FOE Talk

A Glimpse into 6G Wireless Systems

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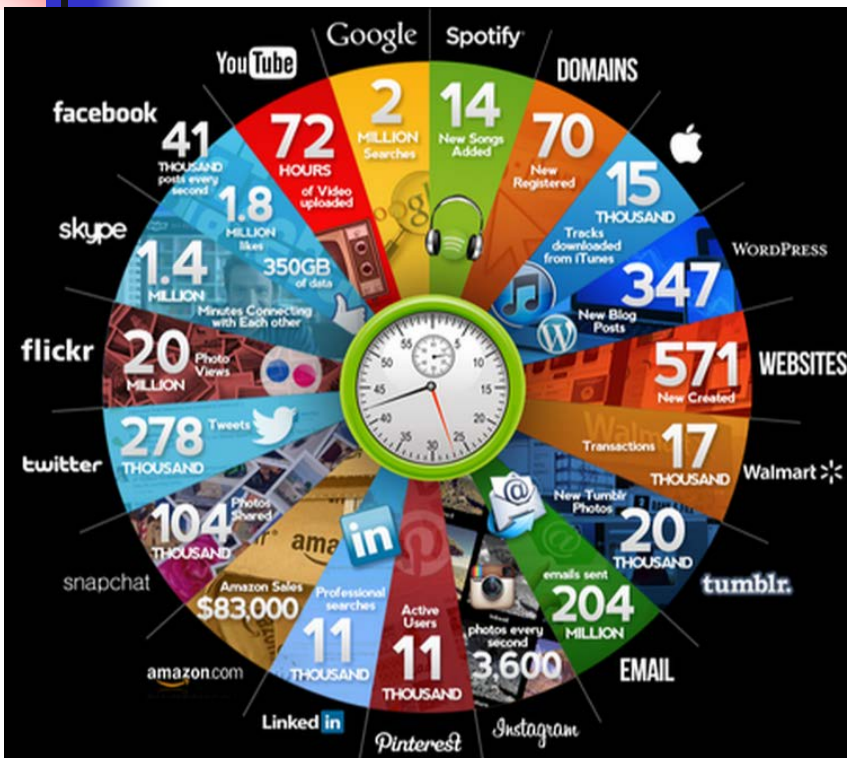
What happens online in 60 seconds?



- www.rethink-wireless.com (January 2012)
  - "[…] iPhones caused disastrous performance problems on AT&T networks"
  - "Verizon Wireless blamed similar factors for several outages on its LTE network"
- A decade of research on 4G/4G+
- 5G will be more **data hungry**

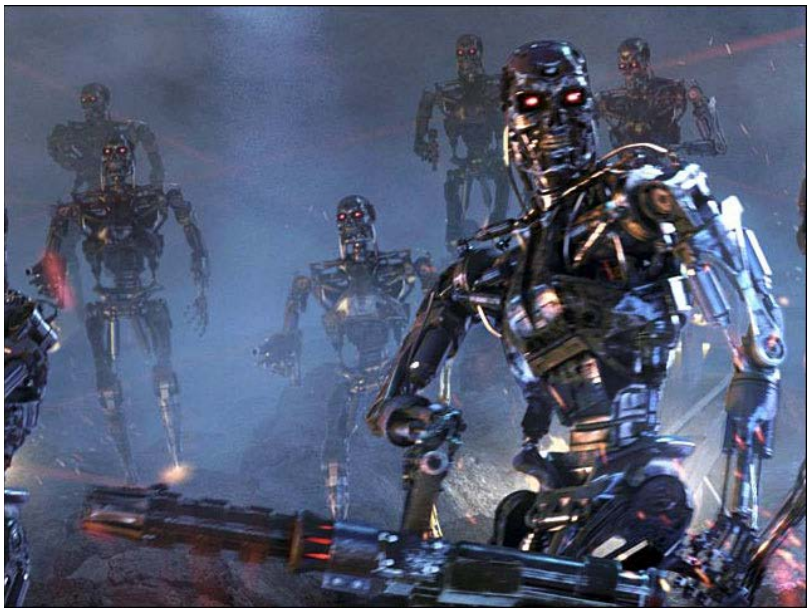
NETFLIX

8K ULTRAHD

4K FULLHD

5G: Rise of Autonomous Things

- All these services connect ***people***
- Next decade….
  - We need to connect autonomous ***things….***

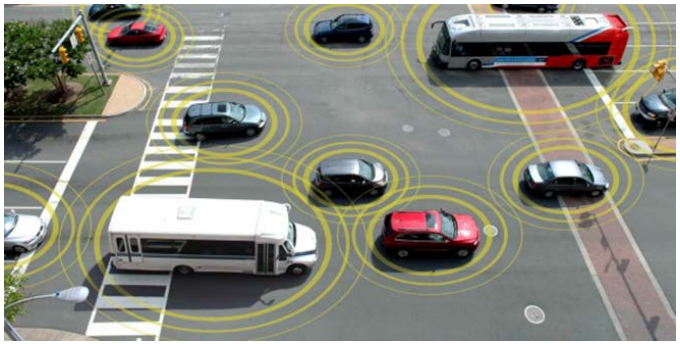


  - ***…..for the well-being of people***

Driver behind 5G (and beyond)

- Data hunger (always) + Internet of Things

© Can Stock Photo



- Massive number of devices with services that are more **critical** than *Facebook/Instagram posts!*

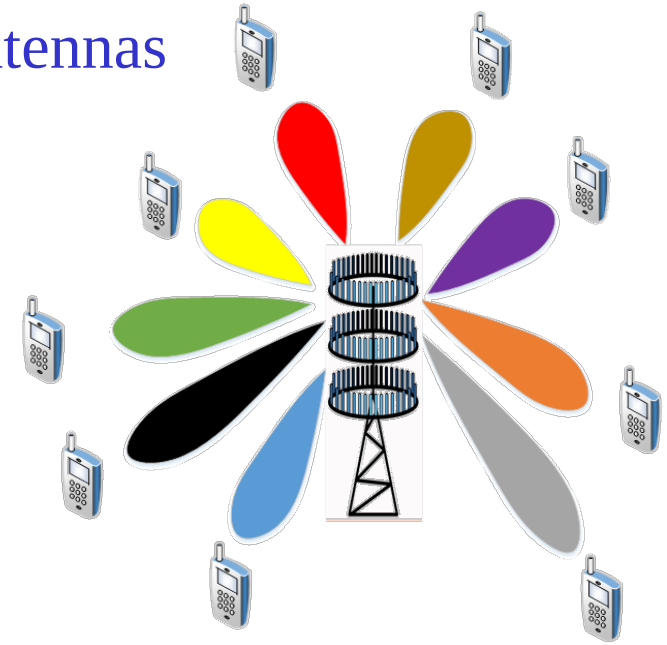
The Internet of Things: A key driver for 5G

	Data-centric services	IoT services
Key goal	• High **data rates**	• **Reliability** (99.999%) and Low **latency** (few ms)
Links	• **Few** transmissions (< 100 simultaneous)	• **Massive** (1000+) transmissions
Direction	• **To** users	• **From** IoT devices
Devices	• **Human-centric:** Smartphones, tablets	• **Machine-centric:** sensors, drones, etc.

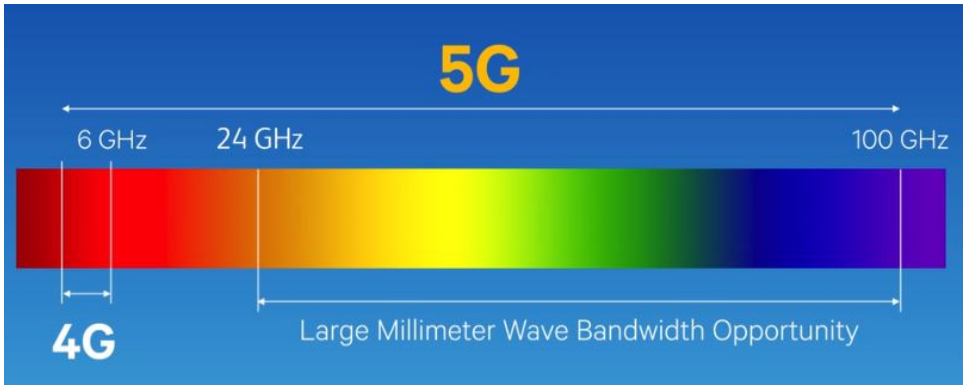
- A shift from data rate (i.e., Gbps) centric communications towards **reliable low latency** communications!

5G: Satisfying Hunger for Rate

- Massive number of antennas



- Higher (millimeter wave) frequencies
  - A lot of available bandwidth but **very limited range**



- Wireless physical layer: **A lot of acronyms ☺**

CP-OFDM | DFT-S-OFDM | F-OFDM (less guard) | LDPC

- The gist: Innovative ways to get more "bits" on a wireless medium

5G: Satisfying Hunger for Rate

Samsung boasts 7.5Gbps mobile speed record in 5G trial

By Liam Tung | October 16, 2014 -- 09:45 GMT (02:45 PDT) | Topic: Networking

M1 and Huawei reach 35Gbps speeds during 5G trial

During a trial of 5G network technology, Huawei and M1 used mmWave spectrum in the 73GHz band to achieve transit speeds of 35Gbps.

By Corinne Reichert | January 18, 2017 -- 04:54 GMT (20:54 PST) | Topic: Telcos

VEON, Nokia launch 5G trial in Kazakhstan

By Catherine Sbeglia on OCTOBER 22, 2019 5G, Network Infrastructure

Initial speed tests in Kazakhstan trial show a downlink speed of 1.0GB per second

MTS drives 5G speeds to 2.1Gbps in 28GHz trials in Moscow

06 September 2019 | Alan Burkitt-Gray

Turkey's Turkcell breaks world 5G network speed record

GSM operator reaches nearly 2.3 Gbps speed via 5G network, says company

Gokhan Ergocun | 06.08.2019

OpenSignal: US has the fastest 5G peak speeds

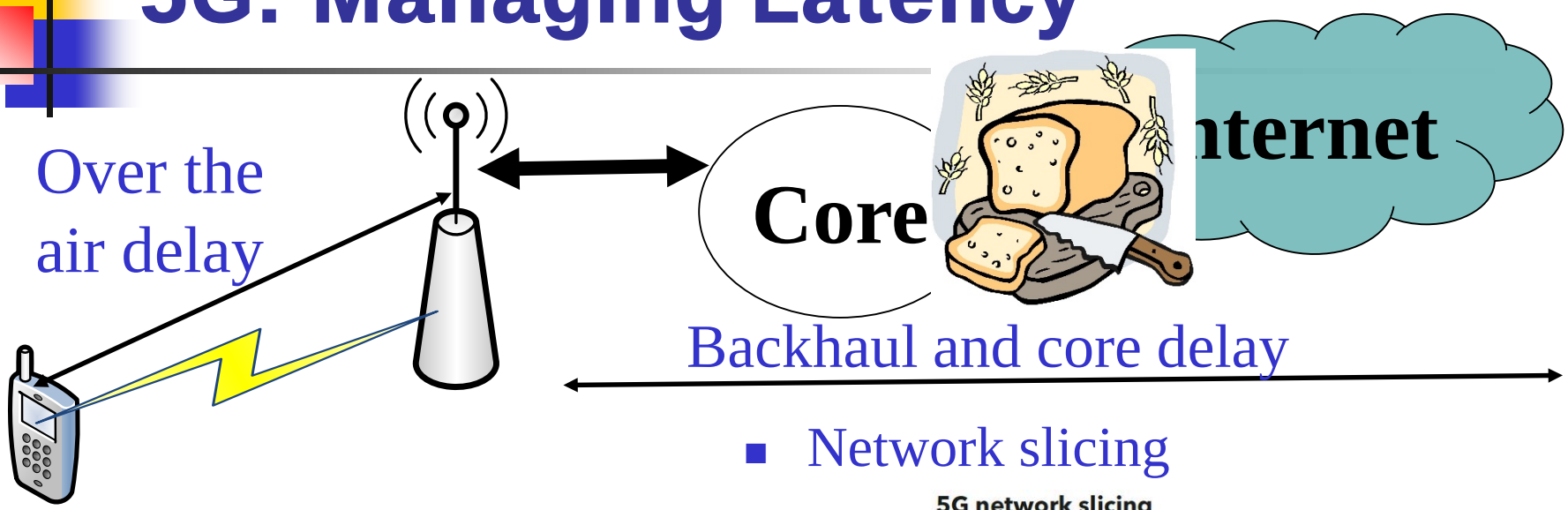
By Kelly Hill on JULY 8, 2019

- So many records!
- What's the truth?
  - Rates at low frequencies: 3.6 Gbps typical can go up to 10 Gbps
  - Rates with millimeter wave: 10 Gbps to 40 Gbps **but static users only**

New 5G speed world record

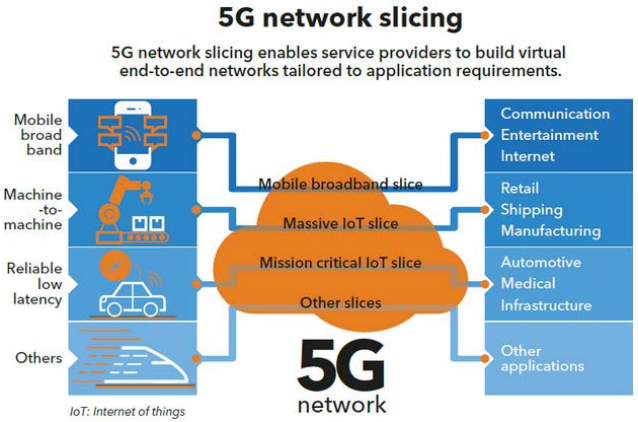
In partnership with SK Telecom and BMW Korea, Ericsson used advanced 5G technology to track a connected car travelling up to 170 km/hour to demonstrate data transmission speeds on a 5G network.

5G: Managing Latency



- Grant free access

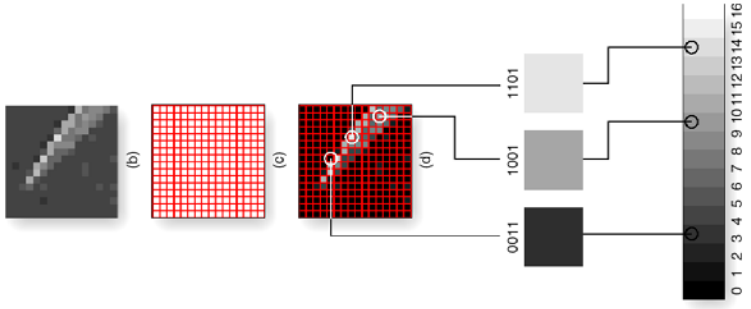
- Network slicing



- Reduced "hops" for transmission, shorter time to build frames, etc.
- **Target/trial latency:** 1 ms, **Reality:** closer to 5-10 ms range when looking at end-to-end latency

5G: Reliability

- Physical layer: improve how we: a) “code” information and b) exploit frequencies so as to reduce errors and retransmissions



Frequency Diversity

- Improving redundancy: packet redundancy and node redundancy

- Core network: Virtualization and slicing (again)
- Achievable reliability? **Five 9s observed in very limited trials**, no clear view on what happens in the real world

Will there be a 6G?

Will there be a 6g after 5g?

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5 Answers

Marcin Dryjański, Principal Consultant / Board Member at Grandmetric.com (20 present)

Answered Ma 2016

Hi, this is an interesting question.

As one principal engineer from one of the MNOs argo said "if we do 5G right, we w not have 6G". And what is meant by this is that if the 5G system will be properly defined, standardized and flexible enough, there will be no need for next Gs, as th new features / technologies could be just added on top of 5G in a "easy" and flexibl manner. One of the design principles for 5G was/is to natively support forward compatibility - to easily add new features (at least at the PHY layer).

However, I believe that unfortunately, even if 5G will be good enough to be able to introduce new features in an easy manner, we will have the 6G for the "hype" and marketing purposes as our industry is used to have a new G every ~10 years.

In Control, Almost from the Beginning Until the Day After Tomorrow

Jan C. Willems*

ESAT-SISTA, K.U. Leuven, Kasteelpark Arenberg 10, B-3001 Leuven, Belgium

One of the differences in working in a mathematics versus a theoretical engineering environment is psychological. Both fields feel insufficiently appreciated. Mathematics reacts to this by blaming the 'others', for misunderstanding them. Engineering reacts by blaming 'themselves', for not doing 'the right thing'. Discussions about theoretical engineering research often feels like visiting a graveyard in the company of Nietzsche. From the beginning of my career until now, I have always been hearing that 'the field is dead', 'circuit theory is dead', 'information theory is dead', 'coding theory is dead', 'control theory is dead', 'system theory is dead', 'linear system theory is dead', '$\mathcal{H}_\infty$ is dead'. Good science, however, is always alive.

- **(Radical) industry view:** 5G is all there is or was or ever will be
- **(Radical) academic view:** 5G is bad, really bad, we need 6G funding ☺
- **Realist view:** 5G provides substantial rate and latency gains, but has several limitations
  - Beyond 5G (5 yrs) vs 6G (10 yrs)

- Wireless research is "dead"

5G Limitations

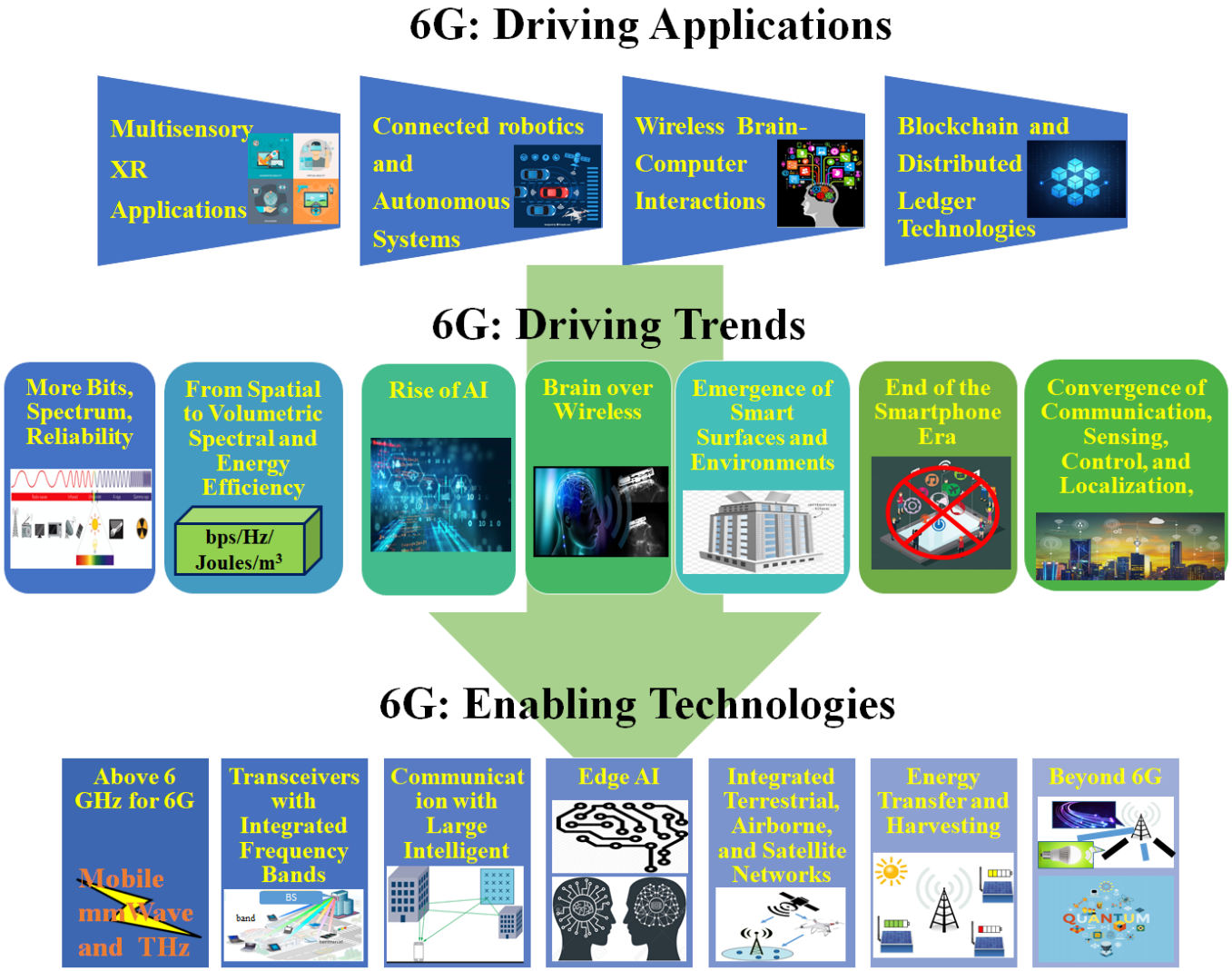
- Reliability (99.999% low latency/error free links): achieved in trials but still hard to achieve in practice
- High speed, high mobility, high frequency
- Coverage: the never ending rural area conundrum

keeping up with the Kardashians™

Technology
TAGLINE HERE

- Emerging and foreseen technologies

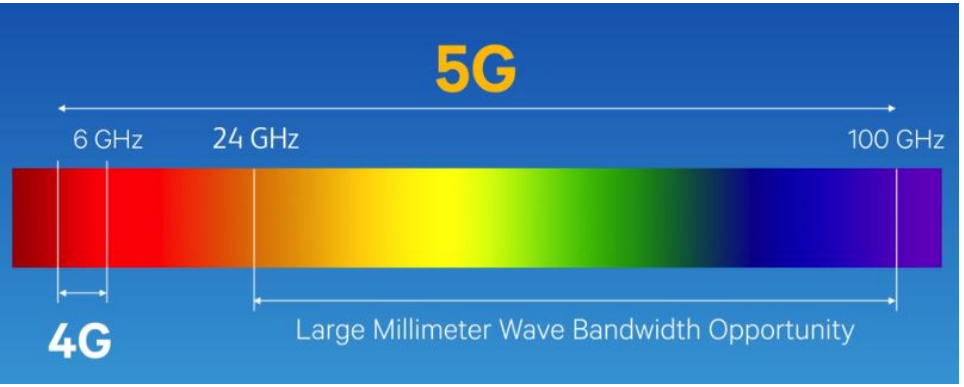
6G: Quick Vision

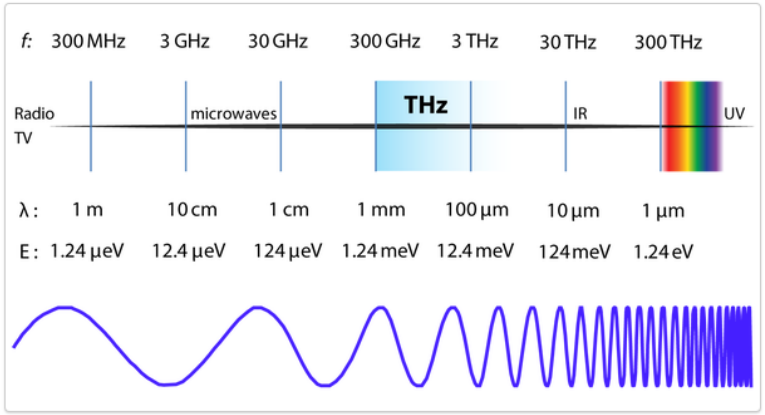


- Rate: 1 Terrabit per second
- Latency < 1 ms
- Reliability (beyond five 9s)
- 1000X improvements
- W. Saad, M. Bennis, and M. Chen, "A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems", *IEEE Network*, to appear, 2019.

Trend 1: More bits, More Spectrum

- From millimeter wave to terahertz: more bandwidth, shorter distances

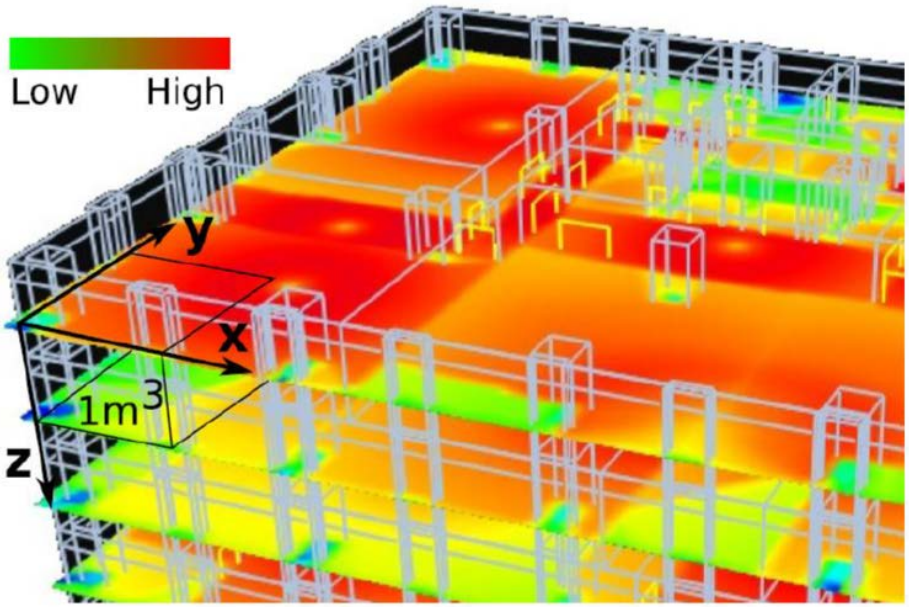


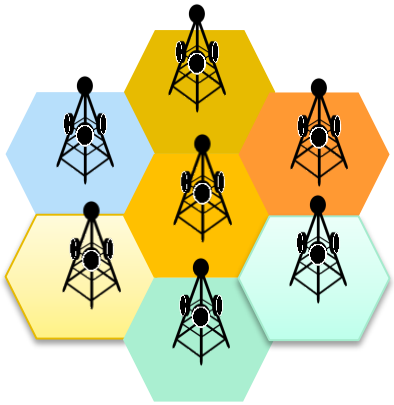


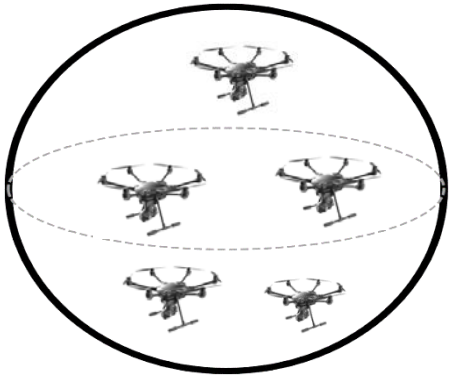
- Going from the Gbps to the Terrabit per second (Tbps)
- Challenges
  - Understanding propagation properties at THz frequencies
  - Overcoming short range and molecular absorption
  - Reliability, reliability, reliability!
- ***Important note: 6G is NOT a case of just using THz!***

Trend 2: 3D Networks

- Communications in 3D: rate, latency, reliability
- Volumetric spectrum efficiency (bps per Hz per cubic meter)
- Rural coverage with drones

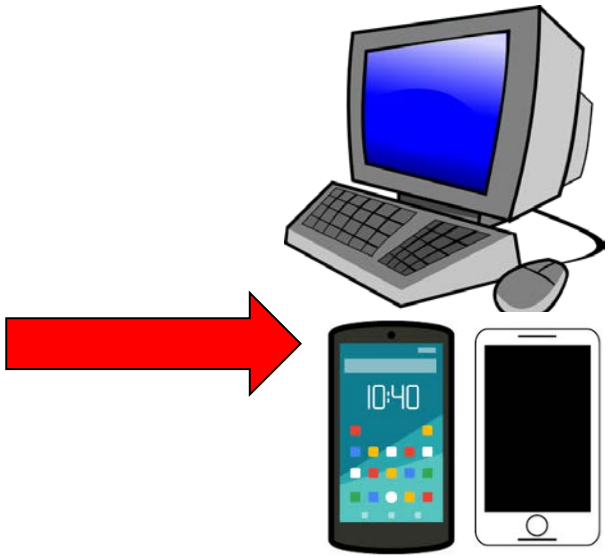






Trend 3: Rise of AI

AI as fiction:
Talos – the "bronze" man of Greek myths



AI to compute:
Computers – can do arithmetic, math, etc

AI to be smart:
Intelligence – can mimic human brain

- **Artificial intelligence** enabled by **machine learning**

Trend 3: Rise of AI

Smart city: Devices and People

Sense

Observe and Connect

- Monitor environment
- Monitor people
- Generate data

……..

Data

Understand

- Residents' needs
- Devices parameters
- City information
- Environment status

……..

Knowledge

Act and adapt

- Self-optimize
- Self-organize
- Provide recommendations to authorities

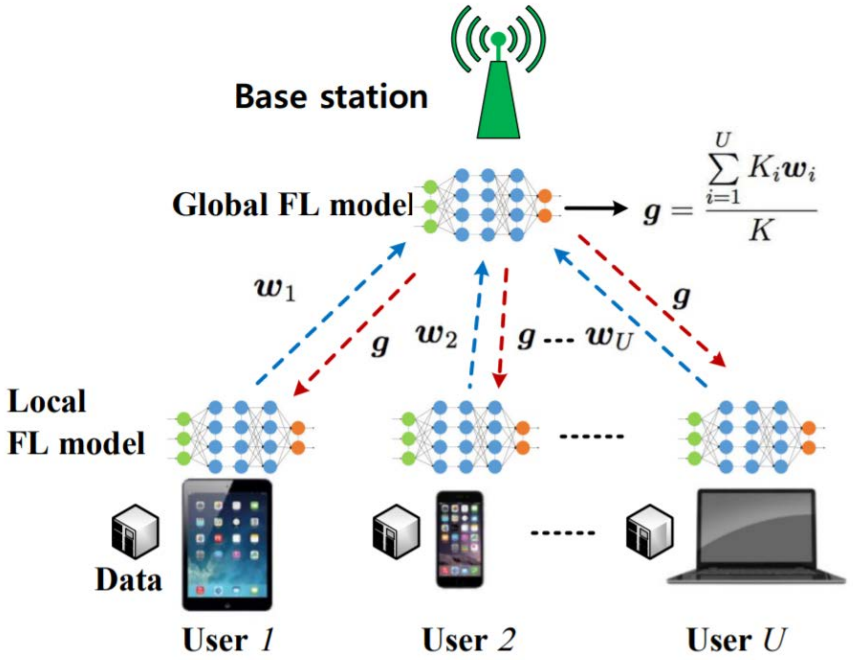
……..

Decision

- Self-sustaining networks
- Analytics
- Smart optimization

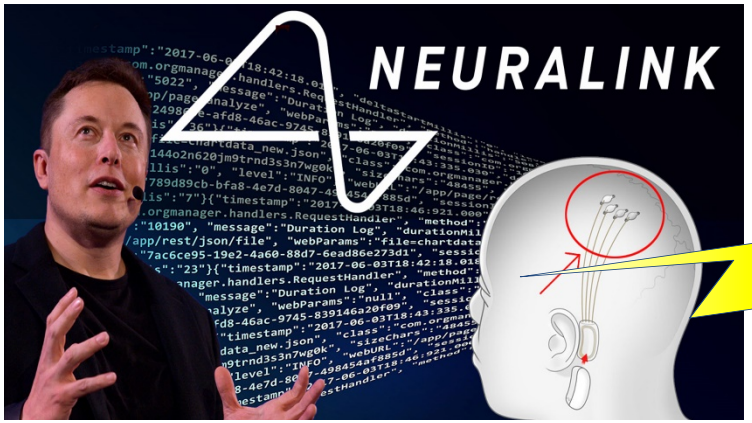
Trend 3: From Big Data to Massive Small Data

- Cloud big data was the norm but data is private and distributed
- Edge, on-device AI/learning

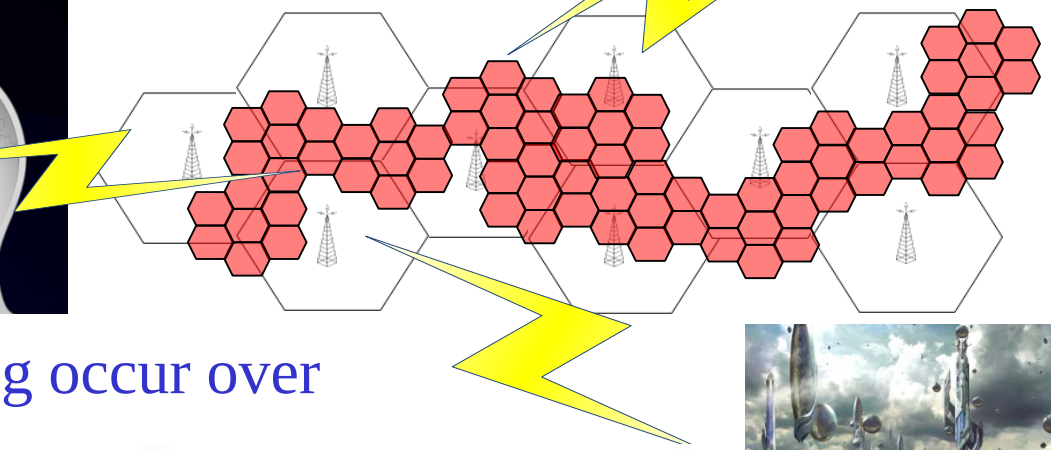


- Can users collaboratively learn a task of interest?
- Learning (at the edge) to communicate?
- Communicate to enable edge learning

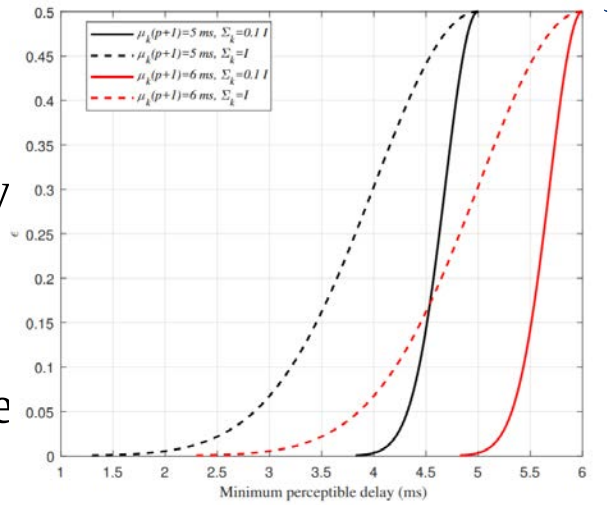
Trend 4: “Brain” over Wireless



- Control a drone



- Can brain-like processing occur over wireless networks?
- Brain-in-the-comm.-loop
  - Recent result: very low latency cannot be perceived by a human brain
  - Save resources via brain-aware communication



- Immerse in a virtual world

Trend 5: Smart Surfaces

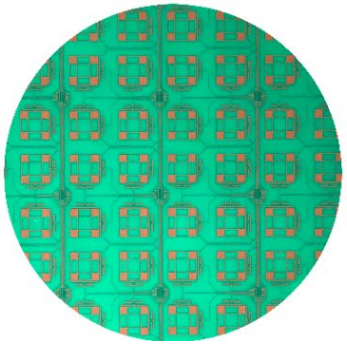
- From massive antennas to antenna surfaces

More antennas

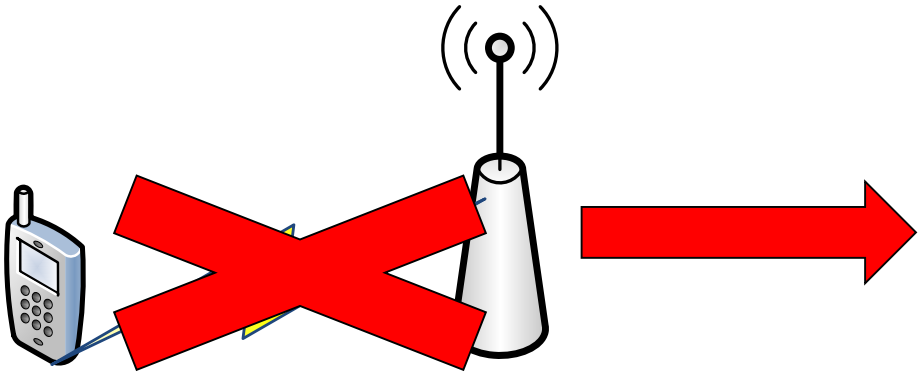
GREENERWAVE

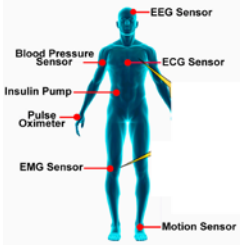
Binary reconfigurable metasurfaces

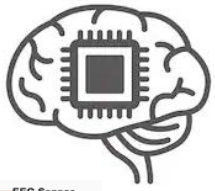
Inspired by metamaterials, simplified through physics

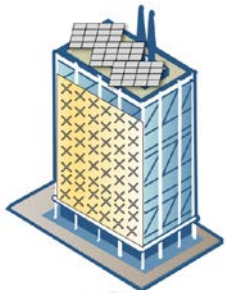


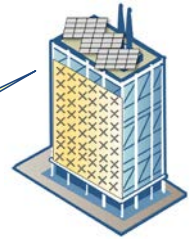
- End of the smartphone – base station communication era







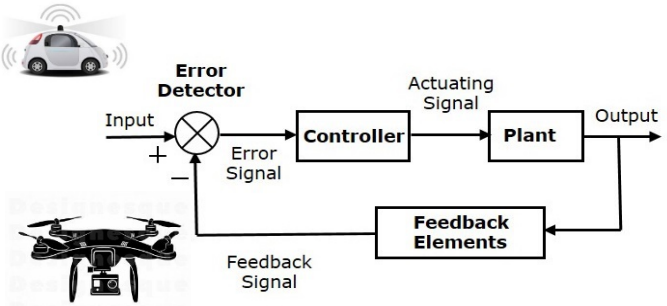




Trend 6: Convergence

- Why did we come up with all of the *"G"s?*
- 6G will go beyond communications to provide…

Communications



Control

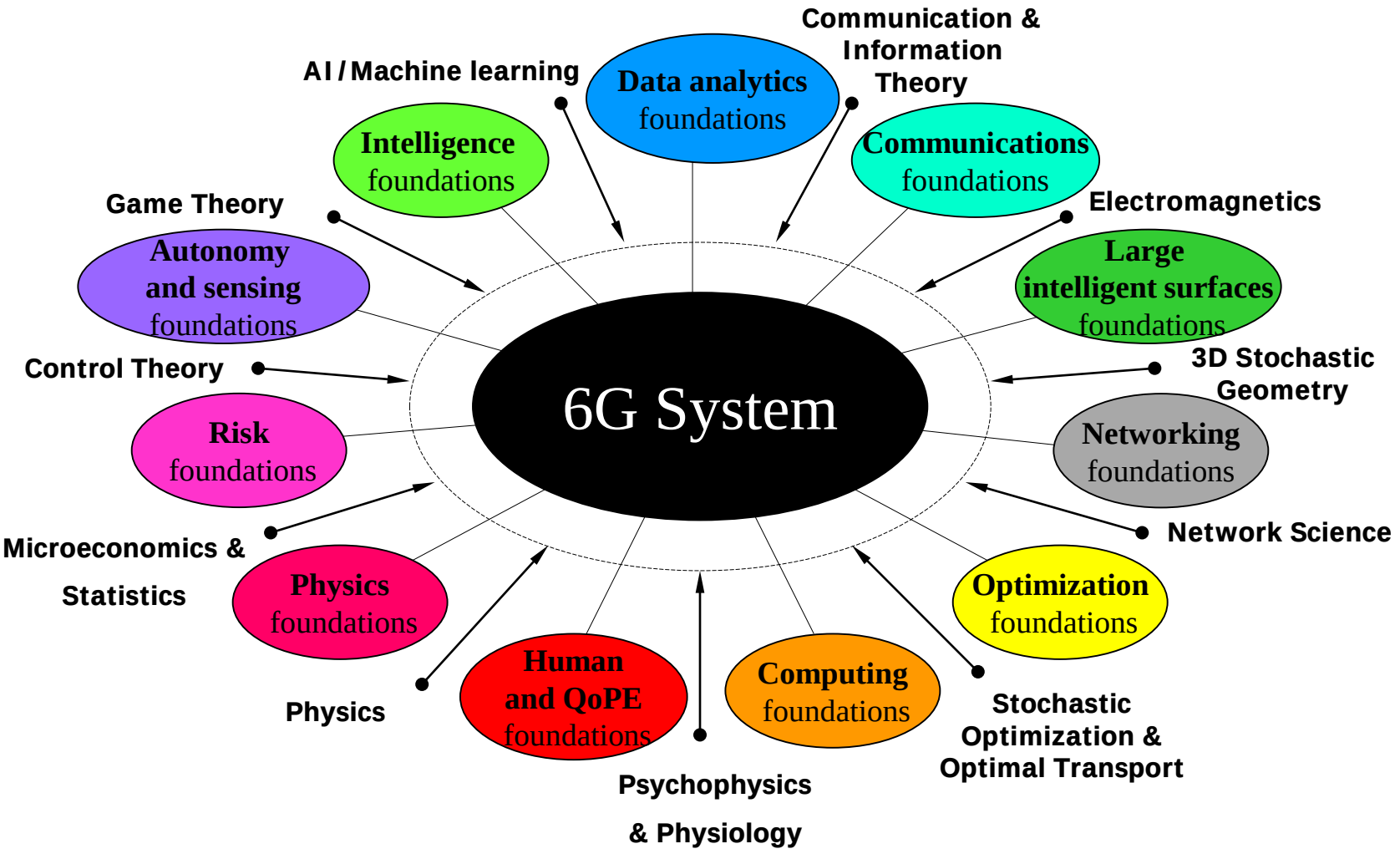
Localization

Sensing

6G:
A multi-purpose System!

Energy

Interdisciplinary Foundations



Conclusio

DEFINITION

Internet of Everything (IoE)

The Internet of Everything (IoE) is a concept that extends the Internet of Things (IoT) emphasis on machine-to-machine (M2M) communications to describe a more complex system that also encompasses people and processes.

"The Internet of Everything connects up all of these separate concepts into one cohesive whole. It's not just about allowing devices to talk to each other; it's about allowing everything to talk about each other. In some ways, you can see the Internet of Things as the equivalent of a rail road line, including the tracks and the connections, whereas the Internet of Everything is all of that, and the trains, ticket machines, staff, customers, weather conditions, etc."

- 2G: Voice
- 3G: Basic multimedia
- 4G: Heavy data/streaming
- 5G: Internet of Things
- 6G: Internet of **Everything?**

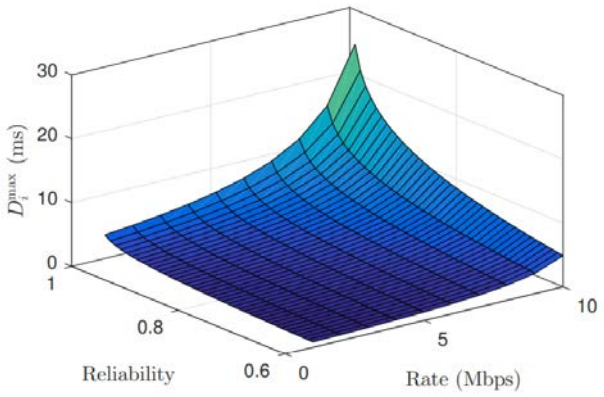
- 7G: **Quantum** Internet of Everything?
- *The "G" principle: "Odd numbered Gs explore new ideas, even numbered Gs perfect them"*
- **Wireless is not dead**

Finally….

Communications

Connect

Thank You



Autonomy

***Act* (intelligently)**