Mobile Crowdsensing (MCS) for Smart Cities

Prof. Chi (Harold) Liu

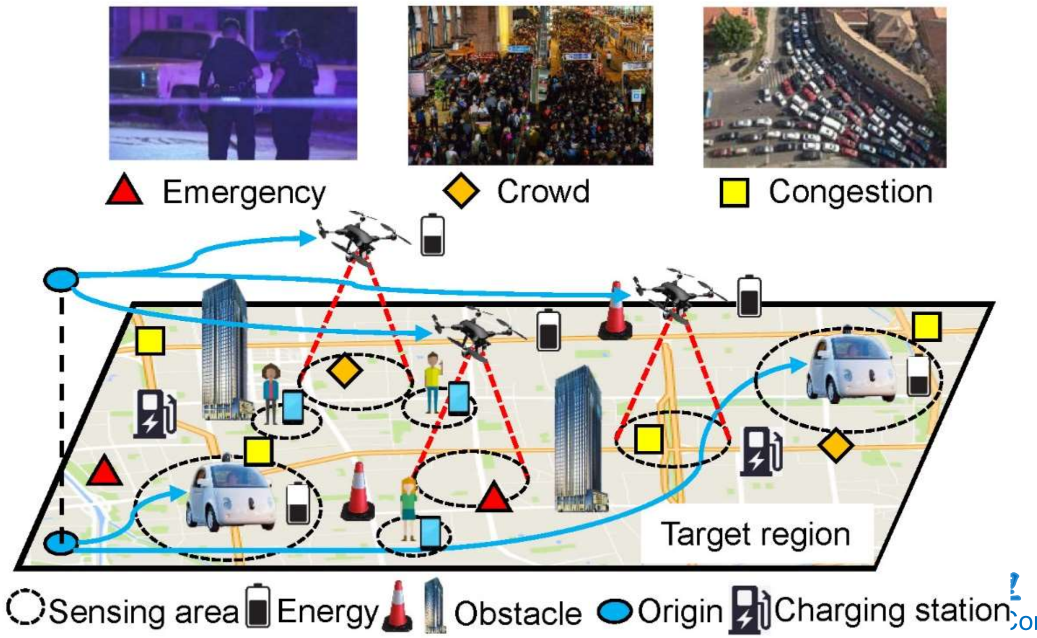
IET Fellow and Vice Dean
Beijing Institute of Technology, China
Email: chiliu@bit.edu.cn
http://haroldliu.weebly.com

Agenda

- History and Key Applications for MCS
- MCS Key Technologies
- My Research
- Conclusion

MCS for Smart Cities

- Traditional IoT refers to physical deployment of sensors that has many challenges like high costs, short sensing range, long response time, poor mobility pattern, etc.
- Smartphones, UAVs, driverless cars etc. all have equipped with rich sensors like camera, microphone, gyroscope, GPS, heartbeat/blood pressure sensors, that form a MCS environment.



Going back to…

In 2008, IEEE Internet Computing: “The Rise of People-Centric Sensing”

Mesh Networking

The Rise of People-Centric Sensing

Technological advances in sensing, computation, storage, and communications will turn the near-ubiquitous mobile phone into a global mobile sensing device. People-centric sensing will help drive this trend by enabling a different way to sense, learn, visualize, and share information about ourselves, friends, communities, the way we live, and the world we live in. It juxtaposes the traditional view of mesh sensor networks with one in which people, carrying mobile devices, enable opportunistic sensing coverage. In the MetroSense Project's vision of people-centric sensing, users are the key architectural system component, enabling a host of new application areas such as personal, public, and social sensing.

Andrew T. Campbell, Nicholas D. Lane, Emiliano Miluzzo, Ronald A. Peterson, Hong Lu, Xiao Zhong, Mirco Musolesi, and Kristóf Fodor
Dartmouth College

Shane B. Eisenman and Gahng-Seop Ahn
Columbia University

The evolution of sensing, computing, and communication technology over the past few years has brought us to a tipping point in the field of wireless sensor networking. A decade ago, research prototype hardware began to emerge, facilitating the genesis of wireless sensor networks as they exist today: small resource-limited embedded devices that communicate via low-power, low-bandwidth radio. A natural first application of these networks of custom devices was solving relatively small-scale specialized problems in the scientific and industrial domains, such as forest monitoring and preventative maintenance.

Although these problems and applications remain important, the recent miniaturization and subsequent introduction of sensors into popular consumer electronics like mobile phones (such as the Apple iPhone), PDAs (such as the Nokia N810), and MP3 players (such as the Nike + iPod) has opened the door to a new world of application possibilities. With wireless sensor platforms in the hands of the masses, and with the proper architectural support, we can leverage wireless sensor networks to address urban-scale problems or provide global information access (such as public-sensing applications). At the same time, people as individuals, or in social or special interest groups, can apply these new sensing networks to applications with a more personal focus. We see a continuing push in this direction and the advent of a new era of people-centric sensing.

In a people-centric sensing system, humans, rather than trees or machines,

Andrew T. Campbell, Nicholas D. Lane, et. al *Dartmouth College*
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Figure 1. People-centric sensing applications can be thought of as having a personal, social, or public focus.

On of the first paper to propose the “people-centric sensing” conception, where humans, rather than trees or machines, become the focal point of sensing.

Campbell A T, Eisenman S B, Lane N D, et al. The Rise of People-Centric Sensing. IEEE Internet Computing, 2008, 12(4):12-21.

Early Apps

ACM SenSys 2008 **Nericell**

A system for rich monitoring of road and traffic conditions, which uses the accelerometer, microphone, GSM radio, and/or GPS sensors in phones to detect potholes, bumps, braking, and honking.

Figure 1: Map of Bangalore with drive routes highlighted

Figure 2: A typical chaotic road intersection with variety of vehicles at loggerheads

Mohan P , Padmanabhan V N , Ramjee R . Nericell: Rich monitoring of road and traffic conditions using mobile smartphones. ACM SenSys 2008

ACM MobiSys 2008 **Micro-Blog**

Internet users can zoom into any part of the map and browse multimedia blogs at those locations. Users may query selected regions for desired information. Queries are serviced either through explicit human participation, or automatic physical sensing.

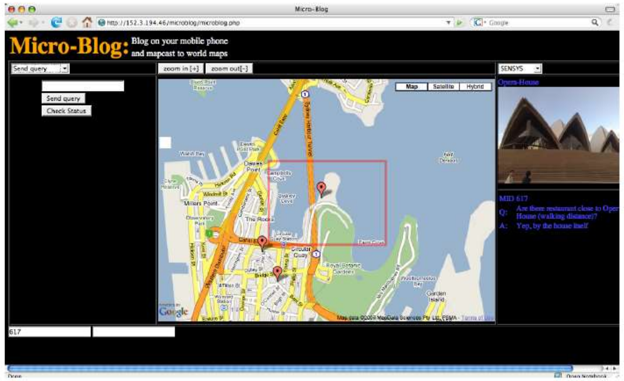


Figure 2: Micro-Blog screenshot and phone query: A microblog of the Opera House in Sydney, Australia, shown on the map. The multimedia blog plays on the right panel. The Internet user selects a region (shown by a square box on the map), and sends a query to phones in that region. The phone on the right, physically located in Sydney, receives the query. The user replies to it, and the reply is transmitted back to the server. The query and reply are associated to the blog, as shown in the right panel. This microblog was created during our demonstration of Micro-Blog at ACM Sensys 2007 [11] held in Sydney, Australia.

Gaonkar S, Li J, Choudhury R R, et al. Micro-blog: sharing and querying content through mobile phones and social participation. ACM MobiSys 2008, pp: 174-186.

Recent Apps

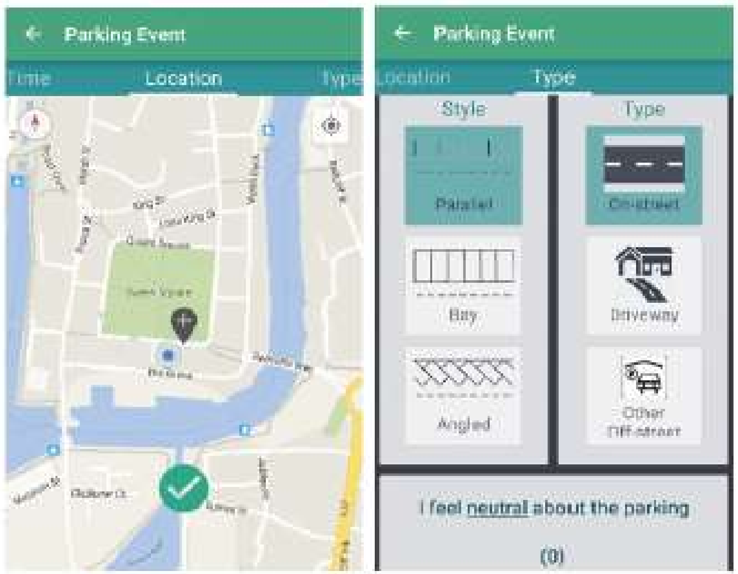
ACM UbiComp 2014 **Atmos**

A weather prediction app that employs any available sensor found on a mobile device to gather objective weather descriptive measurements, such as environmental pressure, temperature, luminosity and humidity levels.

Figure 3: The "PLACES" screen provides an overview of current weather conditions across several locations of interest by summarizing the estimations of other users. Clicking on a specific location grants access to additional information about current and future weather conditions as reported by other users.

AAAI 2017 **ParkUs**

It is for real-time vehicle parking detection. It utilizes accelerometer and magnetometer sensors found in all smartphones within a city environment.



Niforatos E, Vourvopoulos A, Langheinrich M, et al. Atmos: a hybrid crowdsourcing approach to weather estimation. ACM UbiComp 2014, pp: 135-138.

Carnelli P E, Yeh J, Sooriyabandara M, et al. ParkUs: A Novel Vehicle Parking Detection System. AAAI 2017, pp: 4650-4656.

MCS Key Technologies

MCS

- Participant Selection

- Incentive Mechanism

- Privacy Protection

- Truth Discovery

MCS Key Technologies

Participant Selection

IEEE INFOCOM 2015
Selecting Vehicles

It proposes a new strategy to recruit participants by jointly considering the current and future locations of vehicles. Therefore, the quality of crowdsourcing for a period of time in the future can be guaranteed.

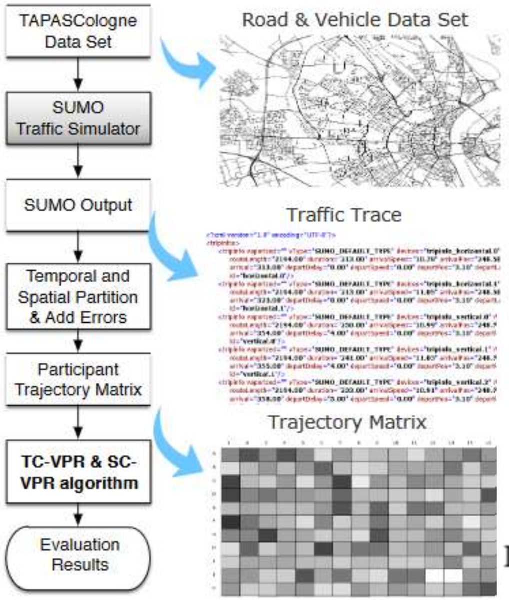
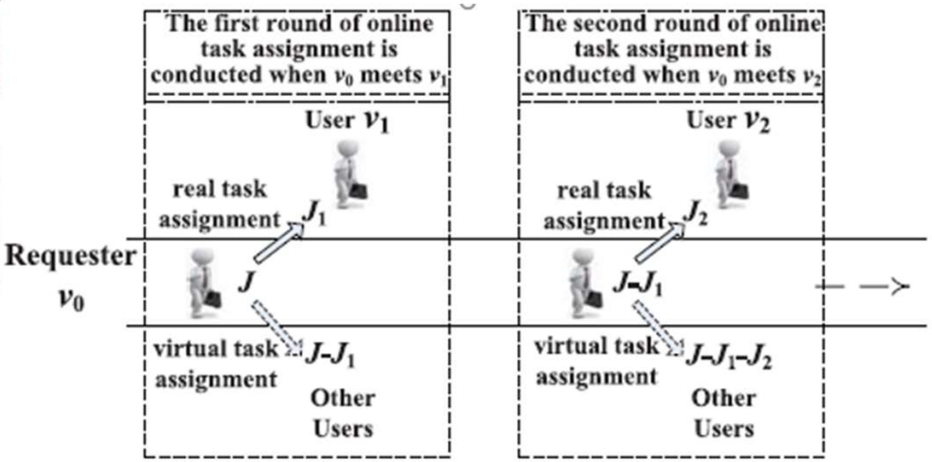


Fig. 4. The design of our experiments

Z. He, J. Cao, X. Liu, "High Quality Participant Recruitment in Vehicle-based Crowdsourcing using Predictable Mobility," in IEEE INFOCOM 2015, pp:2542-2550.

IEEE TMC 2017 **Online Task Assignment**

It proposes and formalizes the makespan-sensitive task assignment problems for MCS based on Mobile Social Networks (MSNs). They take into account the time of sending tasks and receiving results between users, which is subjective to users' mobility.



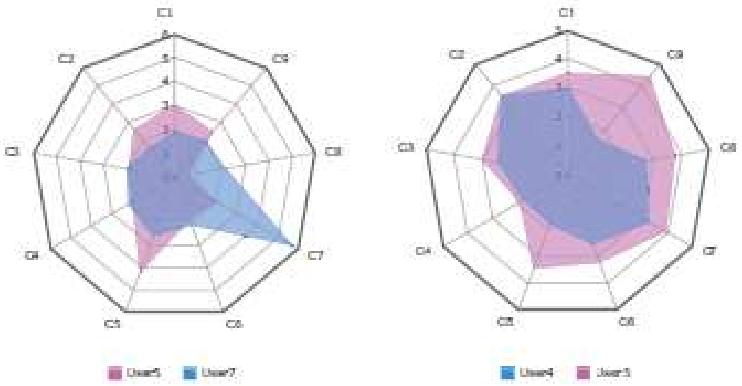
Xiao M, Wu J, Huang L, et al. Online task assignment for crowdsensing in predictable mobile social networks. IEEE Trans on Mobile Computing, 2017.

MCS Key Technologies

Participant Selection

IEEE INFOCOM 2018
Personalized Task Recommender

It proposes a personalized task recommender framework that can recommend tasks to users based on a fine-grained characterization on both the users' preference and reliability.

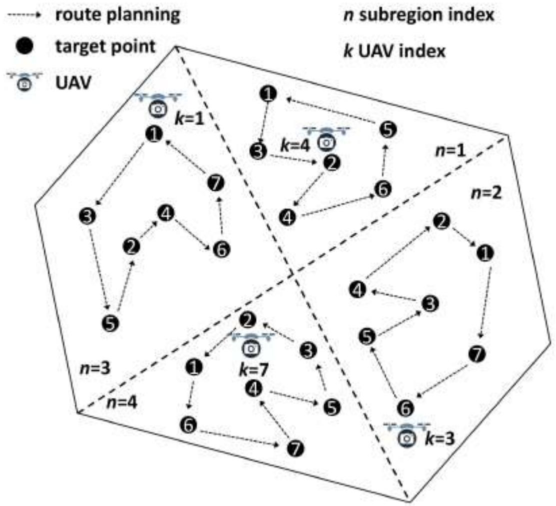


(a) Reliability (b) Preference

Yang S, Han K, Zheng Z, et al. Towards personalized task matching in mobile crowdsensing via fine-grained user profiling. IEEE INFOCOM 2018, pp:2411-2419.

IEEE TCOM 2018 **UAV-aided MCS**

It investigates the joint task assignment and route planning problem in UAV-aided MCS systems from an energy efficiency perspective.



Zhou Z, Feng J, Gu B, et al. When Mobile Crowd Sensing Meets UAV: Energy-Efficient Task Assignment and Route Planning. IEEE Transactions on Communications, 2018, 66(11): 5526-5538.

MCS Key Technologies

Incentive Mechanism

IEEE/ACM ToN 2016 **Online Mechanism**

A more realistic scenario where users arrive one by one online in a random order.

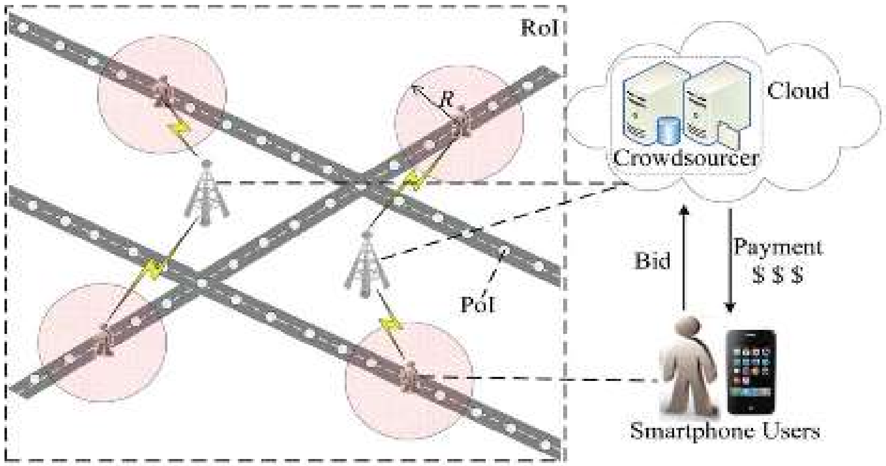


Fig. 1. Illustration of a mobile crowd sensing system.

D. Zhao, X. Y. Li and H. Ma, "Budget-Feasible Online Incentive Mechanisms for Crowdsourcing Tasks Truthfully," in IEEE/ACM Trans Networking, vol. 24, no. 2, pp. 647-661, April 2016.

IEEE INFOCOM 2016 **Network Effect**

An incentive mechanism is proposed which considers the interaction and relationship between the individual behavior of participants and the behavior of other participants. It brings intrinsic rewards into the spotlight, with a focus on how network effects affect the mechanism design when a crowdsourcer provides extrinsic rewards to incentivize crowdsourcing systems.

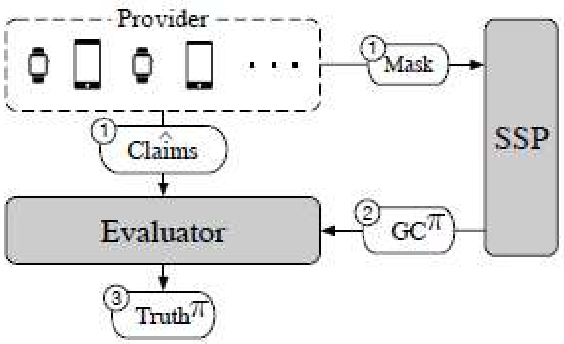
Y. Chen, B. Li, and Q. Zhang, "Incentivizing Crowdsourcing Systems with Network Effects," in IEEE INFOCOM 2016, pp:1-9.

MCS Key Technologies

Privacy Protection

IEEE INFOCOM 2018
Non-Interactive PPTD system

It designs a non-interactive system that removes the online requirement with strong privacy guarantees. It does not reveal any intermediate results, and further supports “late-join” providers without protocol suspension/restart.



Tang X, Wang C, Yuan X, et al. Non-interactive privacy-preserving truth discovery in crowd sensing applications. IEEE INFOCOM 2018, pp: 1988-1996.

IEEE TMC 2018
Personalized Privacy-Preserving

It provides personalized location privacy protection that each worker uploads the obfuscated distances and personal privacy level to the server instead of its true locations or distances to tasks.

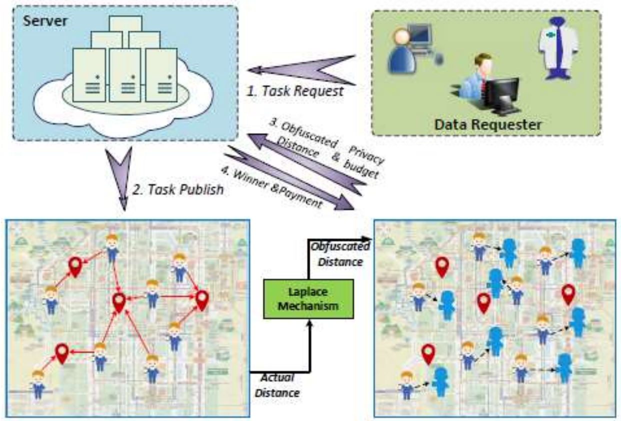


Fig. 1. The proposed framework of personalized privacy-preserving task allocation in mobile crowdsensing with obfuscated distance.

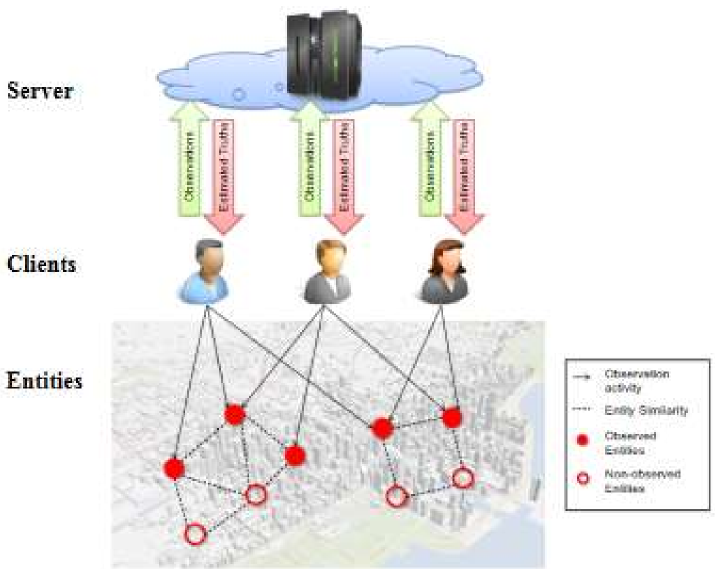
Lin J, Yang D, Li M, et al. Frameworks for privacy-preserving mobile crowdsensing incentive mechanisms. IEEE Transactions on Mobile Computing, 2018, 17(8): 1851-1864.

MCS Key Technologies

Truth Discovery

ACM SenSys 2016 RST

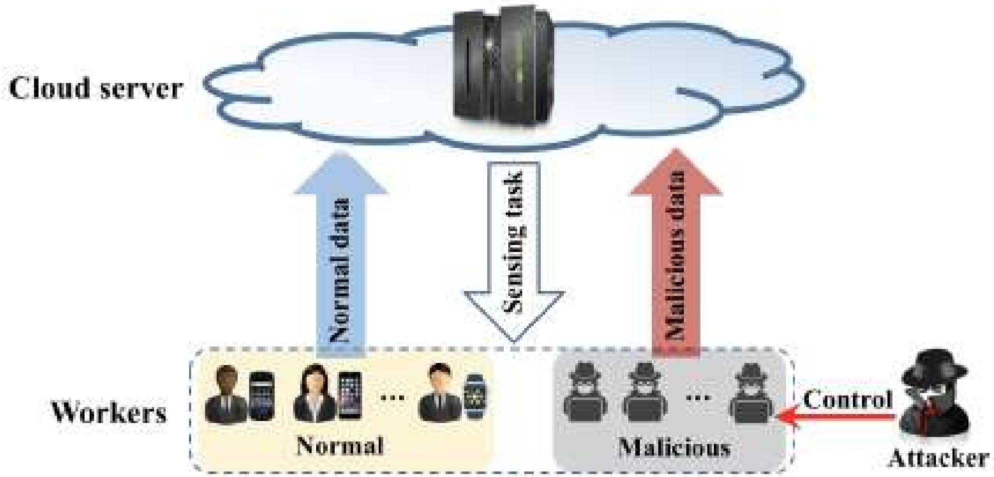
It develops a framework called “**Redundancy and Sparsity Tackling (RST)**” to estimate the true values of entities from redundant and sparse data.



ACM MobiHoc 2018

An optimal attack framework

The attacker can not only maximize his attack utility but also disguise the introduced malicious workers as normal ones such that they cannot be detected easily.

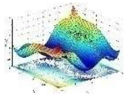


C. Meng, H. Xiao, L. Su and Y. Cheng, "Tackling the Redundancy and Sparsity in Crowd Sensing Applications," in ACM Sensys 2016, pp:150-163.

Miao C, Li Q, Xiao H, et al. Towards Data Poisoning Attacks in Crowd Sensing Systems. ACM MobiHoc 2018, pp: 111-120.

My Research

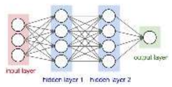
MCS for Smart Cities



Optimization

Participant Selection

Unmanned Vehicle Scheduling



Deep learning

Quality of Information
Data Collection Ratio, Energy

1. Participant Selection (1/2)

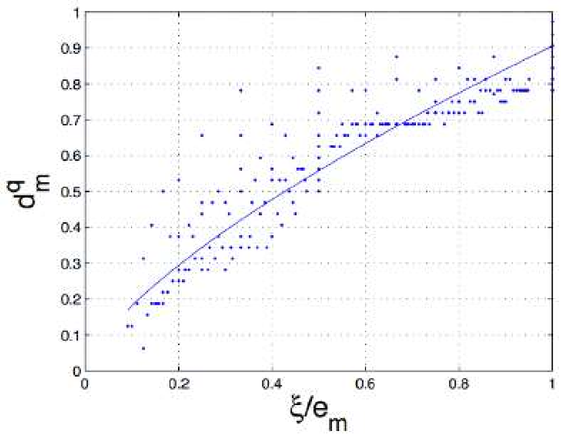
Challenge: Select minimum participants to ensure QoI, minimize energy consumption and satisfy user incentive requirements

> Data quality satisfaction index:

$$u^q(\mathcal{X}) = 1 - \frac{||R^q - O^q(\mathcal{X})||_F}{||R^q||_F}$$

> Energy consumption index:

$$d^q_m \triangleq k\left(\frac{\xi^q}{e_m}\right)^\tau \in [0,1]$$



Questionnaire to find out the parameter

Contributions:

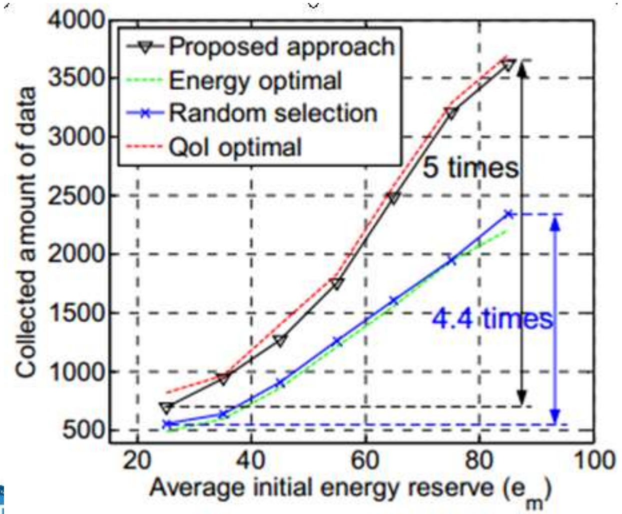
- Proposed a Gur Game based selection method
- Results confirm that **4~5 times** more collected data

Goal: maximize data quality satisfaction ratio & minimizing energy usage.

$$\text{Maximize:} \quad u^q(\mathcal{X}) = 1 - \frac{||R^q - O^q(\mathcal{X})||_F}{||R^q||_F},$$

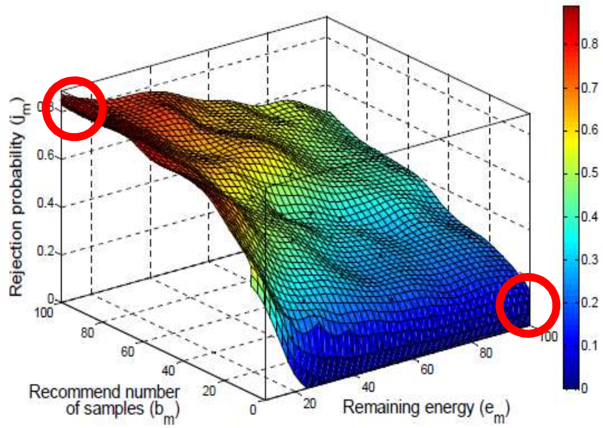
$$\text{Minimize:} \quad \overline{d^q}(\mathcal{X}) = \frac{1}{M}\sum_{\forall m \in \mathcal{X}} \left(k\frac{\xi^q}{e_m}\right)^\tau,$$

$$\text{subject to:} \quad \mathcal{X} \subseteq \mathcal{M}.$$



1. Participant Selection (2/2)

Challenge: overcome human unpredictable behaviors



Questionnaire to study relation between behaviors and energy

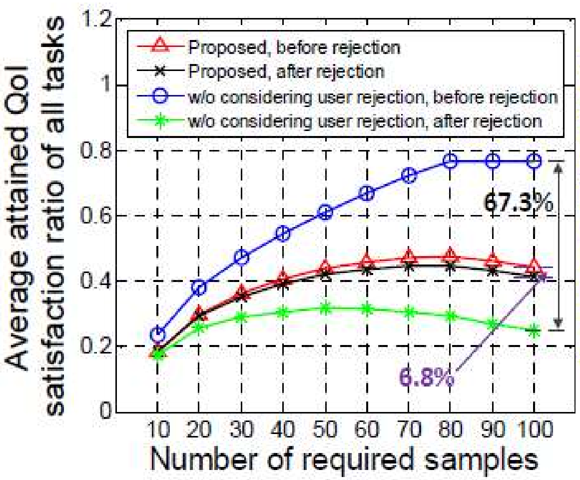
Goal: find optimal set of participants, given data quality and budget constraints

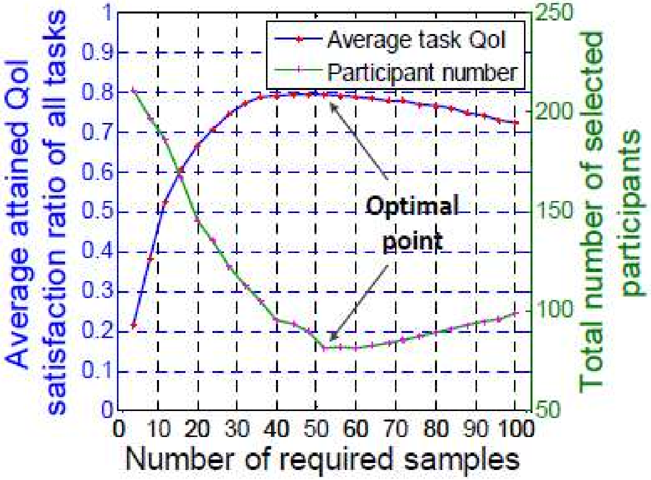
$$\text{Maximize: } u^q(\mathcal{X}) = \frac{\sum_{\forall l\in\mathcal{L}_q, t\in\mathcal{T}_q} u^q_{lt}}{\mathcal{L}_q\mathcal{T}_q}, \quad \forall q \in \mathcal{Q}$$

$$\text{subject to: } \sum_{\forall m\in\mathcal{X}} d_m \le C, \quad \mathcal{X} \subseteq \mathcal{M},$$

Contributions:

- Quantified human behaviors w.r.t. energy consumption, and data contribution
- Improved data quality by **67.3%**





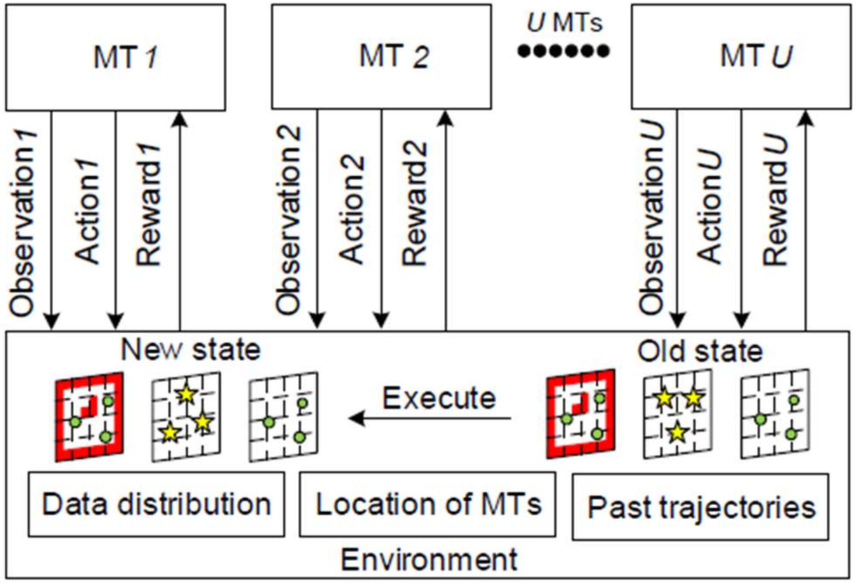
2. Unmanned Vehicle Scheduling

Challenge: MCS with energy constrained unmanned vehicles

Goal: max data collection ratio & geographical fairness
s.t. energy and sensing capability

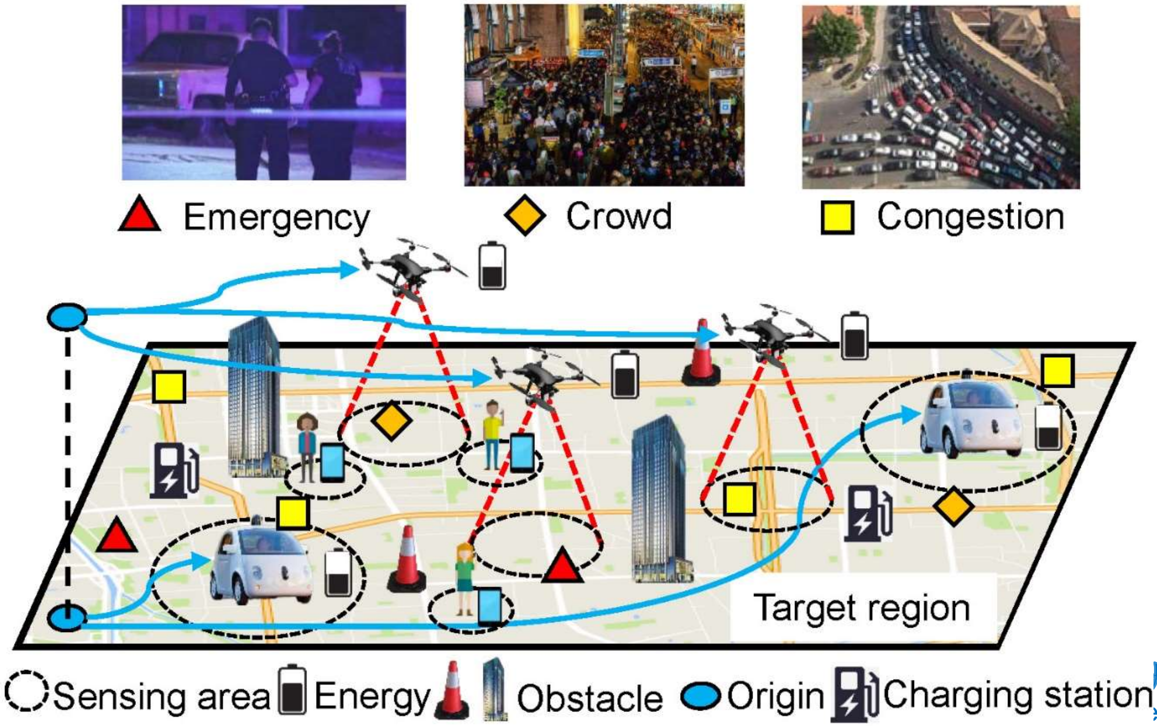
Contributions:

- First to apply deep learning on MCS
- Proposed a new deep model for each vehicle
- Improved DeepMind NIPS'17 model by:
  - Spatiotemporal modelling
  - Prioritized and Recurrent Experience Replay Buffer
  - Decentralized training frameworking



Conclusion

- Next generation of smart cities is powered by MCS data collection, with a **mixture of human and machine intelligence**
- It serves as the fundamental **data source** for many smart city apps



Thanks a lot!

Questions?