

Embedded  
Systems  
Laboratory

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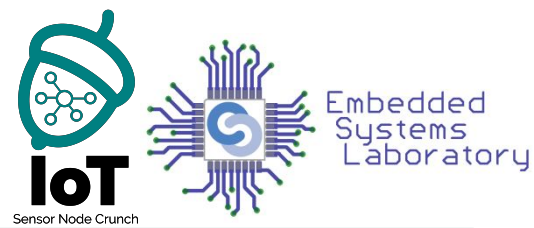
# Internet of Things

Lecture 1 - Introduction

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# Team and schedule

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## Team:

- Lectures: Laura Ruse & invited speakers
- Labs: Cosmin Chenaru

## Schedule:

- Lectures: Thursday 8-10
- Labs: Wednesday 18-20, 20-22
- Register for the lab:

[https://docs.google.com/spreadsheets/d/1YHNZBNeChLtFbQZ7tLxiHYTjGR7EYyTQaR7IY\\_MD0DM/edit?usp=sharing](https://docs.google.com/spreadsheets/d/1YHNZBNeChLtFbQZ7tLxiHYTjGR7EYyTQaR7IY_MD0DM/edit?usp=sharing)

- Wiki page: <https://ocw.cs.pub.ro/courses/iorthings>
  - Lecture slides
  - Labs
  - Assignment
  - Class Register
  - Calendar
- Moodle page:  
<https://curs.upb.ro/2021/course/view.php?id=5413>
- Chapters of reference books
- Selected conference and journal papers
  - MOBICOM, SIGCOMM, Mobisys proceedings

# Grading

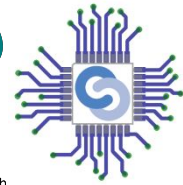
- Labs & Assignment & Tests
  - 0.5p Lab activity
  - 0.5p Lecture tests and attendance
  - 5p Project

2.5p from the lab activity and the project are required to enter the exam.

- Exam
  - 5p Final exam

# Class Project

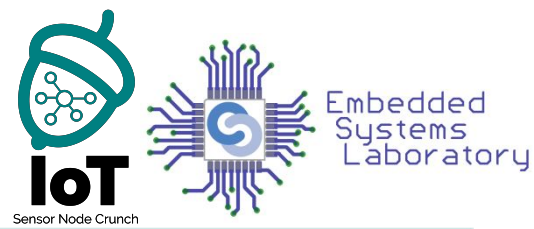
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- Goal: obtain hands-on experience
- Potential topics on the wiki
- You may choose your own topic
- Milestones:
  - Initial proposal
  - Intermediary project presentation
  - Final project presentation

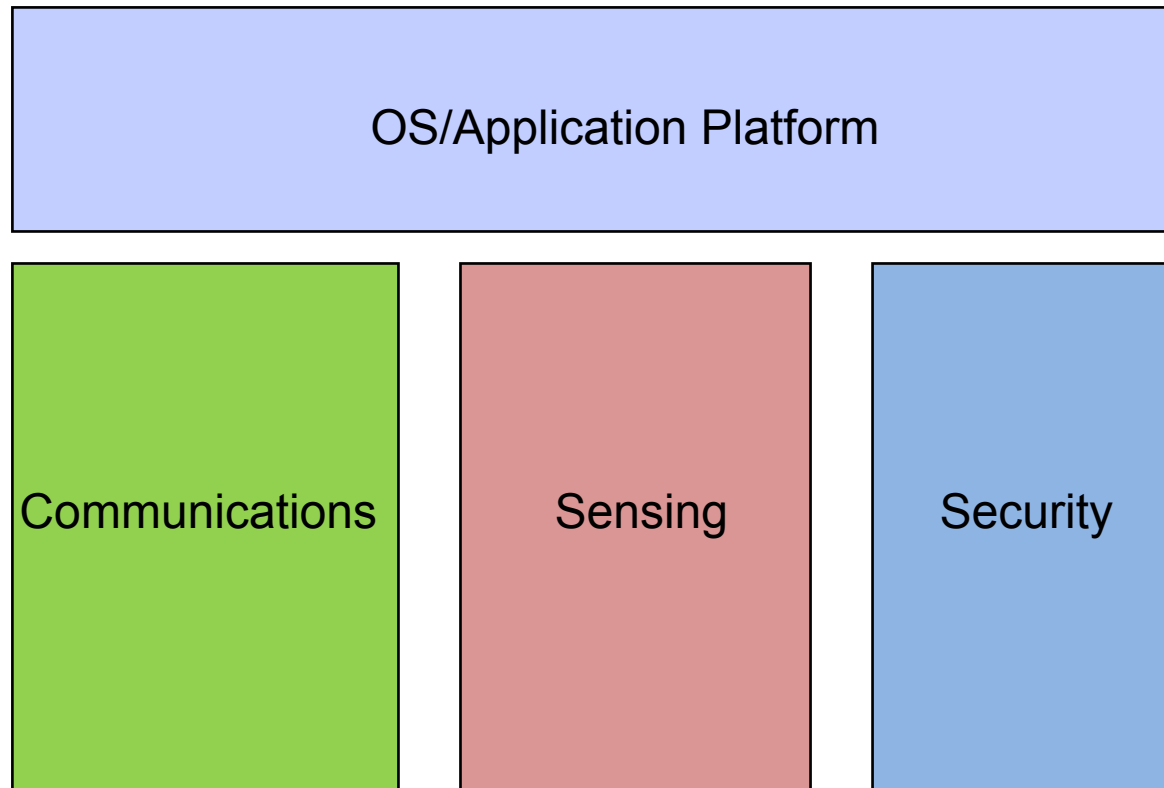
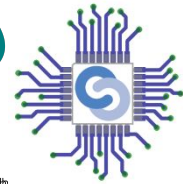
# Course Goals

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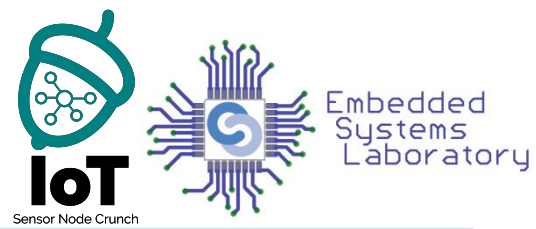
- Learn both fundamentals and applications of IoT networks
- Obtain hands-on experiences on developing IoT applications
- Discuss challenges and opportunities

# Course Topics



# Outline

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- Pervasive wireless IoT applications
- Challenges facing wireless communication



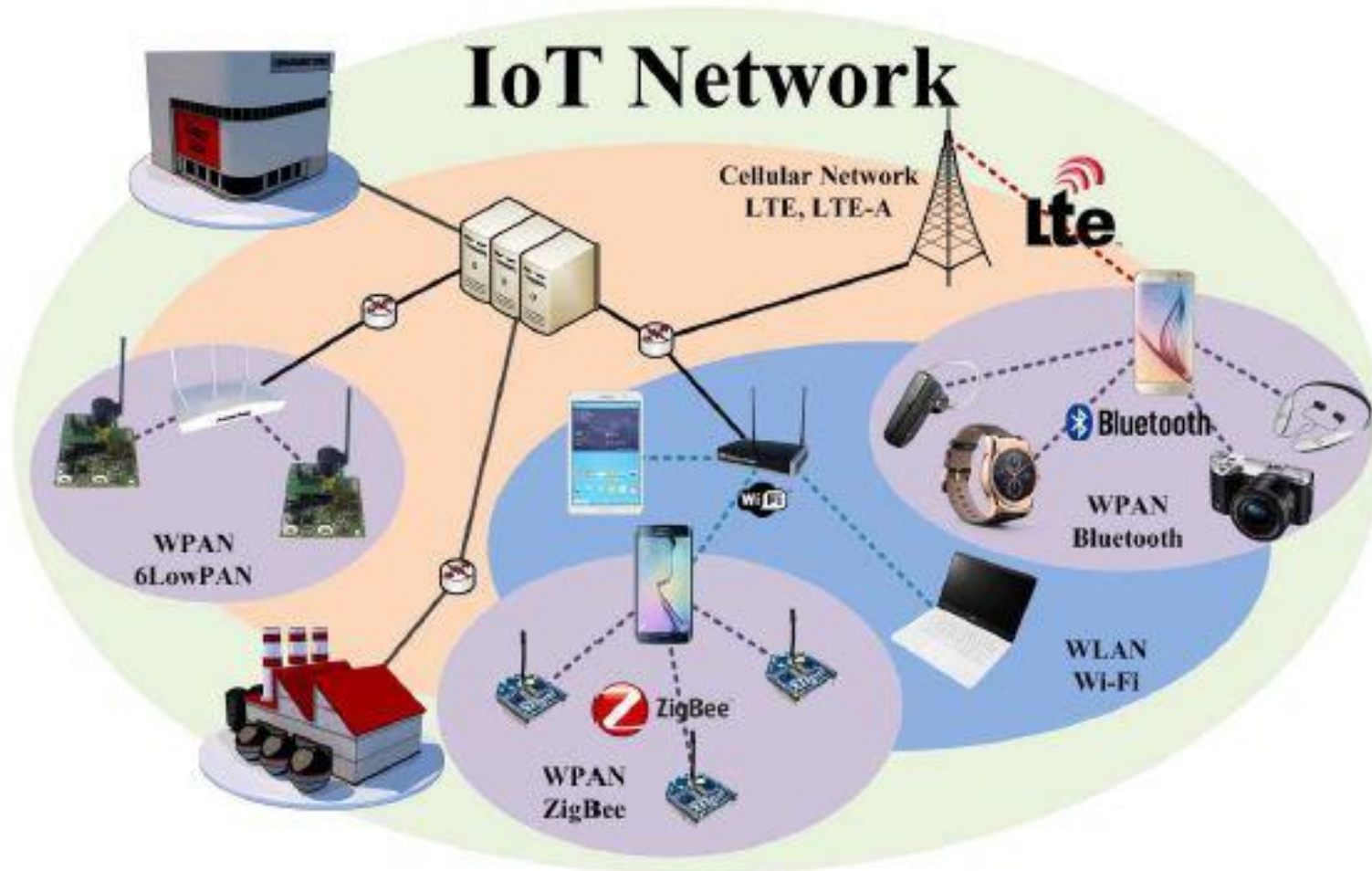
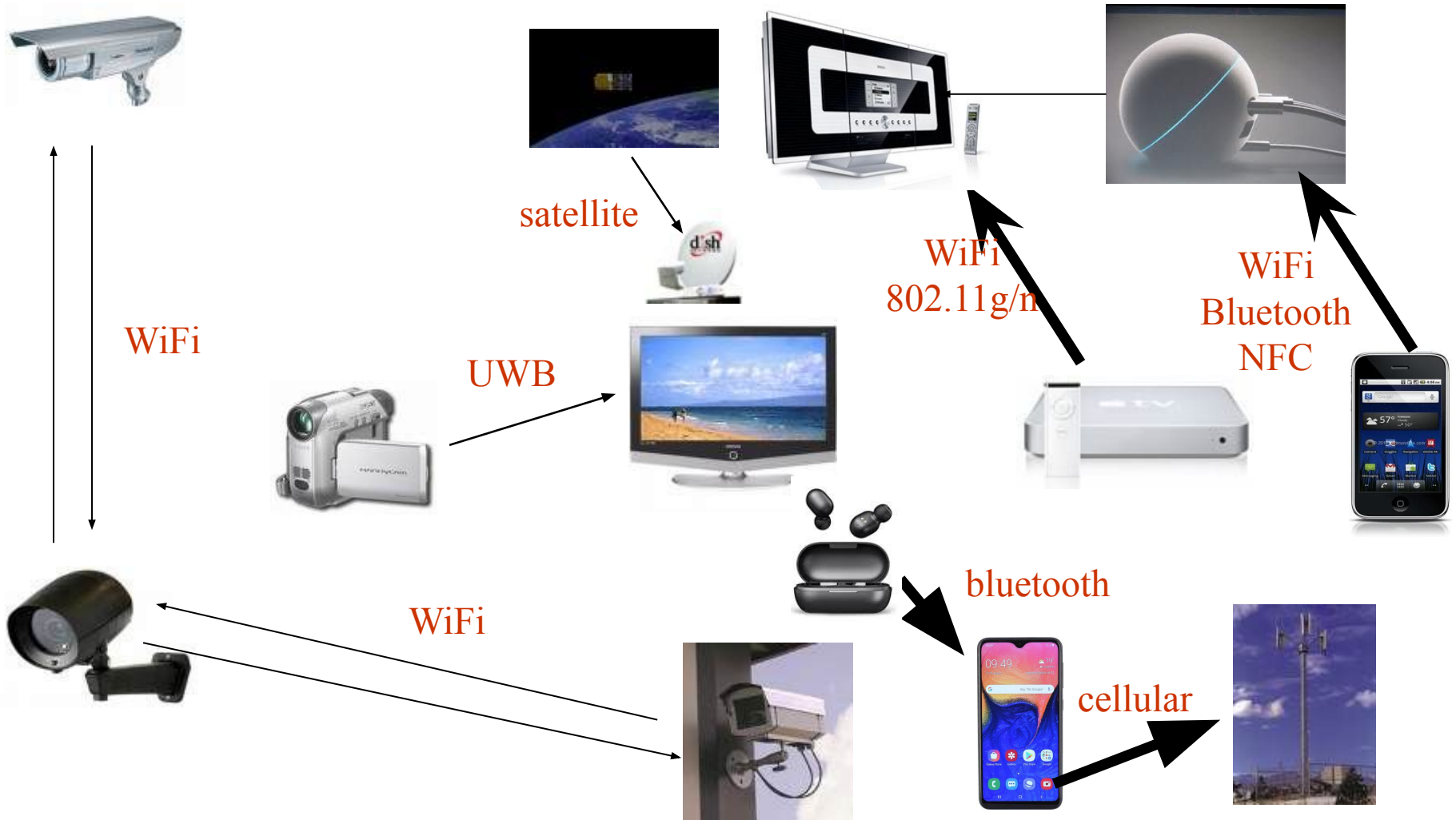


Image source: [opentechdiary.wordpress.com](http://opentechdiary.wordpress.com)

# Use Case: Home Networks



# Use Case: Smart home

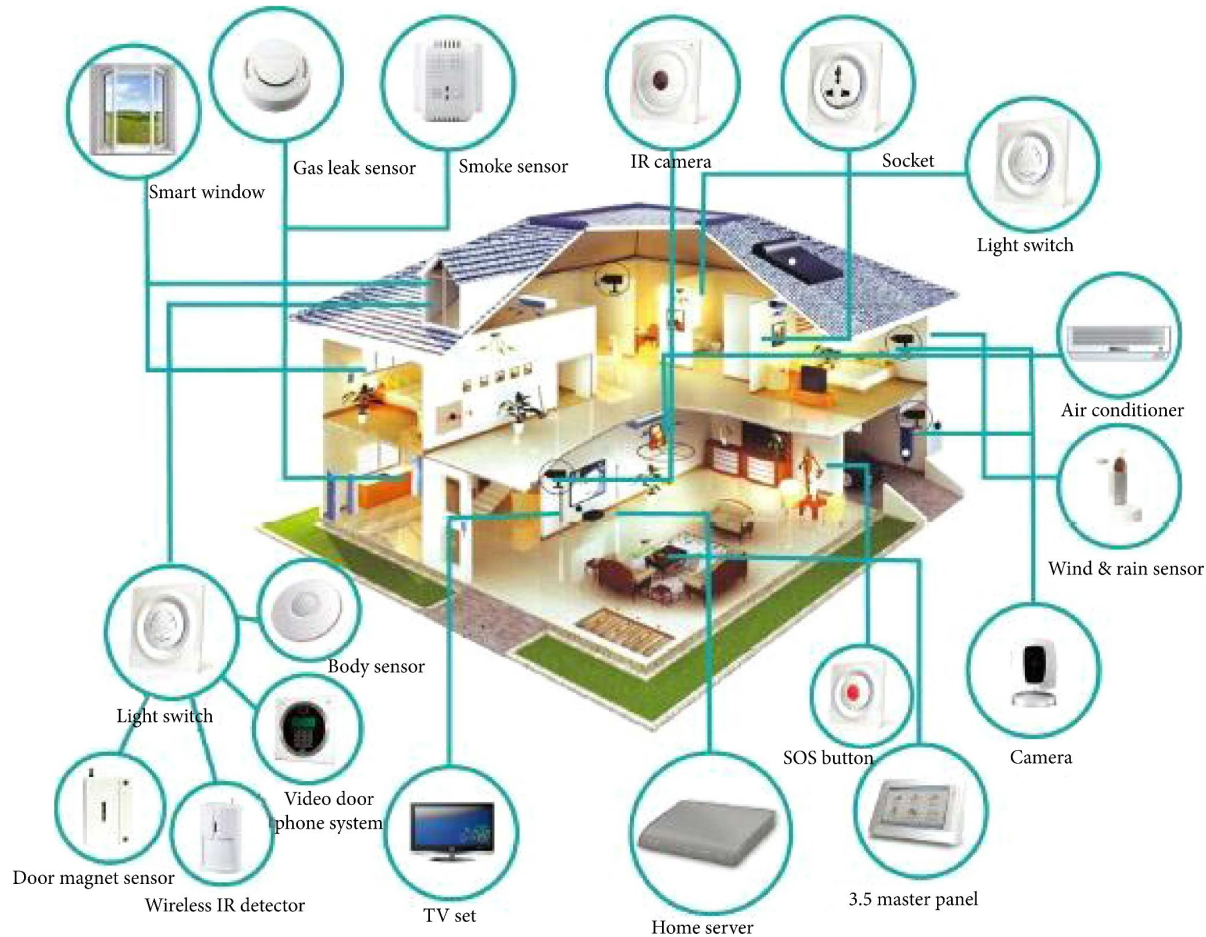


Image source: <https://smarthomeenergy.co.uk/what-smart-home/>



# Use Case: Smart City

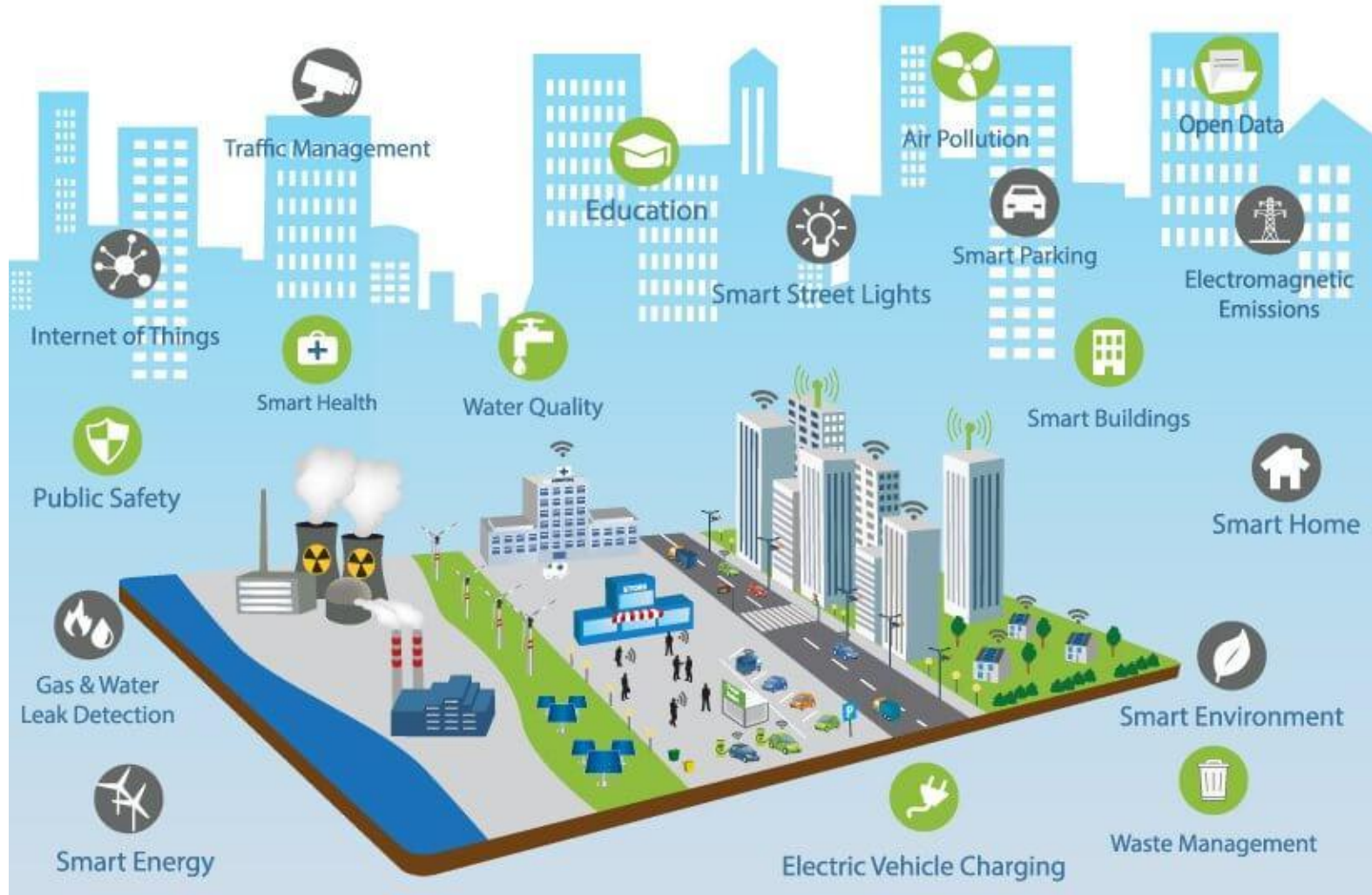


Image source: <https://internetofbusiness.com/global-smart-city-platform-market/>

Smart cities: <https://www.bmw.com/en/innovation/smart-cities.html>

# Use Case: Smart Metering

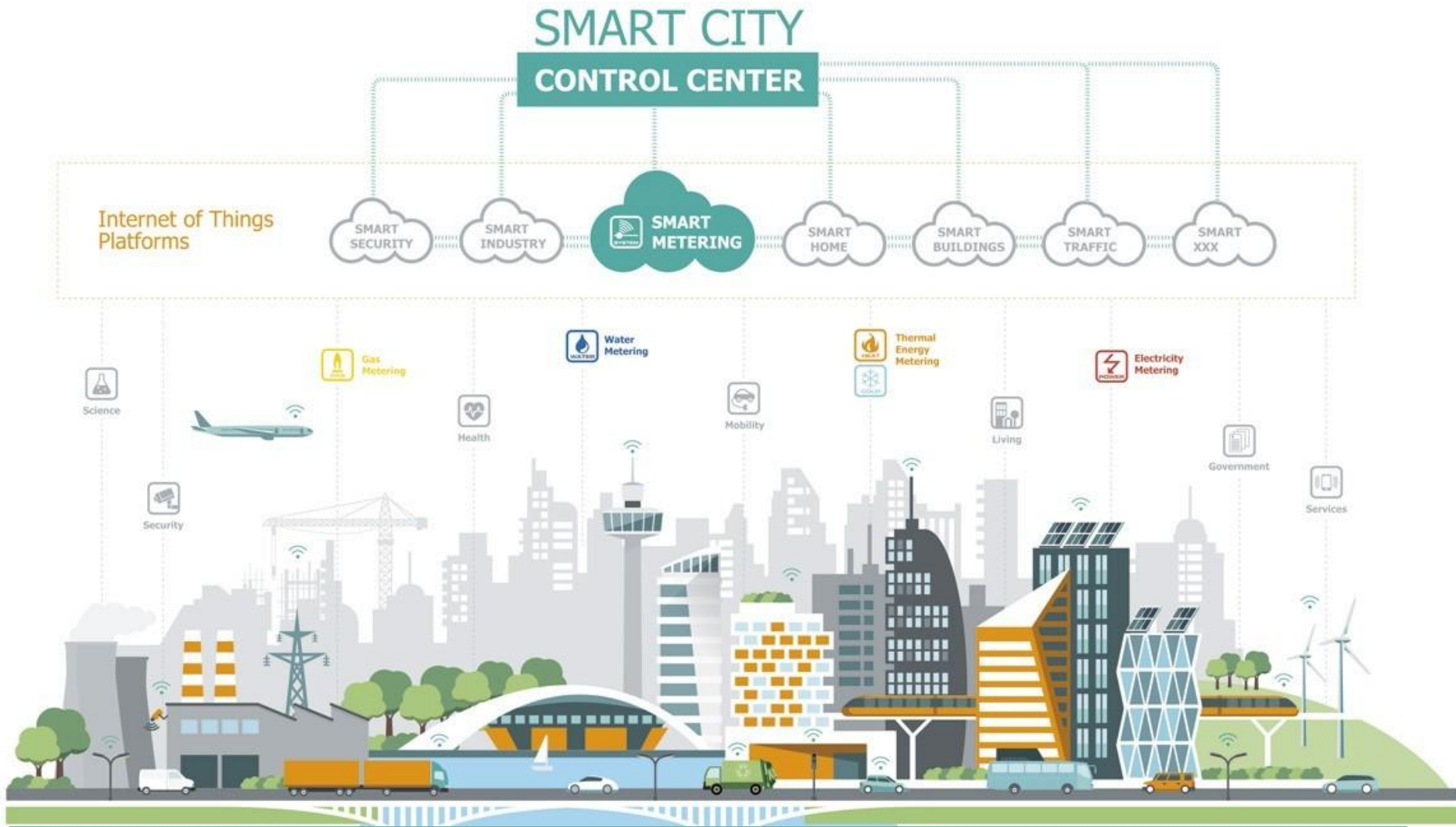
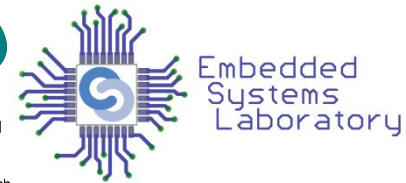


Image source: <https://smartwatermagazine.com/news/diehl-metering/smart-cities-and-industries-iot-solutions-diehl-metering>

# Use Case: Mesh Network for Disaster Recovery/Military



- 9/11, Tsunami, Hurricane Katrina, South Asian earthquake ...
- Wireless communication and mobile computing capability can make a difference between life and death
  - rapid deployment
  - efficient resource and energy usage
  - flexible: unicast, broadcast, multicast, anycast
  - resilient: survive in unfavorable and untrusted environments





# Use Case: Traffic Signal Advisor



Connect Sync Camera Adjust Exposure Auto Exposure Detection: ON

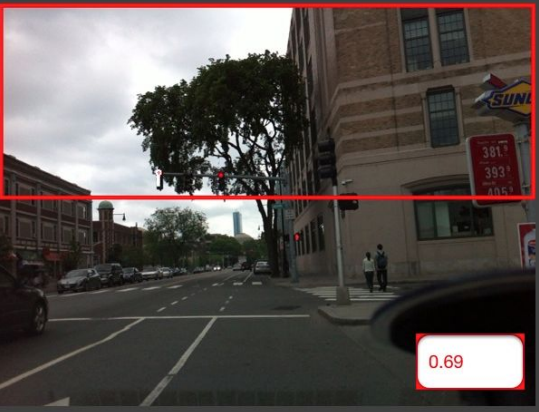
Advisory

3.0 sec

45.0 sec

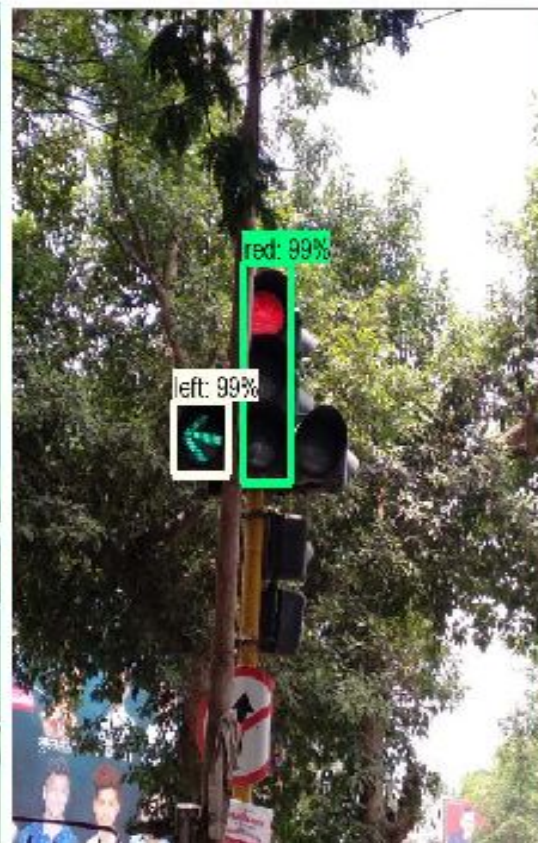
11.9 mph

SignalGuru



Source: <http://www.princeton.edu>

# Use Case: Traffic Signal Advisor



Source: <http://www.princeton.edu>



# Use Case: Vehicular Networks

- vehicle-to-vehicle (V2V),
- vehicle-to-infrastructure (V2I)
- vehicle-to-hand-held-devices (V2D) communications

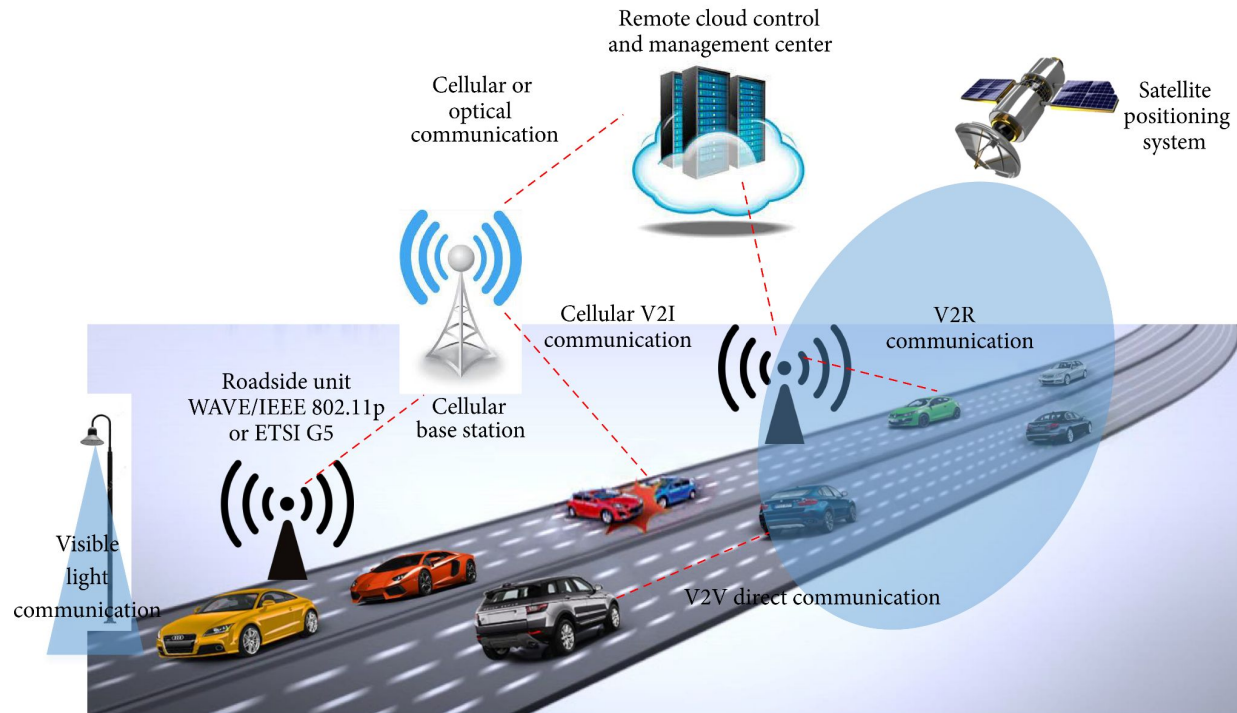
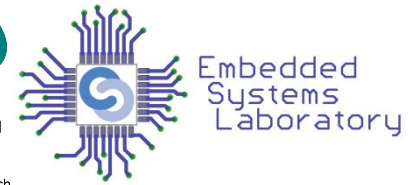


Image source: A Survey on Infrastructure-Based Vehicular Networks, Silva et al.

# Collision Avoidance : V2V Networks



Stalled vehicle warning



Blind spots

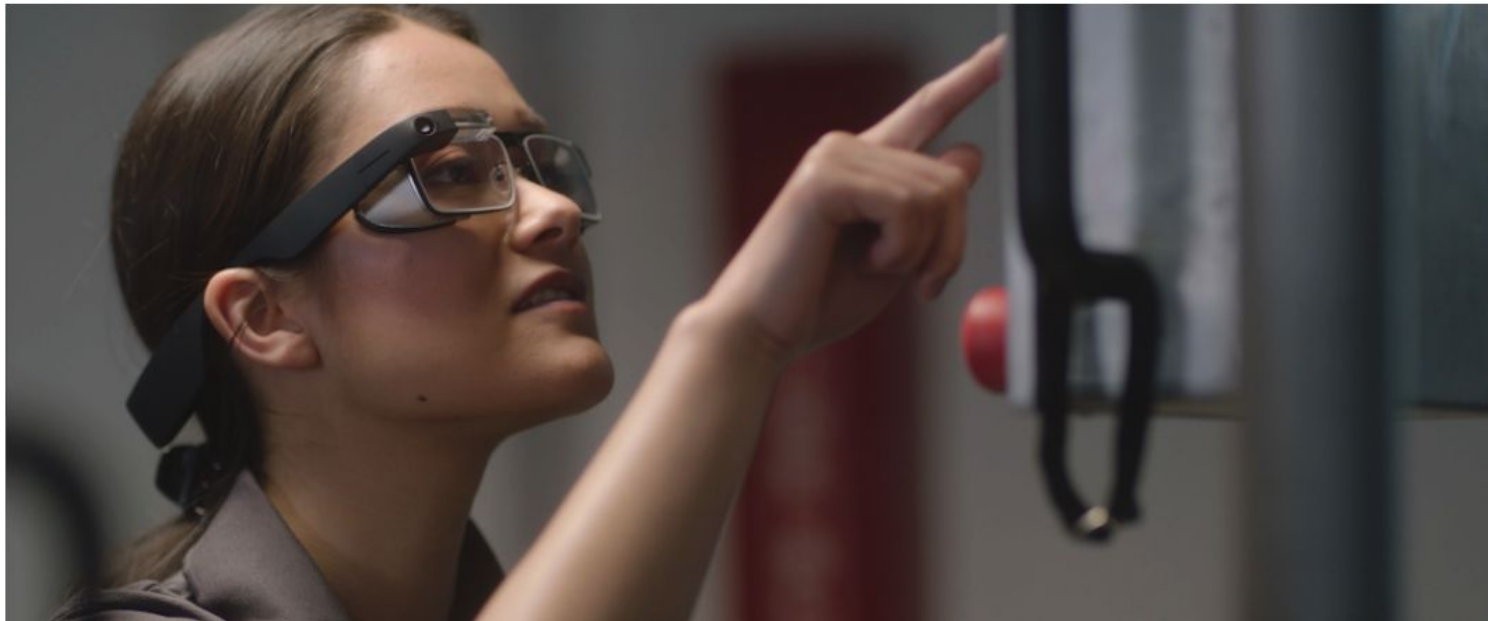


# Google Glass



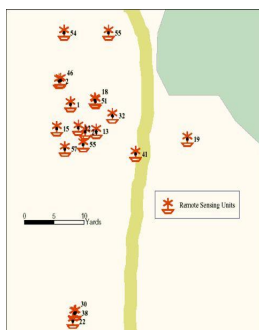
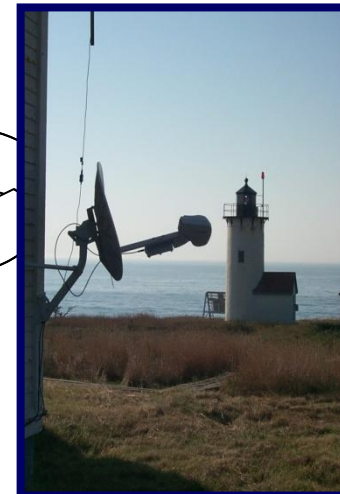
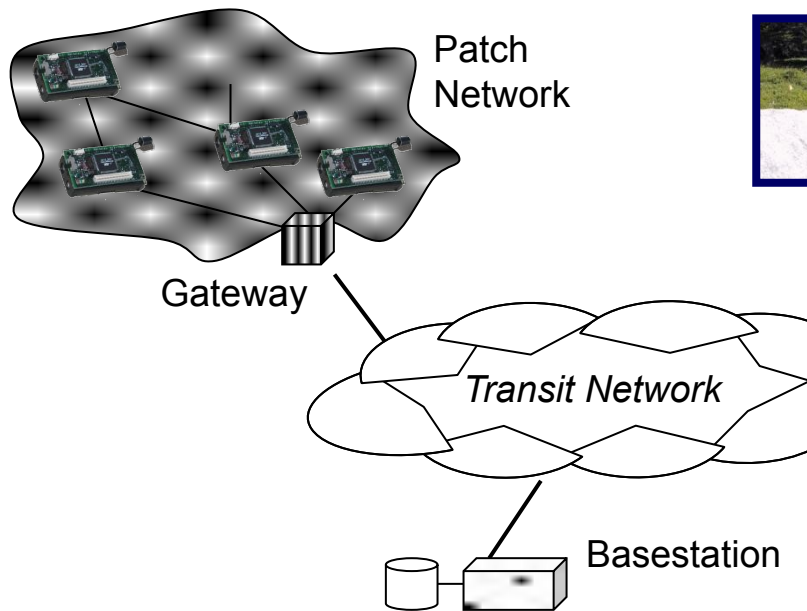
## GLASS ENTERPRISE EDITION

A hands-free device for smarter and faster hands-on work.

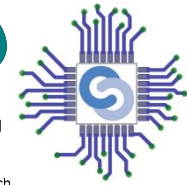


# Use Case: Habitat Monitoring

A 15-minute human visit leads to 20% petrel offspring mortality



Source: Wireless Sensor Networks for Habitat Monitoring, Mainwaring et al.

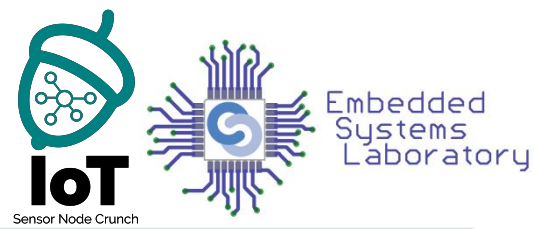


- Driven by technology and vision
  - Mobile device capabilities and platforms
  - Global communication infrastructures
  
- The field is moving fast



# Enabling Infrastructures

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- Development and deployment of wireless infrastructures
  - networking: in-room, in-building, on-campus, in-the-field, MAN, WAN
- Development and deployment of localization infrastructures
  - location: GPS, AGPS, ...
- Development and deployment of sensor networks

## Wi-Fi generations

Generation/IEEE Standard	Maximum Linkrate	Adopted	Frequency
<b>Wi-Fi 6 (802.11ax)</b>	600–9608 Mbit/s	2019	2.4/5 GHz 1–6 GHz ISM
<b>Wi-Fi 5 (802.11ac)</b>	433–6933 Mbit/s	2014	5 GHz
<b>Wi-Fi 4 (802.11n)</b>	72–600 Mbit/s	2009	2.4/5 GHz
<b>Wi-Fi 3 (802.11g)</b>	3–54 Mbit/s	2003	2.4 GHz
<b>Wi-Fi 2 (802.11a)</b>	1.5 to 54 Mbit/s	1999	5 GHz
<b>Wi-Fi 1 (802.11b)</b>	1 to 11 Mbit/s	1999	2.4 GHz

Image source: <https://evanmccann.net/blog/wifi-101/faq>

# Cellular networks

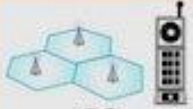












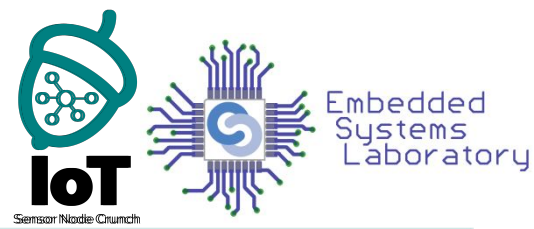
1G	2G	3G	4G	5G
				
speed in kilobit per second <b>2.4 Kbps</b>	speed in kilobit per second <b>64 Kbps</b>	speed in kilobit per second <b>2,000 Kbps</b>	speed in kilobit per second <b>100,000 Kbps</b>	speed in kilobit per second <b>1Gbps</b>
				
<b>Analog Voice</b>	<b>Digital Voice + Simple Data</b>	<b>Mobile Broadband</b>	<b>Faster and Better</b>	<b>Real World Applications</b>
				
			Richer Content (Video)	More Connections

Image source: 5G Technology: An Overview of Applications, Prospects, Challenges and Beyond, Fizza et al.  
[http://ioarp.org/ioarp-admin-panel/upload/articles/1460357886\\_IDL-ICCN15-011.pdf](http://ioarp.org/ioarp-admin-panel/upload/articles/1460357886_IDL-ICCN15-011.pdf)



# Enabling Infrastructure: Networks



Standard	Peak Downlink	Peak Uplink	Tech
GSM GPRS Class 10	0.0856	0.0428	
GSM EDGE Evolution	1.6	0.5	TDMA/FDD
CDMA EV-DO Rev. 0	2.458	0.1536	CDMA/FDD
CDMA EV-DO Rev. A	3.1	1.8	CDMA/FDD
CDMA EV-DO Rev. B	4.9	1.8	CDMA/FDD
WiFi: 802.11b	11	11	DSSS
Flash-OFDM: Flash-OFDM	15.9	5.4	Flash-OFDM
WiFi: 802.11g	54	54	OFDM
WiFi: 802.11a	54	54	OFDM
LTE	300	75	OFDMA/MIMO
WiMAX: 802.16m	365	376	MIMO/SOFDMA
WiFi: 802.11n	600	600	OFDM/MIMO
HSPA+	672	168	CDMA/FDD/MIMO
LTE Advanced (Cat 8)	2998.6	1497.8	MIMO
WiFi: 802.11ac (8aAP; 4a ST)	3470	3470	MU-MIMO

All units are Mbps

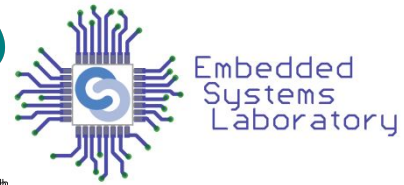
# Improving Infrastructure: Power Efficiency

	$\alpha_u$ (mW/Mbps)	$\alpha_d$ (mW/Mbps)
LTE	438.39	51.97
3G	868.98	122.12
WiFi	283.17	137.01

Source: A Close Examination of Performance and Power Characteristics of 4G LTE; Mobisys'12

# Sensing Capabilities

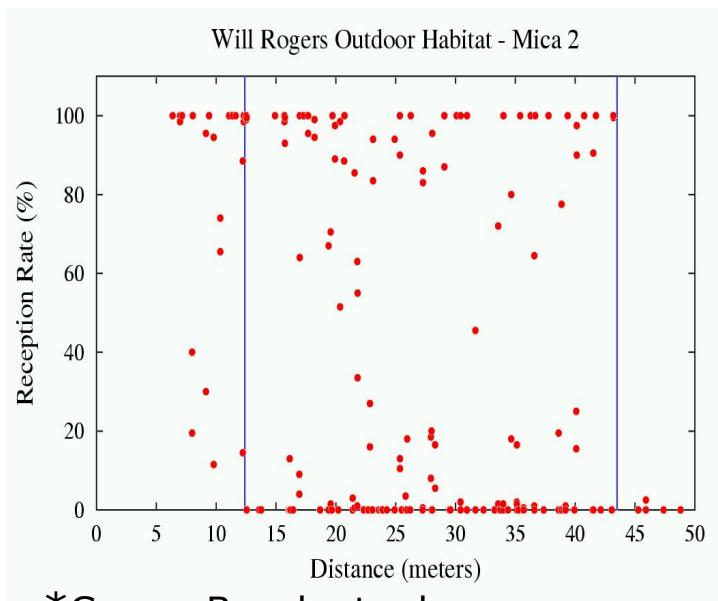
## \*Regular Smartphone



# Challenge 1: Unreliable and Unpredictable Wireless Coverage

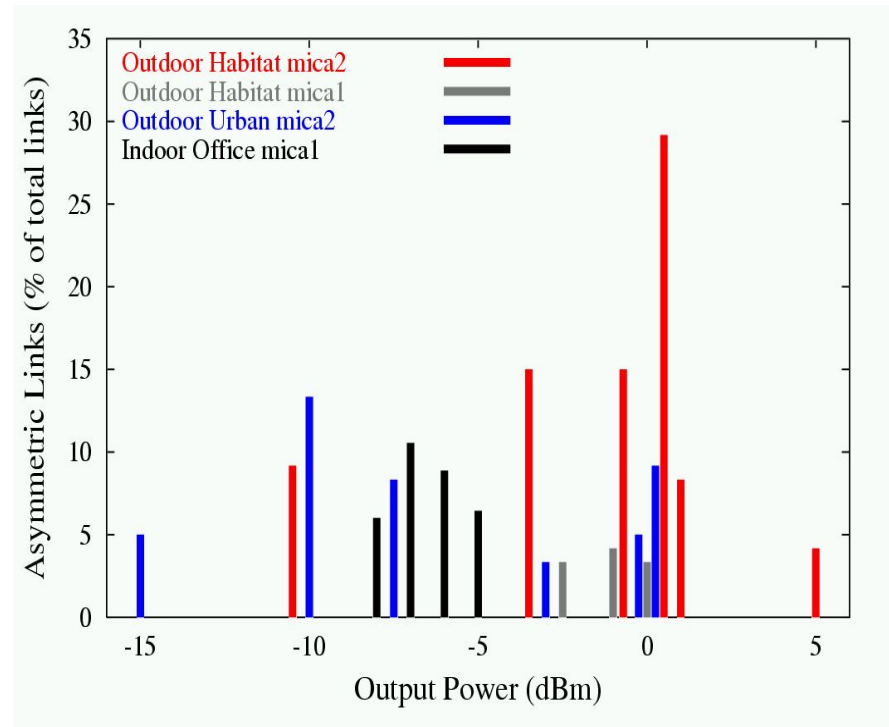
Wireless links are not reliable: they may vary over time and space

Reception v. Distance

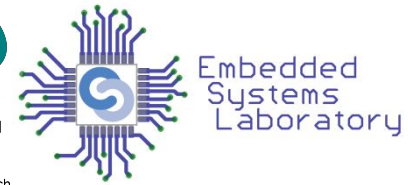


\*Cerpa, Busek et. al

Reception vs. Power



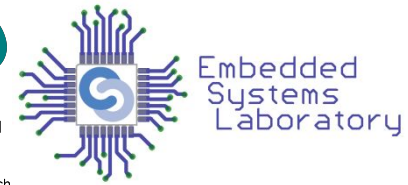
# Challenge 2: Open Wireless Medium



- Wireless interference



# Challenge 2: Open Wireless Medium



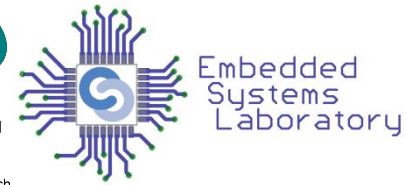
- Wireless interference



- Hidden terminals



# Challenge 2: Open Wireless Medium



- Wireless interference



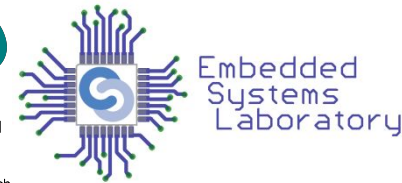
- Hidden terminals



- Exposed terminal



# Challenge 2: Open Wireless Medium



- Wireless interference



- Hidden terminals



- Exposed terminal

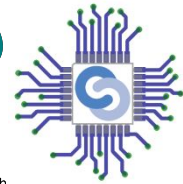


- Wireless security
  - eavesdropping, denial of service, ...



# Challenge 3: Mobility

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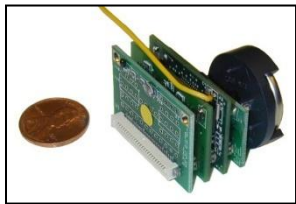


- Mobility causes poor-quality wireless links
- Mobility causes intermittent connection
  - under intermittent connected networks, traditional routing, TCP, applications all break
- Mobility changes context, e.g., location

# Challenge 4: Portability

- Limited battery power
- Limited processing, display and storage

Sensors,  
embedded  
controllers



Mobile phones

- voice, data
- simple graphical display:

Smartphone

- data
- small graphical displays
- Wi-Fi, 3G/4G/5G
- Bluetooth



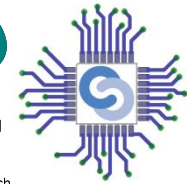
Tablet/Laptop



**Performance/Weight/Power Consumption** 

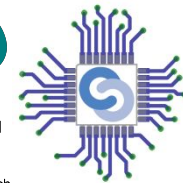
# Challenge 5: Changing Regulation and Multiple Communication Standards

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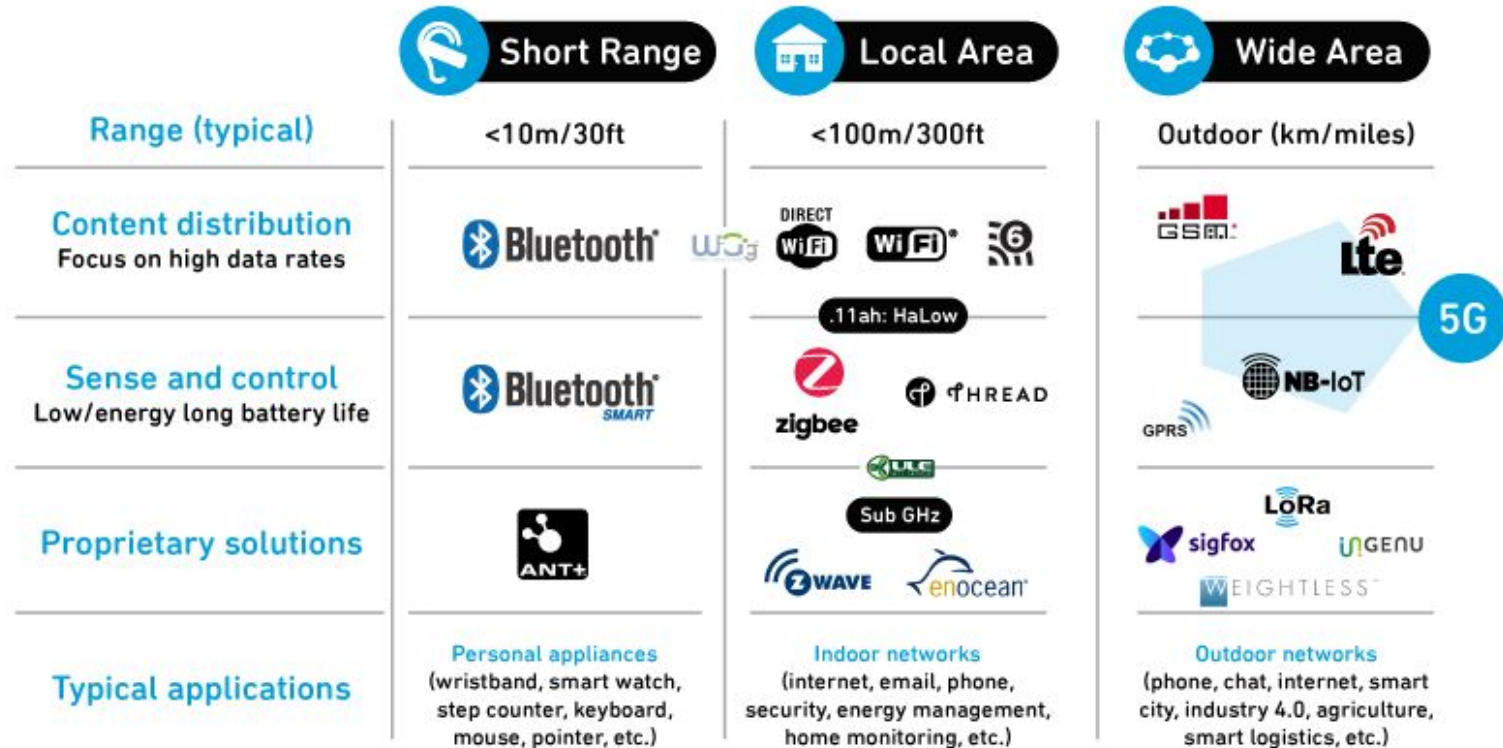


- Different standards and frequencies in different areas
- Mobile devices must implement various standards and frequencies
- While roaming - adapt to local requirements
- The complexity of producing standards
- IEEE, IETF, ETSI

# Challenge 5: Changing Regulation and Multiple Communication Standards

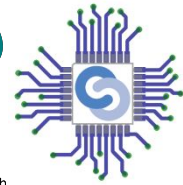


## IoT: A Mix of Industry Standards



# Keywords

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- Internet of Things
- Wireless Sensor Networks
- Smart home
- Smart city
- Mobile Devices
- Wireless Communication
- Wi-Fi
- LTE
- ZigBee
- LoRa