



it ▪ Campus ▪ Pioneering ▪ Research ▪ Technologies ▪ Markets ▪ Social Developments ▪ Visions ▪ Future ▪ Design ▪ Seamless Home Environment ▪ Expertise ▪ amless Home Environment ▪ Expertise ▪ Crystallization ▪ Innovation ▪ Development ▪ Processes ▪ BroadWave ▪ Communications ▪ Industrial Partners ▪ Berlin ▪ cations ▪ Industrial Partners ▪ Berlin ▪ Markets ▪ Innovation ▪ Berlin ▪ Universities ▪ Strategy ▪ Market ▪ Trends ▪ Portfolio ▪ Broadband ▪ Virtual City Guide ▪ olio ▪ Broadband ▪ Virtual City Guide ▪ Pervasive Communications ▪ Intuitive Usability ▪ AAA Architecture ▪ Intelligent Access ▪ Inherent Security ▪ Infrastructure cess ▪ Inherent Security ▪ Infrastructure Development ▪ Industry Partners ▪ Information ▪ Scientists ▪ Market Trends ▪ Contextual Information to Go ▪ Entrepreneurs tual Information to Go ▪ Entrepreneurs ▪ Campus ▪ Pioneering ▪ Research ▪ NetShield ▪ Markets ▪ Experts ▪ Visions ▪ Future ▪ Design ▪ Know-how ▪ Expertise ▪ re ▪ Design ▪ Know-how ▪ Expertise ▪ Innovation ▪ Development ▪ Processes ▪ Industry ▪ Communications ▪ Mobile Tracking Device ▪ Berlin ▪ Laboratories ▪ acking Device ▪ Berlin ▪ Laboratories ▪ Research ▪ Innovation ▪ Media Provisioning ▪ Laboratory ▪ Innovation ▪ Customers ▪ Market ▪ Trends ▪ Community-enabling ▪ Market ▪ Trends ▪ Community-enabling Services ▪ Broadband Wireless Access ▪ Pervasive Communications ▪ Intuitive Usability ▪ Integrated Communication ▪ Intelligent ▪ Integrated Communication ▪ Intelligent Access ▪ Personal Intelligent User Interfaces ▪ Network ▪ Information ▪ Gesture-based Real-time Animated Avatars ▪ Market sed Real-time Animated Avatars ▪ Market Trends ▪ New Business ▪ Speech-based Classification ▪ Campus ▪ Pioneering ▪ Research ▪ Technologies ▪ Markets ▪ Affective rch ▪ Technologies ▪ Markets ▪ Affective Interfaces ▪ New Business ▪ Future ▪ Design ▪ Know-how ▪ Expertise ▪ Sensor Nets ▪ Innovation ▪ Processes ▪ Technologies ▪ Innovation ▪ Processes ▪ Technologies ▪ Communications ▪ Berlin ▪ Laboratories ▪ Projects ▪ Innovation ▪ Development ▪ Laboratory ▪ Quality ▪ Strategy ▪ Communications ▪ Berlin ▪ Laboratories ▪ Projects ▪ Innovation ▪ Development ▪ Laboratory ▪ Quality ▪ Strategy ▪ Continuous Sound for Interaction ▪ Trends ▪ Portfolio ▪ Broadband ▪ Creative Potential ▪ Pervasive Communications ▪ Intuitive

Empirical Evaluation of Hybrid Opportunistic

Pan Hui Deutsche Telekom Laboratories

Joint work with Anders Lindgren and Jon Crowcroft
(University of Cambridge)

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Introduction

- Two trends observed
 - Lots of work done on opportunistic networking/DTN
 - Coverage of WiFi and similar technologies increasing
 - So what's the point of opportunistic networks???
 - We have infrastructure!
 - Installing a wired base station costs as high as US\$5,000!(Jupiter Research)

■ Can opportunistic communication and
infrastructure networks complement each

Introduction (2)

- Under which conditions is opportunistic communication necessary or useful for network operation?
 - Different levels of participation among mobile nodes.
- How is the performance of opportunistic networks improved by the addition of partial infrastructure?



Application Scenarios

- Asynchronous Messaging
 - Peer-to-peer exchange of messages between mobile nodes
 - Direct contact, opportunistic forwarding, infrastructure support
- Data Push
 - Data delivery service (e.g. email delivery)
 - Messages generated at infrastructure
 - Delivered directly to destination upon contact with infrastructure, or with opportunistic forwarding.....

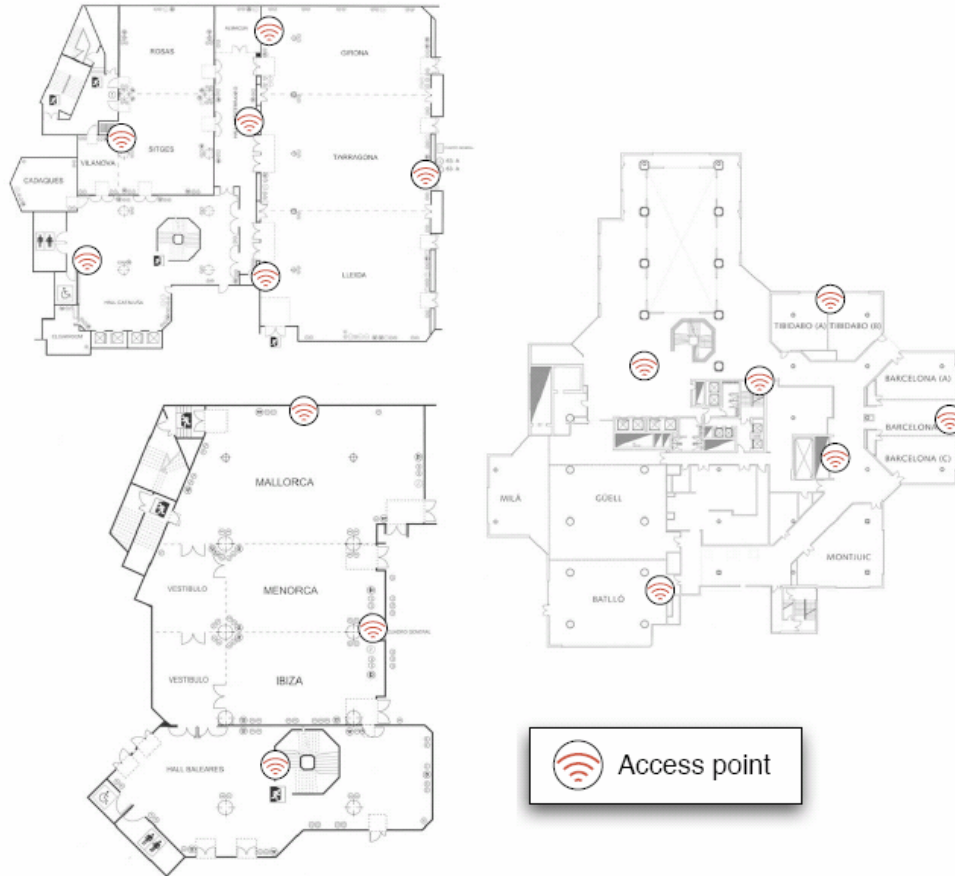
Datasets

Experimental Dataset	Infocom06	Reality	Kaist
Device	iMote	Phone	Phone
Network Type	Bluetooth	Bluetooth	GPS
Duration (days)	3	21	0.33
Granularity (seconds)	120	300	10
Number of experimental	98	97	92
Number of internal	191,336	11,962	40,218
Average no. of contacts/pair/day	6.7	0.061	14.412

- Infocom06, MIT Reality Mining, NCSU Kaist
- 9 months for Reality



Access point placement (1)



- Infocom06
- Conference reception desk, conference rooms, hotel concierge, hotel bar, the lifts of the hotel



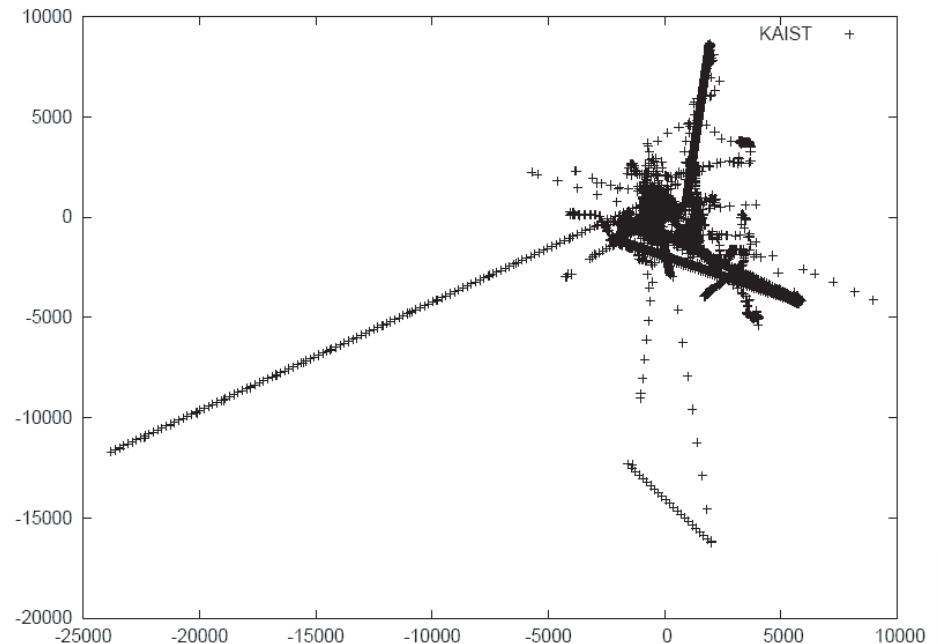
Access point placement (2)

- Reality Mining
- Cellular tower logs
- In total 31,545
- Top 253 mostly accessed towers (the cell towers that have at
- least 100 contacts with mobile nodes logged)
- Mimic APs



Access point placement (3)

- Kaist
- GPS receivers take readings every 10 seconds
- Position accuracy < 3 meters for 95 percent of the time
- No physical deployment of wireless Aps
- Select area with most of the mobilities : (-5000, -5000) to (5000, 5000)
- Uniformly deploy virtual APs wi



Simulations

- HuggleSim
- Trace driven simulator
- Forwarding schemes
 - Opportunistic flooding (epidemic)
 - Opportunistic MCP (Movie-Cricket-Politics☺?)
 - Only APs
- Metrics
 - Throughput, given TTL
 - Utility
 - $U(O) = \frac{T(O + I) - T(I)}{T(O + I)}$

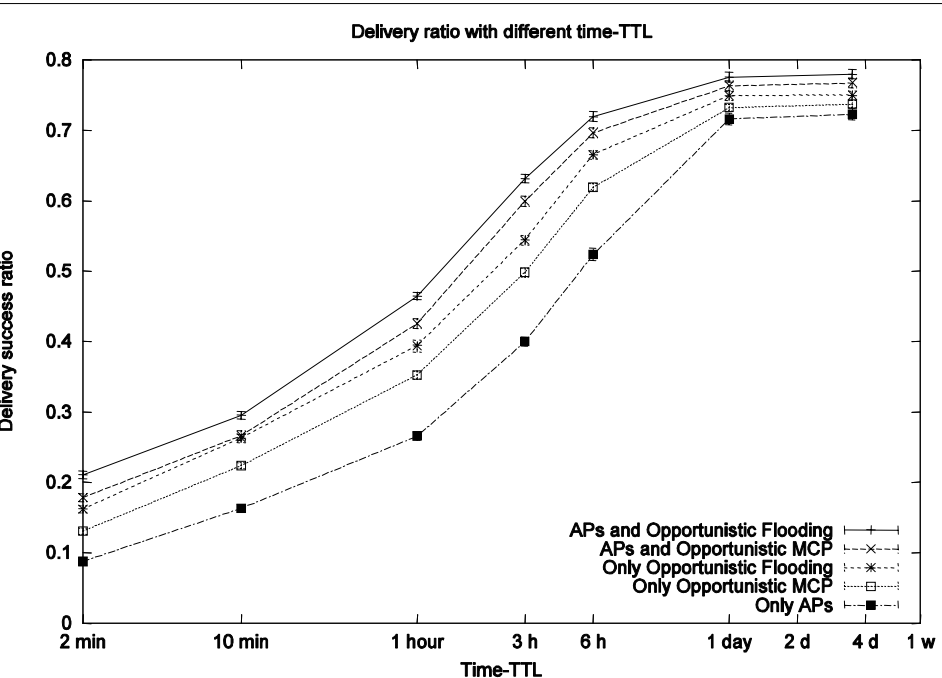


Results and Evaluations

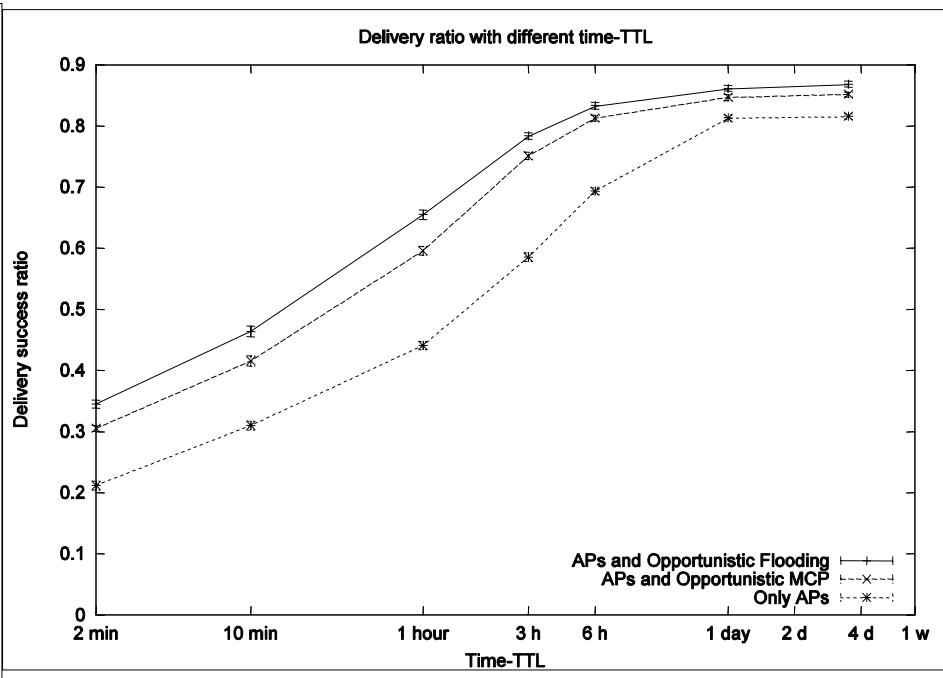
- Delivery ratio
- Utilities of opportunistic network
- Utilities of APs



Delivery - Infocom06 Dataset



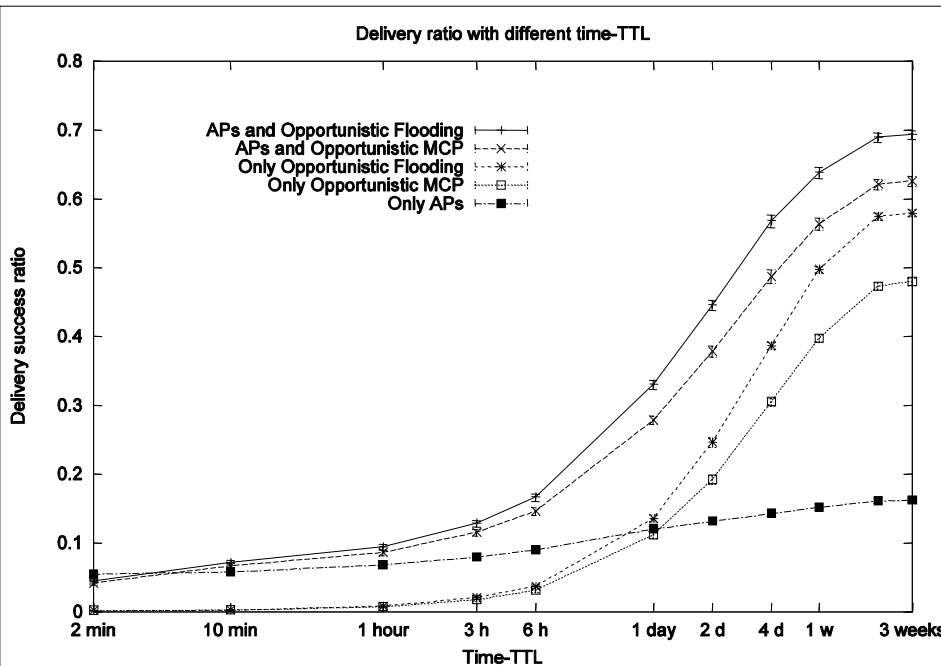
Asynchronous
Messaging



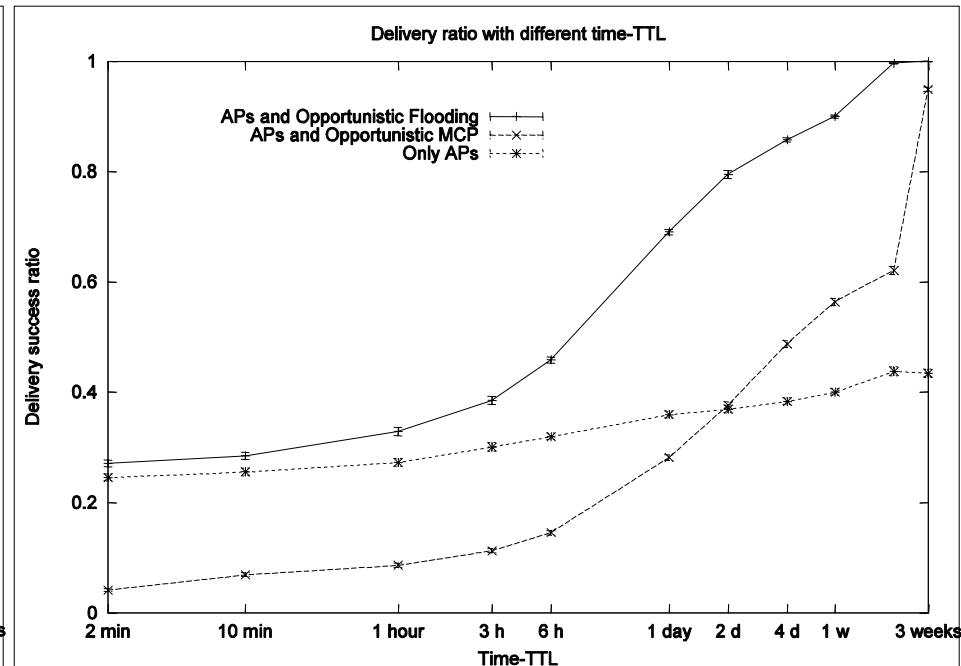
Data
Push



Delivery - Reality Dataset



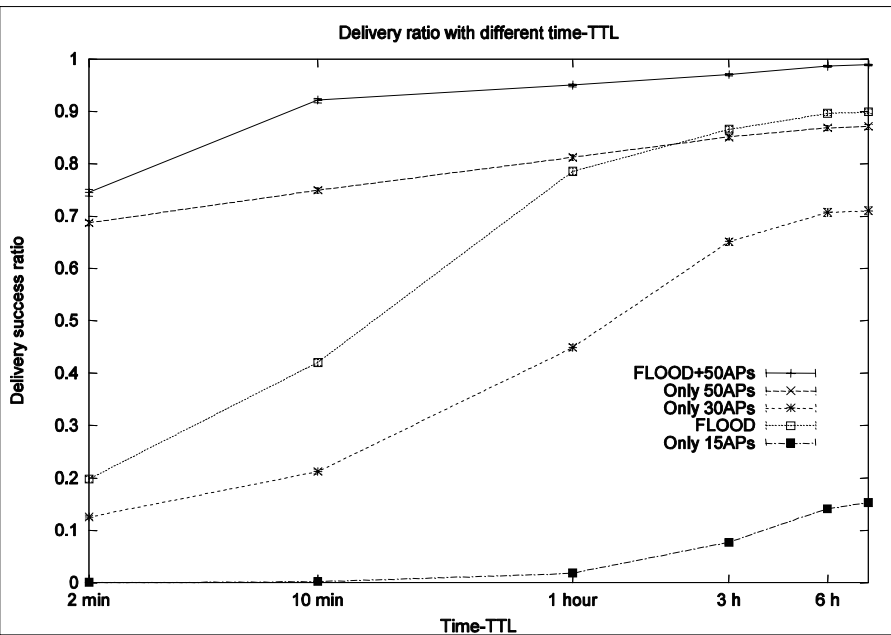
Asynchronous Messaging



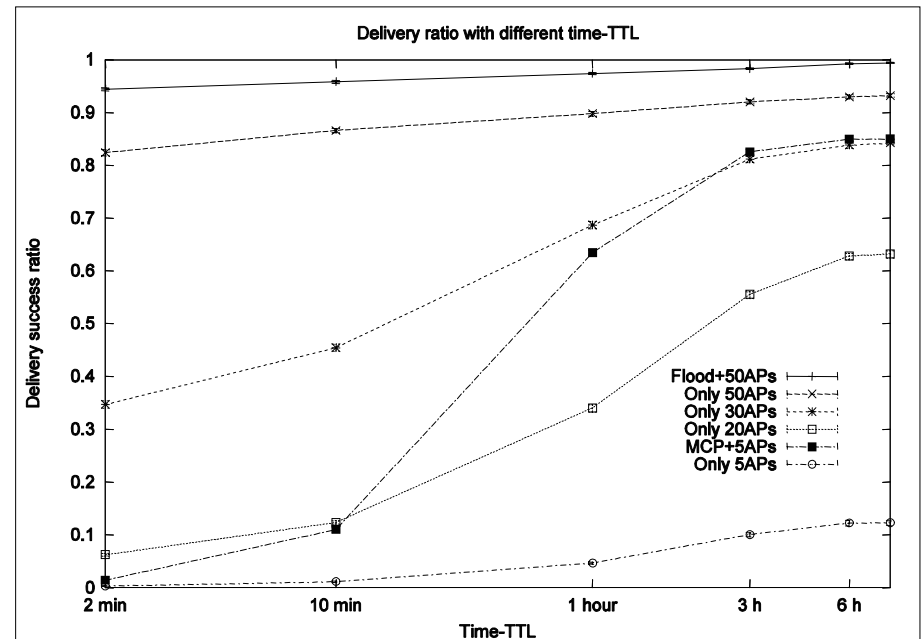
Data Push



Delivery - Kaist Dataset



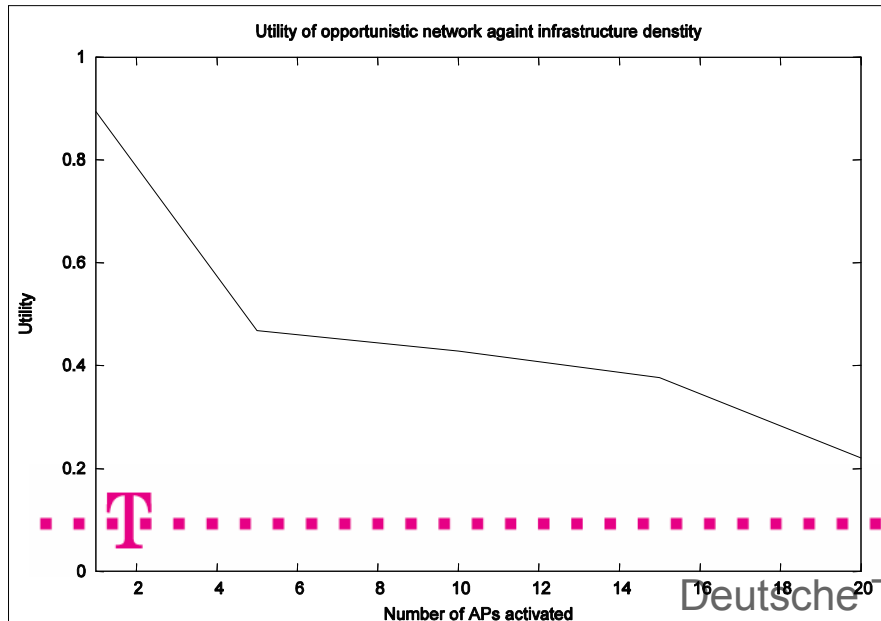
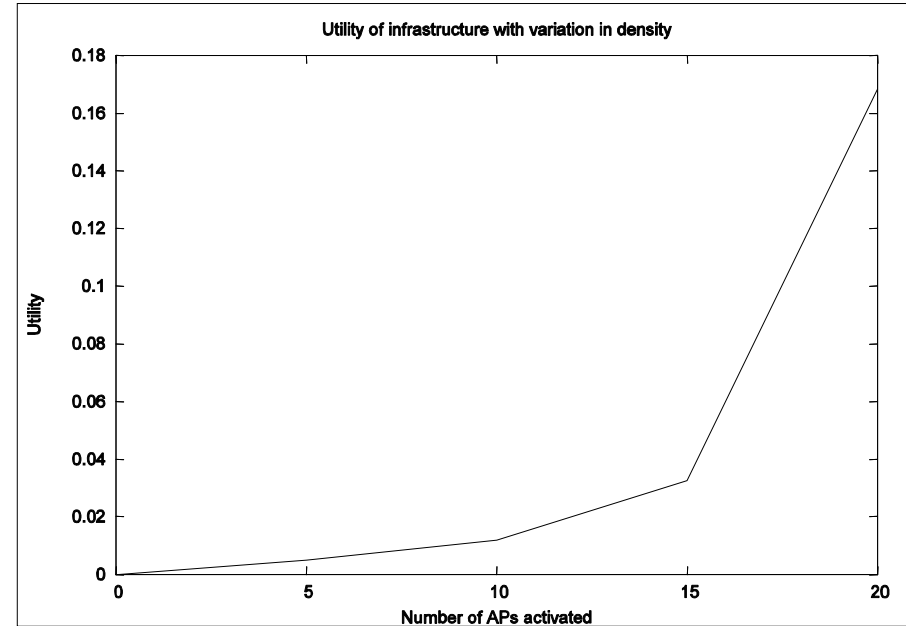
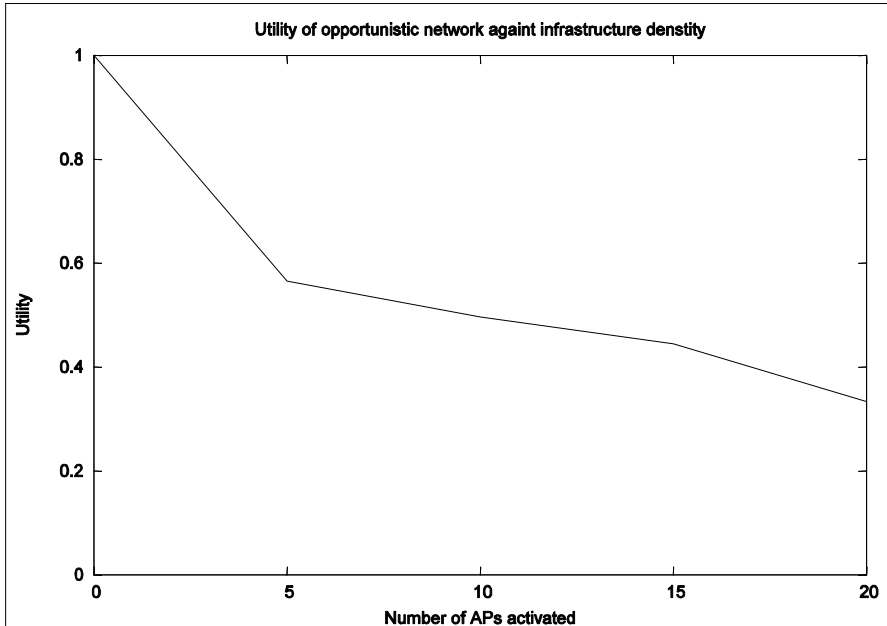
Asynchronous Messaging



Data Push



Utilities – Infocom06 Dataset

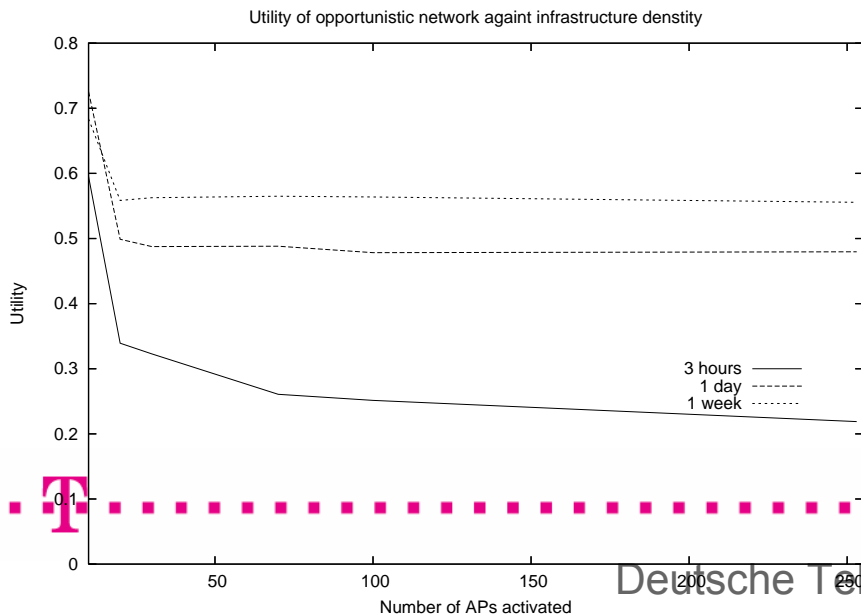
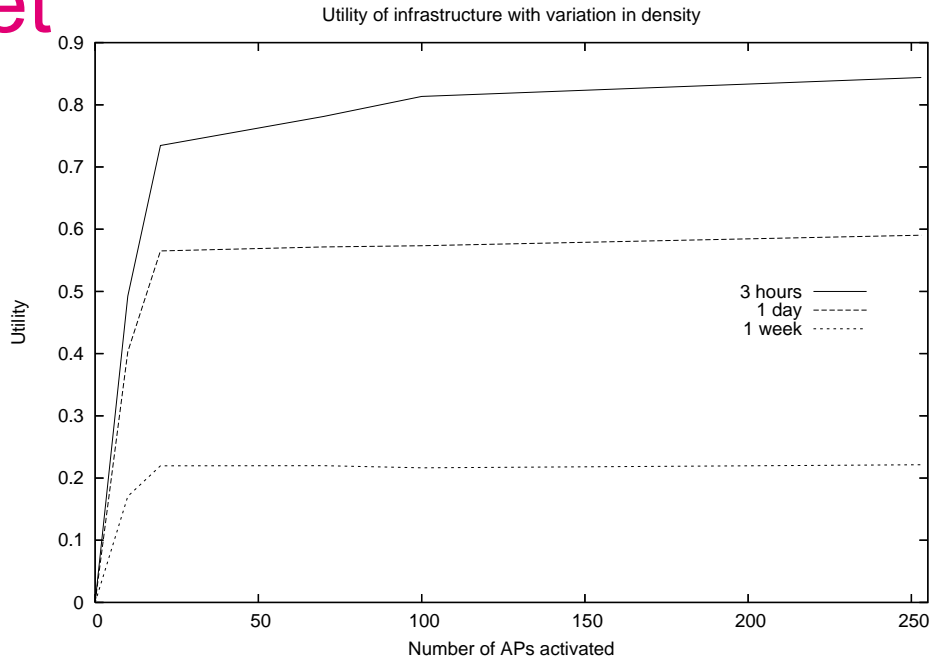
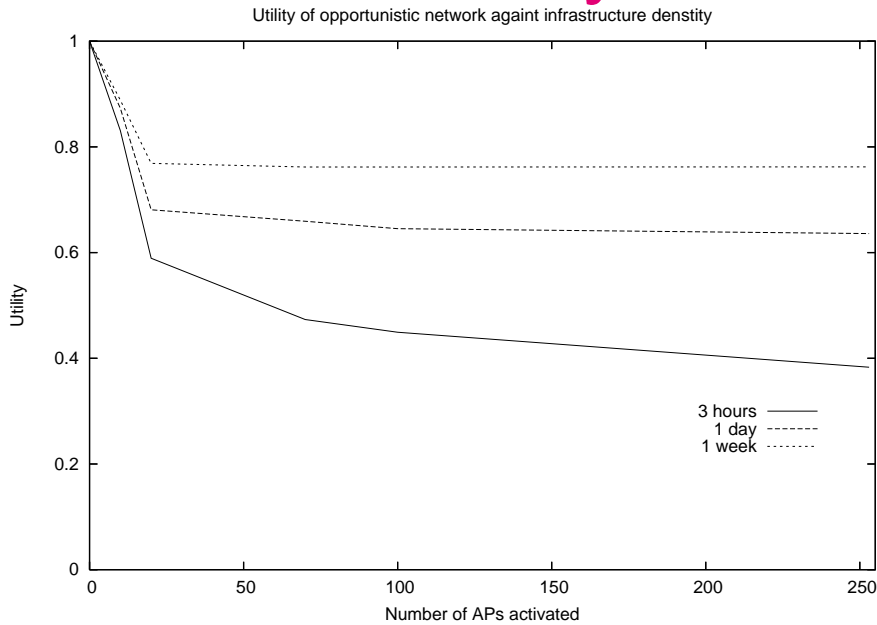


Network Utility:

$$U(I) = \frac{T(O + I) - T(O)}{T(O + I)}$$

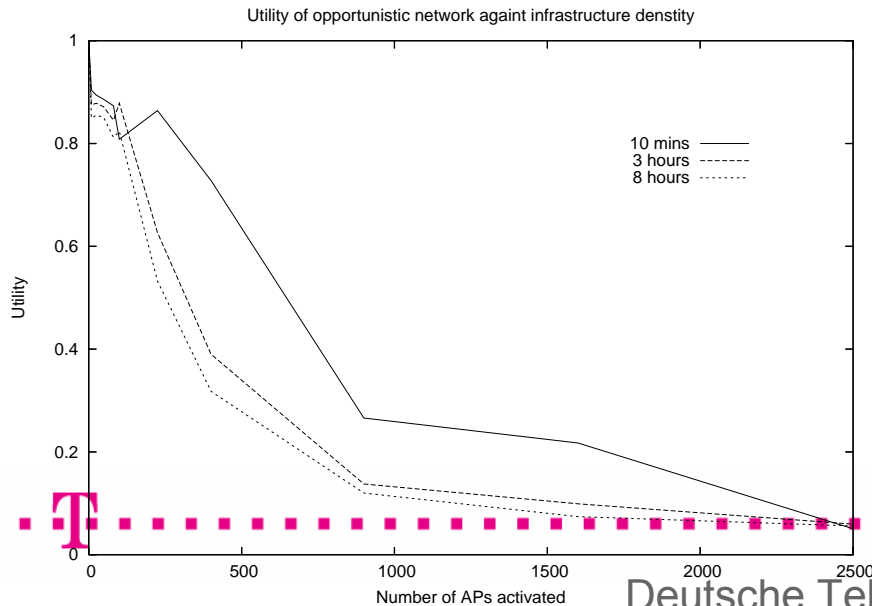
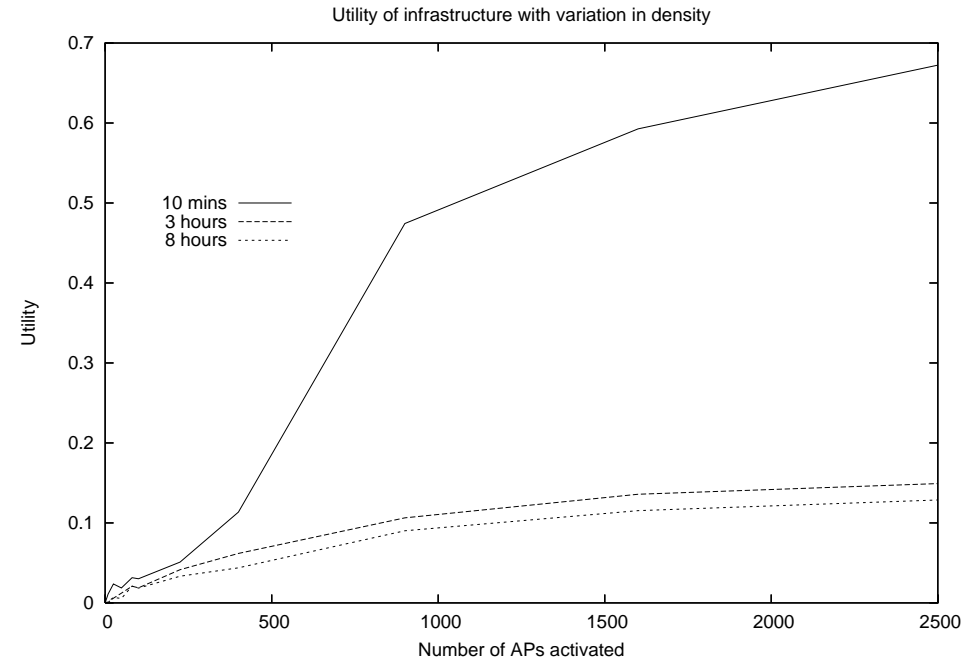
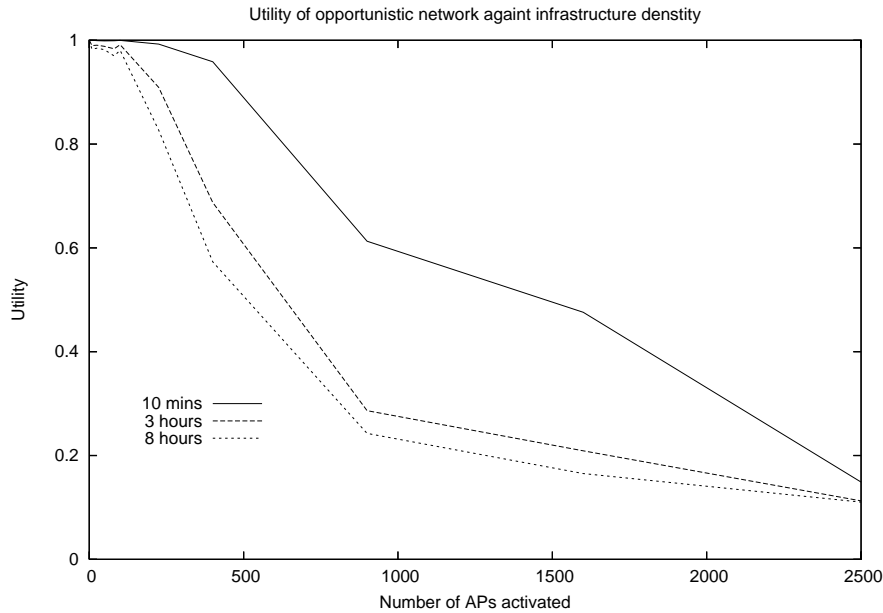
- Left-up : Utility of OppoNet (messaging)
- Left-down : Utility of OppoNet (data-push)
- Right : Utility of APs (messaging)

Utilities – Reality Dataset



- Left-up : Utility of OppoNet (messaging)
- Left-down : Utility of OppoNet (data-push)
- Right : Utility of APs (messaging)

Utilities – Kaist Dataset



- Left-up : Utility of OppoNet (messaging)
- Left-down : Utility of OppoNet (data-push)
- Right : Utility of APs (messaging)

Conclusions and Future Work

- Opportunistic communication can yield a significant increase in network performance, even if infrastructure is present
 - Supported by three experimental datasets
- Can save a lot of money from building a lot of expensive infrastructure, i.e. 900 APs cost US\$4,500,000.
- Compare our observation with previous theoretical works.
- Look for more cost-effective way of infrastructure deployment strategies, e.g. consider human mobility and city topology.

Thank you!

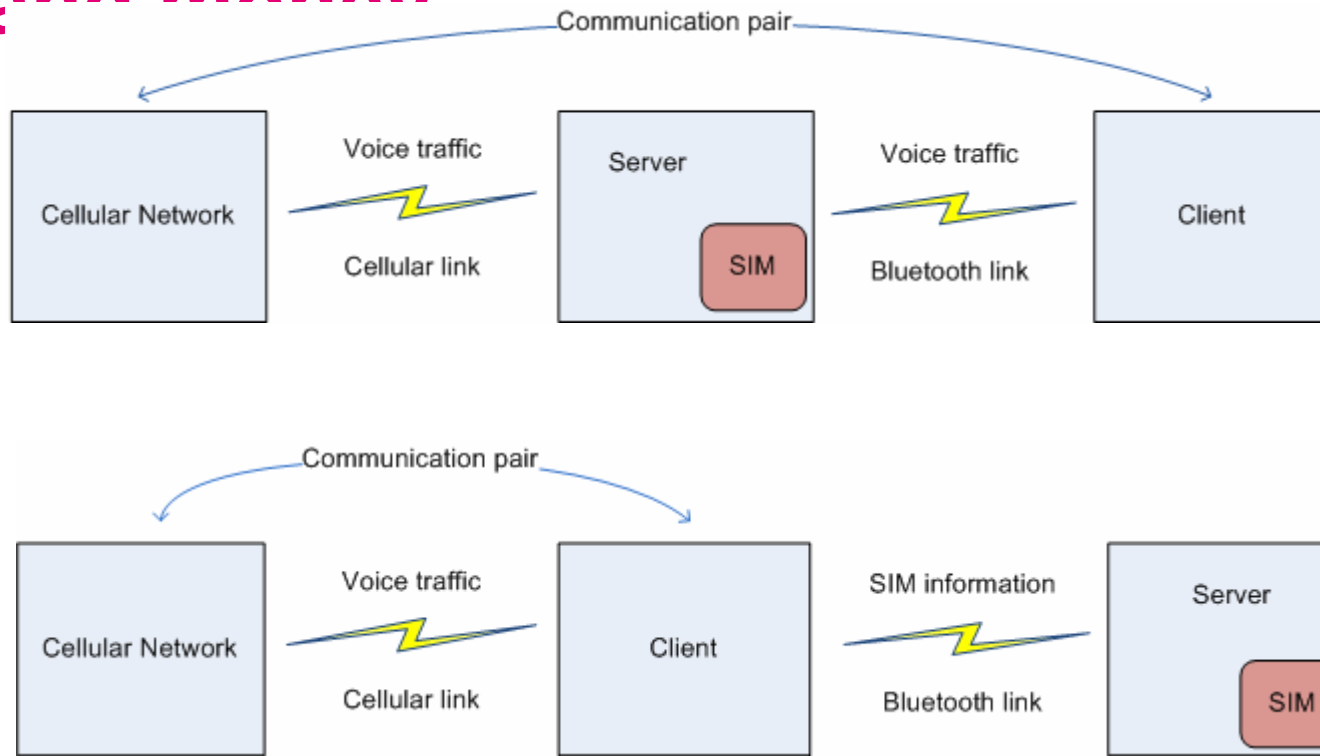
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Additional slides



Sharing airtime with Shair avoids wasting time and money



Hui et al. HotMobile 2009

