IoT in Smart Cities

Technology overview and future trends

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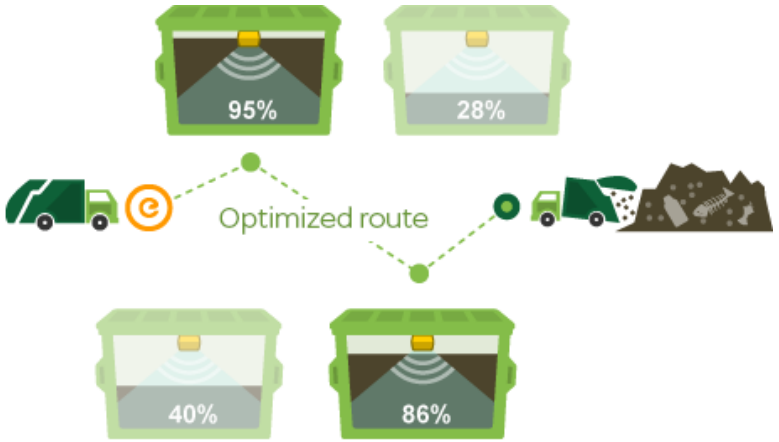
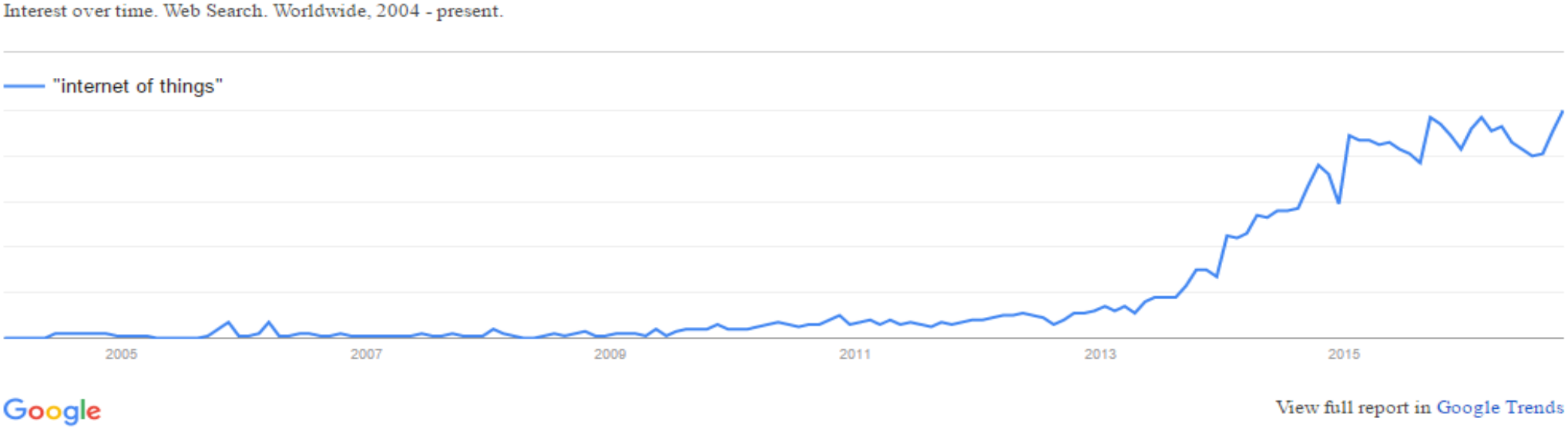
IoT definition

- **Traditional Internet (of People)**
  - Network of machines (PCs, switches, routers, servers, etc.)
  - Content (mostly) generated by people – web pages, e-mails, pictures, videos, etc.
- **Internet of Things (IoT)**
  - People have limited time, attention and accuracy to measure the physical world
    - Let's use machines for that
  - IoT = Network of „smart things", capable of sensing the physical world, and communicating, without human intervention
  - Example: smart waste bin
    - Measures how full is the bin
    - Communicates with a central waste management system
    - Optimized routes for waste collection trucks



Brief IoT history

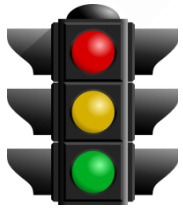
- Internet of Things (IoT) – term first used by Kevin Ashton (MIT) in 1999
- First IoT device?
  - A Coca-Cola machine at Carnegie Mellon university (**in 1982 !!**)
    - cheaper with 10 cents compared to other machines
    - Many students walked to the machine through the large campus, but were upset if the machine was empty
    - **Idea: let's connect it to the Internet, to be able to check its status remotely**
- The term IoT became really popular only after 2012-2013



Smart IoT devices in Smart Cities

Smartphones

Traffic lights



Cars

Weather stations

Smart watches

Buses

Smart meters

Parking sensors

Kiosks

Electronic displays

Thrash bins

Surveillance cameras

And many more…

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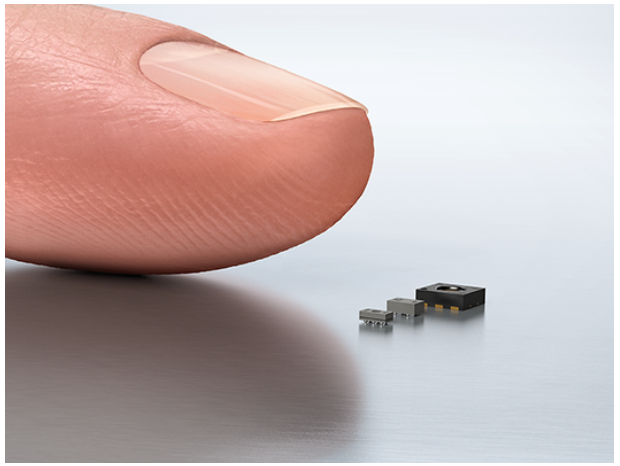
Sensing technology

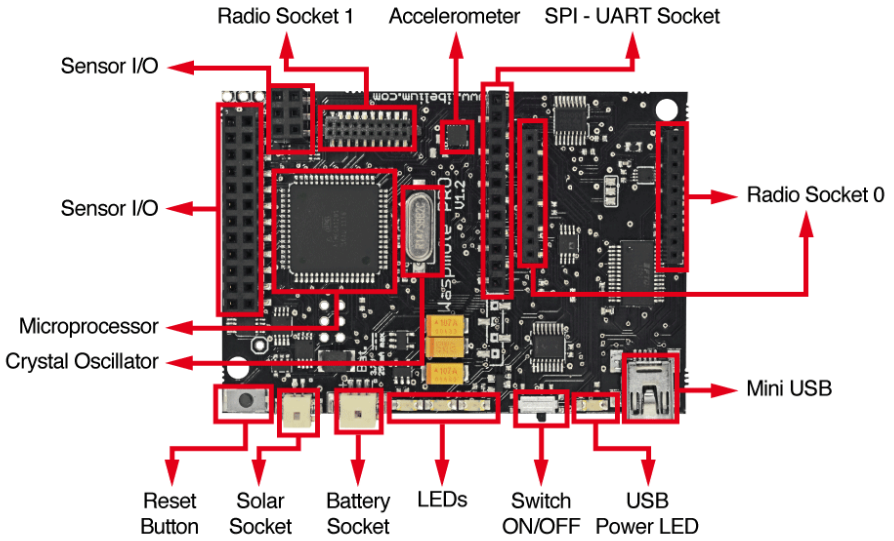


- Significant technological advances recently
  - Mechanical, thermal, electrical, optical, chemical sensors
  - Miniaturization – **MicroElectroMechanical Systems (MEMS)**, nanotechnology
    - MEMS devices smaller than 1 mm
    - Accelerometers, gyroscopes, microphones integrated into smartphones, digital cameras, cars, etc.
- Significant ongoing research efforts
  - **IEEE Sensors Journal** – among the top 5 IEEE journals (out of 180) in number of papers

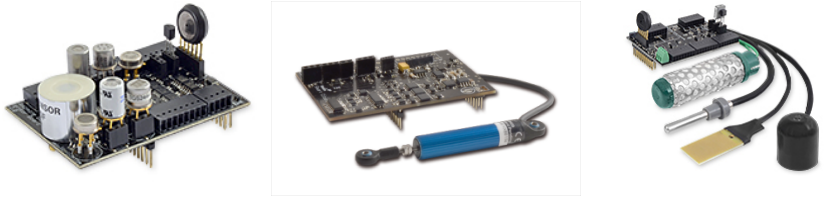
Wireless Sensor Networks

- Sensors should be many, small and cheap
- Limited resources – memory, CPU, energy
- Should be able to operate unattended, for many years
  - Recharging the battery is too difficult or too costly

Libelium Waspmote with some integrated sensors…

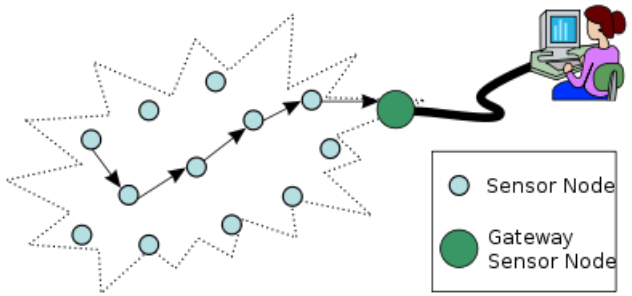


and some external sensors that can be attached….

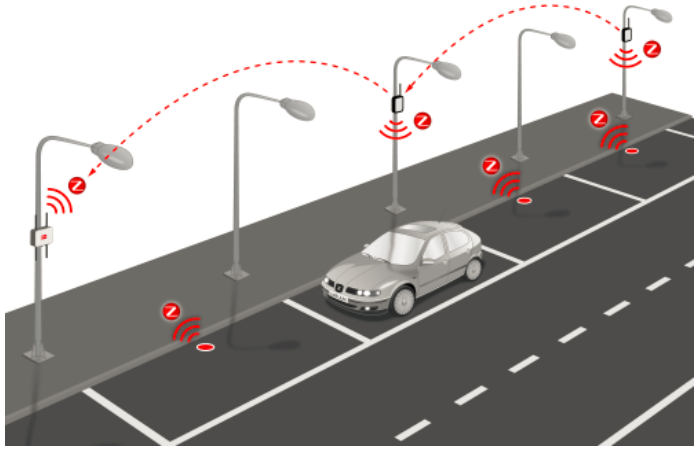


- Most of the energy is consumed by the communication
- **Basic assumption (10 years ago): not possible for all sensors to send data directly to a remote control center**
  - Cellular networks (3G, 4G) too resource-hungry, not suitable
- **Let’s build Wireless Sensor Networks**

Wireless Sensor Networks



- One of the most hyped research topics 10 years ago
  - **Multi-hop networks** – energy efficient routing, load balancing, sleep scheduling, etc.
  - **Single-hop networks** – most of the applications at that time



- Short-range radio technologies – **LR-WPAN (Low Rate Wireless Personal Area Networks)**
  - **IEEE 802.15.4, Zigbee, Bluetooth Low Energy (Smart)**
- Costly infrastructure building
  - Larger distances covered by densely deployed gateways
  - (Still) **costly sensors**
    - Embedded parking sensor today – 60-100 USD
    - Hundreds of thousands of parking slots in Budapest

Sensor communication today

- Emerging **LPWAN (Low Power Wide Area Network)** technologies
  - Covering distances of up to 10-15 km, or even more
  - Extremely low energy consumption, battery lifetime of 10 years

  - **Cellular IoT**
    - Licensed frequency bands
    - NB-IoT, LTE-M, EC-GSM
    - **Under 3GPP standardization, large scale deployments in a few years only**

  - **Unlicensed LPWA**
    - On license-free frequencies
    - Proprietary solutions
    - LoRa, SIGFOX, Weightless
    - **Ready to use, countrywide deployments in more than 20 countries**

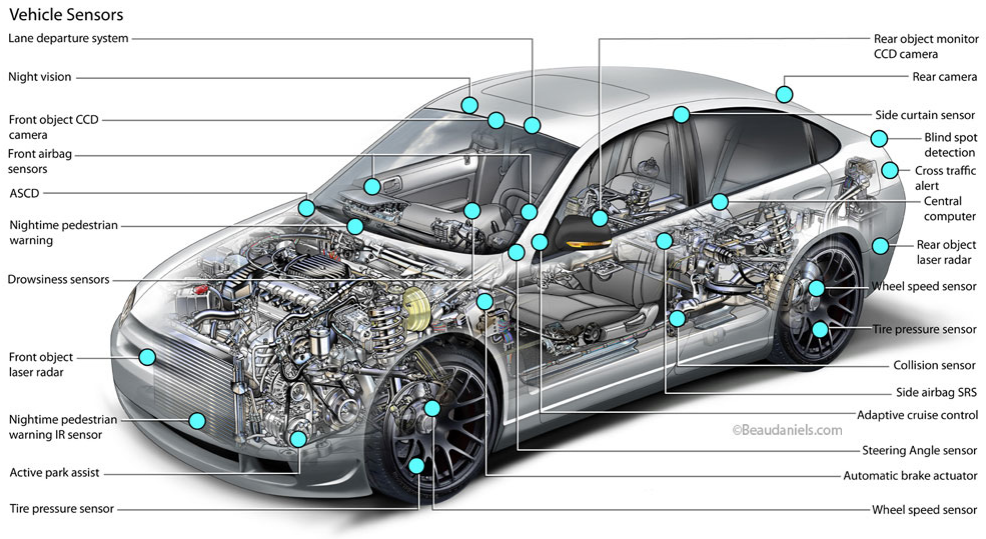
WSN vs. IoT

- **WSN** – homogeneous network of similar sensors, deployed with a specific purpose
- **IoT** – a more general term, heterogeneous network
  - Devices with limited resources – parking sensors, smart meters, etc.
  - Devices with (virtually) no resource limitation – cars, smart phones, coke machines
  - They communicate not for the sake of a specific application, but to provide internet access, or other services to each other
    - E.g., a car could collect data from sensors it passes by, and deliver them to the central database

- IoT devices form **Low Power and Lossy Networks (LLN)**
- IETF ROLL WG – **R**outing **O**ver **L**ow power **L**ossy (2008)
  - **RPL protocol** (pronounce: Ripple) – RFC 6550 (2012)

Special case of vehicular networks (in smart cities)

- Cars are more and more intelligent devices
  - Tons of sensors (engine temperature, brake temperature, tire pressure, parking radars, wheel speed, rain detection, fuel consumption, seat occupancy, etc…)
- Why not integrate them into the IoT, let them communicate?
- **Vehicle-to-vehicle (V2V)** and **vehicle-to-infrastructure (V2I)** communication
  - On-board Units (OBUs) and Road-side Units (RSUs)

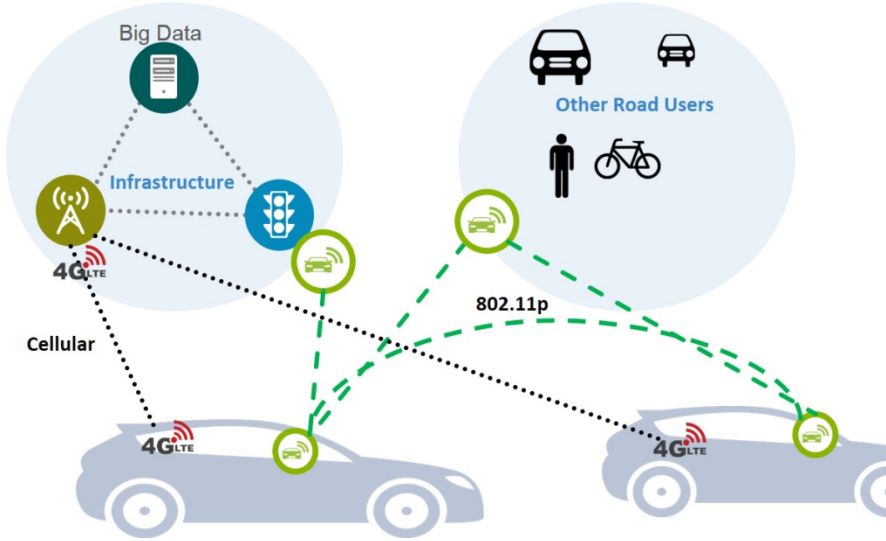


- Different application scenarios
  - **Safety-critical applications** – Emergency brake
    - Low data rate, but very low latency required (< 50 ms)
  - **Cooperative awareness** – Adaptive cruise control, self-driving
    - Might be very high data rate
    - Estimations about a self-driving car in 2020 generating 4 Tbytes of data / day

Communication in vehicular networks

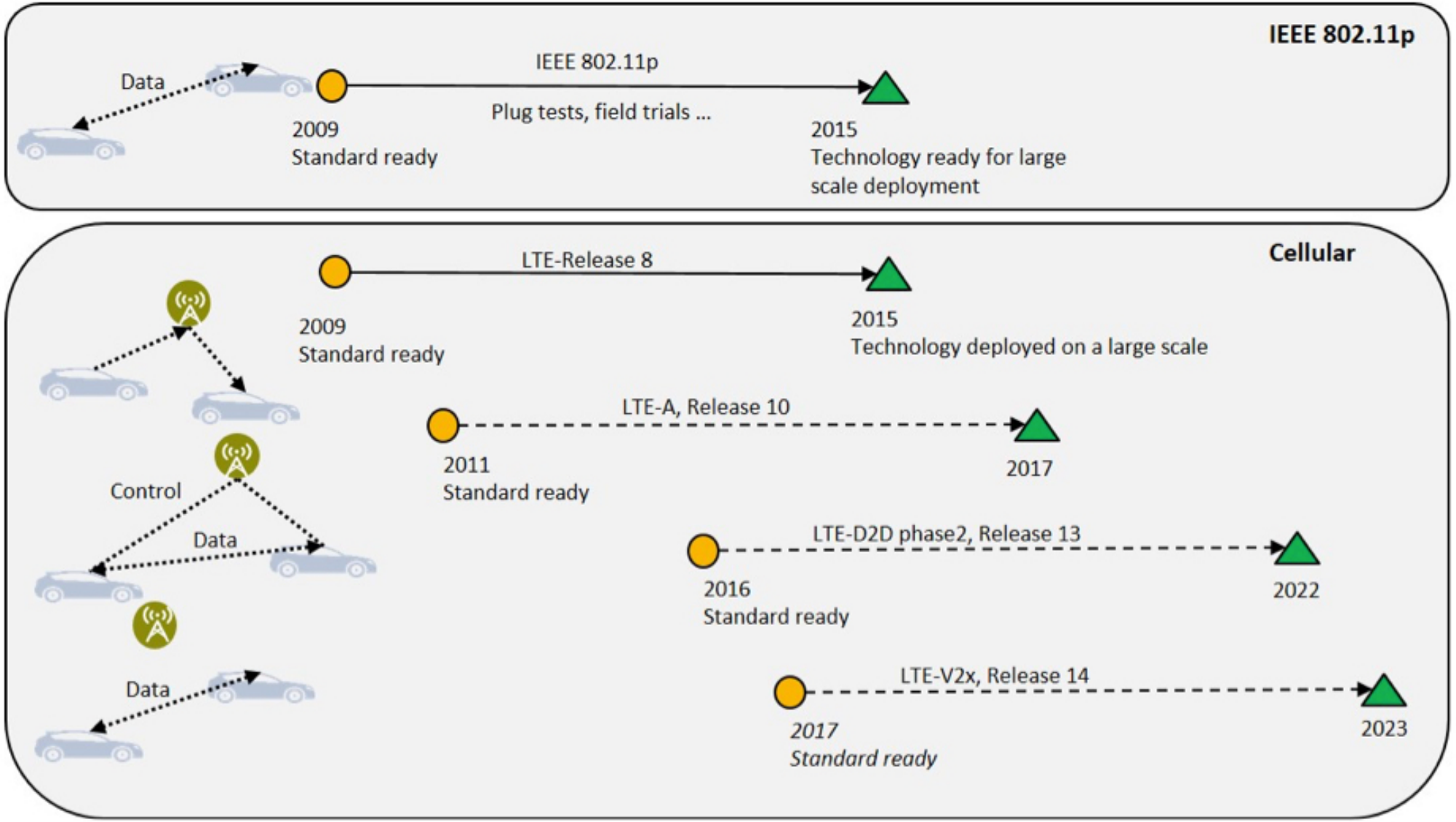
- **IEEE 802.11p** – special standard developed for vehicular communication
  - 75 MHz wide spectrum at 5.9 GHz, modified IEEE 802.11a
  - Enhanced MAC, QoS support, beaconing
- Standard adopted in 2009, many field trials since then, **ready to use**

Cellular and IEEE 802.11p for C-ITS



- **LTE-based V2V support**
  - Current versions of LTE can only address basic ITS use cases
    - No support for low latency and high mobility use cases
    - 3GPP V2x study group established in 2015
  - LTE D2D – Device-to-Device
    - part of Release 12, but not suitable for V2V
    - Signaling/control via the eNodeB
    - Direct data sending between the UEs
  - LTE-V2x probably in release 14, 15, by the end of 2017
    - Much time ahead until large scale deployment

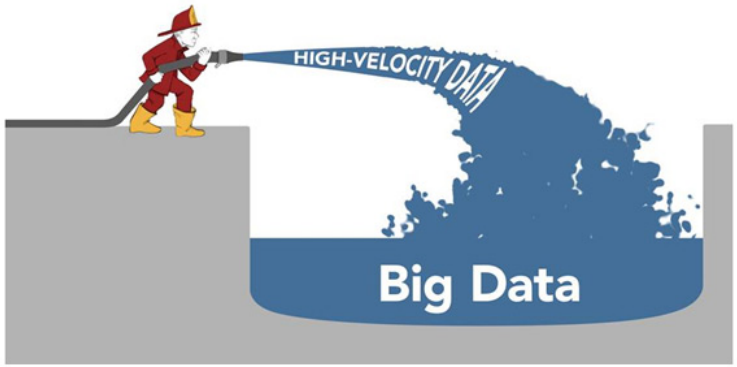
IEEE 802.11p vs. LTE-V2x



Big Data technologies

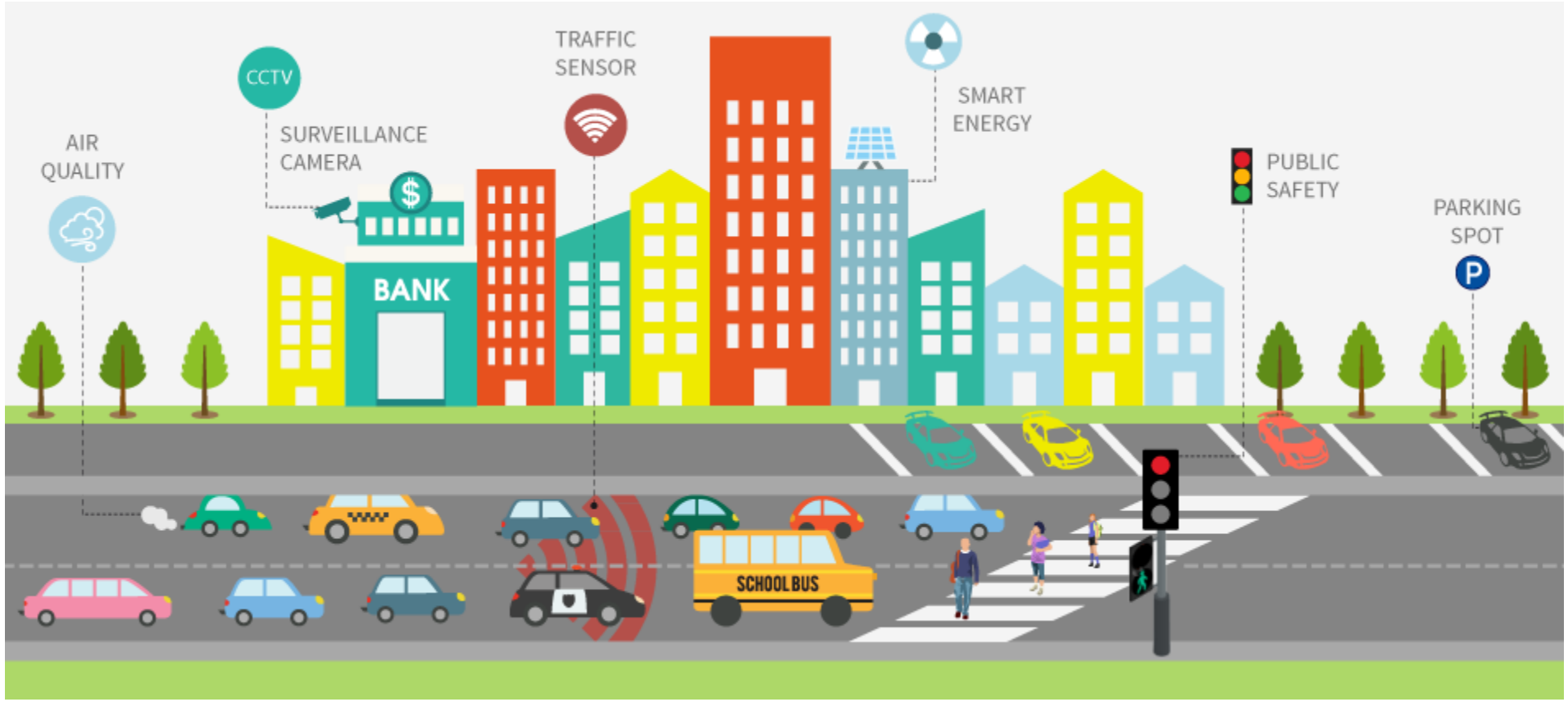
- After the data is sensed and transmitted, it should be processed (filtered, analyzed, aggregated, etc.)
- The „3 Vs of Big Data” for IoT in smart cities

High Volume	High Variety	High Velocity
4 TBytes / day / car UHD cameras Smartphone videos Many sensor data	Data from sensors, cameras, cars, phones, ….	Need for real-time processing



- The final goal would be **personalized and context-aware services** for every person
- **We are still far from there**
  - Example: no personalized routes in Waze, no user profiles
    - Too complex to calculate

waze



Thank you!

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