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
  - \(\text{IoT} = \text{Network of “smart things”, capable of sensing the physical world, and communicating, without human intervention}\)
  - 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
- Buses
- Smart meters
- Kiosks
- Electronic displays
- Cars
- Parking sensors
- Smart watches
- Weather stations
- Surveillance cameras
- Thrash bins
- And many more…
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

- 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 – **Routing Over Low power Lossy** (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**

- **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

- **IEEE 802.11p**
  - 2009: Standard ready
  - Plug tests, field trials ...
  - 2015: Technology ready for large scale deployment

- **Cellular**
  - LTE-Release 8
    - 2009: Standard ready
    - 2011: Standard ready
  - LTE-A, Release 10
    - 2015: Technology deployed on a large scale
    - 2016: Standard ready
  - LTE-D2D phase2, Release 13
    - 2017: Standard ready
  - LTE-V2x, Release 14
    - 2017: Standard ready
    - 2022
    - 2023
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**
    - 4 TBytes / day / car
    - UHD cameras
    - Smartphone videos
    - Many sensor data

  - **High Variety**
    - Data from sensors, cameras, cars, phones, ….

  - **High Velocity**
    - 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
Thank you!

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