

**Industry 4.0**  
**– 5G, Cyberphysical Systems and**  
**Autonomous Driving -**

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# Content

1. Introduction
2. Wireless communication: Key technology for Industry 4.0
3. Cyberphysical Systems
4. Internet of Things and Sensors
5. Cognitive Systems, Cloud Computing, Smart Factory
6. Networked and autonomous vehicles
7. Summary

# Industry 4.0

- Initiative of German Industry.
- Describes entering of Internet of Things (IoT) into manufacturing processes and resulting technological changes
- New industrial revolution: The rise of intelligent networks to connect wireless machines, tools and other system components in enterprises along the total value chain.
- Machines and Tools control each other autonomously, whereby
  - Enterprises exchange digital data,
  - Tools search its own route along manufacturing stations autonomously inside / external to an enterprise.
  - Production is simulated before being implemented; optimally prepared tools enable change of orders and of products on the same manufacture line avoiding start-up problems; preparatory actions and related cost decrease, substantially.

# Networked Devices for Measurement and Control

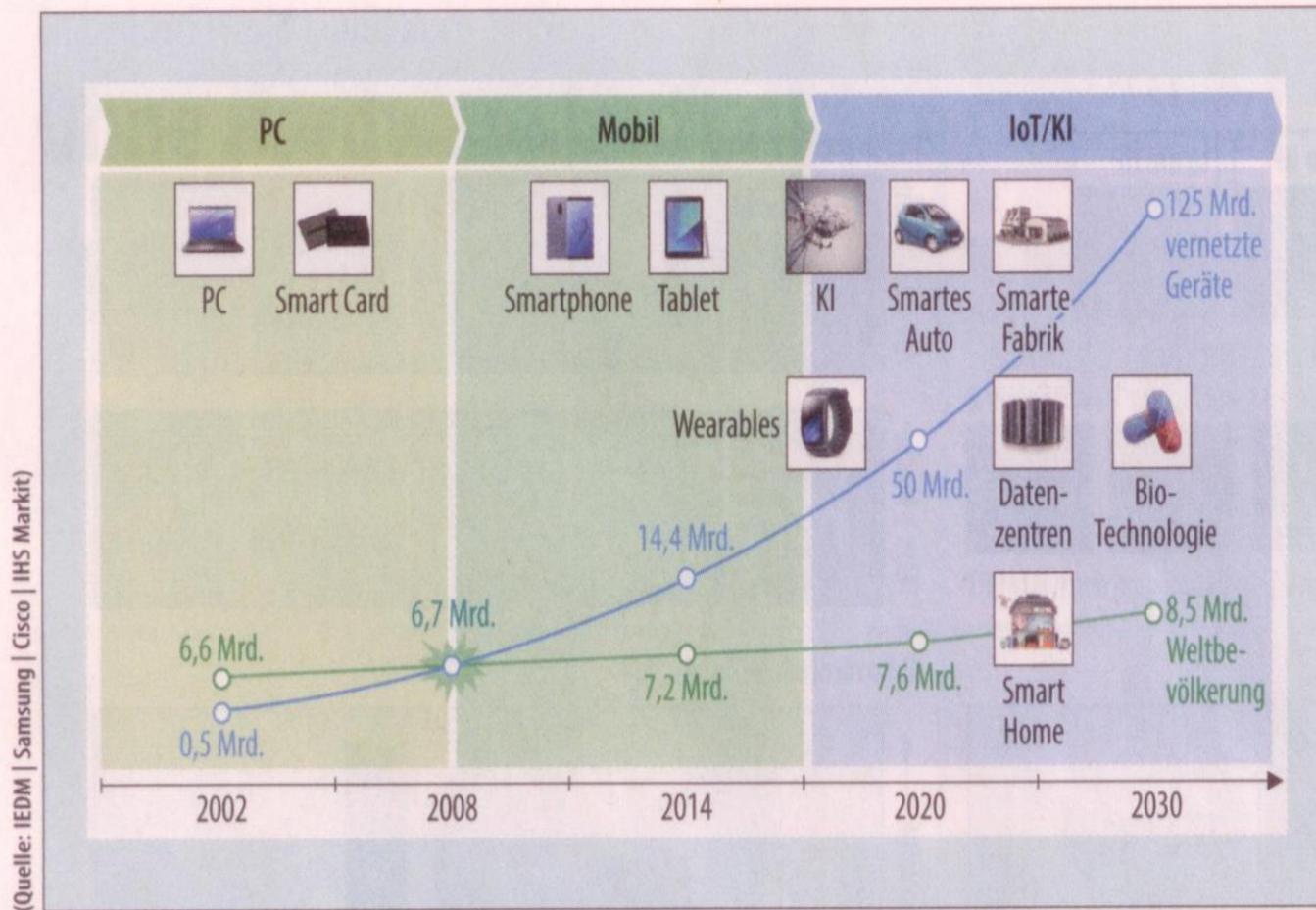


Bild 1. Explosives Wachstum vernetzter Geräte im Zeitalter der 4. Industriellen Revolution.  
Explosive growth of networked equipment in 4th industrial age

# 5G Cellular is a Key Technology for Industry 4.0

5th generation (5G) mobile radio standard from 2020 on will boost Industry 4.0.

Compared to 4G, 5G enables much

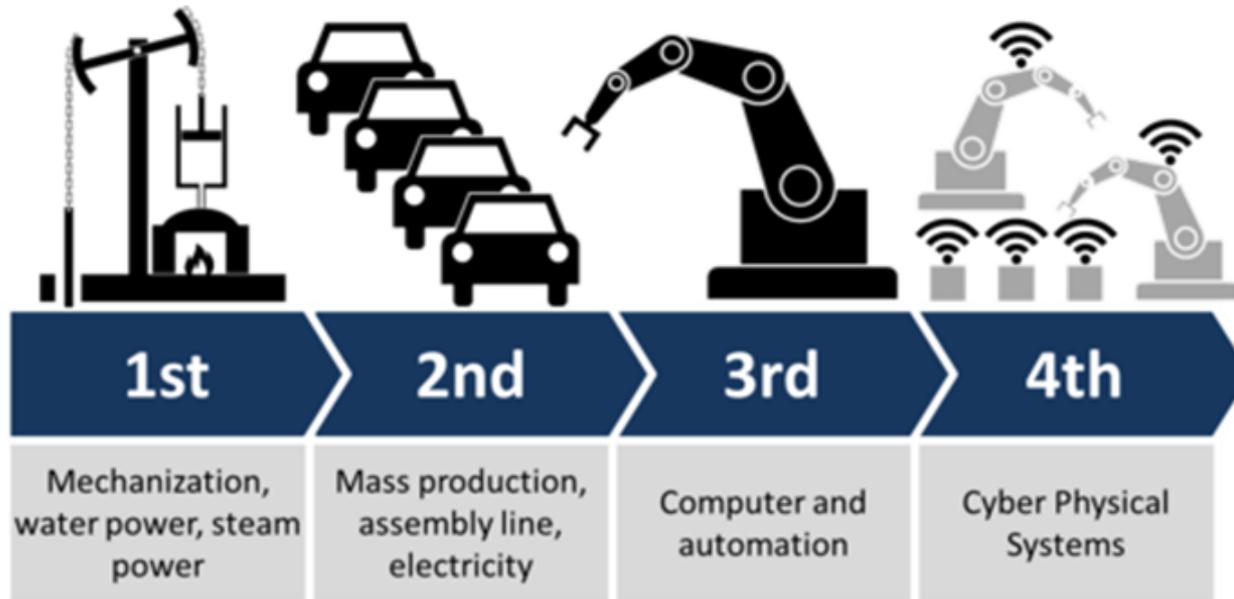
- higher data volume
- less transmission time
- less transmission delay
- more devices connected.

Although industry has progressed towards networked production lines already quite well, experts expect real autonomous acting systems not before 2050.

Industry 4.0 cannot be thought without substantial progresses of information technology (IT) and wireless networks.

Before the vision of Industry 4.0 can happen, cable networks first need an upgrade, since unable to keep up with data rate available from 5G.

# Phases of Industrial Revolution



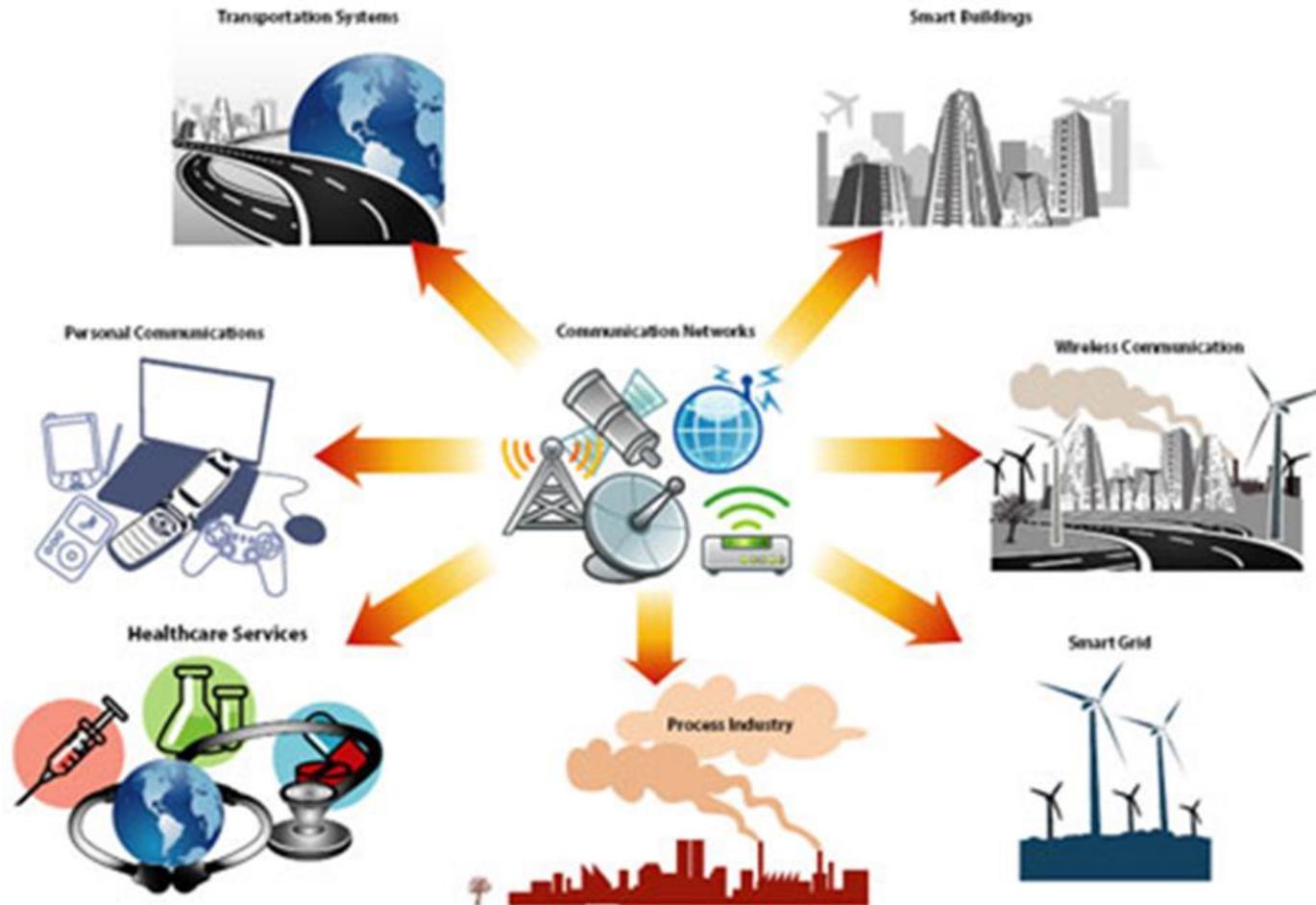
- Industry 4.0 will substitute existent systems and techniques in revolutionary way, like machine engineering, production technique, process engineering, automotive technique, health technique, logistics, road traffic etc. by taking advantage of new technical opportunities in function, production and operations efficiency, respectively.
- Industry 4.0 is characterized by two revolutionary techniques: **Artificial Intelligence (AI)** and **reliable, real-time enabled wireless broadband (5G)**.

# Content

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4. Internet of Things and Sensors
5. Cognitive Systems, Cloud Computing, Smart Factory
6. Networked and autonomous vehicles
7. Summary

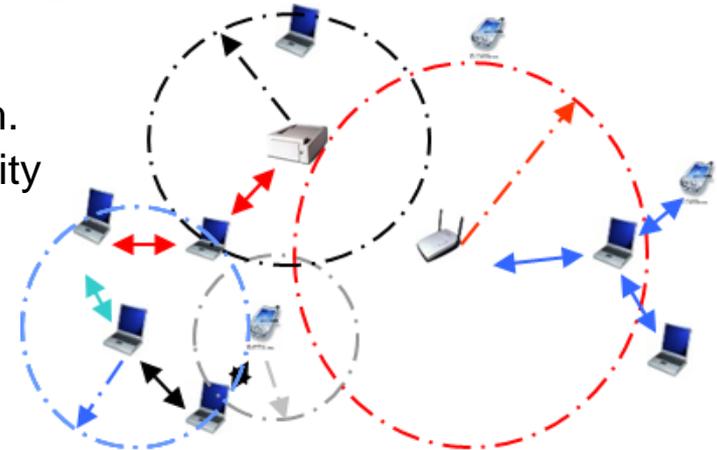
# IoT / Industry 4.0 essentially need wireless access networks

Internet: Cable based telecommunications network. Wireless and mobile access to Internet is provided by WLAN and 5G, respectively.



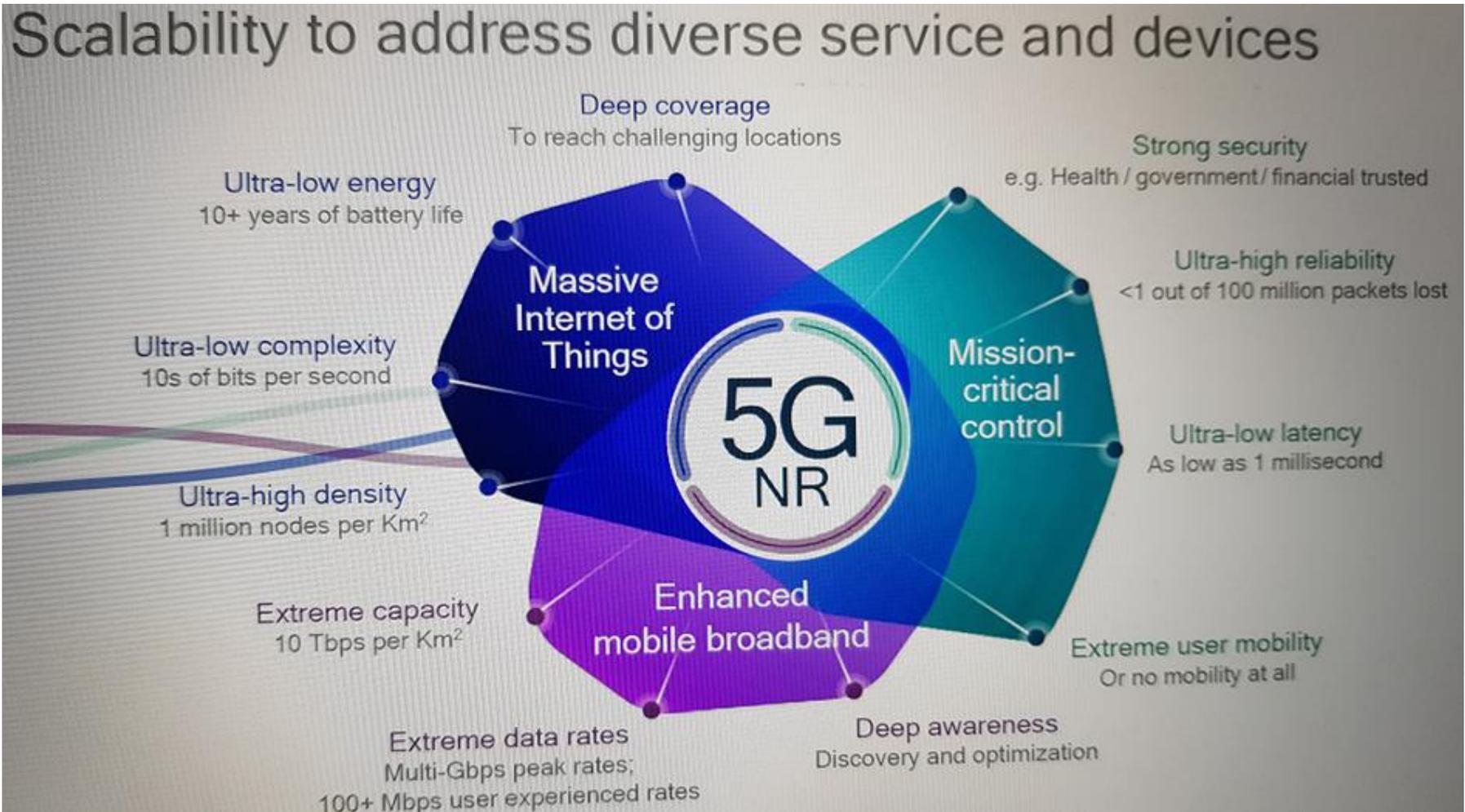
# Wireless (WLAN) and Mobile Radio Networks (4G/5G)

- Wireless networks (WLAN, IEEE 802.11) connect movable devices to Internet.
- Mobile radio networks connect mobile devices (up to high speed of movement) without interruption to Internet. Complexity and cost is much higher than with WLANs.
- WLANs transmit in license free frequency spectrum at 2,4 / 5 GHz. Range: indoors / outdoors 30 / 300 m. WLANs radio cells may overlap, have varying capacity and are not well suited for real-time support.
- Mobile radio networks use complex protocol stacks at the air interface, have fixed cell capacity and support real-time data service.
- For meshing machines by radio reliable (interference-free) radio is required.
- Operation in licensed frequency spectrum (like 5G) enables control of radio interference by systems of same and other standards.  
WLAN could be a severe competitor to 5G if operated in licensed spectrum, too.
- 5G is especially well suited to fulfill mission critical requirements of Industry 4.0.



# 5G as the first will serve any mobile applications

5G will serve multiple applications in an optimal way:



# V2I comms. based on cellular mobile radio was first proposed in 1991

EU project Prometheus/Pro-Com (1987-92) studied benefits of networked vehicles (V2X).

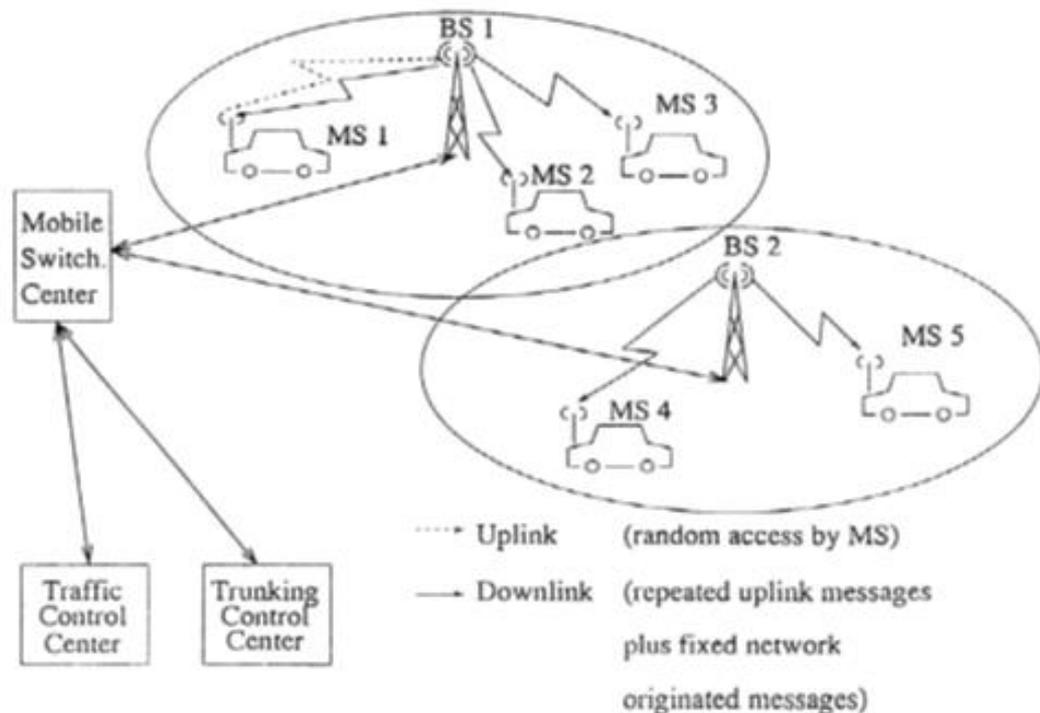
1991: Built a packet-switched service on top of GSM to serve V2X. B. Walke et. al.: CELLPAC: A packet radio protocol applied to the cellular GSM mobile radio network. Proc. 41th IEEE Vehicular Technology Conference (VTC), May 19-22, 1991, 408-413.  
<https://www.comnets.rwth-aachen.de/downloads/publications/1991WaMeHacellpac.pdf>

This new idea triggered development of GPRS (first mobile Internet access network). B. Walke:

The roots of GPRS: the first system for mobile packet-based global Internet access, IEEE Wireless Communications Mai 2013, 12-23

[http://www.comnets.rwth-aachen.de/downloads/publications/Roots\\_of\\_GPRS\\_final.pdf](http://www.comnets.rwth-aachen.de/downloads/publications/Roots_of_GPRS_final.pdf)

Packet Radio Scenario:



V2I: vehicle to infrastructure  
V2V: vehicle to vehicle  
V2X: vehicle to anything

# V2V comms. based on adhoc networks was first proposed in 1991

Networked/autonomous driving **must** work without cellular radio coverage, too.

1991: use V2V adhoc network with dynamic channel access protocol (DCAP).

B. Walke et.al.: DCAP: A Decentral Channel Access Control Protocol: Performance Analysis. Proc. IEEE Vehicular Technology Conf. St. Louis, Missouri, USA, May 1991, 463-467, <http://www.comnets.rwth-aachen.de/downloads/publications/1991ZhuHeWadcap.pdf>

USA: Vehicular Adhoc Network (VANET) standard is based on IEEE 802.11p.

EU today: Co-operative intelligent transport system (C-ITS G5). Basis:IEEE 802.11p

EU future: C-V2X (LTE Rel. 12 (2014) – D2D – a variant of HiperLAN/2 direct mode;

B. Walke, et.a.: IP over Wireless Mobile ATM - Guaranteed Wireless QoS by HiperLAN/2. In Proc. of the IEEE, Vol.89, 21-40, 01/2001 [http://www.comnets.rwth-aachen.de/downloads/publications/WaEsHaHe\\_ProOfIEEE2001.pdf](http://www.comnets.rwth-aachen.de/downloads/publications/WaEsHaHe_ProOfIEEE2001.pdf)

(LTE Rel.16 (2020) – a variant of DCAP with cellular support.

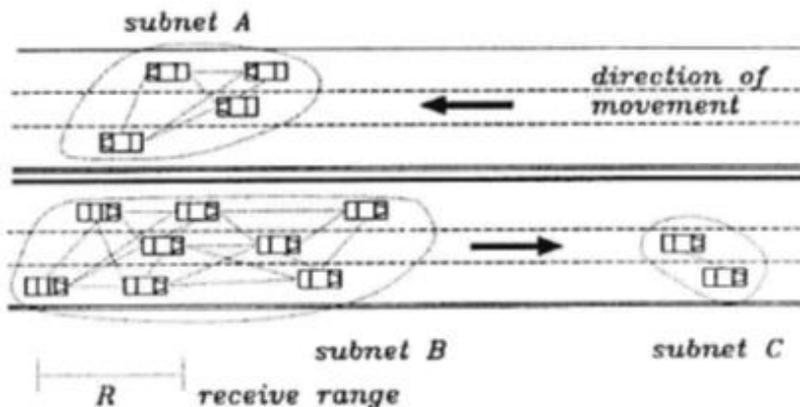


Figure 1: Example of a three lane highway

**DCAP 1991**



**US: VANET/ EU: C-ITS G5 2019**

# 5G and WLAN: Competitors in Industry 4.0

Data traffic load to Industry 4.0 radio channel in applications like smart grid, V2X, healthcare, Robotics, industrial process control) has

- Either random, or periodic arrival process of single short ( $< 1\text{ kB}$ ) data blocks
- Data rate from extremely low to extremely high – application dependend.

Both, 5G and WLAN have very similar physical layer and apply

- Random access (S-Aloha / CSMA/CD) to the radio channel
- Reservation of channel capacity before transmission of a data block

5G also provides semi-persistent connection (reducing number of random access events)

Some Industry 4.0 applications need data block delay  $< 5\text{ ms}$ .

Random access is the more successful the smaller the radio channel is loaded.

A low load WLAN channel has a low delay figure, comparable to a much higher loaded 5G channel. WLAN real-time behavior may be sufficient for many applications.

→ Real-time 5G service is required only, if WLAN channel capacity is insufficient. WLAN may operate in licensed spectrum.

Capital + operations expenditures tend to favor WLAN instead of 5G, owing to cost.

Non-real-time applications may prefer WLAN, in general.

# Contents

1. Introduction
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4. Internet of Things and Sensors
5. Cognitive Systems, Cloud Computing, Smart Factory
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7. Summary

# Autonomous Robots

Autonomously running robots - like a packet delivery bot or a drone - need functions similar to autonomous driving.

Autonomous systems are known long time in non-public domain, e.g. manufacturing plant. An example is the high-bay warehouse served by autonomously driving cars to store pallets.



# Contents

1. Introduction
2. Wireless communication: Key technology for Industry 4.0
3. Cyberphysical Systems
4. Internet of Things and Sensors
5. Cognitive Systems, Cloud Computing, Smart Factory
6. Networked and autonomous vehicles
7. Summary

# Internet of Things (IoT)

**Internet of Things** results from adding sensors/actuators to devices of daily life, thereby connecting to the Internet, e.g.

- smart kitchen devices (for improving quality of life in households),
- bicycles (for improving efficiency, safety, enjoyment of use),
- Toys,
- Multi-media devices,
- Plants on the field (to be monitored in the cloud of a farmer),
- Wild animals and home pets (for localisation, feed monitoring, etc.),
- Commodities of daily life,

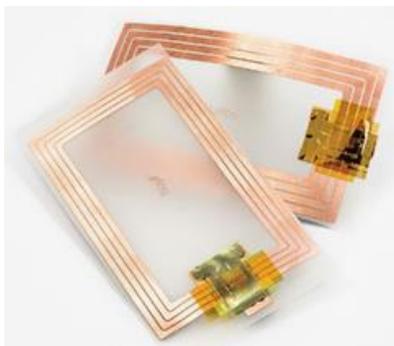
# Sensors for Everything

Convergence of low-cost components like micro-processor, cellular radio, WLAN and micro-electro-mechanical systems (MEMS) enable IoT.

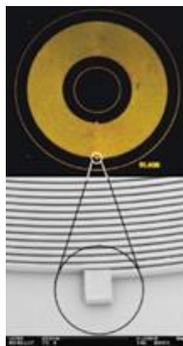
An IoT sensor has two parts:

- Sensor to detect some specific physical or chemical event
- telemetric unit for transport to Internet via radio waves (4G, WLAN, Bluetooth).

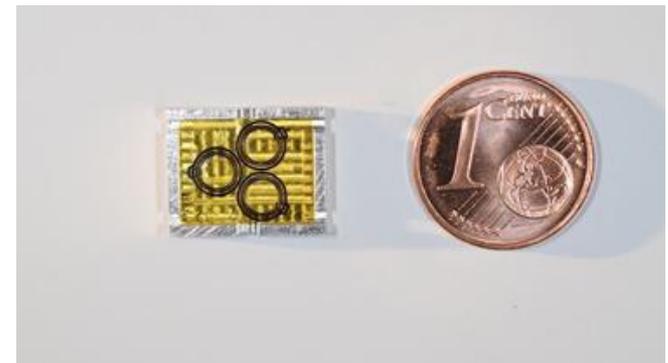
There is no need for a battery if a passive antenna coil exchanges data with a nearby operated radio-frequency identification device (RFID) or with a near-field communication (NFC) reader.



Sensor für RFID



Sensor für NFC



MEMS Sensor

# Sensors and Actuators

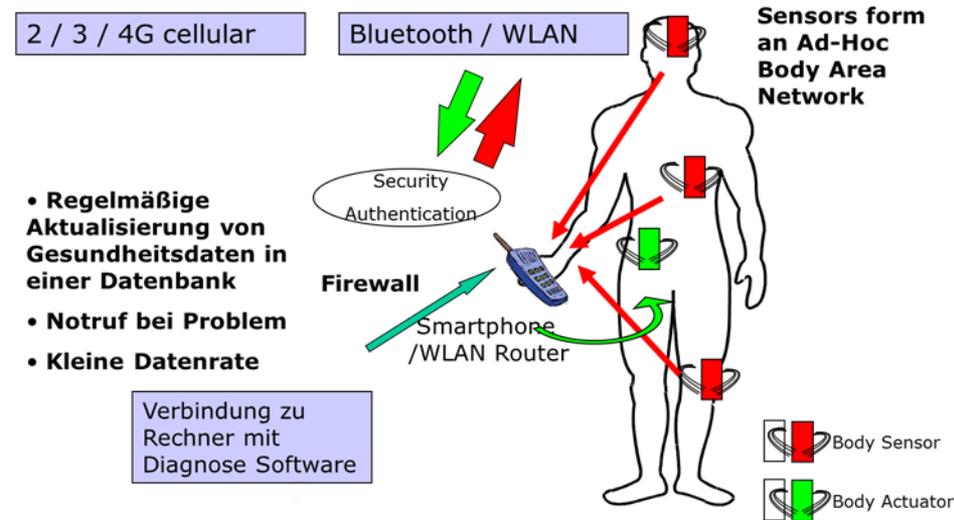
Sensors and actuators in Industrie 4.0 are source of information and implement actions, respectively, under control of AI-based software.

Wearables evaluate parameters by measurement and exchange data on IoT without human interaction with manufacturers, network operators, and sensor-enabled devices, mostly across a smartphone used as relay.

Miniaturisation in general, new sensor materials, new production techniques, energy harvesting from the radio field etc. enable sensor use in IoT. Accordingly, production of large quantities of smart sensors happens; cost is dropping, dramatically.

MEMS sensors in medical applications react to state/activity of a person, e.g. by automatic application of drugs, localisation, identification, transmission and presentation of context specific information, virtual assistance etc.

The market of medical sensors in year 2022 is estimated 14 Billion € worth.



# Wearables may be sensor driven machines

Industry wearable sensors are in use, e.g.

- smart spectacles and smart gloves,
- augmented reality support to worker, where head-mounted data glasses are combined with display, camera and speech set for providing supplementary information
- sensors in protective clothing.

A bionic robot, e.g. an exo-skeleton is a wearable, too. It amplifies human body force interpreting body movement measured by sensors.



# Content

1. Introduction
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4. Internet of Things and Sensors
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6. Networked and autonomous vehicles
7. Summary

# Cognitive Systems

**Software, machines and robots perform self-controlled actions, which so far were controlled by human intelligence. Thereby, they appear to be smart.**

**But they don't think. Instead they analyze large amount of data, learn from interpretation of data and decide data-driven what action in a given context is required.**

**Artificial Intelligence (AI) – better: machine learning (ML) – selects the most probable solution for a problem at hand based on computation, e.g. to win a game (Schach or Go)**

**AI/ML is applied in:**

**search engine, speech assistant (Alexis, Siri), smart home heating control, robotic vacuum, camera, robot, bot, medicine, police, judiciary, autonomous cars, etc.**

**AI/ML is superior to humans in many application domains. However, if empathy, social intelligence, creativity, fine motor skill or adaptation to dynamically changing conditions is required,**

**AI/ML – at least today – has no chance, when compared to a human.**

# Cloud Computing (CC)

CC replaces/supports (for cost reduction) local data processing and –storage of companies/private households over Internet.

High performant central data base computers and storage devices take over tasks in CC using most recent technology with higher speed, efficiency, security etc. compared to local systems.

Expenditures for local IT staff is saved. IBM / Microsoft with Cloud services gain more sales and revenues than with sale of computers and software.

There is no need for local data storage of cloud users, anymore.

CC guarantees strict separation of company specific data from any other users that share cloud services.



**FOKUS:** Rechenzentren sind die Wurzel der Cloud. Die Mischung aus Servern, Speichern, Netzwerken und Kühlung schafft die Voraussetzung für die erfolgreiche Digitalisierung vieler Industrien.

# Smart Factory

Combination of IoT and Industry 4.0 enables more transparency in technical processes and less delay of manufacture of industrial products in factories.

Manufacturers compete for leadership in providing smart platforms for Industry 4.0. The winner owns the data, gaining an enormous competitive edge, and can influence the whole ecosystem.

The key is software and the ability to transform ideas and optimization into products and processes, fastly.

Supplementing plants by **cyberphysical systems (CPS)** result in the **smart factory (SF)**.

Products, resources and processes of SFs are characterized by CPS and provide substantial gain compared to conventional systems in terms of quality, consumed time, resource consumption and cost of manufacturing.

A SF is a flexible, self adaptive, learning, error tolerant, fully automated and, low-risk plant,.

Automation results from a flexible network of cyberphysical production systems that supervise and control the whole production process to a large extent.

# Smart Factory, cont'd

Driverless transport systems replace classical production lines. The products are transported automatically between service stations.

SF based production compared to conventional production has advantages.

SF elements identify/decide their

- tasks domain.

- options of plant configuration,
- production conditions

and communicate wirelessly with one another, independently;

Customer oriented/optimized production is achieved by smart configuration of best suited production systems conditioned on cost, logistics, security, reliability, delay and sustainability.

Other pros:

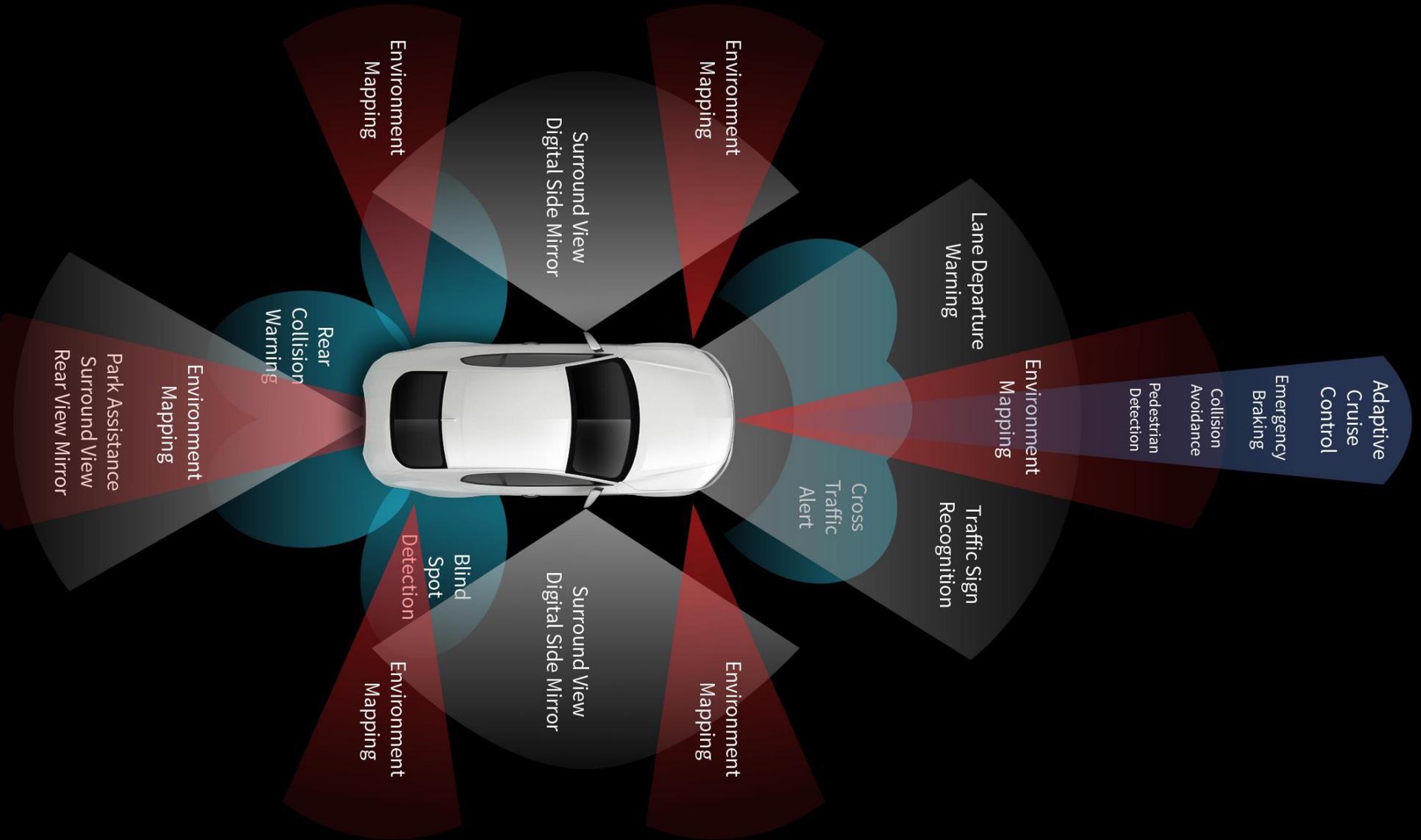
Resource-efficient production; tailored adaptation to human worker (machines adapt to working cycle of humans, not vice versa).



# Inhalt

1. Introduction
2. Wireless communication: Key technology for Industry 4.0
3. Cyberphysical Systems
4. Internet of Things and Sensors
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7. Summary

# Sensor Tasks in Autonomous Driving



# From Networked to Autonomous Driving

**Networking:** Road traffic is seen as a cyberphysical system as part of IoT.

**Autonomy:** Vehicles autonomously decide their action based on sensor data.

**Step 0: No automation** at all; driver involvement: 100%.

**Step 1: Driver assistance;** Vehicle steers either steering or speed, - Not both simultaneously. Driver is completely responsible for supervision of road traffic and take-over assistance system tasks in case of error. Example: *adaptive cruise control*.

**Step 2: Partial automation:** Vehicle under circumstances may steer, accelerate and break. Driver involvement: Responsible for tactical manoeuvres like traffic signs observation, lane change and obstacle detection. Example: Audi Traffic Jam Assist, Mercedes-Benz Driver Assistance Systems, Tesla Autopilot.

**Step 3: Conditioned automation:** Under normal conditions a vehicle handles most driver tasks including supervision of environment. Driver assistance is asked for by the system if a scenario is detected it cannot handle. Stand-by state of the driver is required at any time to take over control of the vehicle. Example: Audi Traffic Jam Pilot.

**Step 4: High automation:** Vehicle acts without human interaction, but only under specific conditions like type of road, location of operation. Driver involvement: Possible none in a leased car driving in given area.



Mit einem Shuttle-Konzept demonstriert Bosch auf der CES die Möglichkeiten autonom agierender Fahrzeuge. Foto: Bosch

# Networked / Autonomous Vehicles, cont'd

A Step 4 private car driver must perform all tasks himself if not driving on a motorway; there he becomes a passenger. No examples.

**Step 5: Full automation:** Driverless vehicle is able to drive on any road, under any environmental condition a human can handle. Driver responsibility: Enter destination. No examples.

Step 4/5 vehicles in critical situations will ask for support by

„remote driver“, e.g. under severe fog or spray on road, where no object recognition or positioning is possible and navigation fails w.r.t. robustness reliability and precision – in spite of mm-wave radar, camera and LiDAR.



# Summary

Industrie 4.0 is the name of 4th industrial revolution

Key technologies are

- Networking by 5G mobile radio, WLAN und Internet
- Artificial intelligence / Machine Learning
- Sensors combined with processor and telco modem
- Cloud Computing, Image processing, LiDAR etc.

Software platforms enable operation of cyberphysical systems based on sensor input.

Examples of Industry 4.0 cyberphysical systems:

- Smart Factory
- Networked /autonomous driving
- Networked Robots in factory and outside
- Sensor networks

Positive side-effects are expected for economy; negative effects for security of Industry 4.0 systems.