Green Internet of Things for Smart Cities

Prof. Victor C. M. Leung

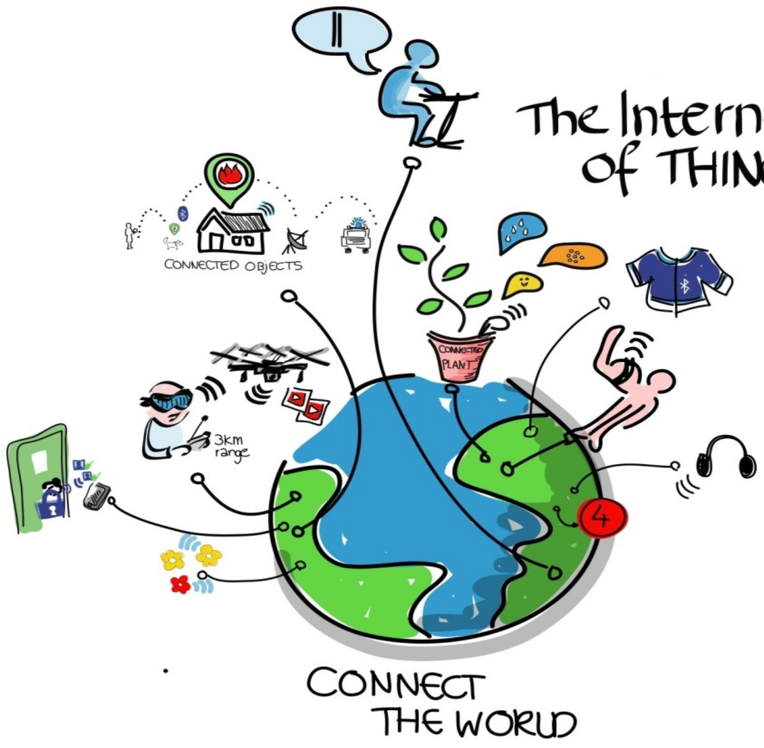
Department of Electrical and Computer Engineering
The University of British Columbia
Vancouver, Canada
http://www.ece.ubc.ca/~vleung/
vleung@ece.ubc.ca

International Workshop on Smart Cities and Urban Informatics, Hong Kong April 27, 2015

Outline

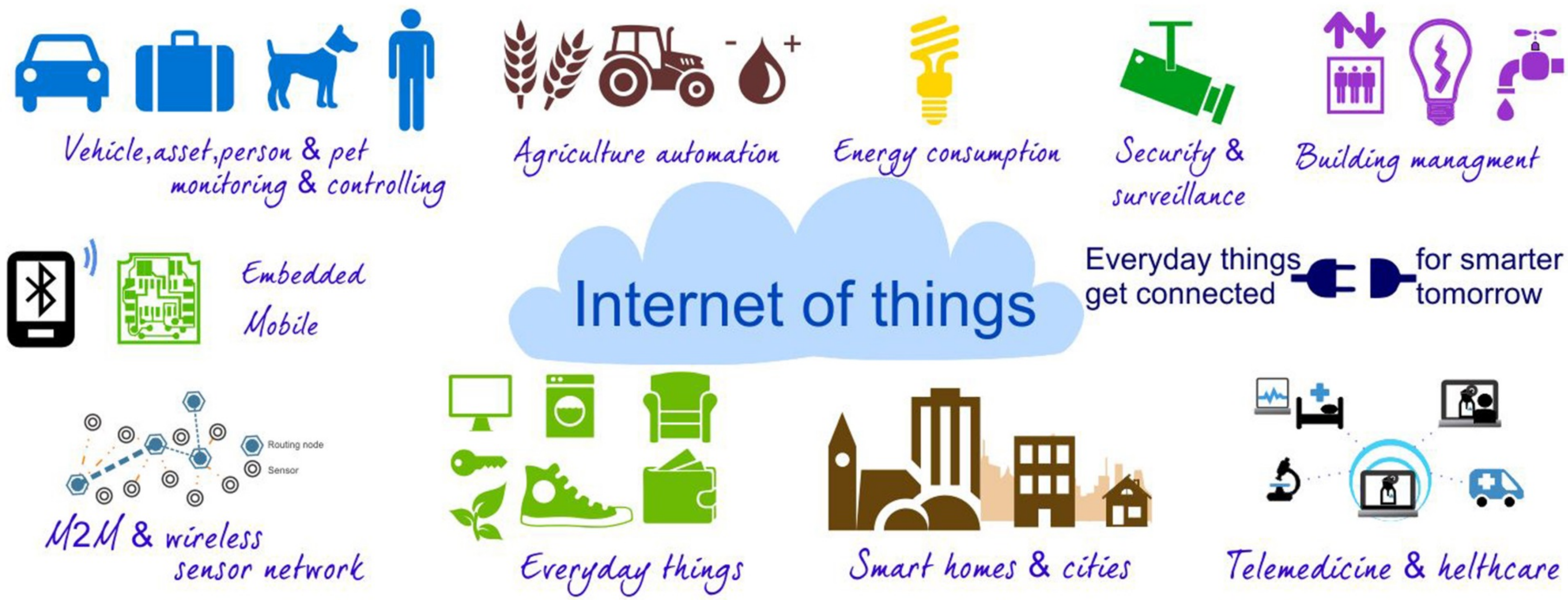
- Internet of Things (IoT)
- IoT as enabler of green society
- Technologies for green IoT
- Sensor-cloud integration schemes towards green IoT
- Research directions and open problems
- Conclusions

Internet of Things (IoT)



What is IoT?

- Internetworking of a variety of objects (e.g., sensors, actuators, mobile phones, appliances) with unique addresses to enable their interactions with each other and with the cyber world
- RFID, WSN, WPAN, WBAN, HAN, NAN, M2M, gateways, IP, telemetry, command-control, client-server, cloud computing, big data

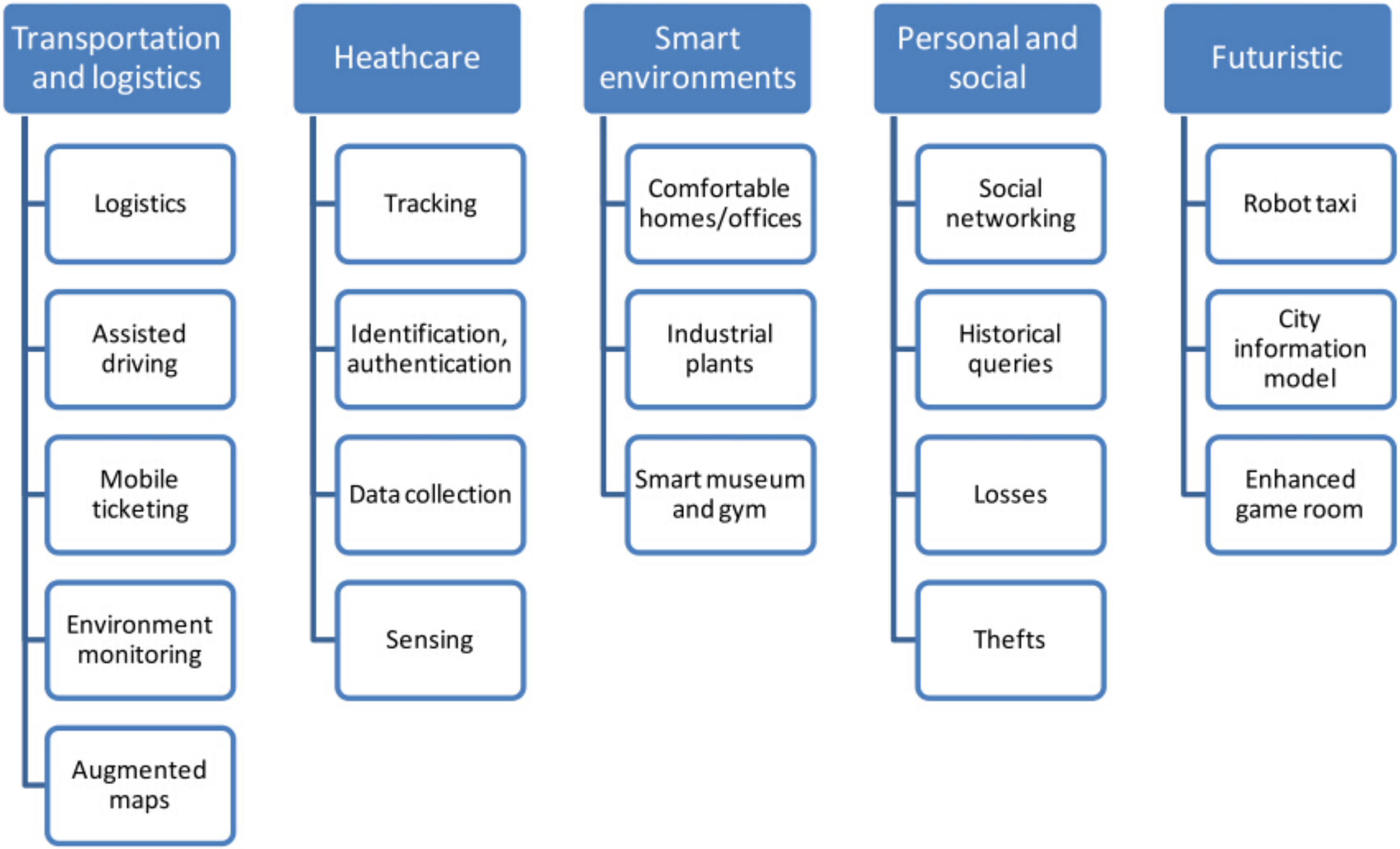


Why is IoT important?

According to the US National Intelligence Council:

- IoT is one of six "Disruptive Civil Technologies" with potential impacts on national power of USA
- "by 2025 Internet nodes may reside in everyday things – food packages, furniture, paper documents, and more"
- "popular demand combined with technology advances could drive wide-spread diffusion of an IoT that could, like the present Internet, contribute invaluably to economic development"
- "to the extent that everyday objects become information security risks, the IoT could distribute those risks far more widely than the Internet has to date"

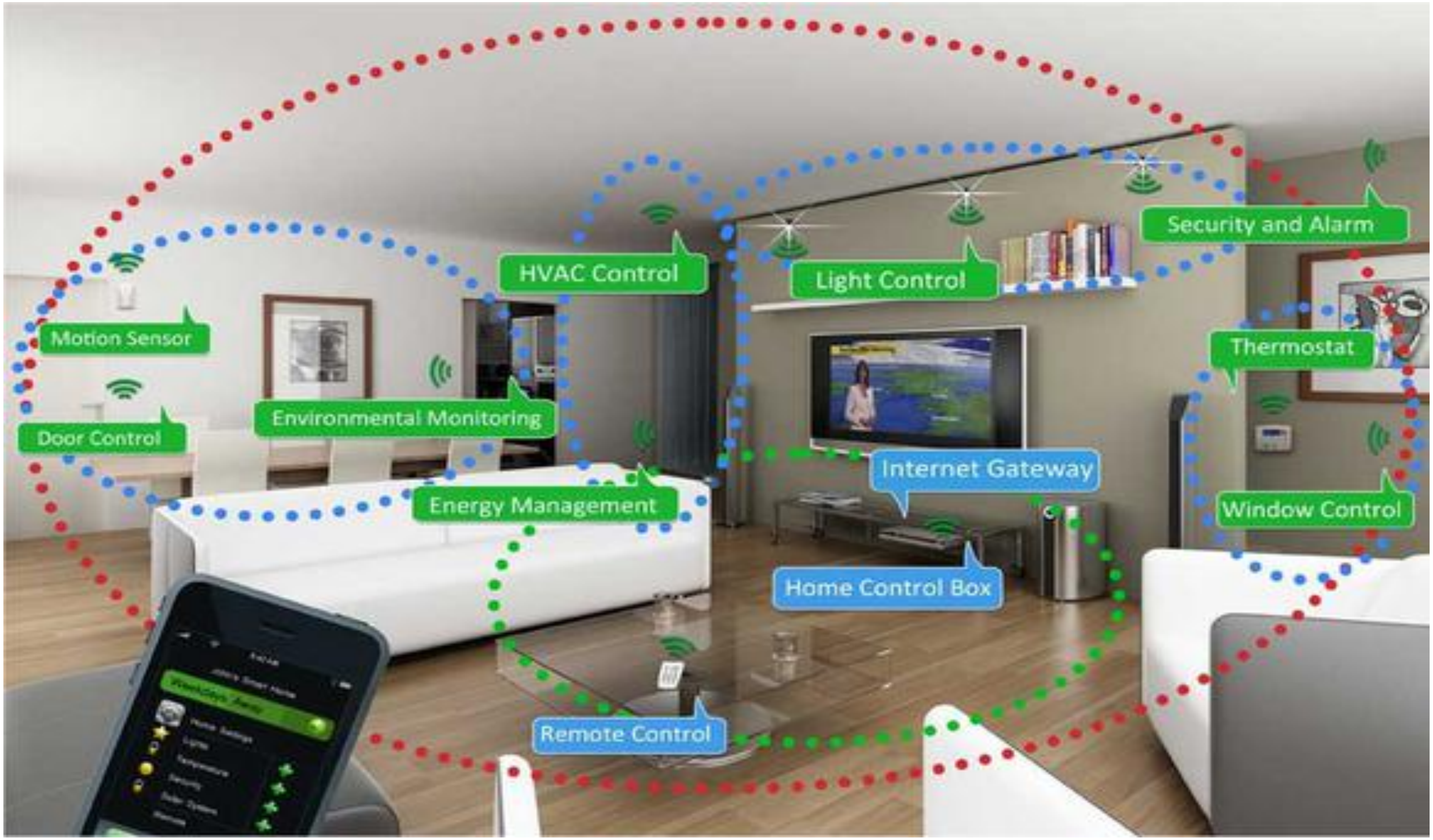
Applications of IoT



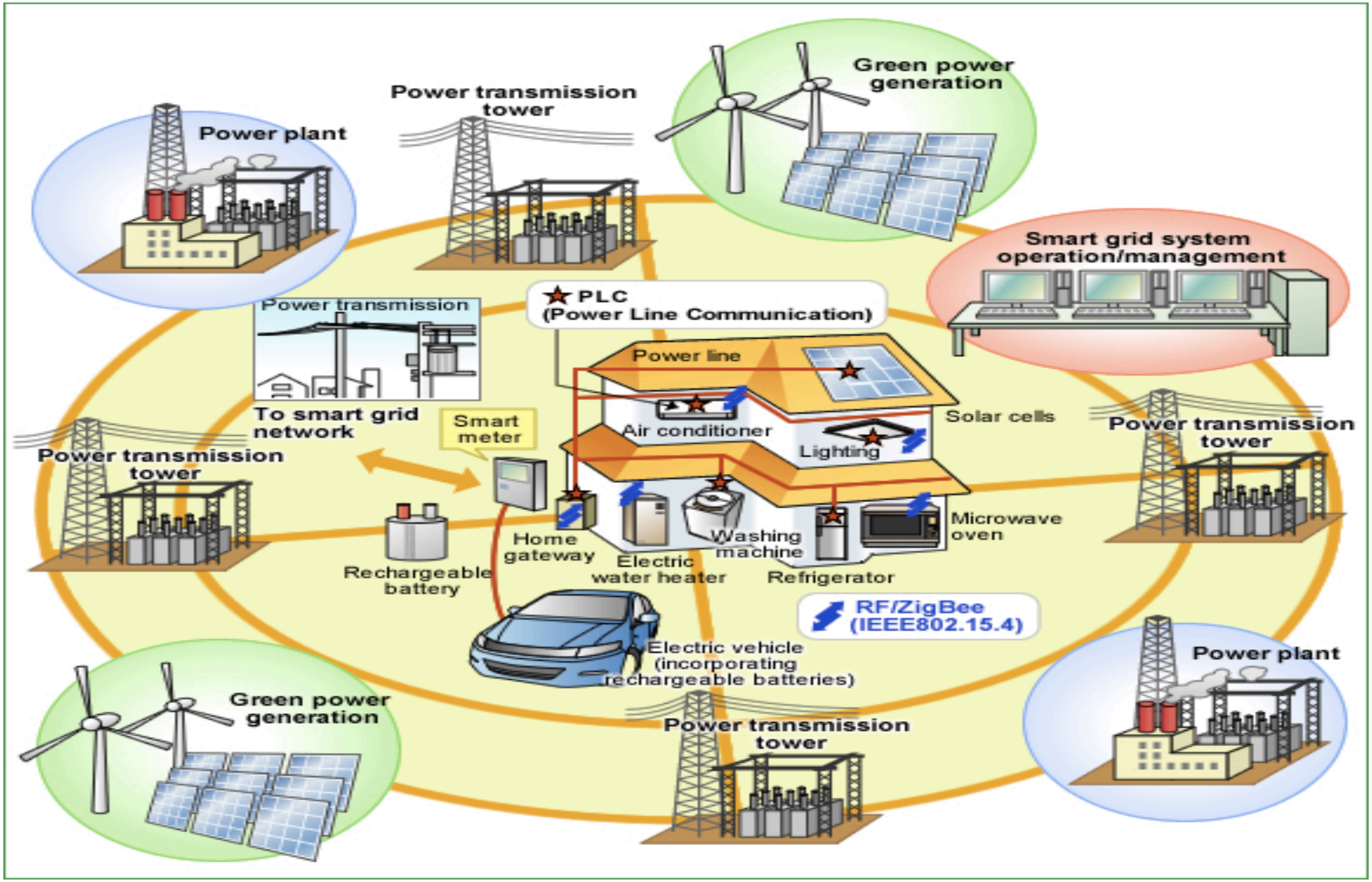
IoT Enables Green Society

- More sustainable society through reduction of energy consumption, GHG emission
- Smart environments (homes, offices, factories)
- Smart grid
- Mobile e-health
- Intelligent transportation
- Smart cities

Smart (Home) Environment



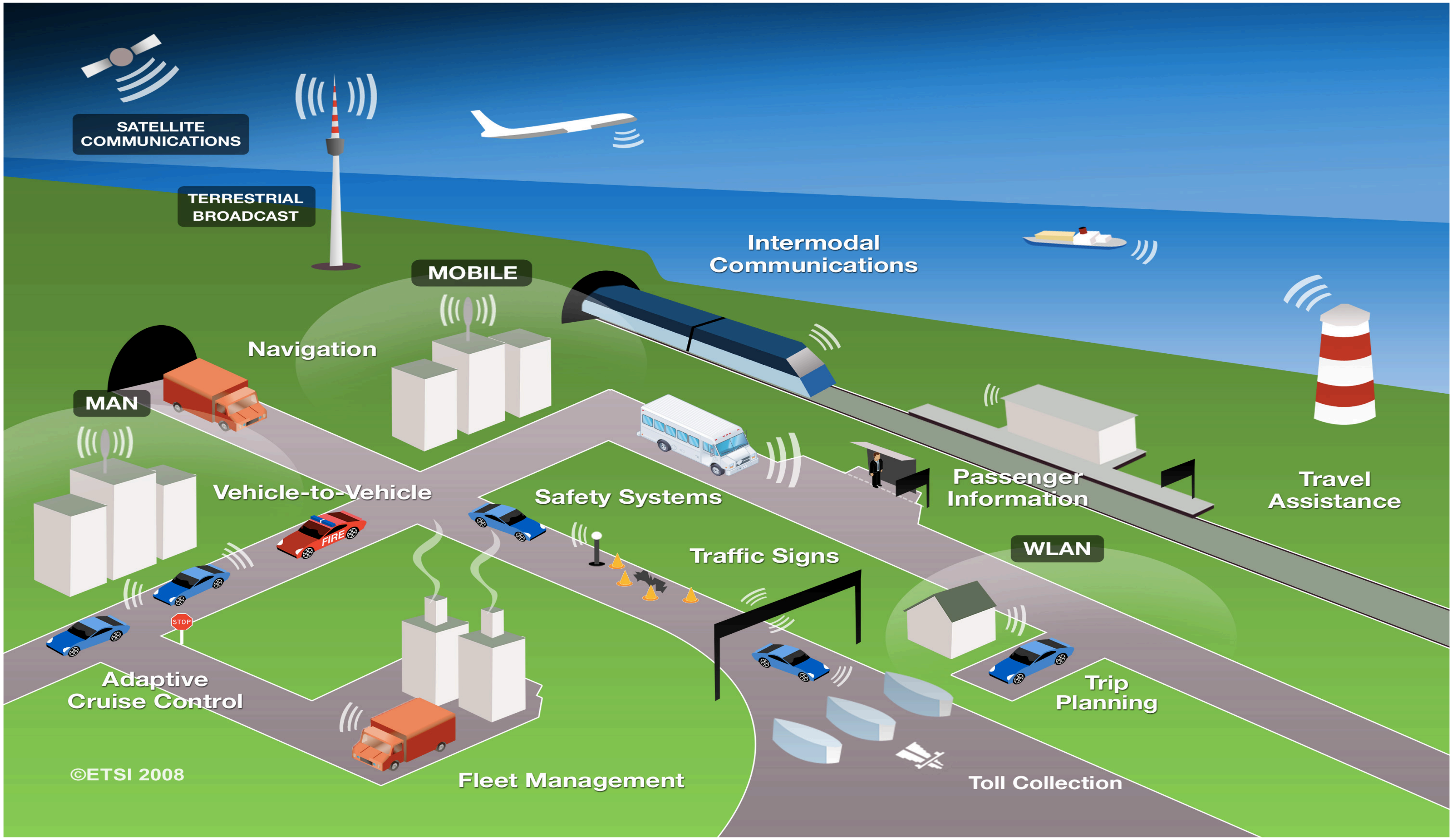
Smart Grid



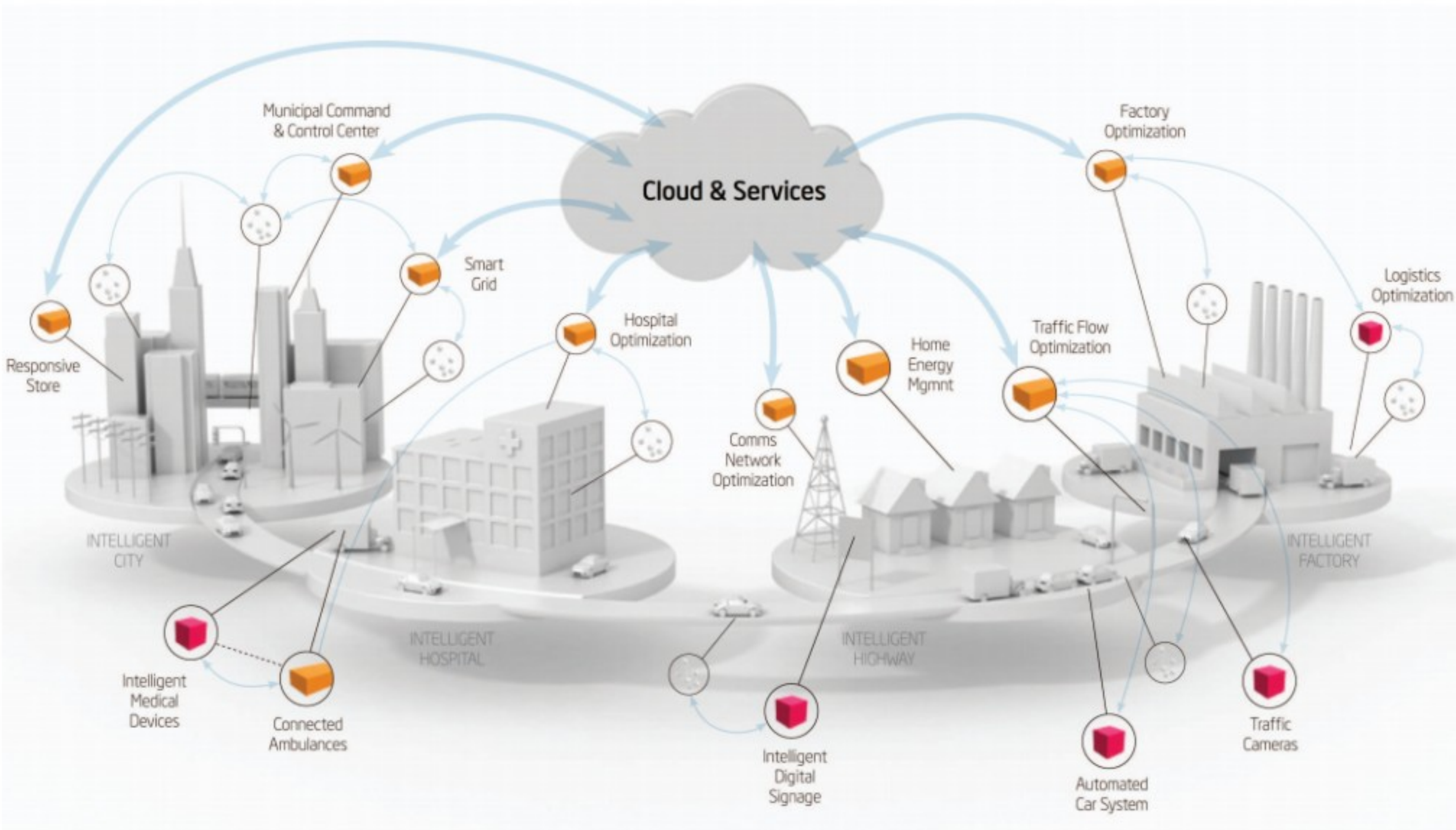
Power plant
Power transmission tower
Green power generation
Smart grid system operation/management
PLC (Power Line Communication)
Power transmission
To smart grid network
Smart meter
Power line
Air conditioner
Solar cells
Lighting
Power transmission tower
Power transmission tower
Microwave oven
Home gateway
Electric water heater
Washing machine
Refrigerator
Rechargeable battery
RF/ZigBee (IEEE802.15.4)
Electric vehicle (incorporating rechargeable batteries)
Power plant
Green power generation
Power transmission tower

Mobile eHealth

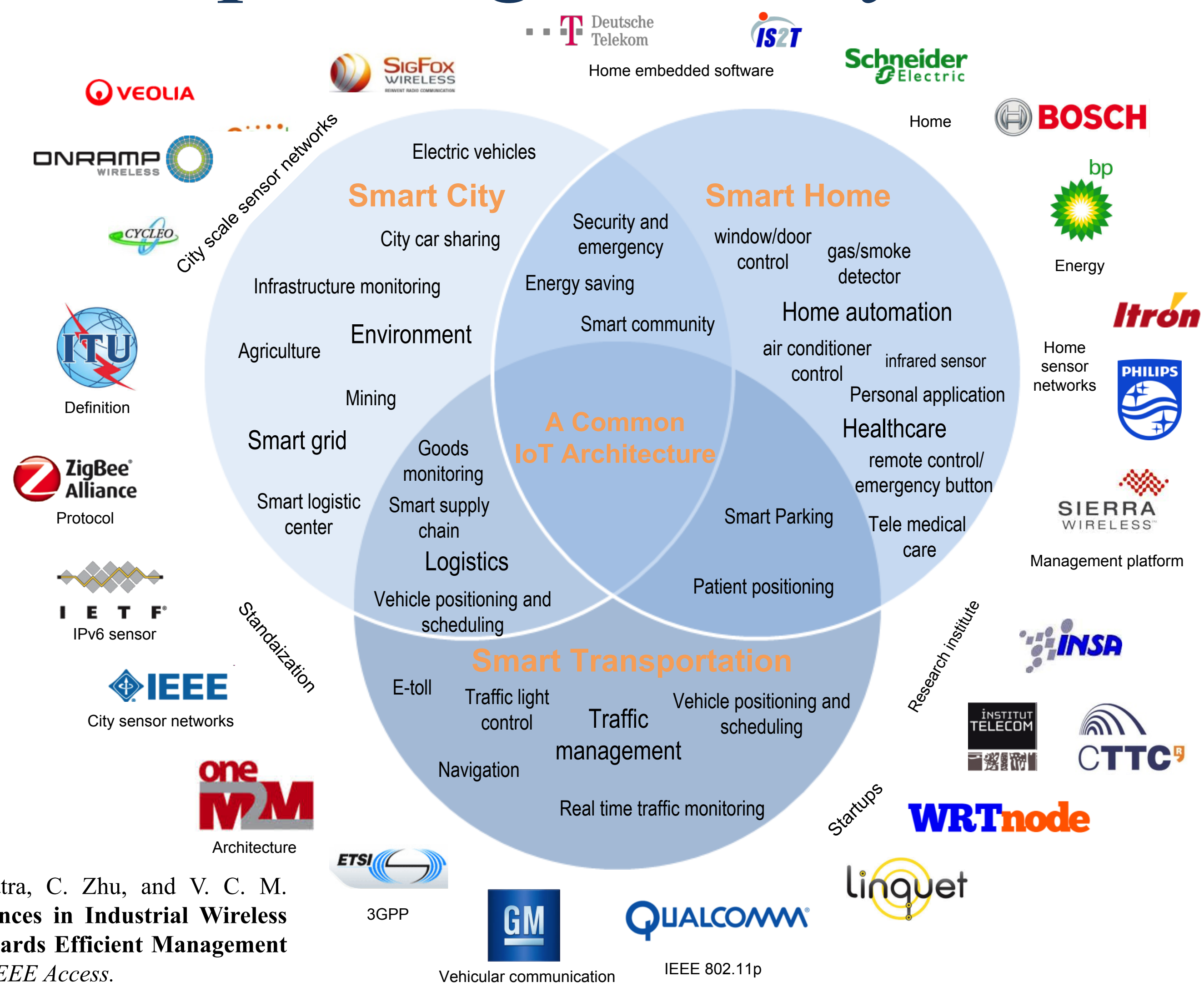
Intelligent Transportation



Smart City


Municipal Command
& Control Center
Cloud & Services
Factory
Optimization
Smart
Grid
Logistics
Optimization
Hospital
Optimization
Traffic Flow
Optimization
Responsive
Store
Home
Energy
Mgmnt
Comms
Network
Optimization
INTELLIGENT
CITY
INTELLIGENT
FACTORY
INTELLIGENT
HOSPITAL
INTELLIGENT
HIGHWAY
Intelligent
Medical
Devices
Connected
Ambulances
Intelligent
Digital
Signage
Automated
Car System
Traffic
Cameras

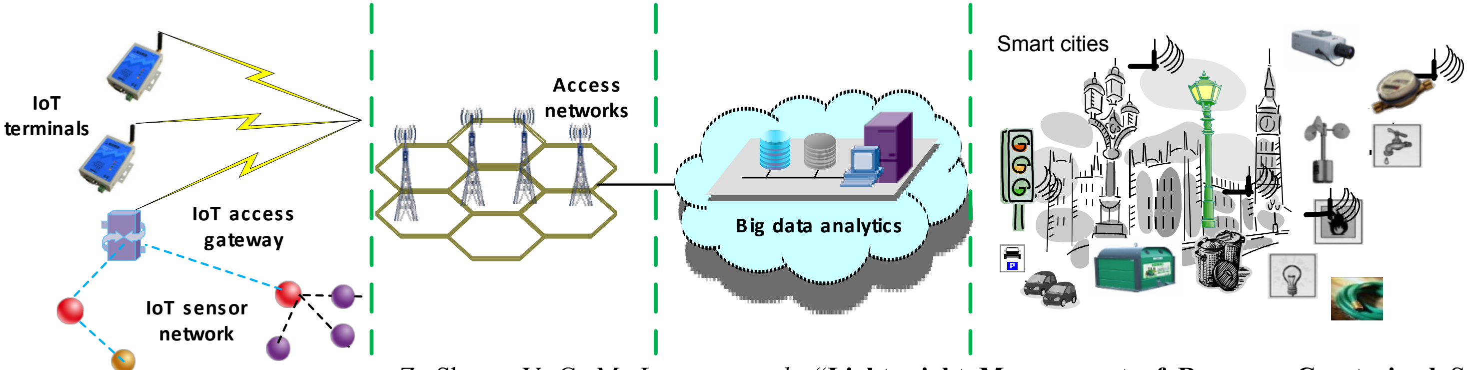
One paradigm, many visions



Z. Sheng, C. Mahapatra, C. Zhu, and V. C. M. Leung, "**Recent Advances in Industrial Wireless Sensor Networks Towards Efficient Management in IoT**," submitted to *IEEE Access*.

Smart city needs green IoT

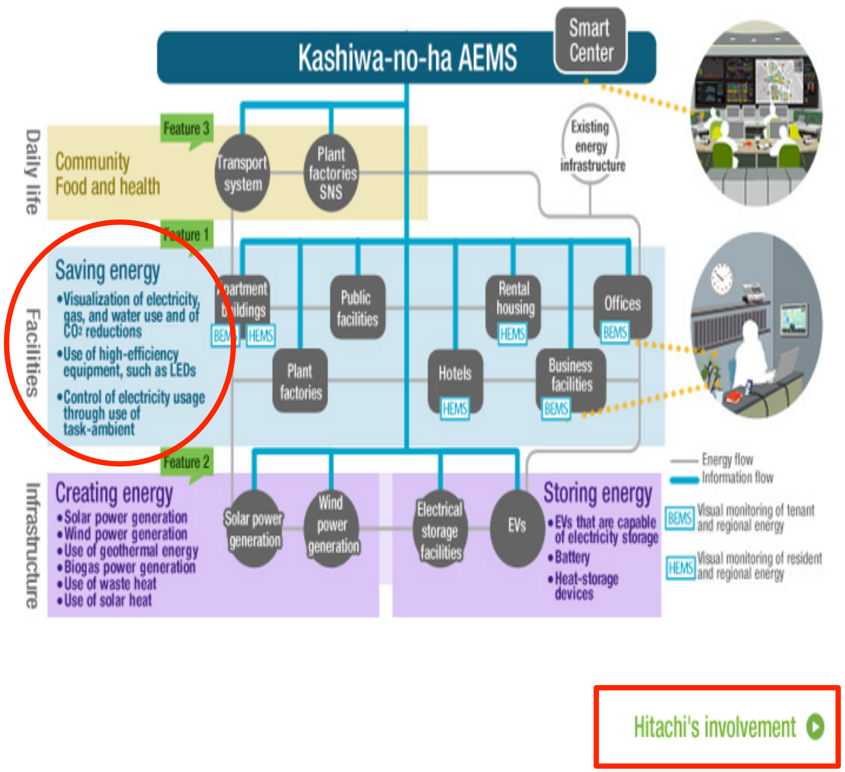
- City developments in a global scale
  - 60% of the world population expected to live in urban cities by 2025
  - 30 mega cities globally, with 55% in developing countries by 2023
- Challenges
  - Reduce costs and resource consumption
  - Engage more effectively and actively with its citizens
- Solution
  - Green IoT to provide sustainability and low-carbon solutions



Z. Sheng, V. C. M. Leung, *et. al.*, "**Lightweight Management of Resource Constrained Sensor Devices in Internet-of-Things**," *IEEE Internet-of-Things Journal, 2015 (to appear).*

Smart city needs green IoT

- Enhance performance and wellbeing
- Reduce costs and resource consumption
- Engage more effectively and actively with its citizens



Green IoT

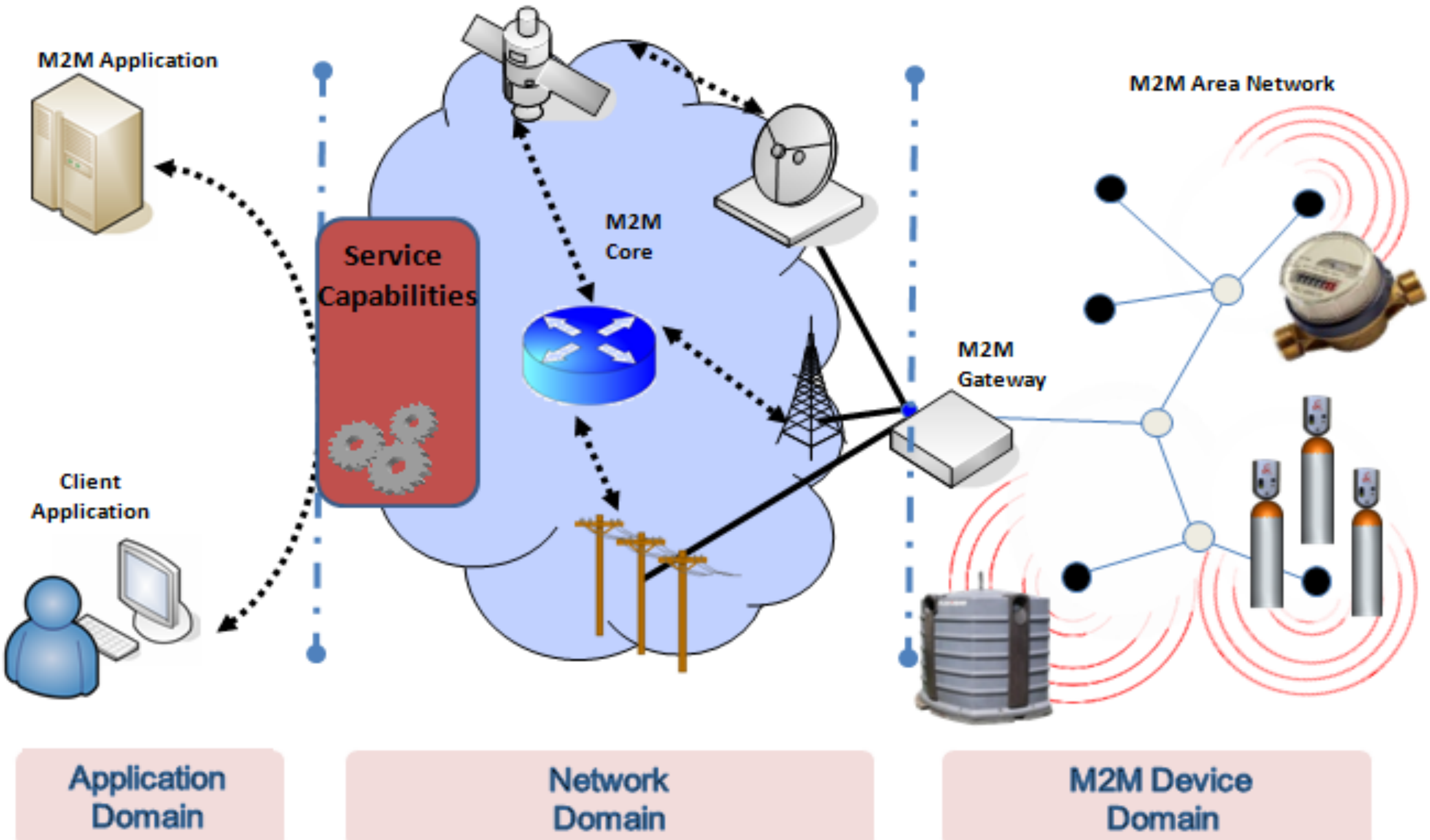
What is green IoT?

- IoT system tasked with enabling a greener society
- Reducing energy consumption of IoT systems while satisfying mission objectives
- Green ICT: communications, networking, data processing

ICT Technologies Enabling IoT

- Identification, sensor and actuator technologies
- Communication technologies
- Network technologies
- Embedded hardware platforms
- Software and algorithms
- Cloud platform
- Data management

ICT Technologies Enabling IoT

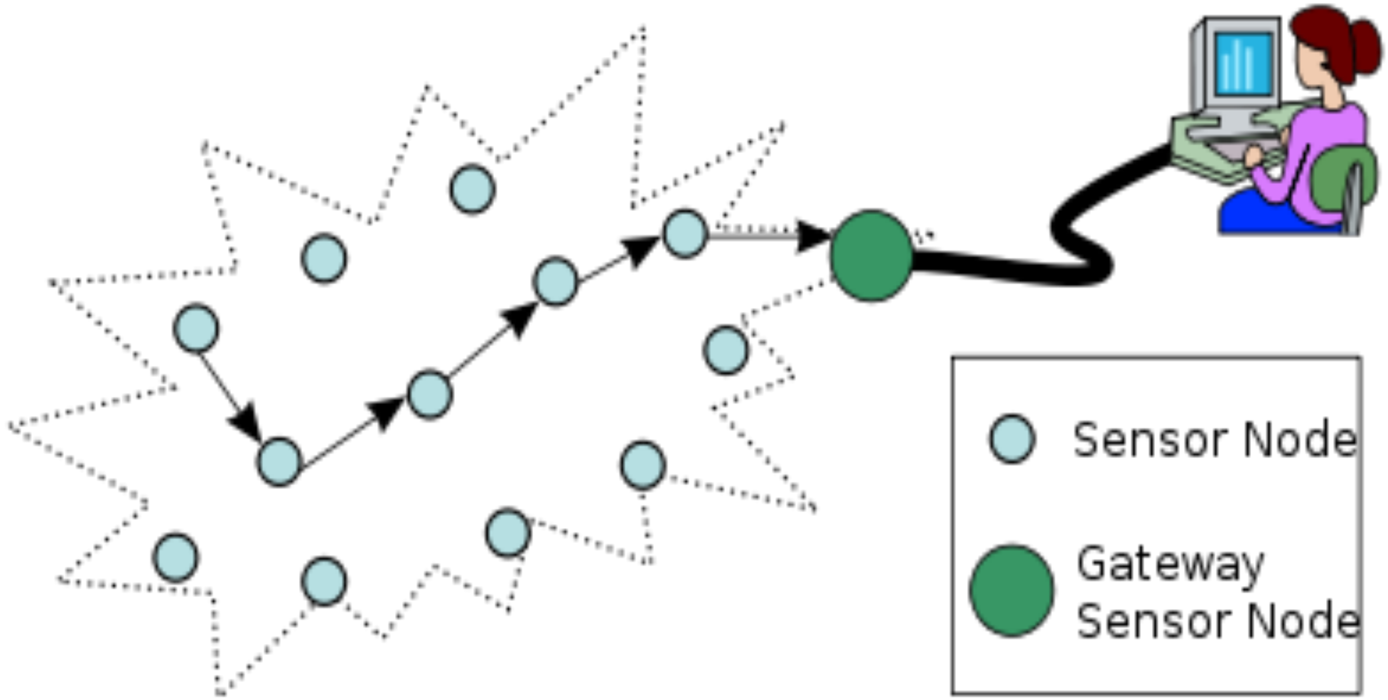


General Principles of Green ICT

- Turn off facilities that are not needed
  - E.g., sleep scheduling
- Send only data that are needed
- Minimize length of data path
  - E.g,, energy-efficient routing schemes
- Minimize length of wireless data path
  - E.g., energy-efficient architectural design, cooperative relaying
- Trade off processing for communications
  - E.g., data fusion, compressive sensing
- Advanced communication techniques
  - E.g., MIMO, cognitive radio
- Renewable green power sources

Green Wireless Sensor Networks

- Battery power conservation has been a key objective of research on WSN topology management, routing, sleep scheduling over the past decade



Cloud Platform

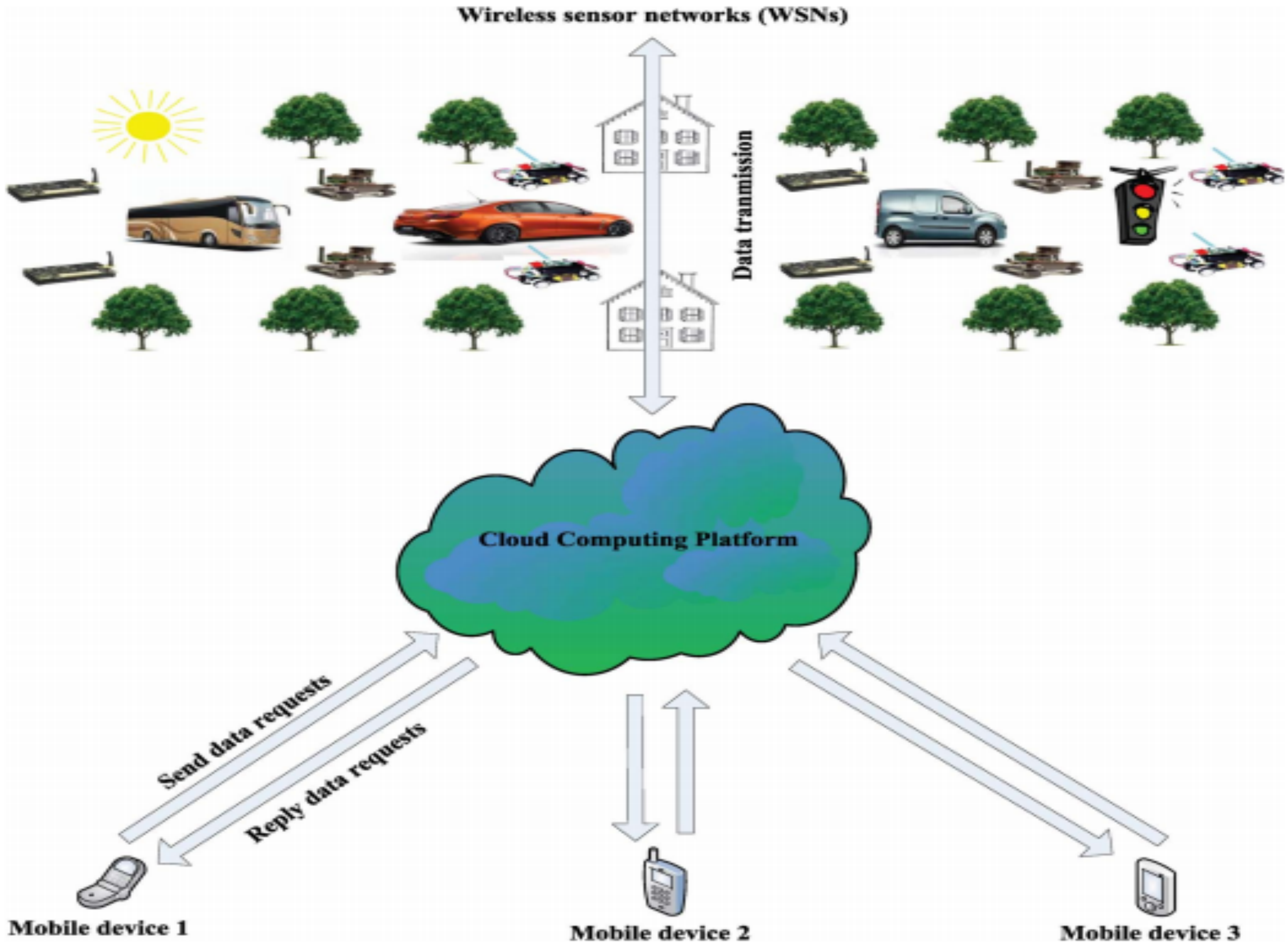
- Increasingly used for processing of the huge volume of data that can be generated by IoT and consumed by users
- Resource virtualization and on-demand assignment to promote efficiency in utilization
- Different service models (IaaS, PaaS, SaaS, …, XaaS) for different applications
- Different business models (e.g., pay per use, dynamic pricing) encourage more efficient behavior and life-cycle management
- Multitenancy, delivering efficiencies of scale to benefit many organizations or business units

Sensor-Cloud Integration for Green IoT

This work is contributed by Chunsheng Zhu, Zhengguo Sheng and other collaborators.

This work is supported by the Canadian Natural Sciences and Engineering Research Council, TELUS "People and Planet Home" Project and other industry partners.

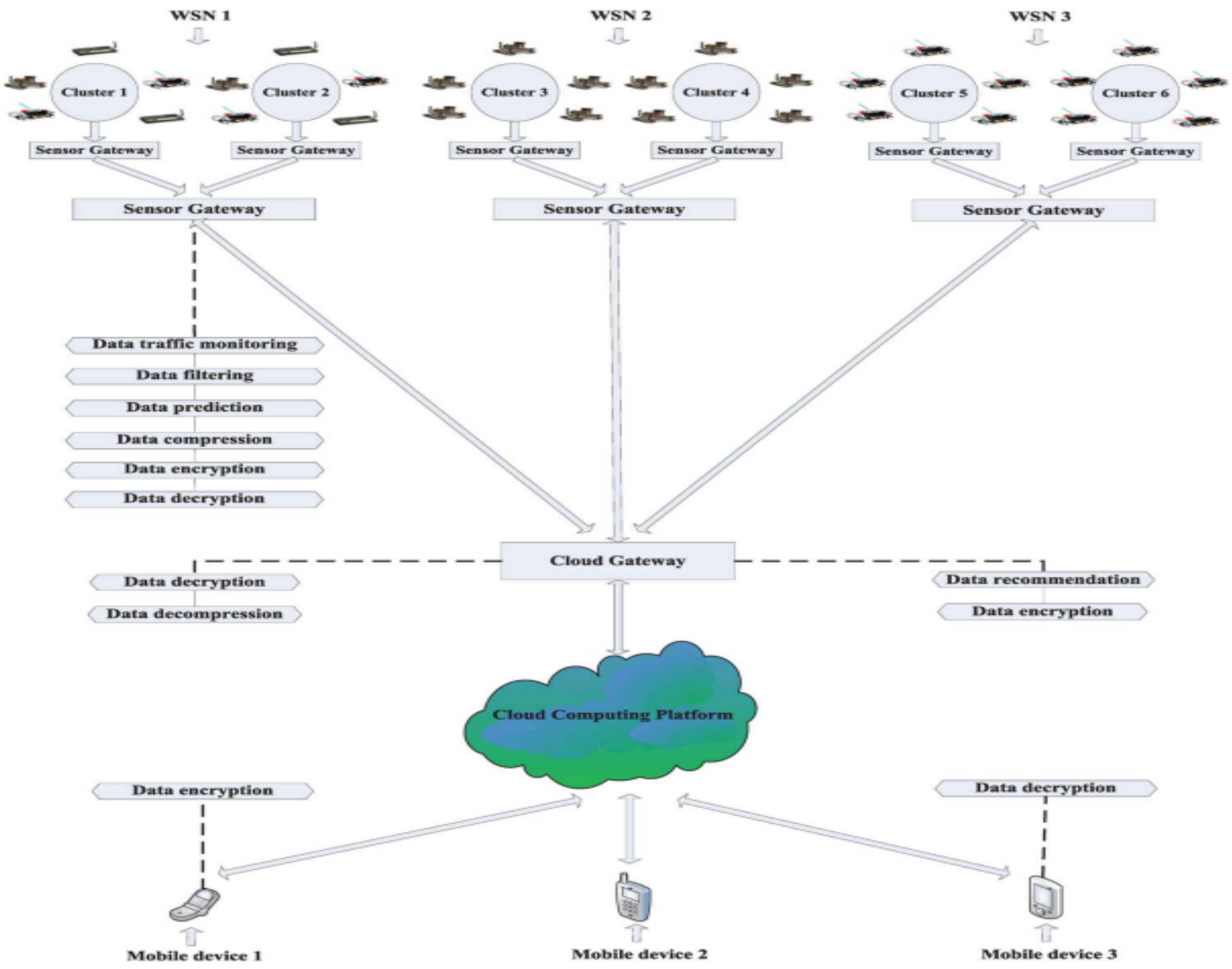
Sensor-Cloud Integration Model



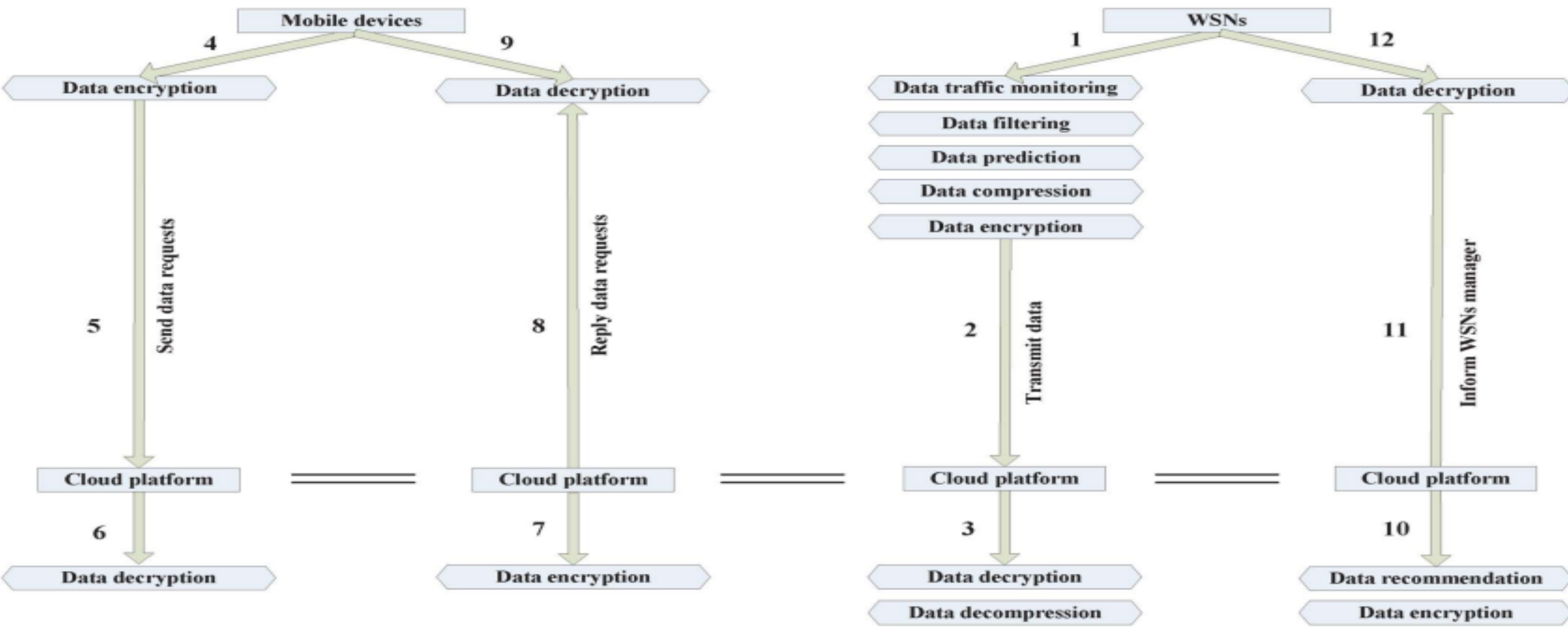
Efficient Integration Framework

- Objectives:
  - Enable transmission of desirable sensory data to mobile users in a fast, reliable, efficient, and secure manner
  - Prolong lifetime of sensor network
  - Decrease storage requirement of sensors and gateway
  - Reduce data transmission bandwidth required
- In the proposed framework:
  - Sensor gateway performs data traffic monitoring, data filtering, data prediction, data compression
  - Cloud gateway performs data decompression
  - Cloud performs data recommendation

Proposed Framework



Data Flow in Proposed Framework



Further reading: C. Zhu, H. Wang, X. Liu, L. Shu, L. T. Yang, and V. C. M. Leung, "**A Novel Sensory Data Processing Framework to Integrate Sensor Networks with Mobile Cloud**," *IEEE Systems Journal*, 2014 (in press).

Location-based Sleep Scheduling

- Motivations:
  - Use of mobile cloud computing applications depend on locations of users
  - In sensor-cloud integration, needs for sensor data are closely related to locations of mobile users
  - Desirable to preserve battery energy of sensor nodes
- Objectives:
  - Propose sleep scheduling algorithms for WSN integrated with cloud, by leveraging location information of mobile users
- Proposed collaborative location-based sleep scheduling (CLSS) algorithms
  - CLSS1 – simpler version maximizing WSN life time
  - CLSS2 – more robust version taking into account of node connectivity and residual energy

Sleep Scheduling Algorithm CLSS1

- Cloud keeps a location list L of each user considering location history and relations between visited locations

Pseudocode of CLSS1 scheme

Step 1: Cloud c obtains mobile user u's current location l_u.
Step 2: If $l_u \in L$, c sends flag A to base station s. Otherwise, c sends s flag Z.
Step 3: s broadcasts flags to sensor nodes.
Step 4: Run Step 5 at each node i.
Step 5: If node i receives flag A, remain awake. Otherwise, go to sleep.

Sleep Scheduling Algorithm CLSS2

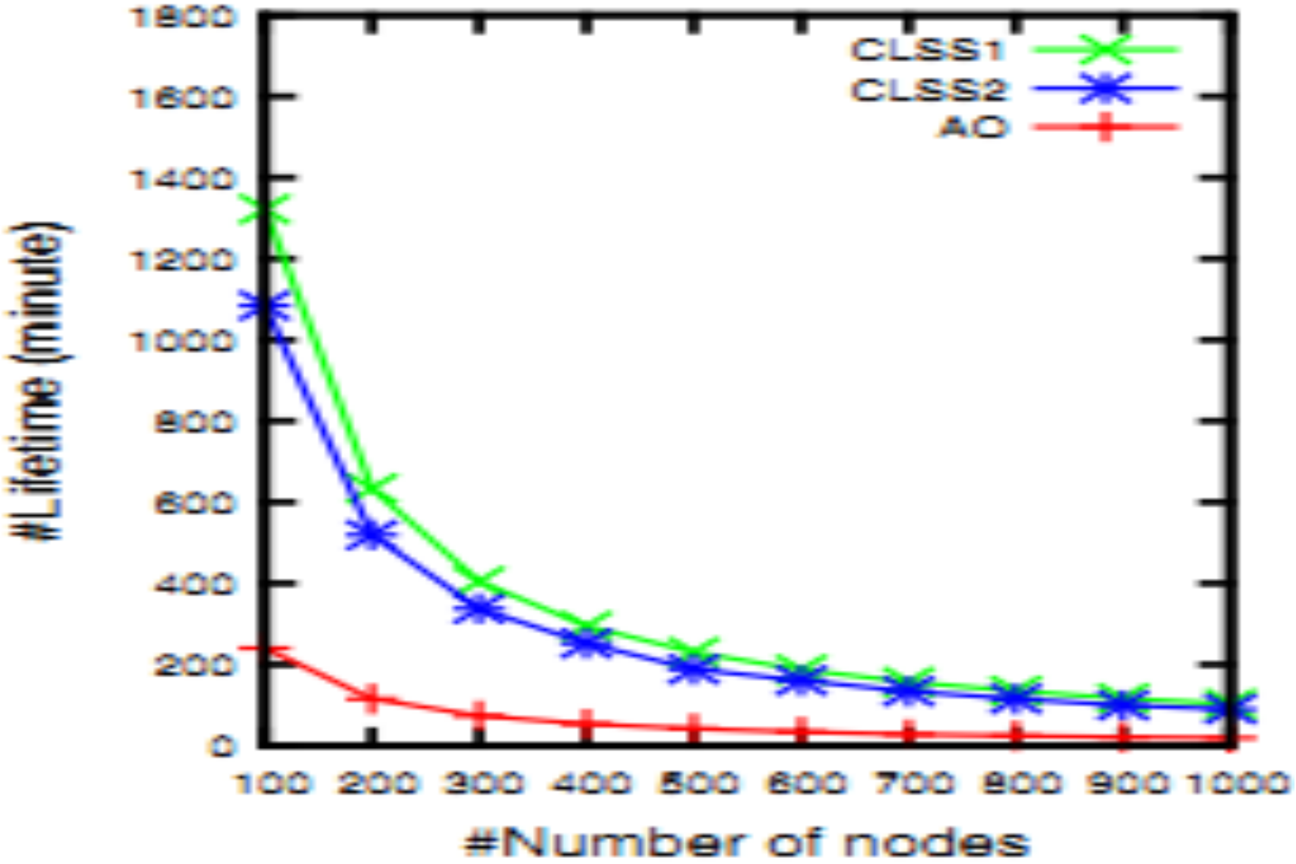
Pseudocode of CLSS2 scheme
Step 1: Cloud c obtains mobile user u's current location l_u.
Step 2: If $l_u \in L$, c sends flag A to base station s. Otherwise, c sends s flag Z.
Step 3: s broadcasts flags to sensor nodes.
Step 4: Run Step 5 at each node i.
Step 5: If node i receives flag A, remain awake. Otherwise, run Step 6 to Step 12.
Step 6 to Step 12 are the pseudocodes of EC-CKN scheme
Step 6: Get the current residual energy $Erank_i$.
Step 7: Broadcast $Erank_i$ and receive the ranks of its currently awake neighbors N_i. Let R_i be the set of these ranks.
Step 8: Broadcast R_i and receive R_j from each $j \in N_i$.
Step 9: If $\|N_i\| < k$ or $\|N_j\| < k$ for any $j \in N_i$, remain awake. Go to Step 12.
Step 10: Compute $C_i = \{j \| j \in N_i \text{ and } Erank_j > Erank_i\}$.
Step 11: Go to sleep if both the following conditions hold. Remain awake otherwise. • Any two nodes in C_i are connected either directly themselves or indirectly through nodes within i's 2-hop neighborhood that have $Erank$ more than $Erank_i$. • Any node in N_i has at least k neighbors from C_i.
Step 12: Return.

Evaluation Parameters

- 3 mobile users with different movement and application access patterns, locations tracked by Startrack service – database *L*
- WSN simulated using NetTopo, results averaged from 100 random topologies

Parameter	Parameter value
Network size	$600\times600\ m^2$
Number of sensor nodes	100-1000
k in EC-CKN	1
Average event rate	50 times/minute
Initial energy	100000 mJ
Transmission energy	0.0144 mJ
Reception energy	0.00576 mJ
Transmission amplifier energy	0.0288 nJ/m^2
Transmission radius	60 m
Packet length	12 bytes
Number of packets	1000
Time epoch interval	1 minute

Evaluation Results



Further reading: C. Zhu, V. C. M. Leung, L. T. Yang, and L. Shu, "**Collaborative Location-based Sleep Scheduling for Wireless Sensor Networks Integrated with Mobile Cloud Computing**," *IEEE Transactions on Computers*, 2014 (in press).

Our Other Works on Sensor-Cloud Integration for IoT

- C. Zhu, L.T. Yang, L. Shu, V. C. M. Leung, T. Hara and S. Nishio, "Insights of Top-k Query in Duty-Cycled Wireless Sensor Networks", *IEEE Transactions on Industrial Electronics*, vol. 62, no. 2, pp. 1317-1328, Feb. 2015.
- C. Zhu, H. Nicanfar, V. C. M. Leung, and L. T. Yang, "An Authenticated Trust and Reputation Calculation and Management System for Cloud and Sensor Networks Integration," *IEEE Transactions on Information Forensics and Security*, vol. 10, pp. 118-131, Jan. 2015.
- C. Zhu, L. T. Yang, L. Shu, V. C. M. Leung, L. Wang, and J. J. P. C. Rodrigues, "Sleep Scheduling for Geographic Routing in Duty-Cycled Mobile Sensor Networks," *IEEE Transactions on Industrial Electronics*, vol. 61, pp. 6346-6355, Nov. 2014.
- C. Zhu, Z. Sheng, L. Shu, V. C. M. Leung, and L. T. Yang, "Towards Offering More Useful Data Reliably to Mobile Cloud from Wireless Sensor Network," *IEEE Transactions on Emerging Topics in Computing*, 2014 (in press).

Open Research Problems

- Green design should be tackled from an overall system energy consumption perspective, subject to satisfying service objectives and achieving acceptable performance, quality of service (QoS) or quality of experience (QoE)
- Need better understanding of characteristics of different IoT applications and service requirements for these applications
- Need realistic energy consumption models of different parts of IoT systems (WSN, core network, embedded and cloud computing)
- With pervasive deployment of sensors, a virtualized sensor as a service (SNaaS) may be envisioned, in which users have access and control to their virtually private IoT

Open Research Problems

➢ Within the context of SNaaS, it is of interest to investigate:

- Energy efficient system architecture
- Energy efficient service composition strategies
- Situation and context awareness regarding users and applications (learn and predict)
- Energy efficient WSN management
- Energy efficient cloud management
- …

Conclusions

- IoT represents an important paradigm shift in ICT that will enable smart cities around the world
- Sensor-cloud integration for green IoT is promising, but research still at its infancy
- We have outlined a framework for green sensor-cloud integration
- We have proposed sensor sleep scheduling schemes that take into account of locations of mobile users consuming sensor information
- Much interesting research is expected to emerge in this area



Thank You!

Wireless Networks and Mobile Systems Laboratory

http://winmos.ece.ubc.ca