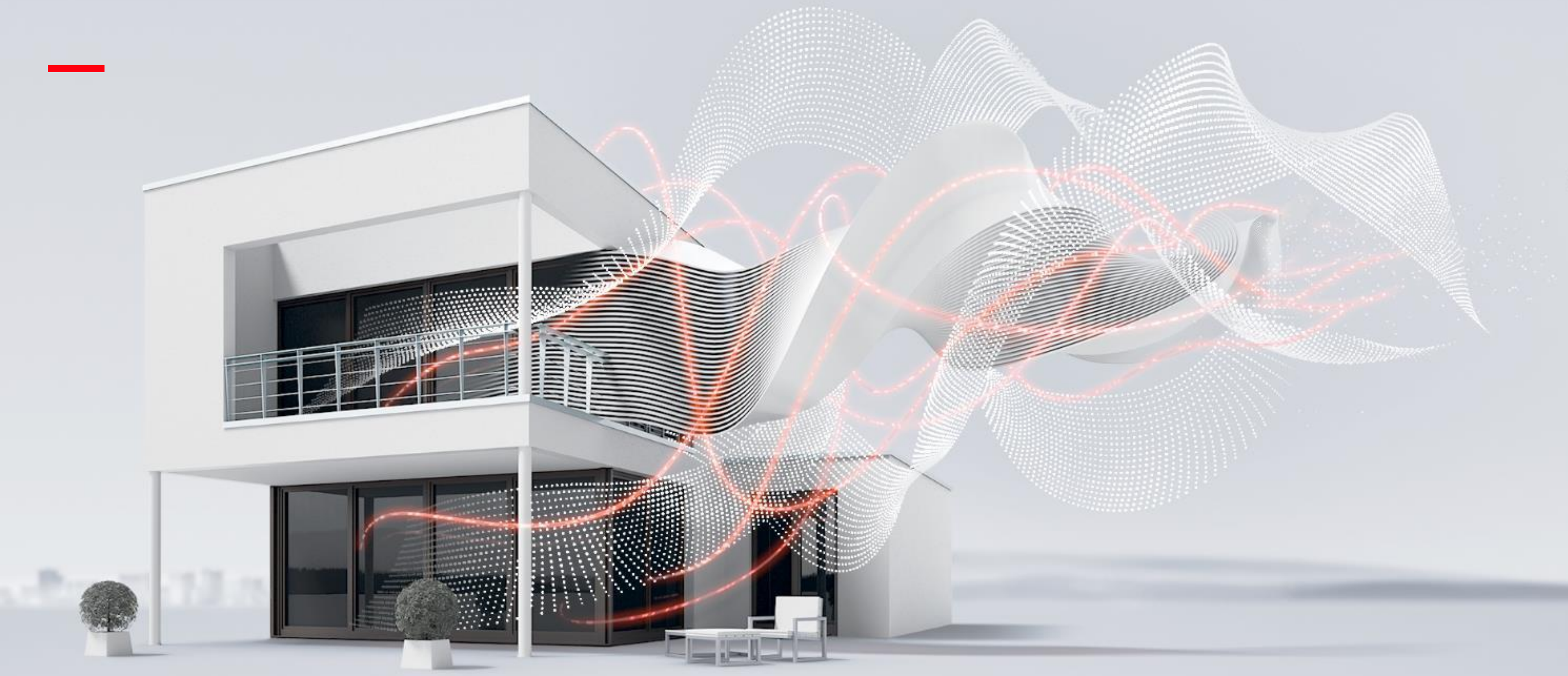

5TH WORKSHOP ON NETWORK 2030, OCTOBER 14-16, 2019

A THz network

A juvenile technology promising grand future

Dook van Mechelen, ABB Corporate Research, Switzerland

Agenda

- ABB's Digitalization and Automatization
- THz technology and its early applications
- A THz network
  - Availability for THz communication
  - First results from THz data links
  - Novel use cases in engineering and beyond

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Digitalization and Automatization by the engineering group ABB

ABB – a global leader in motion and automation technologies

~147,000 employees

$28 billion

In revenue (2018)

Present in +100 countries

Formed in 1988

merger of Swiss (BBC, 1891) and Swedish (ASEA, 1883) engineering companies

Businesses:

Electrification

Industrial Automation

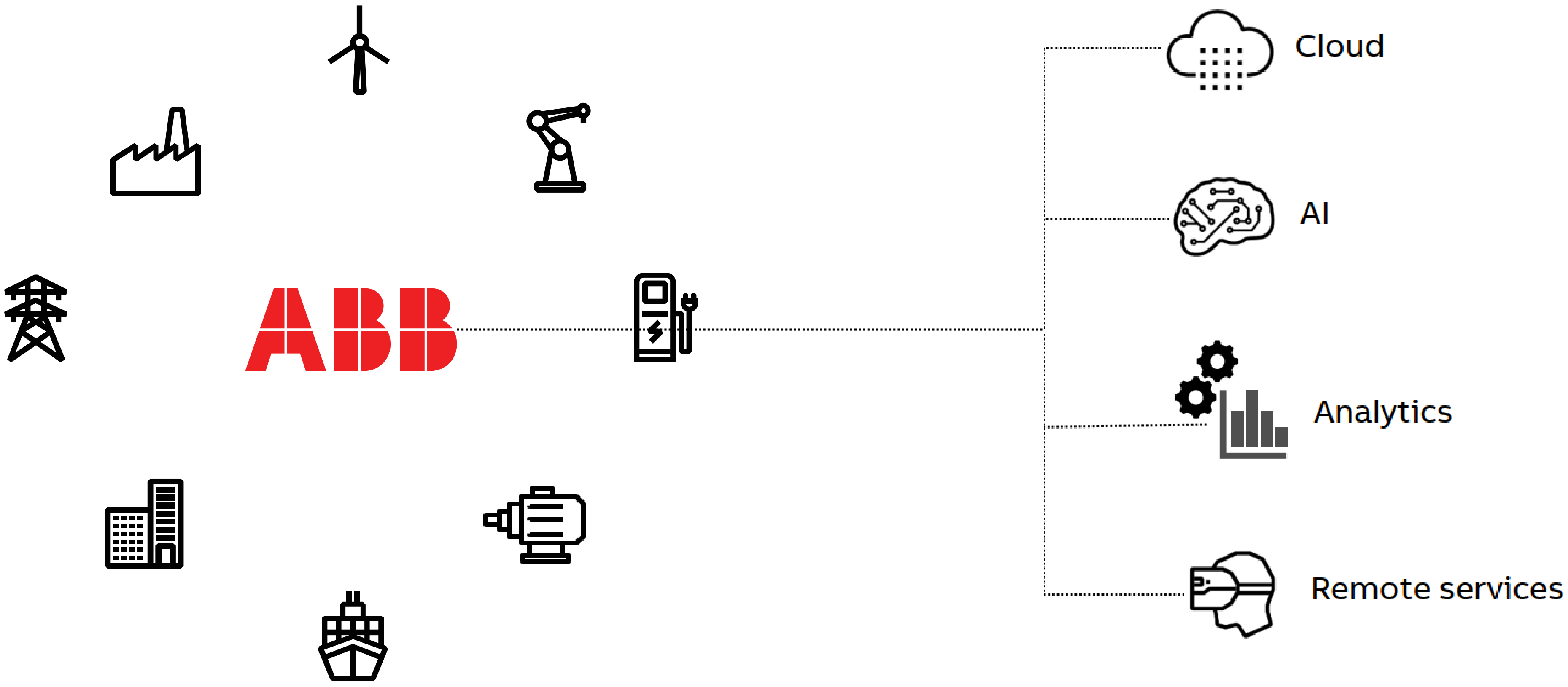
Motion

Robotics & discrete automation

Power Grids

Wide Range of Products and Services

ABB



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Global Market and Seamless Connectivity

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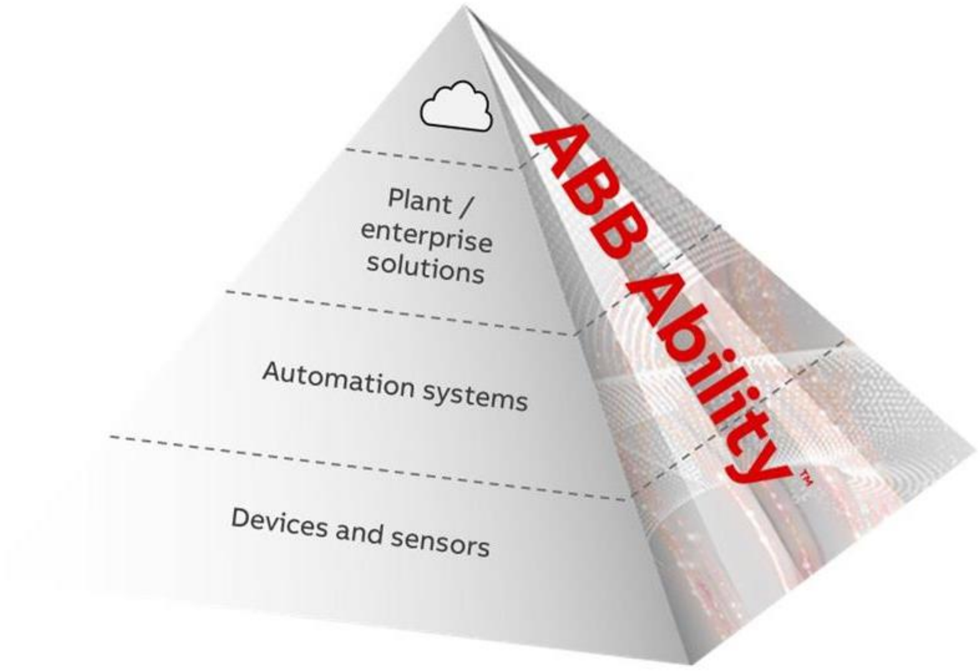
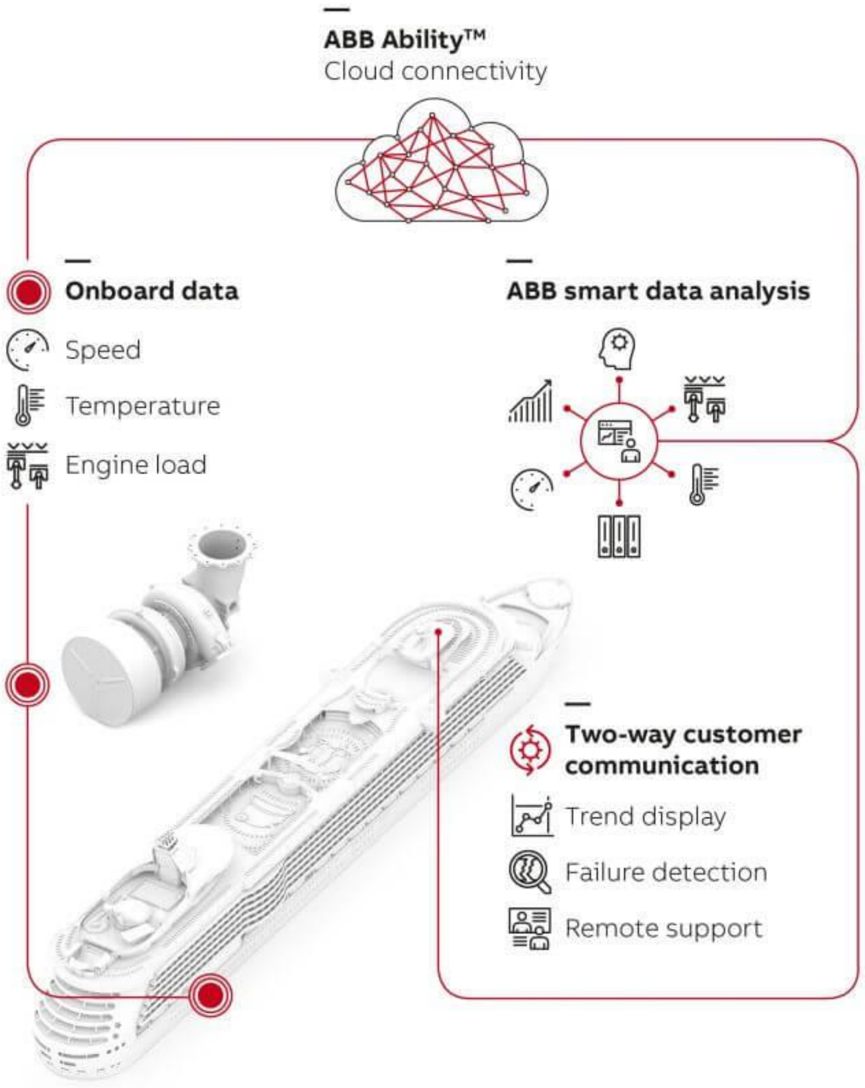
ABB Ability

Digital solutions for the future



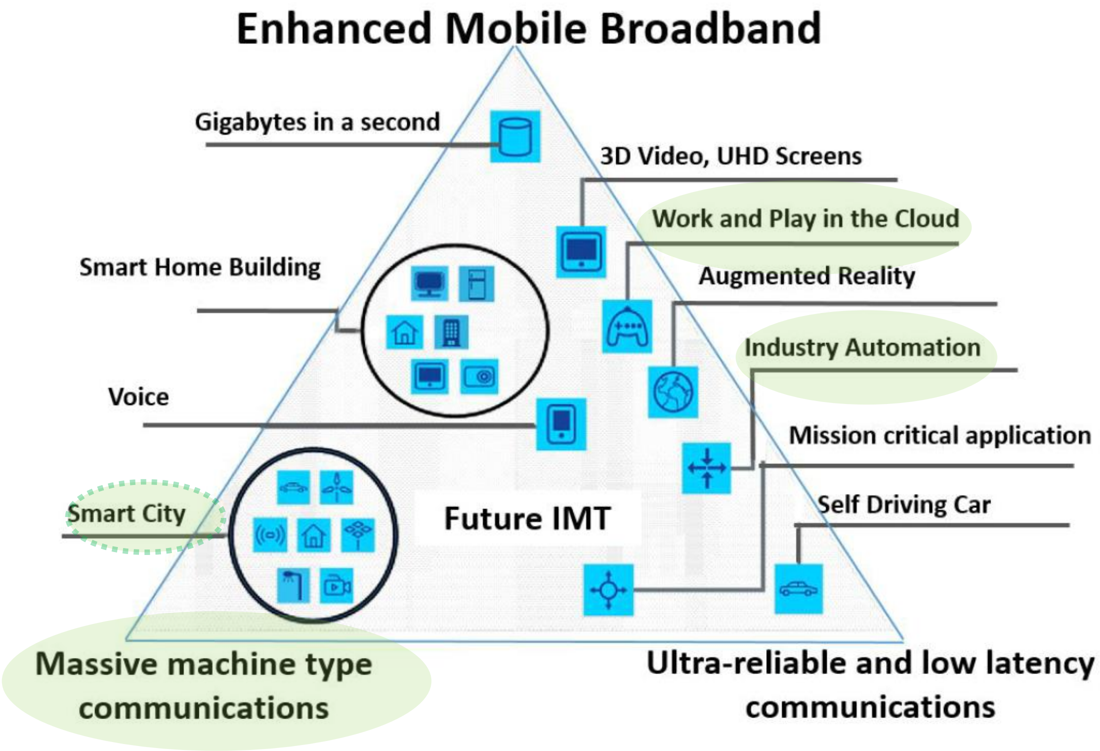


Current networks (wired and 3G/4G wireless) are by far sufficient for the current ABB Ability portfolio

Future wireless networks at ABB

Current activities

- Joint 5G Lab ABB - Ericsson
- Verify benefits and/or limitations of running 5G in products, systems and services
- Identify potential business impact and minimize technology risks
- Early access to 5G technology through close collaboration with 5G technology suppliers and service providers
- Many third party funded projects but also some bilateral research collaborations
- Small scale 6G scouting activity



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World’s first industrial application utilizing 5G and AI

Real-time quality assurance of assembly processes

First industrial application of 5G and AI

- Real-time video feed to data center over 5G
- Assembly of drive power modules
- Improving the quality and productivity
- Stress reduction associated with human errors

Ongoing 5G implementations

- Smart manufacturing
- Synchrophasor-based communication for power grids
- Industrial IoTSP: control-as-a-service for industrial automation
- Line differential protection and control (REF615 using 5G)

©ABB

Press release, ABB Group, 2019-06-14

Our ambitions of the future require novel ways of communication

GREEN CITY
Green Infrastructure
Smart Energy and Utilities
Transport efficiency

ENERGY & UTILITIES
Power Generation Optimization
Grid Protection and Control
Intelligent Utility Network

E-GOVERNANCE
Online Records
Complaint Management
Payment Gateways

TRANSPORT
Unmanned mobility solutions
Airport / Railway Management
Fleet Optimization

PUBLIC SAFETY
Emergency Management
Security and Surveillance

EDUCATION
Analytics and research
Augmented and Virtual Reality
Holographic attendance

SMART BUILDING
Energy Optimization
Appliance Integration and control
Smart Metering

HEALTHCARE
Remote Monitoring
Telemedicine

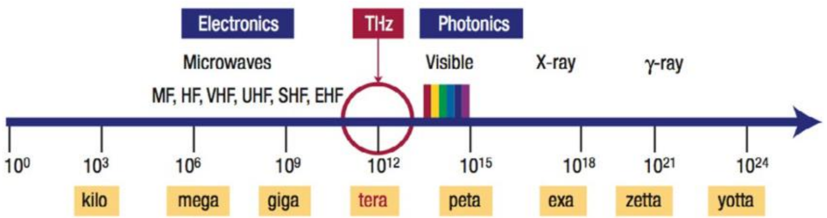
Adapted from Feedback Infra,
Paris Smart City by Vincent Callebaut

THz technology

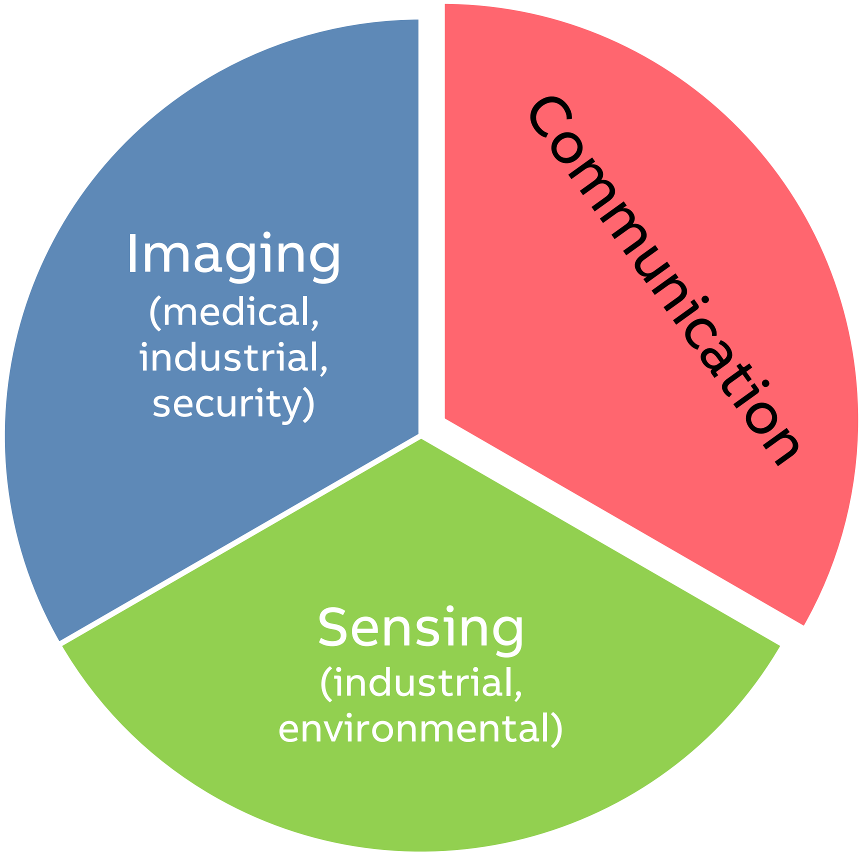
&

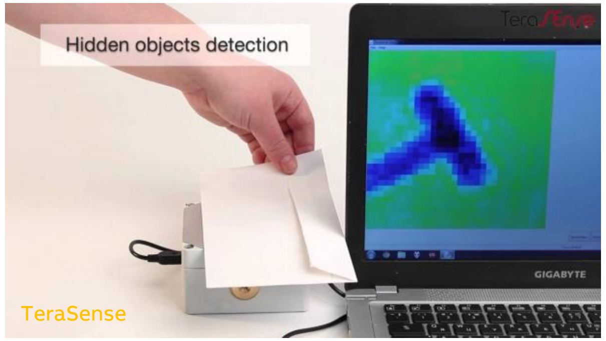
Early Applications

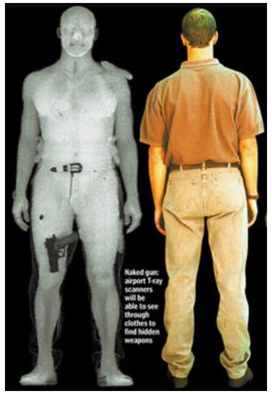
Terahertz technology

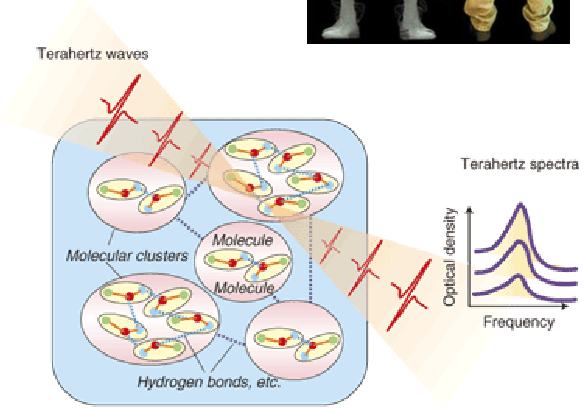


- Conveniently generated and detected only since the early 1990s
- THz radiation is commonly defined as between 0.1 and 10 THz (3 mm – 30 μm)
- Penetrates insulators and is reflected by metals
- Reveals the unique fingerprint of each kind of chemical composition





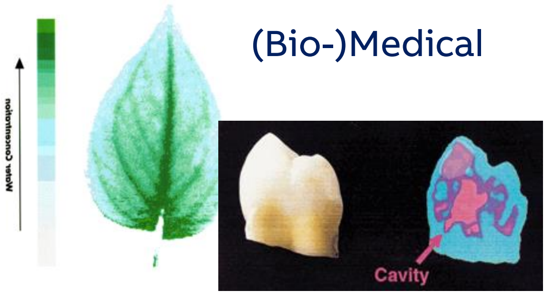




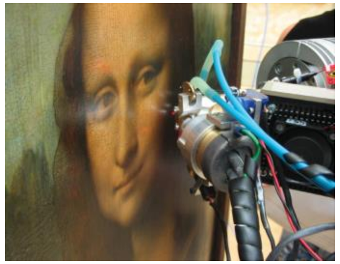
K. Ajito et al, NTT techn. Review 7, 1 (2009)

Terahertz technology

Applications



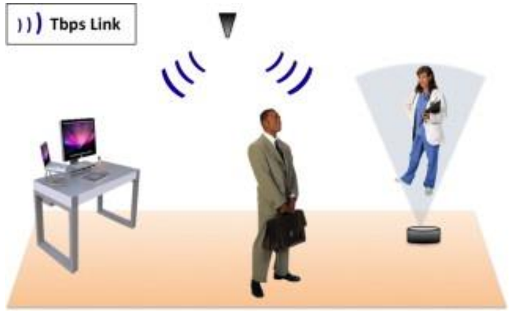
(Bio-)Medical



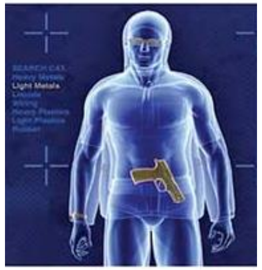
Cultural heritage

Foreseen Applications

Process industries



Communication



Security

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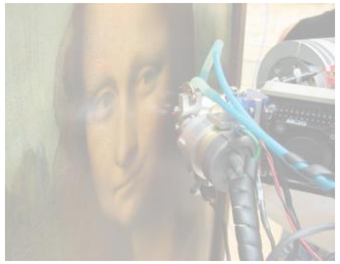
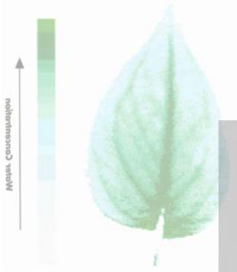
Terahertz technology

Applications



Cultural heritage

Industrial paint quality control

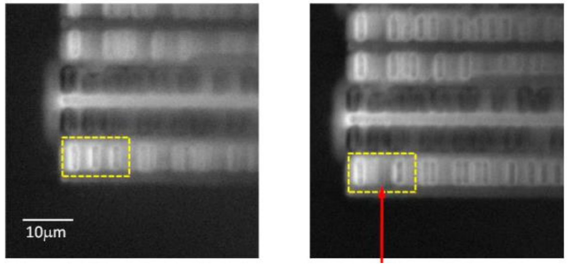


(Bio-)Medical

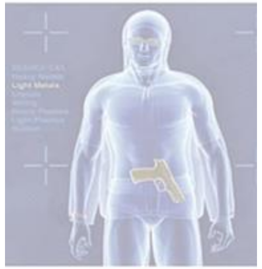
Industrial paper/plastic sheet quality control

Realized Applications

THz communication



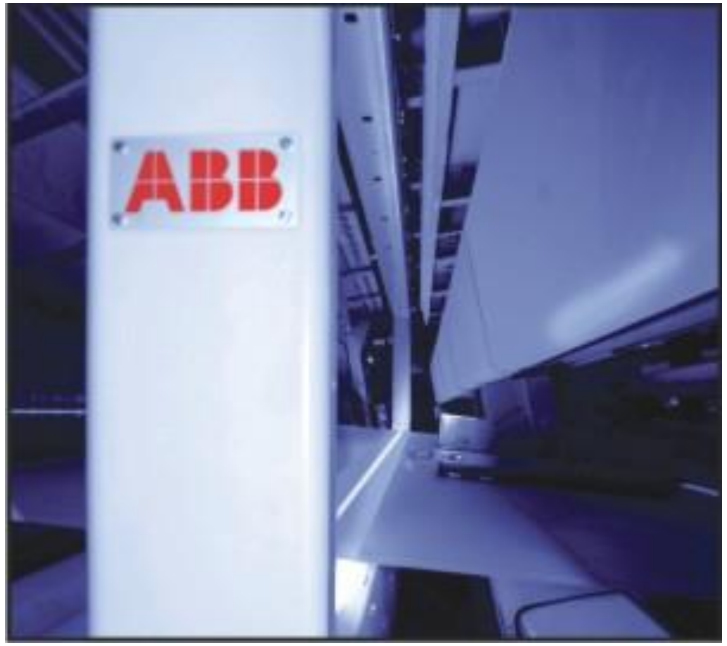
Industrial semiconductor quality control



Security

Terahertz technology

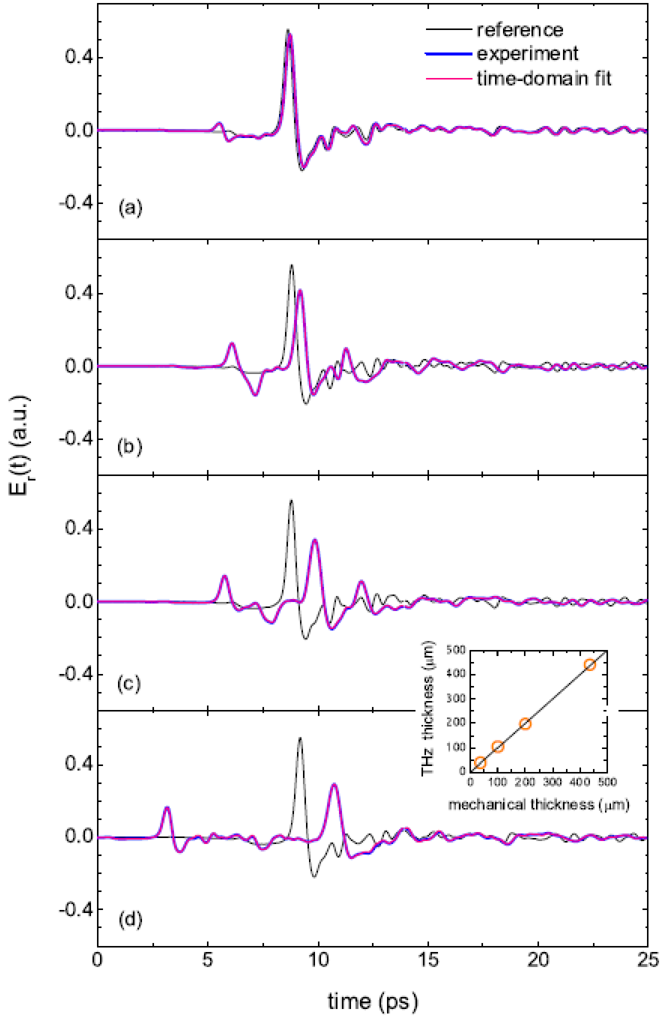
Industrial applications for sensing



Paper/plastic sheet quality control

- Quality inspection of paper parameters during production
- By the interaction of 1ps THz pulses with paper, the following is extracted:
- Weight
  Thickness
  Moisture level
  Filler content
  Fiber orientation

Exact signal processing to reveal material parameters



Tissue

100 gsm copy paper

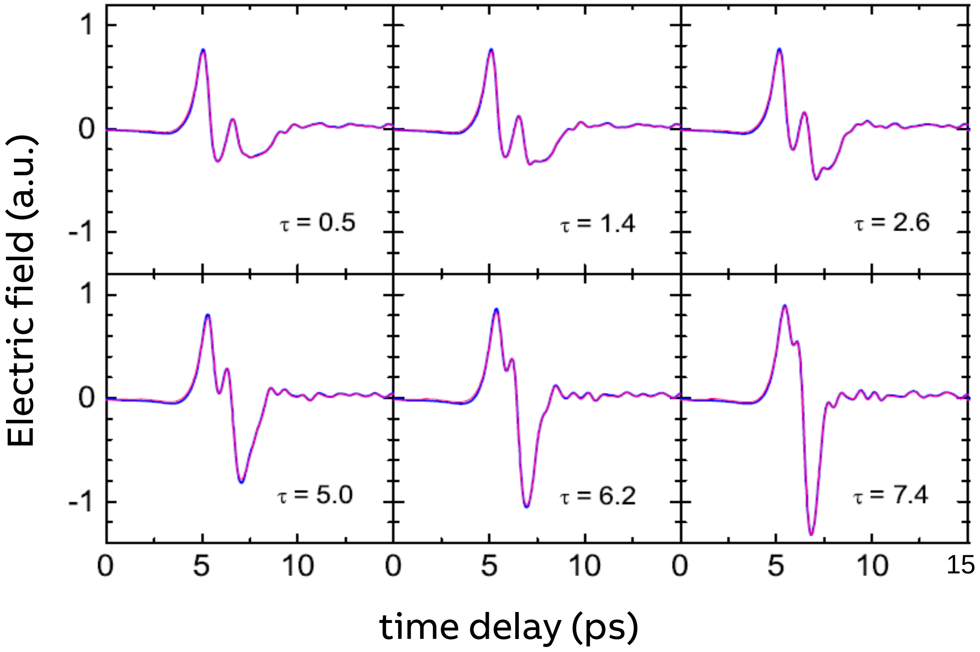
200 gsm copy paper

Single-sided coated board

Terahertz technology

Industrial applications for sensing

Paint quality control

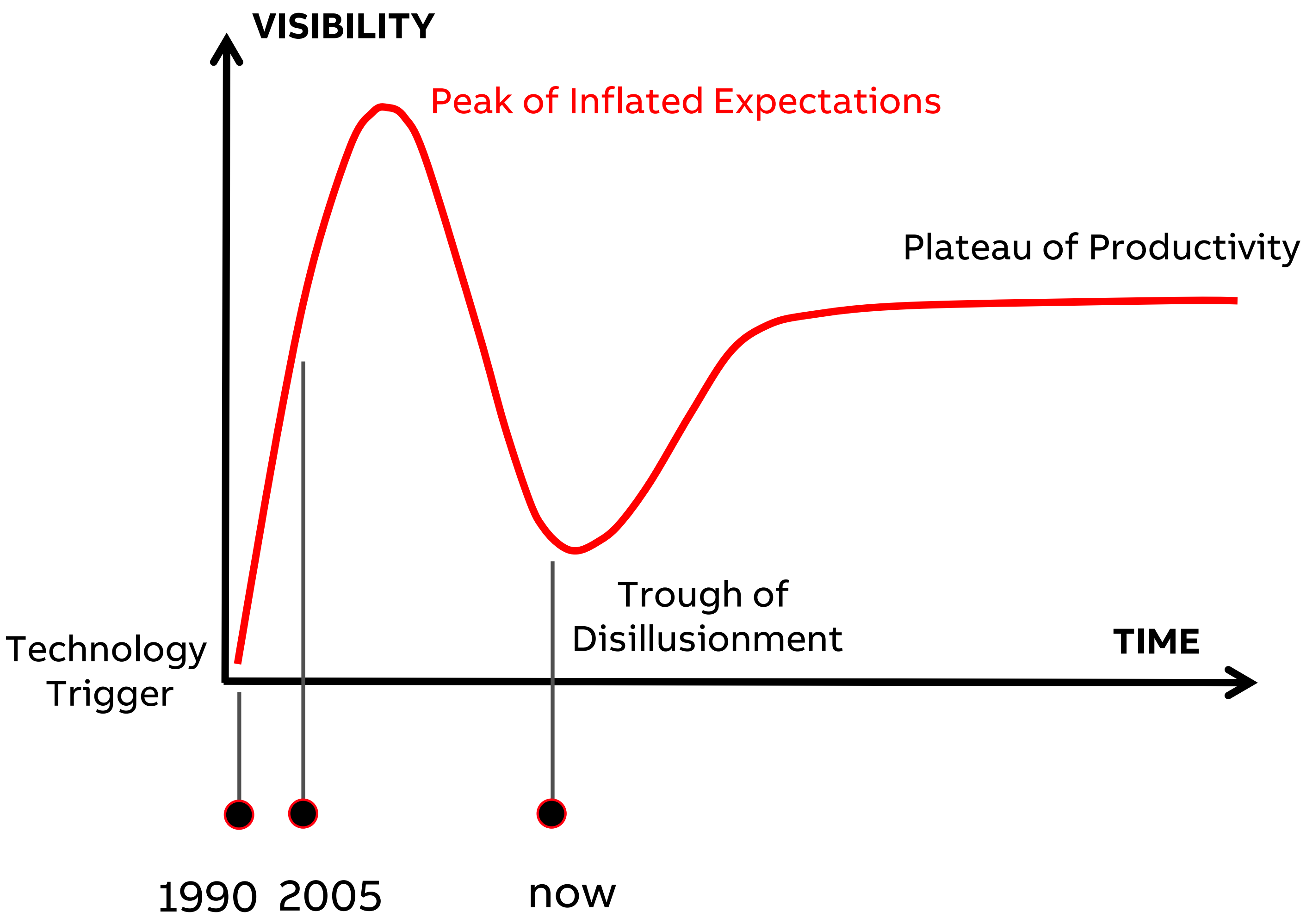


- Quality control of paint on car bodies
- First non-contact inspection device for paints
- Thicknesses (of each individual layer)

Signal processing scheme is applicable to a very large range of materials

DvM, Langmuir 30, 12748 (2014),
D.J.H.C. Maas, A. Frank, DvM, CLEO applications and technology (2019), **DOI:** 10.1364/CLEO_AT.2019.ATh4K.1

A THz Killer Application?



A THz Killer Application?

Why are we approaching the trough of disillusionment?

Status as of today

- Optical generation is expensive:

  500 kUSD (2000s)
  ~ 150 kUSD (2019)

- THz technology has been overhyped to be solving many future problems

- Currently, the first industrial applications are in a phase of prototypical testing

- *The true disillusionment will come when the applications are not accepted by the foreseen customers*

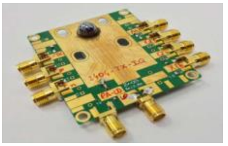
Solutions

- Electronic generation:
  - Cheap (aim at 1-100 USD per module)
  - Convenient and lightweight
  - Programmable (direction, polarization and frequency)
  - Energy efficient

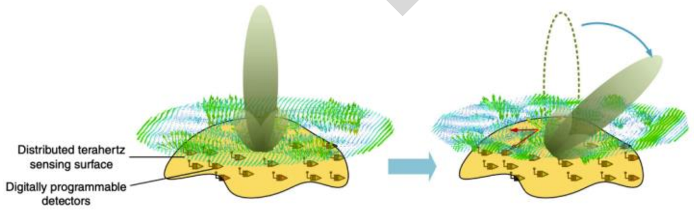
- Widespread (innovative) applications with societal relevance

2004

2009



>2010



X. Wu et al., Nature Comm. 10, 2722

2019

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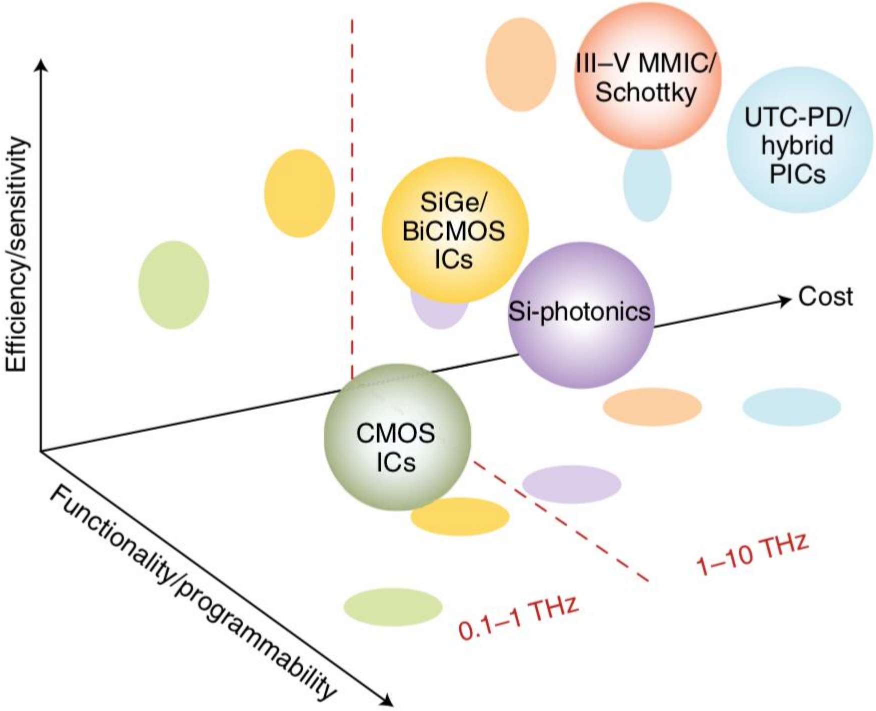
A THz Killer Application?

Why are we approaching the trough of disillusionment?

Status as of today



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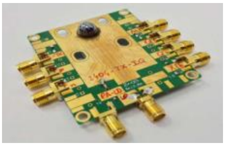
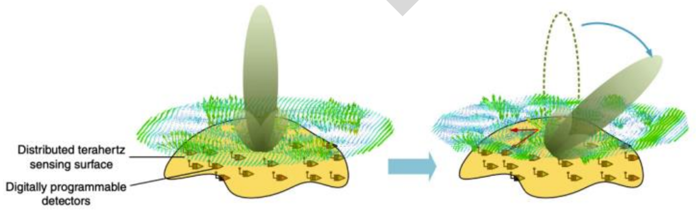


>2010



X. Wu et al., Nature Comm. 10, 2722

2019

A THz network

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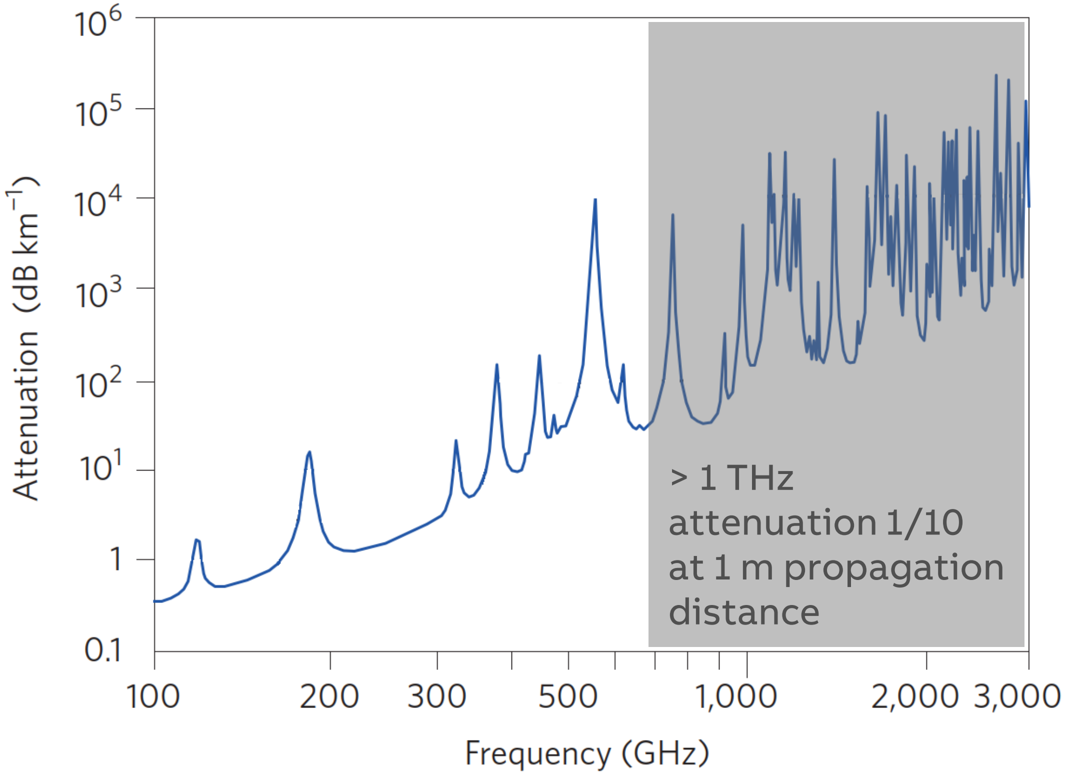
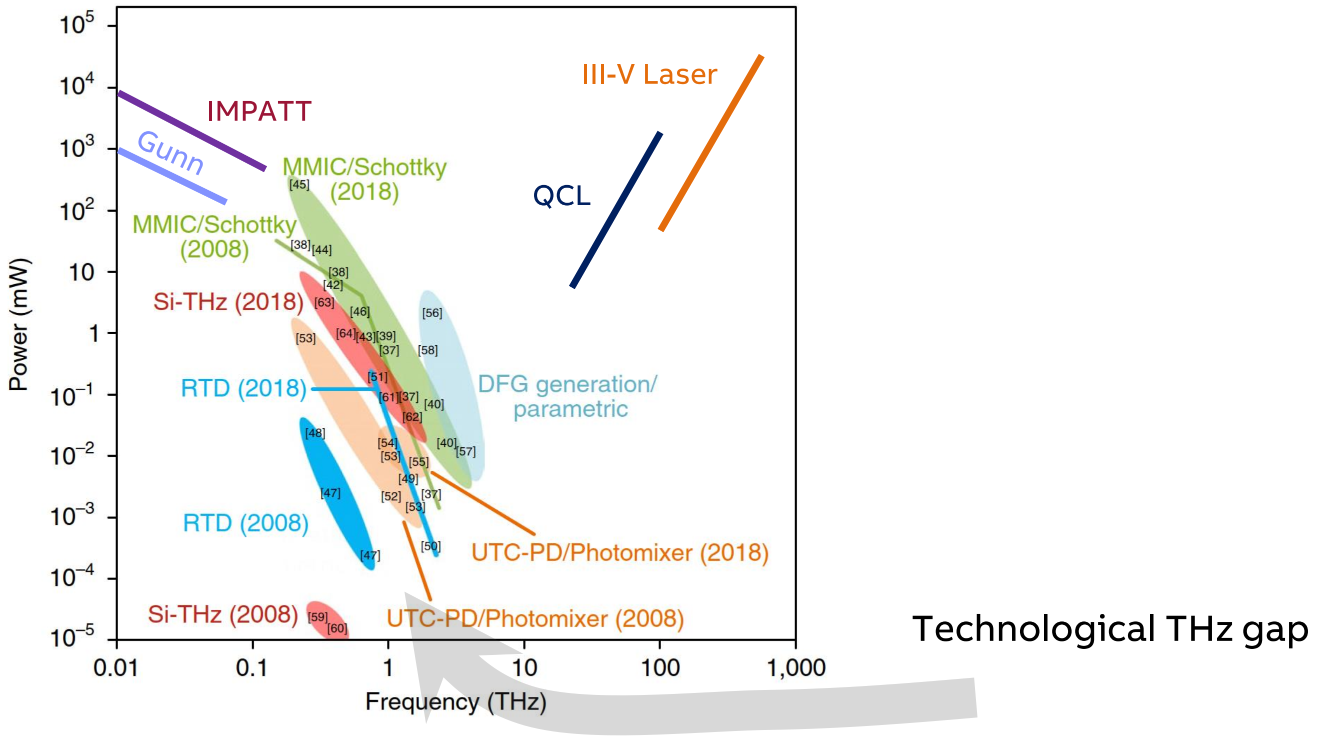
THz radiation for communication

Experimental licenses for 95 GHz to 3 THz – 21.2 GHz for unlicensed devices (FCC)





Bands with very large width, allowing for very large data streams: C (bit s^{-1}) = $W \log_2 (1 + S/N)$

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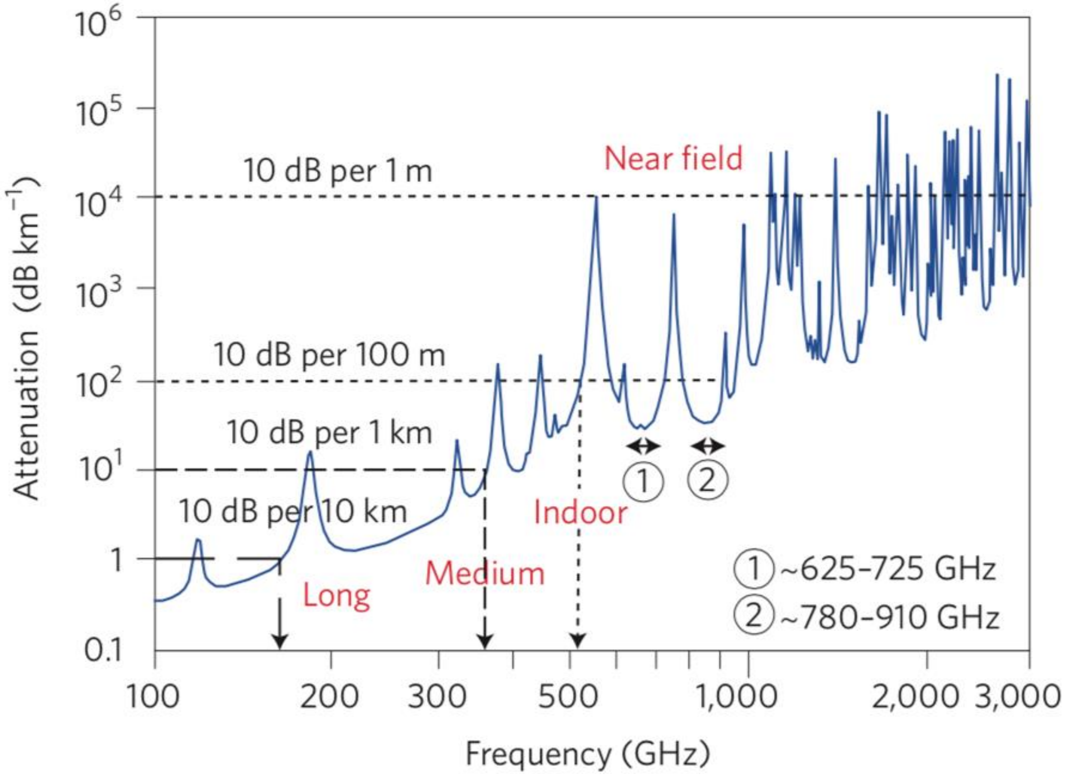
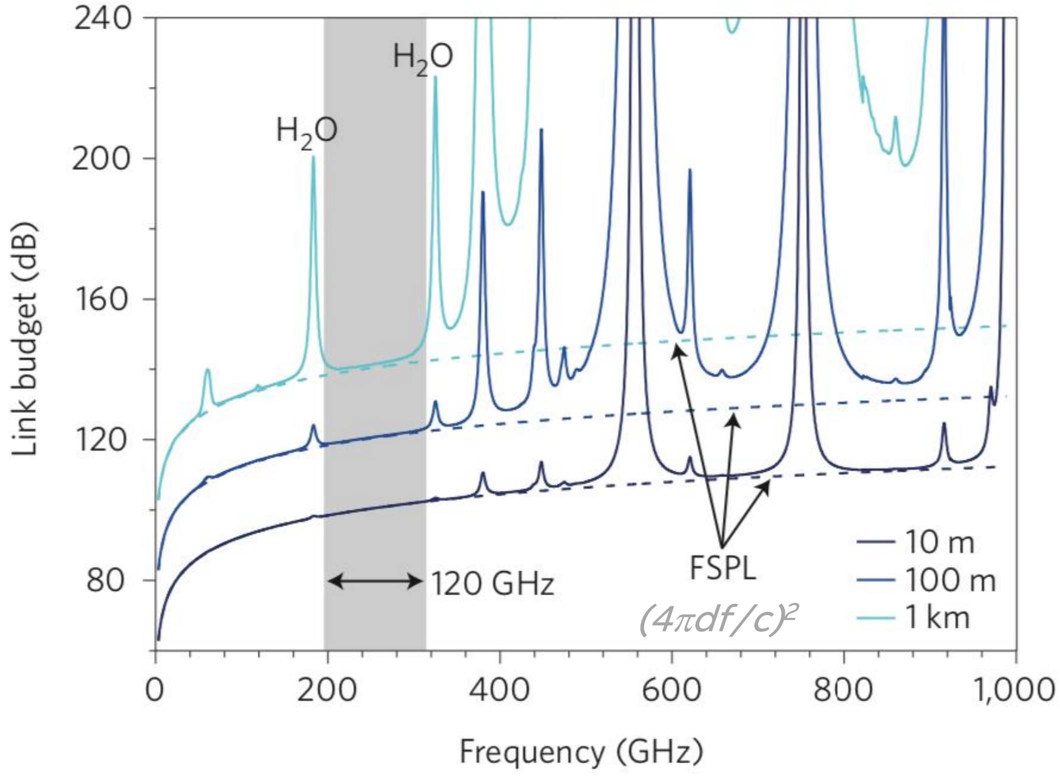
Modified after T. Nagatsuma et al., Nature Photonics 10, 371 (2016)

THz radiation for communication

Outside the water absorptions, there are very wideband windows



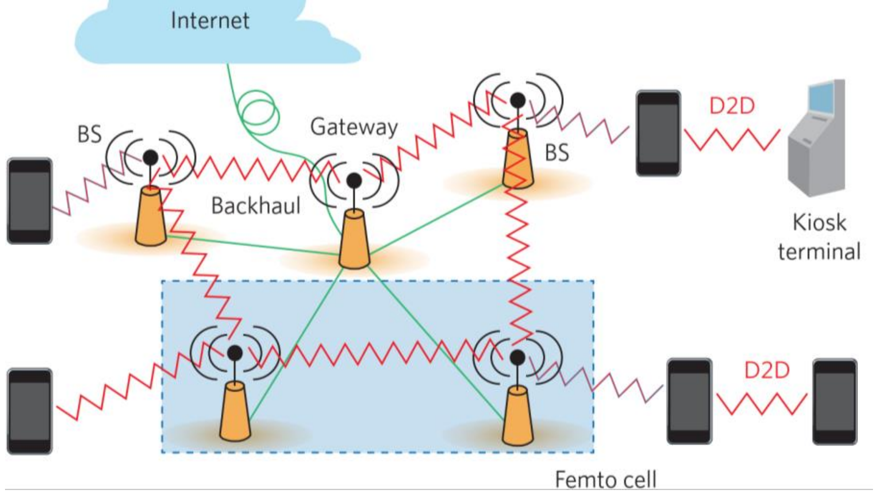


- Appropriate carrier frequency per application (indoor, medium and long distance)
- To compensate losses (e.g. for 1 km backhaul), large gain transmitters and receivers are required: directive antennas & beam steering

T. Nagatsuma et al., Nature Photonics 10, 371 (2016)

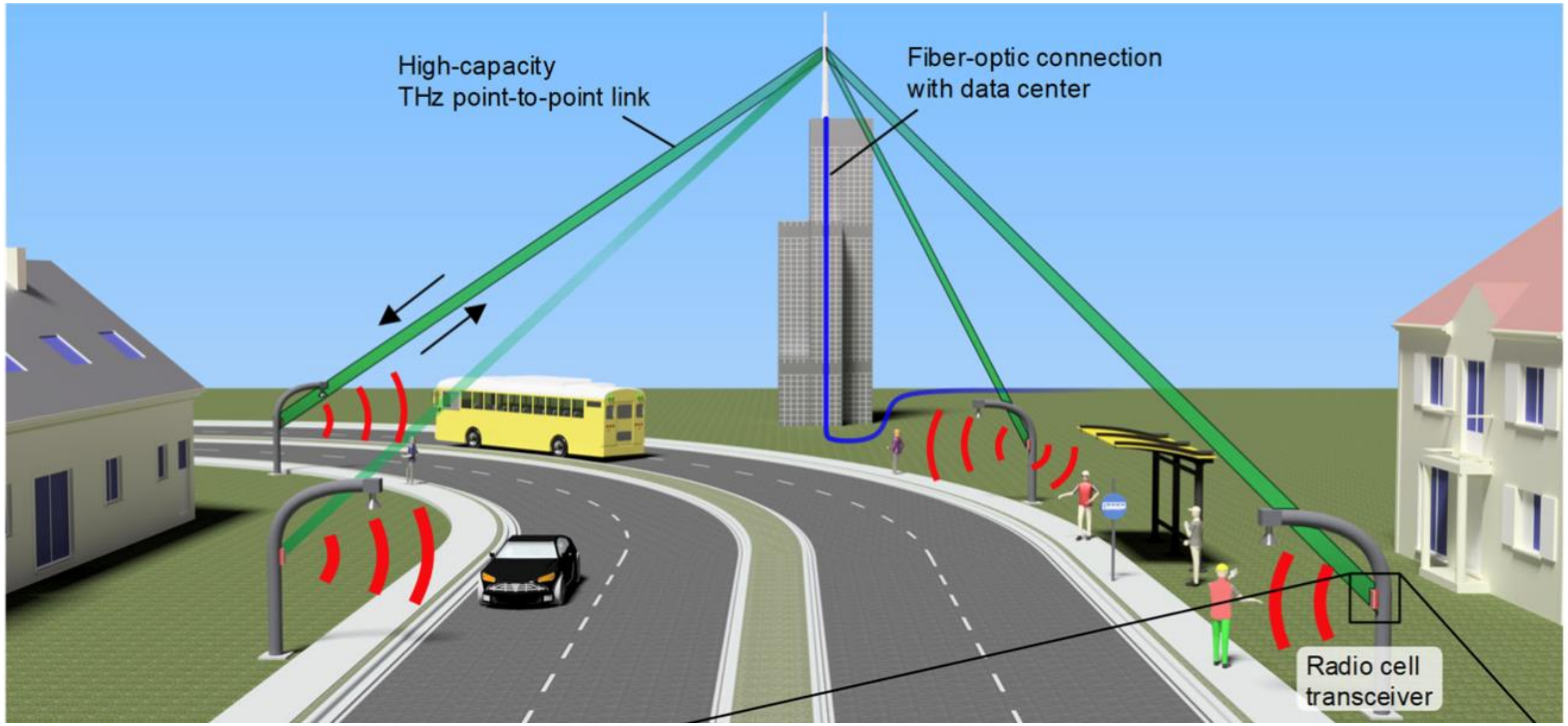
THz radiation for communication

Potential for a THz network



Advantages

- Ultra high bandwidth
- Ultra low latency
- Cell-less network



Down sides

- long distances requires lots of power
- inefficient THz generation at large power (using electronics)
- more immature technology

Adapted after T. Nagatsuma et al., Nature Photonics 10, 371 (2016)
A.J. Seeds et al., J. Lightwave Technology 33, 579 2015

Fibre-optic network
MMW/THz

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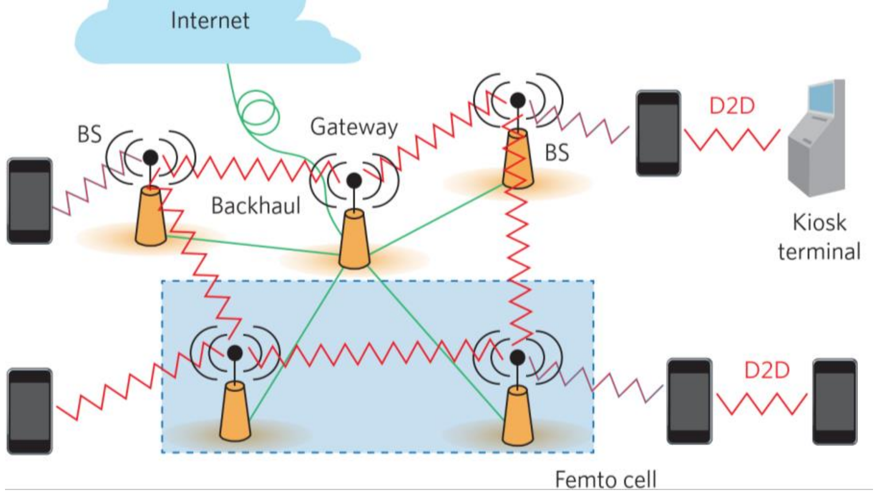
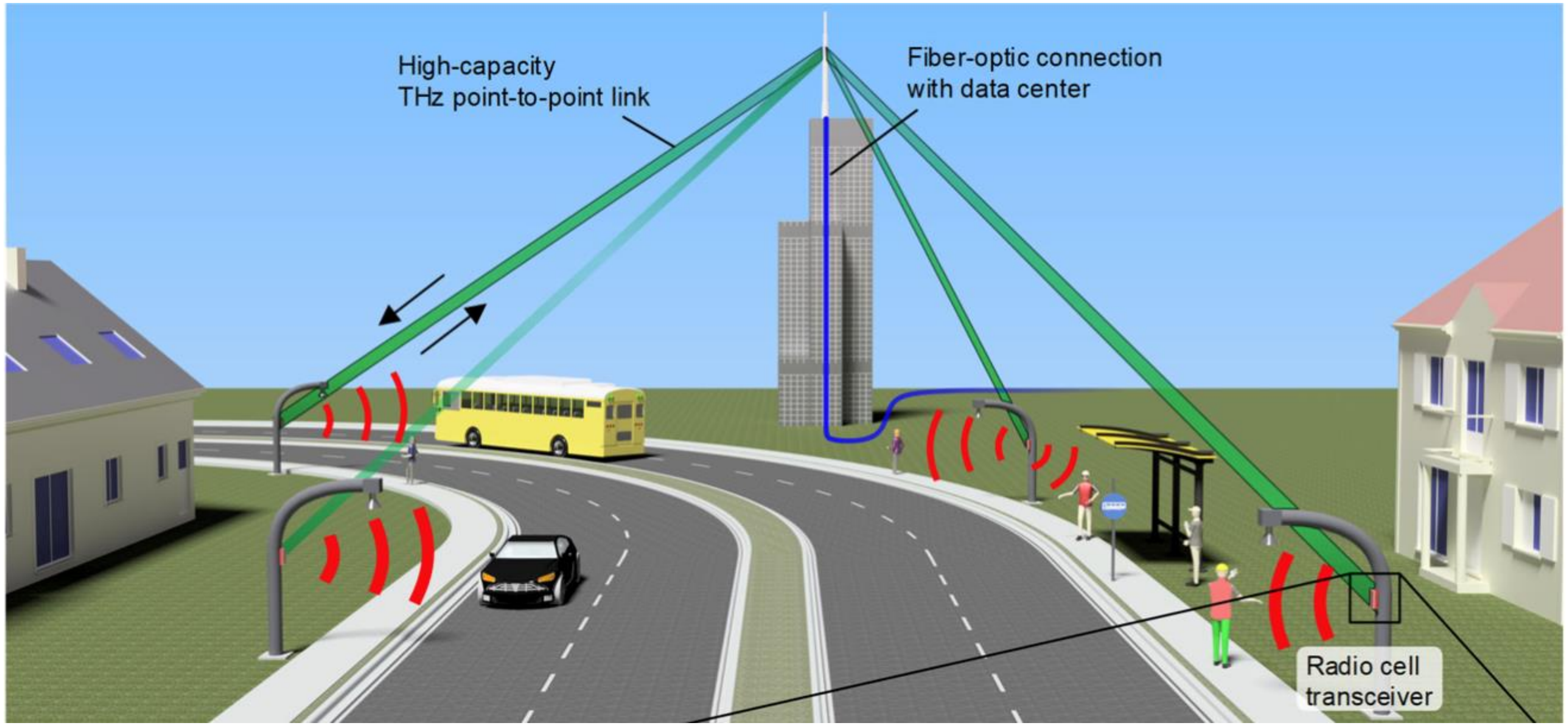
THz radiation for communication

Potential for a THz network



Alternative: Near-IR

- More directionality
- Scintillation effects
- 200 dB km^{-1} due to fog
- Sensitive to smoke and dust
- IR photodetectors less sensitivity
- Influence of ambient light
- More mature technology



Adapted after T. Nagatsuma et al., Nature Photonics 10, 371 (2016)
A.J. Seeds et al., J. Lightwave Technology 33, 579 2015

Terahertz wireless link

Early achievements and challenges

Opportunities

- Real-time systems and post-processing systems (amplitude coding, multi-level modulation schemes)
- THz photonics for backhaul applications (using optical fibers)

Challenges:

- Photonics needs more gain:

  Rx 1 mW at 300 GHz and 40 Gbit s^{-1}
  Tx Schottky-diode at RT 4×10^{-19} W Hz^{-1},
  with 40 dBi antenna: d_{max}=280 m (w/ heavy rain)

- Energy consumption:

  - increase system efficiency
  - photonic integration
    (coupling losses, multiple antenna’s, Si photonics, low-loss waveguides for on-chip direction, Graphene)

Table 1 | Reported THz systems and actual highest performanes achieved using several technologies.

Data rate ($Gbit s^{-1}$)	Distance (m)	Frequency (GHz)	Multiplexing	Technology (Tx/Rx)	Modulation	Bit error rate (type)	Reference	CDP ($Gbit s^{-1}$ km)	Year
200	0.5	100	Polarization (two channels)	PD/SHM	QPSK	10^{-3}, offline	30	-	2013
10	5,800	120	-	UTC+HEMT/ HEMT	ASK	$<10^{-9}$, real time	9	58	2012
11	3	130	-	40-nm CMOS (Tx/Rx)	ASK	$<10^{-9}$, real time	57	0.033	2015
75	0.02	200	Frequency (three channels)	UTC-PD/SHM	QPSK	10^{-5}, offline	28	-	2014
100	20	237.5	Frequency (three channels)	UTC-PD/HEMT	Up to 16 QAM	2×10^{-3}, offline	31	-	2013
64	850	240	-	Metamorphic HEMT/MMIC	QPSK	5×10^{-3}, offline	60	-	2015
64	1	300	-	MMIC (Tx/Rx)	QPSK	-, offline	51	-	2015
40	10	300	-	UTC-PD/SHM	QPSK	10^{-4}, offline	35	-	2015
48	0.5	300	Polarization (two channels)	UTC-PD/SBD	ASK	10^{-10}, real time	33	0.024	2013
3	50	340	-	SHM/SHM	16 QAM	10^{-10}, real time	64	0.15	2014
32	0.5	385	-	UTC-PD/SHM	QPSK	10^{-5}, offline	61	-	2015
46	2	400	-	UTC-PD/SHM	ASK	10^{-3}, offline	29	-	2014
30 or 50	20 or 0.5	300 or 330	-	UTC-PD/SBD or SHM	ASK	10^{-9}, real time	27	0.6 or 0.025	2015
60	0.5	400	Frequency (four channels)	UTC-PD/SHM	QPSK	10^{-3}, offline	62	-	2015
2.5	3	625	-	Multiplier/SBD	Duobinary (ASK)	$<10^{-9}$, real time	63	0.0075	2011

CDP is the capacity × distance product. It is a figure of merit for communication systems assuming the maximal regeneration-free distance in real-time conditions[66]. Most of the highest data rates of THz wireless systems have been achieved using THz photonics technologies at the transmitter (Tx), mainly based on high-speed photodiodes. A combination of polarization and frequencies are now investigated to increase the data rate in the available THz bandwidth. ASK, amplitude shift keying; HEMT, high-electron-mobility transistor; MMIC, monolithic microwave integrated circuit; PD, photodiode; QAM, quadrature amplitude modulation; QPSK, quadrature shift keying; Rx, receiver; SBD, Schottky barrier diode; SHM, sub-harmonic mixer; UTC, uni-travelling carrier.

T. Nagatsuma et al., Nature Photonics 10, 371 (2016)
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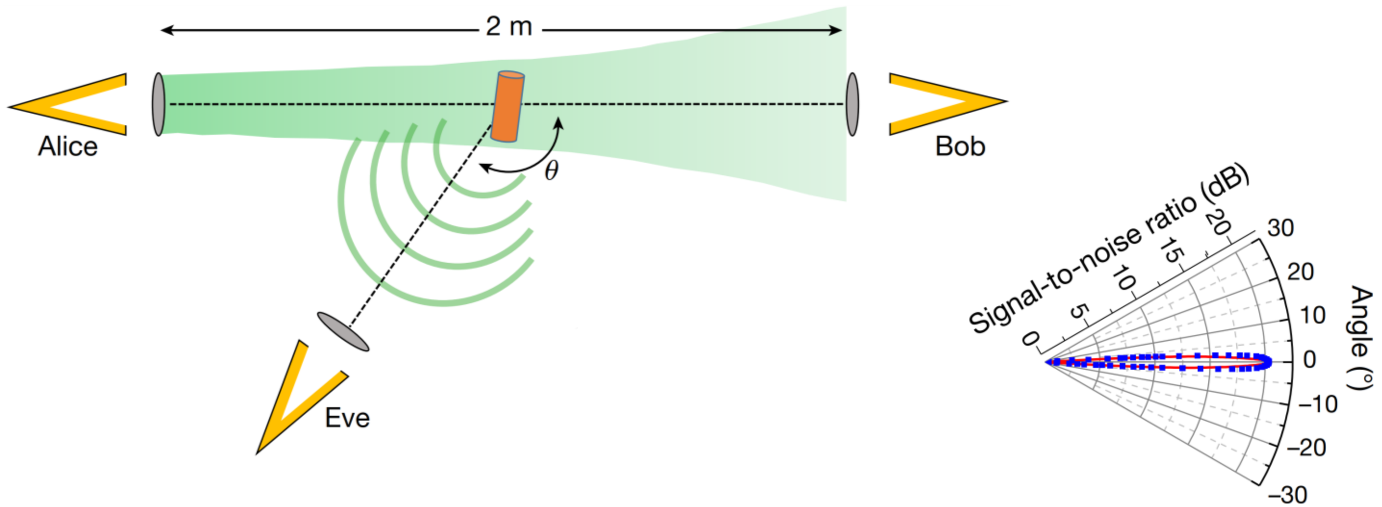
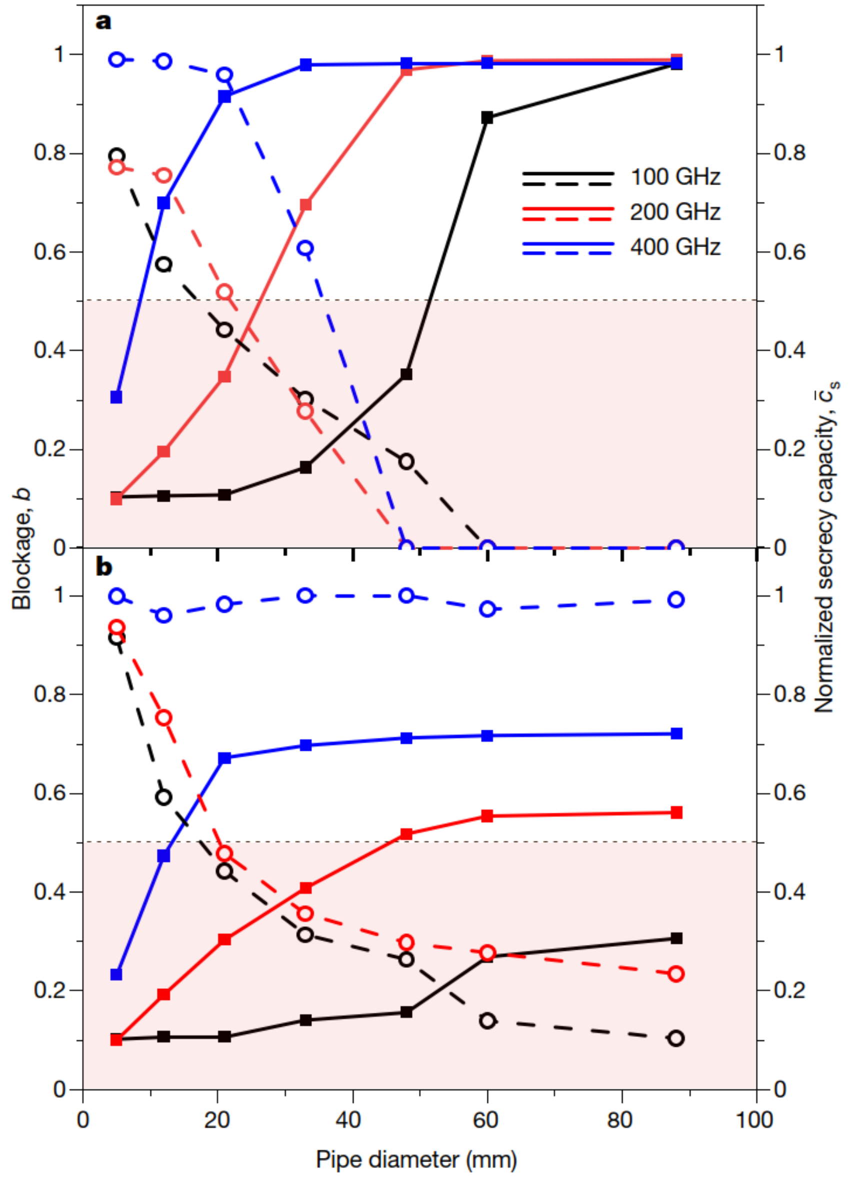
Terahertz wireless link

Eavesdropping with directional beams





- Increasing frequency: omnidirectional to narrow-angle broadcasts
- Becomes then eavesdropping impossible without noticing?
- A cylindrical object placed in the beam (or off-centered) provides a blockage b and a secrecy capacity c_s.
- Researchers from Brown University (USA) show that eavesdropping is possible in many configurations

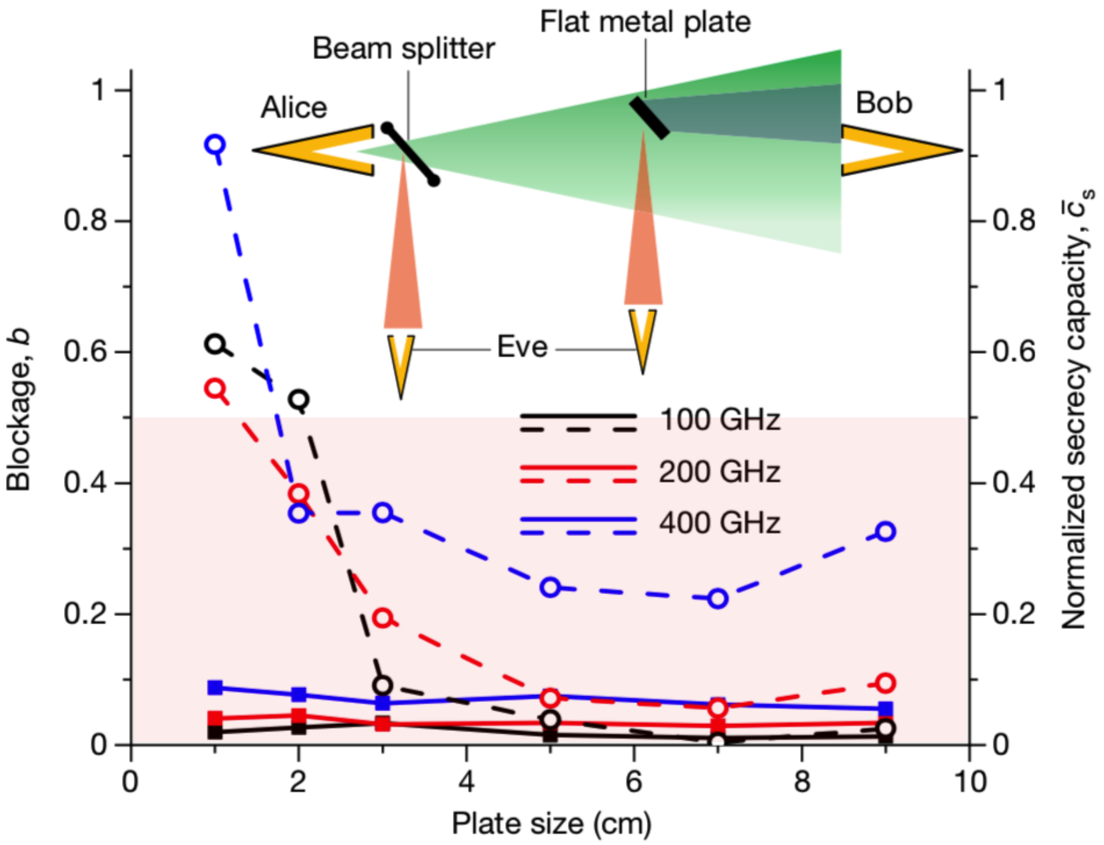
$$b = 1 - \frac{SNR_{Bob}^{object}}{SNR_{Bob}^{no\ object}}$$

$$\bar{c}_s = \frac{\log(1+SNR_{Bob}) - \log(1+SNR_{Eve})}{\log(1+SNR_{Bob})}$$

Terahertz wireless link

How to avoid eavesdropping?

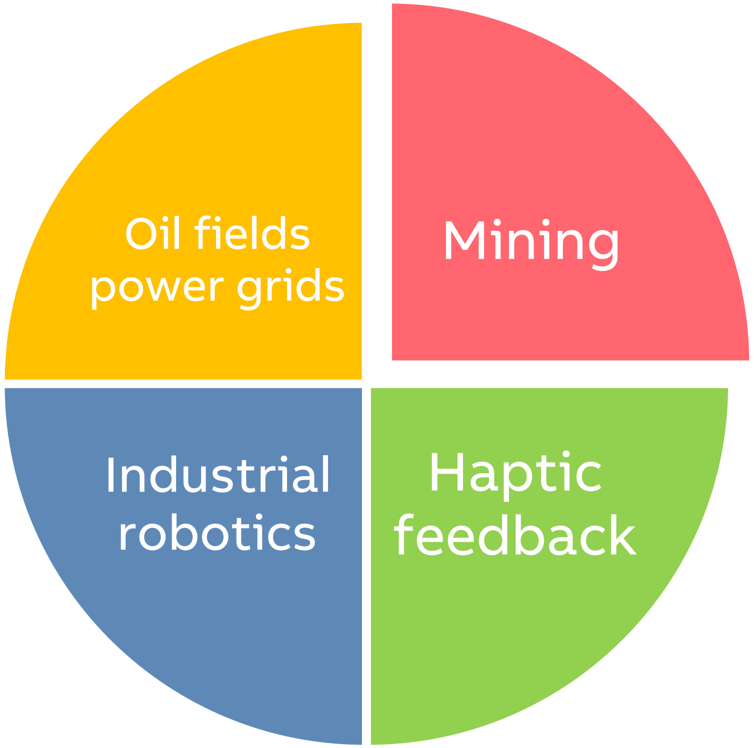
- Detection of backscattered radiation from an object back to Alice (if she measured the background first)
- This avoids eavesdropping in some cases for which $b<0.5$ and $c_s<0.5$ for Bob
- Place a square planar metal reflector off-axis: blockage is low and secrecy capacity is low too
- Lossless beam splitter encompassing the entire beam is fruitful and even more when Alice cannot measure backscattered signals

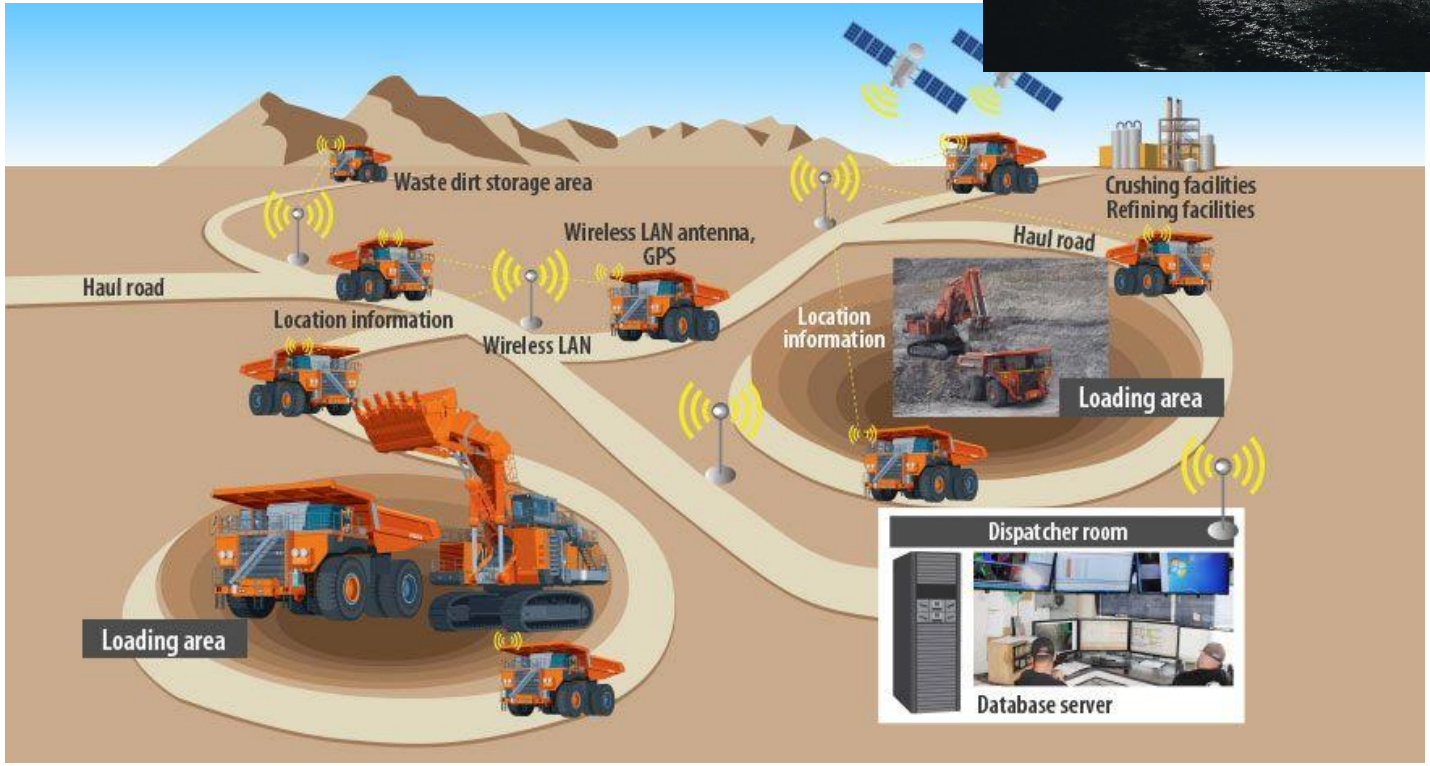


Security by encryption is essential even at 100-1000 GHz frequencies

Future use cases

Industrial Mobile Communication in Mining





Smart mine: control of wheel vehicles, sensors in mine to verify stability, air ventilation, communication, hoist performance monitoring, remote diagnostics

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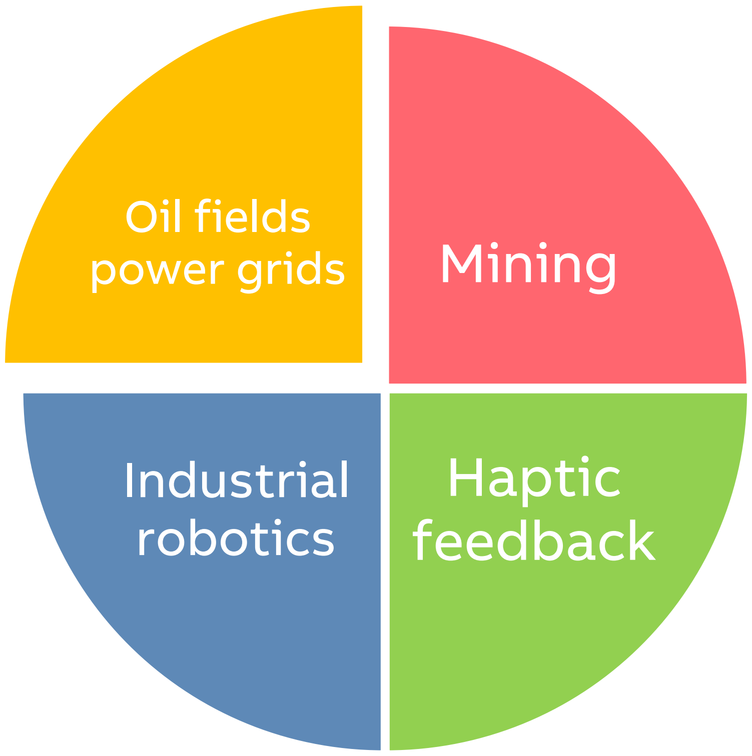
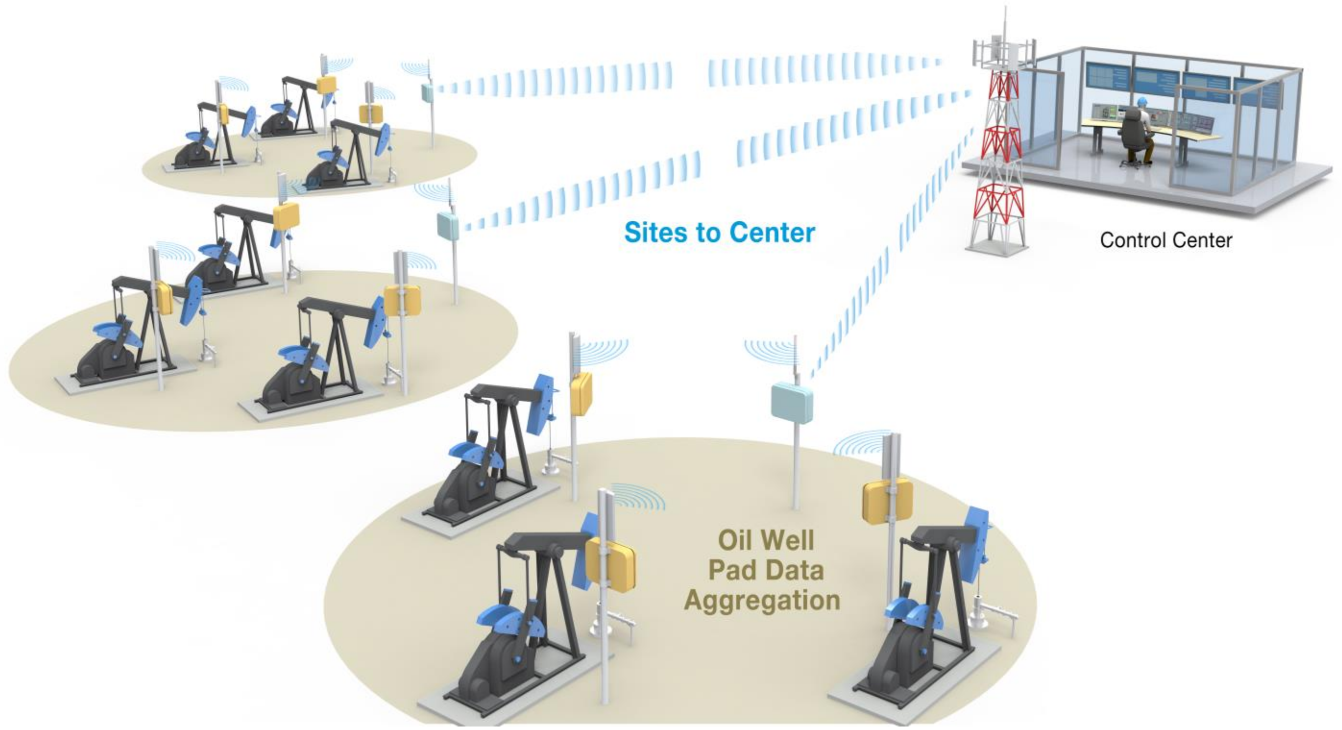
Future use cases

Communication in oil fields & power grids



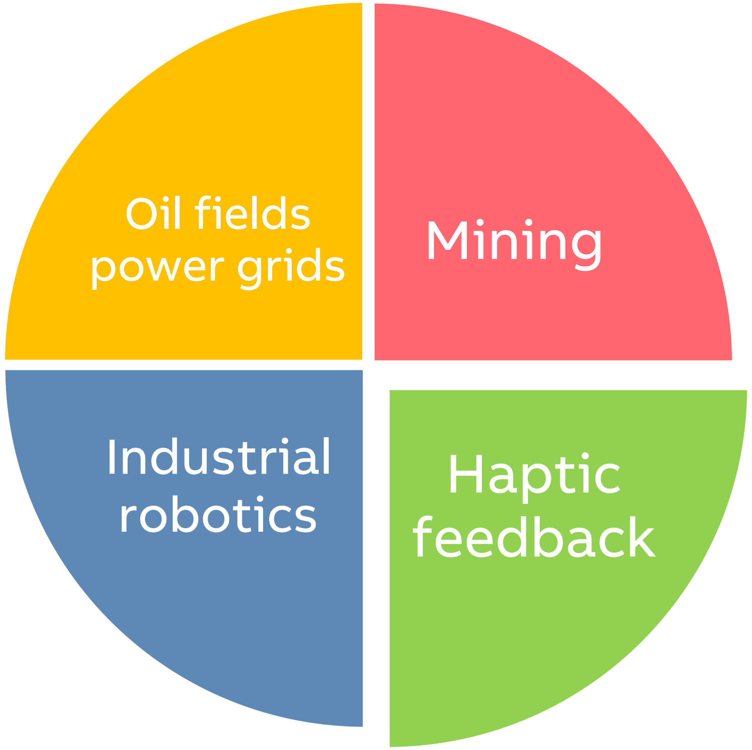


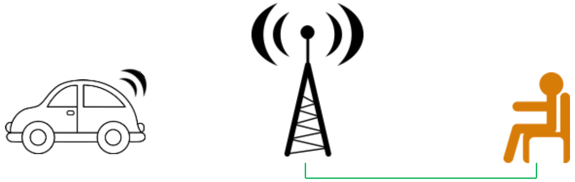
- Communication for smart grid development (for distributed grids)
- Fault communication in power grids

- On-site monitoring at oil fields: manual and wired are too expensive, wireless is the only cost-efficient method
- Wellhead monitoring

Future use cases

Tactile reactions





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https://www.ericsson.com/en/cases/2017/abb

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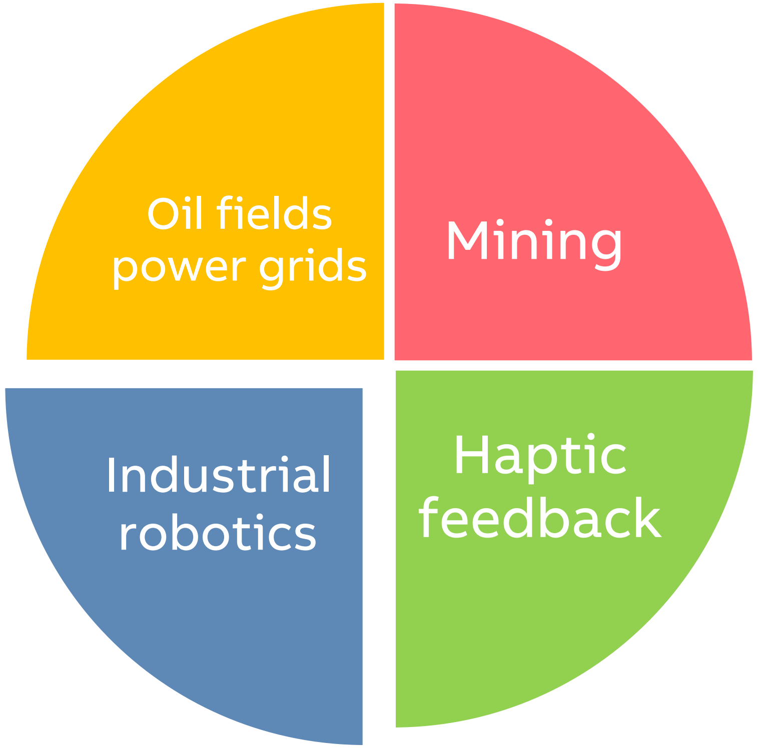
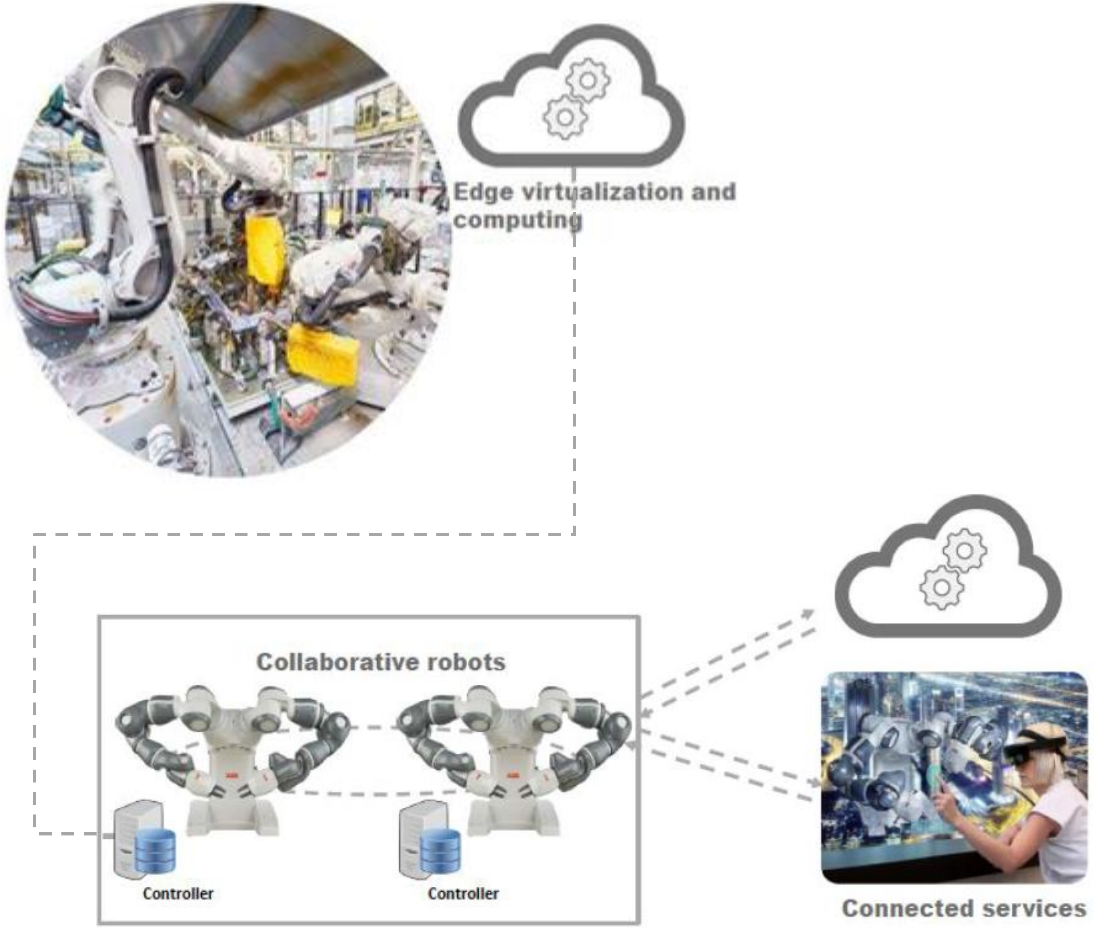
Future use cases

Industrial robotics





- Robot control moved from embedded processor to a local cloud
- Machine-vision assisted robot control,
  with video processing and analysis in the local cloud
- Visualization of Factory Floor (AR/VR)

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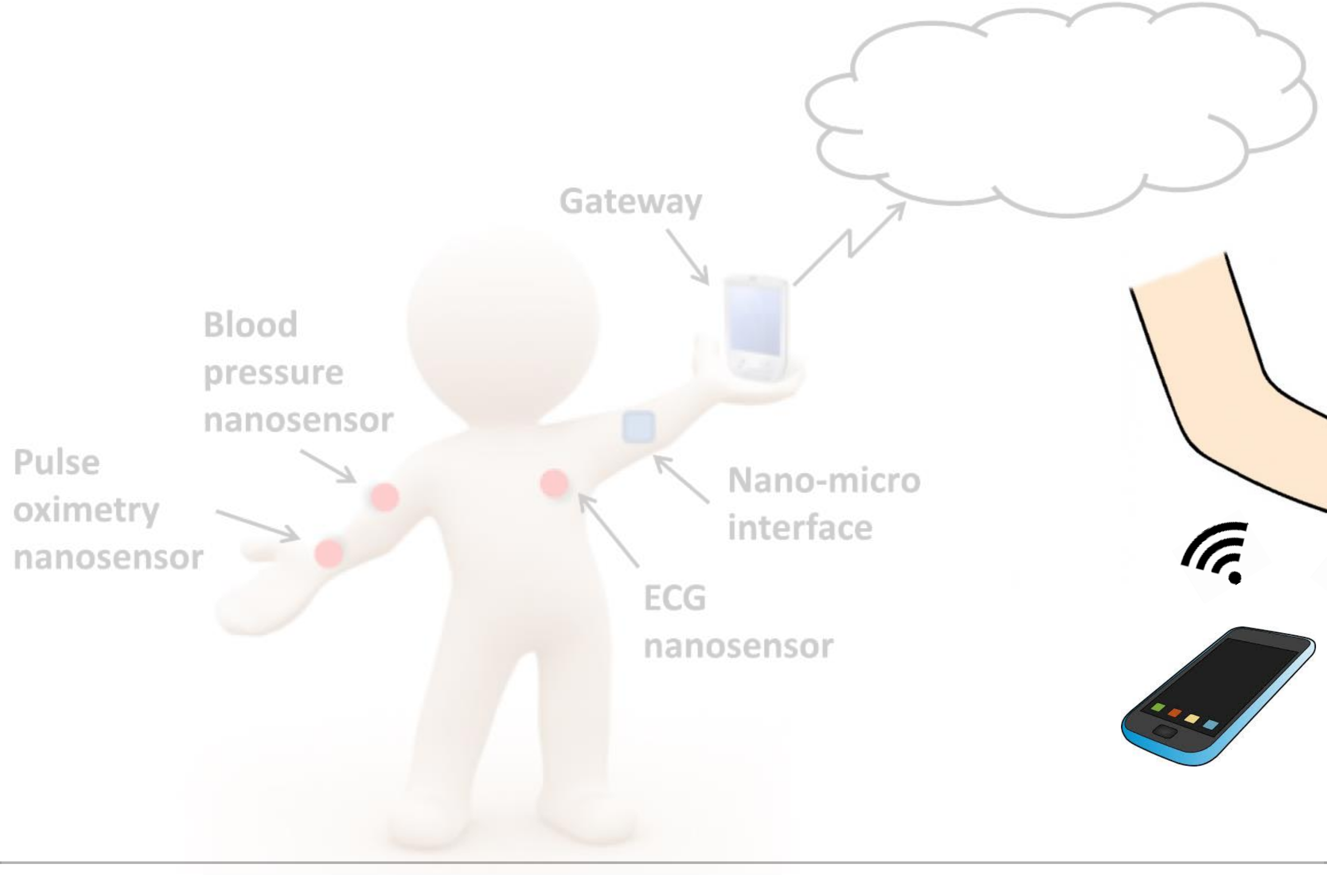
Future use cases

Combining sensing and communication

Food quality inspection
using THz radiation



Simple medical diagnosis
using THz radiation

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