Bubble Rap: Forwarding in Small World DTNs in Ever Decreasing Circles
Part 2 - People Are the Network

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Outline

- Multiple levels human heterogeneity
  - Local community structures
  - Diversity of centrality in different scales
  - Four categories of human relationship
- Heterogeneous forwarding algorithms
  - Design space
  - RANK (centrality based forwarding)
  - LABEL (community based forwarding)
  - BUBBLE RAP (centrality meets community)
- Approximation and predictability
  - Decentralized approximation of centrality
  - Human predictability

Understanding multiple levels of heterogeneity

The first goal of this research is to move to a third generation of human mobility models, understanding heterogeneity at multiple levels of detail.

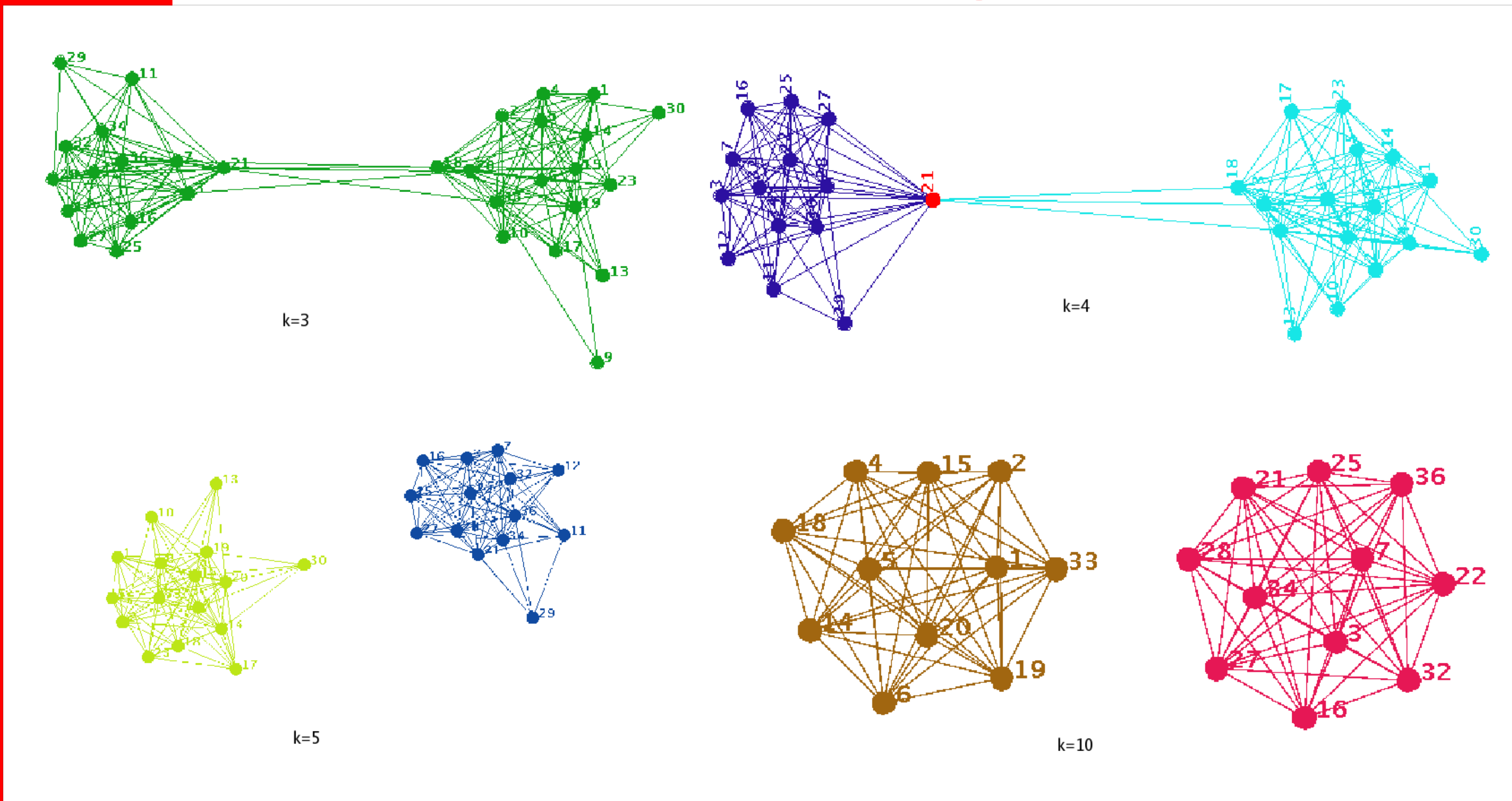
Social Structures Vs Network Structures

- Community structures
  - Social communities, i.e. affiliations
  - Topological cohesive groups or modules
- Centralities
  - Social hubs, celebrities and postman
  - Betweenness, closeness, inference power centrality

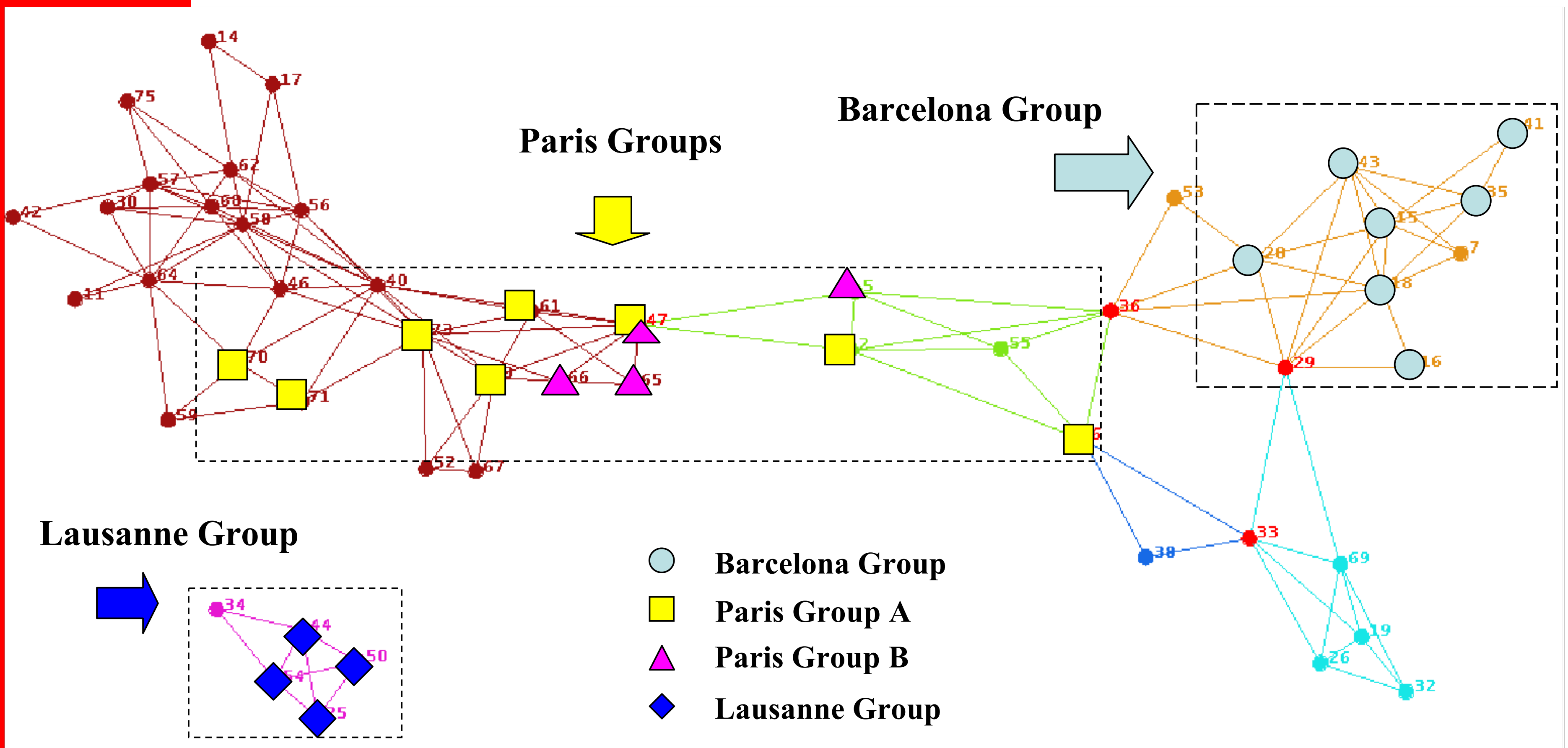
K-clique Community Definition

- Union of k-cliques reachable through a series of adjacent k-cliques [Palla et al]
- Adjacent k-cliques share k-1 nodes
- Members in a community reachable through well-connected well subsets
- Examples
  - 2-clique (connected components)
  - 3-clique (overlapping triangles)
- Overlapping feature
- Percolation threshold **$p_c(k) = 1/[(k-1)N]$^(1/(k-1))**

K-clique Communities in Cambridge Dataset

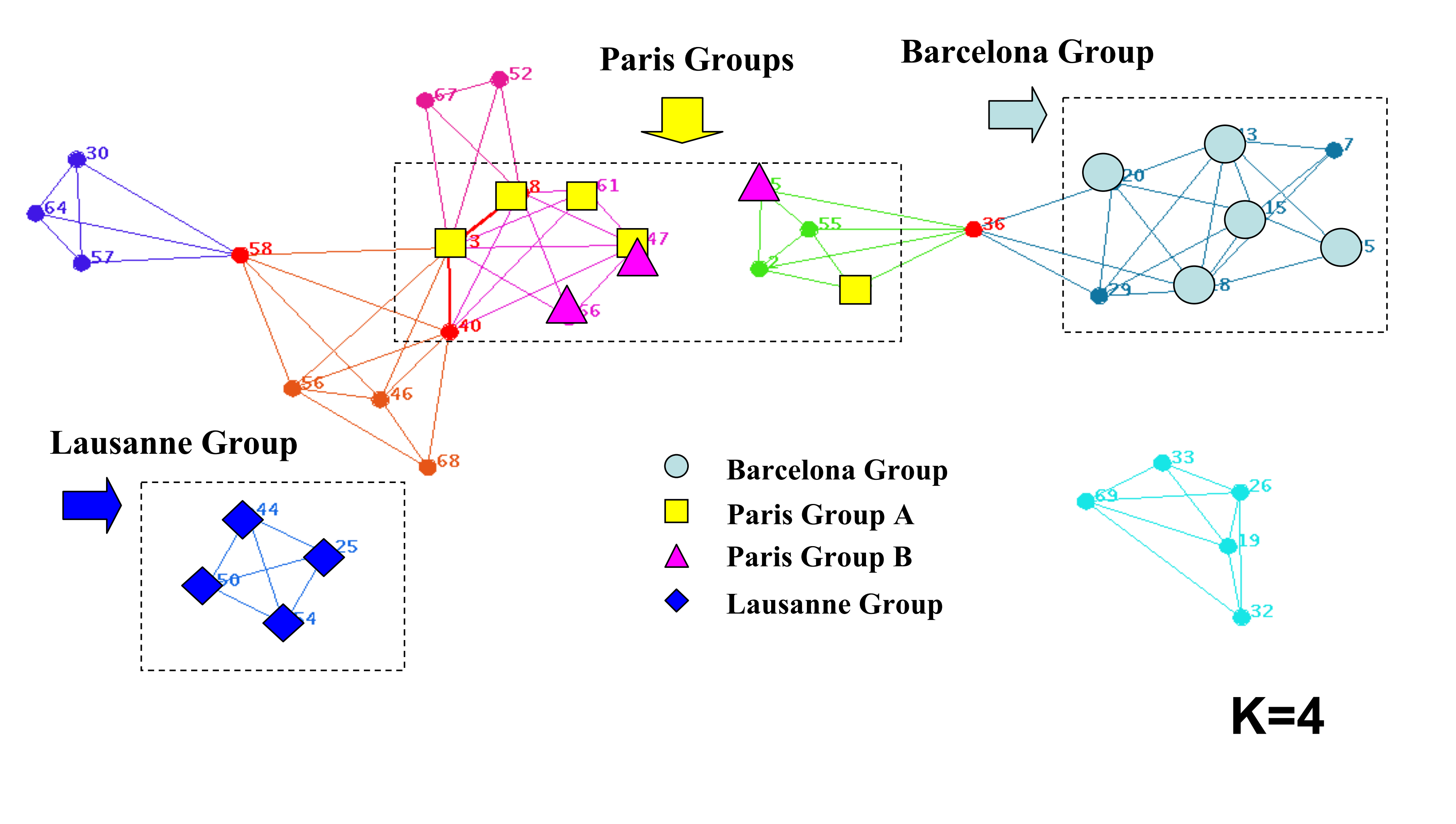


K-clique Communities in Infocom06 Dataset

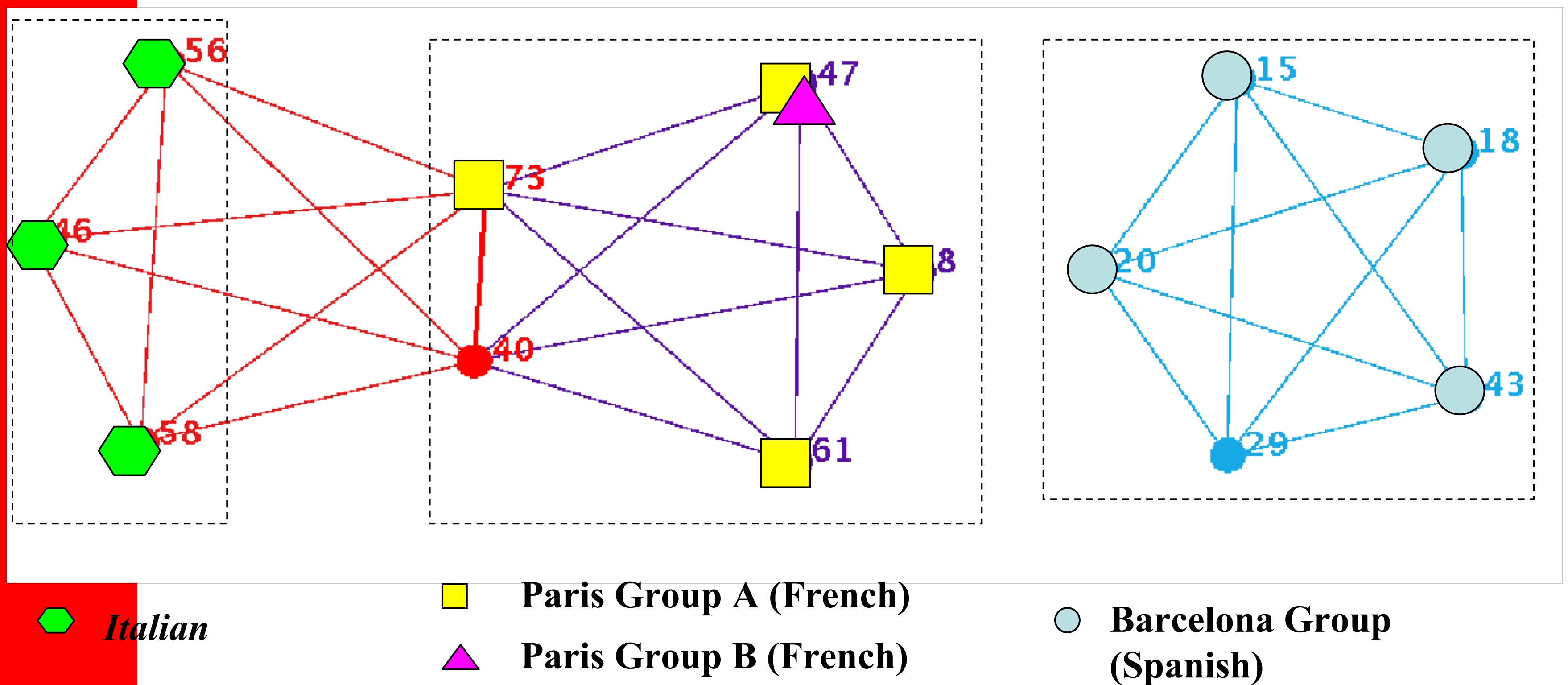


K=3

K-clique Communities in Infocom06 Dataset



K-clique Communities in Infocom06 Dataset



K=5

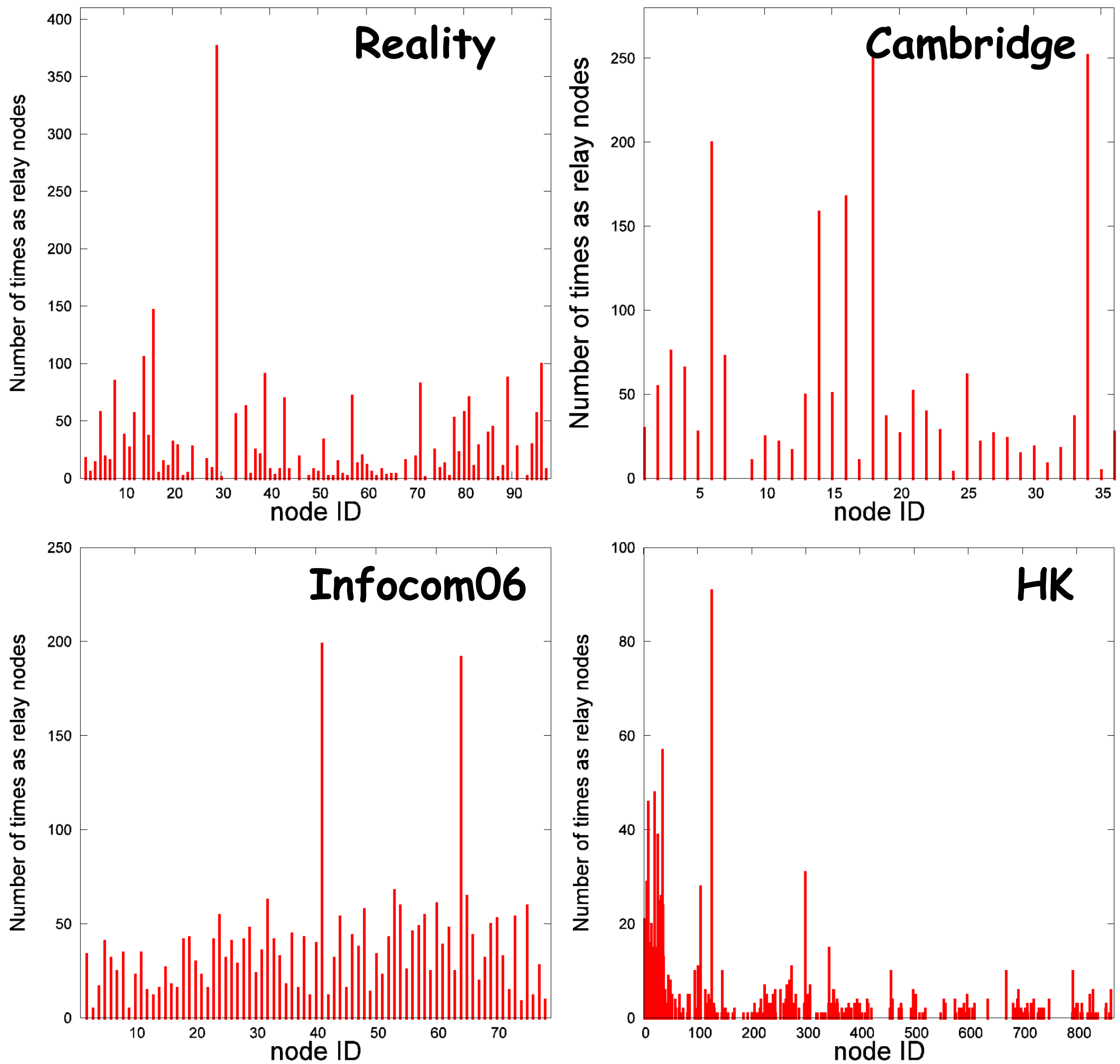
Other Community Detection Methodologies

- Betweenness [Newman04]
- Modularity [Newman06]
- Information theory[Rosvall06]

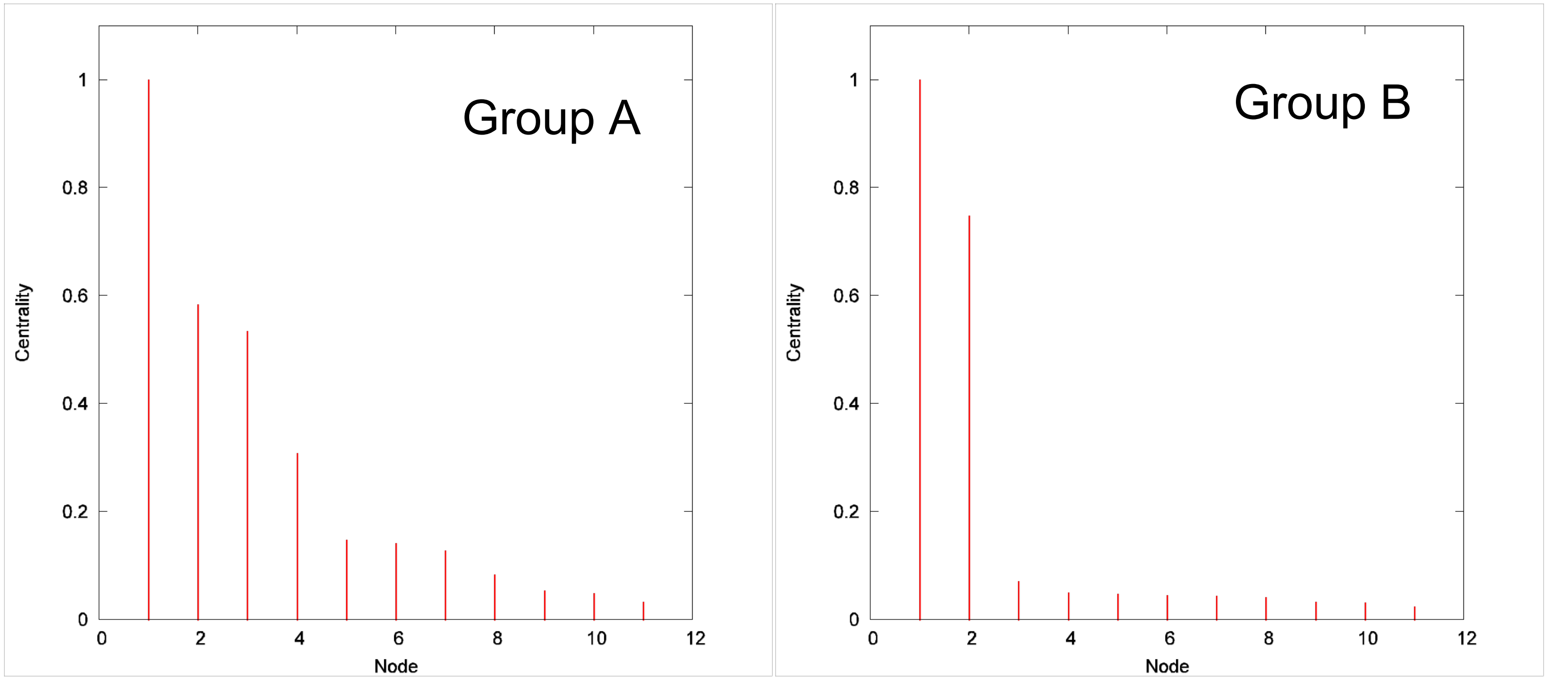
Centrality in Temporal Network

- Large number of unlimited flooding
- Uniform sourced and temporal traffic distribution
- Number of times on shortest delay deliveries
- Analogue to Freeman centrality [freeman]

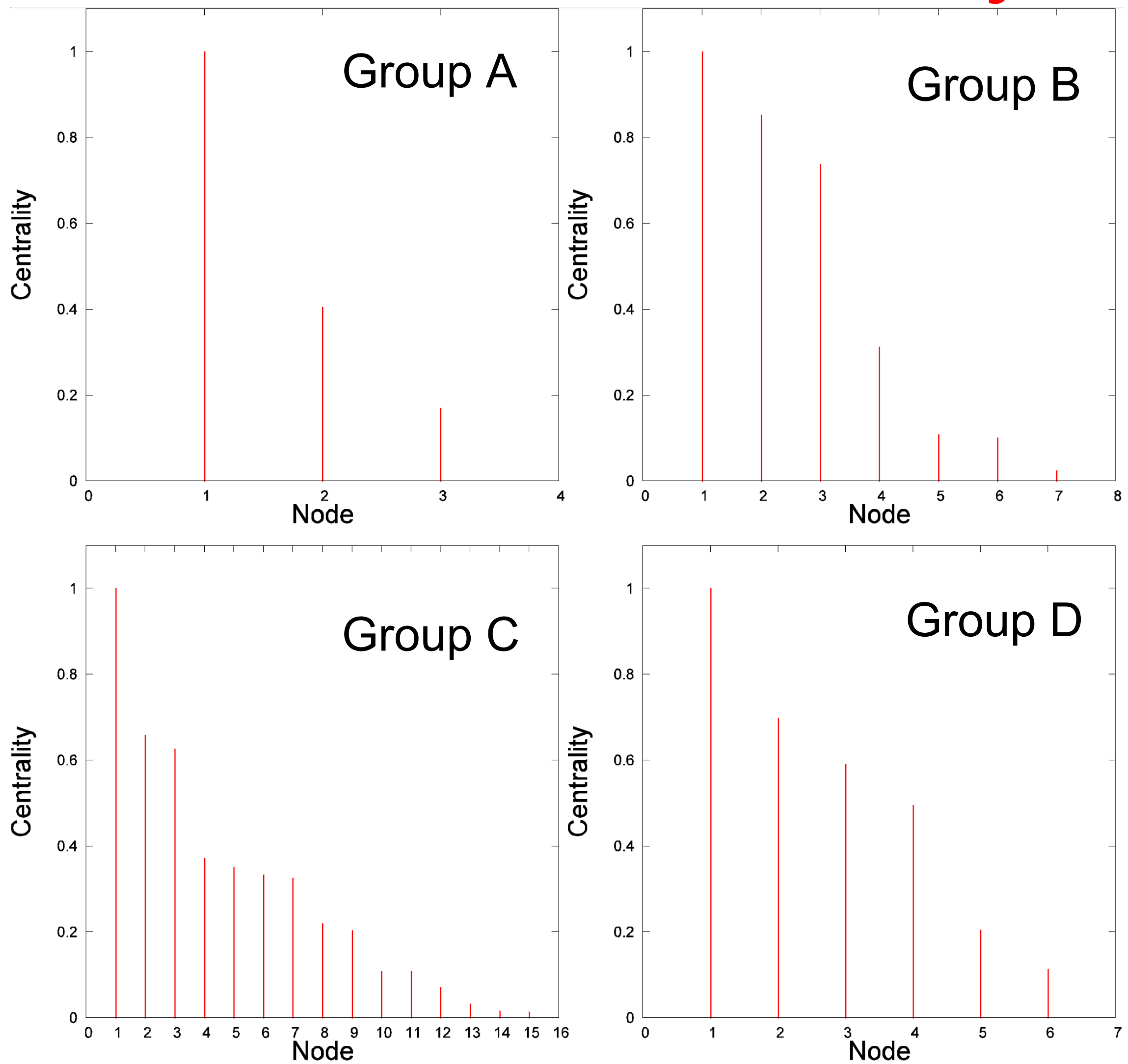
Homogenous Centrality



Within Group Centrality Cambridge Dataset



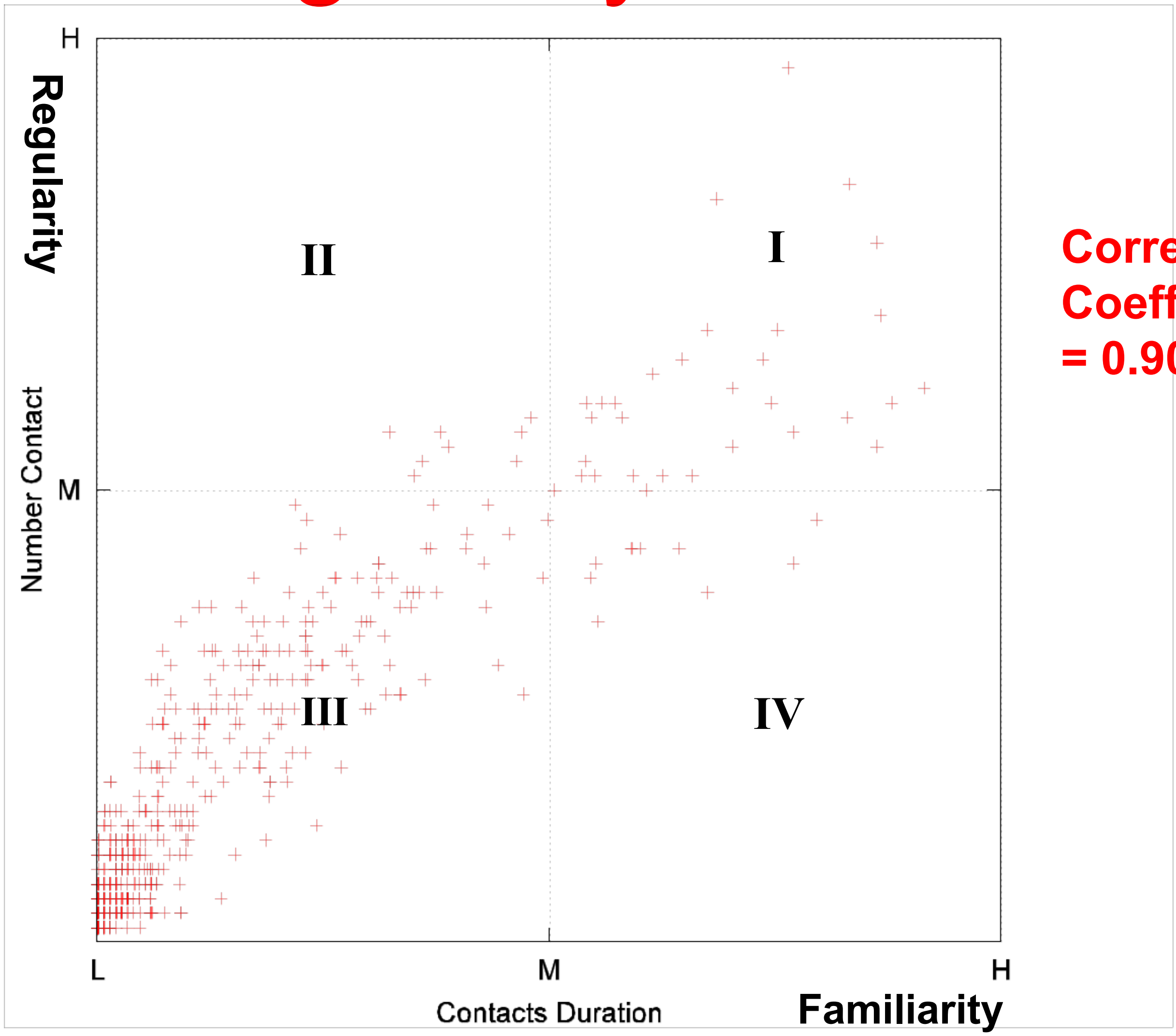
Within Group Centrality Reality Dataset



Model Node Centrality

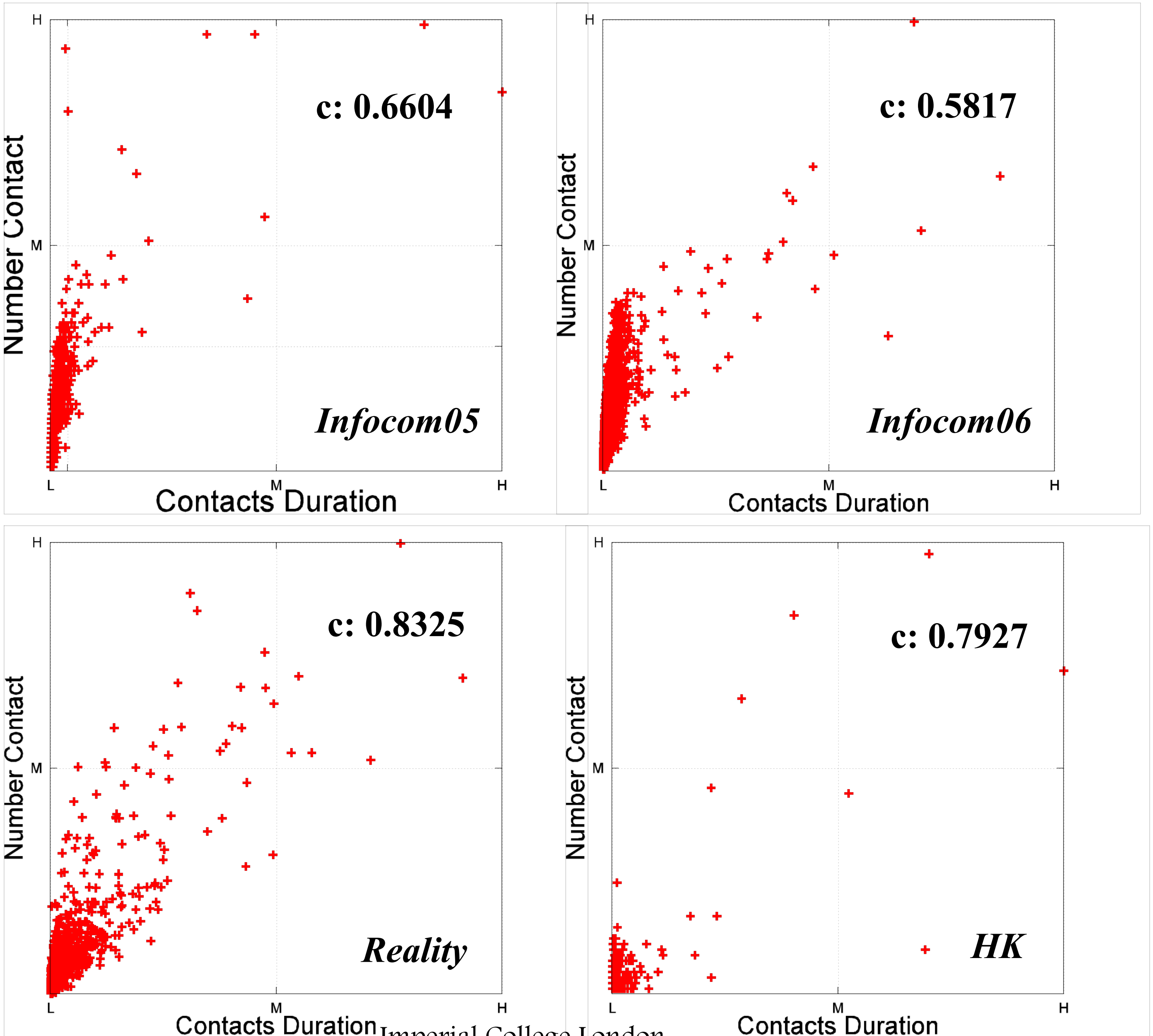
Node centrality should be modelled in different levels of heterogeneity

Regularity and Familiarity



Correlation Coefficient = 0.9026

I: Community II. Familiar Strangers III. Strangers IV. Friends


c: 0.6604
Infocom05
c: 0.5817
Infocom06
c: 0.8325
Reality
c: 0.7927
HK
Number Contact
Contacts Duration
L
M
H

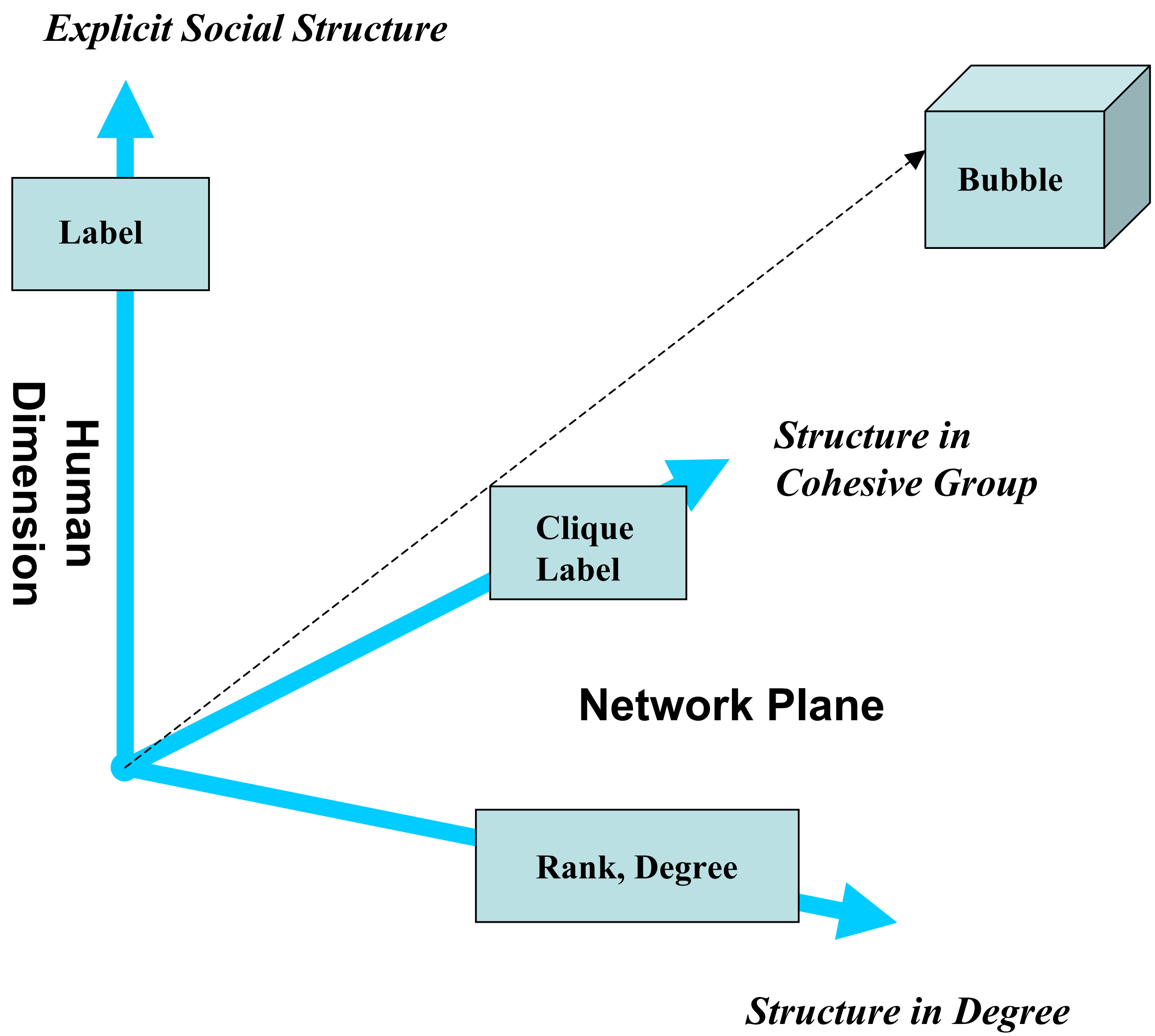
Heterogeneous Forwarding

The second goal of this research is to devise efficient forwarding algorithms for PSNs which take advantage of both a priori *and learned knowledge of the structure of human mobility.*

Interaction and Forwarding

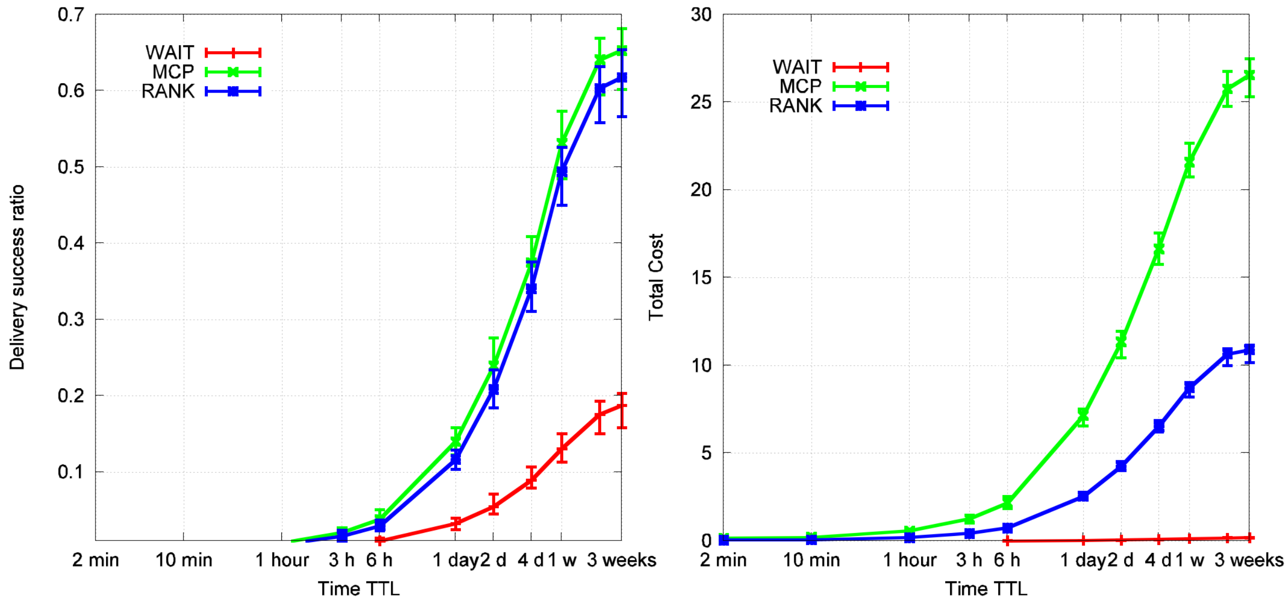
- Third generation human interaction model
  - Categories of human contact patterns
  - Clique and community
  - Popularity/Centrality
- Dual natures of mobile network
  - Social network
  - Physical network
- Benchmark Forwarding strategies
  - Flooding, Wait, and Multiple-copy-multiple-hop (MCP)

Design Space



Greedy Ranking Algorithm (RANK)

- Use pre-calculated centrality/rank
- Push traffic to nodes have higher rank
- Good performance in small and homogeneous



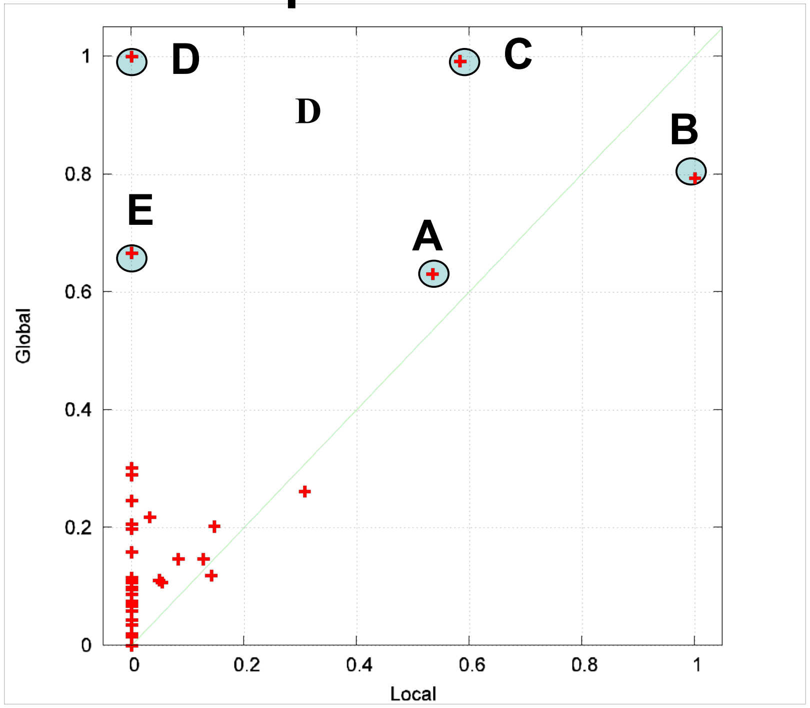
Greedy Ranking Algorithm

- Hierarchical organization
- Hierarchical paths [Trusina et al]
- High percentage in most dataset

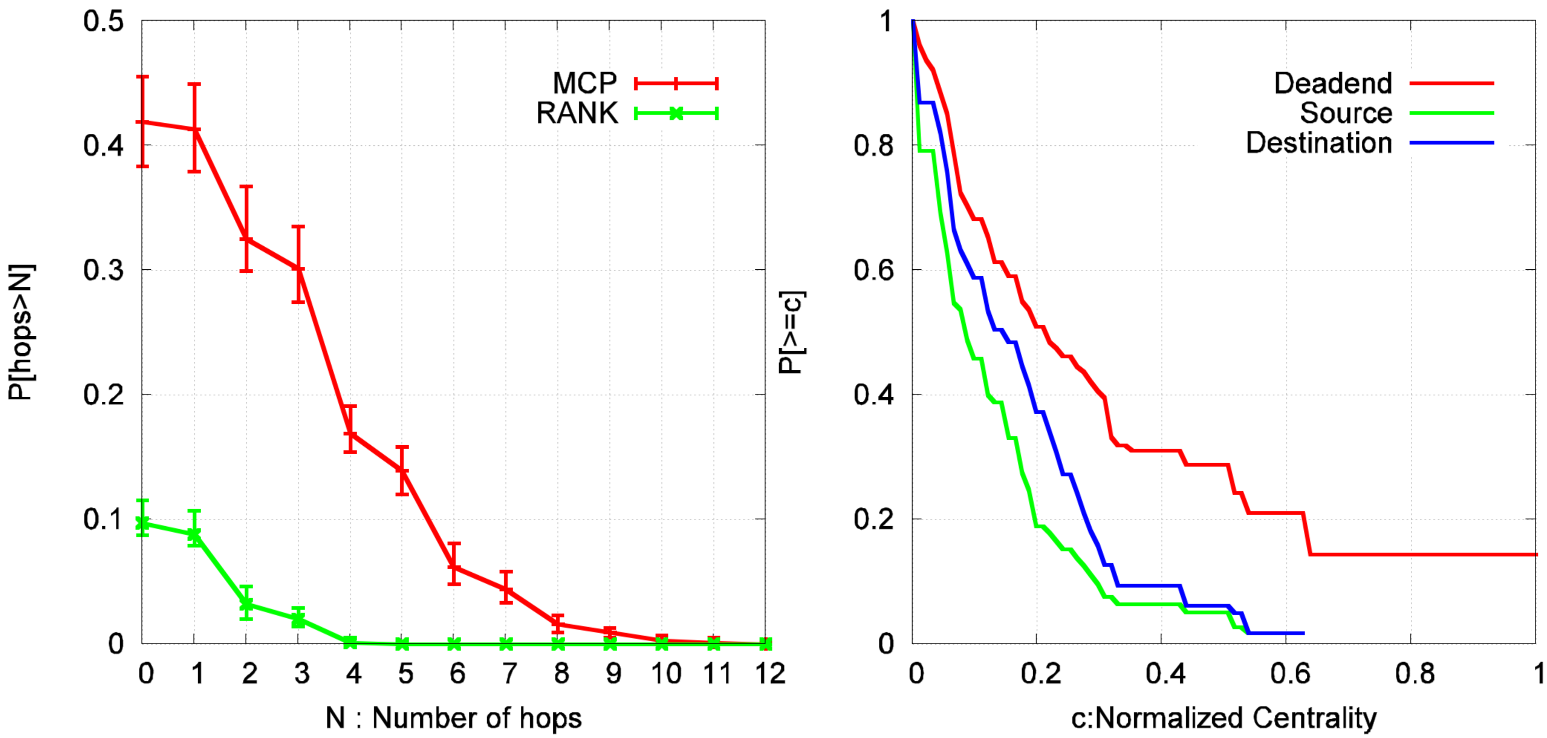
Experimental data set	% hierarchical paths
Rummidge	87.2 (-2.4,+4.3)
Reality	81.9 (-3.1,+3.3)
Infocom05	62.3 (-2.5,+2.5)
Infocom06	69.5 (-4.1,+2.4)
Hong Kong	33.5 (-4.0,+4.0)

Problem with RANK

- Heterogeneous at multiple levels
- Best node for the whole system may not be best node for a specific community



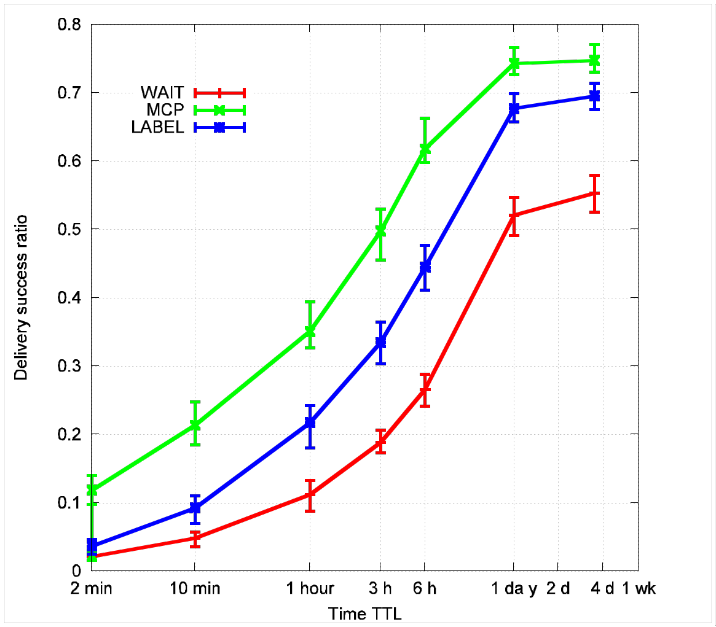
Problem with RANK

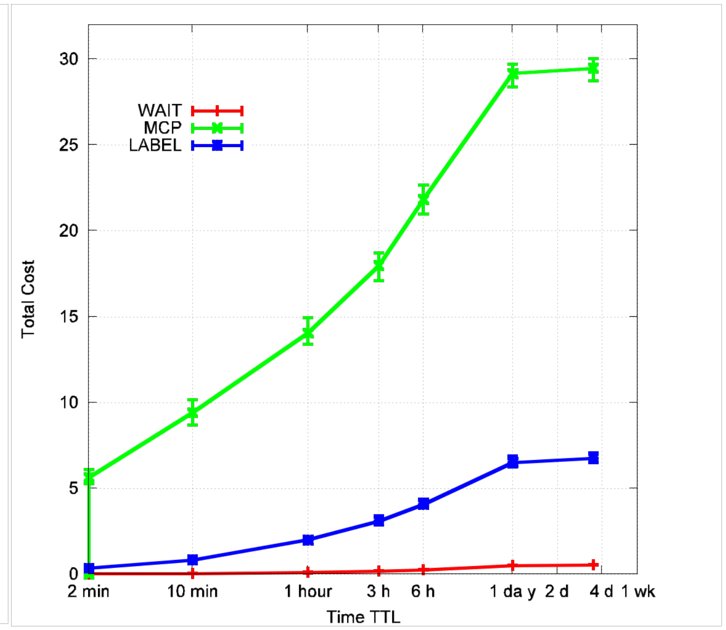


Hop distribution and rank at dead-end for HK dataset

Label Strategy (LABEL)

- Priori label, e.g. affiliation
- Correlated interaction
- Forward to nodes have same label as the destination
- Good performance in conference mixing environment

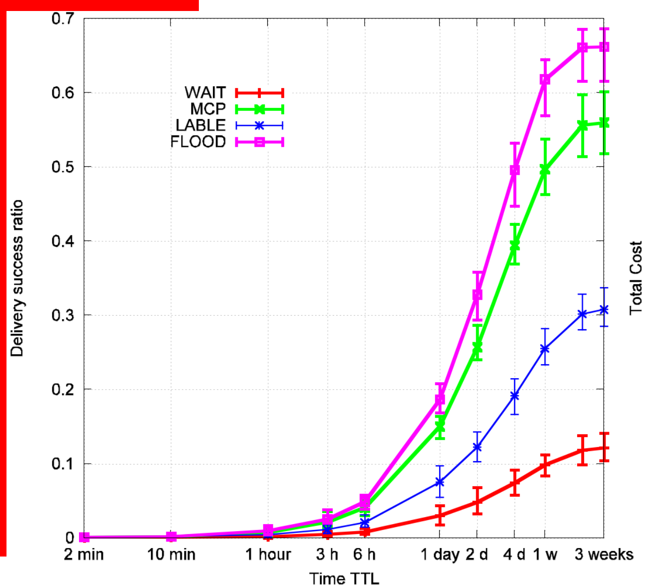


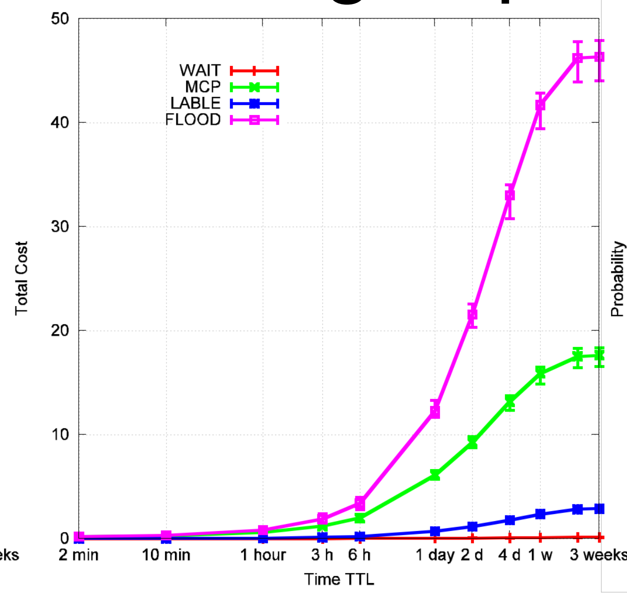


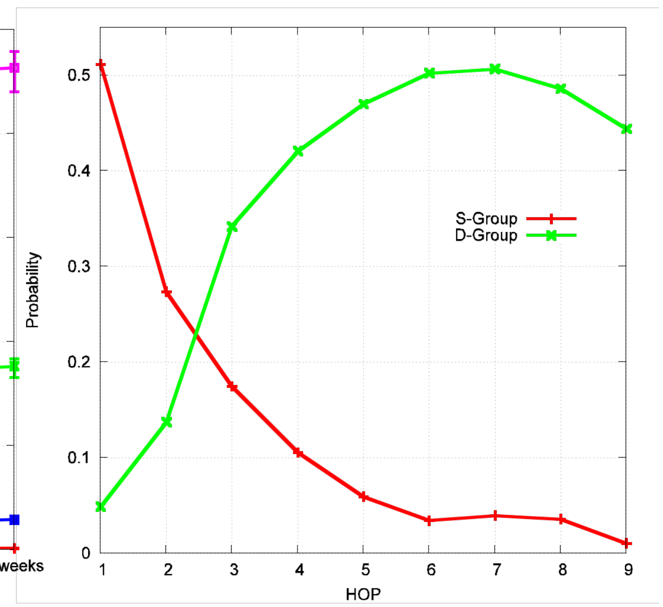
Infocom06

Problem with LABEL

- In a less mixing environment (e.g. Reality)
- A person in one group may not meet members in another group so often
- Wait for destination group not efficient

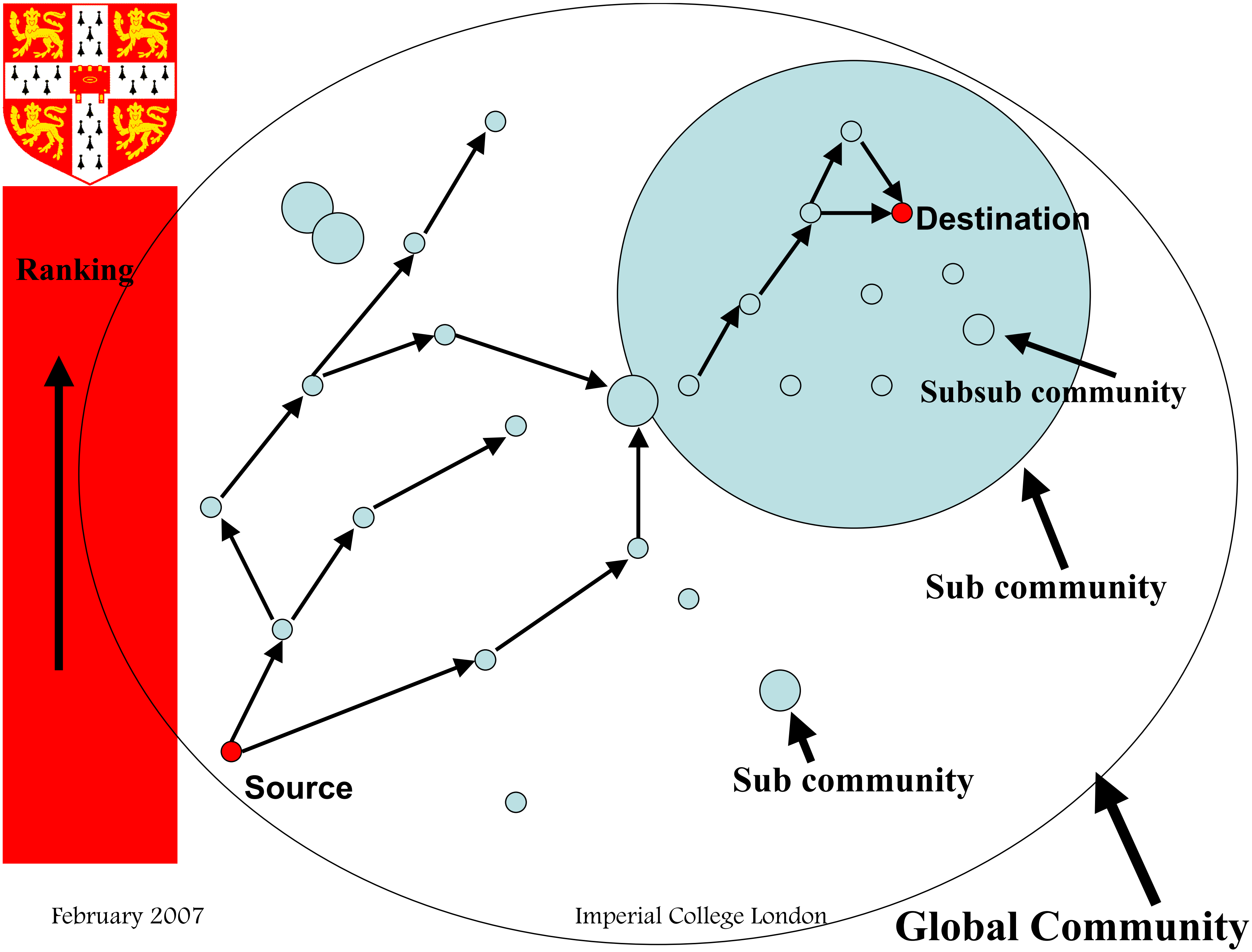




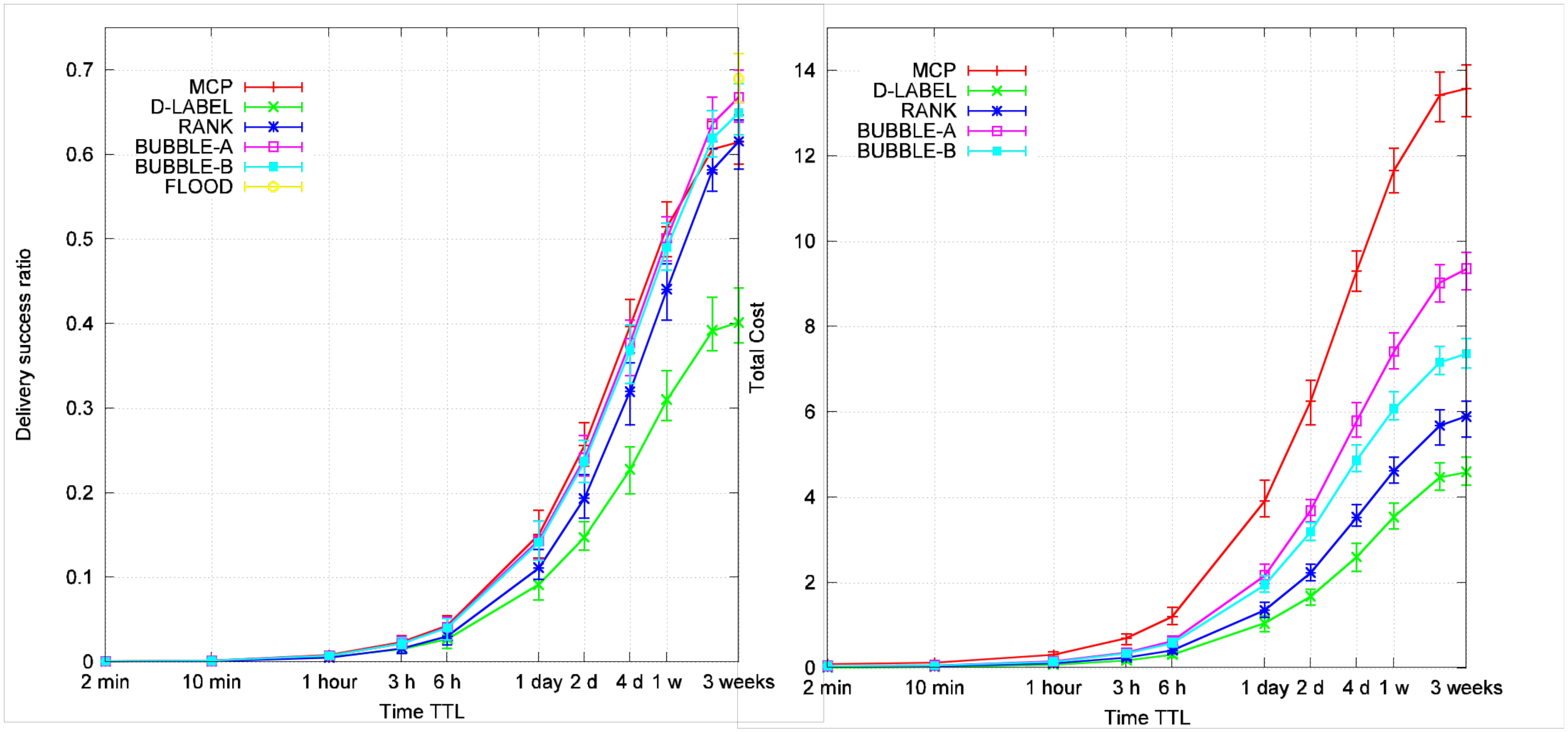


Centrality meets Community

- Population divided into communities
- Node has a global and local ranking
- Global popular node like a postman, or politician in a city
- Local popular node like Christophe Diot in SIGCOMM
- BUBBLE-A
- BUBBLE-B


Ranking
Destination
Subsub community
Sub community
Source
Sub community
Global Community

Centrality meets Community

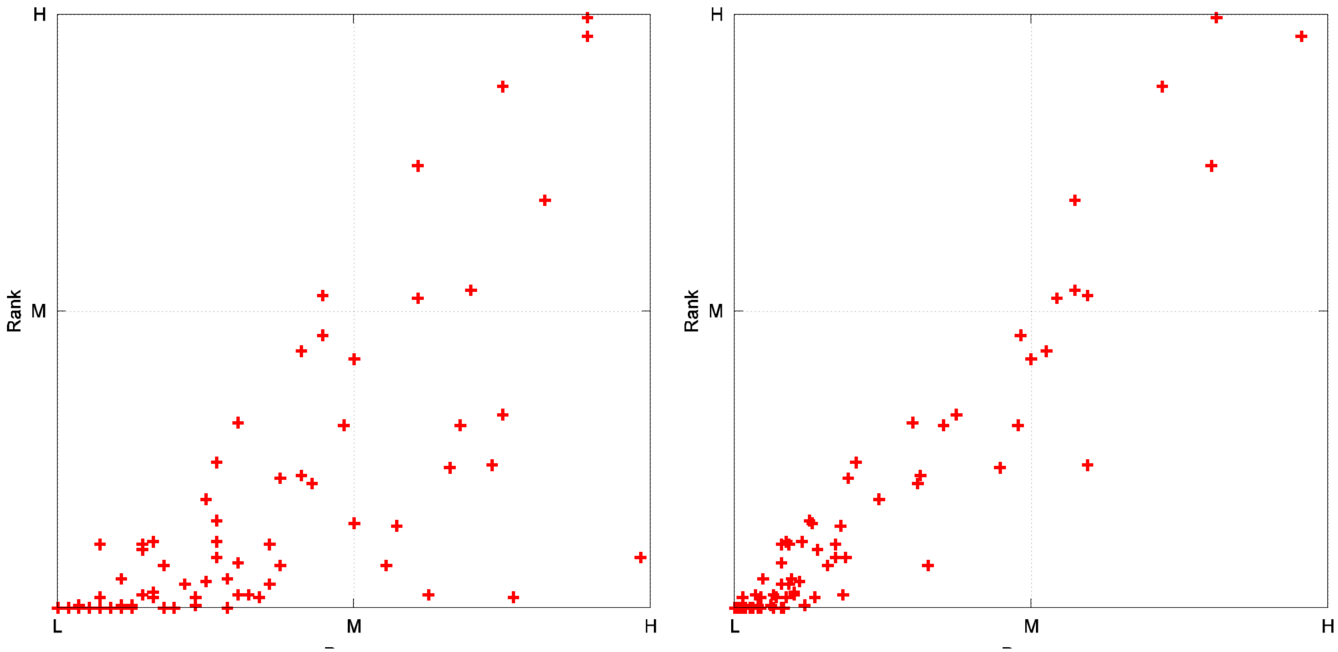


Making Centrality Practical

How can each node know its own centrality in decentralised way?

How well does past centrality predict the future?

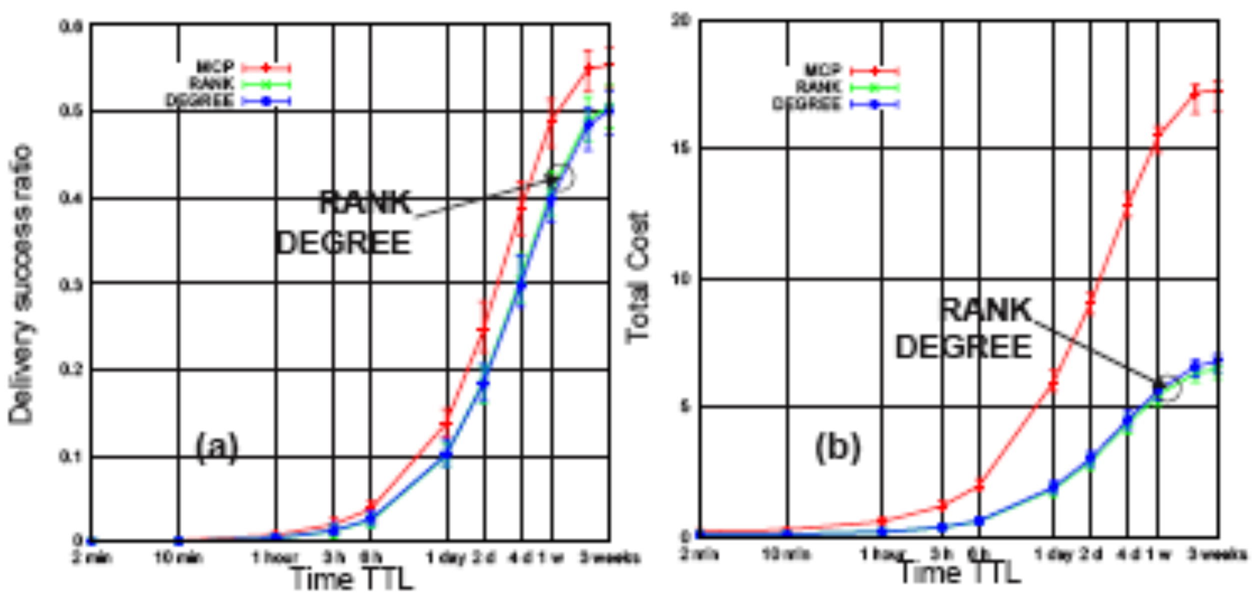
Approximating Centrality



- Total degree, per-6-hour degree
- Correlation coefficients, 0.7401 and 0.9511

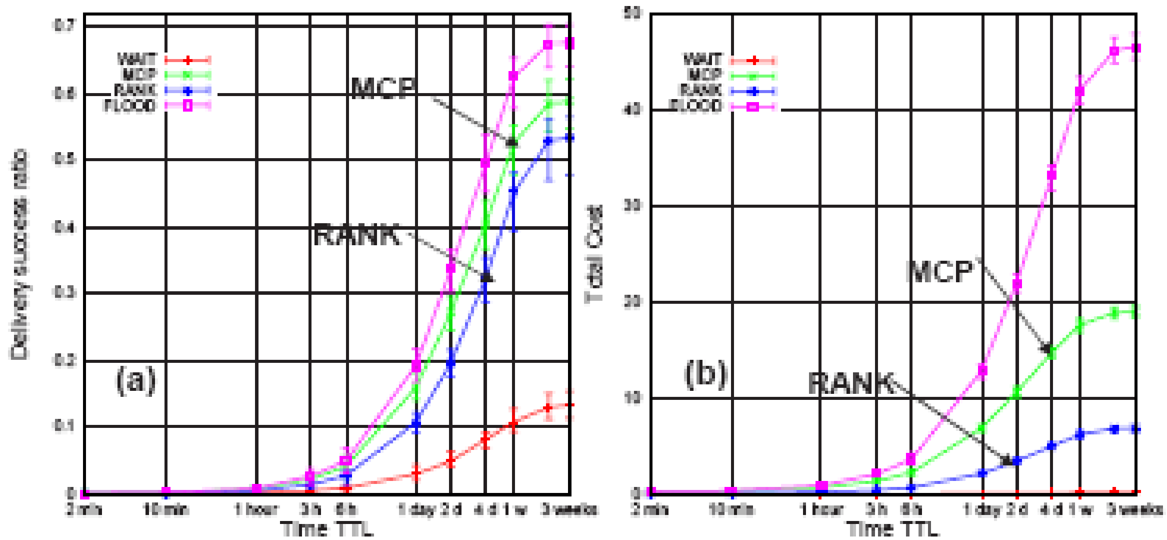
Approximating Centrality

- DEGREE
- S-Window
- A-Window (Exponential Smoothing)



Predictability of Human Mobility

- Three sessions of Reality dataset
- Two sessions using the ranking calculated from the first session
- Almost same performance



Conclusion and Future Woks

- Forwarding using priori label or social structure inferred through observation
- Distributed k-clique building through gossiping
- Why per-6-hour?
- Weighted version of k-clique detection
- Third generation modeling

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