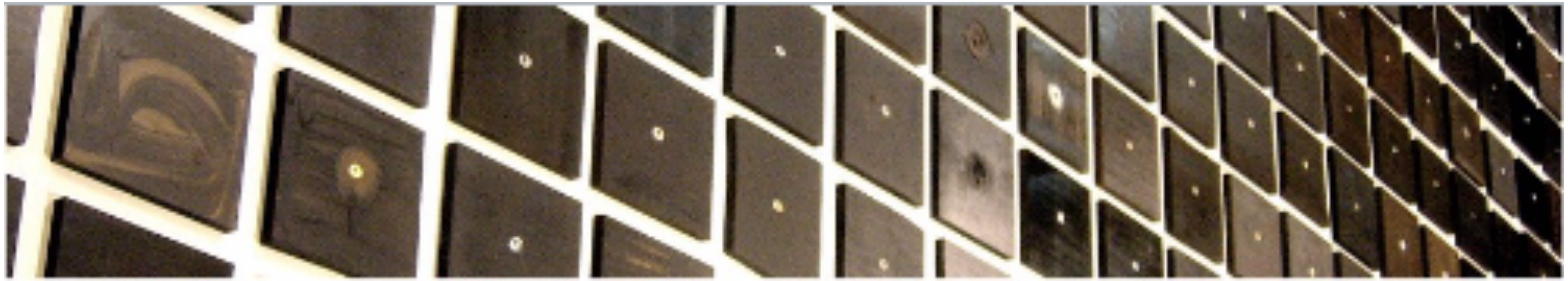

UiO : Universitetet i Oslo

TEK5110

L9 Mobile Systems

Josef Noll
Secretary General and Co-Founder at BasicInternet.org, Professor at UiO, Head of Research at Movation
Oslo Area, Norway | Telecommunications

Current: Basic Internet Foundation, University Graduate Studies (UNIK), University of Oslo (UiO), Movation AS
Previous: MobileMonday, Telenor R&I, Telenor R&D
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PhD Fellow at Eye Networks AS
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| Information Technology and Services

Current: Eye Networks AS
Previous: Høgskolen i Oslo og Akershus, State Organization for Registry of Deed & Property, Karaj Islamic Azad University
Education: University of Oslo (UiO)

TEK5110 - Before we start

- Leftover from L2 - Range, see slide 31 in L2 Radio
- Questions to L2 - Radio?

- Questions to group work?

Lecture plan is detailed on:
its-wiki.no/wiki/TEK5110

TEK5110 - Lecture Plan

- 28Aug - L1 Intro
- 4Sep - L2 Radio
- 11Sep - L3 Propagation Characteristics
- 18Sep - L4 Real time monitoring
- 25Sep - no lecture; presentation preparation
- 2Oct - Presentations
- 9Oct - Maghsoud (Josef travel)
- 16Oct - Group work (Josef travel)
- 9Oct - L7 Network Management (M)
- 16Oct - L8 IoT Raspberry Pi (M)
- 23Oct - L9 Mobile Systems
- 30Oct - L11 Hands-on Wireless (M)
- 6Nov - L10 Wireless Systems
- 13Nov - L12 Basic Internet Infrastructure
- 20Nov - L13 Hands-on monitoring (M)
- 27Nov - L14 Group work/Monitoring
- 4Dec - L15 Group Presentation
- 11Dec - Oral exam (25 min, 3 parts)

http://its-wiki.no/wiki/Building_Mobile_and_Wireless_Networks_Compendium

Learning outcomes

- Antennas
  - ➡ Gain and directivity
- Multipath propagation
  - ➡ Non Line of Sight (NLOS) communications
  - ➡ Multipath
- Propagation Models
  - ➡ Outdoor, impulse response
  - ➡ Indoor

⌘ B-Antennas and Propagation

Free Space Propagation

Antennas, Gain, Radiation Pattern
Multipath Propagation, Reflection, Diffraction
Attenuation, Scattering
Interference and Fading (Rayleigh, Rician, …)
Mobile Communication dependencies

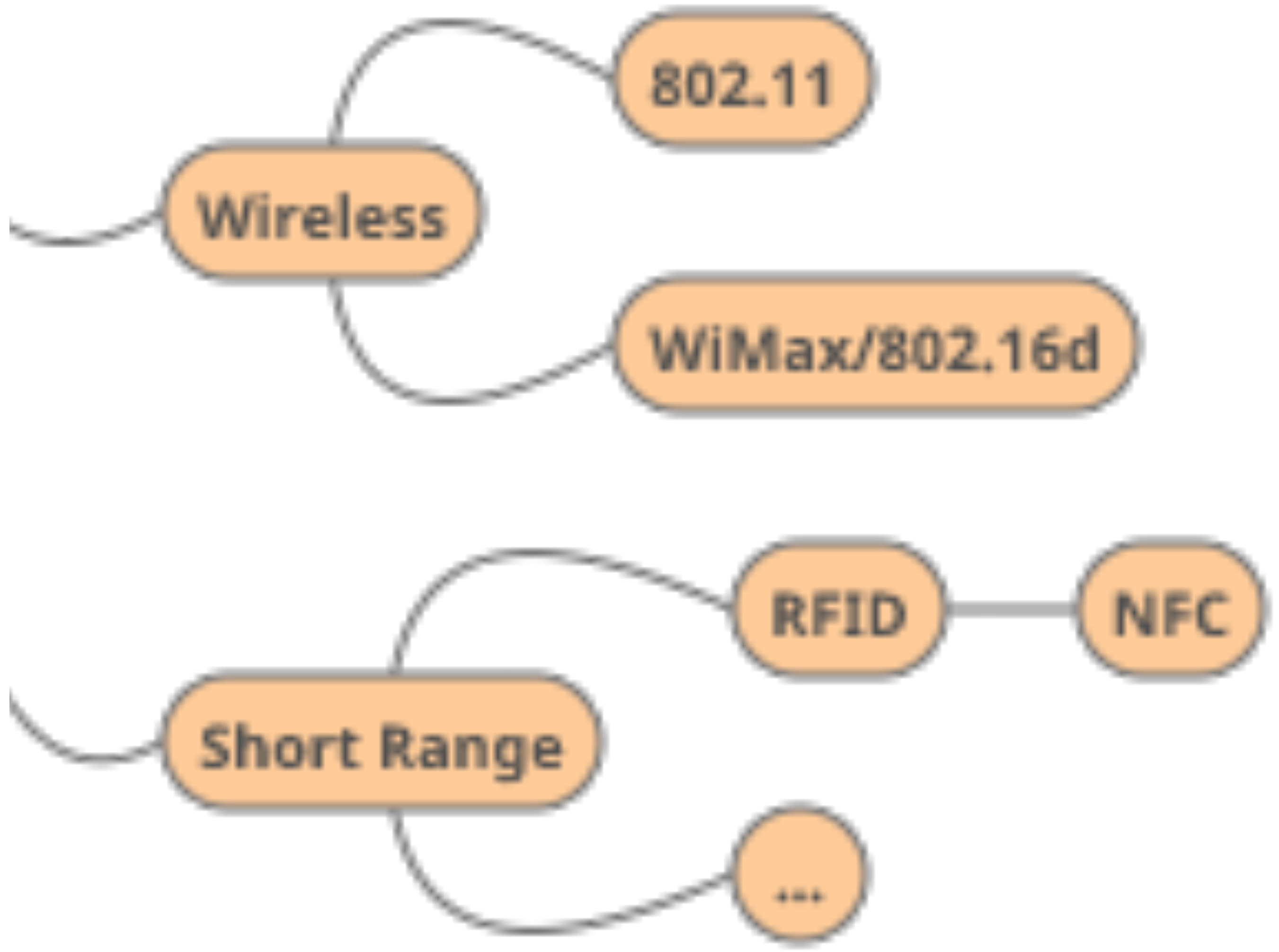
C-Propagation models

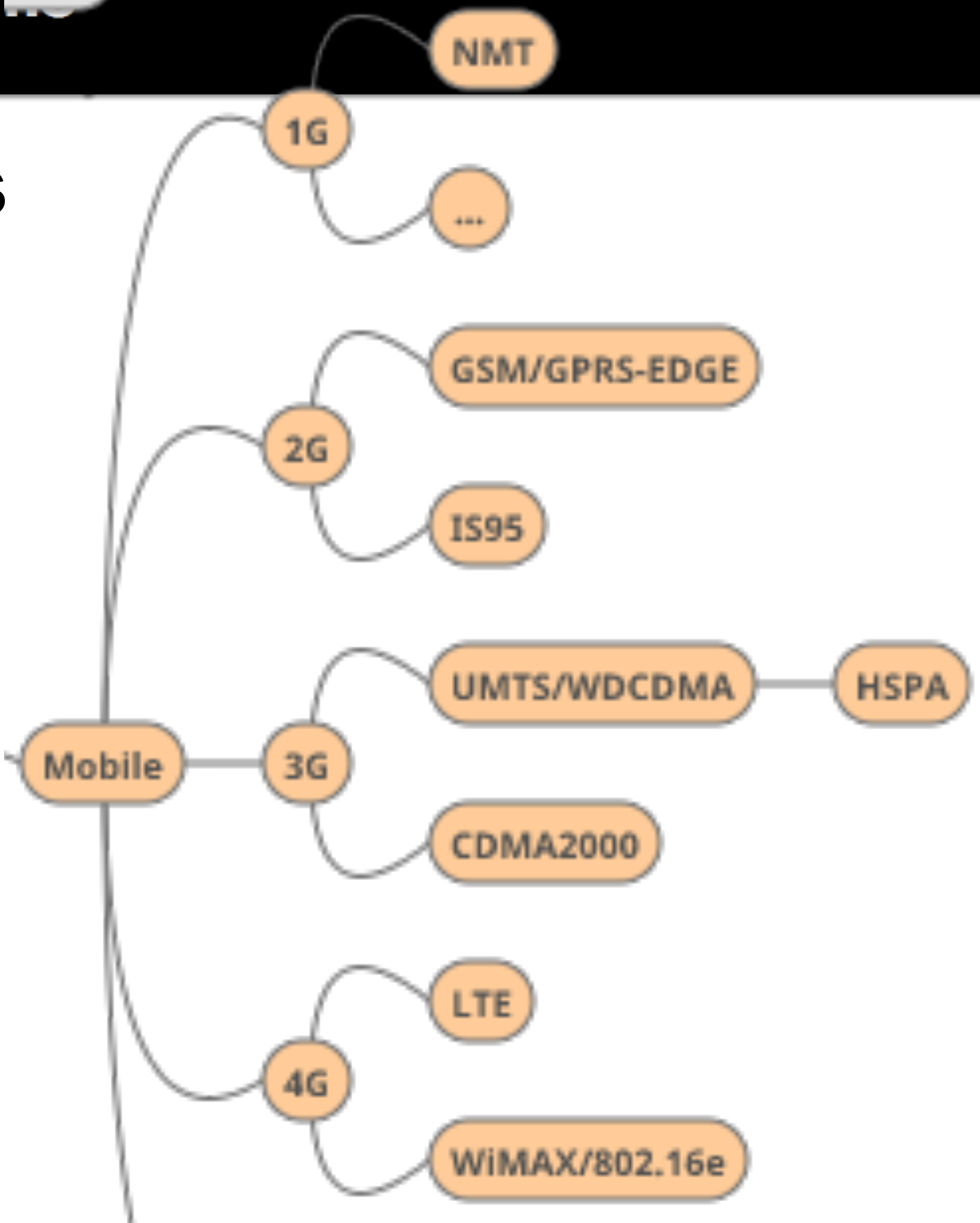
Environments (indoor, outdoor to indoor, vehicular)
Outdoor (Lee, Okumura, Hata, COST231 models)
Indoor (One-slope, multiwall, linear attenuation)

Mobile Systems and Propagation Characteristics

Mobile and Wireless Systems

- https://drive.google.com/file/d/0B2fQNOmvY08oOVp1RXVJaFNkSEk/view?usp=sharing





ITU-R propagation scenarios

- indoor, outdoor to indoor, vehicular

Typical Propagation parameters

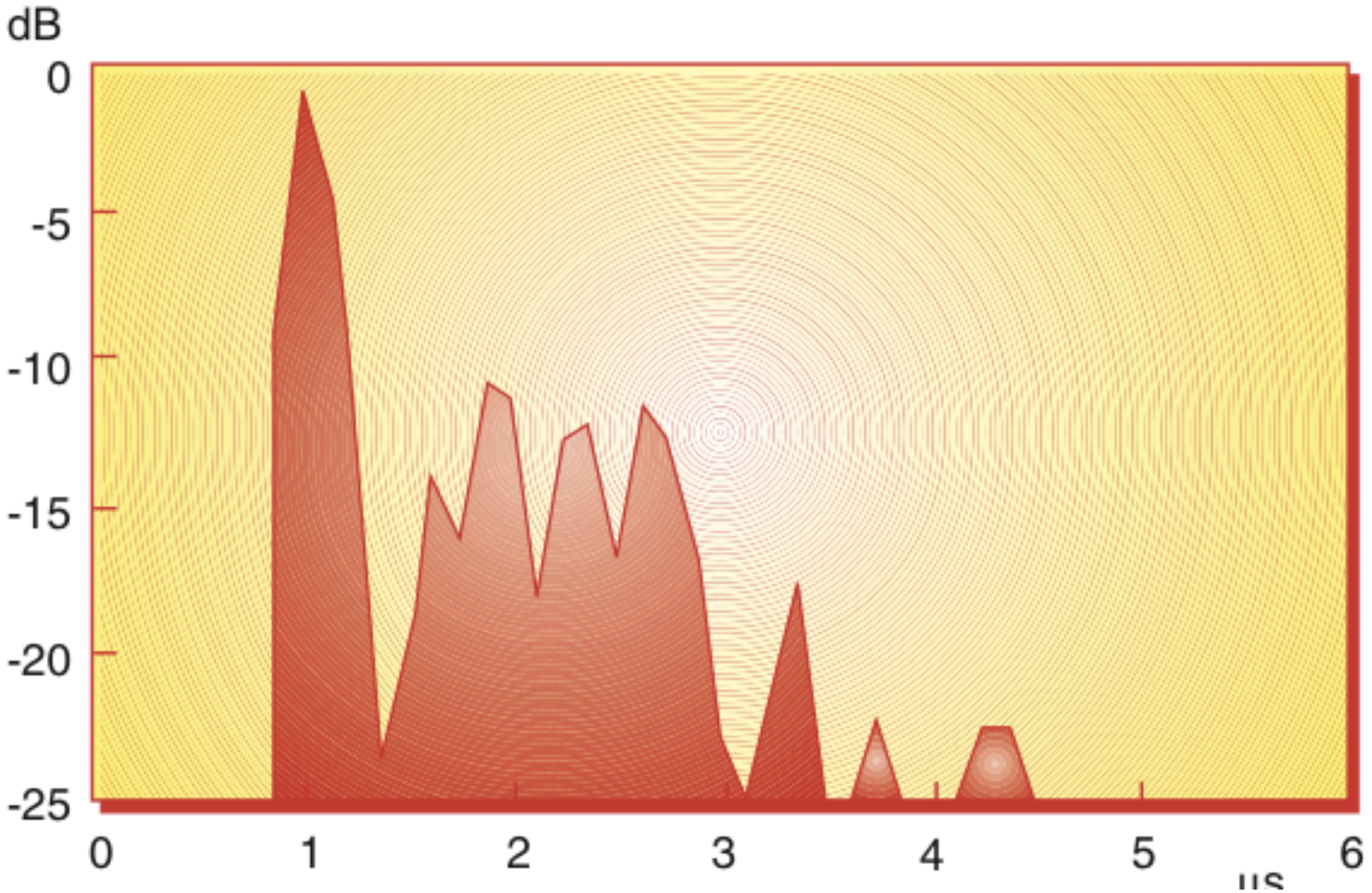
	Radio coverage [km^2]	Distance [km]	speed of mobile [km/h]	type of cell
Indoor office environment	0.01	0.1	3	picocell in open space environment
Pedestrian mode	4	2	3	Microcell
Vehicle	150	13	120	Macrocell

- see page 31 of ETSI TR 101 120 report for test environments

Impulse Response, rural farmland

- 1718 MHz. P_{RX) = –84 dBm,
- 20 dB above GSM sensitivity level

- Q (all impulse responses):
  - describe characteristics of reflection
  - from delay, calculate reflection factor and free space attenuation
  -

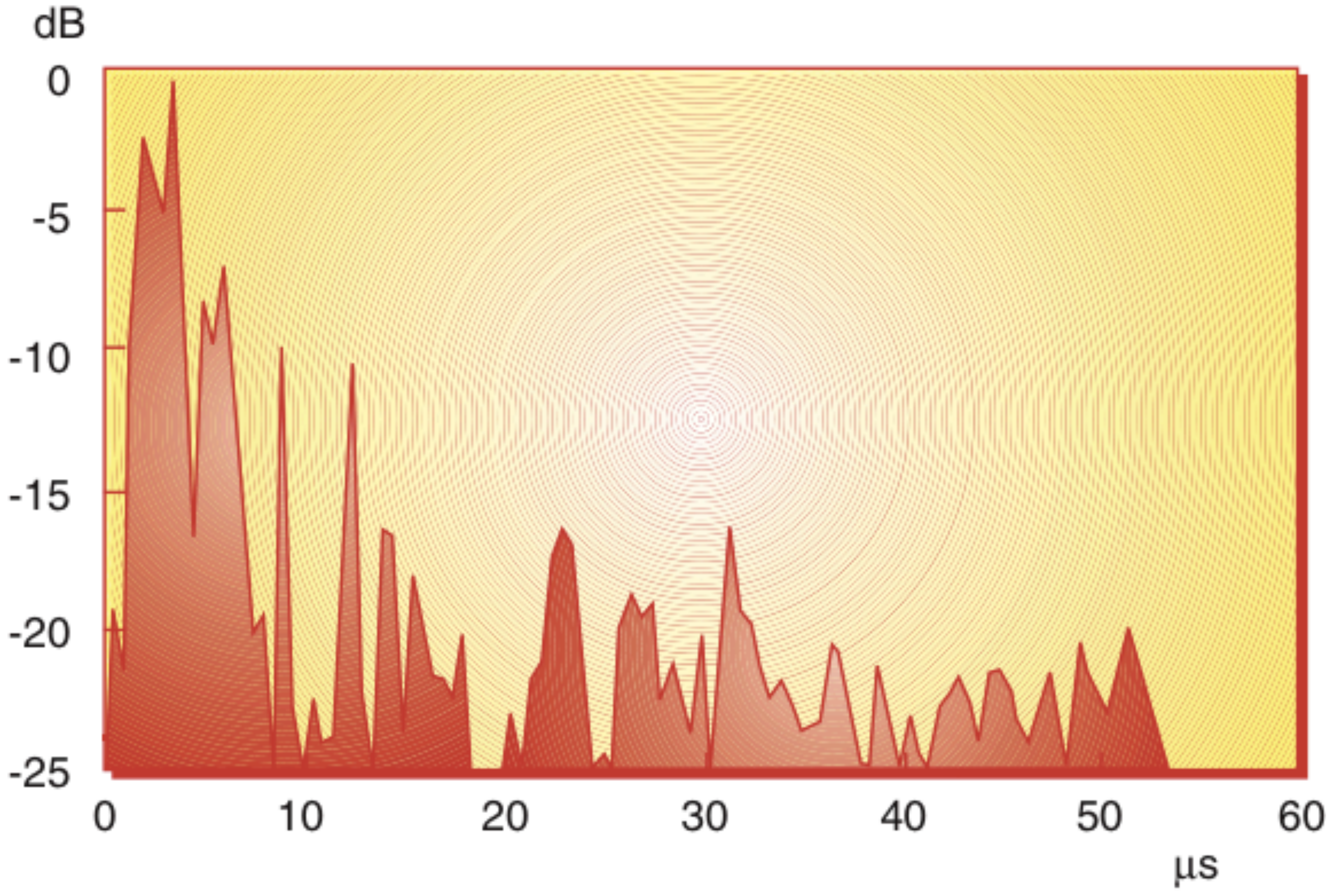


[Source:R Rækken, G. Løvnes, Telektronikk]

Impulse Response, rural farmland

- 953MHz.
- Total received power was <93dBm

- Q (all impulse responses):
  - describe characteristics of reflection
  - from delay, calculate reflection factor and free space attenuation
  -

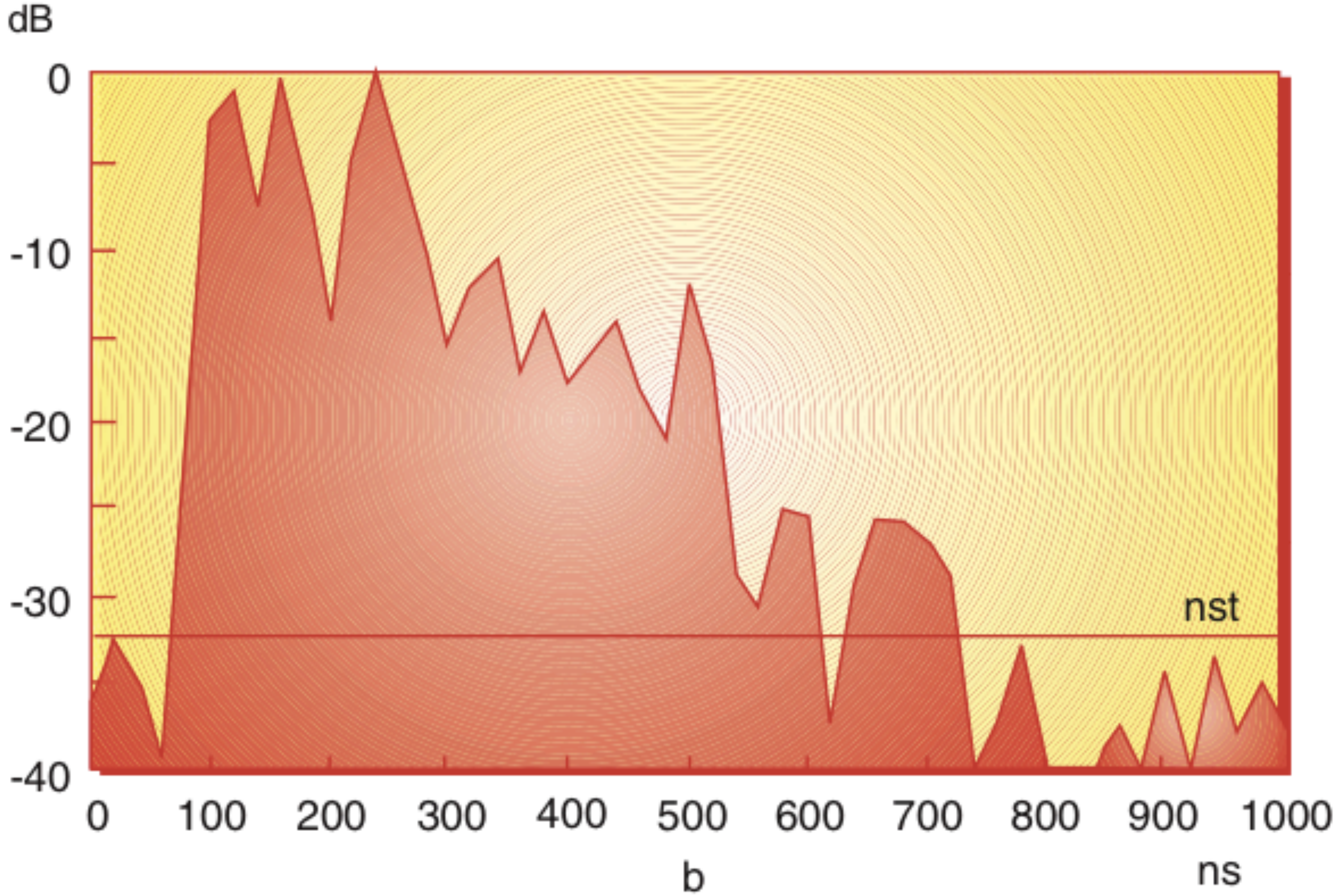


[Source:R Rækken, G. Løvnes, Telektronikk]

Impulse Response, Urban Measurements

- 1950 MHz, Oslo.
- Output power 25 dBm

- Q (all impulse responses):
  - describe characteristics of reflection
  - from delay, calculate reflection factor and free space attenuation
  - why almost equal distribution?
  - Physical effects?



[Source:R Rækken, G. Løvnes, Telektronikk]

How did we measure?

ETSI urban pedestrian

$$L_{pedest}[dB] = 40 \log r + 30 \log f + 49$$

- Outdoor to indoor and pedestrian test environment, based on Non LOS (NLOS)
- Base stations with low antenna height are located outdoors, pedestrian users are located on streets and inside buildings and residences
- TX power is 14 dBm, f = 2000 MHz and r is distance in m
- Assumes average building penetration loss of 12 dB
- Q: Difference to Free space propagation model?

COST Walfish-Ikegami Model

$$L_{rooftop}[dB] = 45\log(r + 20) + 24$$

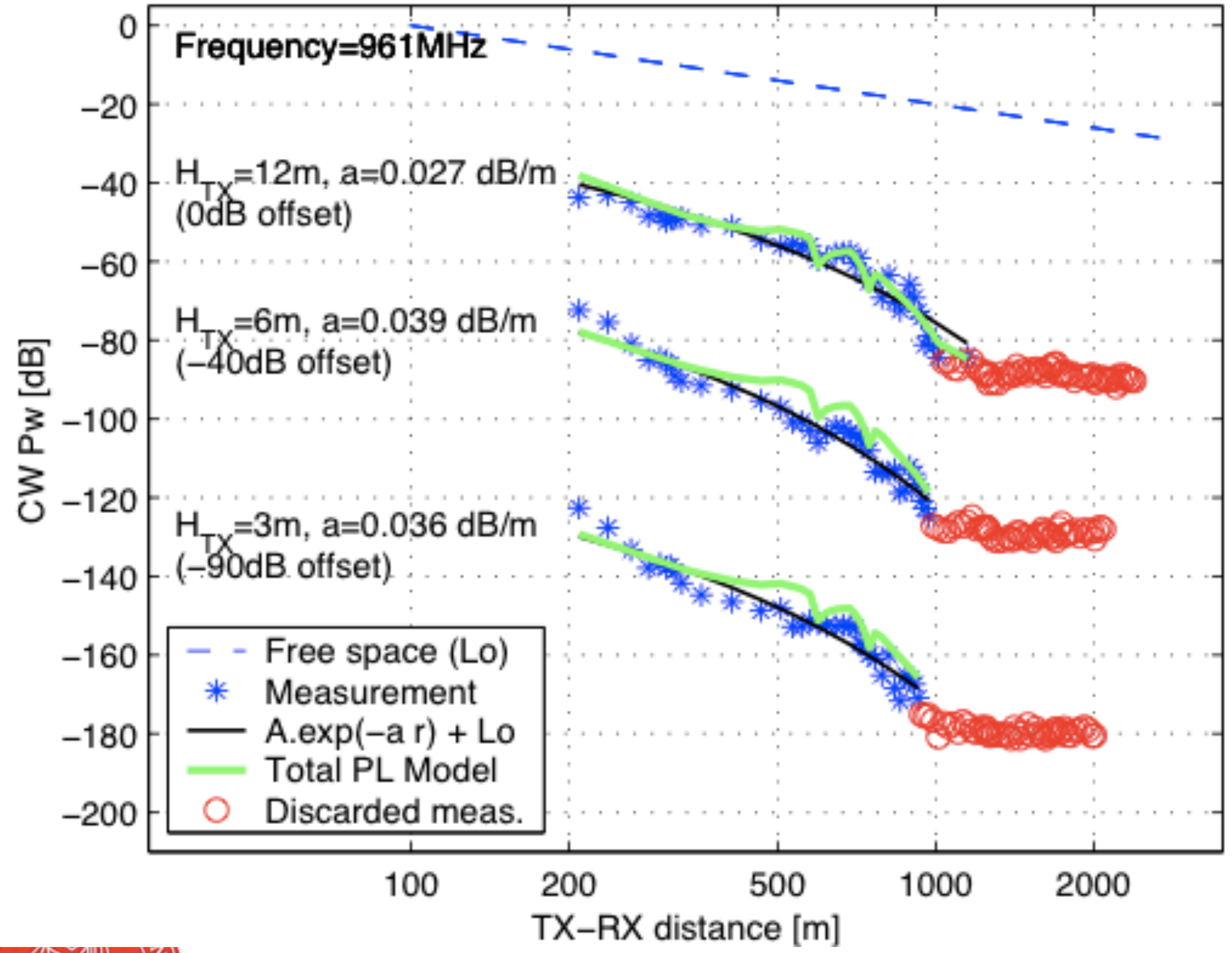
- propagation over roof tops
- assumes antennas below roof top

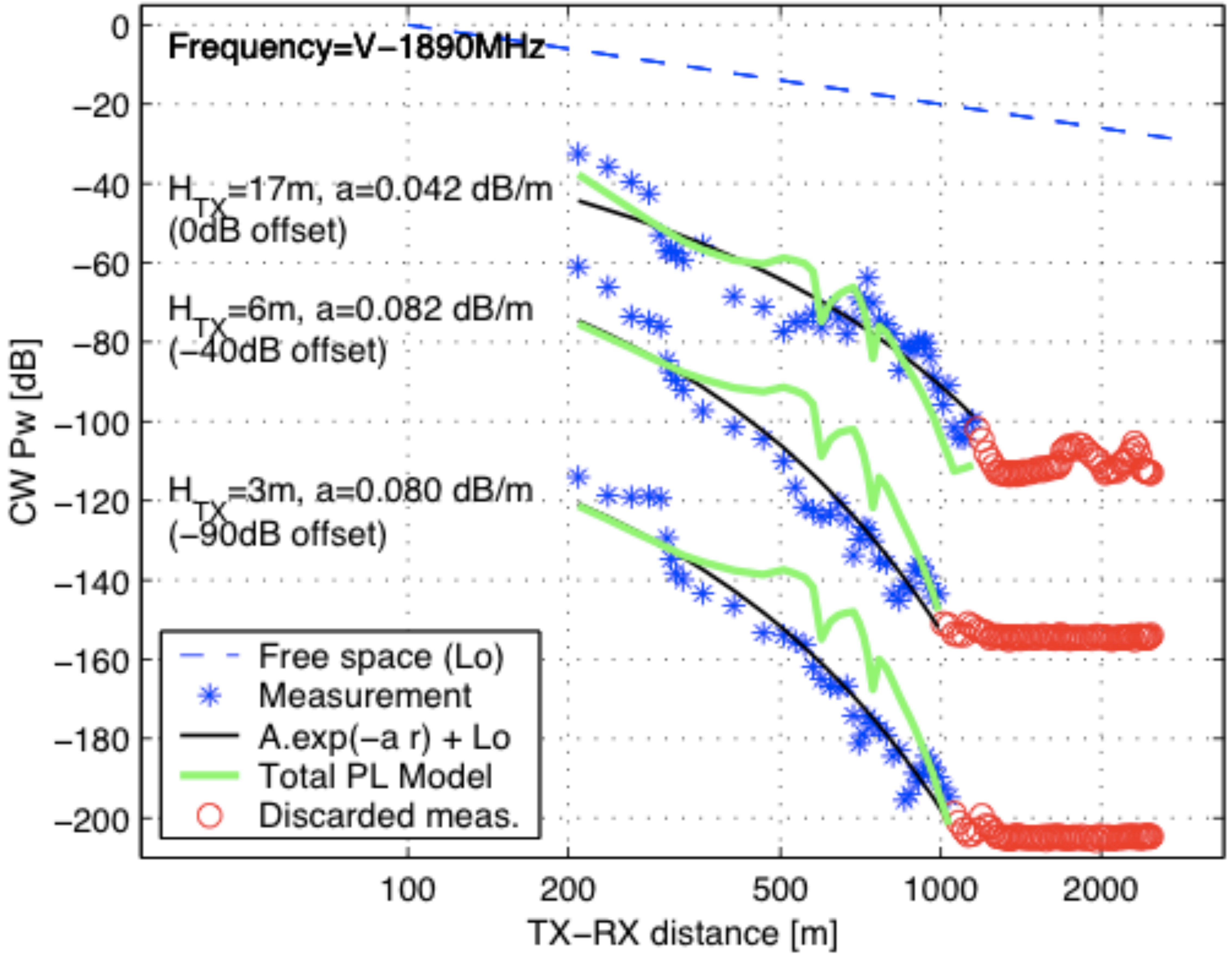
ETSI vehicular

$$L_{vehicular}[DB] = 40(1 - 4 \cdot 10^{-3}\Delta h)\log r - 18\log \Delta h + 21\log f + 80$$

- large cells, typical few km
  - TX power 24 dBm for mobile phone,
  - transmit antenna height Δh over roof top (typical 15 m),
  - distance *r* in km,
  - *f = 2000 MHz*

Forest, Path Loss *L*, slightly hilly terrain, forest





(Source:István Z.Kovács,Ph.D.Lecture,CPK, September6, 2002;p.27/45)

Exercise

- establish table (L free space, pedestrial, outdoor vehicular) with typical values
- *f = 900 MHz, f = 2000 MHz*
- *r = 100… 3000 m*

ETSI indoor office environment

$$L_{indoor}[dB] = 37 \log r + 18.3\ n^{((n+2)/(n+1)-0.46}$$

- *r* is transmitter-receiver distance in m;
- *n* is number of floors in the path
- path loss L should always be more than free space loss. Log-normal shadow fading standard deviation of 12 dB

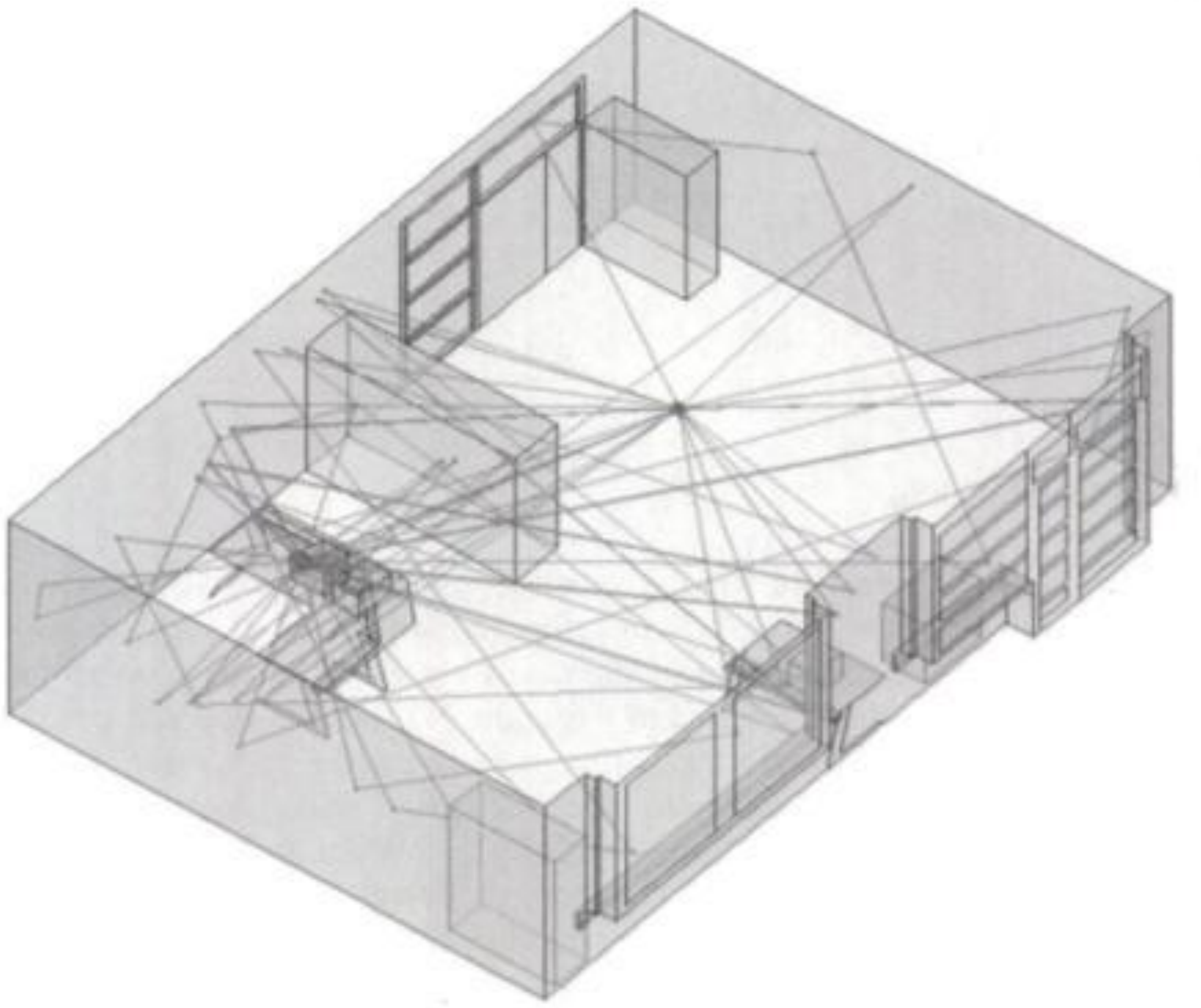
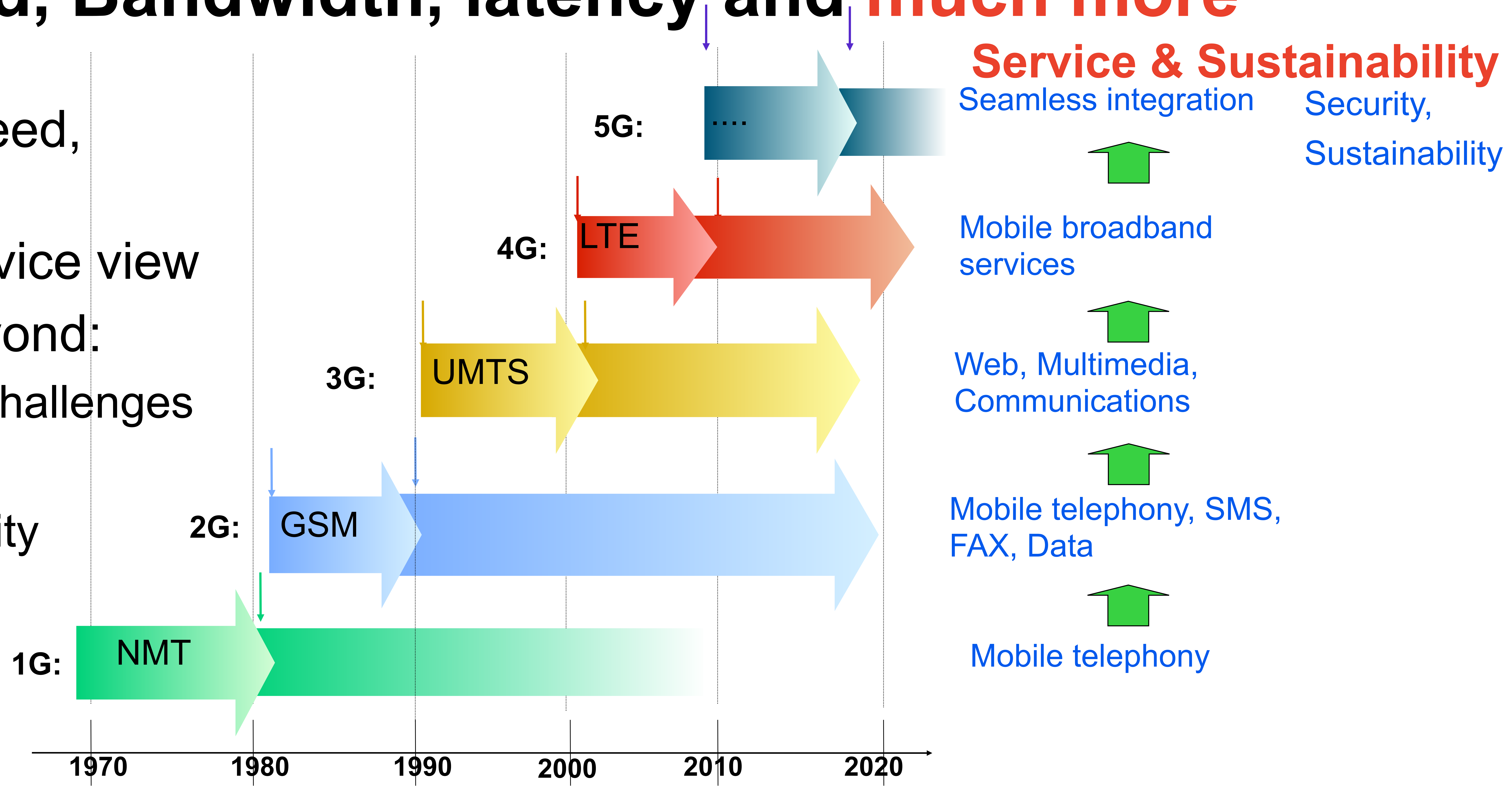


Fig. 7.26. Ray tracing in indoor environment

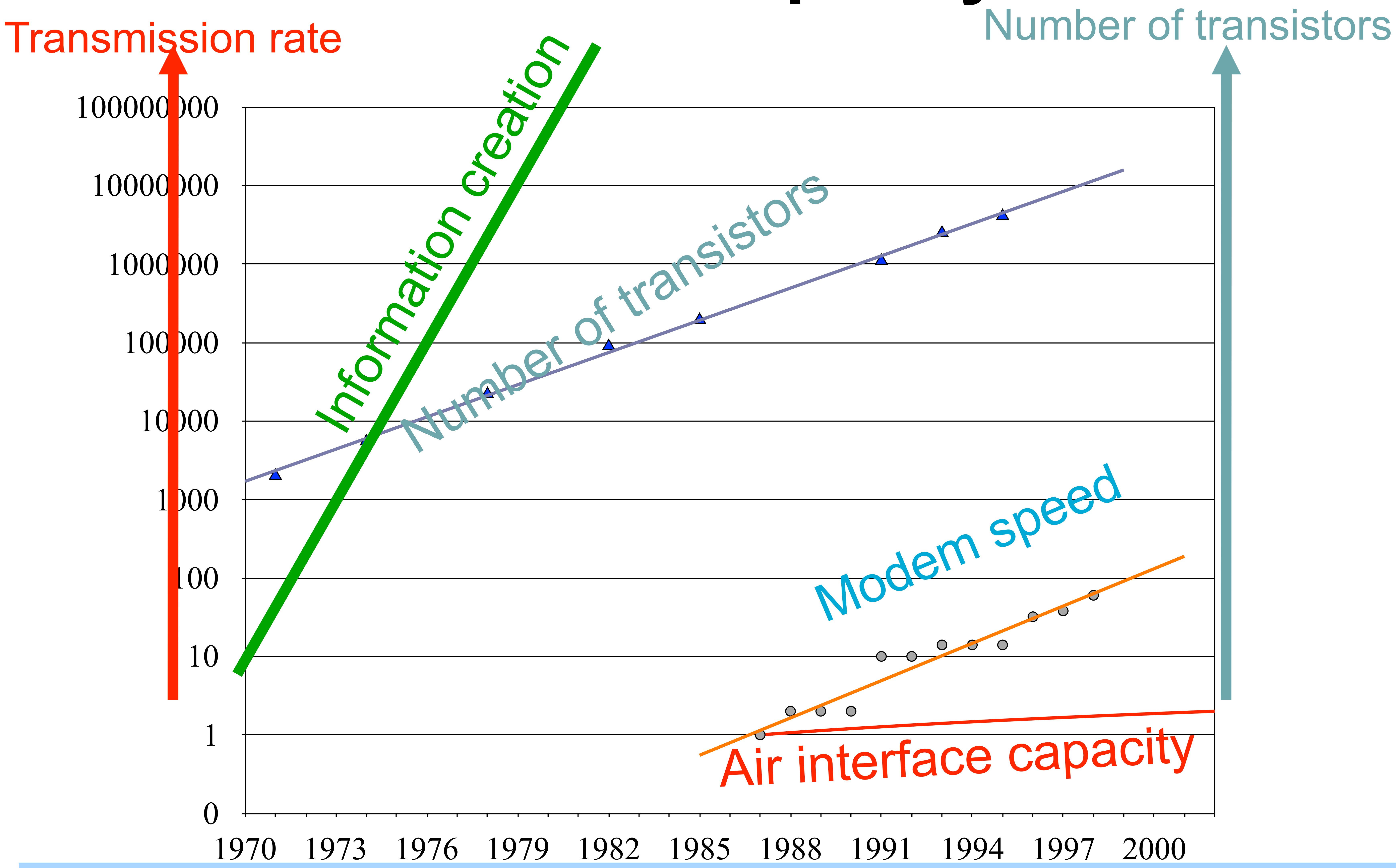
5G: Speed, Bandwidth, latency and much more

- 1G-3G: Speed, flexibility
- 3G-4G: service view
- 5G and beyond:
  - ➡ Business challenges
  - ➡ ownership
  - ➡ sustainability



[adapted from Per Hjalmar Lehne, Telenor, 2000]

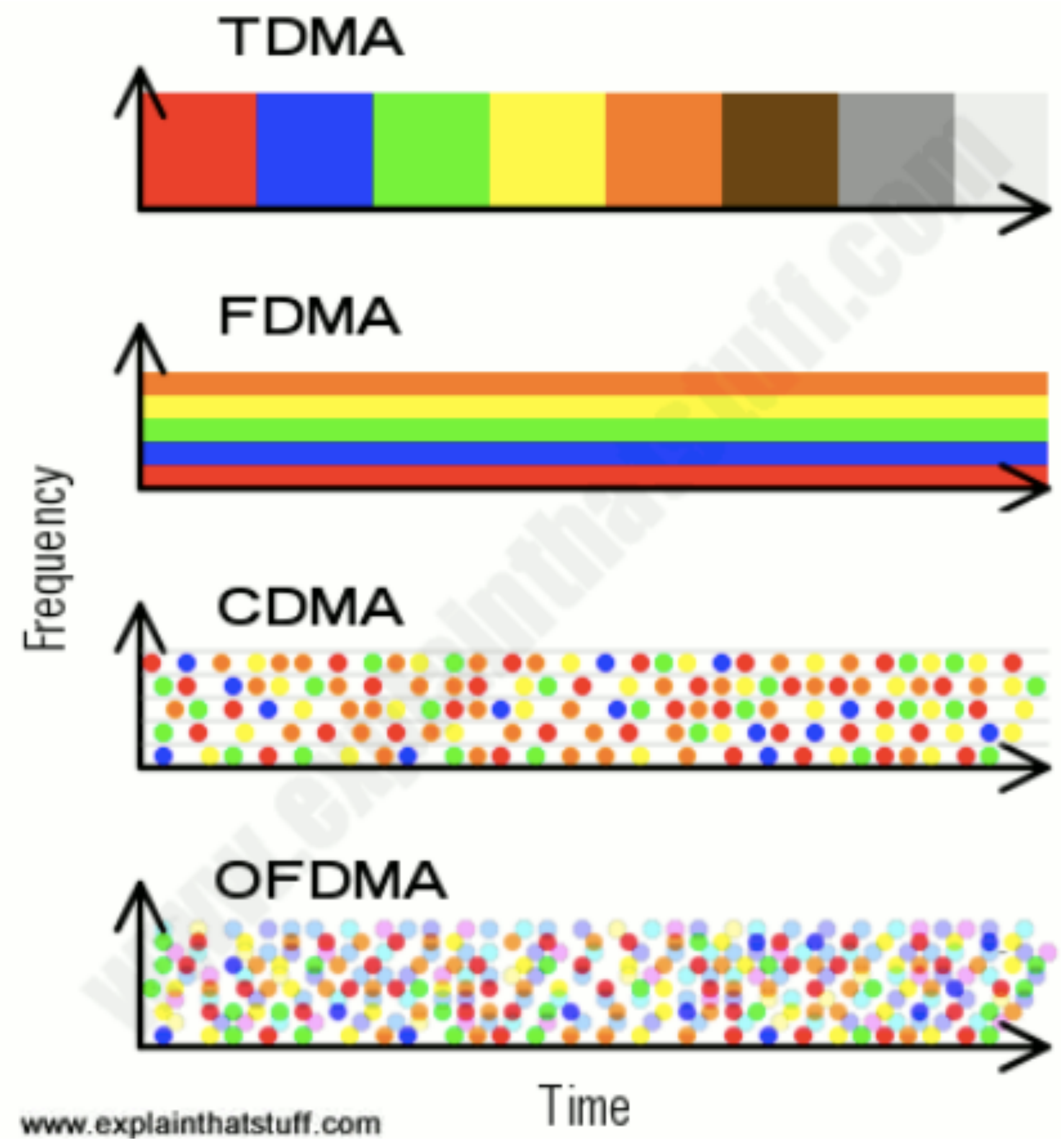
Moore’s law in ‘air interface capacity’



Þ Air interface capacity is the most valuable resource

Main differences 2G-5G

- Coverage/Range (2G, 4G)
  - ➡ frequency, time, code
  - ➡ allocation
- Capacity (3G, 4G, 5G)
- Security (2G, 3G, 4G,…)
- Radio technology
- Internet of Things (4G, 5G)
- Control systems (5G)
  - ➡ latency, reliability



Frequencies

- Refarming
  - ➡ technology used across bands
  - ➡ e.g. U900, L21

Currently Available Cellular bands:

- GSM 900: 35 (uplink) + 35 (downlink) = 70 MHz
- GSM 1800: 75 (uplink) + 75 (downlink) = 150 MHz
- Cellular 850: 25 (uplink) + 25 (downlink) = 50 MHz
- UMTS: 60 (uplink) + 60 (downlink) = 120 MHz
- PCS 1900: 60 (uplink) + 60 (downlink) = 120 MHz
- AWS: 45 (uplink) + 45 (downlink) = 90 MHz

"Spectrum Analysis for Future LTE Deployments" (white paper) by Motorola Inc., 2007.

Band	Uplink (MHz)	Downlink (MHz)	Carrier Bandwidth (MHz)	Comments
700 MHz	746-763	776-793	1.25 5 10 15 20	Digital Dividend. U.S. commercial spectrum is scheduled to be auctioned in January 2008. Potential future alignment with Europe
AWS	1710-1755	2110-2155	1.25 5 10 15 20	U.S. Auctions completed September 2006
IMT Extension	2500-2570	2620-2690	1.25 5 10 15 20	Initially Western Europe. Offers a unique opportunity for the deployment of LTE in channels of up to 20 MHz.
GSM 900	880-915	925-960	1.25 5 10 15 20	Reallocate this spectrum to advanced networks, such as LTE, from 2009 onwards
UMTS Core	1920-1980	2110-2170	1.25 5 10 15 20	Europe and Asia Pac. Potential for unused WCDMA carriers
GSM 1800	1710-1785	1805-1880	1.25 5 10 15 20	Europe and Asia Pac. Refarm underutilized band along with GSM 900
PCS 1900	1850-1910	1930-1990	1.25 5 10 15 20	U.S. Refarm after new 700 MHz and AWS spectrum is consumed.
Cellular 850	824-849	869-894	1.25 5 10 15 20	U.S. Refarm after new 700 MHz and AWS spectrum is consumed.
Digital Dividend	470-854		1.25 5 10 15 20	Identified at WRC-07.

Security - example: phone call

Threats/attacks	Security services	Security mechanisms
A MitM attacker can eavesdrop on the call.	Confidentiality	Encryption

[source: Lars Strand, UiO]

2G Mobile systems: GSM (IS 95 - USA)

- Developed in the late 1980s, deployed 1992.
  - Norway a key developer and inventor
- Today: Coverage 80% of world population (5+ billion users), gsmworld.com.
- GSM security goal: “as secure as the wire”
- GSM network consists of several network elements
  - Radio Subsystem (RSS)
    - Base station Subsystem (BSS)
    - Mobile Equipment (ME) (cell phone/handset)
  - Network and Switching Subsystem (NSS) – core network
  - Operation Subsystem (OSS)

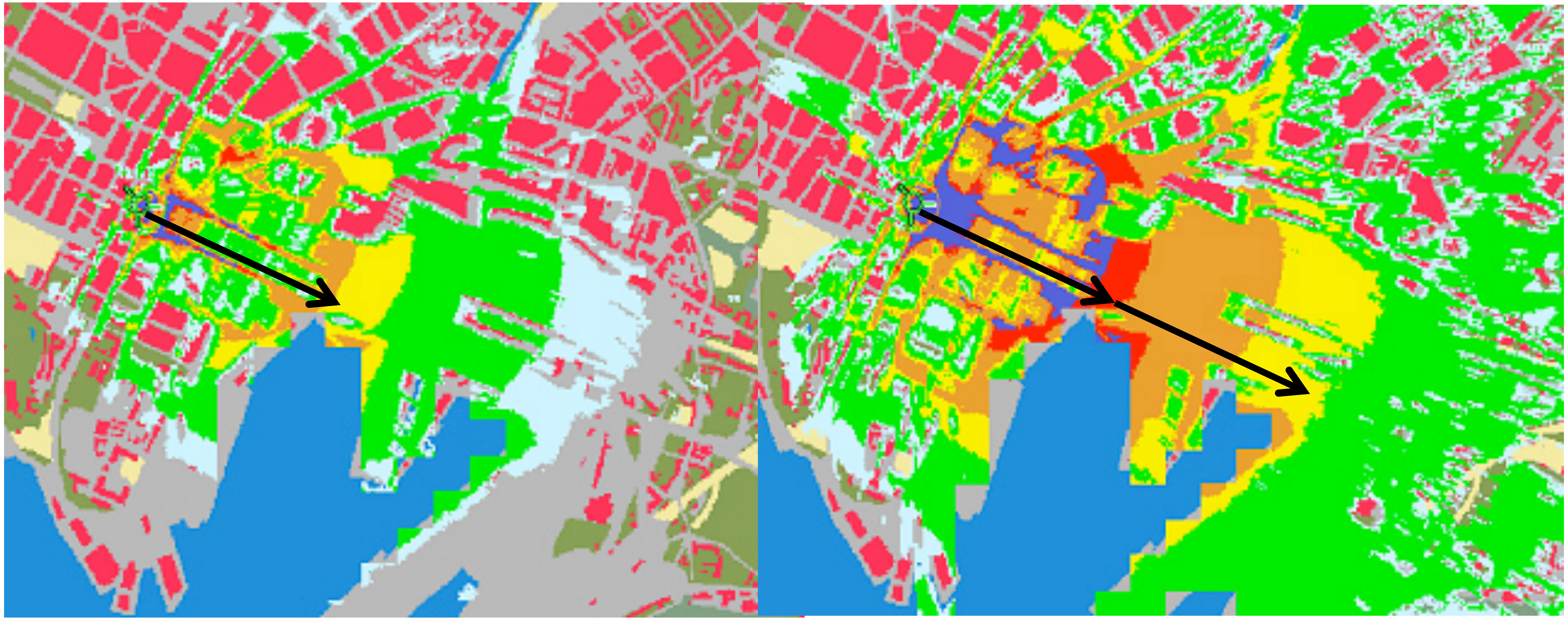
[source: Lars Strand, UiO]

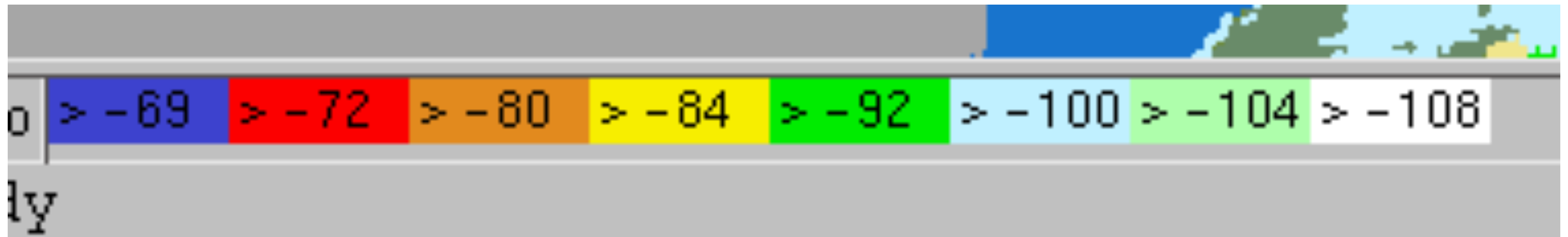
GSM 1800 (UMTS coverage)

source: Helge Dommarsnes, Telenor Mobil

Tx power: 25 dBm

Tx power: 35 dBm

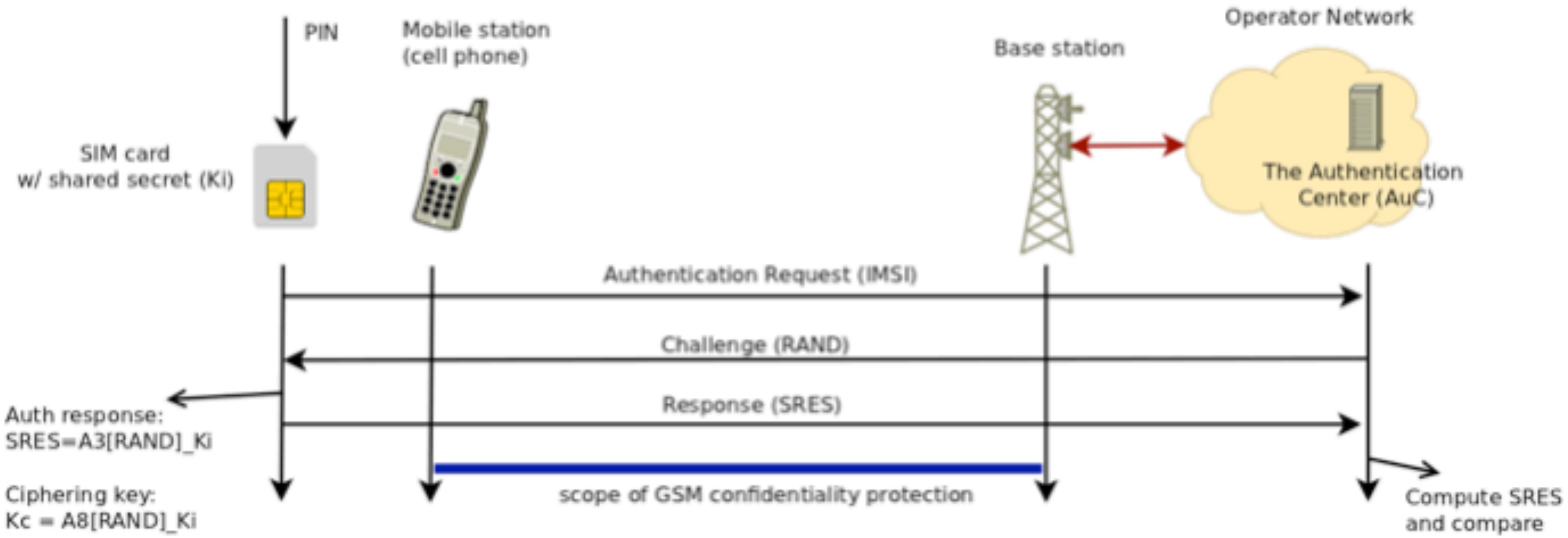




Tx 10 dB <=> Range 1.8…2

2G Threat environment

1. Vulnerability: Cloning
   - GSM security service: Authentication
   - GSM security mechanism: Authentication mechanism
2. Vulnerability: Content (voice) sent in clear
   - GSM security service: Call content confidentiality
   - GSM security mechanism: A5/1, A5/2, A5/3, A5/4
3. Vulnerability: Spying (subscriber location tracking)
   - GSM security service: Identity confidentiality
   - GSM security mechanism: Location security (TMSI)



[source: Lars Strand, UiO]

Mobile systems: 3GPP

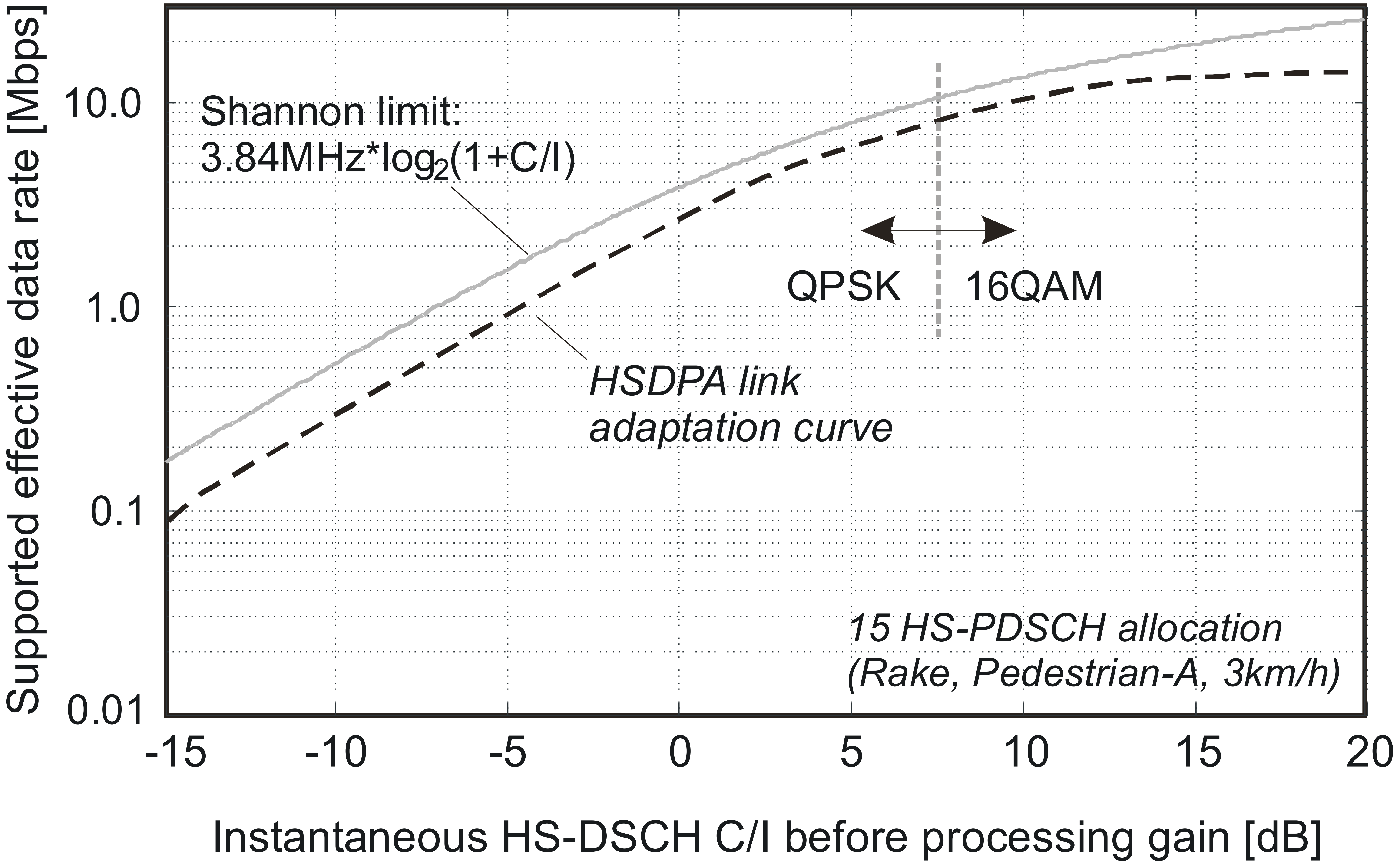
A GLOBAL INITIATIVE

- Third generation partnership project (3GPP)
  - Structured in releases – latest is v11 published sept 2011
- Includes mobile technologies like:
  - UMTS (3G) – Deployed by Telenor in 2001
  - LTE (not 4G) – Deployed by Netcom in 2010, Telenor in 2012.
  - LTE Advanced (4G) – specification ready 2011Q1
- Building on and evolved from GSM
  - Upgrade path: GSM -> WCDMA (Europe, Asia), IS 95 -> CDMA 2000 (USA)
  - Backward compatible with a system with weaker security is undesirable – but commercial reality dictated otherwise

Evolution: "Nobody" thought about co-existence

[adapted from: Lars Strand, UiO]

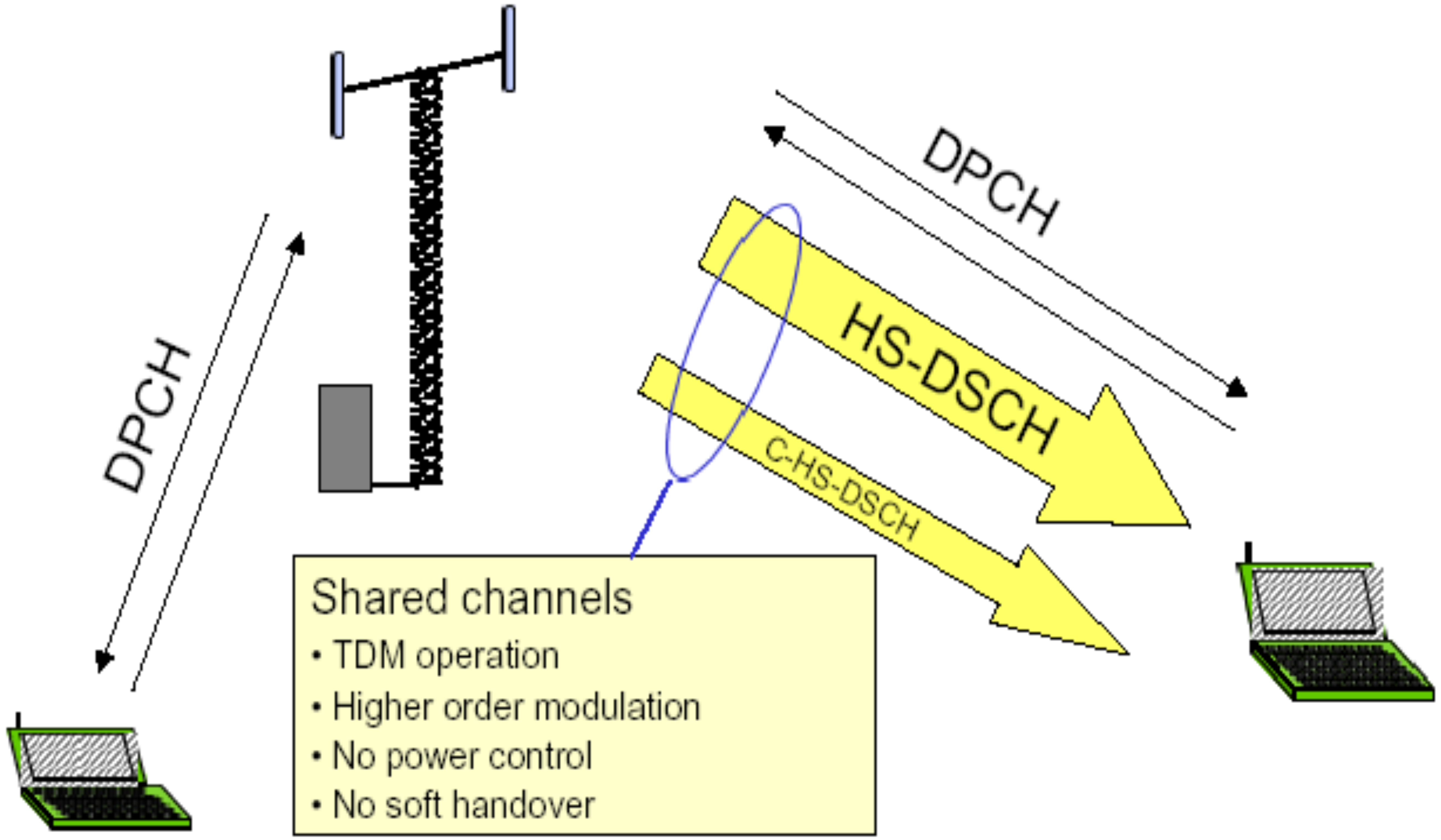
- **WCDMA/HSDPA with 5 MHz bandwidth very competitive technology, as performance is rather close to the Shannon limit**



[Ref: WCDMA for UMTS, 3Rd edition]

3G (UMTS, WCDMA, HSPA)

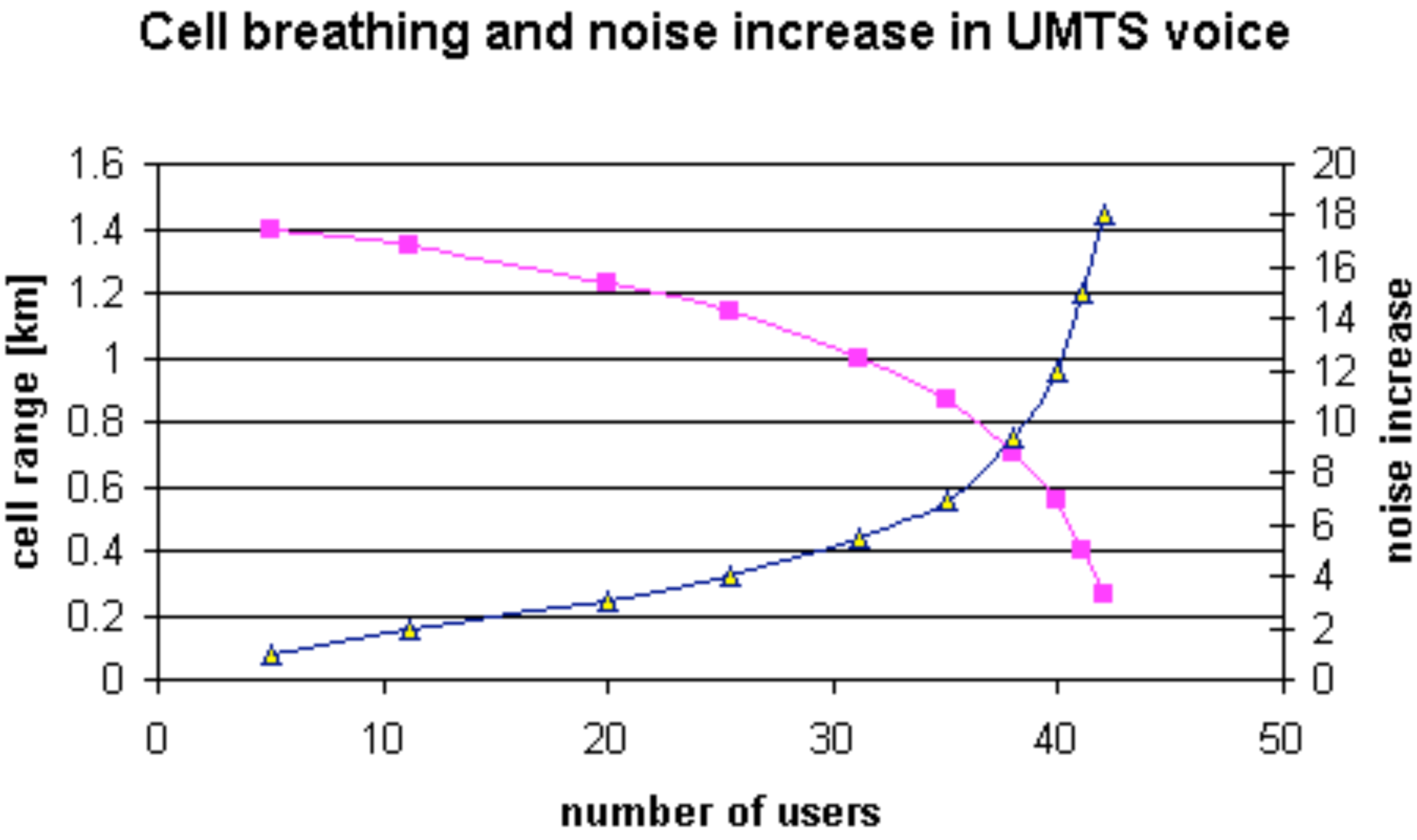
- Wideband CDMA
- Exploit the High-Speed Downlink Shared channels (HS-DSCH) to gain peak information rate of 10 Mbps
- Downlink Dedicated Physical Channel (DPCH) – peak information rate of 2.3 Mpbs (spreading factor 4, 3 parallel codes)



source: Anders Spilling, Telenor

System level simulations

- Cell radius decrease depending on
  - QoS of application
  - location
  - load of network
  - traffic mix (voice + data)
- System level simulation:
  - Base station, mobile user equipment
  - Propagation model, data mix
  - Simulator manager



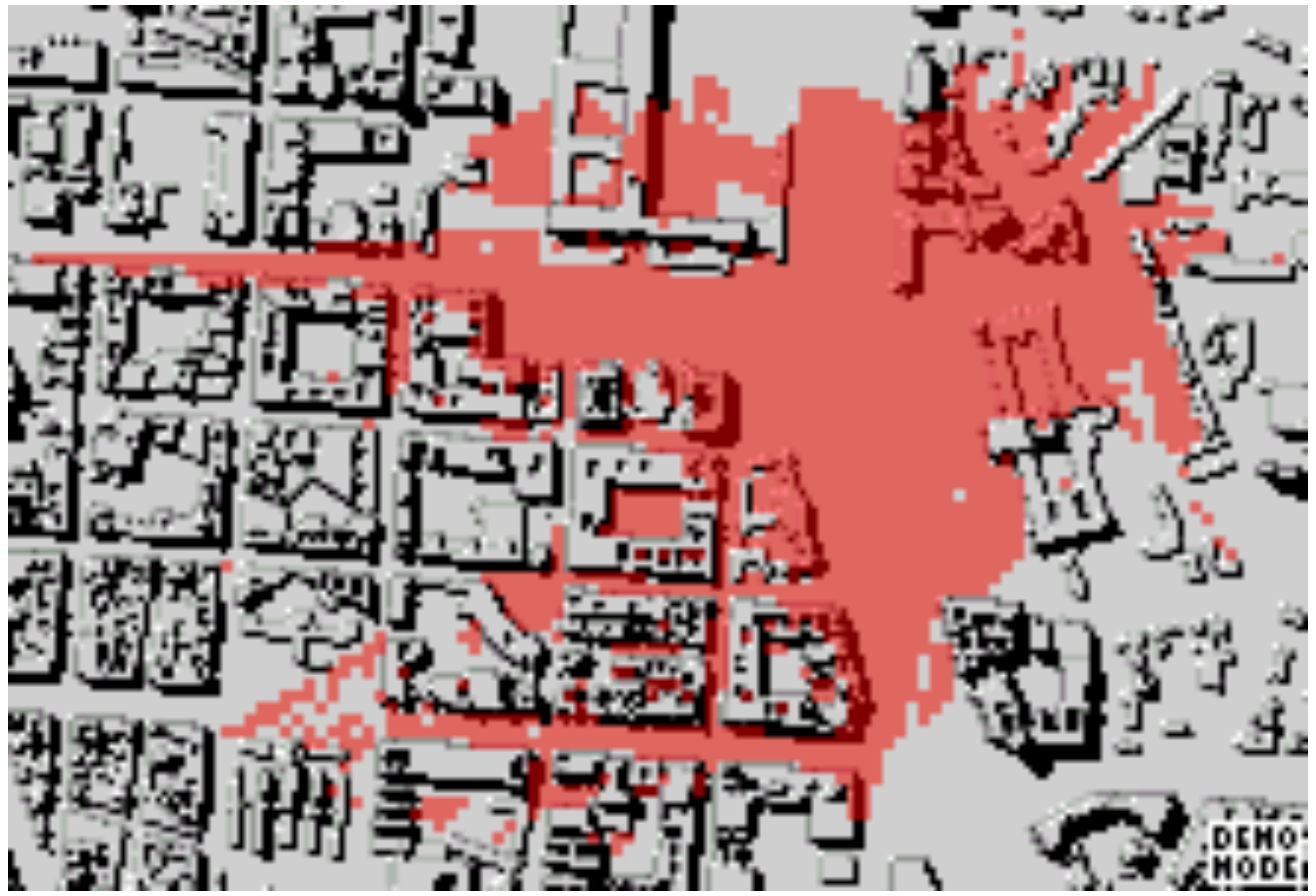
source: Eurescom P921, D2

UMTS system behaviour

GSM: Interference limited

UMTS: Noise limited

- each call increases noise level
- Capacity vs. Quality
- ”soft” capacity, increase capacity by reducing quality



- Varying traffic à varying cell size
- **Cell breathing** (up to 50 %)

source: Eurescom P921, D2

Security architecture: UMTS

- Main tasks of the security architecture (Køien, 2004):

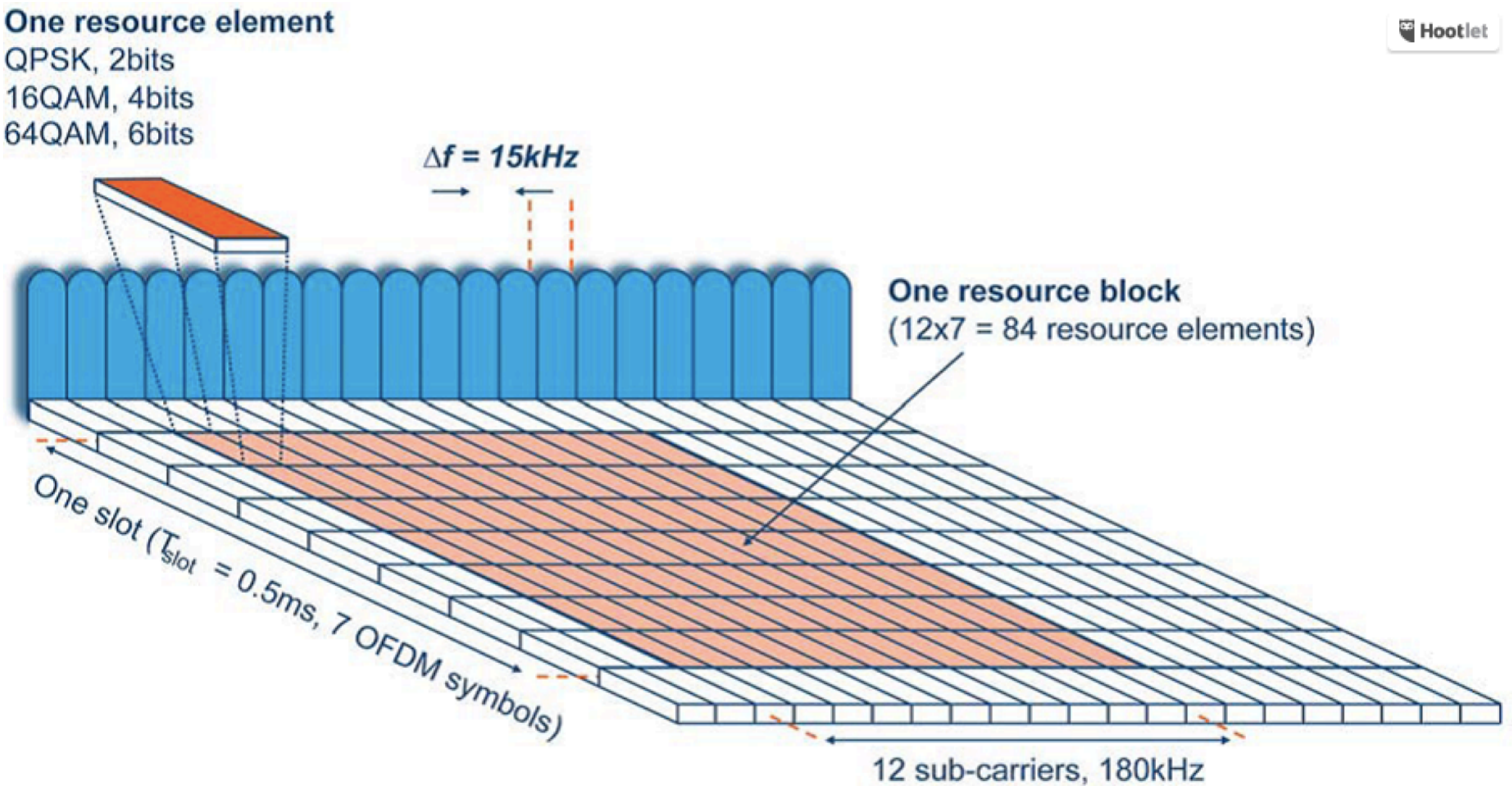
1) Authentication
   - GSM vulnerability: False BST
   - UMTS: Mutual authentication, new algorithm (MILENAGE)
2) Replace algorithms/New key generation
   - GSM vulnerability: Inadequate algorithm
   - UMTS: New algorithm (KASUMI)
3) Encryption/integrity protection
   - GSM vulnerability: Cipher keys and auth data sent in clear in operator network
   - UMTS: Extend confidentiality and integrity service to the operator network

4G - LTE

- Long Term Evolution/System Architecture Evolution (LTE/SAE)
- Overall architecture of Evolved Packet System (EPS) consists of:
  1) Access network
  2) Evolved Packet Core (EPC) network
     - IP Multimedia Subsystem (IMS)
- *"Improved overall security robustness over UMTS"*
- Major changes from UMTS:
  - All IP network (AIPN)
  - Higher bandwidth
  - May use non-3GPP access networks

4G resource allocation

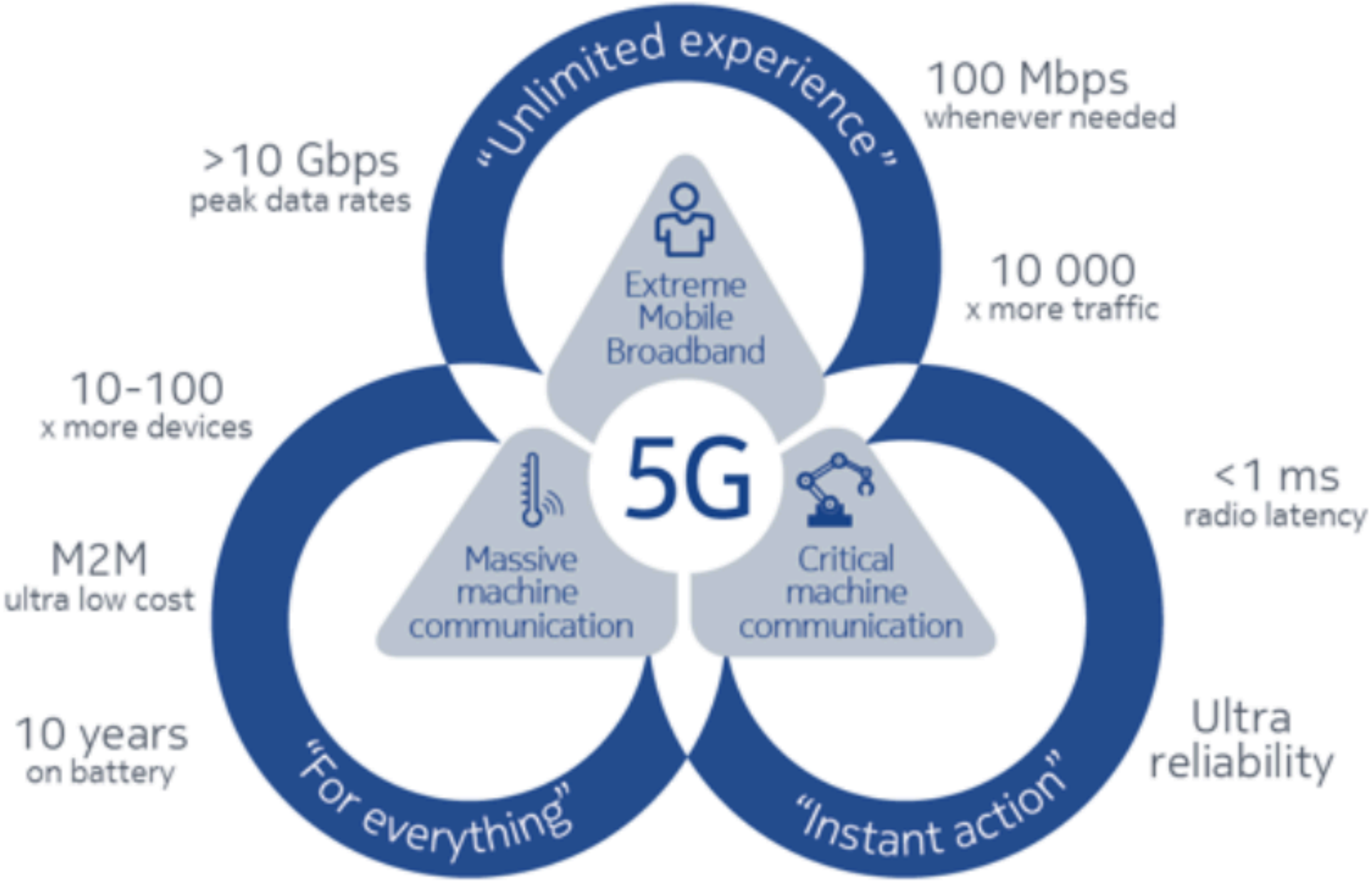
- OFDM
- frequency
- time
- code



https://irisxyan.wordpress.com/category/technology/lte-4g/

5G

- Dhananjay Gore, Qualcomm Research, India at COMSNETS 2018
  - ➡ 3GPPP Rel-15 specifications aligned with Qualcomm Research white paper Nov2015
  - ➡ http://www.qualcomm.com/invention/technologies/5g-nr/mmwave



[source: Nokia https://networks.nokia.com/5g/get-ready]

5G Air Interface

- Scalable OFDM-based 5G NR air interface
  - ➡ Scalable numerology, scalable slot duration (efficient multiplexing of diverse latency and QoS requirements)
  - ➡ Frequency localisation
  - ➡ lower power consumption
  - ➡ Asynchronous multiple access
- Flexible slot-based 5G NR framework
  - ➡ Self-contained slot structure (independently decode slots and avoid static timing relationships across slots)
  - ➡ Blank subcarriers
  - blank slots

Network refarming

- Mobile frequencies
- GSM bands in 800 – 900 MHz and 1800 – 1900 MHz
- UMTS bands are typically within the 1900/2100 MHz frequencies;
- LTE is found at (450)/700/1900/2100/2400/2650 MHz in the spectrum.

- Refarming: new frequency distribution for 2G, 3G, 4G
  - ➡ What is the optimum combination?

5G Channel coding

- Channel coding
  - Advanced ME-LDPC channel coding
  - more efficient than LTE Turbo code, 4x at Code rate (R)=0.65, 5 at R=0.9
- 3x increase in spectrum efficiency
  - explicit 3D beam forming with up to 256 antenna elements
  - typical 3.8x increase from 4x4 MIMO to 5G NR Massive (256 antennas) MIMO (52 Mbps to 195 Mbps)
- Large BW opportunity for mmWave
  - 5G NR sub-6GHz (3.4-3.6 GHz)
  - 5G NR mmWave (e.g. 24.25-27.5 GHz, 27.5-29.5 GHz)

5G Challenges

- require:
- overcome significant path loss in bands above 24 GHz
- robustness: innovation to overcome mmWave blockage from hand, body, walls, foliage - non-LOS is a problem
- Device size/power integration into a mobile
- Dense network topology and spatial reuse (150-250m distance)
- colocation of 28 GHz on LTE channels

5G Ultra Reliable, Low Latency

- Application areas
  - ➡ process industry, alarm, wireless-connected vehicles
  - ➡ latency <1 ms, <10 ms,... in process control
  - ➡ 99.99997% uptime, delivery within 5 ms
- #5GforAll
  - ➡ radio interface: Large cell low mobility sites (low density rural areas)
  - ➡ freemium model for access (freemium = free + premium)
- Missing aspects in 5G
  - ➡ interface mobilehome network
  - application-specific routing (service quality)
  - interference with unlicensed technologies

Refarming case study (Sweden 1800 MHz)

- 2x10MHz renewed for each incumbent to ensure service continuity of 2G GSM service;
  - Restructured the band into 5MHz blocks, making it fit for UMTS and
  - other technologies that could co-exist with GSM & UMTS;
- Vacant spectrum was auctioned, technology & service neutral;
- A newly formed joint-venture by several incumbents to consolidate their spectrum assets and operation in the band.

- Full case study can be found here: http://www.gsma.com/spectrum/wpcontent/uploads/2012/07/refarmingcasestudysweden900mhz20111129.pdf/

[Source: Shola Sanni, GSMA]

Refarming, LTE 450 MHz

- Band 31, limited bandwidth of 2 x 10 MHz
- Ovum: http://450alliance.org/wp-content/uploads/2014/07/Ovum-LTE450-presentation.pdf

Technical pros and cons of LTE450

ovum

Cons:

- Limited bandwidth
- Interference challenge (5Mhz guard band between the uplink and downlink)
- Limited ecosystem
- So far standardized for Brazil only

Pros:

- Propagation - covers more territory with fewer base stations than higher bands
- Cost is appealing for covering large rural areas.
- Technical issues are being addressed
- Clear evidence of vendor interest in supporting LTE450.

Frequency (MHz)	Cell radius (km)	Cell area (km2)	Relative cell count
450	48.9	7521	1
850	29.4	2712	2.8
950	26.9	2269	3.3
1800	14.0	618	12.2
1900	13.3	553	13.6
2500	10.0	312	24.1

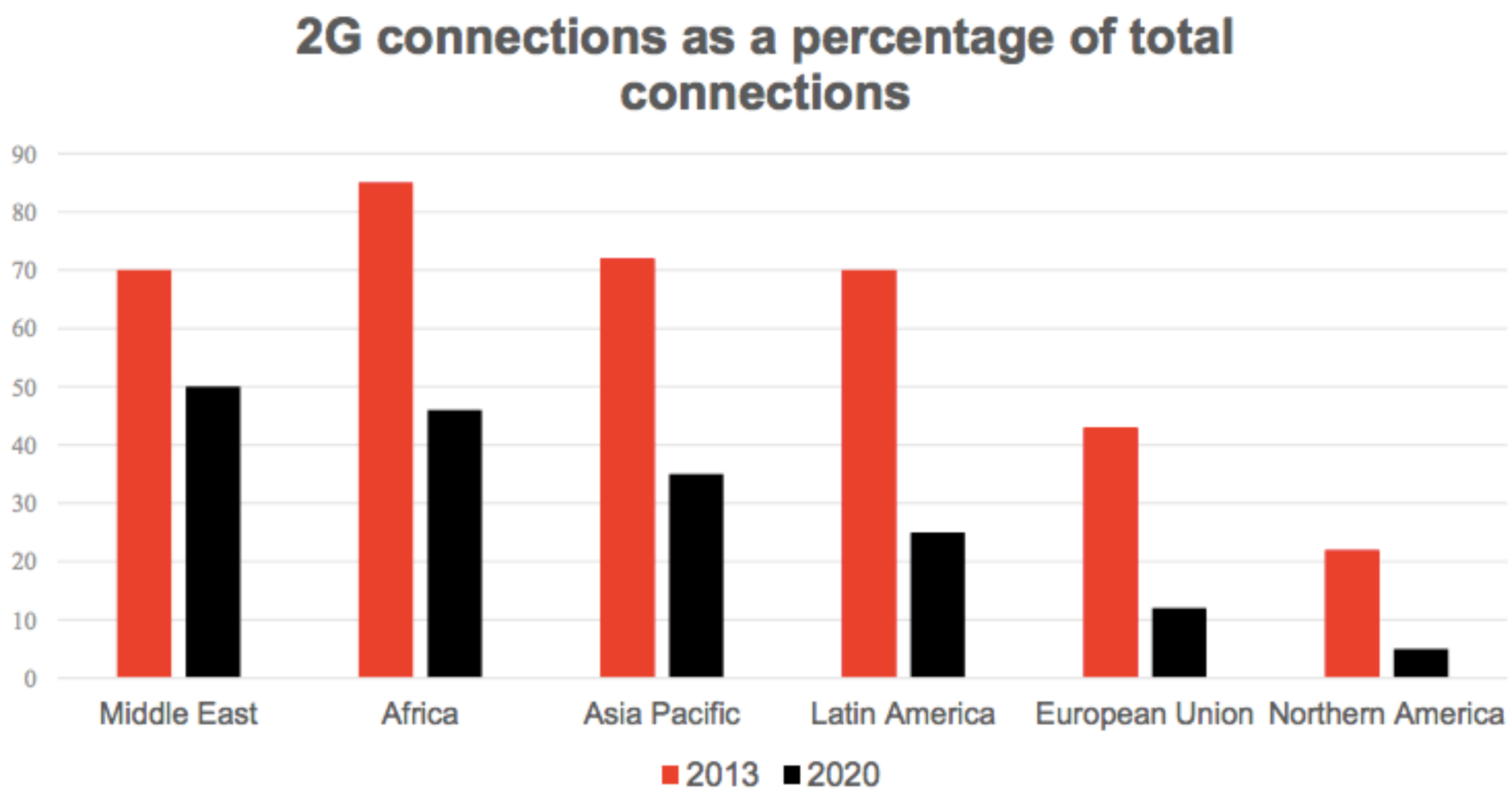
Theoretical comparison of base station coverage at different spectrum bands. This performance is based on flat terrain, tower mounted amplifier with radio 60 meters above ground, and no interference

The challenge of area coverage

- Land area Norway, 385.178 km^2 - 7500 basestasjons
  - ➡ http://www.mynewsdesk.com/no/telenor/pressreleases/sjekk-naar-du-faar-4g-der-du-bor-1399662

- Tanzania 947,303 km^2 = 3 x Norway,
- Mali 1.240.000 km^2 = 4 x Norway
- DR Congo 2.345.000 km^2 = 8 x Norway

- Economy in building Wireless Broadband
  - ➡ #5Gforall - *Discuss*



Upcoming Topics

Upcoming Topics / To do for next week

Upcoming Topics

- L11 Hands-on Wireless

To Do:

- Group work: your group/your topics?