Crowd-Powered Mobile Computing and Its Applications: *Collective Computing on the Move*

Seng W. Loke

Pervasive and Mobile Computing Lab

Department of Computer Science and Information Technology

La Trobe University

Bundoora, Melbourne, Australia

s.loke@latrobe.edu.au

http://homepage.cs.latrobe.edu.au/sloke

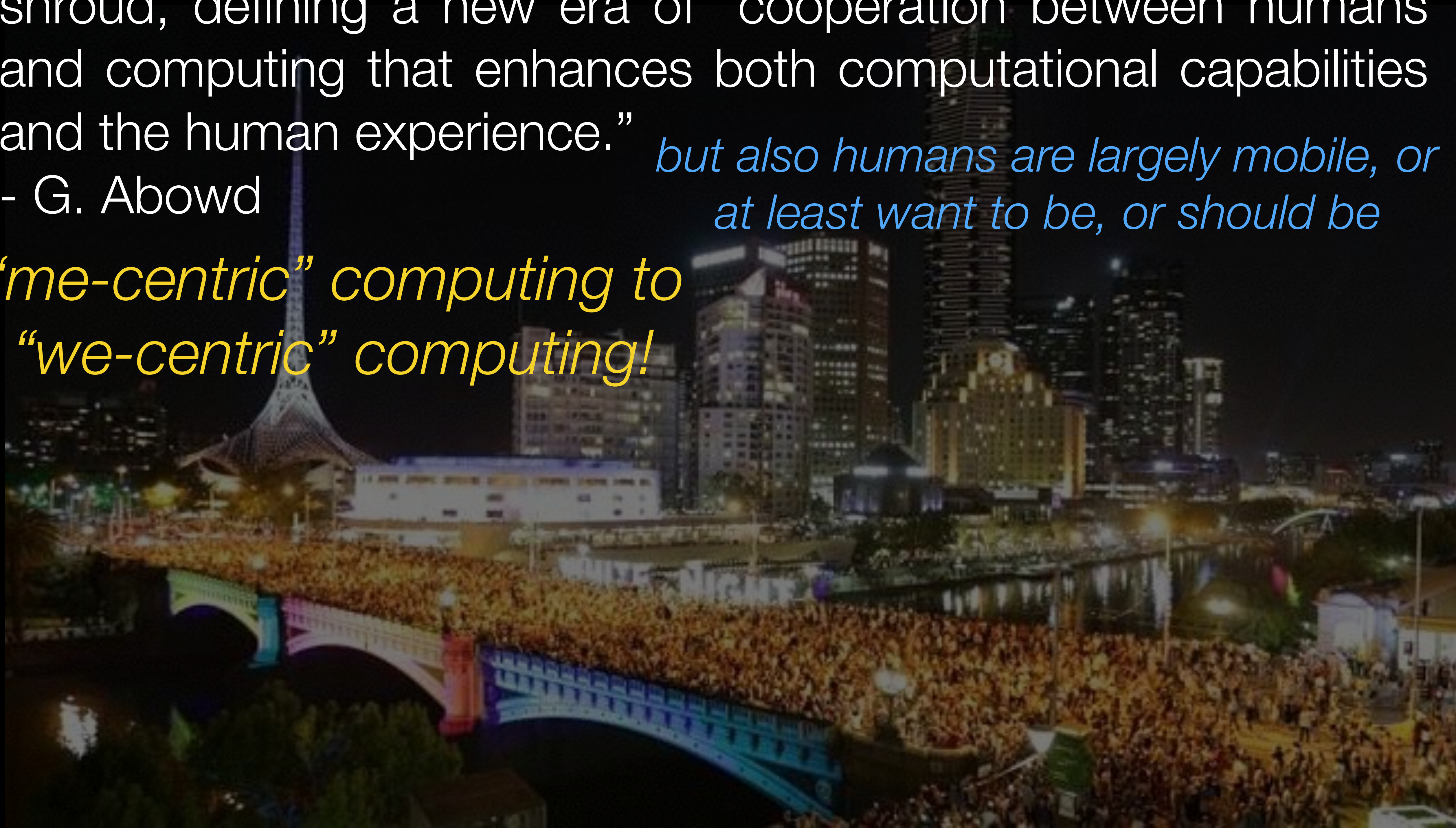
Collective Computing?

Collective computing integrates the cloud, the ***crowd*** and the shroud, defining a new era of "cooperation between humans and computing that enhances both computational capabilities and the human experience."

- G. Abowd

but also humans are largely mobile, or at least want to be, or should be

"me-centric" computing to "we-centric" computing!



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WHAT'S NEW ARCHIVE

HOME CLOUD BIG DATA MOBILE NETWORKING SECURITY SOF

Top Technology Trends for 2015

1) Time is Right for Wearable Devices

Apple in 2015 will join other device makers in launching watches that not only tell time but allow messaging, email, calendars, and fitness apps.

Imagine a wearable device that tells time, sends and receives email and messages, makes calls, and even tracks your exercise routines. Smartwatches hitting the market do all that and more. Both established players and small startups in 2015 will be actively involved in developing new devices, applications, and protocols for the wearable electronics market, which Juniper Research expects to account for $53 billion in sales by 2019. Apple Watch, a potential game changer, will join Microsoft's Band, and Android Wear-based smartwatches from Motorola, Samsung, LG, HTC, and Asus, in competing for a share of the growing smartwatch market. Likewise, users, mobile application and hardware developers, network operators, content providers, and regulatory authorities will be working to better understand the capabilities of wearable devices.

IEEE Computer Society resources:

- *IT Pro* September/October 2015 issue on Wearable Computing
- *IEEE Internet Computing* September/October 2015 issue on Small Wearable Internet
- *IEEE Pervasive* October-December 2014 issue on Wearables
- *Computer* June issue on Wearables, guest co-edited by Google glass developer Thad Starner
- Rock Stars of Wearables conference; September 22, 2015; Austin, Texas

2) Internet of Anything Becoming All-Encompassing

Overarching Internet operating system envisioned to accommodate explosion of connected devices

The reality that up to 50 billion things will be connected on the Internet by 2020 is sinking in: sensors and smartwatches, smart meters and smartphones, washing machines, fridges, wearable devices, and much more. The Internet of Things, Industrial Internet, and Internet of Everything in 2015 will morph into the Internet of Anything. IoA envisions a common software "ecosystem" capable of accommodating any and all sensor inputs, system states, operating conditions, and data contexts — an overarching "Internet Operating System." IoA also suggests contextually and semantically integrated information. As a sign that the world is preparing for this great wave of connectivity, British telecommunications company Arqiva has announced plans to build a national network next year using ultra-narrowband technology suitable for connecting objects over long distances.

IEEE Computer Society resources:

- *IT Pro* May/June 2015 issue on Internet of Anything
- *Computer* September issue on Activating the Internet of Things

Gartner Identifies the Top 10 Strategic Technology Trends for 2016

Analysts Explore Top Industry Trends at Gartner Symposium/ITxpo 2015, October 4-8 ir Orlando

Gartner, Inc. today highlighted the top 10 technology trends that will be strategic for most organizations in 2016. Analysts presented their findings during the sold-out Gartner Symposium/ITxpo, which is taking place here through Thursday.

The top 10 strategic technology trends for 2016 are:

The Device Mesh
The device mesh refers to an expanding set of endpoints people use to access applications and information or interact with people, social communities, governments and businesses. The device mesh includes mobile devices, wearable, consumer and home electronic devices, automotive devices and environmental devices — such as sensors in the Internet of Things (IoT).

"In the postmobile world the focus shifts to the mobile user who is surrounded by a mesh of devices extending well beyond traditional mobile devices," said Mr. Cearley.

While devices are increasingly connected to back-end systems through various networks, they have often operated in isolation from one another. As the device mesh evolves, we expect connection models to expand and greater cooperative interaction between devices to emerge.

4/10 TRENDS FOR 2015

INTERNET OF SHARING THINGS

Nothing gets trend watchers more excited than when two sexy trends get all amorous (even if most mainstream consumers have hardly heard of either ;) In 2015, the Internet of Things and the Sharing Economy collide to allow a whole new world of asset sharing: spontaneous, useful, fun, profitable and more.

Last year we urged innovators to put basic human needs at the center of their connected object initiatives. And there *have* been some exciting INTERNET OF CARING THINGS innovations, such as Chinese tech giant Baidu's set of smart chopsticks, which can detect the freshness of cooking oil. Now, where next for the Internet of Things?

Enter the INTERNET OF SHARING THINGS. **As more objects become connected, new ways of deriving value from them will become possible for consumers, shared access being one.**

The Collaborative/'Mesh' economy has long been predicted, but the coming months will see it start to become a consumer reality via the INTERNET OF SHARING THINGS. One signal: currently only 4% of consumers own an in-home IoT device, but nearly two-thirds plan to buy one in the next five years (Acquity Group / Accenture, August 2014).

Umbrella Here, BitLock and Breather

The Audi Unite initiative (in FAIR SPLITTING above) is a great example of the INTERNET OF SHARING THINGS. Three more:

Shipping in January 2015, Hong Kong-based group Umbrella Here's USD 28 donut-shaped Bluetooth device fixes onto the top of umbrellas. When it rains, owners can use the companion app to signal (via colored LEDs) to nearby strangers they are willing to share their umbrella.

Reaching its Kickstarter funding target during November 2013, the BitLock smart bike lock verifies a user's identity via Bluetooth when they are nearby; users simply press a button to unlock the bicycle. The BitLock app also enables users to unlock their bicycle remotely and/or share it with others using the app.

Launched in Q4 2013, and now available in four cities – New York, San Francisco, Montreal, and Ottawa, Breather allows people to find unused urban spaces to rent for as little as 30 minutes, to recharge or work in. After booking, users are granted temporary access to unlock the property via the NFC keyless entry system.

Human Computation

science.s

The power of crowds

Pietro Michelucci[1], Janis L. Dickinson[2]

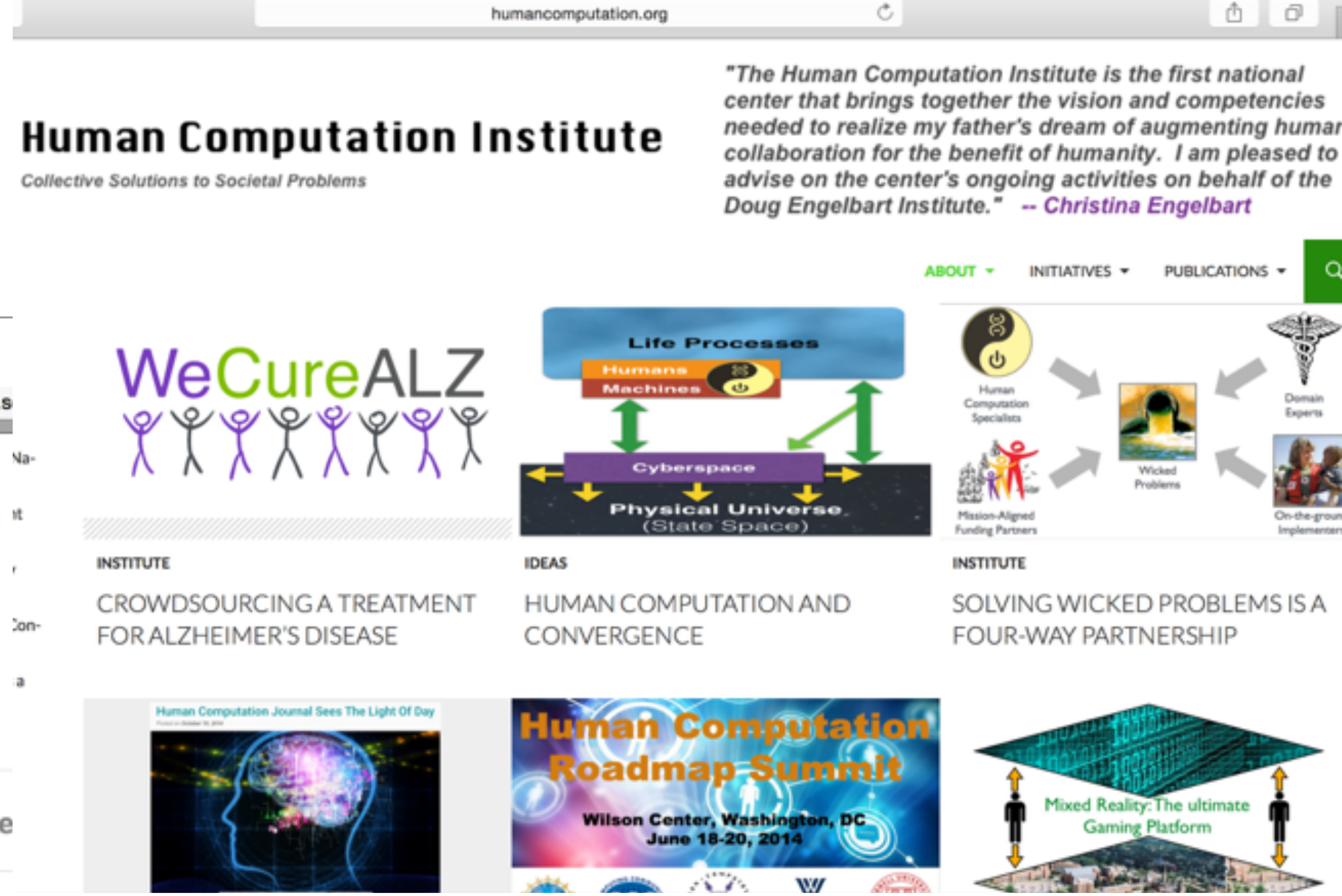
+ Author Affiliations

E-mail: pem@humancomputation.org

Science 01 Jan 2016:
Vol. 351, Issue 6268, pp. 32-33
DOI: 10.1126/science.aad6499

Article Figures & Data Info & Metrics e

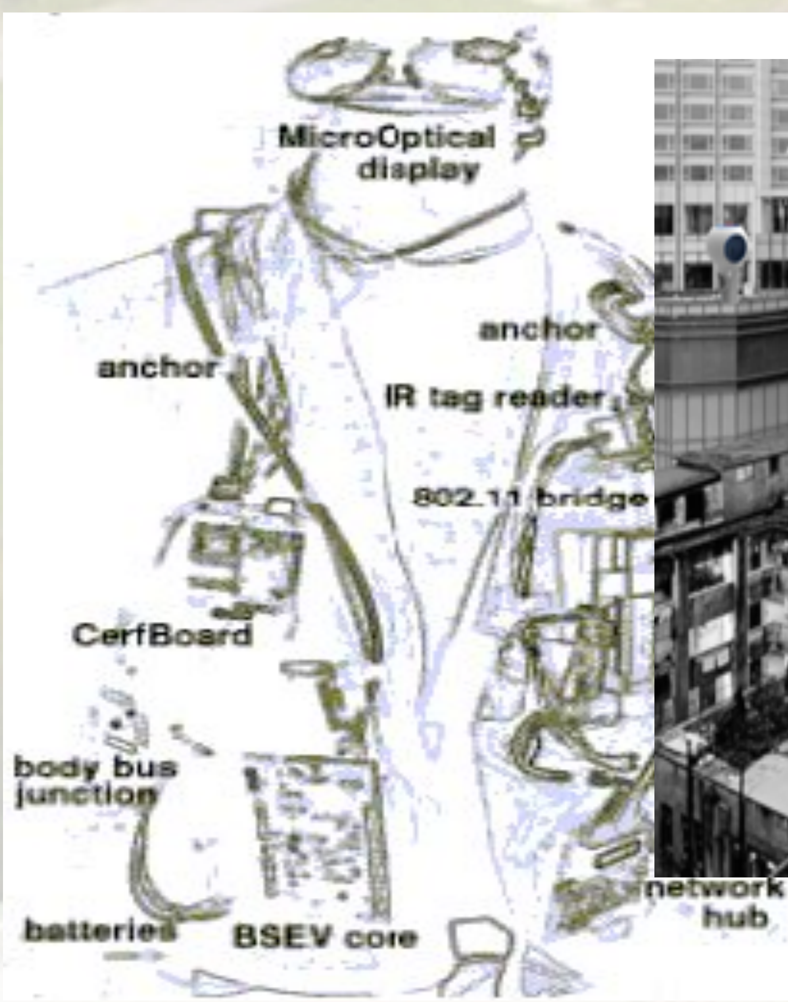
Human computation, a term introduced by Luis von Ahn (*1*), refers to distributed systems that combine the strengths of humans and computers to accomplish tasks that neither can do alone (*2*). The seminal example is reCAPTCHA, a Web widget used by 100 million people a day when they transcribe distorted text into a box to prove they are human. This free cognitive labor provides users with access to Web content and keeps websites safe from spam attacks, while feeding into a massive, crowd-powered transcription engine that has digitized 13 million articles from *The New York Times* archives (*3*). But perhaps the best known example of human computation is Wikipedia. Despite initial concerns about accuracy (*4*), it has become the key resource for all kinds of basic information. Information science has begun to build on these early successes, demonstrating the potential to evolve human computation systems that can model and address wicked problems (those that defy traditional problem-solving methods) at the intersection of economic, environmental, and sociopolitical systems.



Technology Trends

https://en.wikipedia.org/wiki/Cloud_computing

- crowds: 7,000,000,000+ mobile phones in use in the world today, each *riding on the "Moore's law" wave* & *green*
- cloud computing
- Internet of Things: smart things, jackets, shoes, glasses, etc.
- Big Data, personal/mobile analytics
- crowd computing, human computation, social media
- culture of sharing: car sharing, bike sharing, thing sharing
- participatory systems



Crowd-Powered Mobile Computing

Mobile computing of today and of the future:
tens to thousands (to millions to billions?) of mobile nodes can cooperate in new ways, in order to provide new capabilities and applications, from massive context-awareness to new distributed computational platforms

Mobile crowdsourcing, crowdsensing, crowd-steering, participatory social systems, mobile device clouds, and cooperative Intelligent Transport Systems are examples.

crowd-powered mobile computing

In this talk, four ideas:
Crowd Machines (Crowd-Powered Systems)
Scalable Context-Awareness
Extreme Cooperation
Drone Services for Mobile Crowds

Crowd Machines

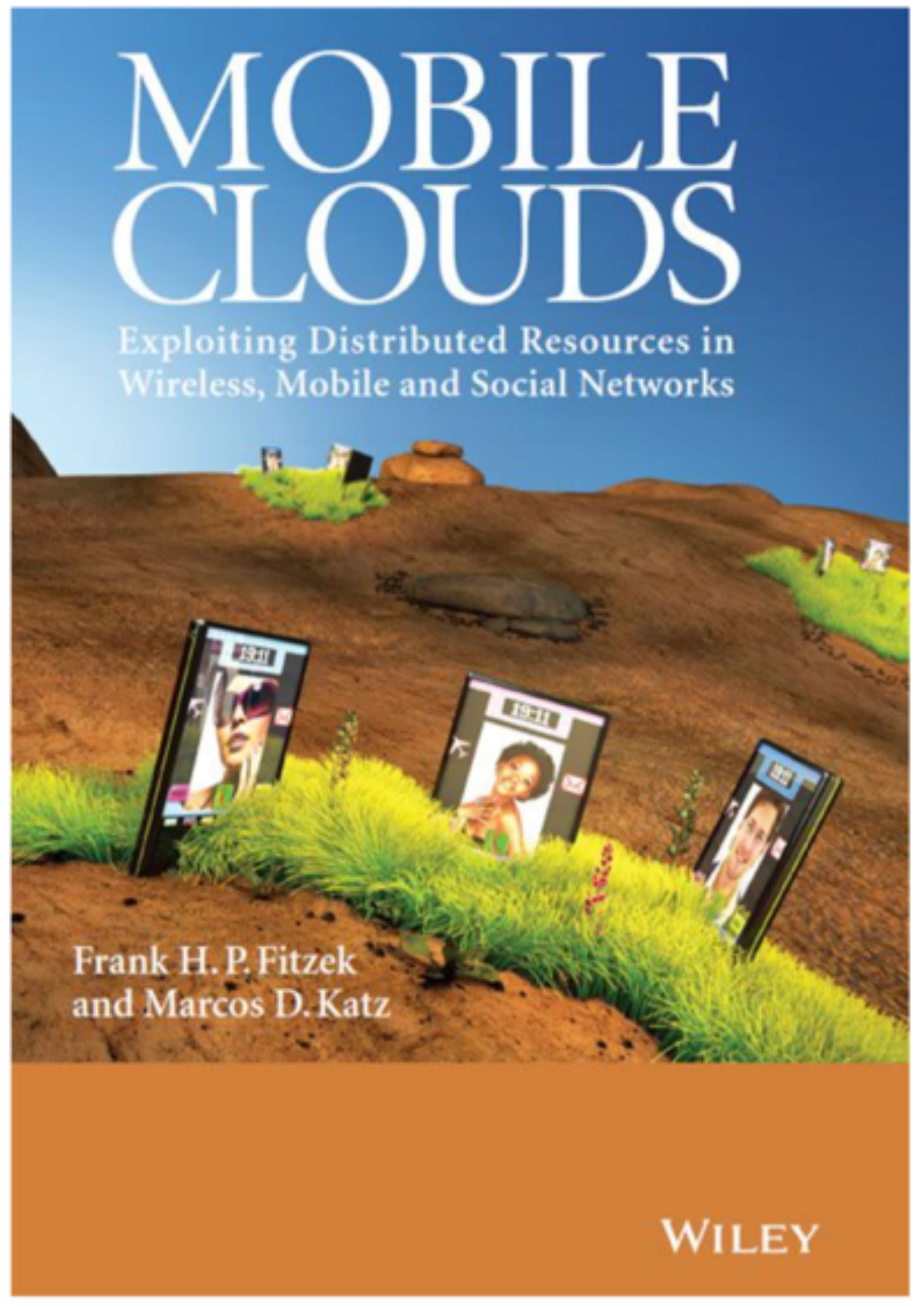
- a crowd machine: a computer formed by a crowd of people, each with their own (network of) devices (e.g., smartphone, smartwatch, smartcar, smart*) , inter-network-able to each other, providing human and machine computational capabilities; the crowd machine changes boundaries seamlessly, and
  - distributed ownership
  - heterogeneous devices
  - dynamic environment: devices coming & going, joining & leaving
  - ad hoc and opportunistic
  - context-aware: sensitive to what is available
  - localized: proximity and in vicinity
  - minimal assumed knowledge of devices/resources
  - can combine human and machine computation capabilities
  - incentive-driven
  - energy-aware (resource-aware)
  - elasticity
  - resources shared? storage, processing, sensors, etc

Types of Mobile Clouds

- Vehicular clouds
  - pool together a collection of cars as a supercomputer
  - e.g., cars at parking lot as data centre
  - Intelligent Transportation Systems apps
- Personal clouds
  - pool together devices worn/carried by a user
  - mobile health apps
- Cloud at the Edge (Cloudlet) / Fog Computing
  - intermediary cloud servers between mobile users and the greater Cloud
  - reduces latency and improves security
  - e.g., data centres at telecommunications base stations
- Mobile crowd clouds / mobile device clouds
  - pool together devices from a nearby crowd of people

Crowd Machines

- A broader view?
- 2014 view



2.2.1 Generic Mobile Cloud Definition

Definition 2.1

A mobile cloud is a cooperative arrangement of dynamically connected nodes sharing opportunistically resources.

Cooperative The social relationship among nodes defines the willingness to cooperate and shape the way cooperation takes place in a cloud.

Dynamically Wireless channels are prone to temporal and spatial fluctuations as well as changes in nodes (user mobility, nodes joining in, leaving out).

Connected Nodes are connected with each other directly (peer–to–peer) or logically (through overlay networks).

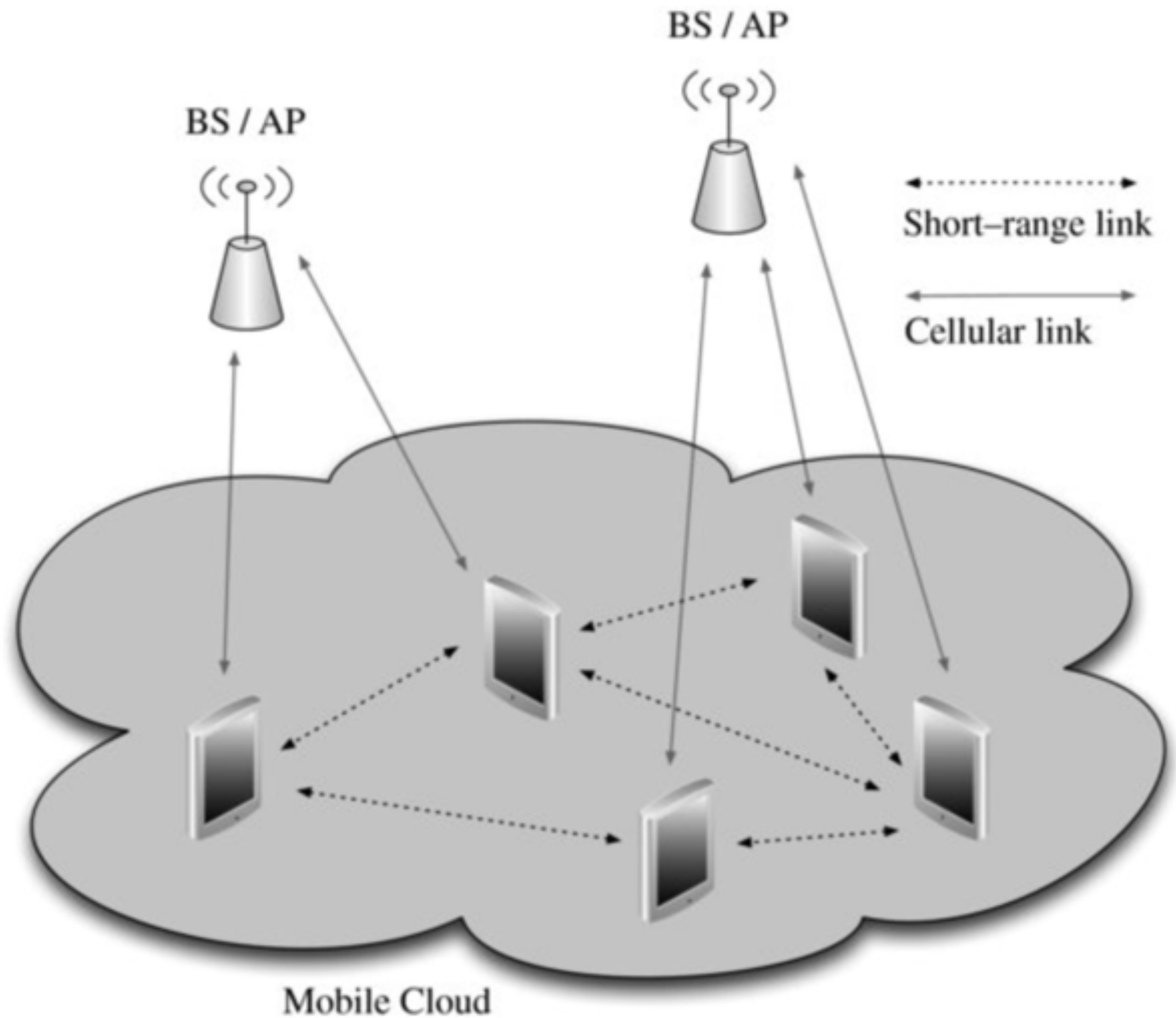
Nodes Any form of communication device with capabilities to connect to each other.

Opportunistically Taking advantage of opportunities as they arise.

Resources Any sharable or composable entity/means available in the network or embedded in the nodes.

Crowd Machines

Figure 2.2 Basic distributed–centralized architecture of a mobile cloud. BS = base station; AP = access point.



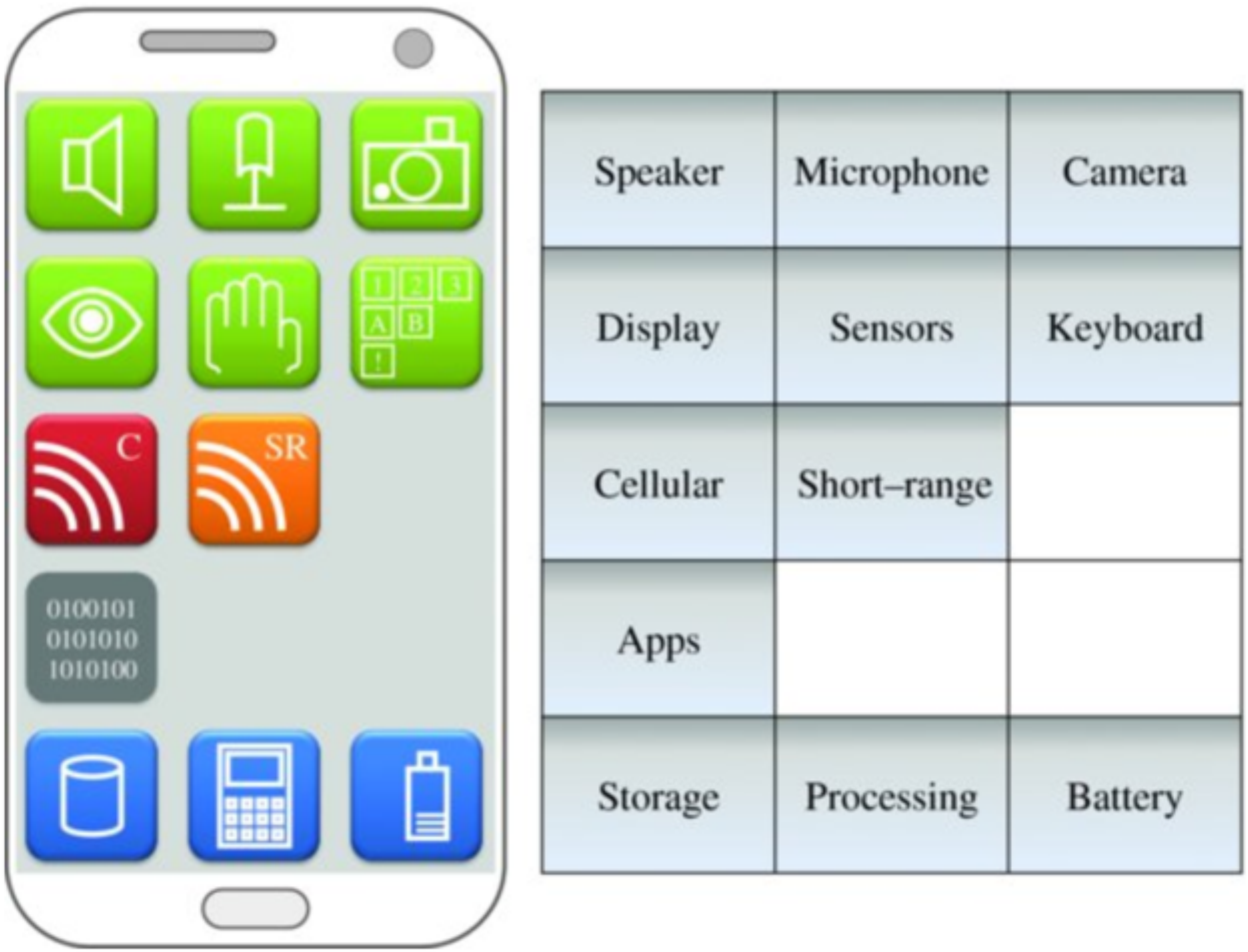
Definition 2.2

A mobile cloud is a cooperative arrangement of closely located wireless devices, each of which can also be connected to other networks through access points or base stations.

Crowd Machines

What is shareable?

Figure 3.3 Mobile device with potential resources for sharing.



GPS,
Human power,
access to
3G services,
access to
greater Cloud,
etc…

Crowd Machines

Figure 3.4 Sharing loudspeakers to create social stereo and 3D social sound.

-what if we scale this up to 10,000 devices?

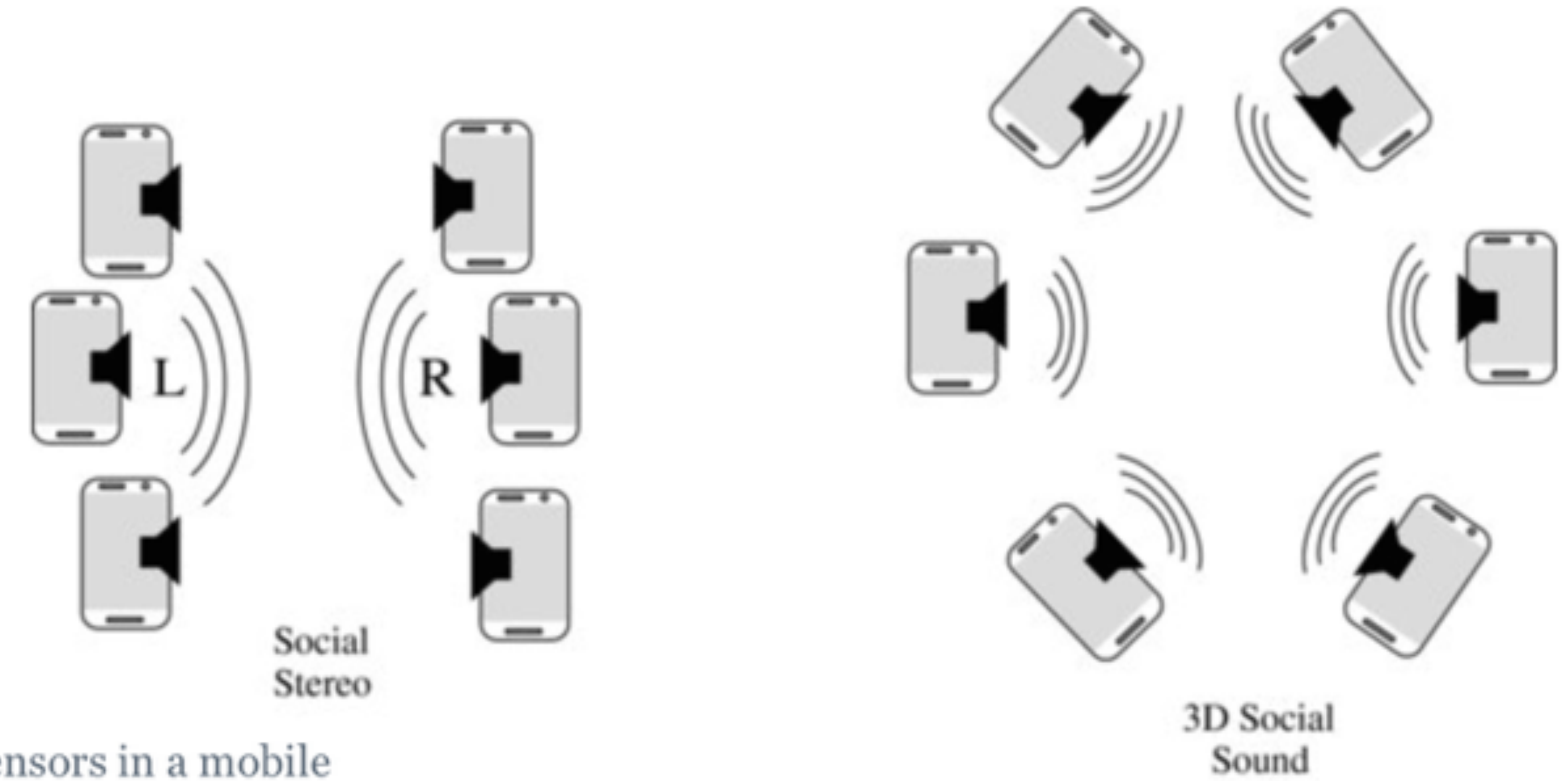


Figure 3.7 Different principles for sharing image sensors in a mobile cloud.

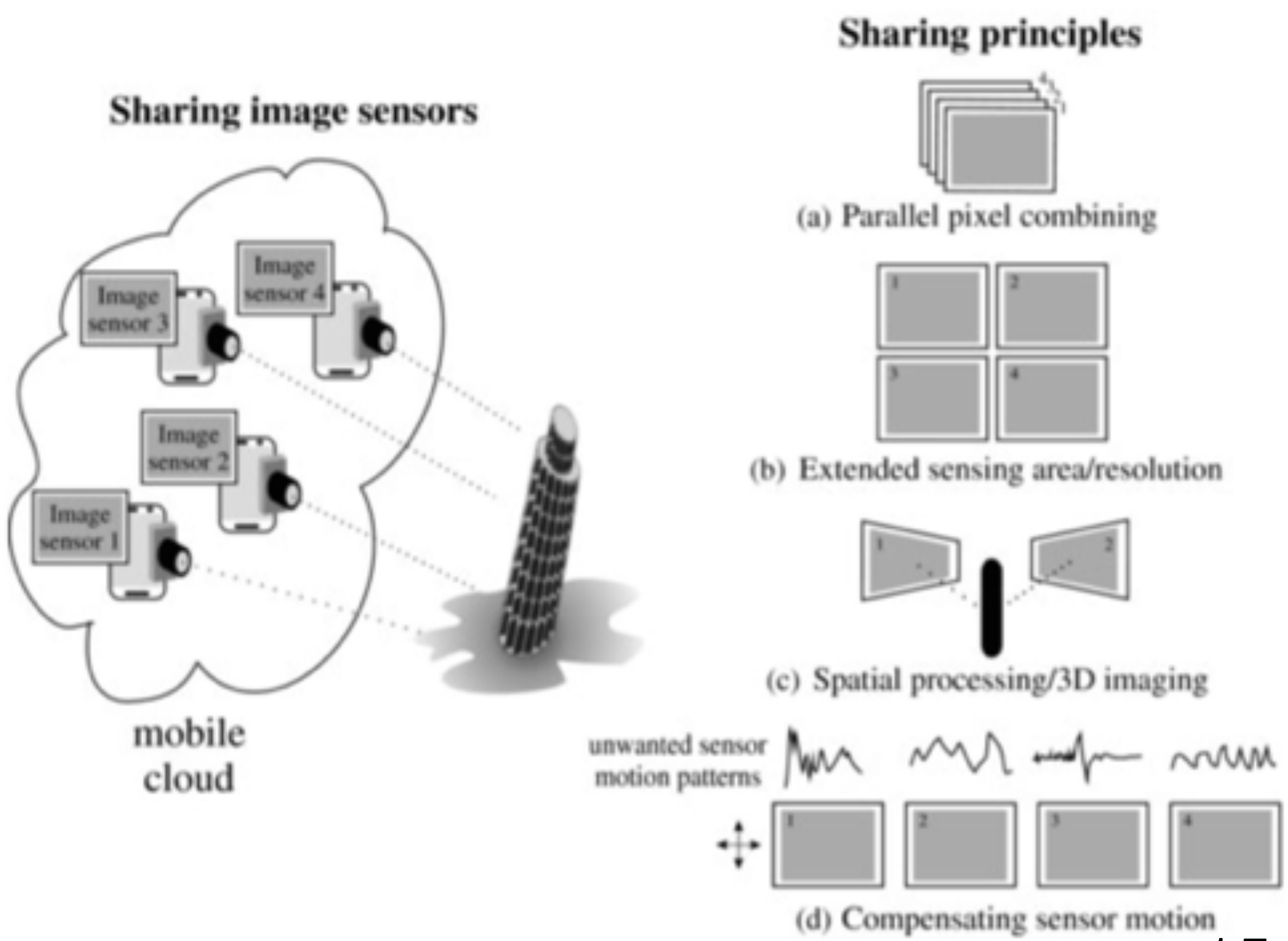
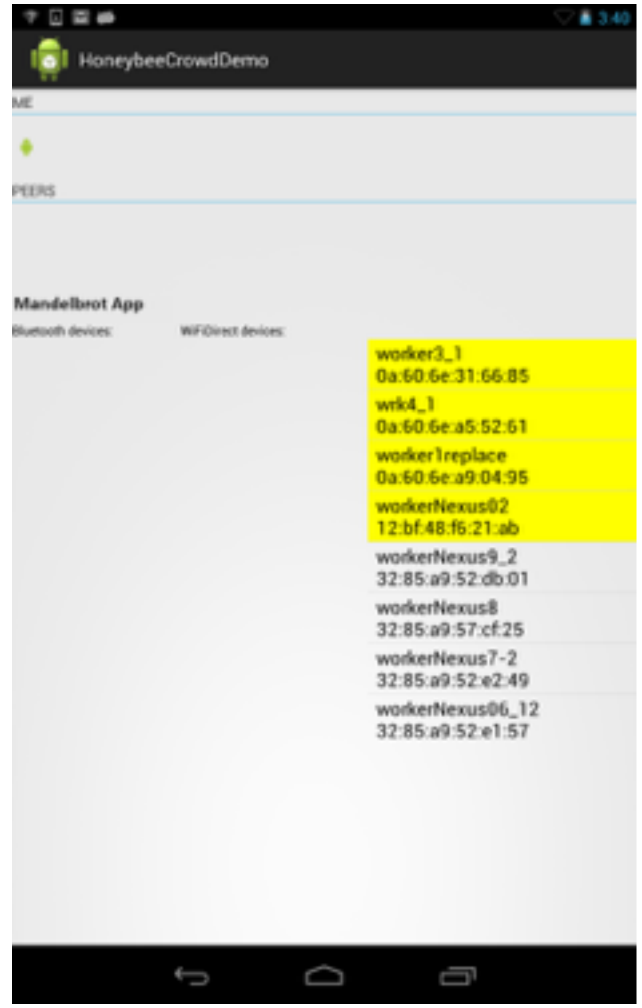


Figure 10.3 Final outcome of the collaborative screen.

Crowd Machines

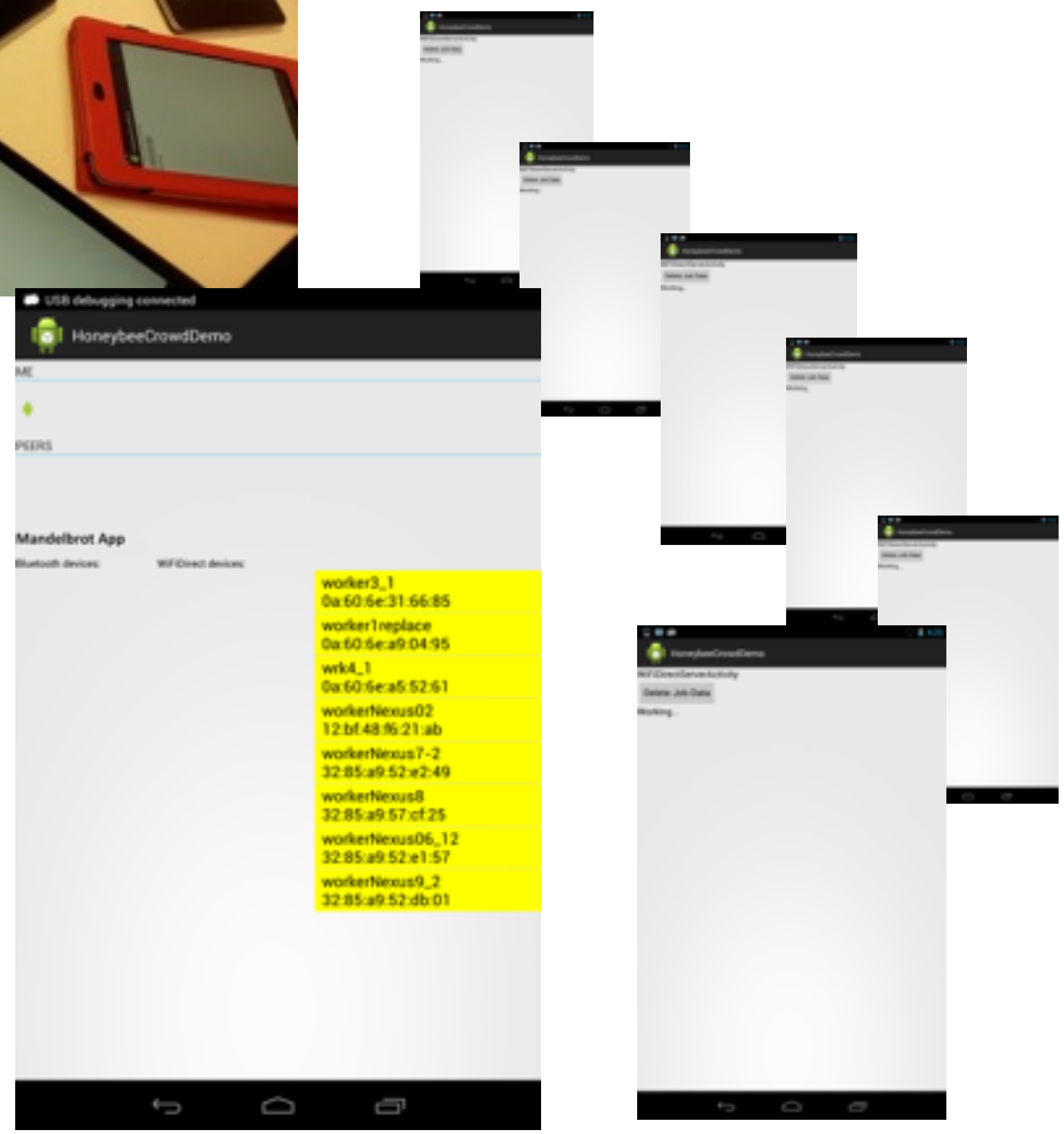
Mobile Crowd Computing with Honeybee: get the mobile crowd around you to help you do computations



Form a p2p group via Wi-Fi Direct, with Delegator as the group owner.

[src: http://nfernando.org]

Crowd Machines



Workers:
- Work
- Steal from Delegator
- Send results
- Let Delegator steal

Delegator:
- Work
- Let Workers steal
- Collect results
- Steal from Workers

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Honeybee properties

- Opportunistic: Periodic resource discovery enables connecting to nodes as and when they are encountered
- Load-balancing with unknown & heterogeneous nodes: Node capabilities vary and are unknown a priori. Work stealing method enables distribute jobs as per node capabilities
- Supports mobility via FT mechanisms: Monitors workers via heartbeats and upon disconnection, adds stolen jobs back to the queue
- Proactive: Workers proactively 'take' on jobs

Implementation: Honeybee API

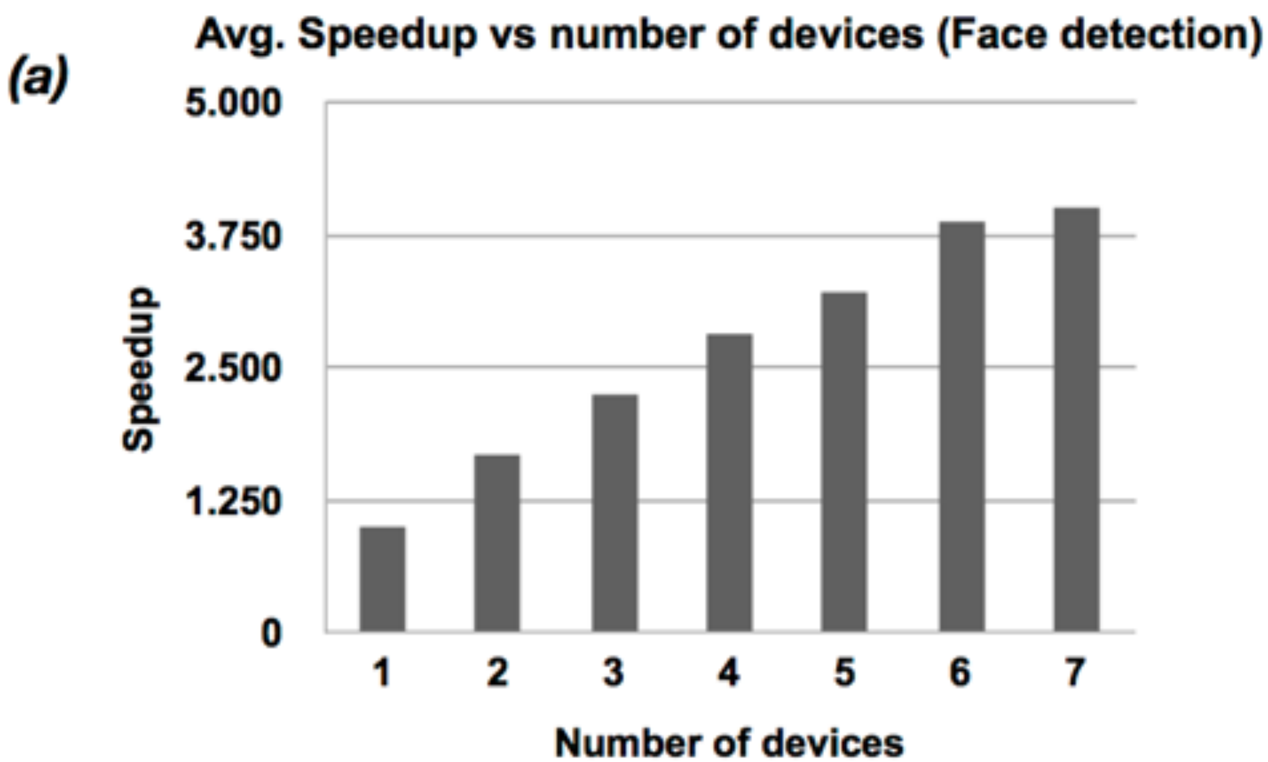
- Android
- Wi-FiDirect

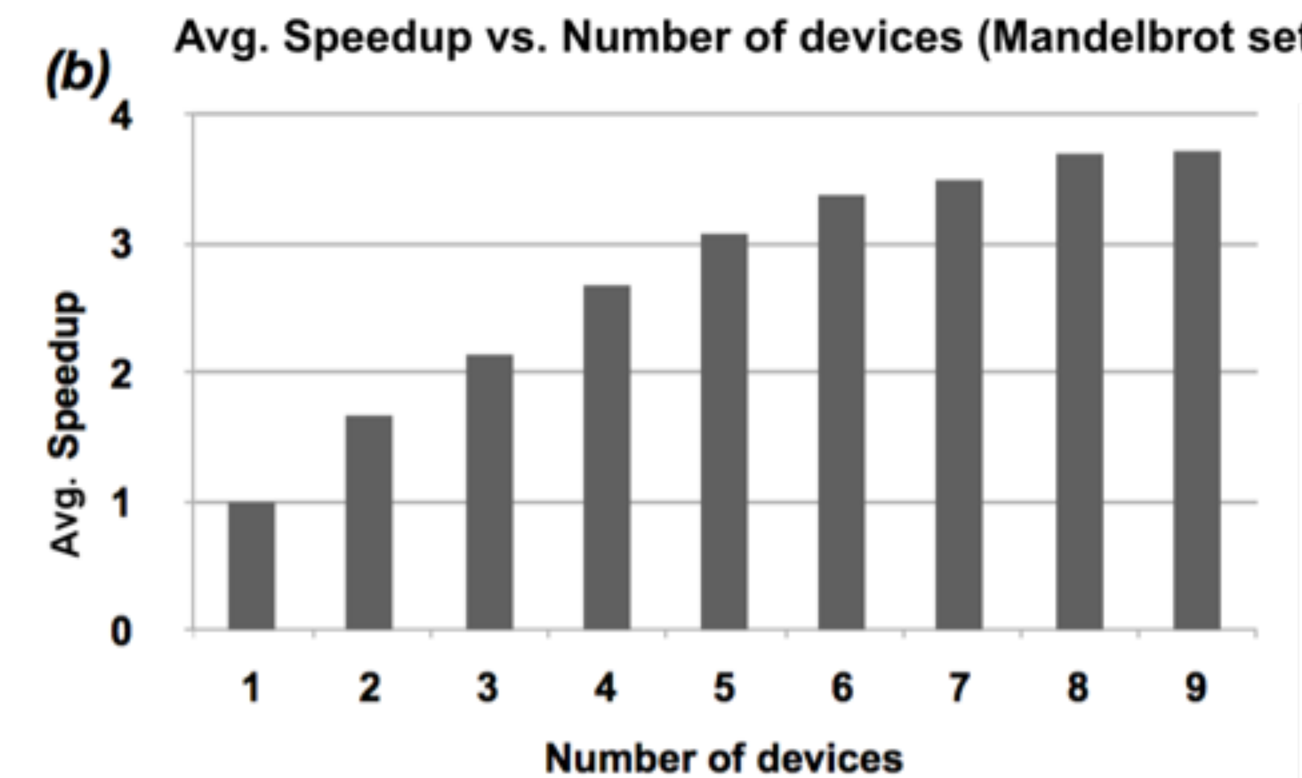
Experimental Evaluation

Application	Job Type	Data size of I/O
Face detection	Machine centric: CPU & memory intensive	Big inputs/small outputs
Mandelbrot set generation	Machine centric: CPU intensive	Small inputs/big outputs
Collaborative photography	Human centric	Small inputs/ big outputs

Crowd Machines

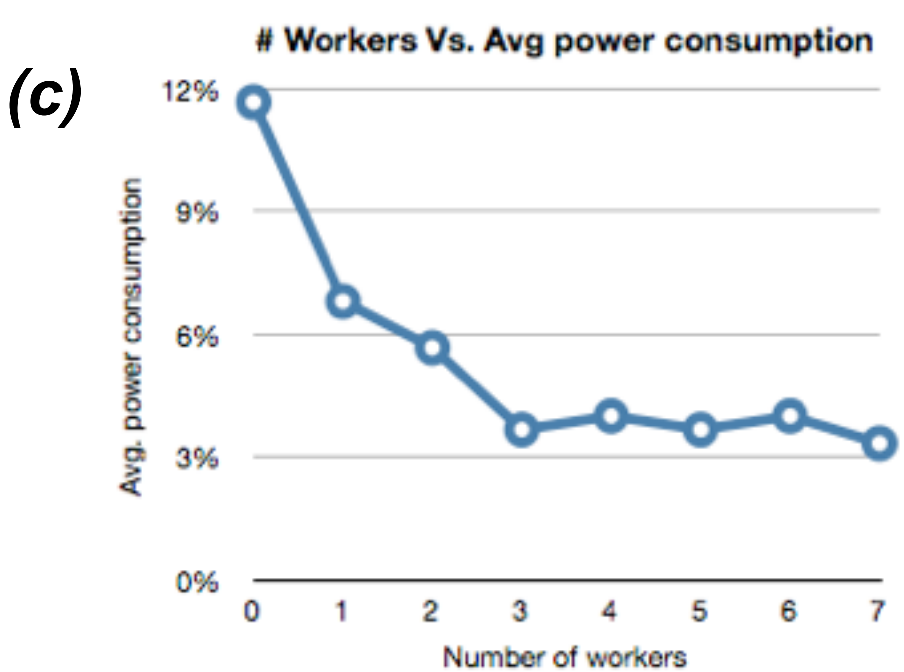
Experiments with WiFi Direct: Performance gain & Energy saving





Speedup is proportional to the number of devices

Face detection: maximum average speedup observed was 4.01 for 7 devices.
Mandelbrot set generation: maximum average speedup was 3.7 for 9 devices.



Measured via the Android battery API.

Experiments with the FaceMatch app for 1920 images in Figure (c) shows how the energy consumption of the delegator is almost halved from 11.7 % to 6.8% with just one worker.

Crowd Machines

Related questions

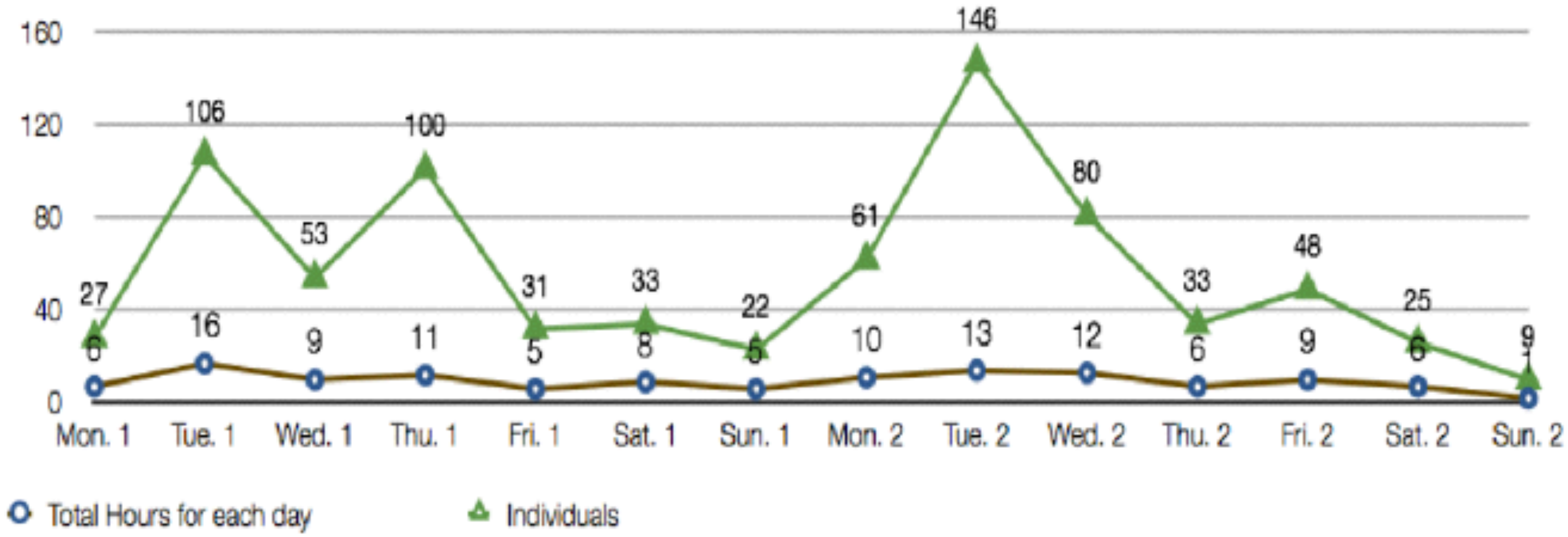


Fig. 4. The hours of scanning and adjusted discovery instances each day.

are we normally surrounded by a big crowd?

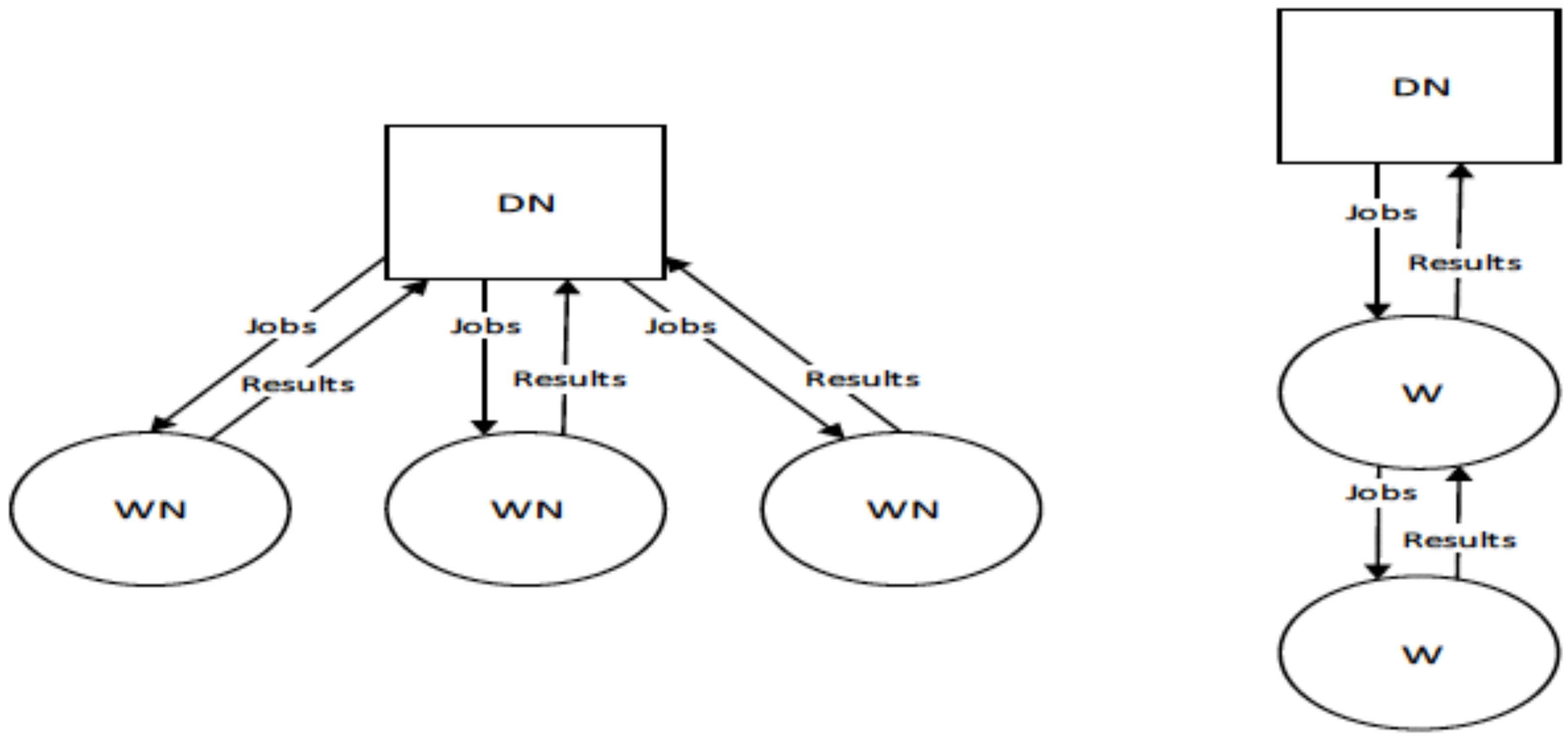


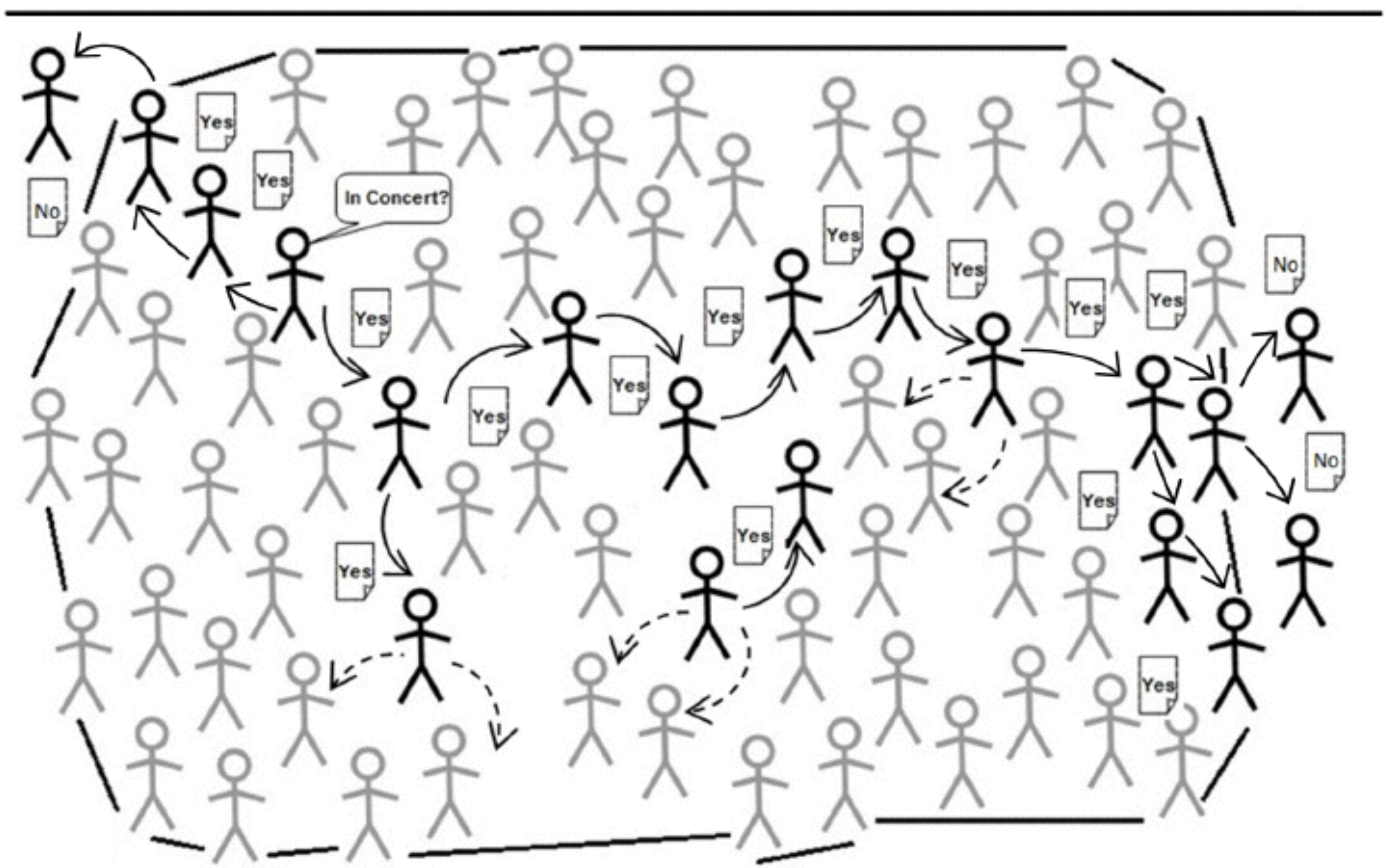
Fig. 8. Fan-out Topology on the left, Linear Topology on the right

can we use peer-to-peer computing to create a network of collaborating devices?

[more in: Seng W. Loke, Keegan Napier, Abdulaziz Alali, Niroshinie Fernando, and Wenny Rahayu. 2015. Mobile Computations with Surrounding Devices: Proximity Sensing and MultiLayered Work Stealing. *ACM Trans. Embed. Comput. Syst.* 14(2) (February 2015), 25 pages.]

Crowd Machines

ask the crowd to find the crowd boundaries…e.g., at a concert; here, using the platform called LogicCrowd: use Prolog to program mobile crowdsourcing apps



[src: Phuttharak, J., and Loke, S.W. **Towards Declarative Programming for Mobile Crowdsourcing: P2P Aspects**. Proceedings of the 1st International Workshop on Mobile Collaborative cROwdsourcing and Sensing (M-CROS), in conjunction with the 15th IEEE International Conference on Mobile Data Management(MDM 2014).]

Crowd Machines

- Spatial finding: get the mobile crowd to help you find car parks, crowds, noisy/quiet areas, high bandwidth spots

Our Problem. Assume a a large area R partitioned into n regions $\{r_1, \ldots r_n\}$. The problem is to find a set $S \subseteq R$ of at least $k \leq n$ regions, each of which evaluates to true for a given predicate F representing some criteria, i.e. $F(r) = TRUE$, for each $r \in S$. We also want to solve this problem with the lowest cost (assuming we need to pay to get a question about a region answered) and in a most efficient way (the number of rounds of questions required).

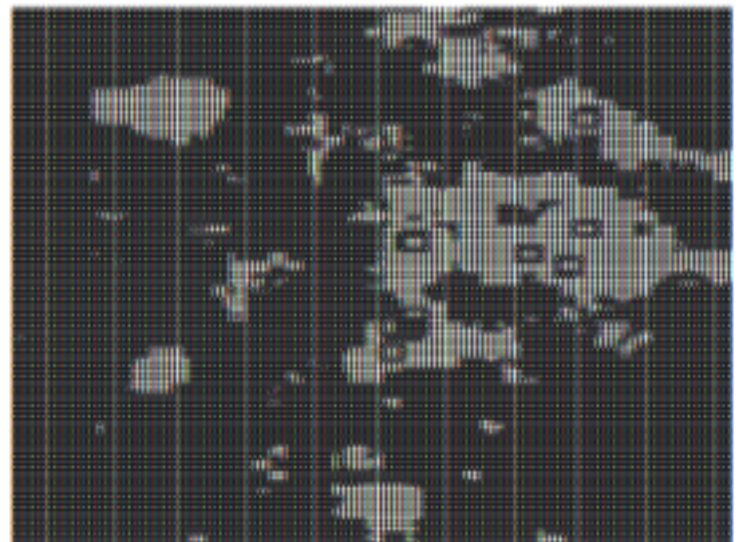
For example, we want to find at least k regions with available car parking spaces, and can divide a large area into a set of regions, about which we can then ask the crowd about, but each time we ask the crowd about a region, we assume that we incur a cost. Another example is to find a not-so-crowded cafe and can issue a query to find at least k regions with a not-so-crowded cafe, answers being given by people near or within the region. A third example is to find a high bandwidth (WiFi, 4G or otherwise) region.

[more in: Loke, S.W. **Heuristics for Spatial Finding using Iterative Mobile Crowdsourcing**. Human-Centric Computing and Information Sciences (to appear), 2016, Springer]

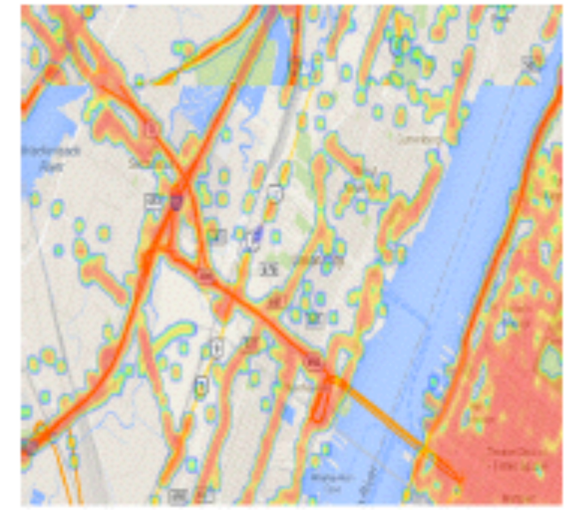
Crowd Machines

spatial finding examples…

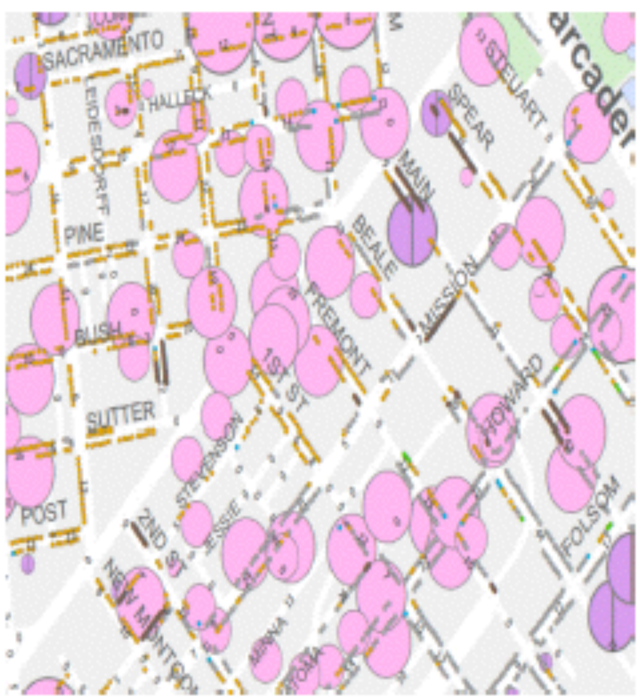
(a) Crowd map from Citysense project (http://www.sensysmag.com/-spatialsustain/citysense-app-aims-to-connect-tribes.html) of sine roughly 3.6km by 4.2km; red regions are where the crowds are



(b) Abstracted discretized view of crowd map with α=0.1968039468039468, with 126x148 regions, each region corresponding to roughly 28.5mx28.5m; '1's (or lighter regions) representing regions with crowds.



(a) 3G/4G coverage map from http://opensignal.com/ of a part of New York city, of size roughly 10km by 8km; orange regions have 3G/4G coverage



(a) Parking map from http://sfpark.org/resources/parking-census-data-context-and-map-april-2014/, of size roughly 1km by 0.7km; pink regions have parking spaces

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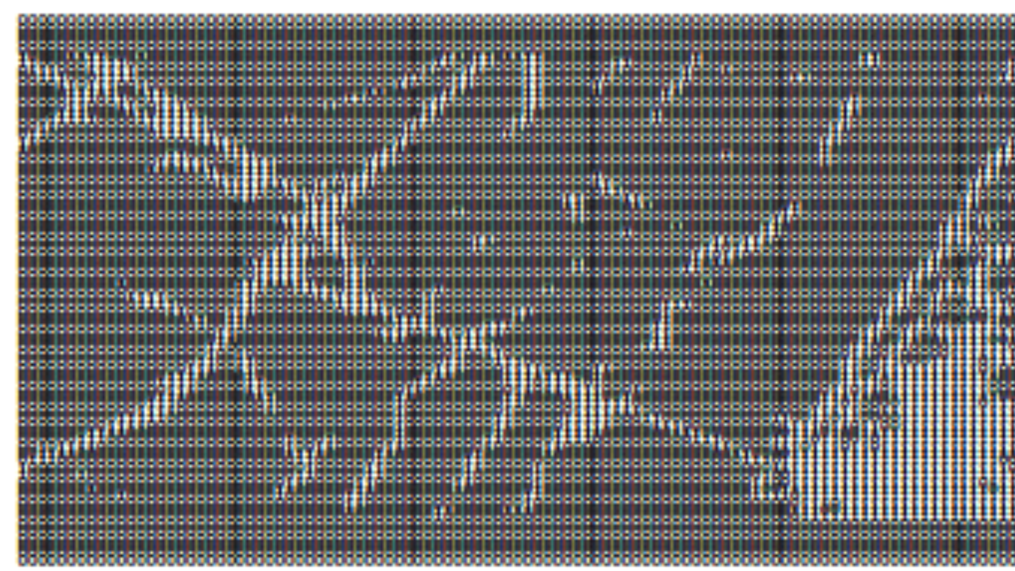
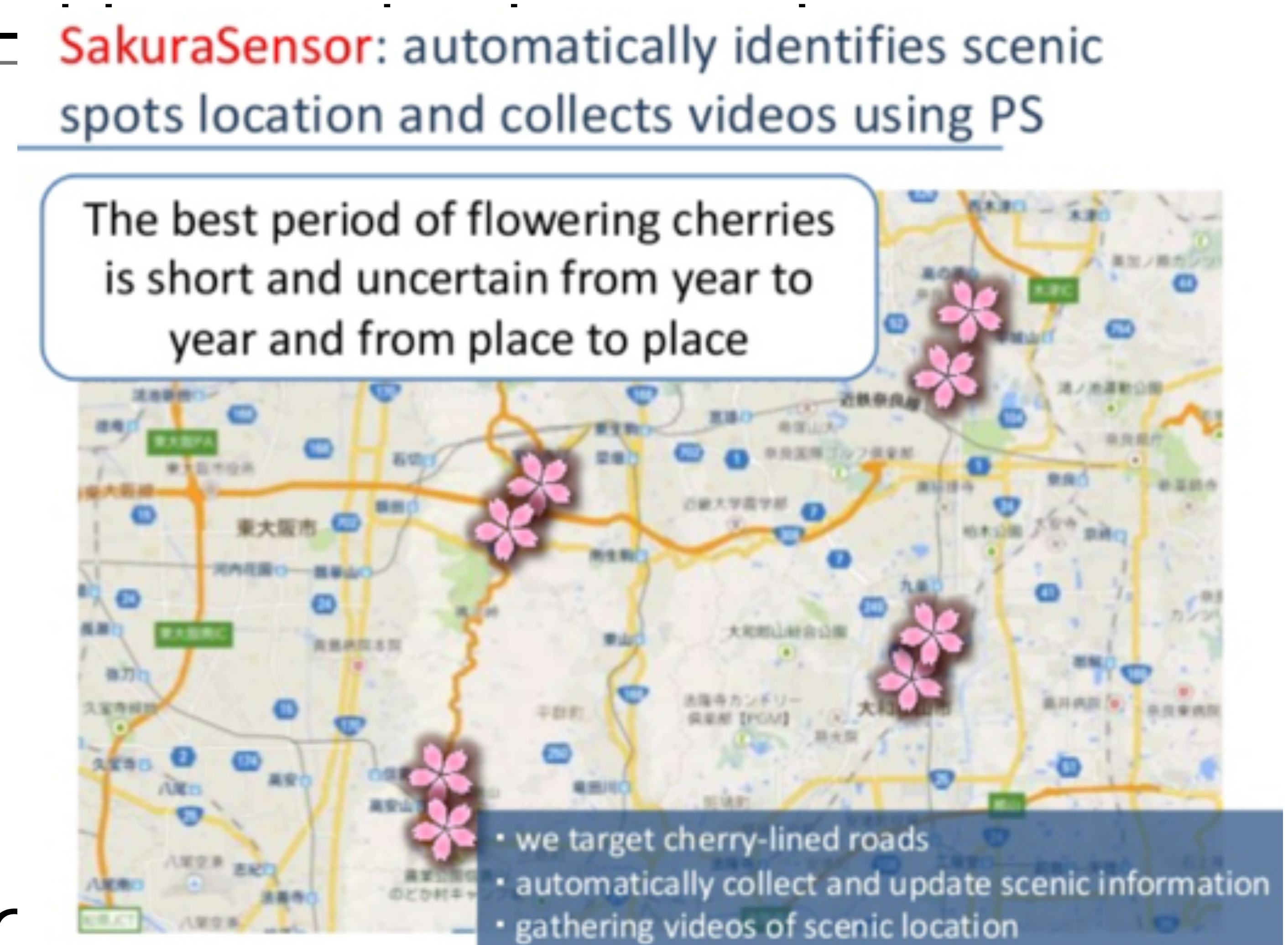
(b) Abstracted discretized view of parking map with α=0.2076923076923077 with 26x20 regions, each region corresponding to roughly 37m by 37m; '1's representing regions with parking spaces.



(b) Abstracted discretized view of coverage map with α=0.1784138191905182 with103x77 regions, each region corresponding to roughly 100m by 100m; 1s representing regions with coverage.

Crowd Machines

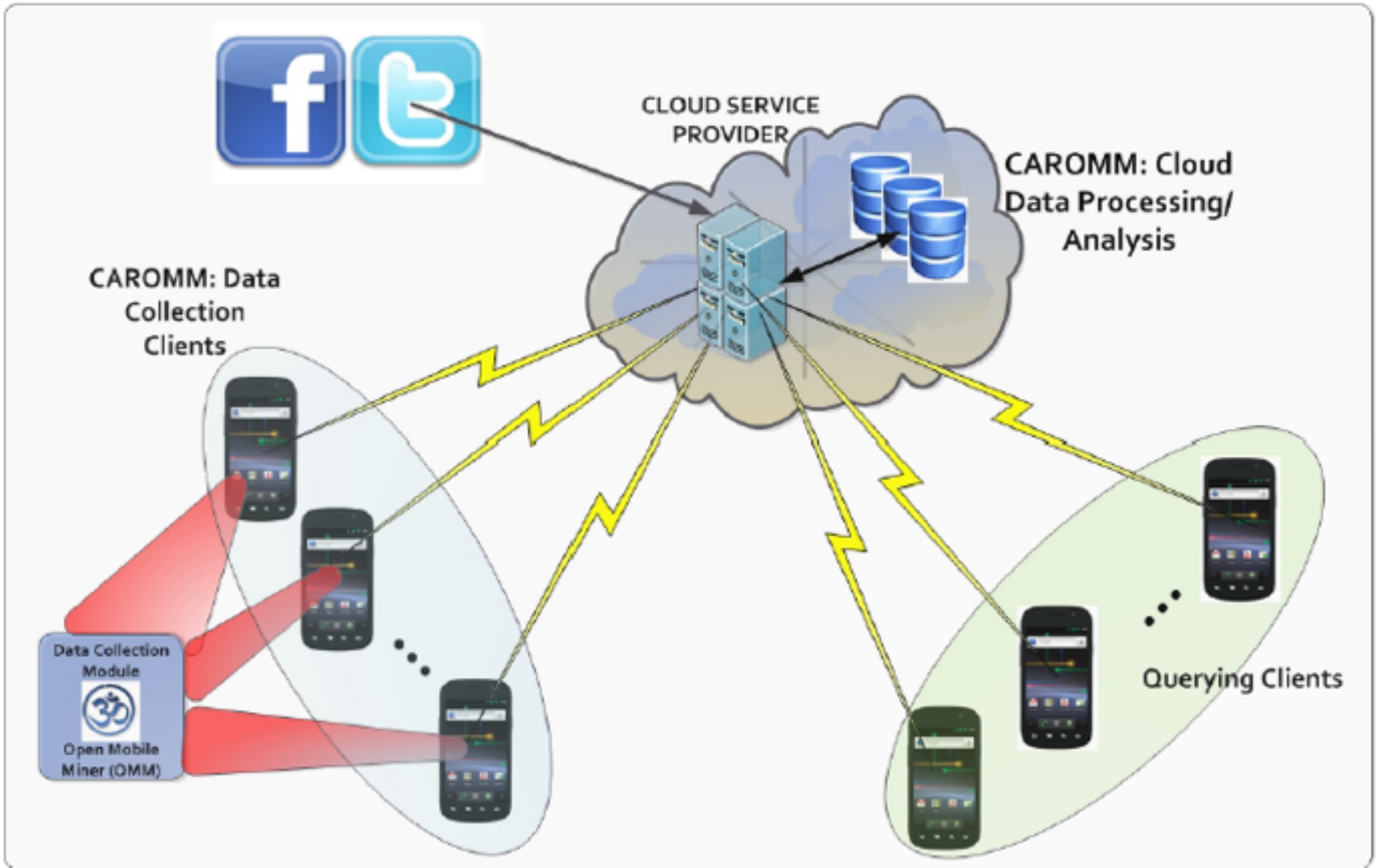
- but you can also crowdsource finding cherry blossoms to cars…via car-mounted cameras (to find scenic routes, road/traffic situations, driver behaviours, not just the shortest, use that for parking too?) [src: http://www.slideshare.net/ubilab_naist/ubicomp15sakurasensor-quasirealtime-cherrylined-roads-detection-through-participatory- Morishita et al. (2015)]



Crowd Machines

Mobile Crowdsensing

- get the mobile crowd to help you sense people behaviours in the city and place usage (understanding the city)



The CAROMM Framework

[more in: Sherchan, W.; Jayaraman, P.P.; Krishnaswamy, S.; Zaslavsky, A.; Loke, S.; Sinha, A., "Using On-the-Move Mining for Mobile Crowdsensing," 2012 IEEE 13th International Conference on Mobile Data Management (MDM), pp.115,124]

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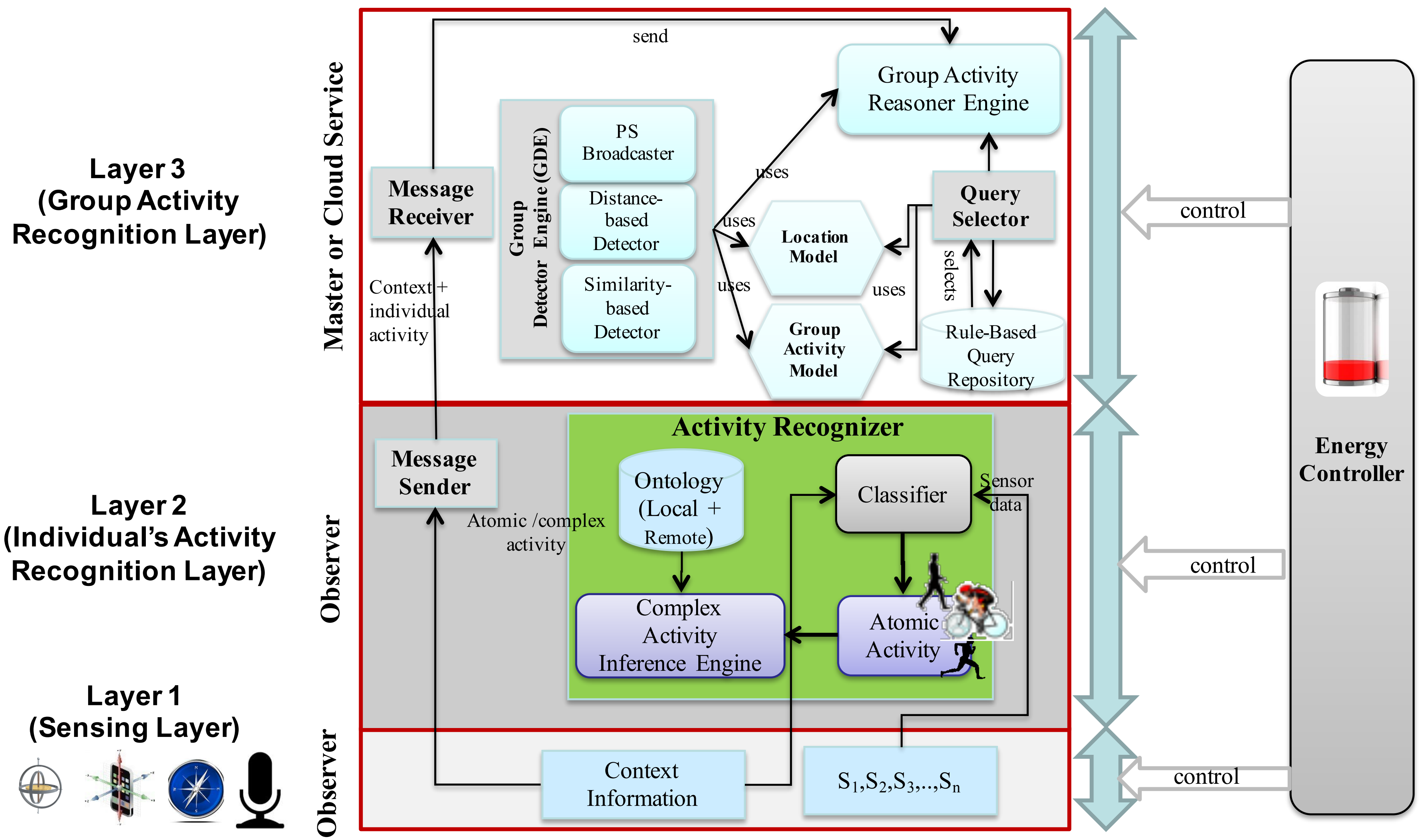
Crowd Machines

Group/Crowd Activity Recognition

- what is a crowd doing? sense group/crowd activities by aggregating and reasoning about the recognised activities of a set of individuals

Generic Architecture



[src: A. Abkenar, S.W. Loke, W. Rahayu, and A. Zaslavsky. Energy Considerations for Continuous Group Activity Recognition Using Mobile Sensor Data: the case of GroupSense, AINA'16.]

GroupSense@ LA TROBE UNIVERSITY

Inform transport decisions?

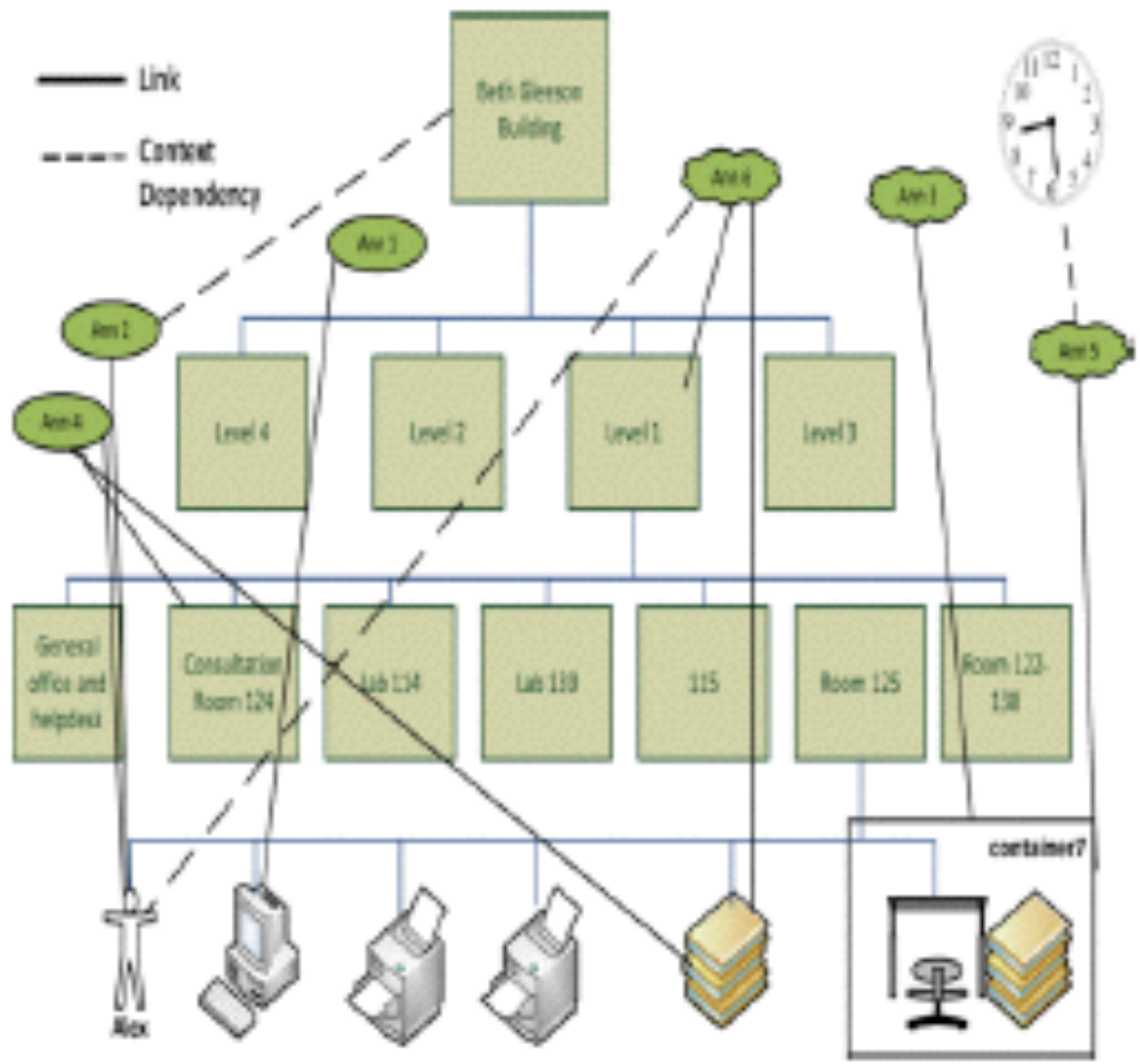
Crowd Machines

- get the mobile crowd to help you annotate the world: places and objects; others: GeoNotes, Augmented reality style apps

centralised Cloud architecture

Drones/robots/vehicles can "read" the annotations!

[src: Alzahrani, A.A., Loke, S.W., and Lu, H. An Advanced Location-Aware Physical Annotation System: from Models to Implementation. *Journal of Ambient Intelligence and Smart Environments* 6, 2014, pp. 71-91, IOS Press]



Crowd Machines

- get the crowd to help the disabled navigate from A to B or to read signs: the crowd machine is an "eye" for the blind and an "ear" for the deaf

  Loke, S.W. and Prabhanjan, B. **GuideMate: A Crowd-Powered System to Assist the Disabled.** Proceedings of the Workshop on Mobile and Situated Crowdsourcing (WMSC '15) (at Ubicomp 2015)

- others: Chorus View (http://web.eecs.umich.edu/~wlasecki/projects-conv.html) and VizWiz (http://vizwiz.org)

Crowd Machines

More from Percom 2016 and etc…

- crowdsource riding comfort/quality in buses etc (Tan et al.) [close the "loop": real-time feedback to driver?]
- crowdsource audience heartbeats for music visualization (Geigel et al. and http://www.project01x.com/pulse/)) [close the "loop": real-time usage by the musician?]
- crowds of mobile phones connect as p2p network, some nodes are relays, some nodes needing rescue can listen for messages (TeamPhone, Lu et al.)

Scalable Context-Awareness

- vision? you or your apps can become more aware of:
  - your own self: self physical activity recognition
  - the "group" of people you are currently with: group activity recognition
  - the environment and situation 20m around you
  - the environment and situation 100m around you
  - the environment and situation 300m around you
  - the environment and situation 3km around you
  - …
  - the environment and situation 500m from me, radius of 200m
  - …
- combining social media data, crowd sensed data, and sensor network data

[image for illustration from: https://dzone.com/articles/executing-and-testing]

Extreme Cooperation

- Vision: people (with their devices such as cars, smartphones, smart*) can now *cooperate more than ever: as needed, ad hoc, transient*, e.g., to find carpark, to avoid congestion, to get coffee, etc…

Extreme Cooperation

v2v communication is here, for Autonomous Vehicles and/or normal cars…

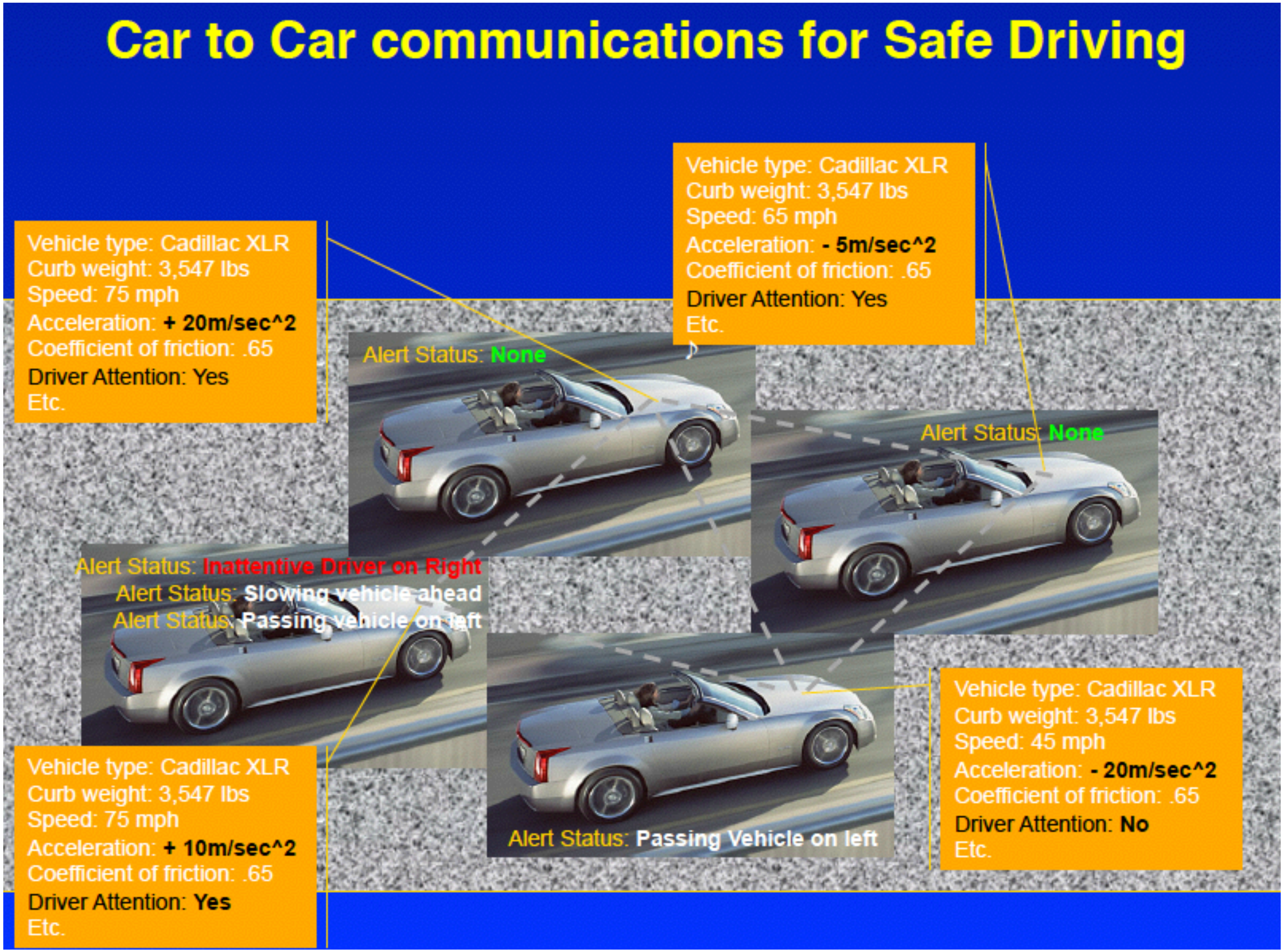
e.g.,

- https://www.technologyreview.com/s/534981/car-to-car-communication/
- GM: V2V technology in its 2017 Cadillac CTS sedans? [http://www.claimsjournal.com/news/national/2015/06/26/264208.htm]

And v2p (e.g., http://www.digitaltrends.com/cars/google-patents-car-to-pedestrian-communication-system/), v2i, etc…

[src: M. Gerla, Professor at UCLA, http://nrlweb.cs.ucla.edu/publication/slides/779/Gerla_Vision.pdf]

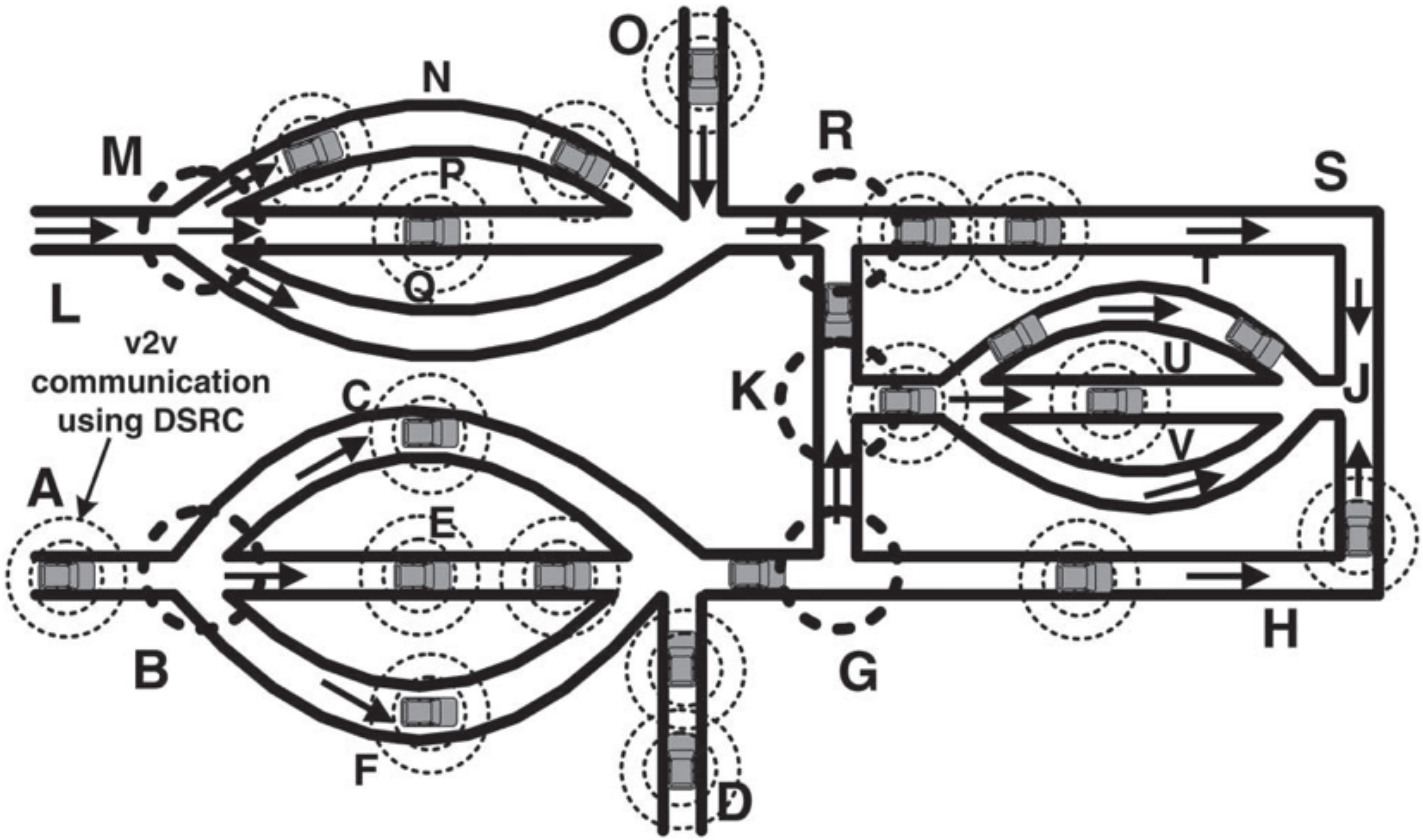
Extreme Cooperation



[src: M. Gerla, Professor at UCLA, http://nrlweb.cs.ucla.edu/publication/slides/779/Gerla_Vision.pdf]

Extreme Cooperation

Cars cooperate to avoid congestion



[src: Prajakta Desai, Seng Wai Loke, Aniruddha Desai, Jugdutt Singh: CARAVAN: Congestion Avoidance and Route Allocation Using Virtual Agent Negotiation. IEEE Transactions on Intelligent Transportation Systems 14(3): 1197-1207 (2013)]

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Extreme Cooperation

Cars cooperate to avoid congestion

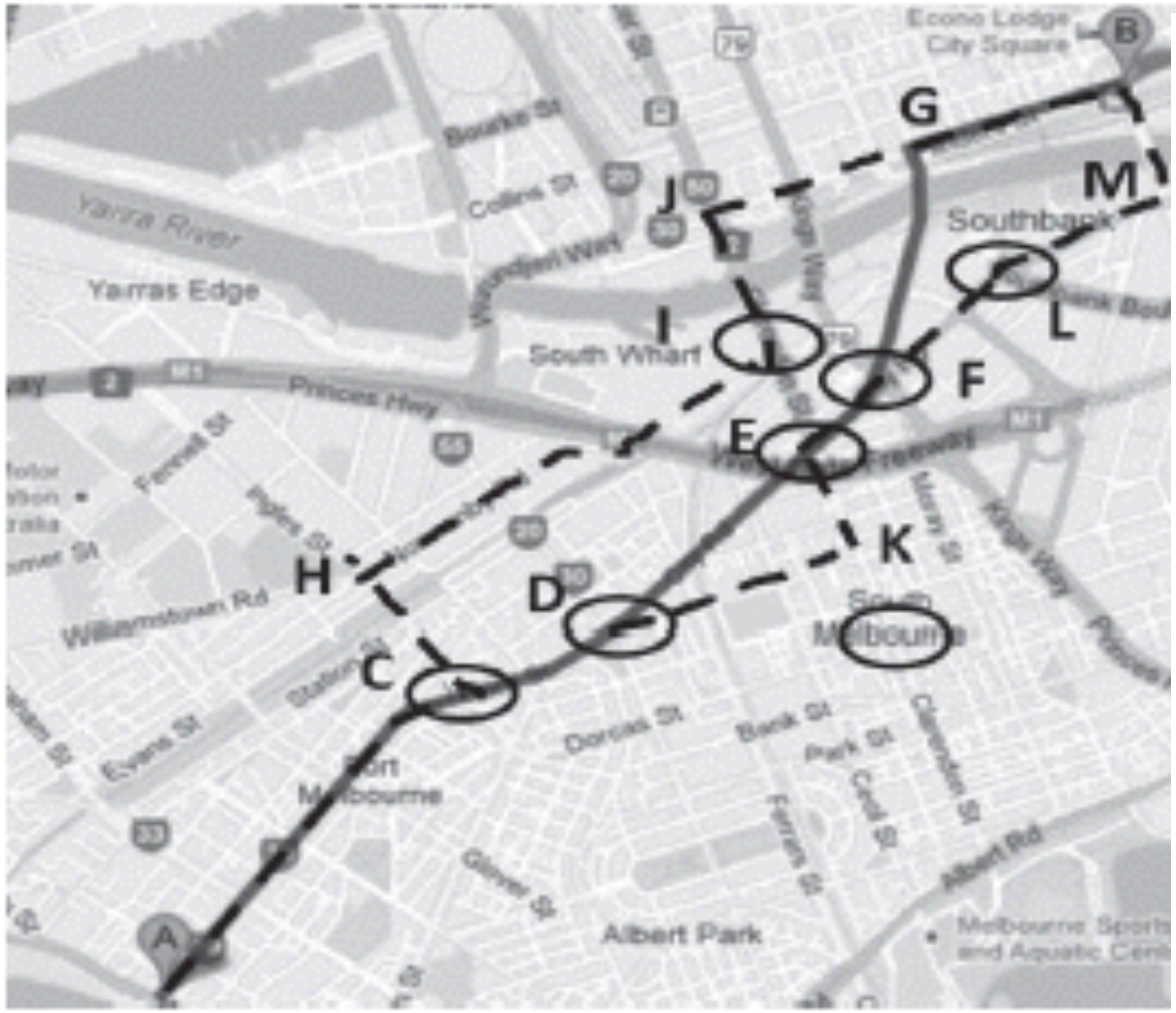

Fig. 5. Road network near the Melbourne Central Business District. (Ovals) Seven junctions. (Continuous line) Shortest path from A to B (A-C-D-E-F-G-B). (Dotted lines) Paths from applying CARAVAN for random vehicles #13 (A-C-H-I-J-G-B) and #19 (A-C-D-K-E-F-L-M-B).

TABLE V

PERFORMANCE OF CARAVAN FOR A MULTIJUNCTION SCENARIO (% GAIN IN TRAVEL TIME OVER NONCOOPERATIVE SHORTEST PATH)

No. of Junctions	No. of Vehicles	Social Welfare	Rational Welfare	Mixed Welfare
15	36	36.42	36.12	36.31
10	36	34.04	33.60	33.90
	30	38.79	38.64	38.72
5	36	33.81	33.21	33.68
	30	34.27	33.98	34.12
	24	43.31	43.29	43.31
3	18	32.91	32.64	32.64
	15	32.96	32.38	32.65
	12	38.31	38.30	38.31
1	16	26.07	25.22	25.22
	13	24.00	22.00	23.00
	10	21.26	21.26	21.26

[src: Prajakta Desai, Seng Wai Loke, Aniruddha Desai, Jugdutt Singh: CARAVAN: Congestion Avoidance and Route Allocation Using Virtual Agent Negotiation. IEEE Transactions on Intelligent Transportation Systems 14(3): 1197-1207 (2013)]

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Extreme Cooperation

Cars That Think | Transportation | Efficiency

Cooperative Route Planning Could Make Driving Slightly Less Terrible For Everyone

By Evan Ackerman
Posted 15 Mar 2016 | 16:00 GMT

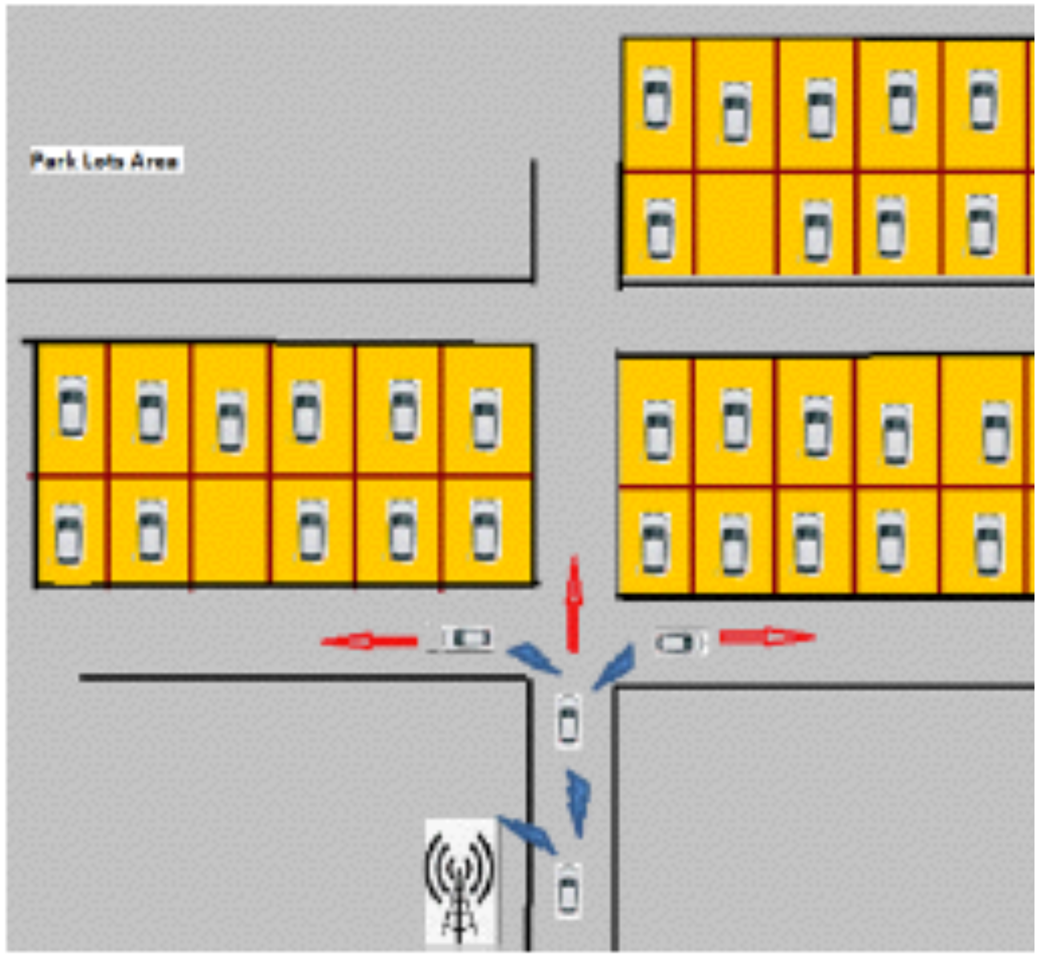
Researchers at MIT have shown (in simulations, anyway) that if we were all willing to take a wider variety of coordinated routes that may not be optimized on an individual level, it would yield an overall reduction in congestion. Your route might not be the most direct, but you'd be helping most other drivers—and though it's counterintuitive, probably yourself too—save a few minutes, because of a reduction in overall congestion (the additional travel time due to traffic compared with free flow conditions). In simulations of traffic conditions in cities such as San Francisco and Boston, congestion was reduced by as much as 30 percent. And all you have to do is be just a tiny bit considerate.

Image: Mapbox/OpenStreetMap/MIT

The figure on the right shows three possible routes from downtown San Francisco to the San Francisco airport. The purple route straight down the bay is the fastest, most "selfish." It rates a zero. Ideally, it would take the driver 20 minutes. The socially optimal route on the far left, which rates a 1, would take the driver 25 minutes to traverse. Taking the little optional offshoot in the middle (with a value of 0.1) would add 2 minutes to the trip, for a total of 22 minutes. However, if a significant number of people followed that 0.1-rated route, the average trip length for everyone attempting to get to the airport from downtown would be reduced by 2 minutes. The upshot: a small fraction of drivers might spend an extra 5 to 7 minutes on the road, but most drivers would save a few minutes, and some drivers would save more than 10 minutes. "Some," in the case of a city like San Francisco, means tens of thousands.

Extreme Cooperation

Cars cooperate to improve car parking



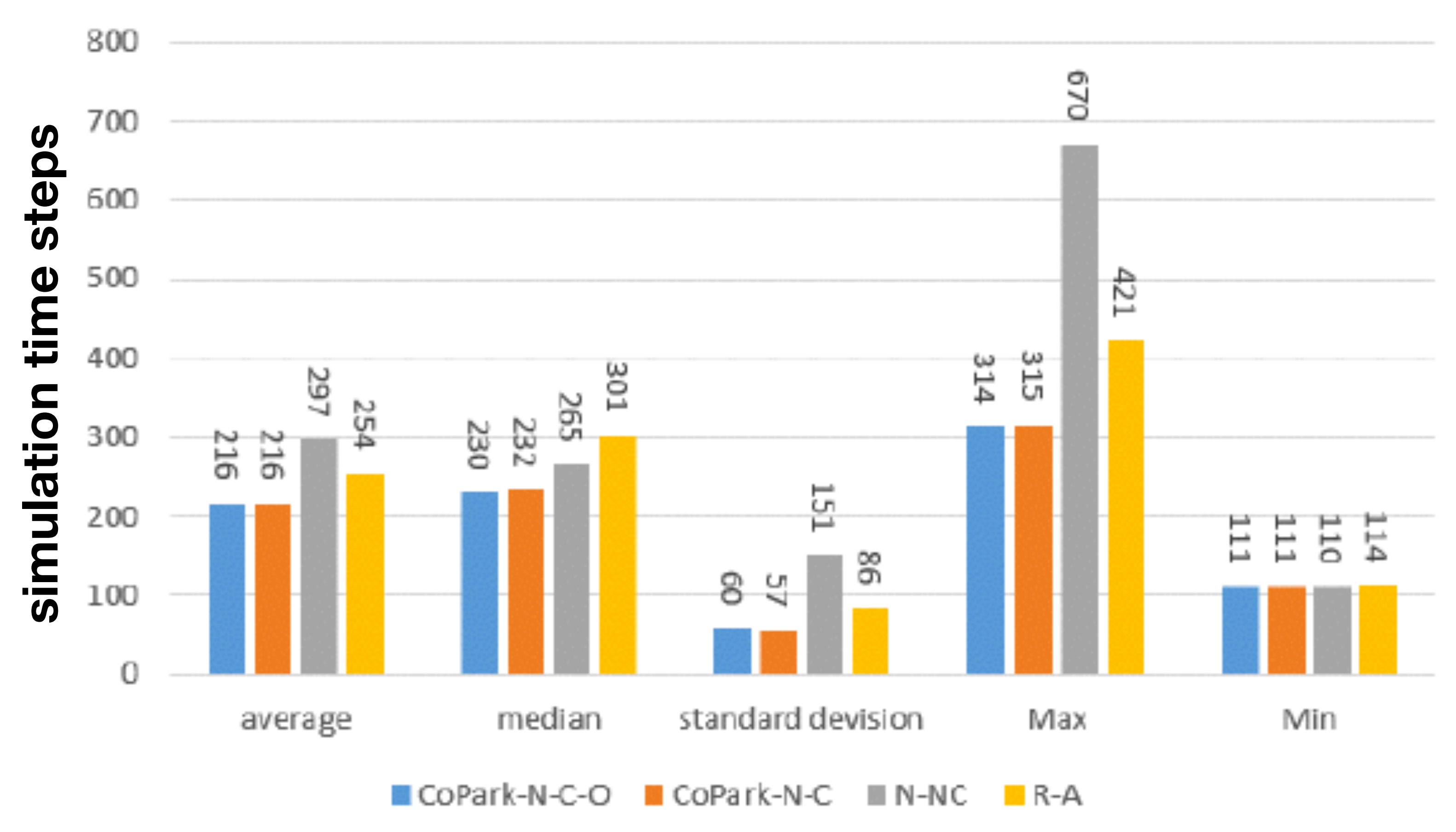


Figure-8 the comparison among CoPark-N-C-O, CoPark-N-C, N-NC and RA algorithms by determining the time to park (measured based on number of simulation execution step) of eleven cars and collecting minimum, maximum, average, median and standard division.

Setting: 20 cars targeting 11 spaces in a carpark area, using SUMO and Jade

[src:Ali N.M. Aliedani, PhD Student, unpublished]

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Extreme Cooperation

From: Article in IEEE ITS Magazine, summer 2015

Cars cooperate and share info (a msg on leaving and on occupying) to improve car parking

The Potential Impact of Vehicle-to-Vehicle and Sensor-to-Vehicle Communication in Urban Parking

Geert Tasseron, Karel Martens, and Rob van der Heijden
Nijmegen School of Management, Radboud University Nijmegen, The Netherlands
E-mails: g.tasseronfm.runl, k.martens@fm.ru.nl, r.vanderheijden@fm.ru.nl

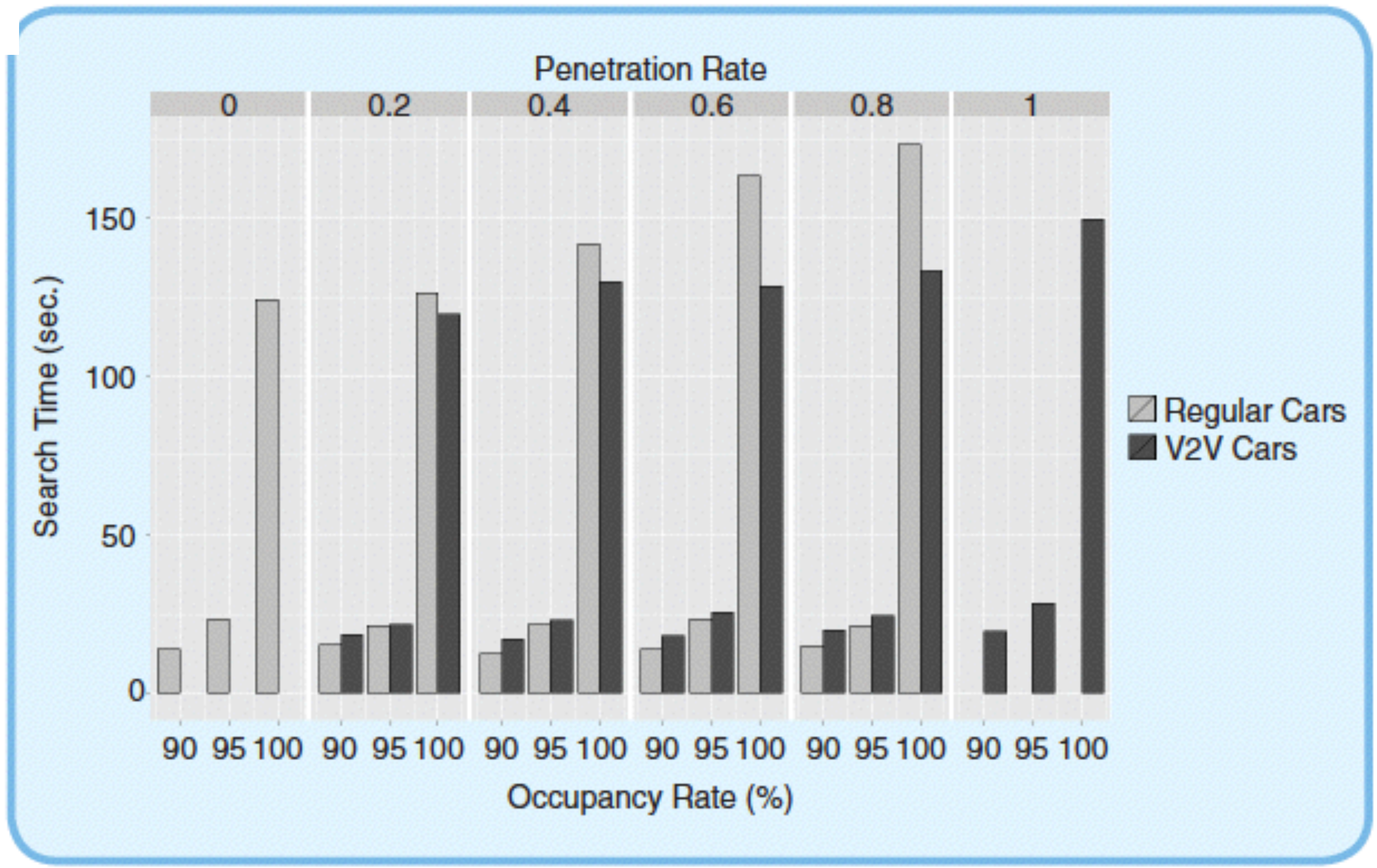


FIG 4 Search time for regular cars and V2V cars, for different occupancy rates and penetration rates, for V2V communication strategy.

Extreme Cooperation

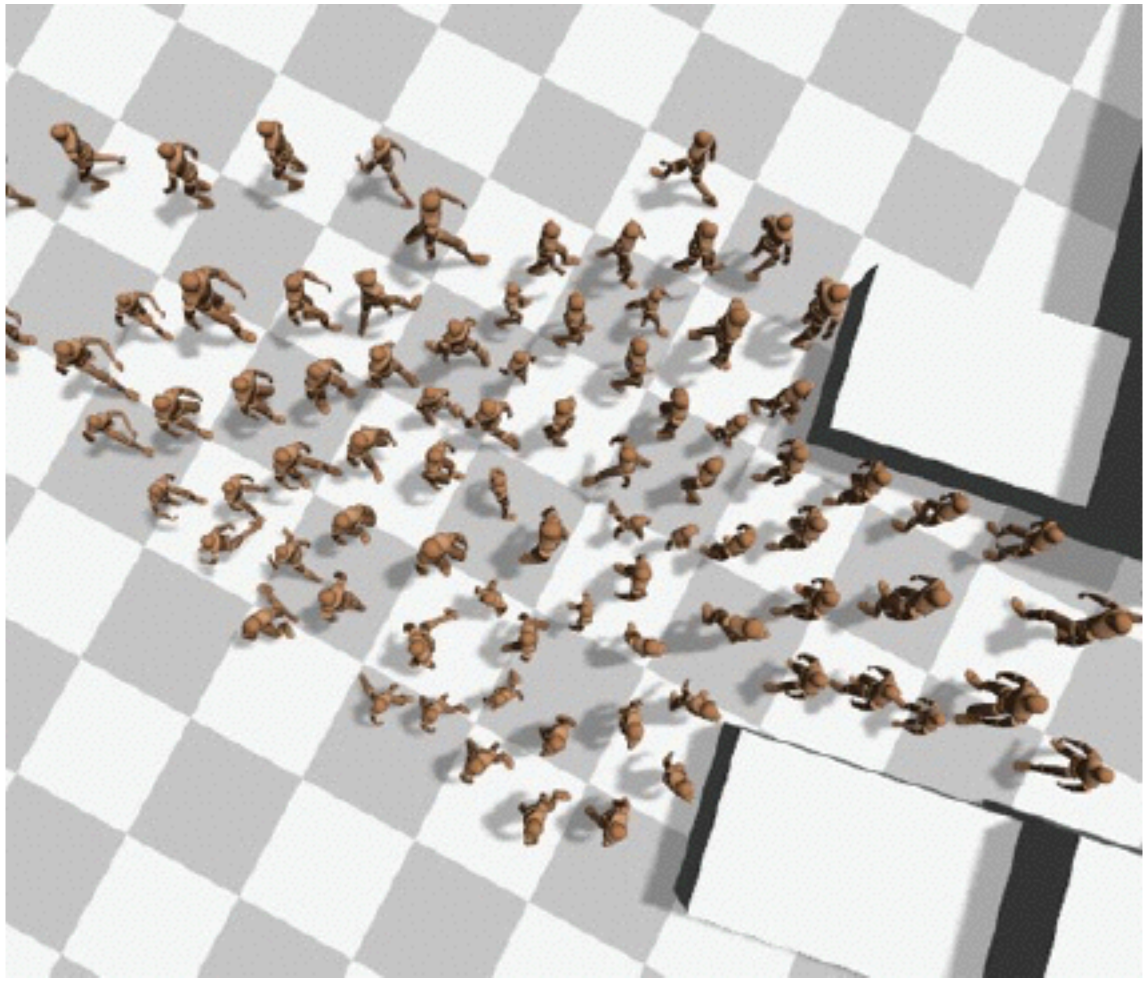
- a basic game theory analysis: illustrating the case for cooperation (coordinating actions)

	Car B chooses route1	Car B chooses route2
Car A chooses route1	Travel time for A: 25min Travel time for B: 25min	Travel time for A: 15min Travel time for B: 20min
Car A chooses route2	Travel time for A: 20min Travel time for B: 15min	Travel time for A: 30min Travel time for B: 30min

	Car B chooses space1	Car B chooses space2
Car A chooses space1	Time to park for A: 30min Time to park for B: 30min	Travel time for A: 15min Travel time for B: 20min
Car A chooses space2	Travel time for A: 20min Travel time for B: 15min	Time to park for A: 30min Time to park for B: 30min

Extreme Cooperation

- crowd-steering: e.g., each of 1000 or 100,000 mobile users is given some instructions (in emergency evacuation, in simple crowd control, in going home…, etc)[http://www.seas.upenn.edu/~mubbasir/]; see also http://www.aware-project.eu/documents/awass-2012/CrowdSteeringCaseStudy.pdf (music festival)



Drone Services for Mobile Crowds

- drones to provide services for crowds of people on the move: e.g., emergency, photo-taking from “impossible angles”, data storage on-demand, guidance on demand, safety cameras that follow you, etc…

[src: http://calmfiredrones.com/drone-commercial-services/]

Loke, S.W. **Smart Environments as Places Serviced by k-Drone Systems**. *Journal of Ambient Intelligence and Smart Environments.* (to appear, 2016)

[src: http://www.dailymail.co.uk/sciencetech/article-2520818/DHL-tests-delivery-drone-airborne-robots-used-deliver-medicine.html]

- what happens when a crowd of drones belonging to a crowd of people get together and are shared?

Concluding Remarks

collective computing + mobile computing = crowd-powered mobile computing

From this talk, four ideas to keep exploring?
Crowd Machines
Scalable Context-Awareness
Extreme Cooperation
Drone Services for Mobile Crowds
Lots of challenges!

For a future of smarter transport?!

Thank you!

Please check out papers at
http://homepage.cs.latrobe.edu.au/sloke