ELEC6214 AWCNSs: Advanced Topics Seminar

Social-Aware D2D Communication Underlaying Cellular Network: Where Mobile Network Meets Social Network

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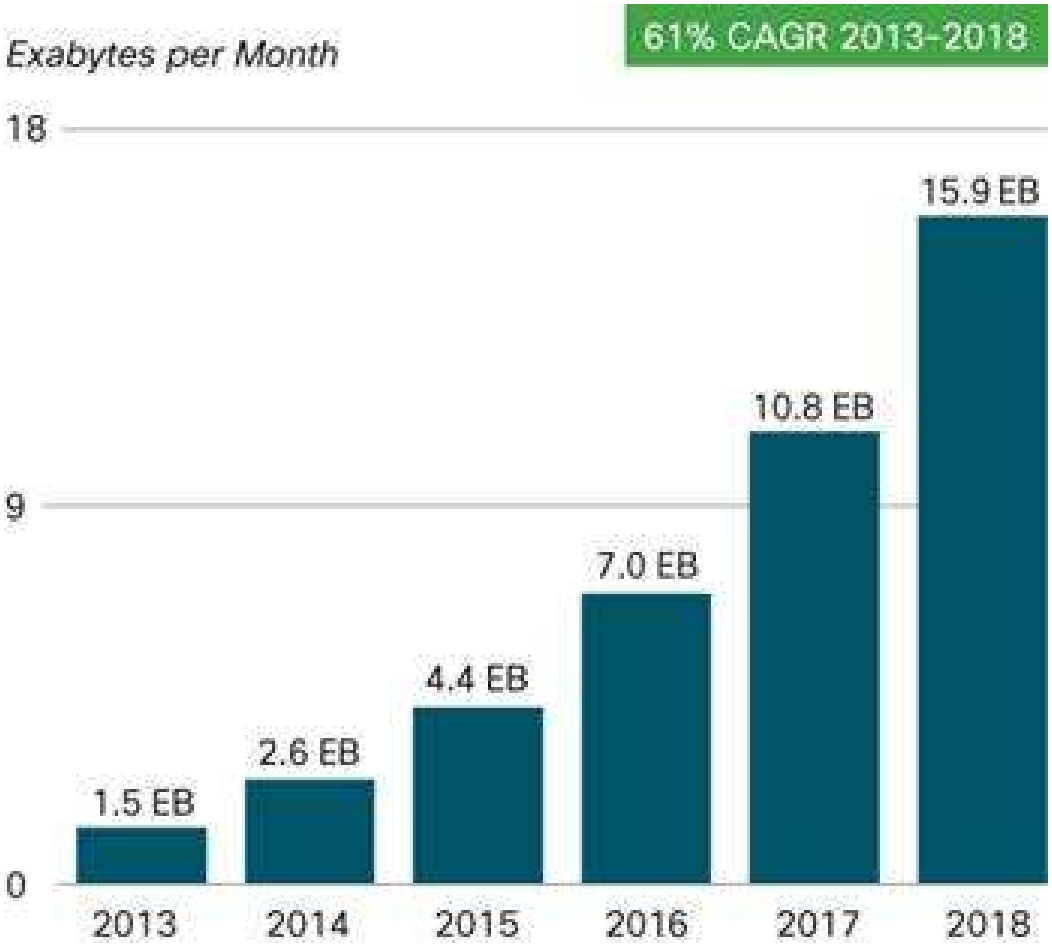
Cisco Forecast 2013-2018

- Global mobile data traffic grew 81 percent in 2013
- Mobile video traffic was 53 percent of traffic in 2013
- 45 percent of global mobile data traffic was offloaded in 2013
- Mobile data traffic will increase 11-fold between 2013 and 2018
- Monthly global mobile data traffic will surpass 15 exabytes in 2018
- Over two-thirds of the world's mobile data traffic will be video by 2018



Source: Cisco VNI Mobile, 2014

1 exabyte$= 10^{18}$ **bytes**

New G Mobile Network

- Mobile communications landscape shows that current technology could not meet demand
  - You with your smart phones are creating this exponentially increasing demand
- We are going to "save" future world by **new generation mobile network**
- **Long term evolution-advanced** (LTE-A) supports mobile content downloading
- A key component of LTE-A: **Device-to-device** (D2D) communication
  - Enhancing bandwidth efficiency and increasing system capacity
  - while reducing power consumption
- New generation mobile network will be **D2D underlaying** cellular network

Birth of Social Networks

- Digital world reality: where those huge volume of mobile traffics come from ? **social networks** !
- Mobile devices carried by human beings who form social networks of certain **social structures and phenomenons**
- Birth of social networks $\Rightarrow$ thanks to mobile networks
- More and more people are living in two worlds: "real" **physical** world and "virtual" **digital** world
- As they usual to say

  ©The future is bright the future is orange

  We are going to say

  ©The future is social network the future is mobile network

Social Characteristics

1. Social **tie**: characterise strength that two individuals are related to each other
   - In mobile network, social ties identify weak or strong connections among mobile users

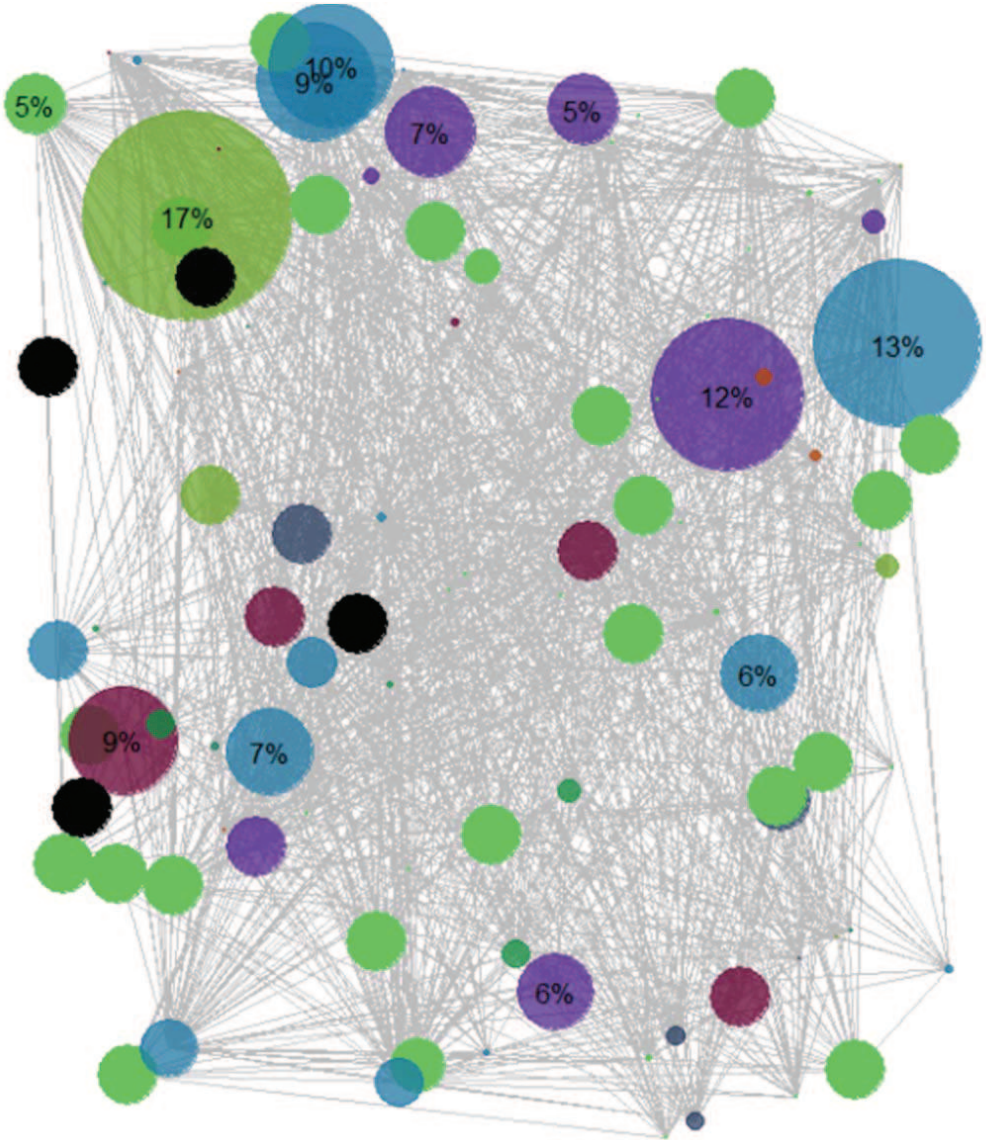
2. Social **community**: identify groups of individuals sharing same interests or behaviours
   - In mobile network, social communities represent social groupings by interests or background

3. Social **centrality**: quantify structural importance of an individual
   - A central user has a stronger capability of connecting others in the network

4. Social **bridge**: manifest as connections between communities
   - A bridge provides path to connect two communities, along which information or influence can flow between two groups

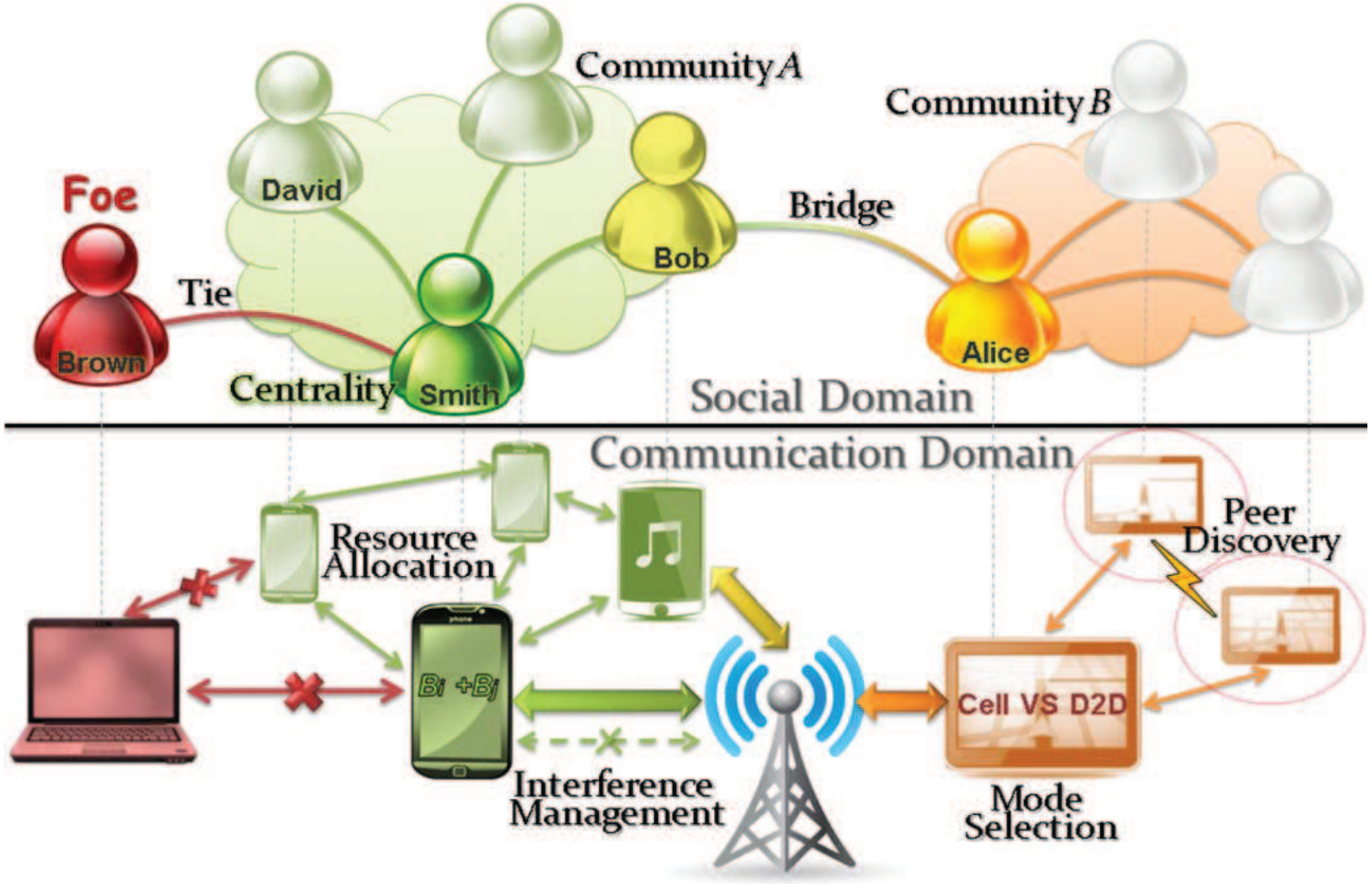
Reality Mining

- 100 smart phones $\Rightarrow$ MIT staff and students for nine months $\Rightarrow$ human social interactions and dynamics
- Users are coloured to identify 9 different **communities**
- User in community has different **centrality**, by size of circle
- Social **ties**: some user pairs have strong relations, while others have weak ones
- When strong relations occur across two communities, social **bridge** is observed



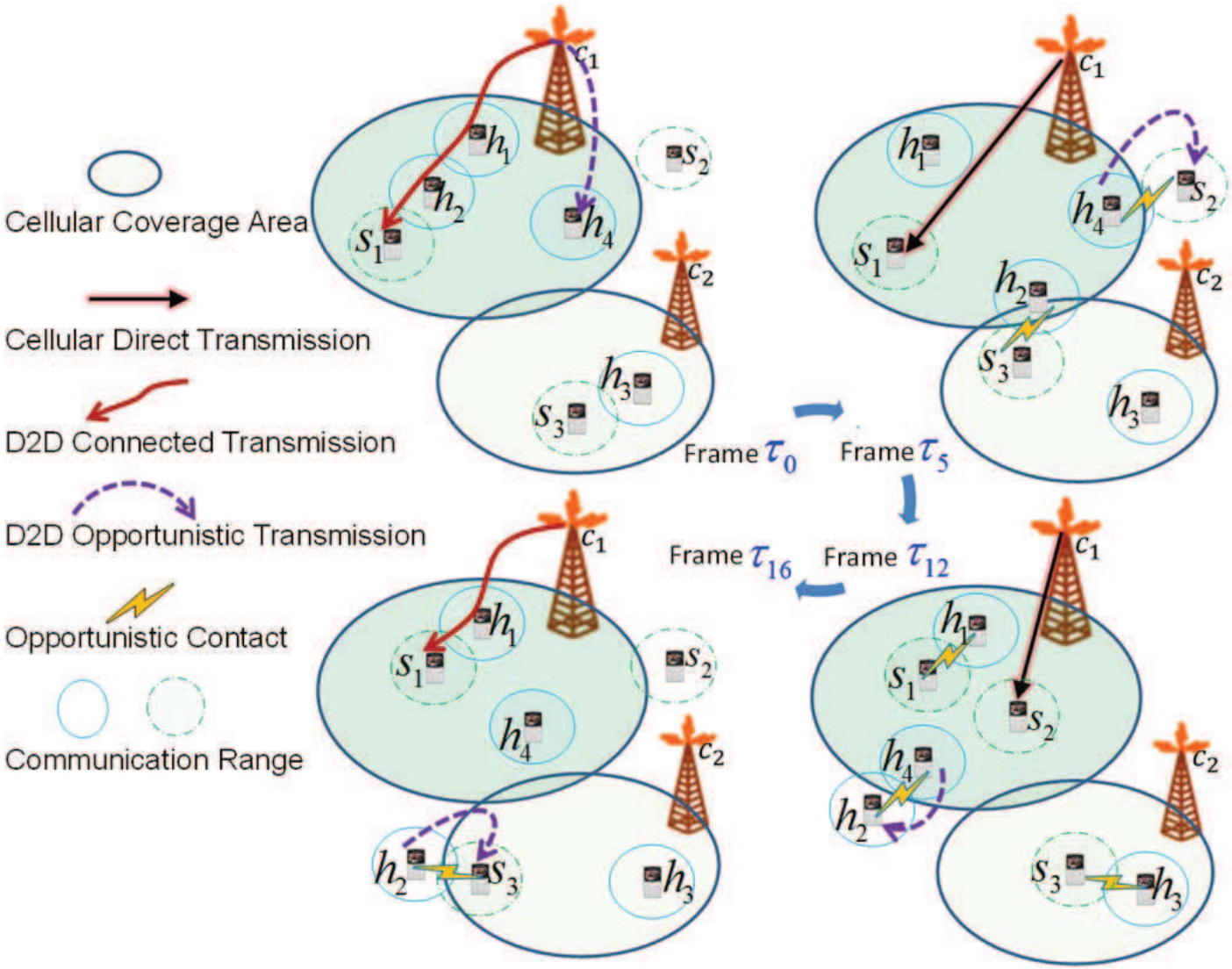
What We Want

- Social networks have benefited greatly from advance of mobile communication technology



- We want to leverage social network characteristics for establish new paradigm of mobile network design

D2D Underlaying Cellular Network



1. **Cellular direct** (original mode); 2. **D2D connected** (relay); 3. **D2D opportunistic** (no end-to-end path) – new paradigm, store-carry-and-forward

Key Technical Problems

1. Service and Peer **Discovery**: identify candidate D2D pairs and required services
   - Cellular mediates discovery process, a centralized single-point-of-failure solution, stability and scalability problems
   - Ad hoc network approach, peer discovery by UE themselves, e.g. through beaconing

2. Communication Mode **Selection**: how to utilize all potential transmission modes to maximize data transmission capacity from all BSs to all UEs

3. Spectrum Resource **Allocation**: how to share spectrum between D2D and cellular to attain maximum system throughput

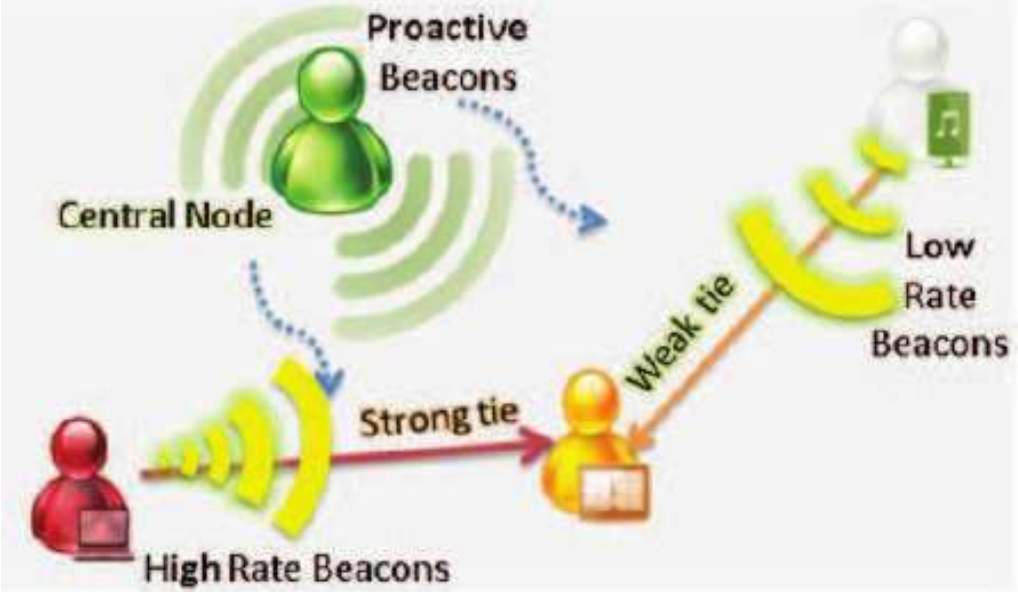
4. Interference **Coordination** and Management: how to manage interference between cellular and D2D and across multiple cells
   - Interference coordination for D2D connected can be managed centrally by BSs
   - Interference coordination for D2D opportunistic may require distributed management involving handsets

Conventional Solutions

- We have been working on communication-domain designs/solutions
  - Collaborative vehicular content dissemination with directional antennas, *IEEE Trans. Wireless Communications*, vol.11, **2012**
  - Optimal beaconing control for epidemic routing in delay tolerant networks,
  - An optimal relaying scheme for delay-tolerant networks with heterogeneous mobile nodes, *IEEE Trans. Vehicular Technology*, vol.63, **2013**
  - Exponential and power law distribution of contact duration in urban vehicular ad hoc networks, *IEEE Signal Processing Letters*, vol.20, **2013**
  - Coding or not: optimal mobile data offloading in opportunistic vehicular networks, *IEEE Trans. Intelligent Transportation Systems*, vol.15, **2013**
  - Multiple mobile data offloading through disruption tolerant networks, *IEEE Trans. Mobile Computing*, vol.13, **2014**
  - A Markov jump process model for urban vehicular mobility: modeling and applications, *IEEE Trans. Mobile Computing*, vol.13, **2014**
  - Optimal mobile content downloading in device-to-device communication underlaying cellular networks, *IEEE Trans. Wireless Communication*, vol.13, **2014**

Social-Enhanced Solutions: Social Ties

- **Social tie**-aware **peer discovery**:
  - links correlated to strong ties offer more communication contacts and have higher data loads



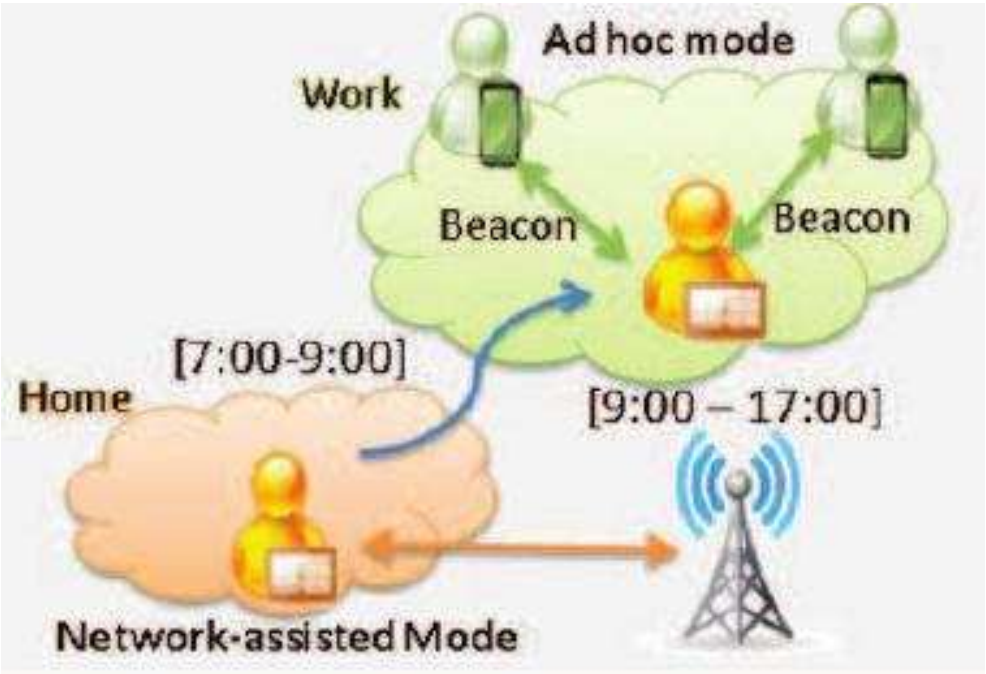
- Instead of randomly beaconing, adjust **beacon rates** according to strengths of ties

- Allocating more spectrum and energy resources to users with strong ties increases peer discovery ratio, avoid congestion, and improve spectral efficiency

- **Social tie**-aware resource allocation and **relay selection**: Strength of a tie reflects trustfulness of two peers
  - In relay selection, taking social tie information into account improves **privacy** and **security**

Social-Enhanced Solutions: Social Community

- **Peer discovery**: community structure and encounter patterns helps peer discovery process
  - User in population-dense community can utilise community encounter patterns to aid ad hoc based peer discovery procedure
- **Resource allocation**: user obtains information and content from community neighbors with less effort, owing to similar interest



- Allocating more resources in D2D communication for these community links helps to reduce duplicated network load
- **Mode selection**: relies on knowledge of channel condition, inter-cell interference and network load
- Community structure information simplifies detection and helps to make mode selection quickly and accurately

Social-Enhanced Solutions: Social Centrality

- High degree **centrality** indicates that the user plays **key role** in data dissemination
- As multiple communication paths are built up on it, a central node has **higher demand** on **resources**
- **Centrality** users should possess **high capacity** for data transmission volume and frequency
- A central node has high proximity-encounter possibility with nearby devices
- Central devices may provide **alternatives** to **relieve** synchronization and communication work load on BSs
- Instead of randomised beaconing, central node can **proactively** send **beacons** to improve peer discovery ratio

Social-Enhanced Solutions: Social Bridges

1. A **bridge** undertakes task to provide information and content exchange among communities
   - Prone to **congestion** under heavy network load conditions
2. Resource allocation needs to schedule **more resources** to bridge users
   - **To avoid congestion**
3. Mode selection needs to give **higher preference** of cellular communication to bridge nodes
   - **To avoid congestion**
4. Bridge user **detection**, bridge-aware resource **allocation** and mode **selection** schemes are challenging problems
   - Have potential for significantly improving overall **throughput** and **coverage** of D2D enabled cellular network

Social-Aware D2D Summary

Peer Discovery

Ties	Community	Centrality	Bridge
beacon rate	peer density	proactive beacons	–
adjustment	encounter patterns	communication demands	–

Mode Selection

Ties	Community	Centrality	Bridge
–	community density	cellular preferential	inter-community
–	community interests	bottleneck detection	demands

Resource Allocation

Ties	Community	Centrality	Bridge
com demands	community sharing	resource demands	dissemination dominant
security, privacy	com demands	bottleneck prediction	bottleneck prediction

Interference Management

Ties	Community	Centrality	Bridge
relay selection	resource partition	–	–
spectrum allocation	distributed coordination	–	–

Social Meets D2D: Quantitative Evaluation

System set up for simulated D2D enabled network:

1. Use **Reality Mining** trace, the most recognised human social and mobility trace, to drive simulation

2. In the area covered by Reality trace, multiple BSs, each with a coverage radius of 400 m, provide a seamless coverage

3. Maximum transmission range of D2D nodes is 50 m, and achievable link data rate depends on distance of two UEs

4. Other network parameters are based on standard wireless propagation settings

   - **D2D** channel based on scenario that two communicating UEs are physically in close proximity
   - **Cellular** channel is simulated according to urban microcell scenario

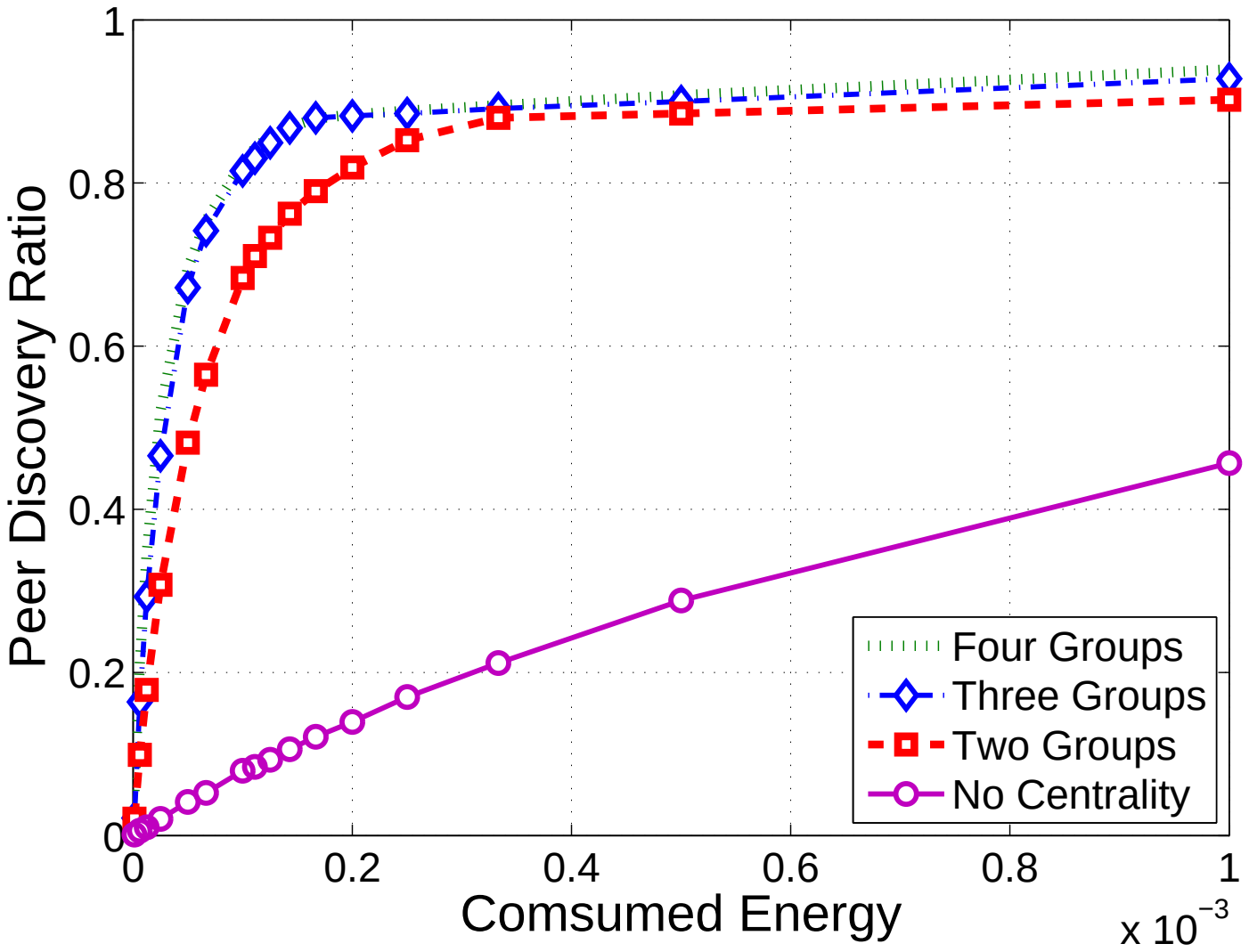
Social-Aware D2D Designs

1. **Centrality-Aware Peer Discovery**: adjust users' beacon rates proportional to centrality values
   - Group users by their centrality values, and allocate a different beacon rate to each group

2. **Bridge-Aware Mode Selection**: first throughput-maximisation to decide transmission modes
   - Amend results by setting all bridge users to cellular mode in downloading phase
   - Then set them to D2D mode in data sharing phase to disseminate data to other users

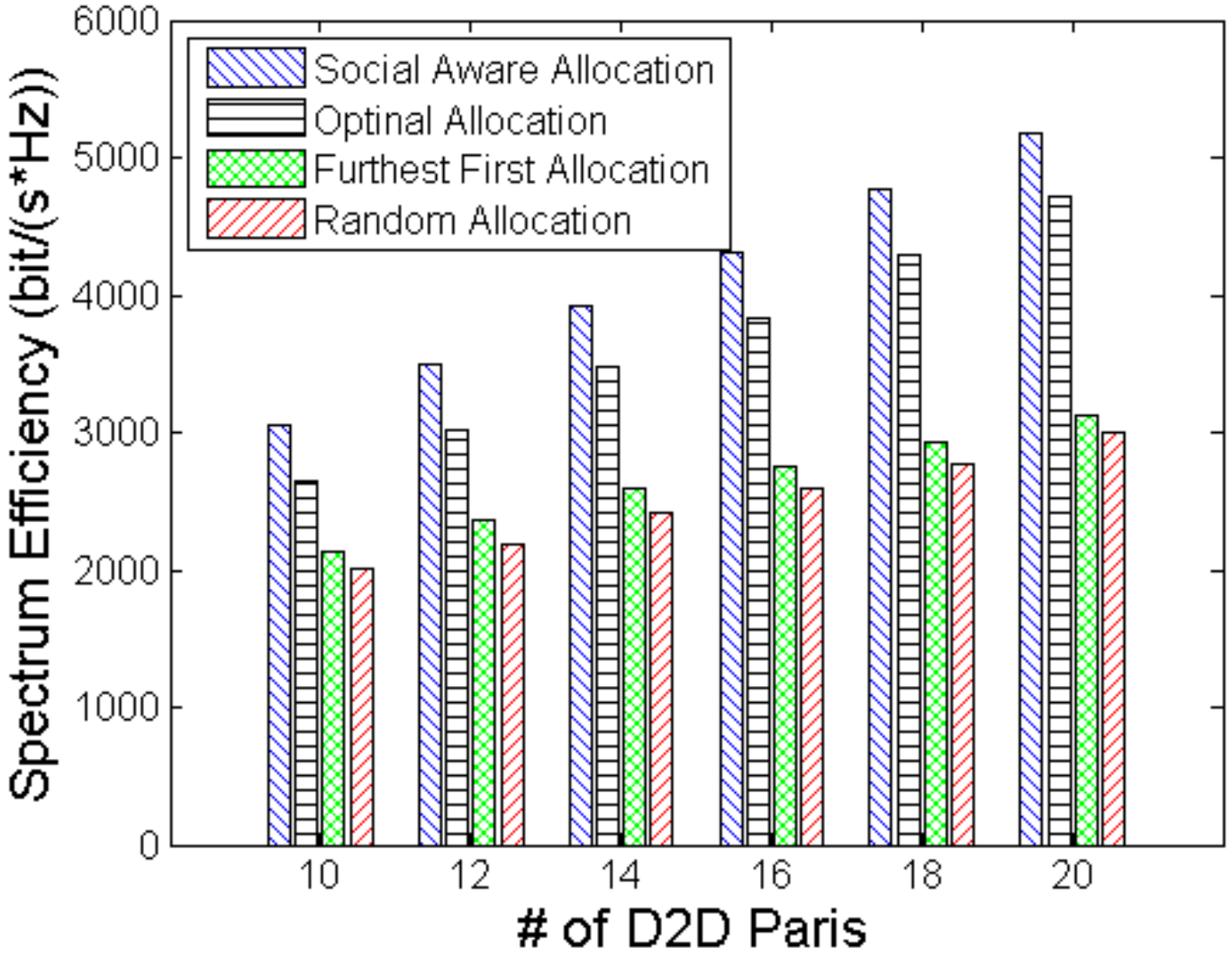
3. **Community and Ties Guided Resource Allocation**:
   - Allocate D2D pairs with same resources of cellular users in different communities (usually not in physical proximity)
   - Within a community, allocate resources for D2D pairs to be proportional to their social tie strengths

Peer Discovery Efficiency



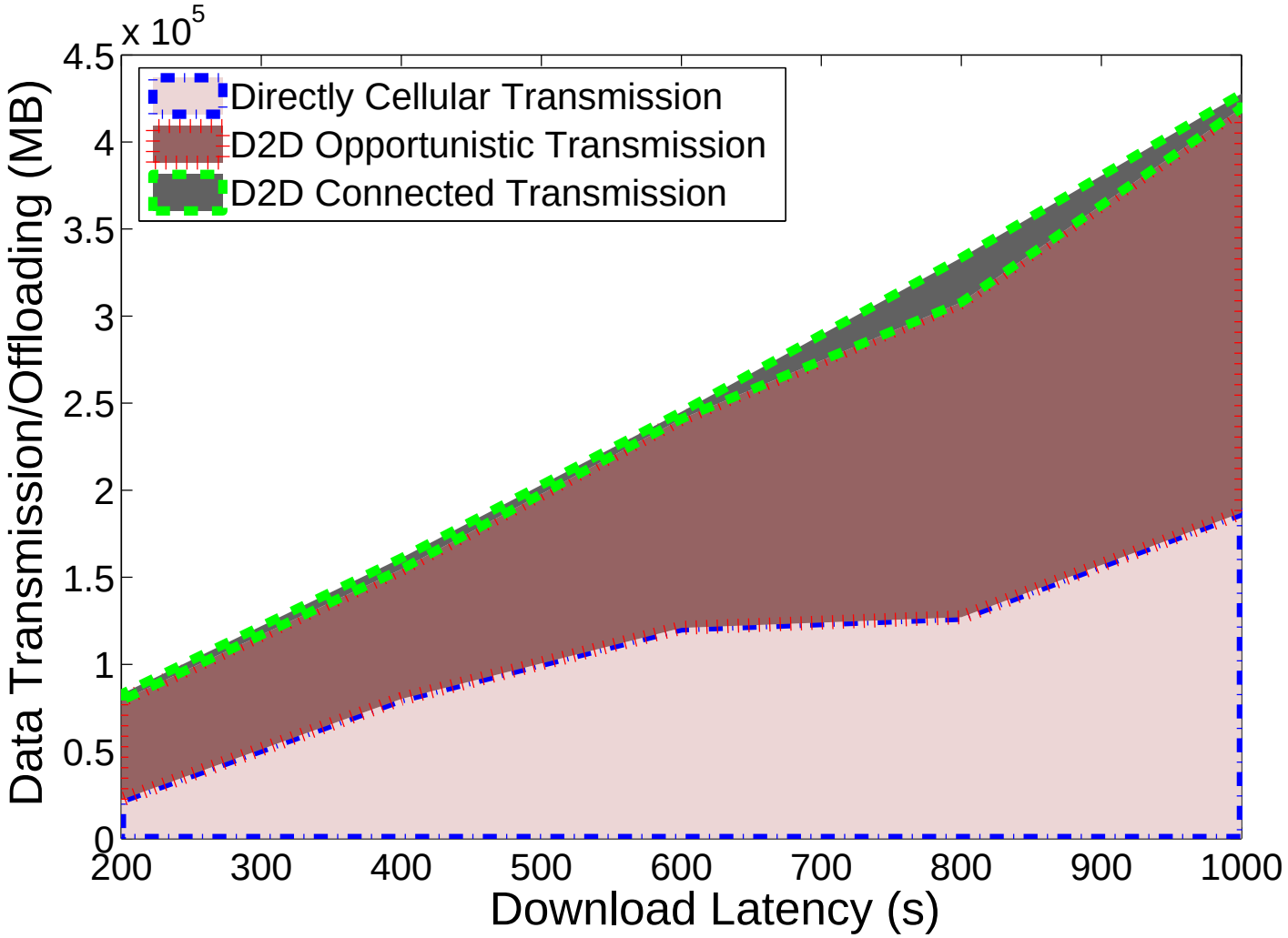
Comparison of **peer discovery** performance as function of normalised energy consumed for **non-social centrality aware** and **social centrality aware** schemes

Resource Allocation Performance



Comparison of **spectrum efficiencies** in terms of sum rate achieved (**further first**: allocate D2Ds with same resources of cellular users that are furthest away from the D2D pairs; **non-social aware optimal**: throughput-maximisation)

Social Bridge Guided Mode Selection



Throughputs attained by three different modes as function of content downloading latency

- **D2D opportunistic** offloads large amount of data from the traditional cellular transmission

Conclusions

- Social networks we inhibit inhibit in mobile networks

  1. Understand interplay between social network's characteristics and mobile communication problems
  2. Beneficial to exploit social network's characteristics in mobile network design

- Open up new direction for designing next-generation social-aware D2D underlaying cellular system

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