Efficient detection of contagious outbreaks in massive metropolitan encounter networks

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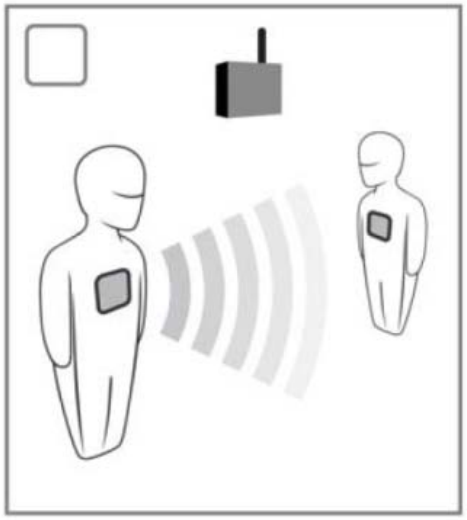
Efficient detection of contagious outbreaks in massive metropolitan encounter networks

Kay W. Axhausen, ETH Zurich

Der-Horng Lee, NUS

Manuel Cebrian, University of Melbourne

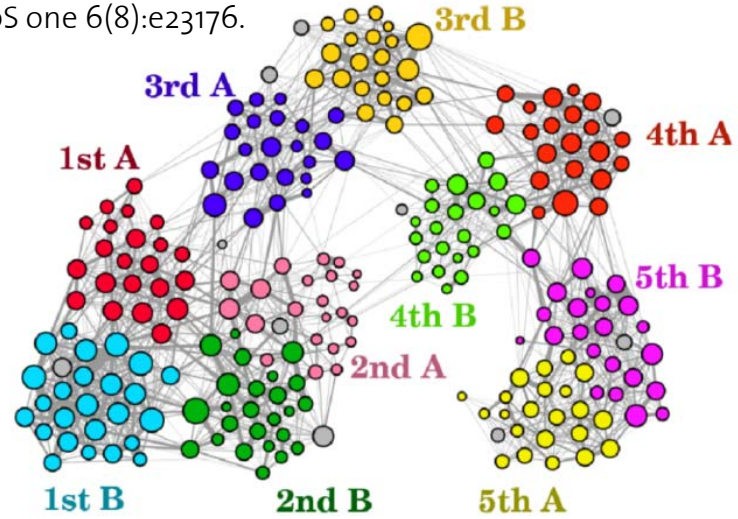
Digital traces for infectious disease



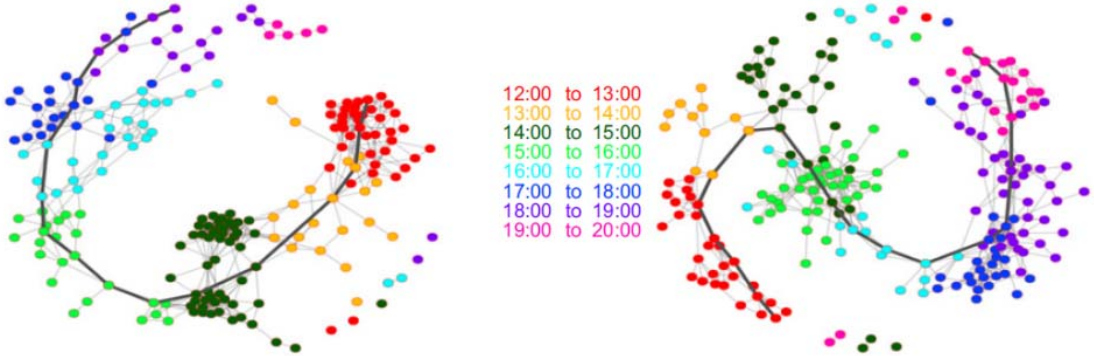
Cattuto C, et al. (2010) Dynamics of person-to-person interactions from distributed RFID sensor networks. PloS One 5(7):e11596.

Bluetooth
RFID
Wi-Fi
Wearable sensors
...Smart phones
Active data collection

Stehlé J, et al. (2011) High-resolution measurements of face-to-face contact patterns in a primary school. PloS one 6(8):e23176.



Isella L, et al. (2011) What's in a crowd? Analysis of face-to-face behavioral networks. J Theor Biol 271(1):166-180.



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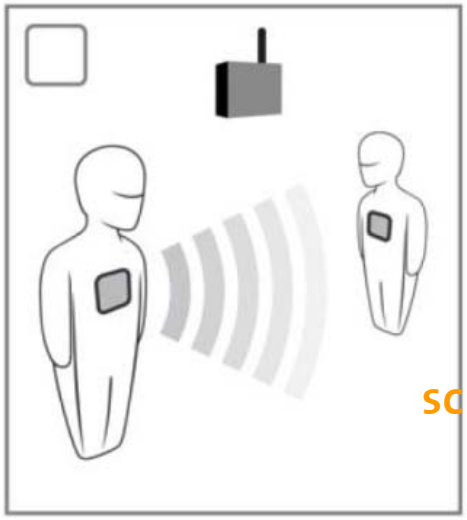

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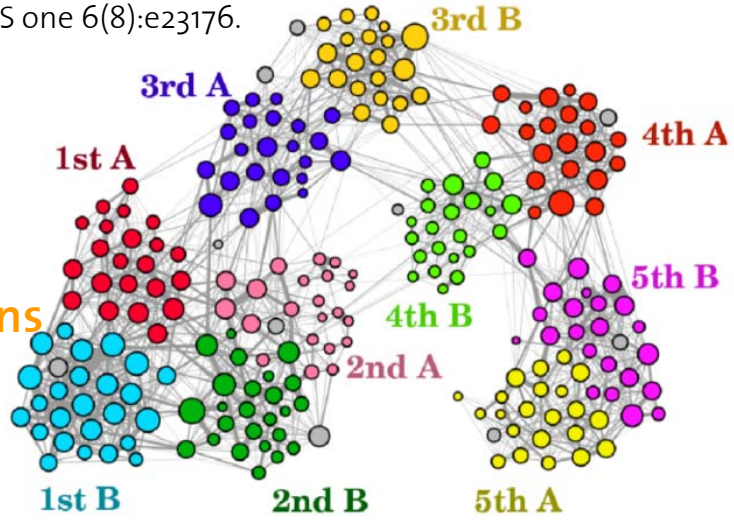
high resolution
high accuracy

limited in scales
schools, conferences, exhibitions

Stehlé J, et al. (2011) High-resolution measurements of face-to-face contact patterns in a primary school. PloS one 6(8):e23176.



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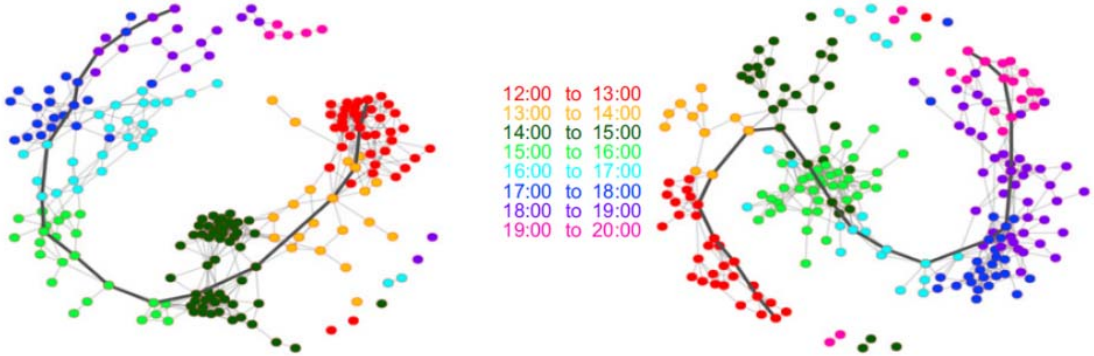


Digital traces for infectious disease

- **It is important to get the contact network structure**

Digital traces for infectious disease

- **It is important to get the contact network structure**

- **Expensive to collect**
- **Laborious in filtering of data**
- **Privacy sensitive**

Digital traces for infectious disease

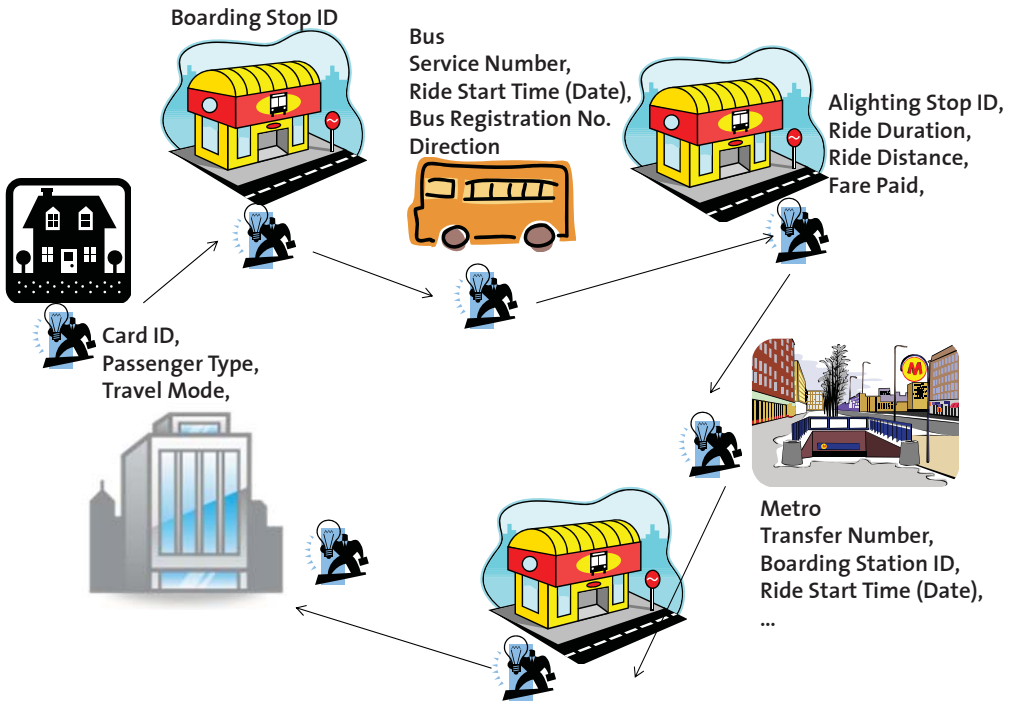
- **It is important to get the contact network structure**
- **Think about data capturing physical proximity**
- **Large-scale long-term time-resolved high-resolution physical proximity data**

Digital traces for infectious disease

- **It is important to get the contact network structure**
- **Think about data capturing physical proximity**

- Public transit smart card
- Ez-link card in Singapore

Digital traces for infectious disease



Digital traces for infectious disease

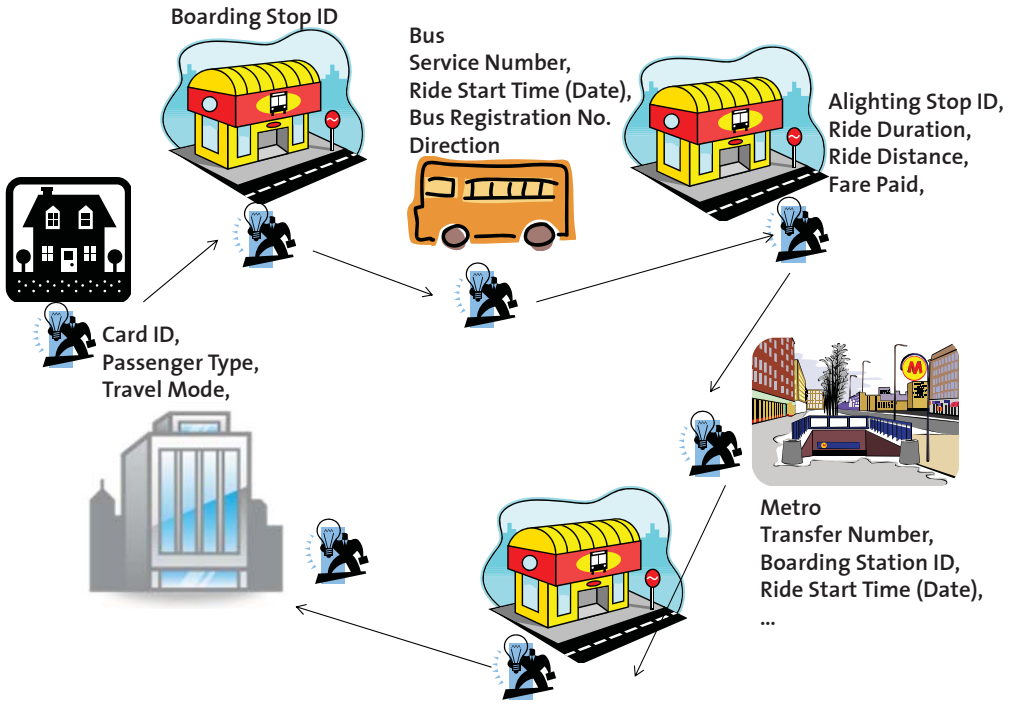
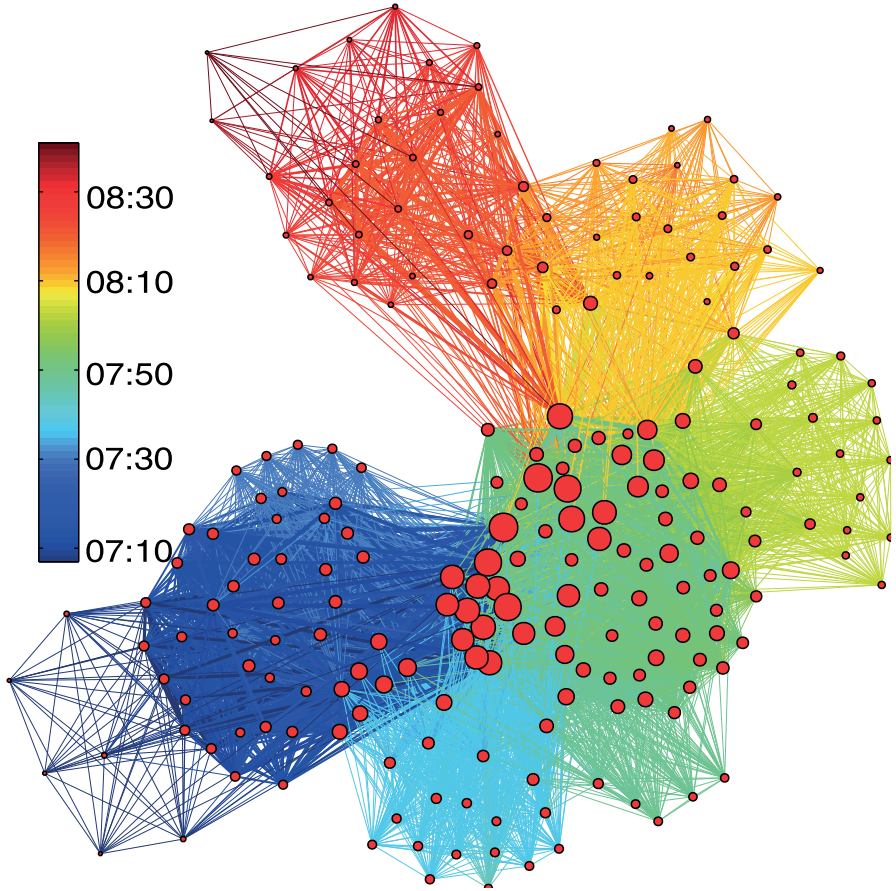


TABLE S1. Fields and contents of trip record dataset

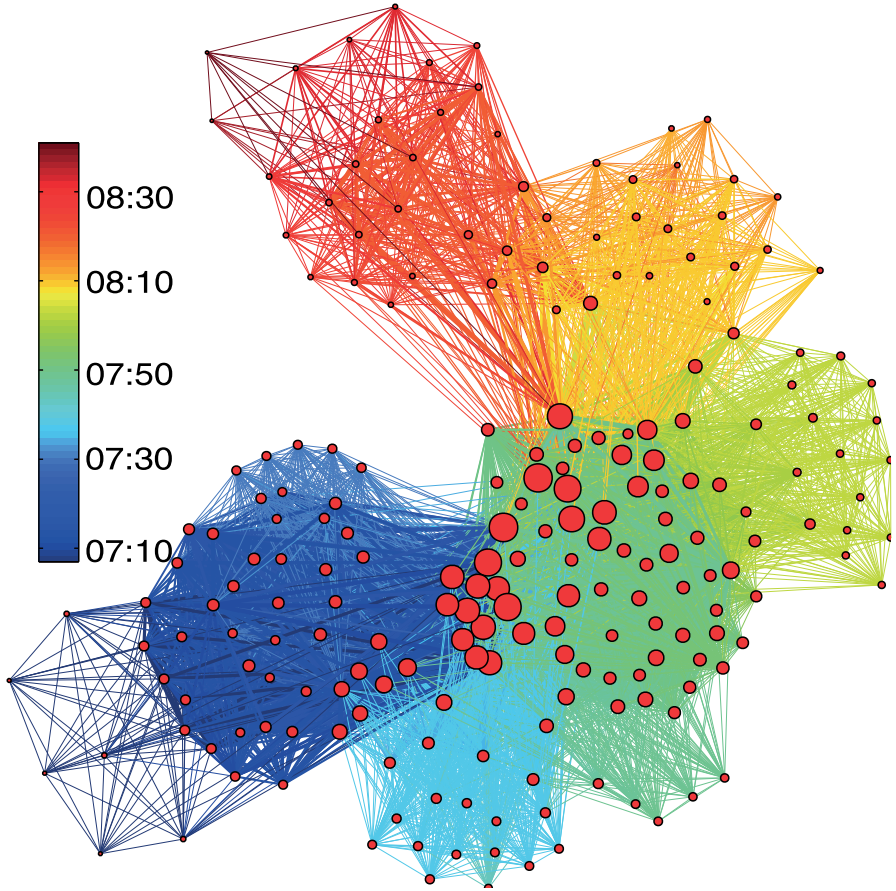
Field	Description
Trip ID	A unique number for each transit trip
Card ID	A unique coded number for each smart card (anonymised)
Passenger Type	The attribute of cardholder (Adult, Senior citizen and Child)
Service Number	Bus route service number (e.g. 96)
Direction	Direction of the bus route (0 and 1)
Bus Registration No.	A unique registration number for each vehicle (e.g. '0999')
Boarding Stop ID	A unique number for boarding stop (e.g. 40009)
Alighting Stop ID	A unique number for alighting stop (e.g. 40009)
Ride Date	Date of a trip (e.g. '2012-03-26')
Ride Start Time	Start (tapping-in) time of a trip (e.g. 08:00:00)
Ride End Time	End (tapping-out) time of a trip (e.g. 08:00:00)
Ride Distance	Distance of the trip (e.g. 12.0 km)

A contact network in high resolution



A contact network in high resolution

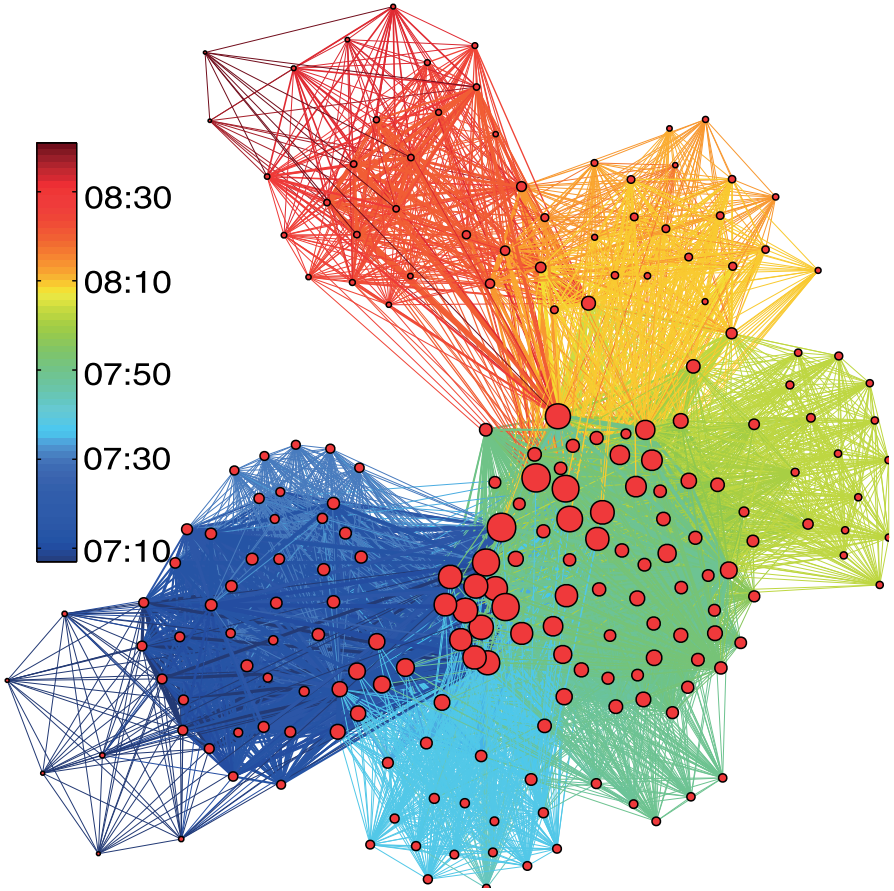
- 3 million users
- 1 week
- 1 billion contacts



A contact network in high resolution

- 3 million users
- 1 week
- 1 billion contacts

- time-resolved (second)
- spatial dimension included

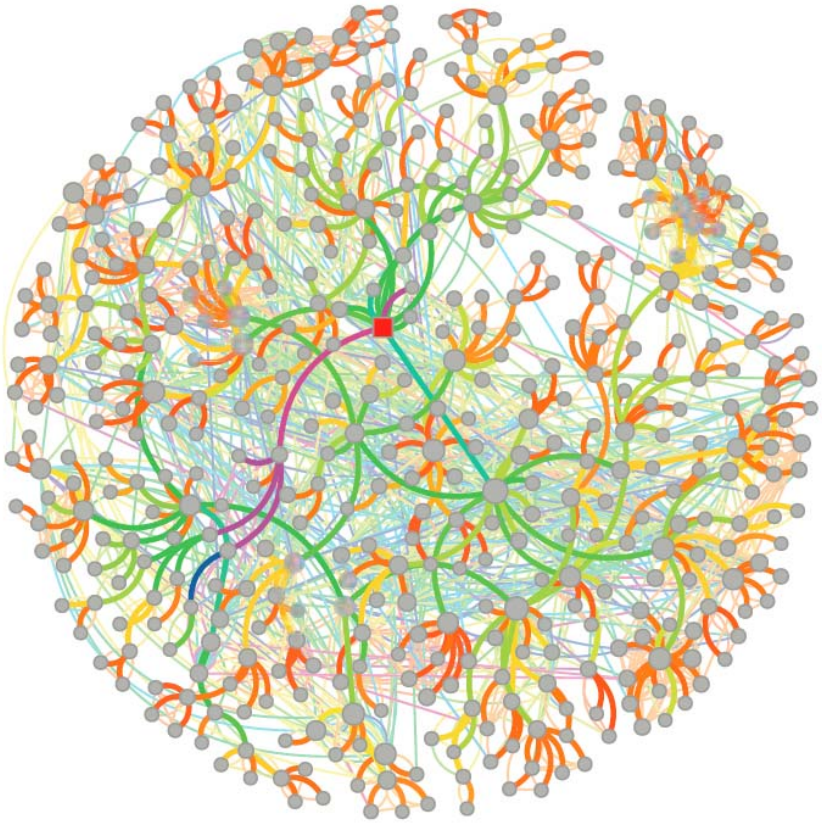


A simple study

- Simulating contagious outbreaks in such a network

A simple study

- Simulating contagious outbreaks in such a network
- SI model with E (for 2 hours)



A simple study

- Simulating contagious outbreaks in such a network
- SI model with E (for 2 hours)

- A simple and effective strategy for early detecting contagious outbreaks without mapping the full contact network structure is to find friend sensors
- Friendship paradox

OPEN ACCESS Freely available online

PLoS one

Social Network Sensors for Early Detection of Contagious Outbreaks

Nicholas A. Christakis[1,2*], **James H. Fowler**[3,4]

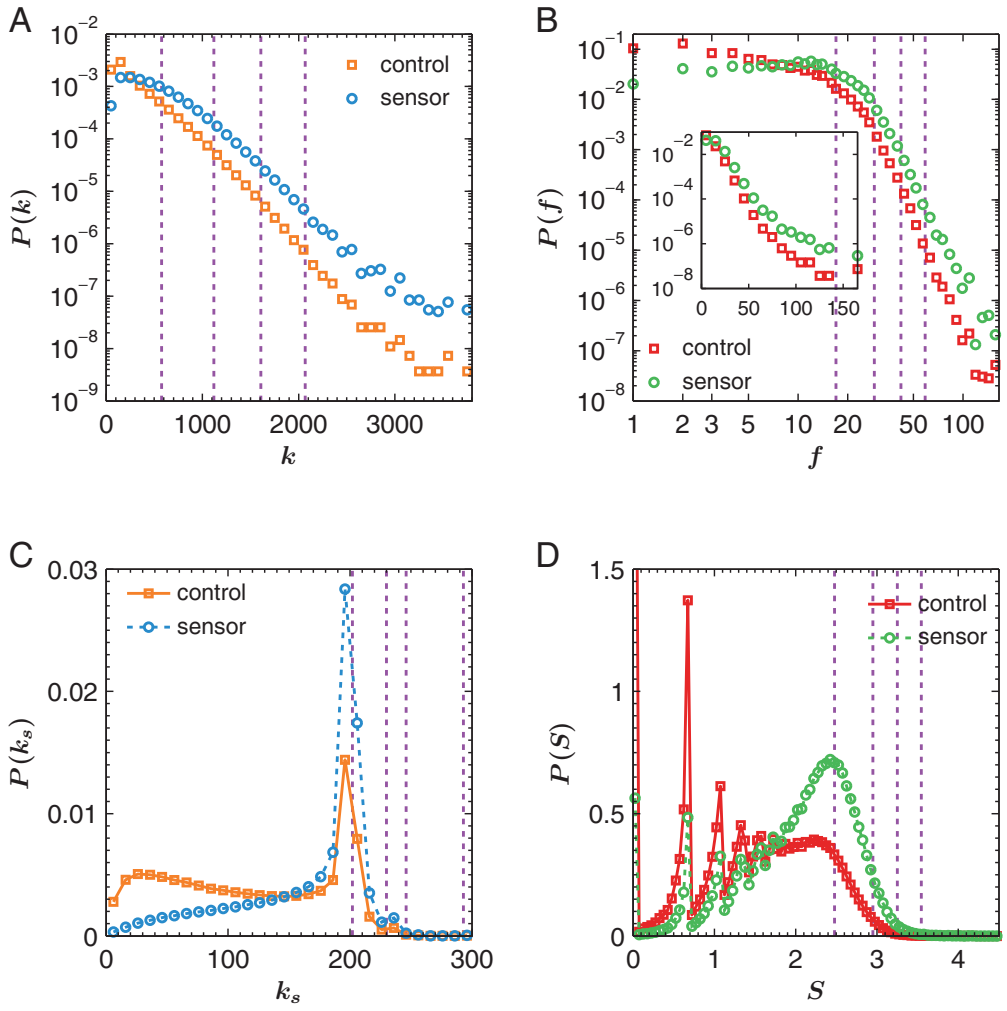
1 Faculty of Arts & Sciences, Harvard University, Boston, Massachusetts, United States of America, **2** Health Care Policy Department, Harvard Medical School, Boston, Massachusetts, United States of America, **3** School of Medicine, University of California San Diego, La Jolla, California, United States of America, **4** Division of Social Sciences, University of California San Diego, La Jolla, California, United States of America

Centrality measures

- Degree (Number of encountered people, k)
- Travel frequency (f)
- k-shell index in the aggregated network (ks)
- Temporal entropy (the hourly distribution of edges, S)

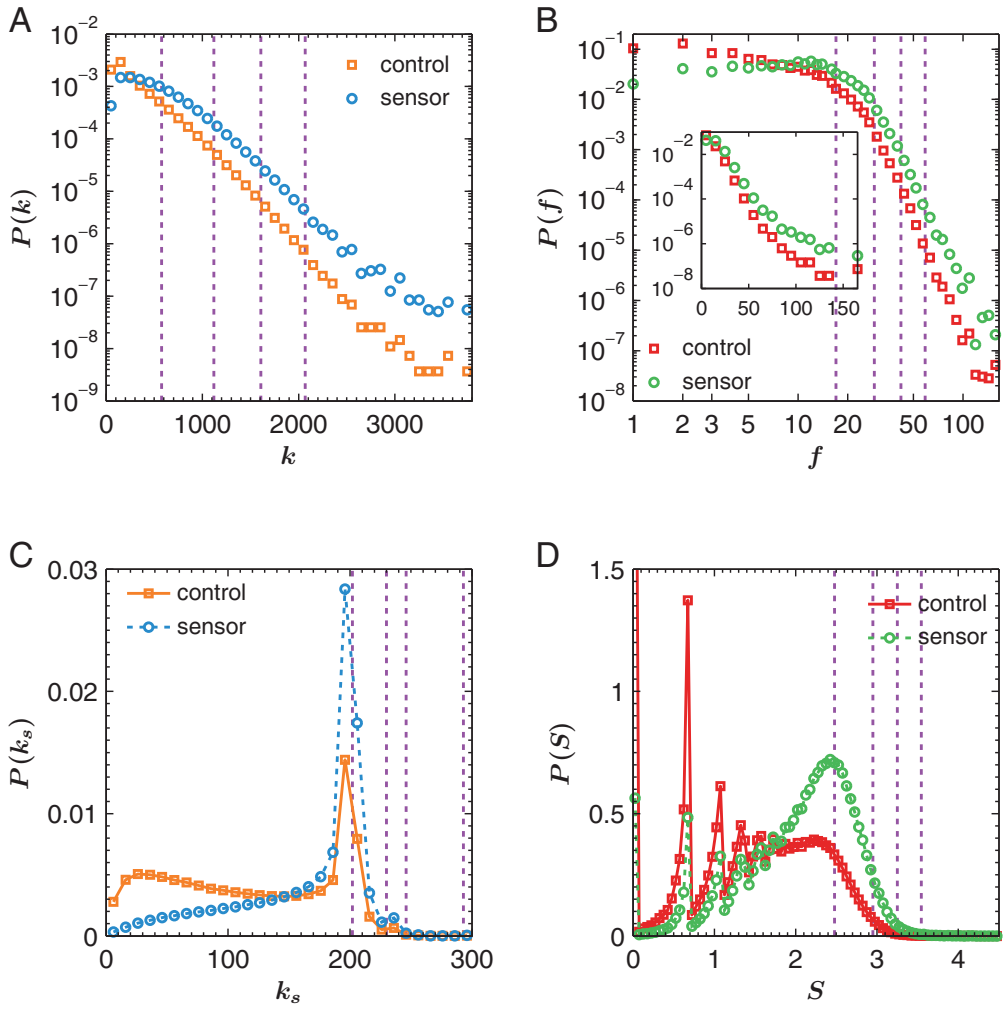
- Correlated measures
- All present friendship paradox

Centrality measures



The dashed lines are 90th, 99th, 99.9th, 99.99th percentiles

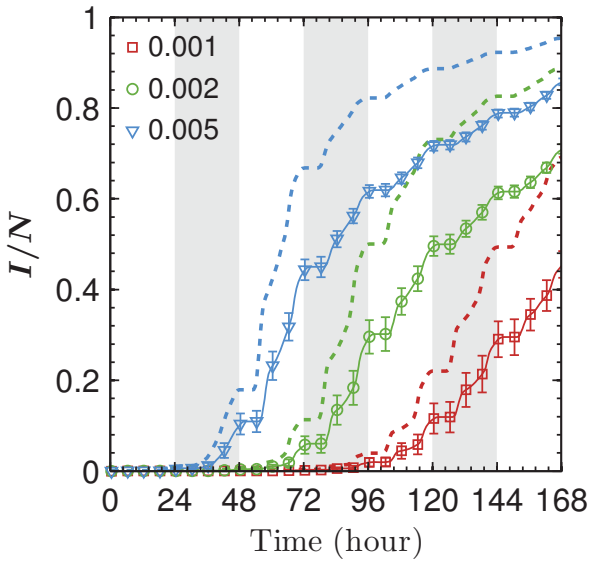
Centrality measures

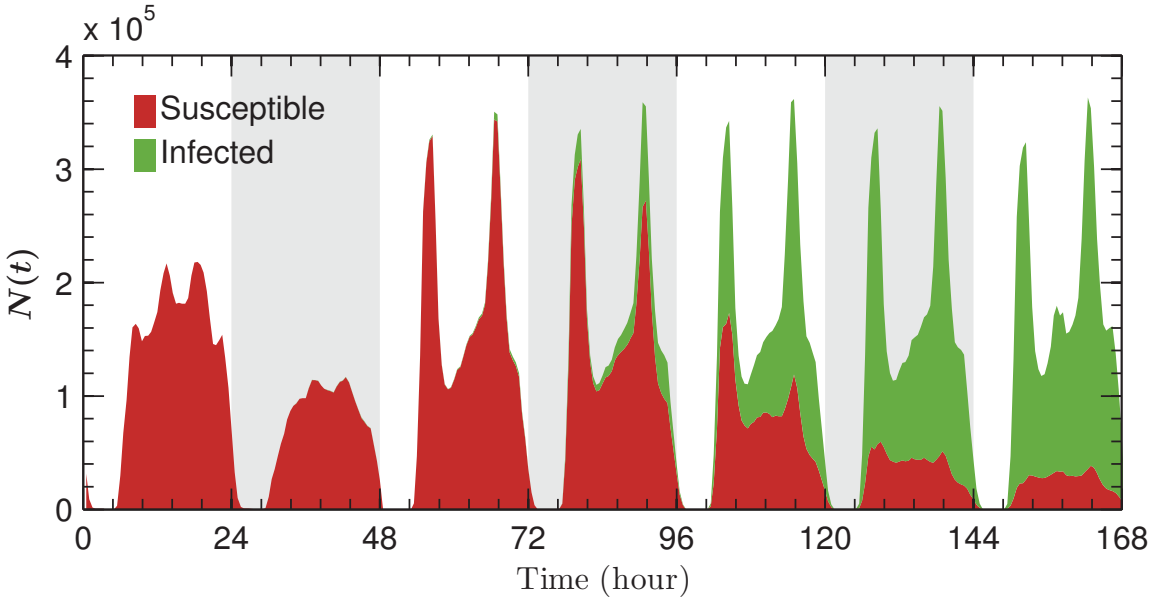


The paradox can be generalized given the correlation in measures.

A simple study

- Simulating contagious outbreaks in such a network
- beta = 0.0015/20 seconds





A simple study

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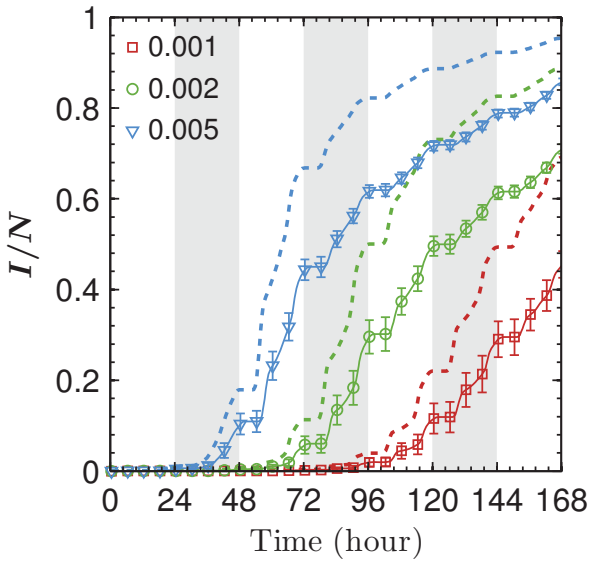
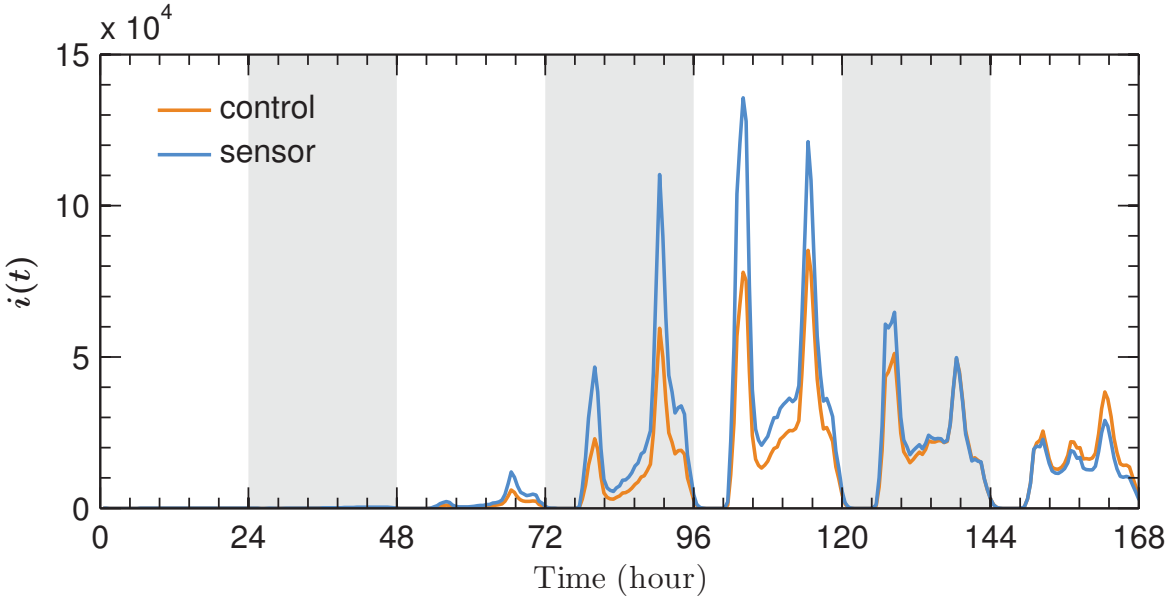
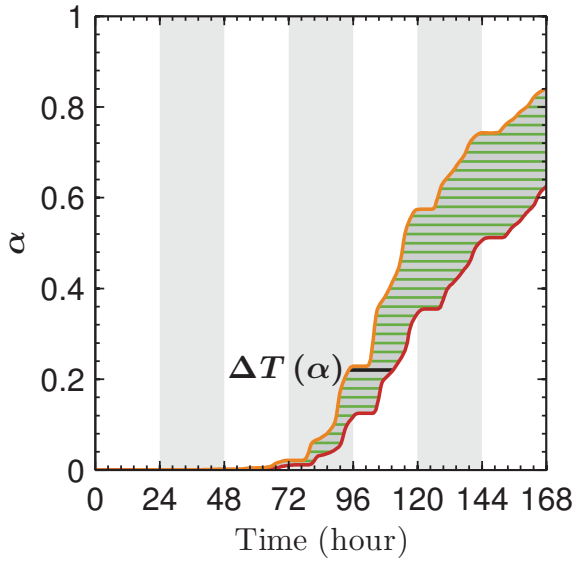




A simple study

- Simulating contagious outbreaks in such a network
- beta = 0.0015/20 seconds

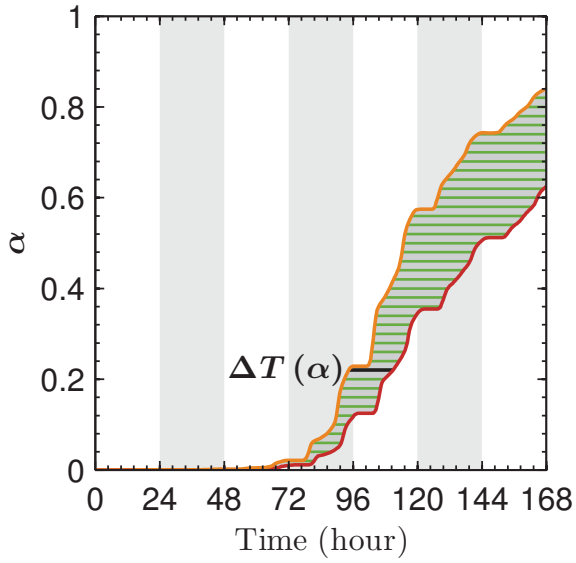
- Lead-time?



A simple study

- Simulating contagious outbreaks in such a network
- beta = 0.0015/20 seconds

- Lead-time?
- Average Delta T for 5%<=alpha<25%



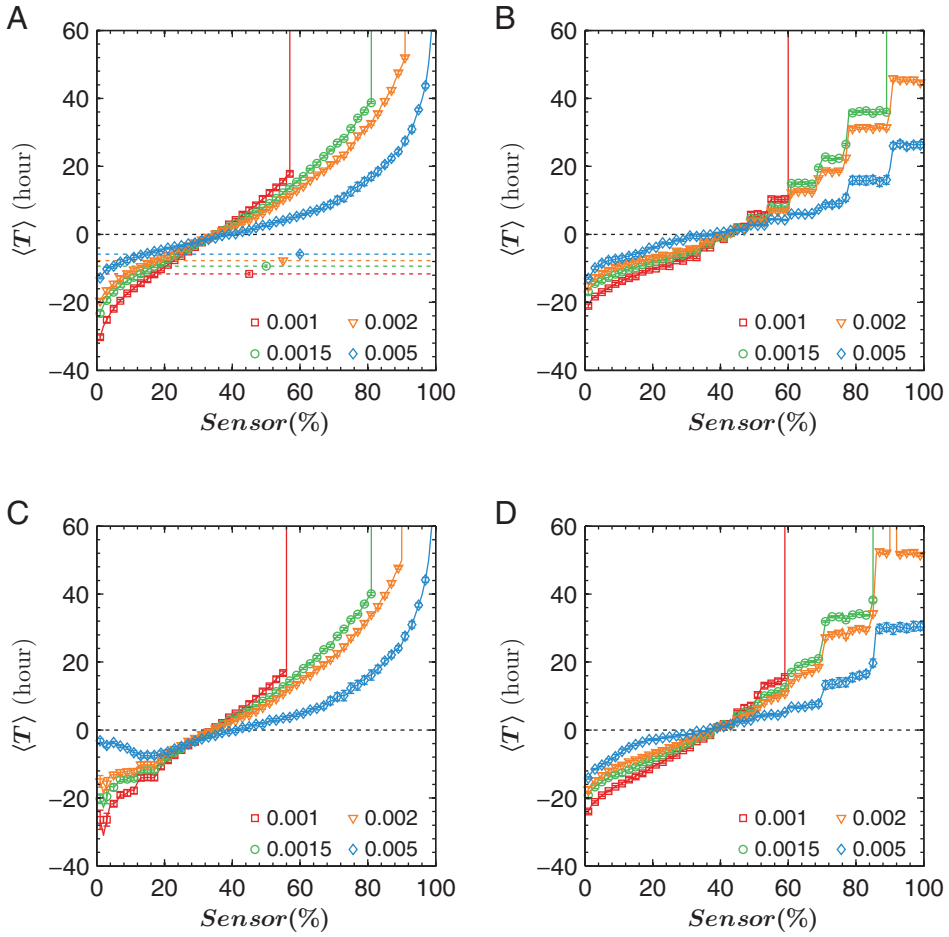
Performance of sensors

- Order individuals using centrality measures and divide the population into 100 slices.

- The performance of friend sensors.

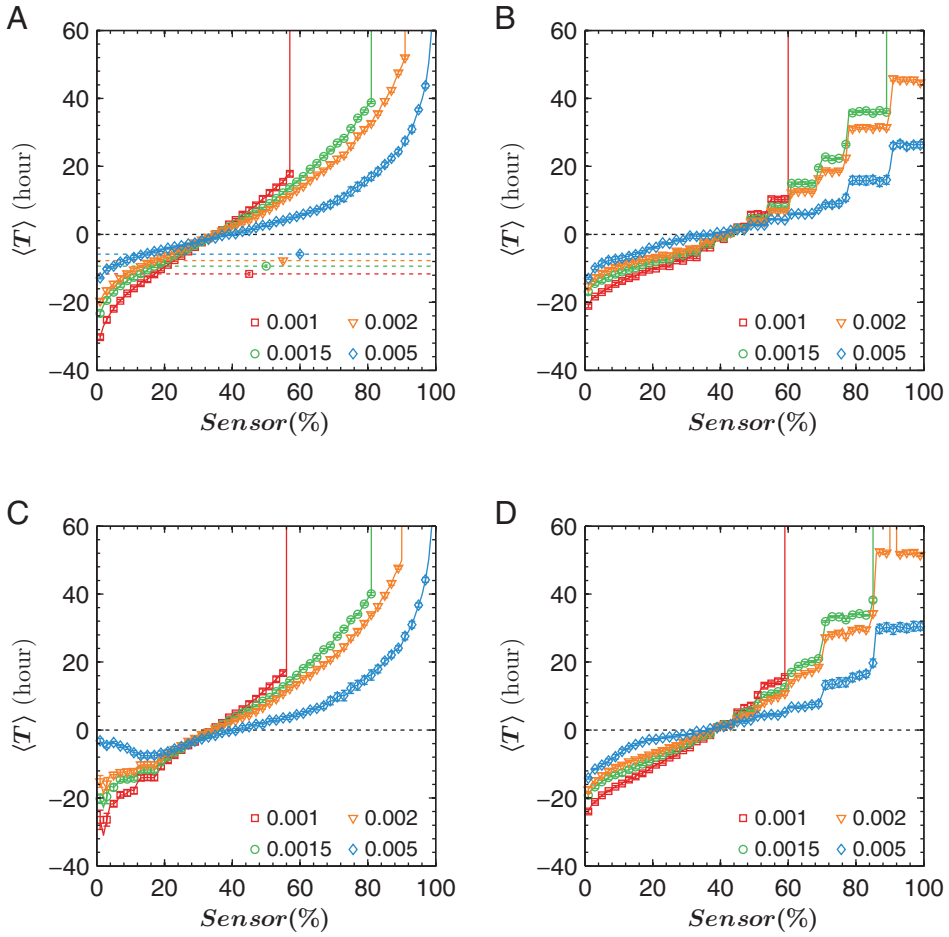
Performance of sensors

- Order individuals using centrality measures and divide the population into 100 slices.



Performance of sensors

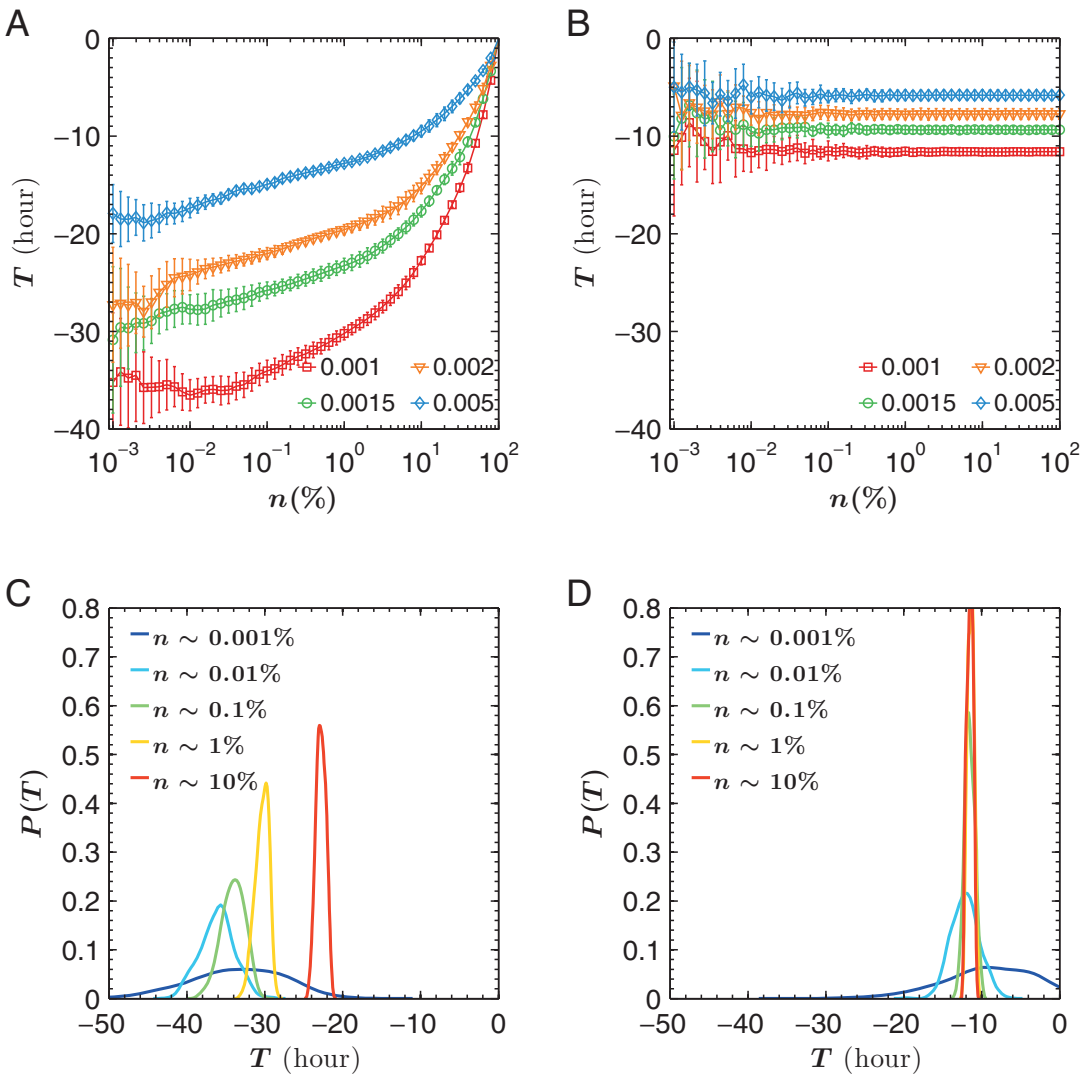
- All top slices provide good warning, (except ks with beta=0.05). Which is better?



Performance of sensors

- Better sensor
- Average lead-time provided
- Sensor size (monitoring cost and efficiency)
- Sensor reliability

Performance of sensors



Discussion

- **Still, the data only covers a small fraction of daily-life**
- **Bias of such encounters:** Such encounters on transit vehicles occur more often between perfect strangers than among friends, colleagues or families, making the network incomplete for predicting epidemic spreading via all possible transmission pathways.
- **No shortest path based centrality measures used**
- **SIR / SEIR models**

Conclusion

- Using transit data to build a time-resolved physical proximity network
- Friendship paradox can be generalized in correlated centrality measures
- We examine the friendship paradox in SI spreading
- The simple centrality --- degree, can provide sensors which provide substantial and reliable lead-time, but only cover 0.01% of the population.
- **arxiv:1401.2815**

Thank you!

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Appendix