Introduction to Mobile Wireless Networks

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Partly based on lecture slides by Fredrik Brännström, SSY145 Wireless Networks VT17.

Outline

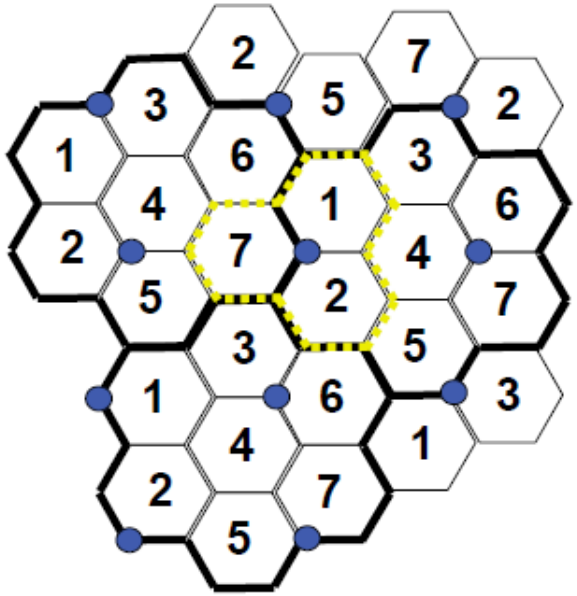
- **Brief history, Cellular Systems**
  - **1G, 2G, 3G**
  - **FDMA, TDMA, CDMA**
- 4G and advanced wireless access technologies
  - OFDM/OFDMA
  - MIMO
- Visions of 5G (and beyond)

Brief history

- 1864: James Clerk Maxwell predicts radio waves
- 1886: Heinrich Rudolph Hertz demonstrates the existence of radio waves
- 1896: Guglielmo Marconi invented the wireless telegraph
- Also in 1890s: Nikola Tesla, Alexander Stepanovich Popov, and others demonstrate different forms of wireless communications
- Marconi gets the credit for attempting wireless communications (1909 Nobel prize in Physics)

Cellular Systems

- System resources (frequency, time) are limited. How can we reuse them and keep interference at low level?
- Cellular is a good idea! Radio signals attenuate with distance, interference can be kept low
  - Resources can be at least partially reused in every cell
  - Significant breakthrough, introduced in 1947 by AT&T



- Sophisticated handovers that would not drop the call

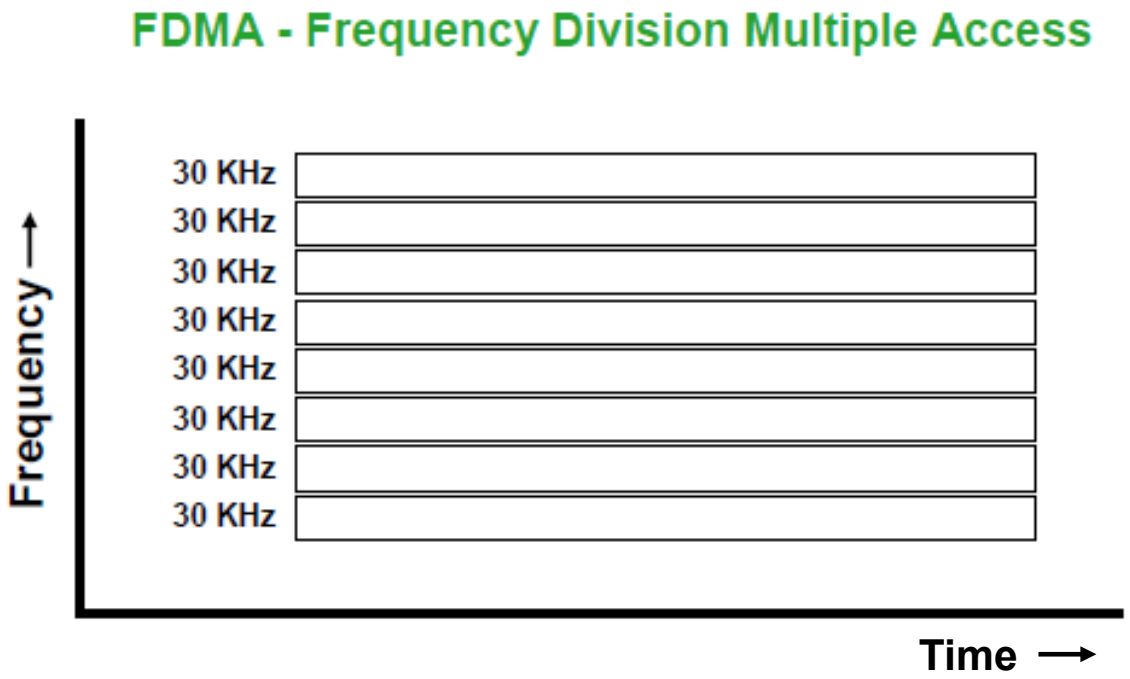
1G Cellular Systems (1)

- Analog systems (1980s)
- Supported only ”plain old telephony services” (POTS)
- Incompatible standards
  - NMT (*Nordic countries*), AMPS (*USA*), TACS (*UK*), Radiocom 2000 (*France*), C-450 (*West Germany*), RTMI (*Italy*), J-TACS (*Japan*)

1G Cellular Systems (2)

- Bulky, mainly car-borne equipment
- Inconsistent voice quality due to high inter-user interference
- Spectrally inefficient
  - low achievable bits/sec/Hz
- 1G is based on Frequency Division Multiple Access (FDMA)

1G Cellular Systems - FDMA



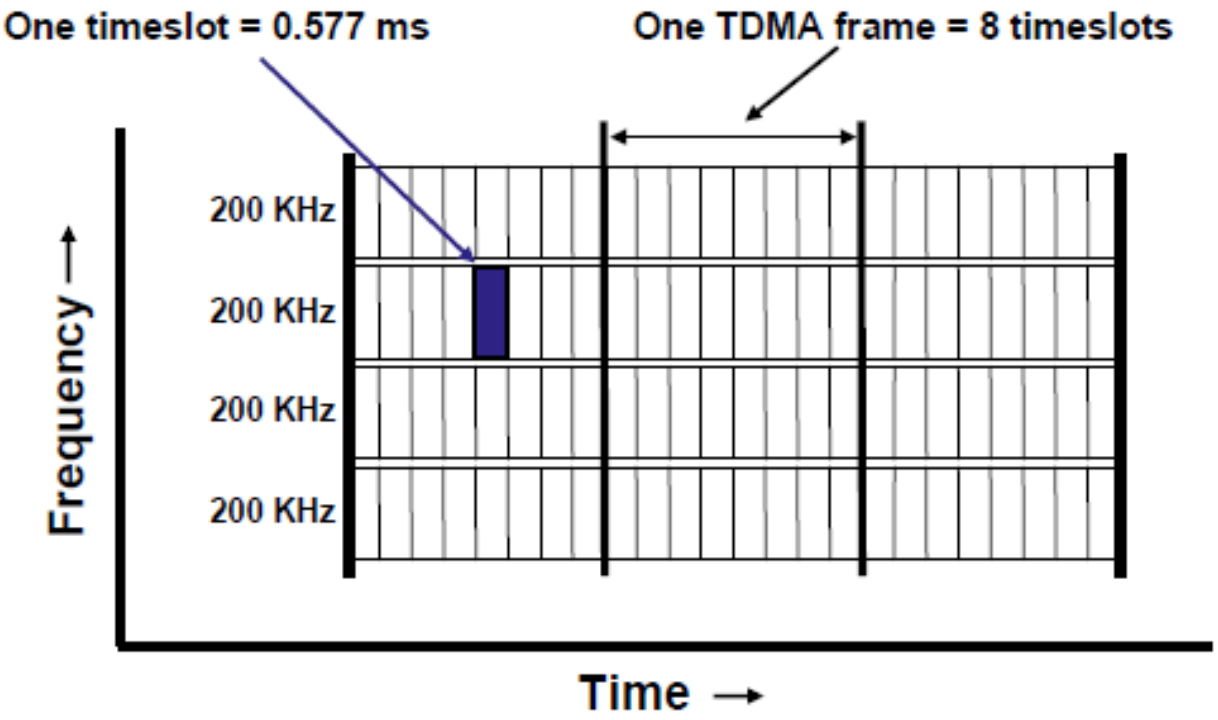
2G Cellular Systems

- 1980s: to face the problems of 1G, development of 2G systems started
- 2G leverages digital technology
  - Speech compression and signal processing
- Increased capacity and QoS
- 2G systems:
  - GSM (Europe): based on TDMA/FDMA
  - IS-95 and IS-136 (*USA*): based on CDMA
  - PDC (*Japan*): based on TDMA/FDMA
  - PHS, DECT (cordless phones): based on TDMA/FDMA

2G - GSM

- Global System for Mobile communications (GSM)
  - Launched in 1992
  - Joint European effort which started in 1982
  - Based on TDMA and FDMA
  - 900 MHZ band
- Supports voice services and basic data services (SMS)
- GSM is still the dominant world standard
  - Well defined interfaces
  - Many competitors resulting in good prices

GSM –TDMA / FDMA



2G/3G – CDMA (1)

- Although GSM is based on TDMA/FDMA, IS-95 and IS-136 (D-AMPS) are based on CDMA
- Code Division Multiple Access:
  - All users share the same frequency band.
- Most success in the USA and also Korea
- Advantage: easy migration to 3G since they both use the same modulation

2G/3G- CDMA (2)

- Spread spectrum modulation
  - Original developed for the military
  - Resists jamming and many kinds of interference
  - Modulation is hidden from those without the spreading code
  - With wide bandwidth robust links possible by harnessing frequency diversity
- All users share the same block of large spectrum
  - Drawback: Interference due to Near-far-problem
- All 3G radio standards based on CDMA
  - CDMA 2000, W-CDMA, and TD-SCDMA

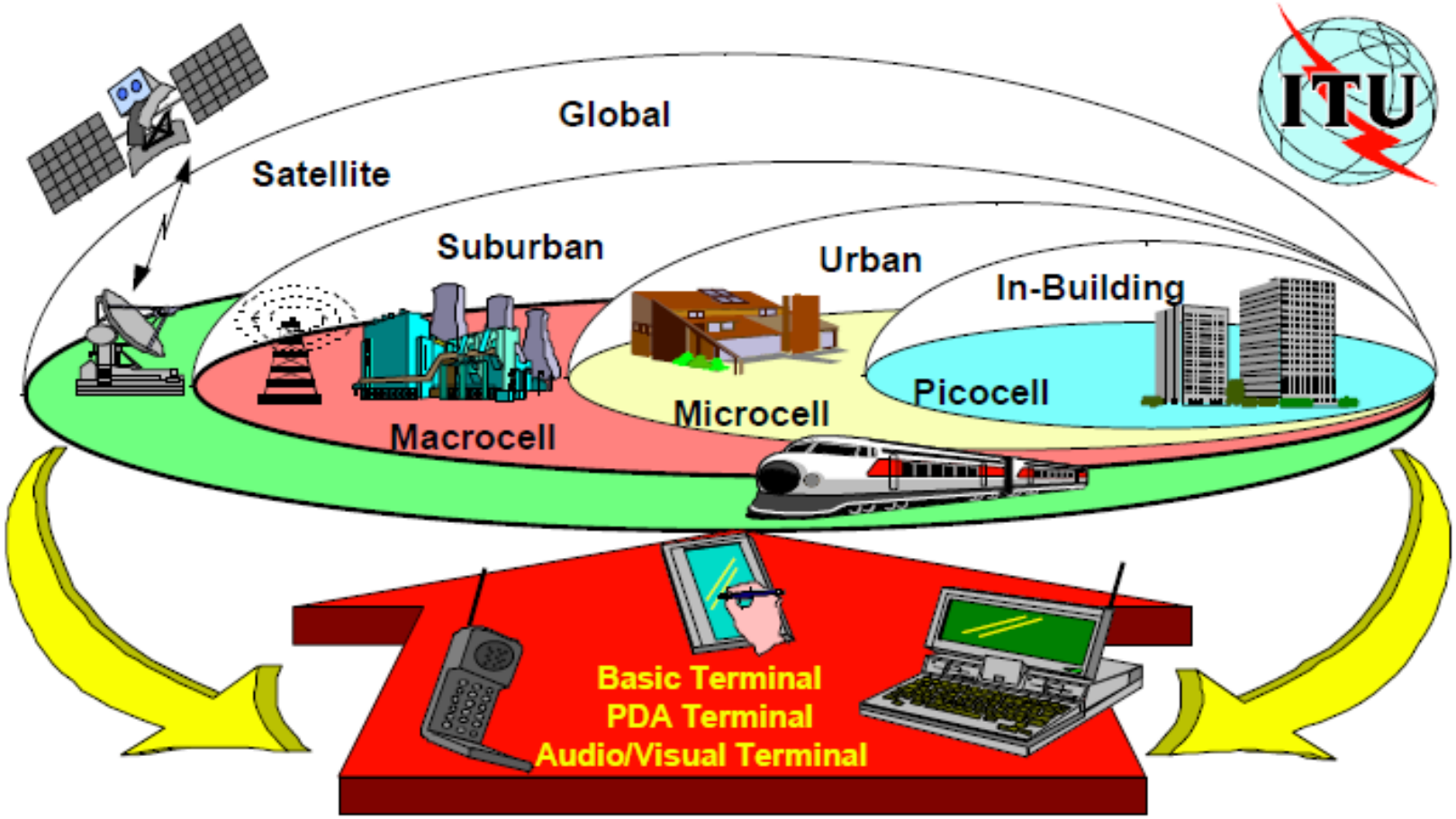
2G - GSM Evolution

- GSM supported voice and low data rate packet services (peak 9.6 kbit/s)
  - Need for supporting packet oriented services of higher rates
- General Packet Radio Service (GPRS) was the first step, marked as 2.5G
- Enhanced Data Rates for GSM Evolution (EDGE) was a further significant evolution, marked as 2.75G

The 3G Vision

- High data rates for packet oriented services
- Universal global Roaming (1 standard and not several)
- Multimedia traffic (voice, data, video)
- High spectral efficiency
- Data-centric architecture
- 3G is based on CDMA

The 3G Vision (2)



PDA: Personal Digital Assistant

3G Radio Technology Today

- **UMTS** (Universal Mobile Telephone service): based on Wideband CDMA (W-CDMA)
- **CDMA 2000**: based on Multi-Carrier CDMA
- **TD-SCDMA**: Time Division Synchronous CDMA

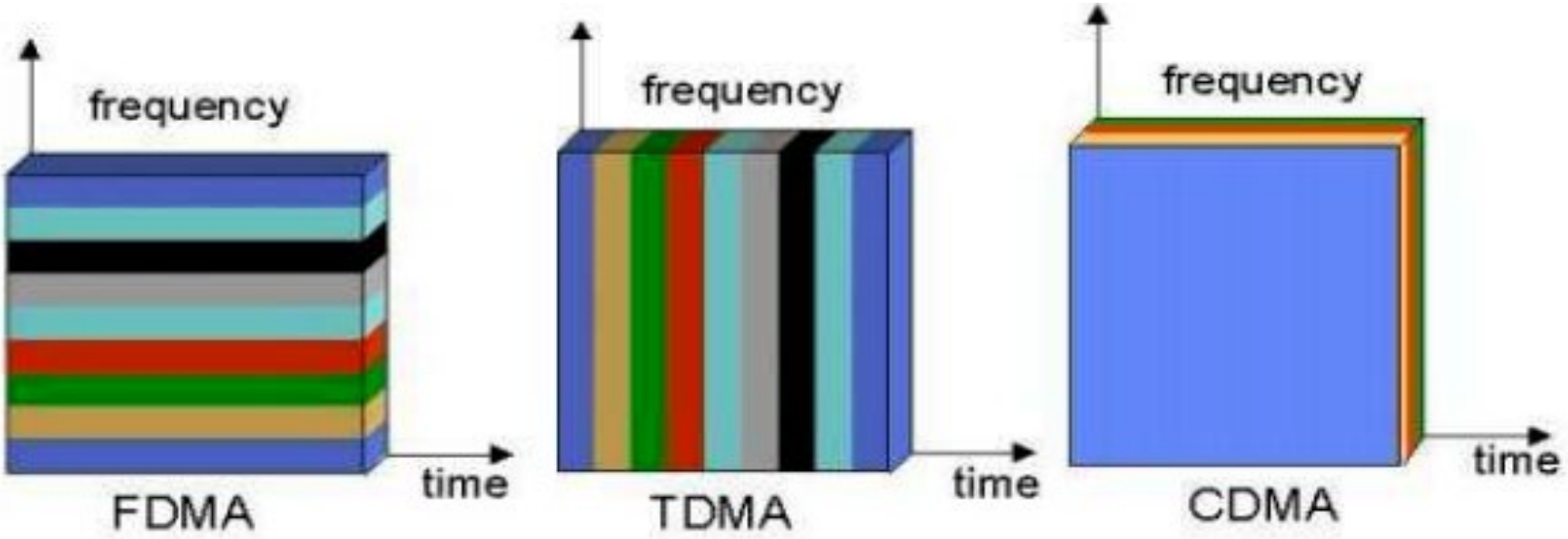
3G - UMTS

- Market leader
- GSM evolution path: leveraged GSM's dominant position
- Requires substantial BW each way
- Slow start but now leading
  - Since it was building on GSM's 80% market share.

3G - CDMA 2000

- Evolution of original Qualcomm CDMA (IS-95)
- Better migration from 2G to 3G
  - CDMA operators do not need additional spectrum
  - Higher data rates than UMTS, at least at first
- Could not compete with GSM's critical mass

1G, 2G, 3G Multi-Access Technologies



Courtesy of Petri Possi, UMTS World

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  - **OFDM/OFDMA**
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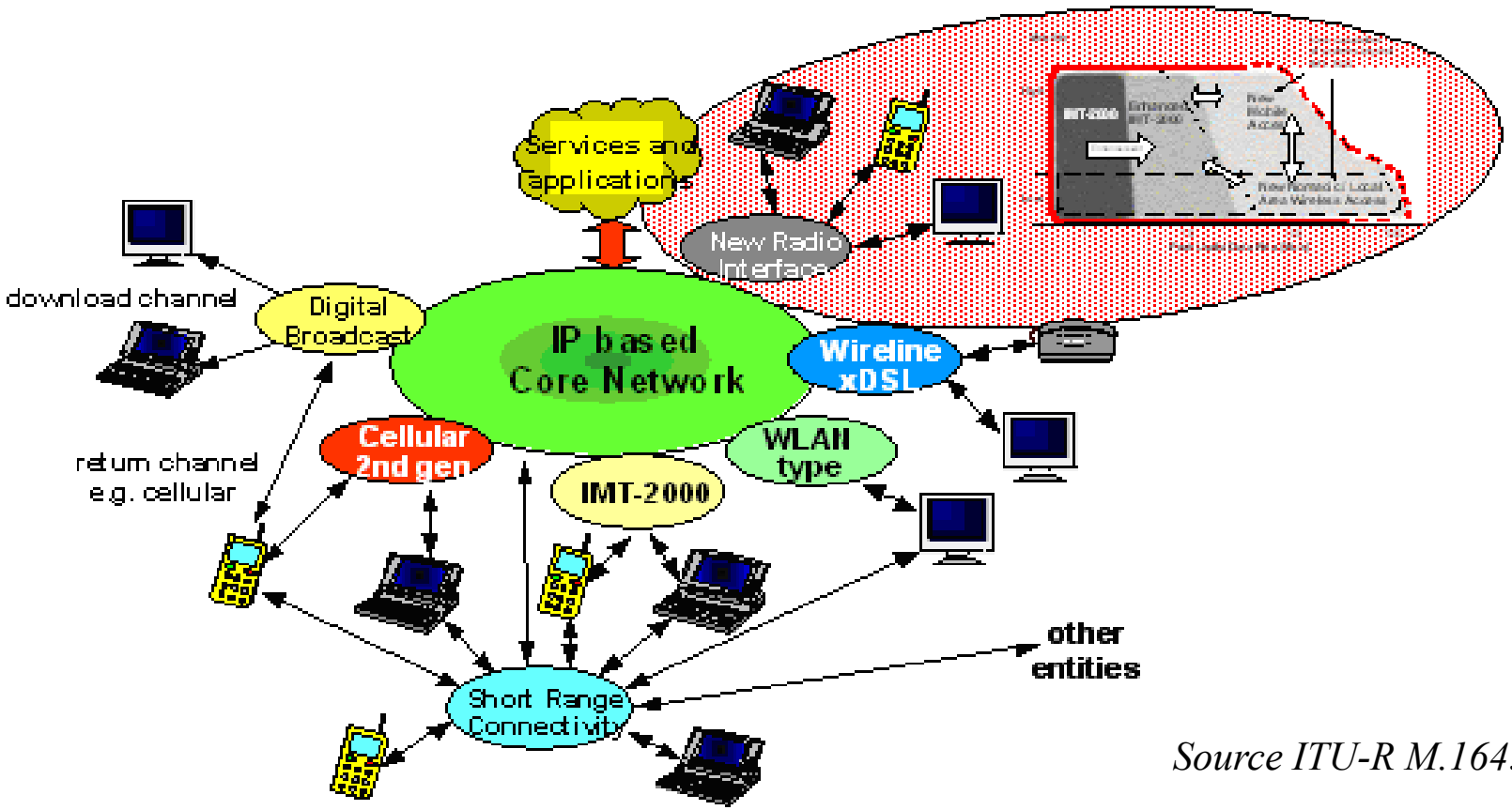
Shortcomings of 3G

- 3G was accompanied by huge financial investments for spectrum acquisition
- It was less successful commercially than anticipated
  - Enhanced GSM (mainly EDGE) provided sufficient rates for a range of applications
  - UMTS did not greatly outperform EDGE
- Need for evolution!
  - HSPA was a first attempt, marked as 3.5G

Why 4G?

- Mobile subscribers use a range of applications requiring different QoS level and ubiquitous coverage
- 4G requirements
  - Very high peak rates and spectral efficiency
  - Fairness, especially for cell-edge users
  - Easy deployment
  - Ability to co-exist with legacy technologies

ITU-R Vision for Systems Beyond 3G



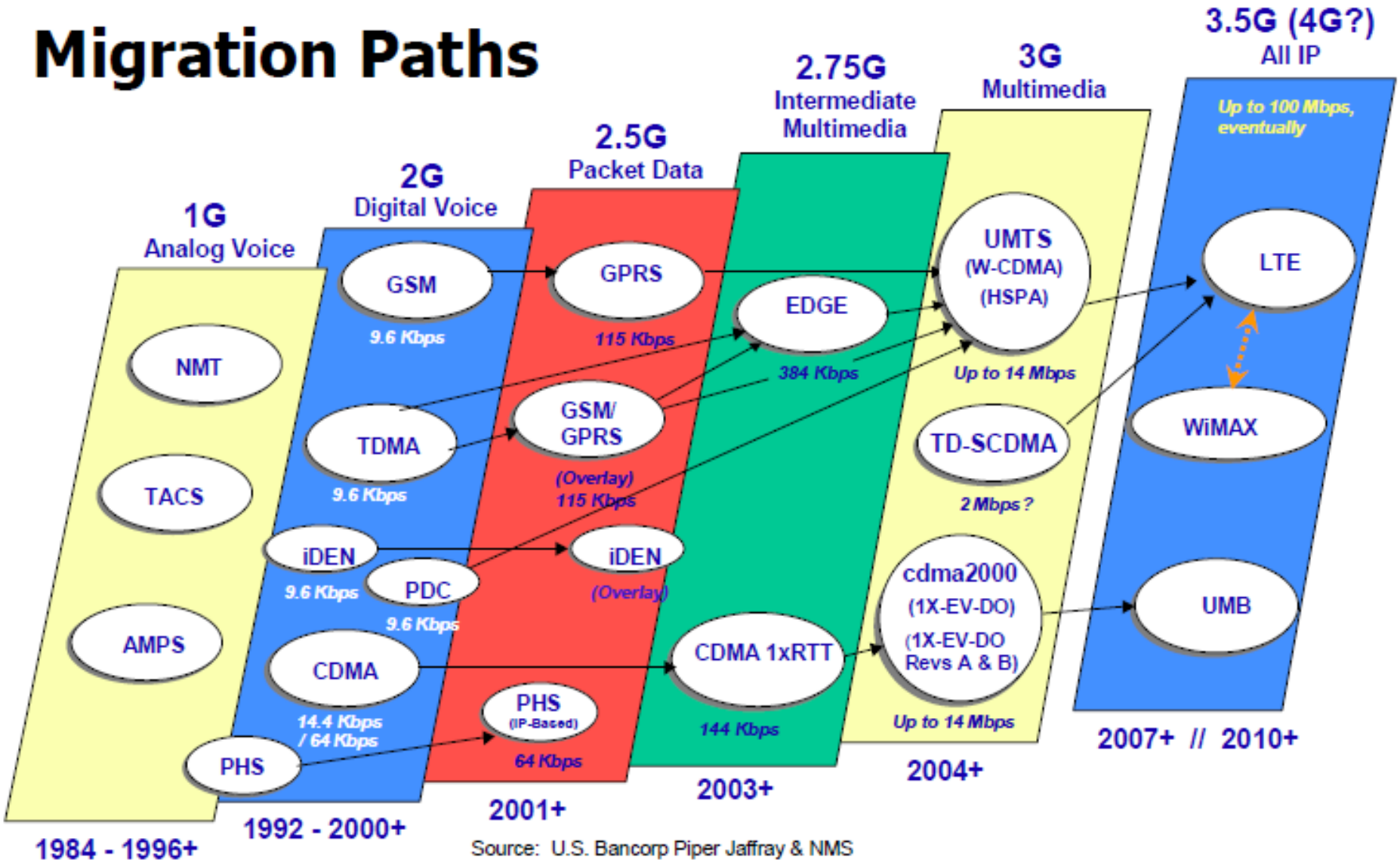
Source ITU-R M.1645

Integrate existing and evolving access systems on a *packet-based* platform to enable cooperation and interworking.

"Optimally connected anywhere, anytime"

Towards 4G - LTE

- Sophisticated multiple access schemes
  - Downlink: OFDMA with cyclic prefix (CP)
  - Uplink: single carrier FDMA with CP
- Adaptive modulation and coding
  - QPSK, 16QAM, and 64 QAM.
- MIMO spatial multiplexing techniques
  - (2, 4, or more) × (2, 4 or more) downlink and uplink

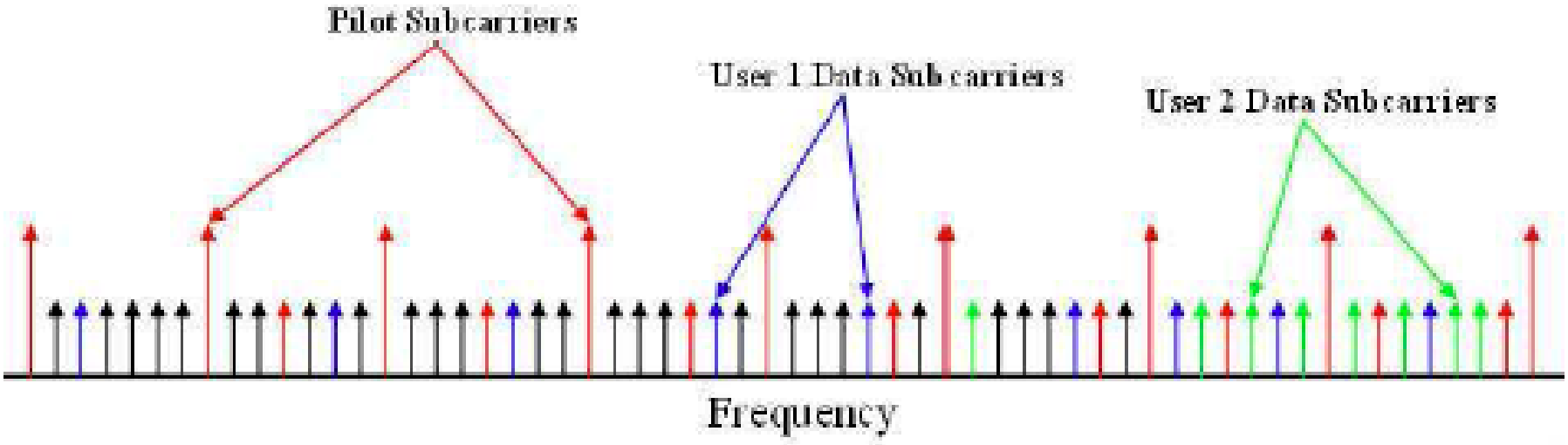

Migration Paths
1G
Analog Voice
2G
Digital Voice
2.5G
Packet Data
2.75G
Intermediate Multimedia
3G
Multimedia
3.5G (4G?)
All IP
Up to 100 Mbps, eventually
NMT
TACS
AMPS
GSM
9.6 Kbps
TDMA
9.6 Kbps
iDEN
9.6 Kbps
PDC
9.6 Kbps
CDMA
14.4 Kbps / 64 Kbps
PHS
GPRS
115 Kbps
GSM/ GPRS
(Overlay)
115 Kbps
iDEN
(Overlay)
PHS
(IP-Based)
64 Kbps
EDGE
384 Kbps
CDMA 1xRTT
144 Kbps
UMTS
(W-CDMA)
(HSPA)
Up to 14 Mbps
TD-SCDMA
2 Mbps ?
cdma2000
(1X-EV-DO)
(1X-EV-DO Revs A & B)
Up to 14 Mbps
LTE
WiMAX
UMB
1984 - 1996+
1992 - 2000+
2001+
2003+
2004+
2007+ // 2010+
Source: U.S. Bancorp Piper Jaffray & NMS

OFDM and OFDMA

- OFDM: Orthogonal Frequency Division Multiplexing:
  - Multiple subcarriers that are assigned to a user
  - CP is used to eliminate ISI
  - Vary bits per subcarrier based on instantaneous SNR
- OFDMA: Orthogonal Frequency Division Multiple Access
  - The subcarriers are assigned to multiple users
  - Optimization of frequency and time

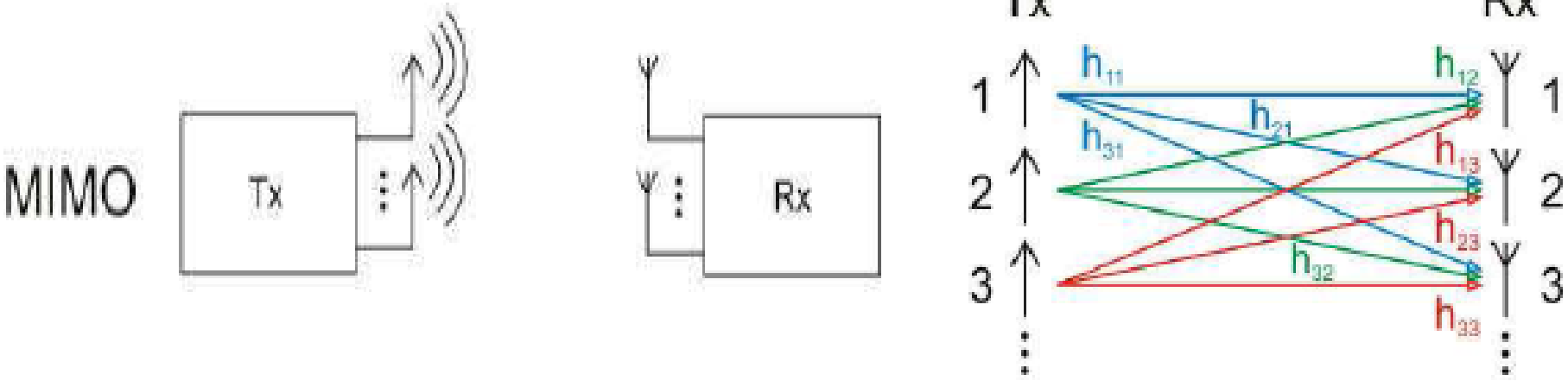
OFDMA

- Dynamically allocate user data to sub-carriers based on instantaneous data rates and varying subcarrier capacities
- Highly efficient use of spectrum



4G Technology - MIMO

- Multiple-Input Multiple-Output antenna technologies
- Multiple path improve reliability and/or increase spectral efficiency.



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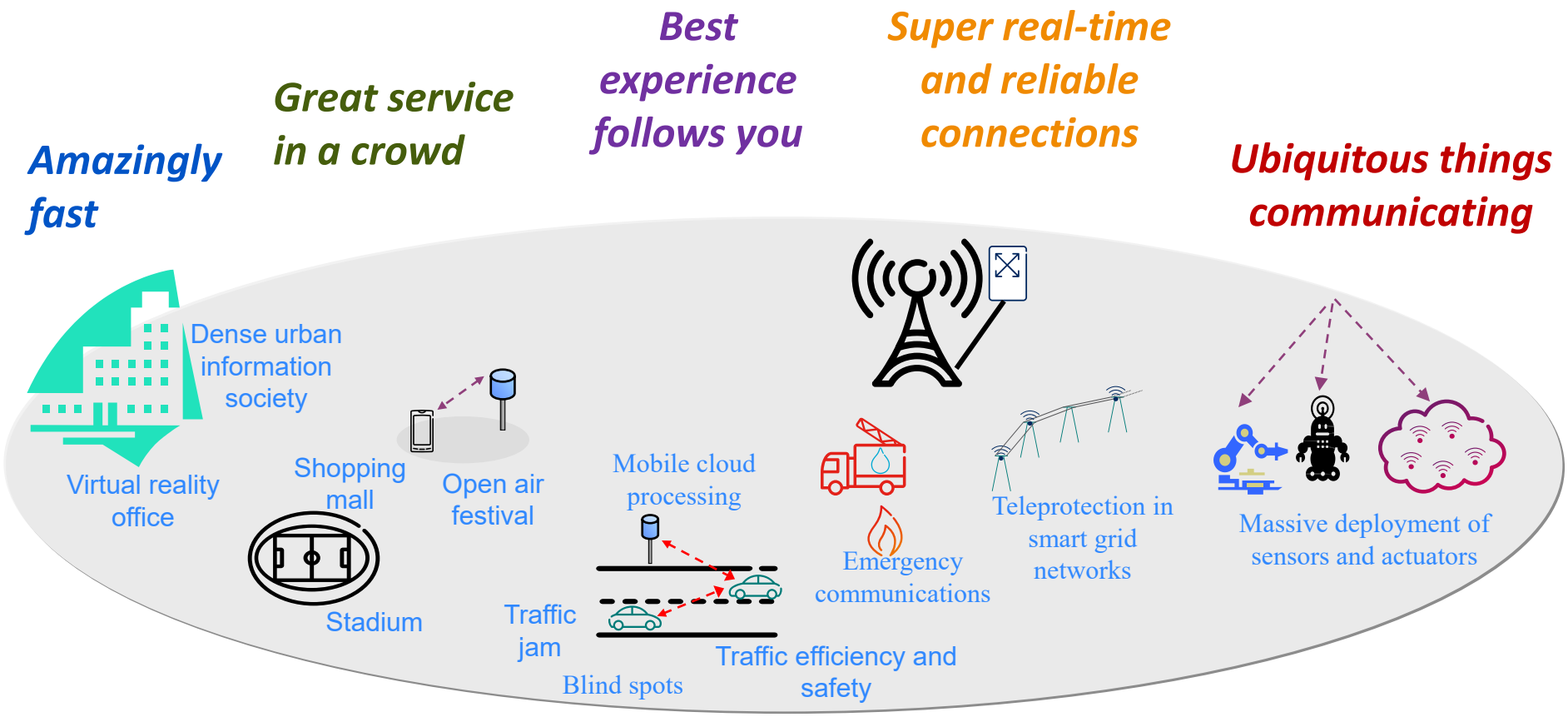
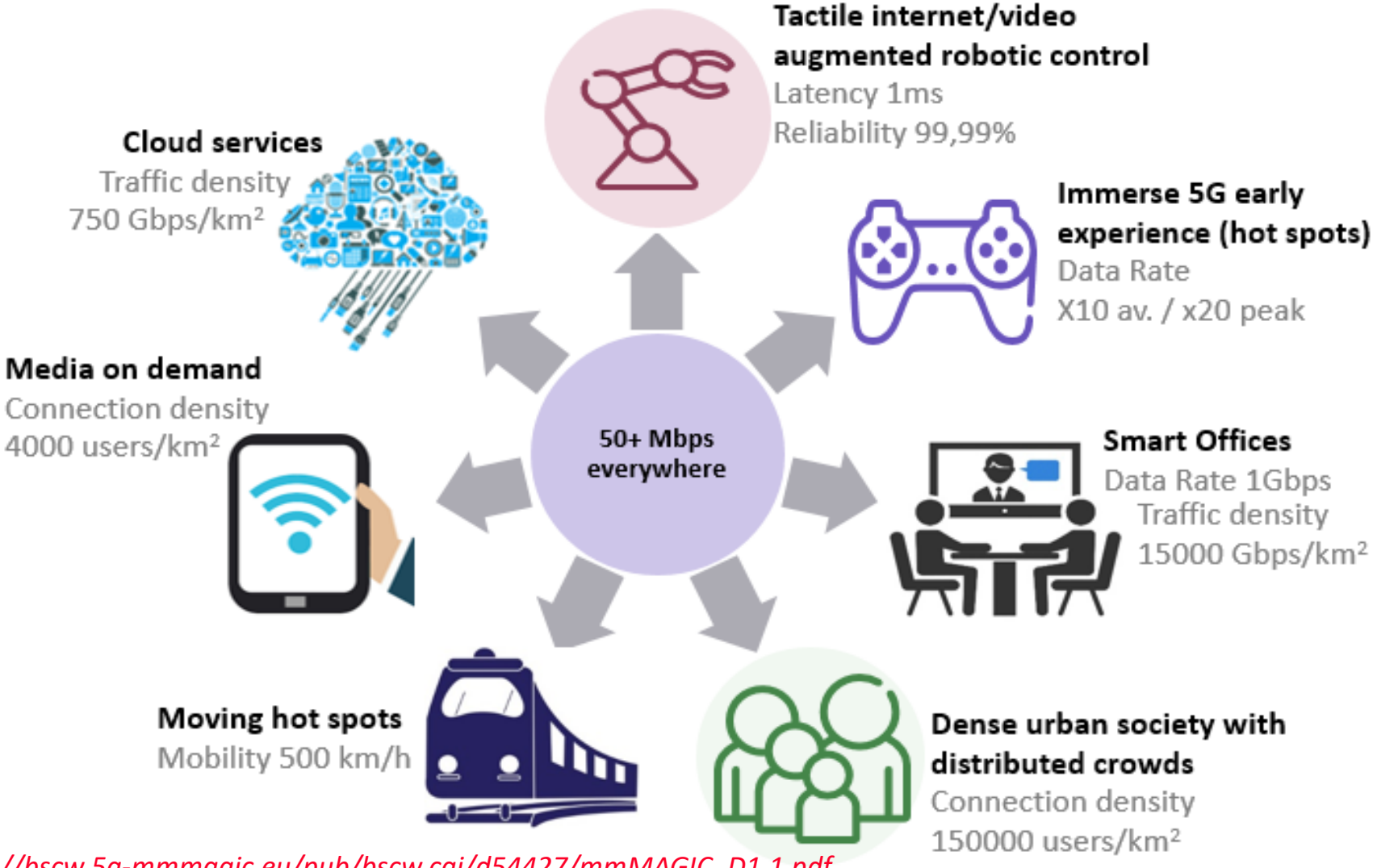
METIS Scenarios and Test Cases



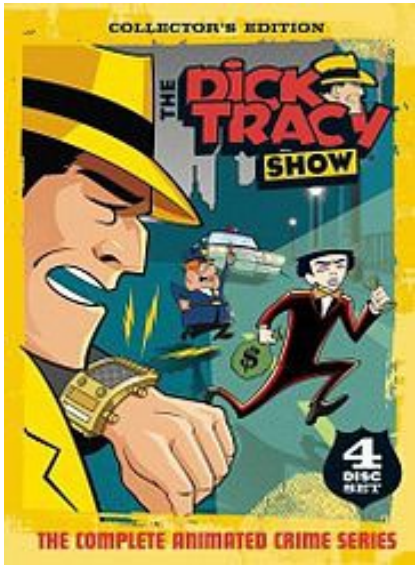
Source: METIS Deliverable D1.1 "Scenarios, requirements and KPIs for 5G mobile and wireless system", https://www.metis2020.com/

8 Use Cases in mmMAGIC



https://bscw.5g-mmmagic.eu/pub/bscw.cgi/d54427/mmMAGIC_D1.1.pdf

Power of Visions - Dick Tracy Comic Strip



Dick Tracy (originally Plainclothes Tracy), a square-jawed, hard-hitting, fast-shooting, and intelligent police detective.
Created by Chester Gould, the strip made its debut on October 4, 1931, in the Detroit Mirror. [Wikipedia]

James Bond - Tomorrow Never Dies – BMW Car Chase

http://www.youtube.com/watch?v=qKAME9fAA-4&feature=youtu.be&t=4s

General Motors' EN-V concept

https://www.youtube.com/watch?v=0tiHwzGsotA

Eureka - SARAH

The house SARAH (Self Actuated Residential Automated Habitat) implements "ambient intelligence".

Eureka is an American science fiction television series that premiered on Syfy on July 18, 2006. The fifth and final season ended on July 16, 2012. [Wikipedia]

http://www.youtube.com/watch?v=O8Jm-AIRqwQ&feature=youtu.be&t=2m11s

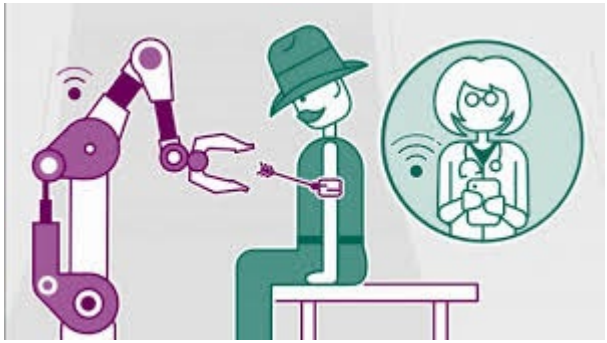
A New Era Begins

Internet -> Mobile Internet -> …

-> Wireless => Internet of Things

Source: https://www.aeteurope.com/news/technologies-secure-internet-things/

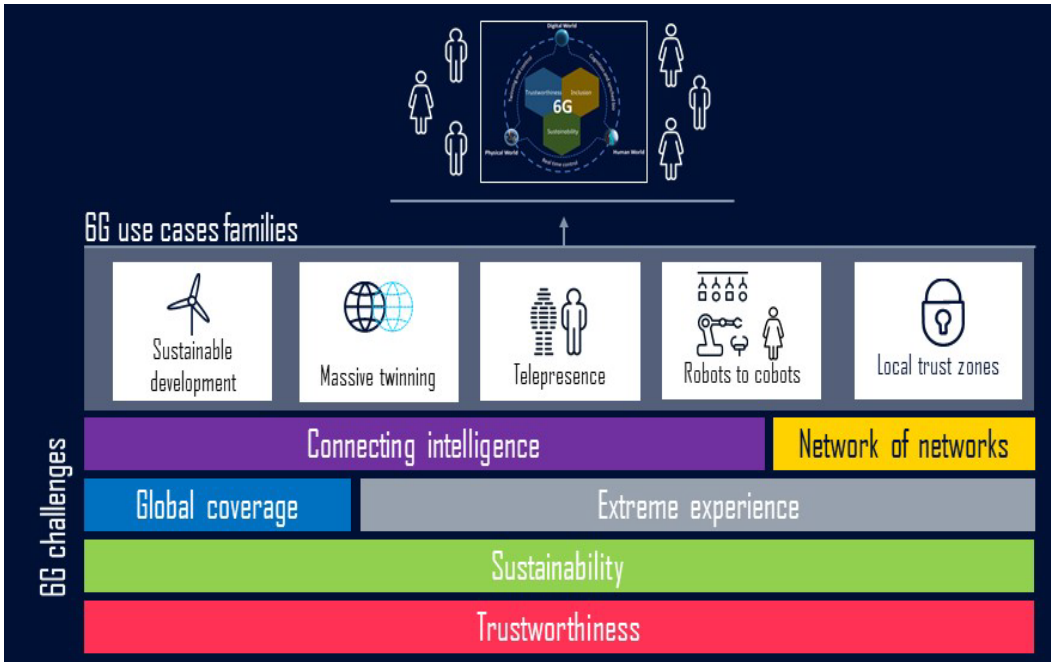
-> Robustness, Low latency => Internet of Skills!



Source: https://www.ericsson.com/thinkingahead/the-networked-society-blog/2017/02/14/virtual-reality-comes-age-internet-skills/

Hexa-X vision on 6G: connect human, physical, and digital worlds with a fabric of 6G key enablers.

https://hexa-x.eu/ Hexa-X



Source: Hexa-X "D1.1 6G Vision, use cases and key societal values", Feb 2021, https://hexa-x.eu/deliverables/

Recap: Next steps in the Course

- Each of you choose your four preferred Project Topics, with priority 1 (highest), 2, 3, and 4 (lowest).
  - The Project topic priority list should be submitted in Canvas to: "Quizzes>>Surveys>>Submit your priority list" no later than **13:00 on Wed March 20** (in less than two days!).
- **10:00-11:45 Thu March 21**, ES51, "Academic Technical Writing", Baraa Khuder, *Centre for Language and Communication*

  - Book your consultation time based on instructions during the lecture on Thu March 21.
- Read your Chalmers emails and Canvas messages and check the latest Course-Memo! There might be updates on the Guest lecturers' schedule.