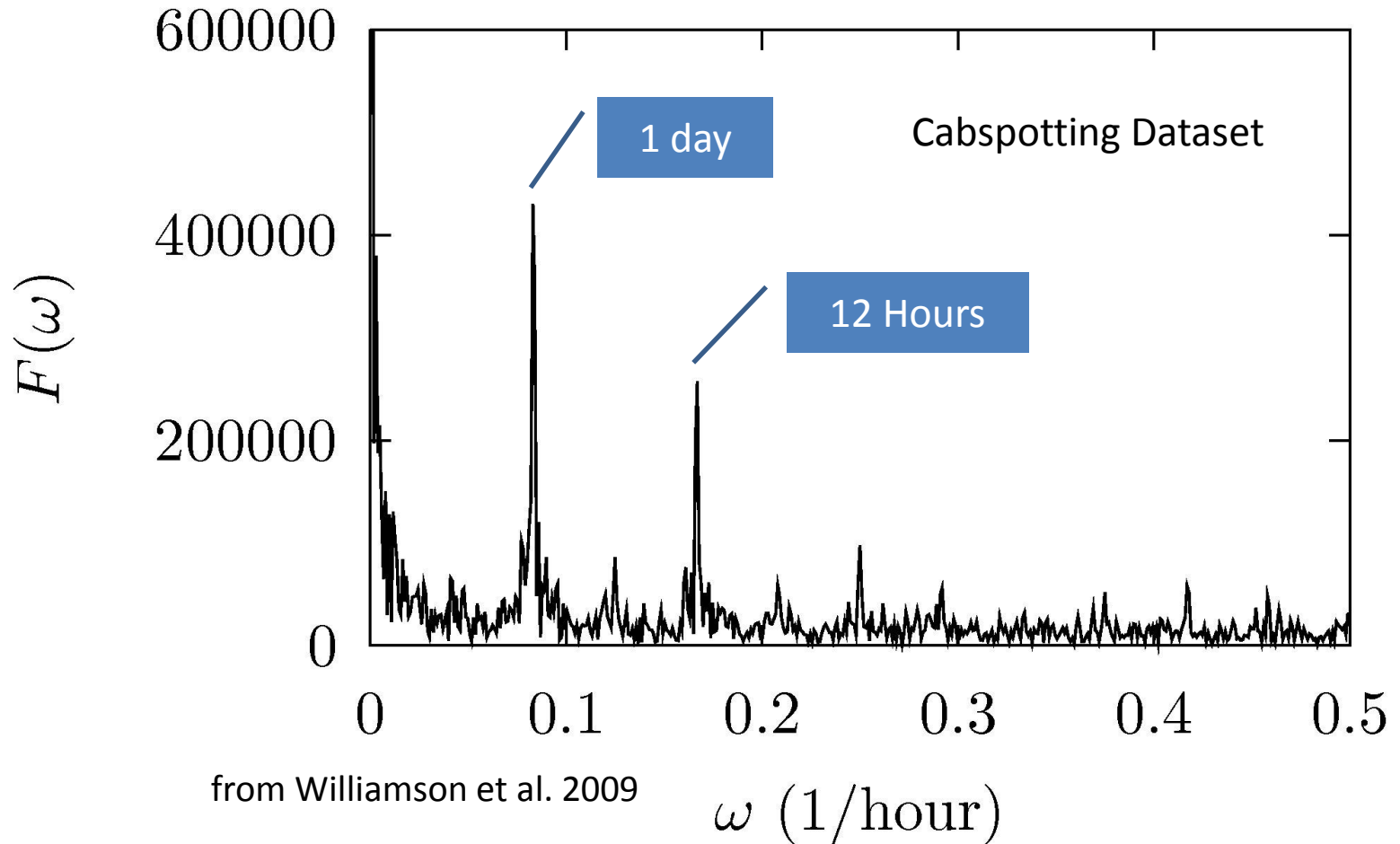


# Efficiency of Routing (Reality Mining)



Efficiency (defined as delivery ratio divided by cost) of routing based on the degree calculated over different time intervals. (from Williams et al, 2009)

# CABSPOTTING Periodicity



# An idea about location centrality vs. degree

$$\mu = \max \left\{ (c(d) - \bar{c}), (l(r) - \bar{l}) \right\}$$

Messages forwarded to nodes with highest value of  $\mu$

$c(d)$  a notion of centrality based on local connectivity

$l(r)$  a location popularity based on the position  $r$  and the history of the node itself

$\bar{c}$   $\bar{l}$  create a threshold depending on network type