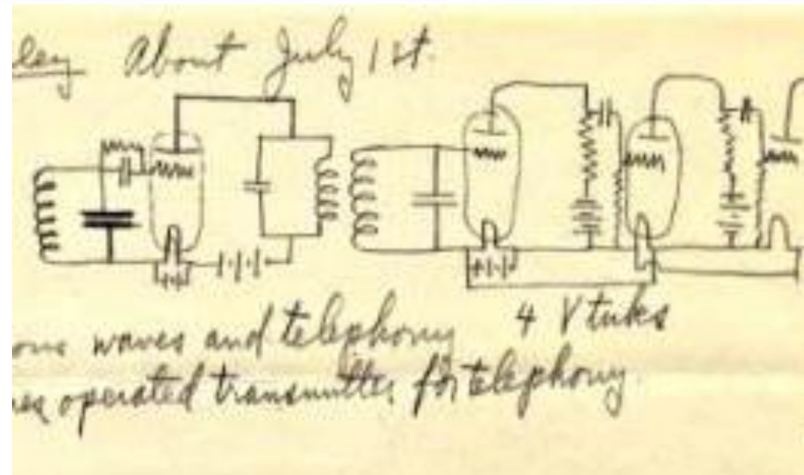


RF COMMUNICATIONS IN THE FRONT END

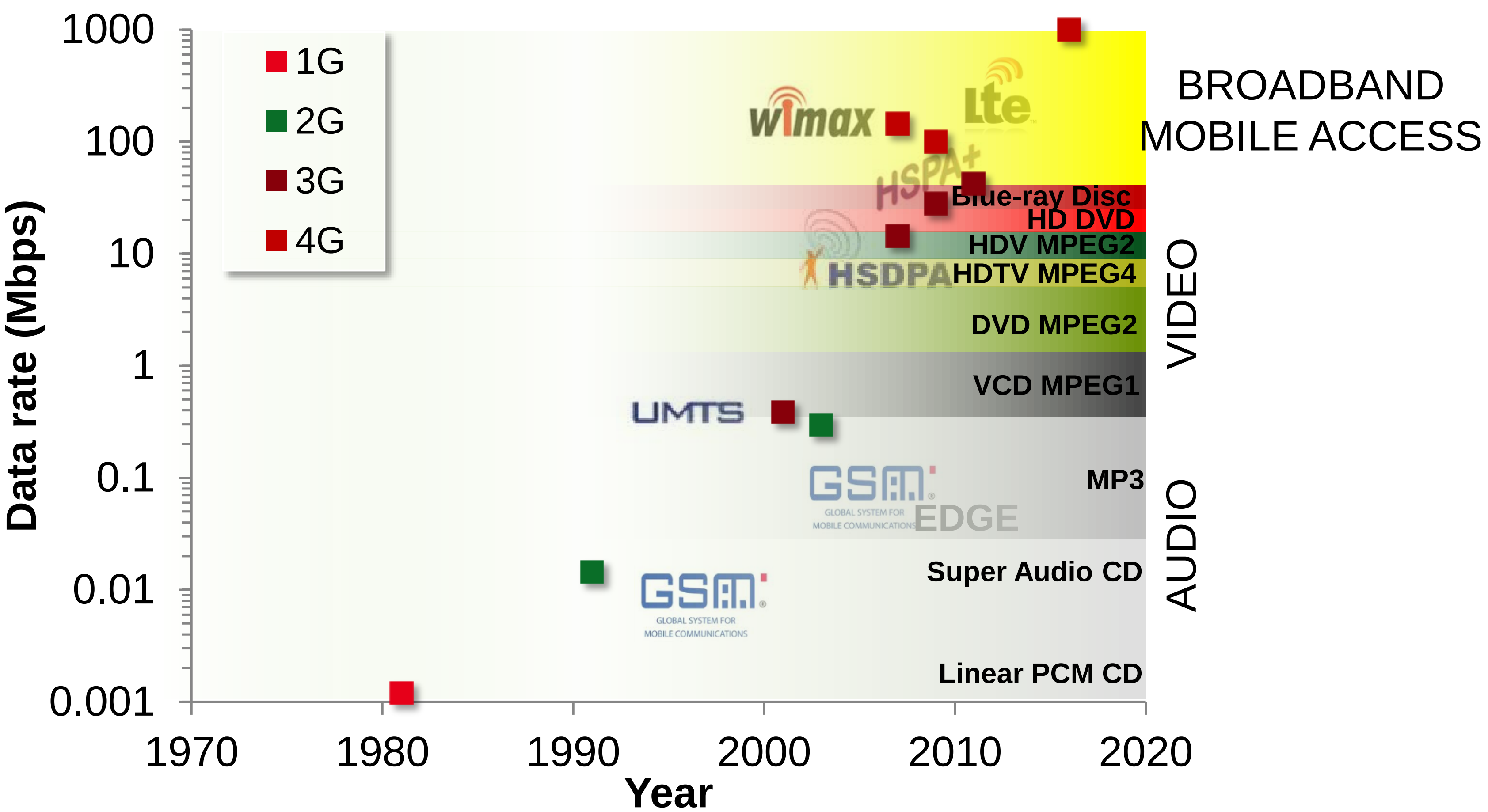
Ecole DAQ Emergeants| Cedric DEHOS/Jose Luis GONZALEZ | 12 Novembre 2018

SOMMAIRE

SOMMAIRE

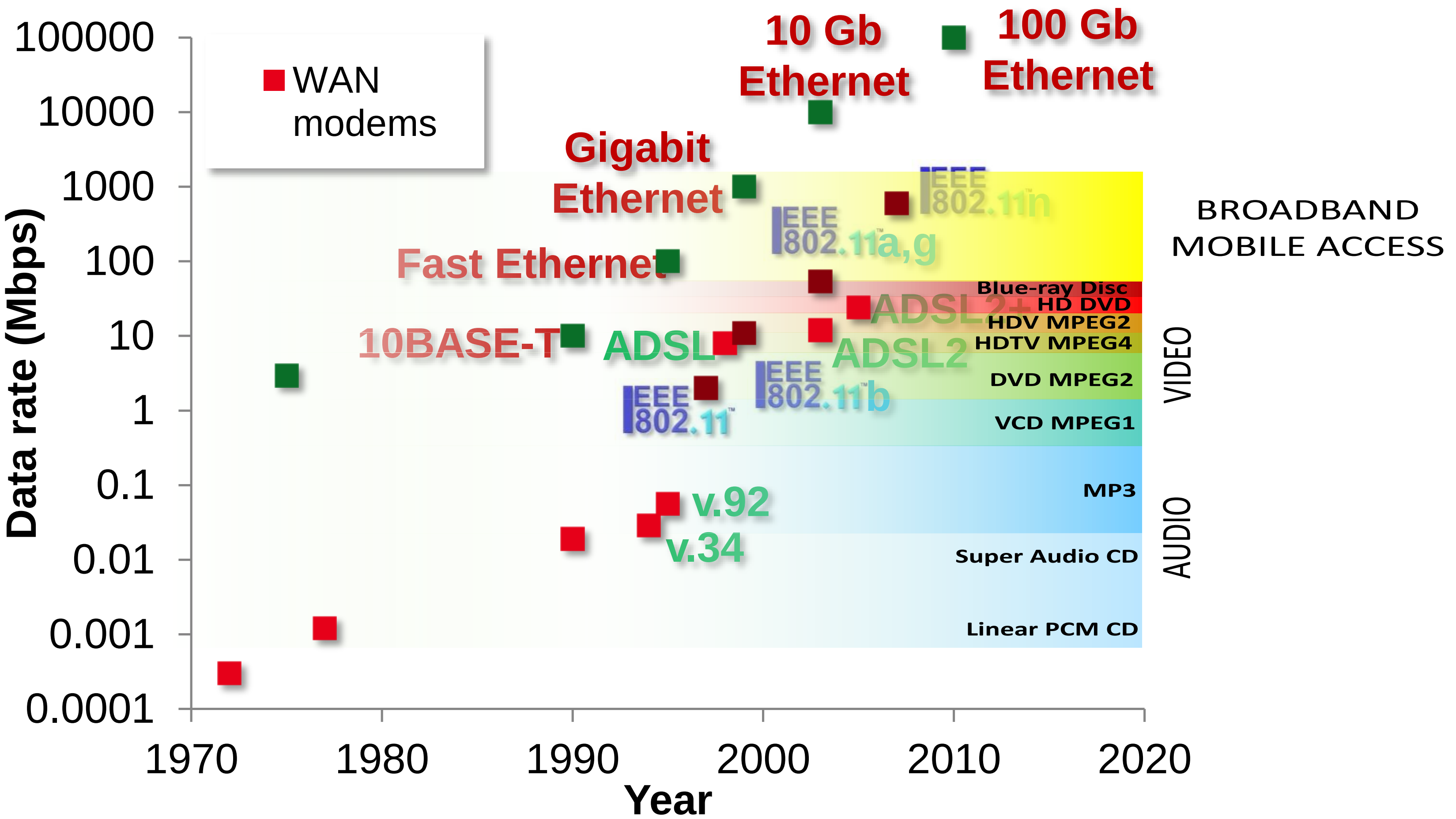
AT THE BEGINNING IT WAS THE AETHER…

CHRONOLOGY: THE QUEST FOR THE GIGA-B/S
CELLULAR NETWORKS



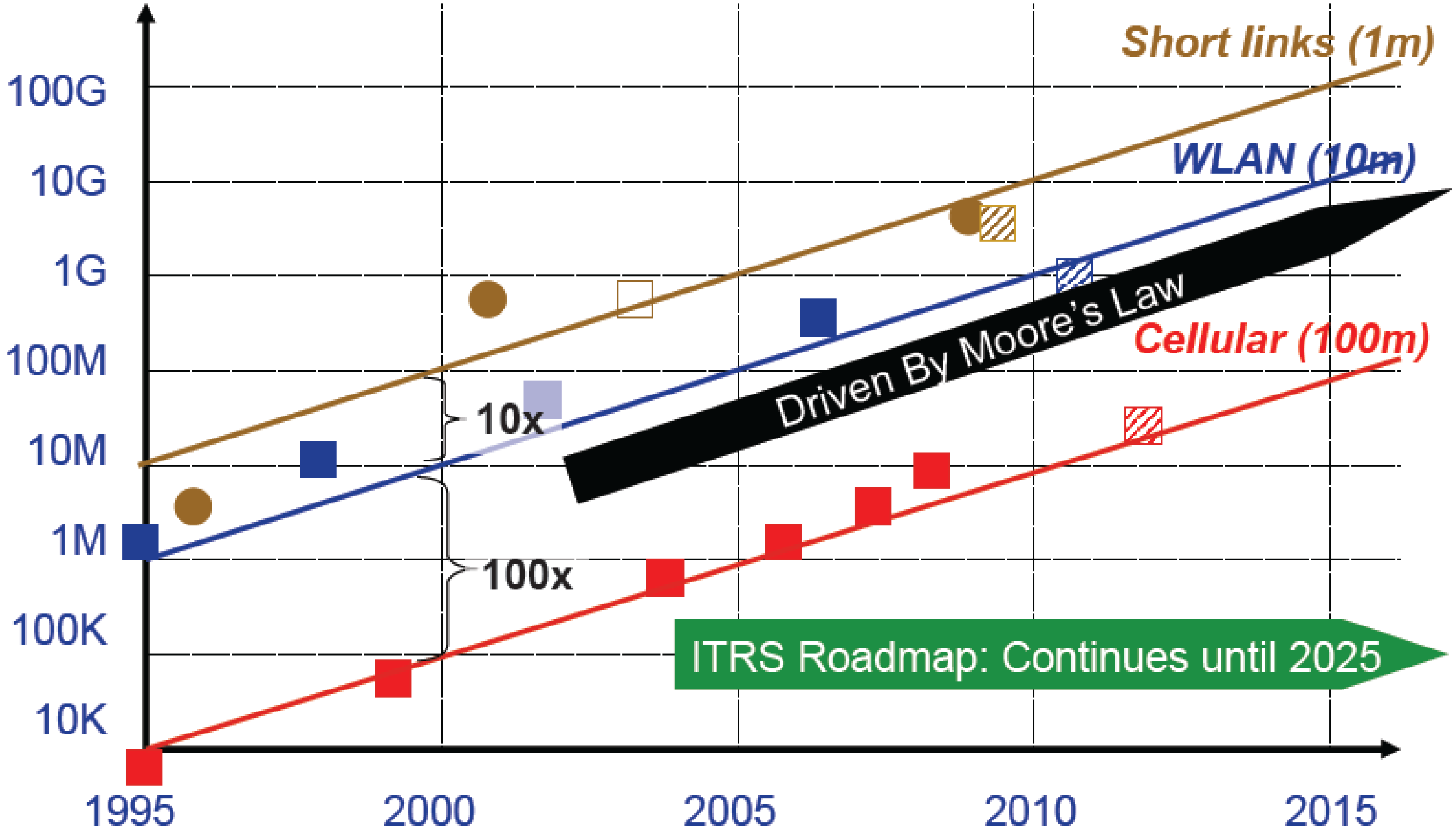
CHRONOLOGY: THE QUEST FOR THE GIGA-B/S

LOCAL AND WIDE AREA NETWORKS



CHRONOLOGY: THE QUEST FOR THE GIGA-B/S

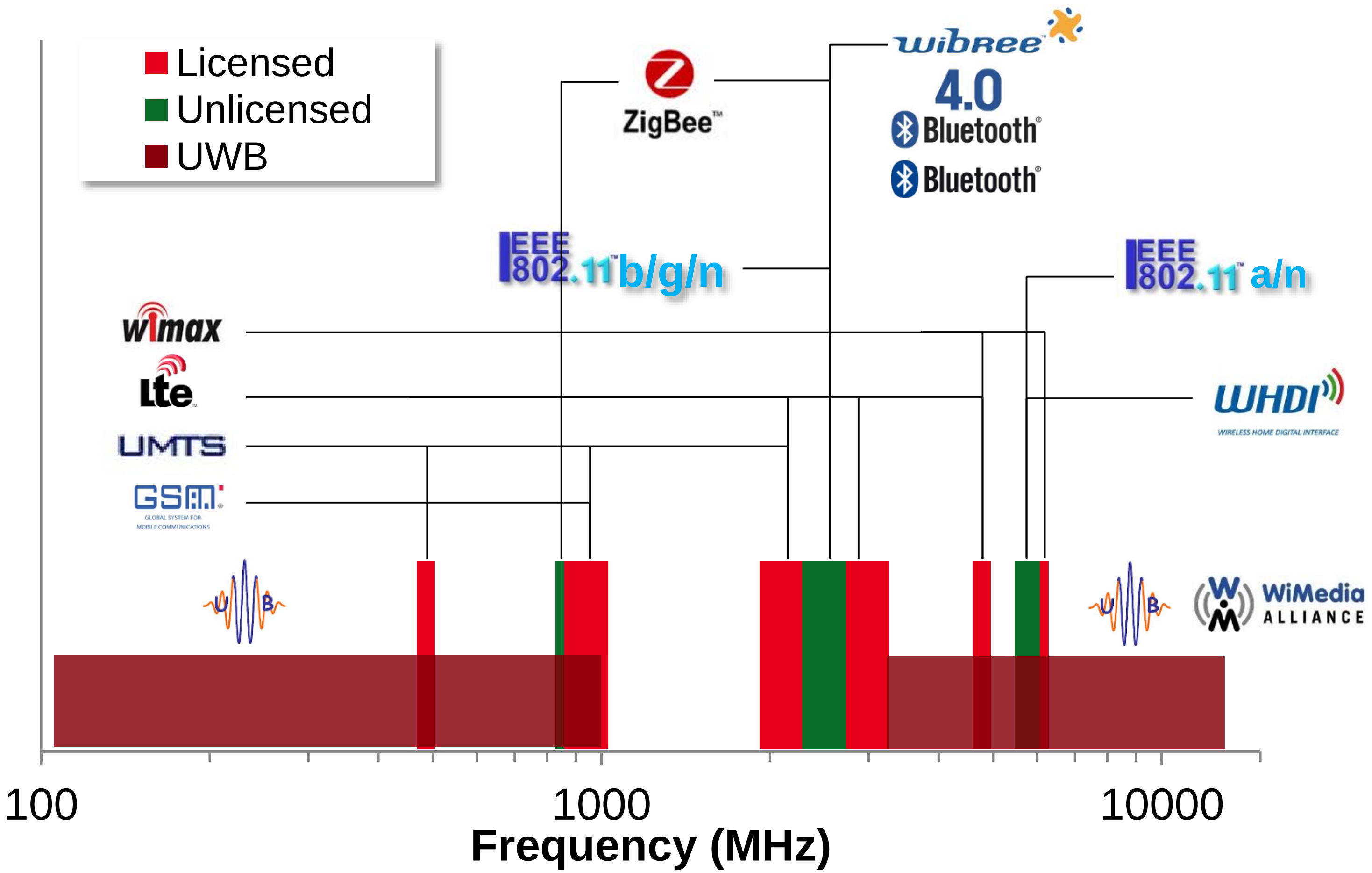
SUMMARY



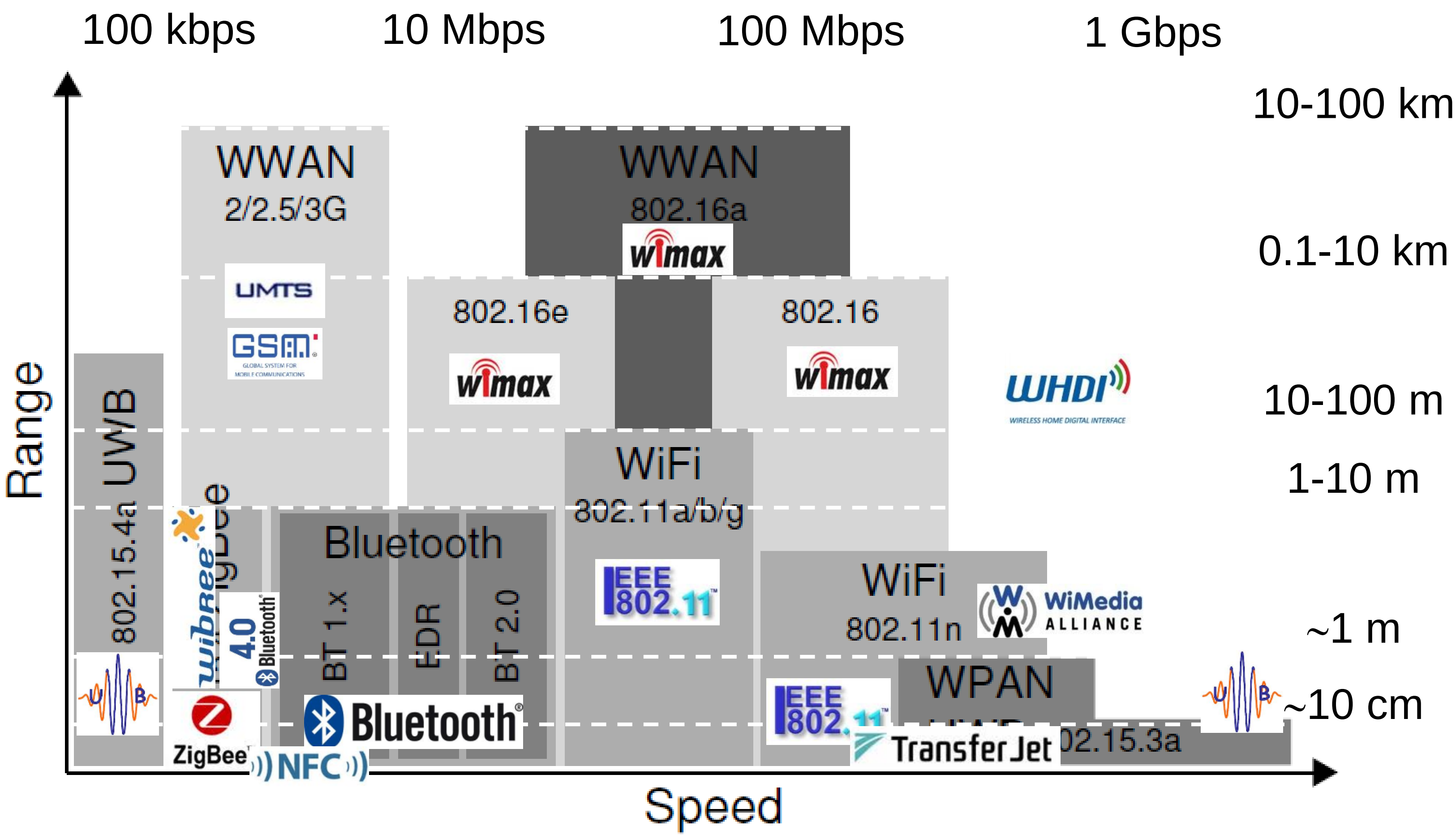
Source: Gerhard Fettweis
Vodafone Chair –TU Dresden –Germany

MORE BANDWIDTH, MORE BANDWIDTH!

MORE BANDWIDTH, MORE BANDWIDTH!



ACCESS EVERYWHERE…



leti
cea tech

…BUT FOR HOW LONG?

TABLE I
COMPARISON OF THE BLUETOOTH, UWB, ZIGBEE, AND WI-FI PROTOCOLS

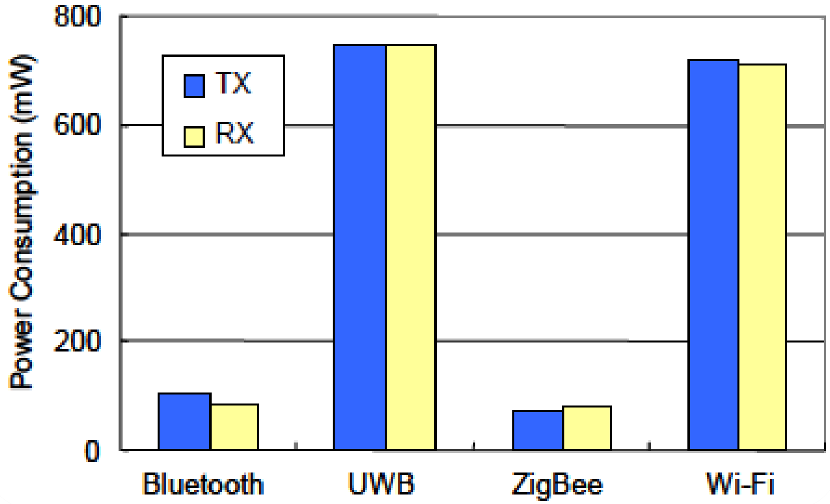
Standard	Bluetooth	UWB	ZigBee	Wi-Fi
IEEE spec.	802.15.1	802.15.3a *	802.15.4	802.11a/b/g
Frequency band	2.4 GHz	3.1-10.6 GHz	868/915 MHz; 2.4 GHz	2.4 GHz; 5 GHz
Max signal rate	1 Mb/s	110 Mb/s	250 Kb/s	54 Mb/s
Nominal range	10 m	10 m	10 - 100 m	100 m
Nominal TX power	0 - 10 dBm	-41.3 dBm/MHz	(-25) - 0 dBm	15 - 20 dBm
Number of RF channels	79	(1-15)	1/10; 16	14 (2.4 GHz)
Channel bandwidth	1 MHz	500 MHz - 7.5 GHz	0.3/0.6 MHz; 2 MHz	22 MHz
Modulation type	GFSK	BPSK, QPSK	BPSK (+ ASK), O-QPSK	BPSK, QPSK COFDM, CCK, M-QAM
Spreading	FHSS	DS-UWB, MB-OFDM	DSSS	DSSS, CCK, OFDM
Coexistence mechanism	Adaptive freq. hopping	Adaptive freq. hopping	Dynamic freq. selection	Dynamic freq. selection, transmit power control (802.11h)
Basic cell	Piconet	Piconet	Star	BSS
Extension of the basic cell	Scatternet	Peer-to-peer	Cluster tree, Mesh	ESS
Max number of cell nodes	8	8	> 65000	2007
Encryption	E0 stream cipher	AES block cipher (CTR, counter mode)	AES block cipher (CTR, counter mode)	RC4 stream cipher (WEP), AES block cipher
Authentication	Shared secret	CBC-MAC (CCM)	CBC-MAC (ext. of CCM)	WPA2 (802.11i)
Data protection	16-bit CRC	32-bit CRC	16-bit CRC	32-bit CRC

* Unapproved draft.
• Acronyms: ASK (amplitude shift keying), GFSK (Gaussian frequency SK), BPSK/QPSK (binary/quardrature phase SK), O-QPSK (offset-QPSK), OFDM (orthogonal frequency division multiplexing), COFDM (coded OFDM), MB-OFDM (multiband OFDM), M-QAM (M-ary quadrature amplitude modulation), CCK (complementary code keying), FHSS/DSSS (frequency hopping/direct sequence spread spectrum), BSS/ESS (basic/extended service set), AES (advanced encryption standard), WEP (wired equivalent privacy), WPA (Wi-Fi protected access), CBC-MAC (cipher block chaining message authentication code), CCM (CTR with CBC-MAC), CRC (cyclic redundancy check).

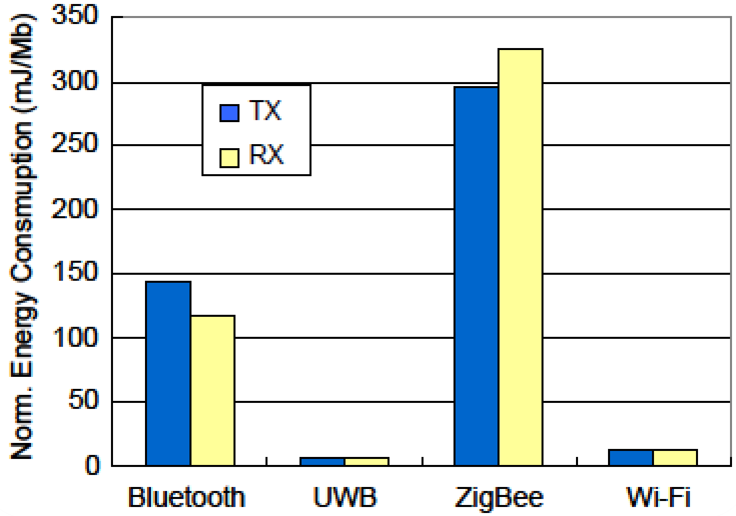
From: Jin-Shyan Lee; Yu-Wei Su; Chung-Chou Shen; , "A Comparative Study of Wireless Protocols: Bluetooth, UWB, ZigBee, and Wi-Fi," Industrial Electronics Society, 2007. IECON 2007. 33rd Annual Conference of the IEEE , vol., no., pp.46-51, 5-8 Nov. 2007

…BUT FOR HOW LONG?

Power



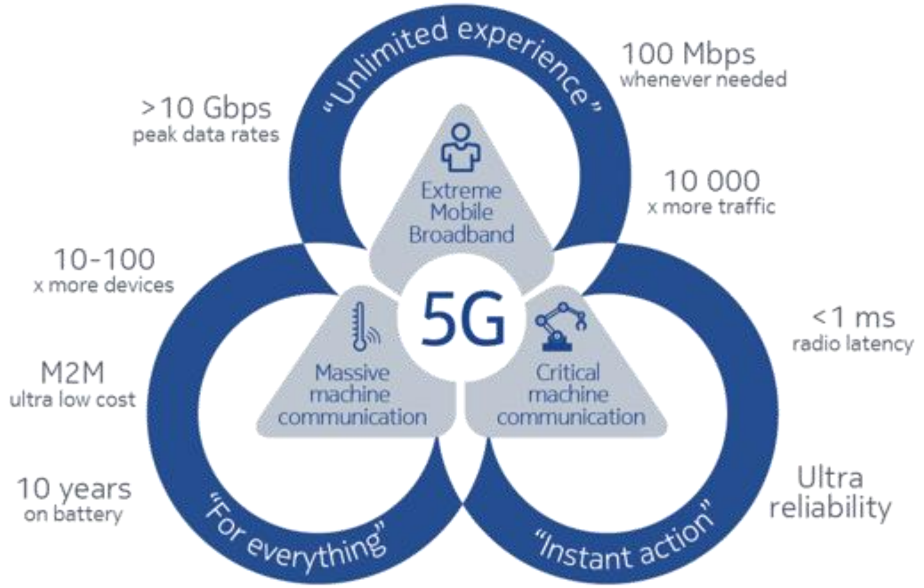
Energy

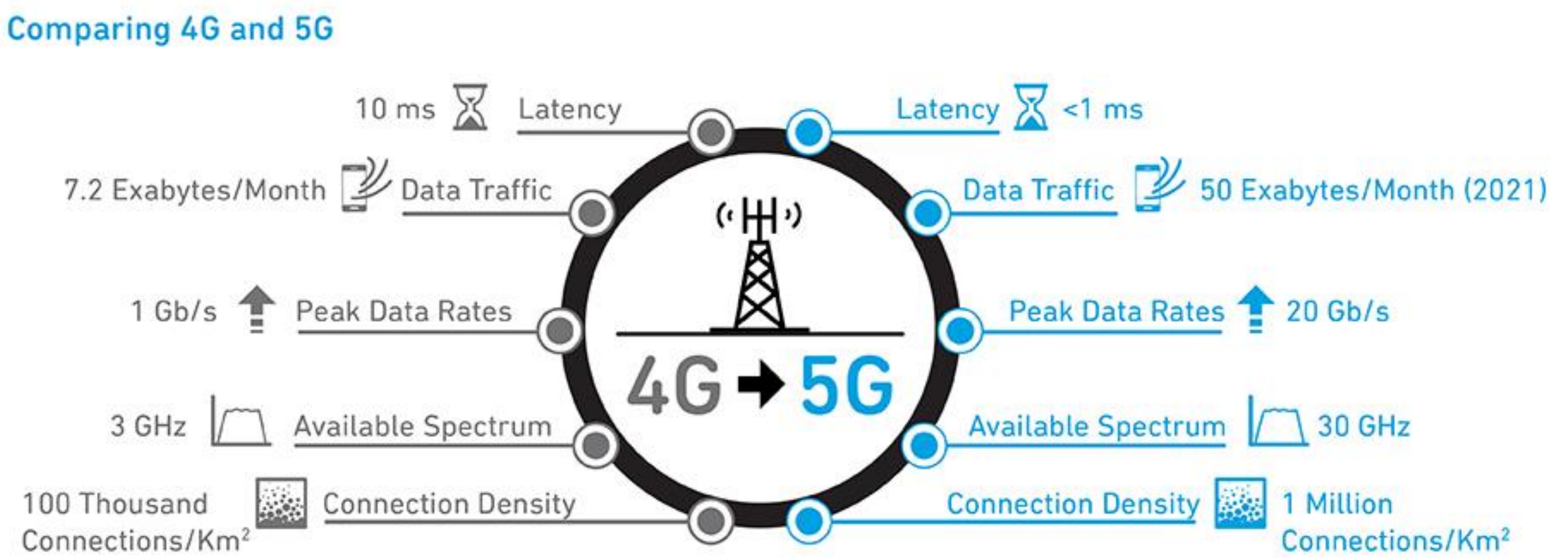


From: Jin-Shyan Lee; Yu-Wei Su; Chung-Chou Shen; , "A Comparative Study of Wireless Protocols: Bluetooth, UWB, ZigBee, and Wi-Fi," Industrial Electronics Society, 2007. IECON 2007. 33rd Annual Conference of the IEEE , vol., no., pp.46-51, 5-8 Nov. 2007

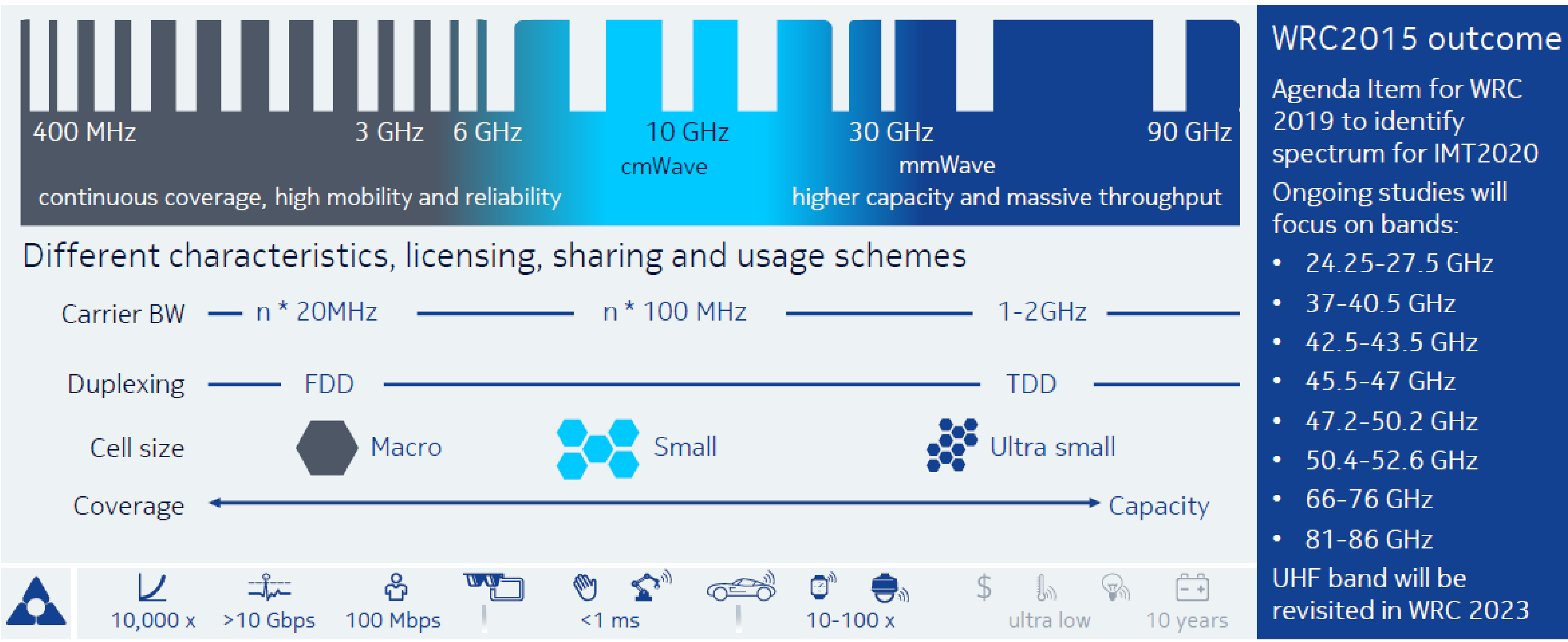
AT THE BEGINNING IT WAS THE AETHER…

5G FOR BEGINNERS



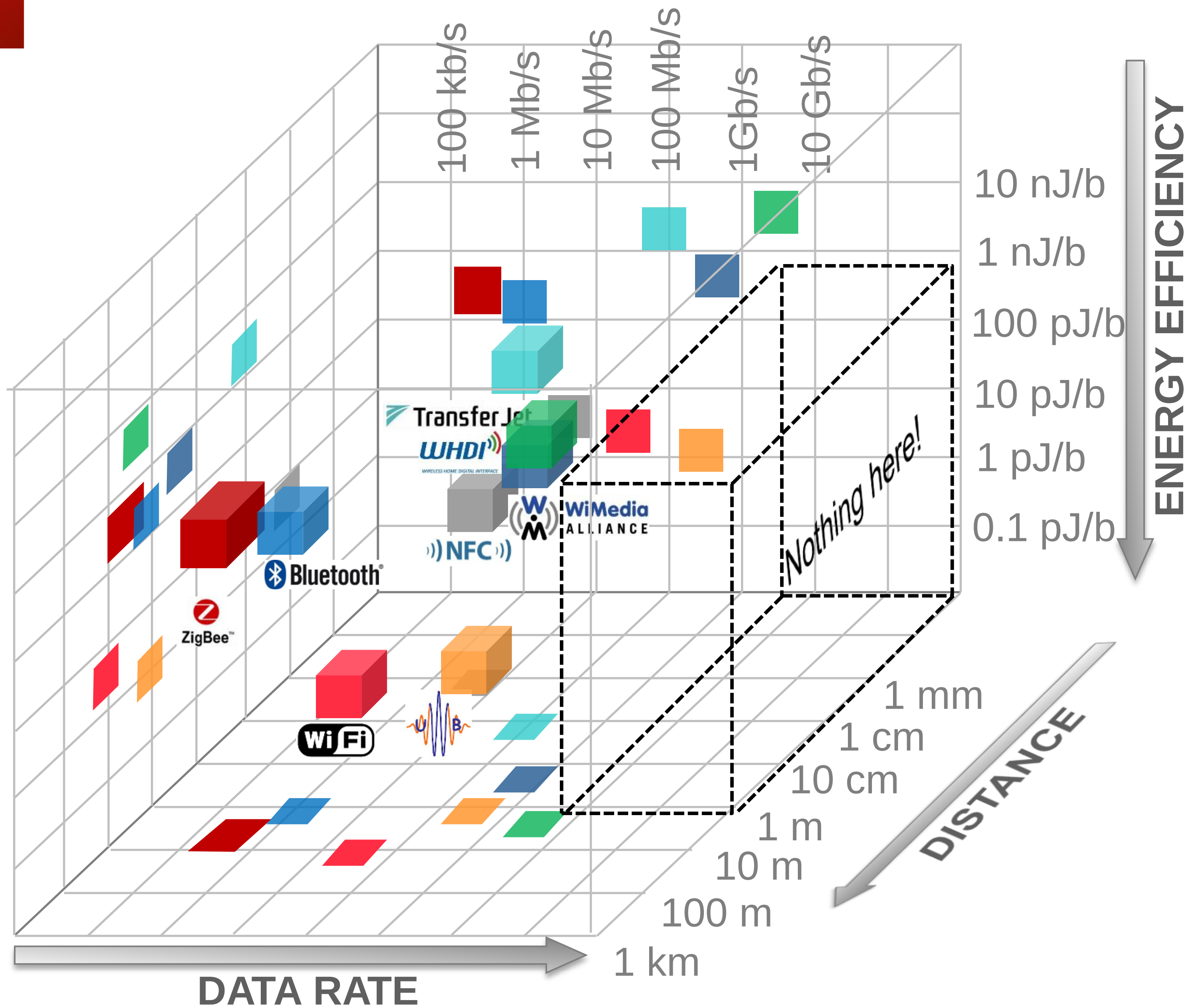


The number of frequency bands exploses…



- **Sub-6 GHz bands**
  - Many bands xxxMHz … GHz
  - Long range.
  - Medium and high-data rate.
- **mmW bands**
  - 28 GHz … 140 GHz
  - Short range.
  - Ultra-high data rate.

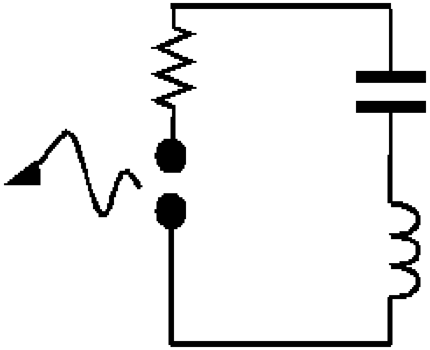
A 3D VIEW OF RF COMMUNICATION STANDARDS



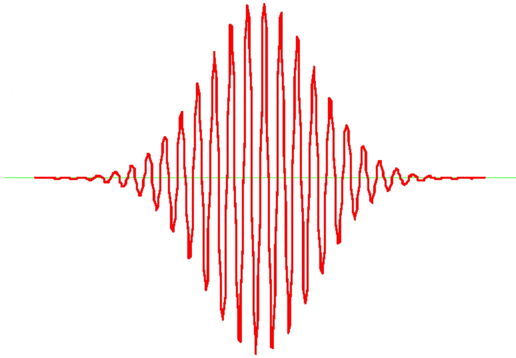
SOMMAIRE

The Spark transmitter: Hertz ~1888

- Hertz “invented” the first transmitter (*emitter*) when trying to demonstrate Maxwell’s theory about the existence of electromagnetic waves.
- A capacitor is charged to a high voltage by an induction coil.
- When the potential across it is sufficiently high to break down the insulation of air in the gap, a spark occurs.
- Some sort of antenna launches a wave (rich in harmonics - ***first UWB system****!).*
- Since the spark has a low resistance (an ohm or two), the spark discharge is equivalent to the closing of an L-C-R circuit. The condenser then discharges through the conducting spark, and the discharge takes the form of a damped oscillation, at a frequency determined by the resonant frequency of the spark transmitter.



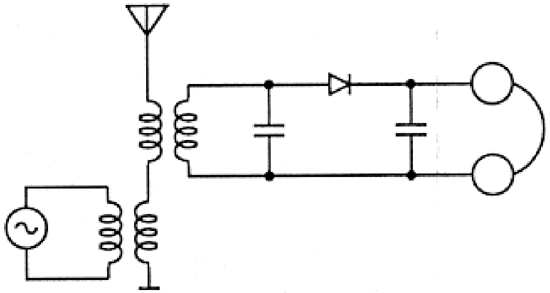
Symplified scheme



The Heterodyne receiver: Fessenden 1902

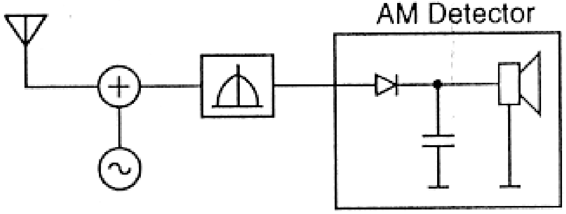
- Fessenden also patented in 1902 the heterodyne receiver. (to heterodyne=to mix different signals)

- The local oscillator was introduced for the first time. It allowed tuning to the received carrier.



- Sensitivity was also increased: the oscillator signal was strong enough to switch the diode on (despite weak incoming signals).

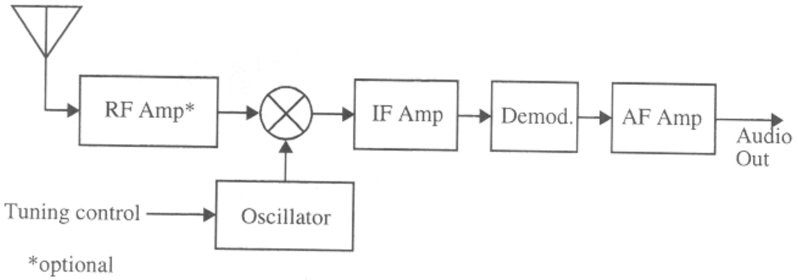
- A significant problem (in later years) was that the oscillator tone was also radiated to the antenna. In subsequent receivers, isolation between the oscillator and the antenna became critical.

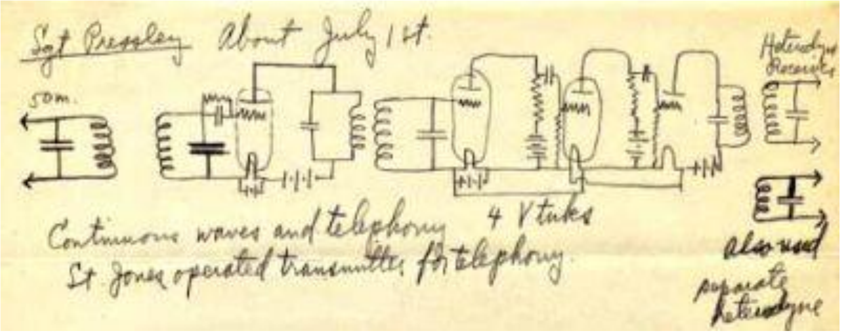


- The heterodyne receiver used frequency conversion for the first time (although this concept was still unrecognized by the inventors).

The Superheterodyne receiver: Armstrong 1918

- Following Fessenden's heterodyne concept, he proposed a two-stage receiver. The input RF signal was translated to a intermediate frequency (IF), which could be easily amplified and demodulated.
- The amplifier and detector work at a fixed IF frequency, while the only tuning happens at the LO. This allows using the same receiver for many RF signals.
- This superheterodyne receiver was the first mass-produced AM radio by RCA, and is still the basic receiver architecture used today.





Scheme of early superheterodyne receiver

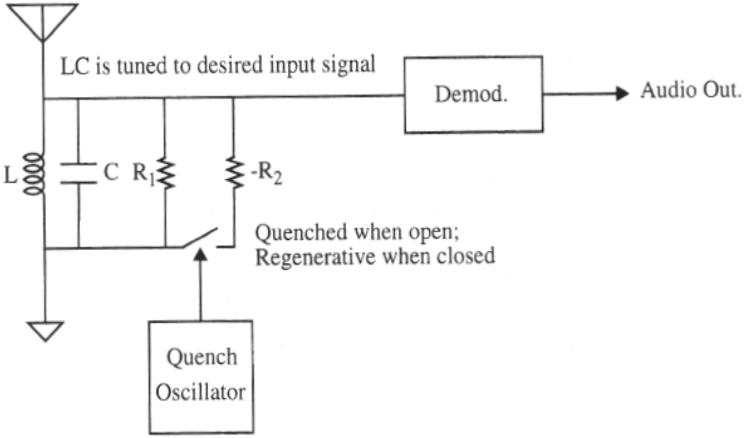
The Superegenerative receiver: Armstrong 1922

- It can achieve gains as high as 100.000 with the minimum number of components (still used today in cheap circuits)

- Based on an unstable regenerative amplifier. The circuit is initialized periodically, thus it never saturates. The final oscillation is proportional to the initial condition (the input).

- The resulting output is a series of oscillation bursts whose amplitude is the input's amplitude amplified, detected by a simple AM amplifier.

- The circuit amplifies samples of the input, with a frequency higher than the signal bandwidth and lower than the RF carrier.



The Homodine receiver: Colebrook 1924

- The homodyne receiver can be understood as a superheterodyne where the LO frequency equals the RF input, thus providing a zero-IF and no need of detection (demodulator).

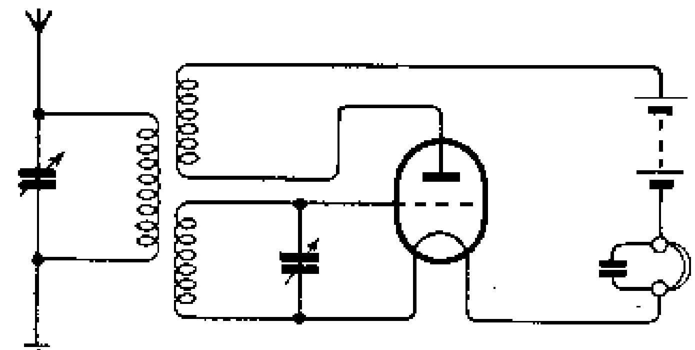
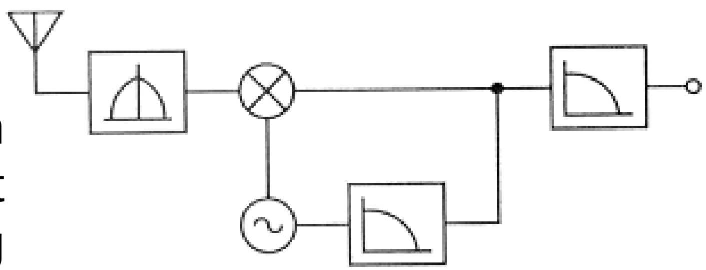


Fig.1. Colebrook's homodyn receiver

- Colebrook first observed this effect, by using a regenerative receiver in which output was overcoupled to the input, thus an oscillation was produced. When oscillation frequency matched the input frequency, no detection was needed.



- Synchronization between input and oscillation was critical. De Bellescize introduced a circuit that guaranteed synchronization by detecting the difference frequency and corrected the LO. This is the principle of the phase-locked loop, and de Bellescize is considered the inventor of the PLL.

SUMMARY

- Ultra-Wideband Impulse Radio
  - Simple Tx and acceptable Rx complexity.
  - Simple modulations schemes.
  - Low energy operation inherent (duty cycle system).

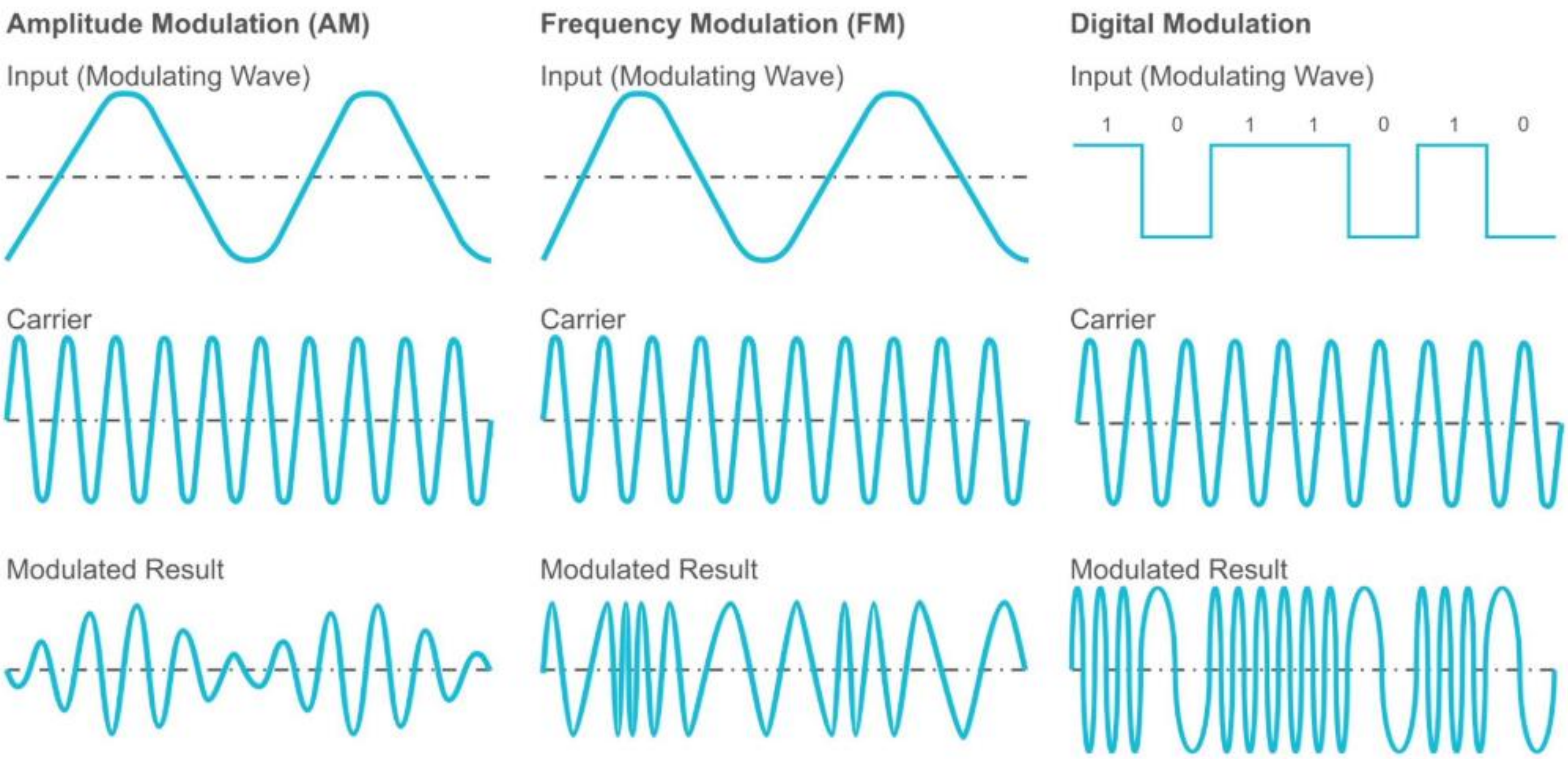
- Homodyne or Heterodyne
  - Large flexibility on RF and Baseband architectures.
  - Complex modulations possible (OFDM).

- Near Field
  - Simple electromagnetic links.
  - Simple Tx and Rx.
  - Possible remote powering.

SOMMAIRE

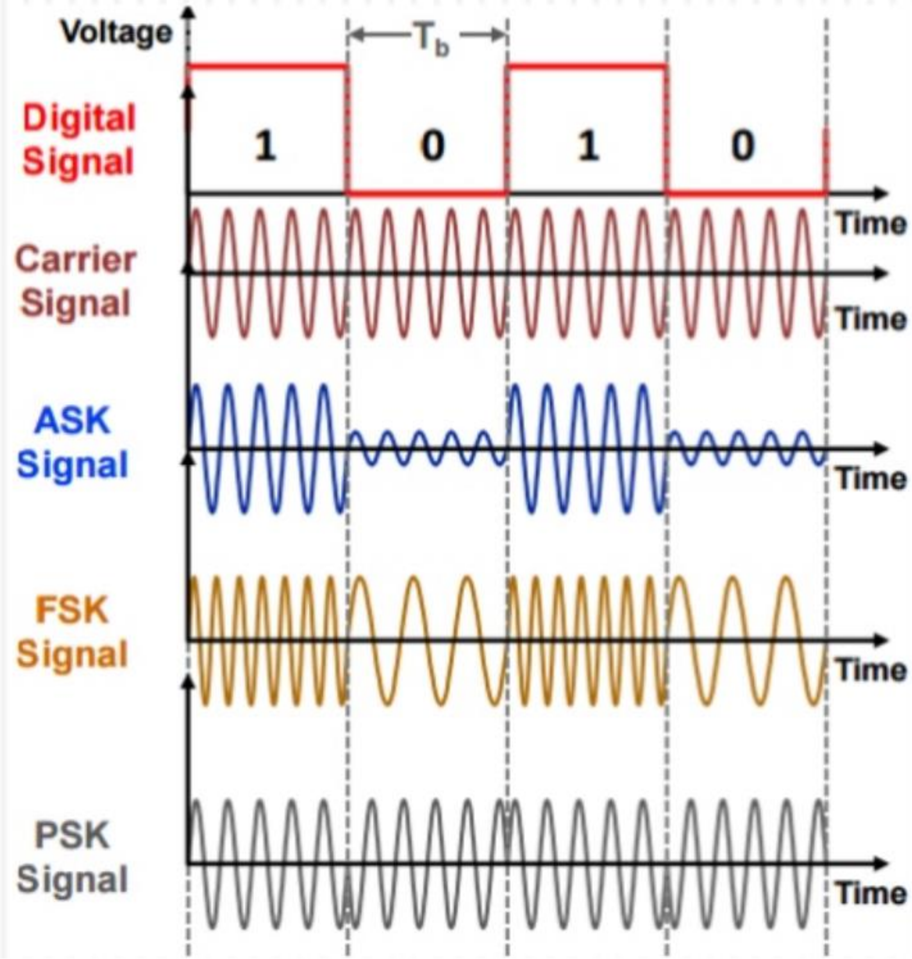
RF COMMUNICATIONS FUNDAMENTALS

AN OVERVIEW OF MODULATION

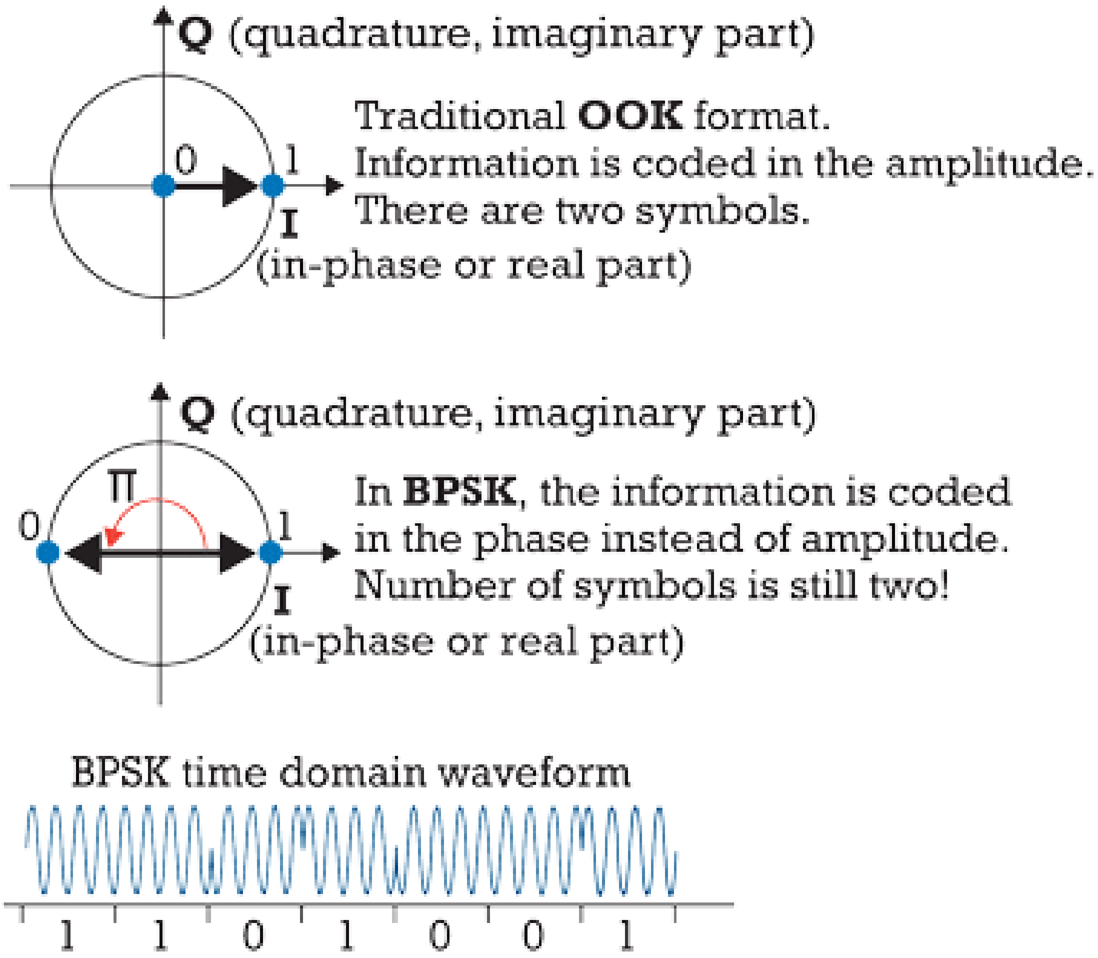


Digital modulations:

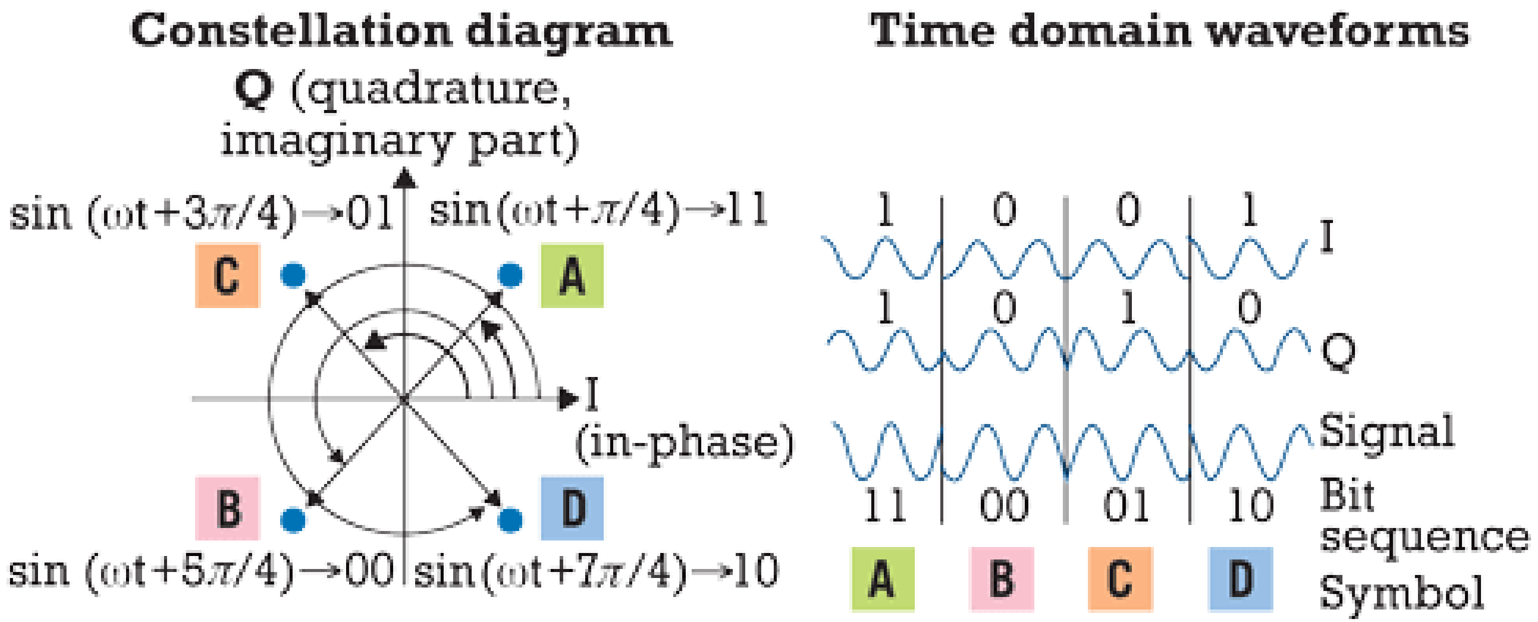
1. **Baseband digital message signal**: $m(t)$
2. **Analog sinusoidal carrier signal**:
   A. Carrier signal: $A_c \cos(2\pi f_c t + \phi_c)$
3. **ASK: Amplitude Shift Keying.**
   A. Message signal changes the carrier's **amplitude** : $A_i(t)$.
4. **FSK: Frequency Shift Keying.**
   A. Message signal changes the carrier's **frequency** : $f_i(t)$.
5. **PSK: Phase Shift Keying.**
   A. Message signal changes the carrier's **phase** : $\phi_i(t)$.



IQ diagrams of binary modulations



Complex modulation schemes



We have constructed four vectors.
→One vector position in the complex plane codes 2 bits

Complex modulation schemes

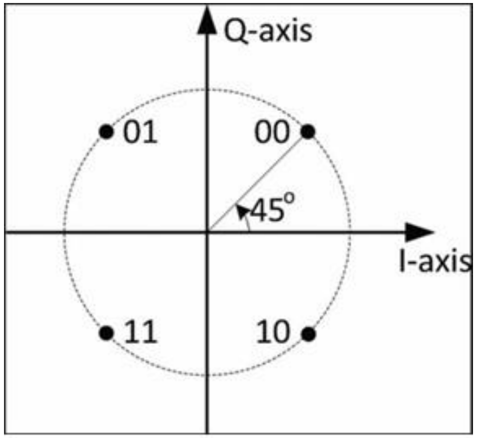
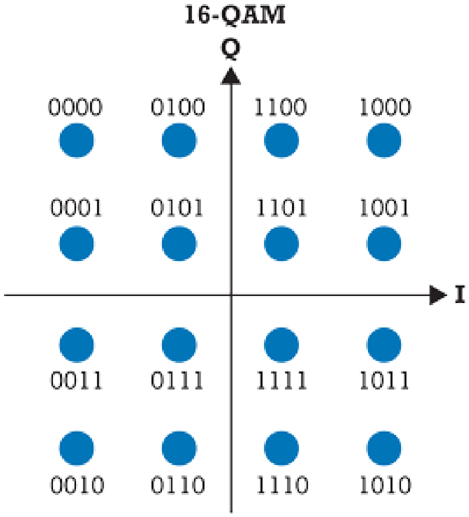
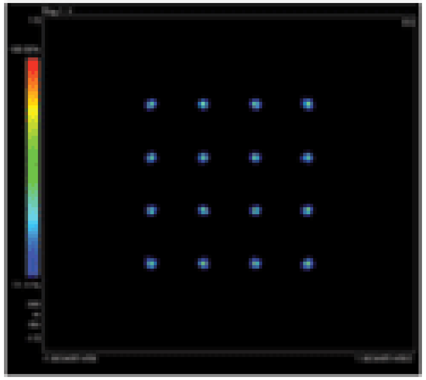
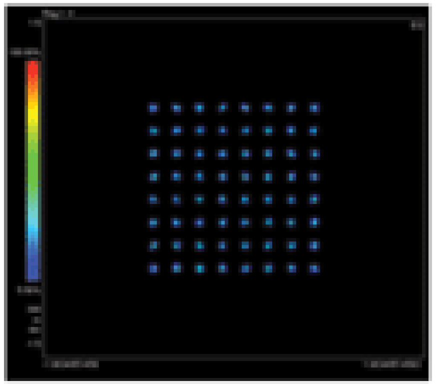


Figure 1. Constellation View of QPSK

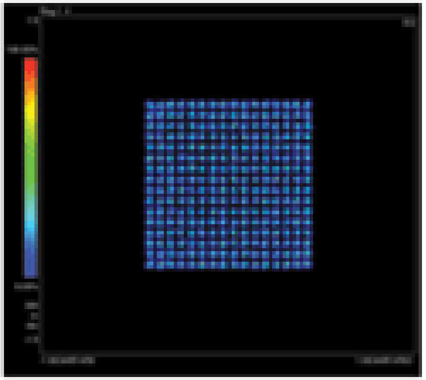




16-QAM
4 bits/symbol



64-QAM
6 bits/symbol



256-QAM
8 bits/symbol

Complex modulation schemes

TABLE 2: SPECTRAL EFFICIENCY FOR POPULAR DIGITAL MODULATION METHODS

Type of modulation	Spectral efficiency (bits/s/Hz)
FSK	<1 (depends on modulation index)
GMSK	1.35
BPSK	1
QPSK	2
8PSK	3
16QAM	4
64QAM	6
OFDM	>10 (depends on the type of modulation and the number of subcarriers)

SOMMAIRE

The Shannon theorem

bandwidth of the channel

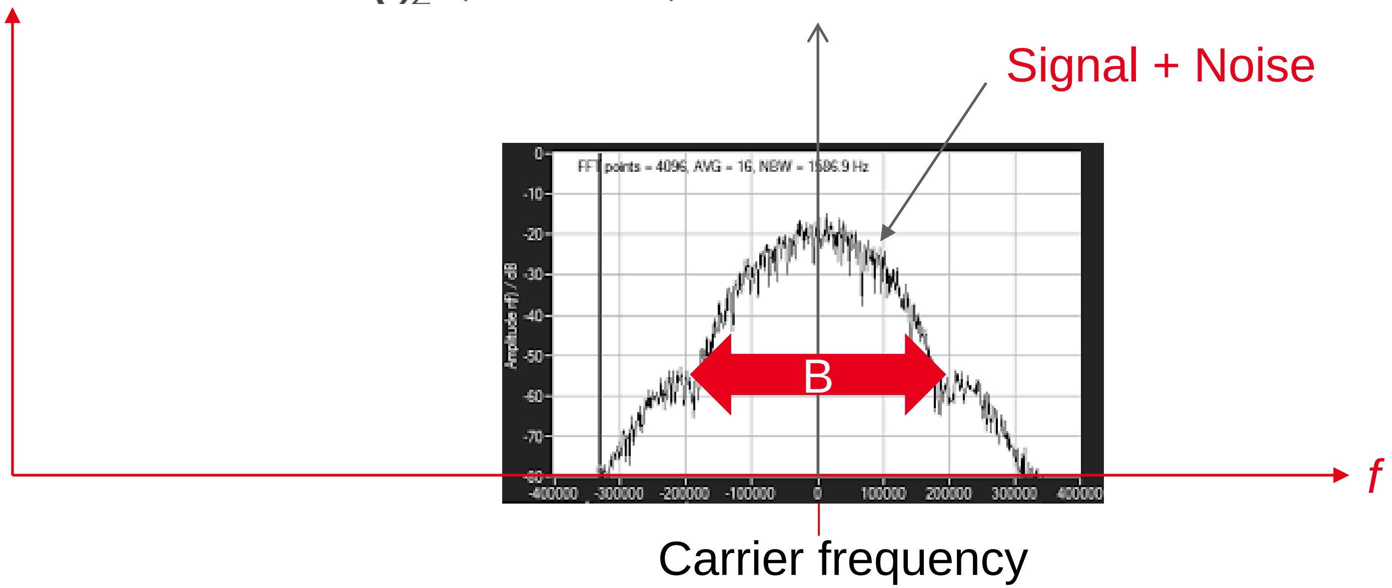
$$C = B \log_2 (1 + S/N)$$

Channel capacity in bits/s

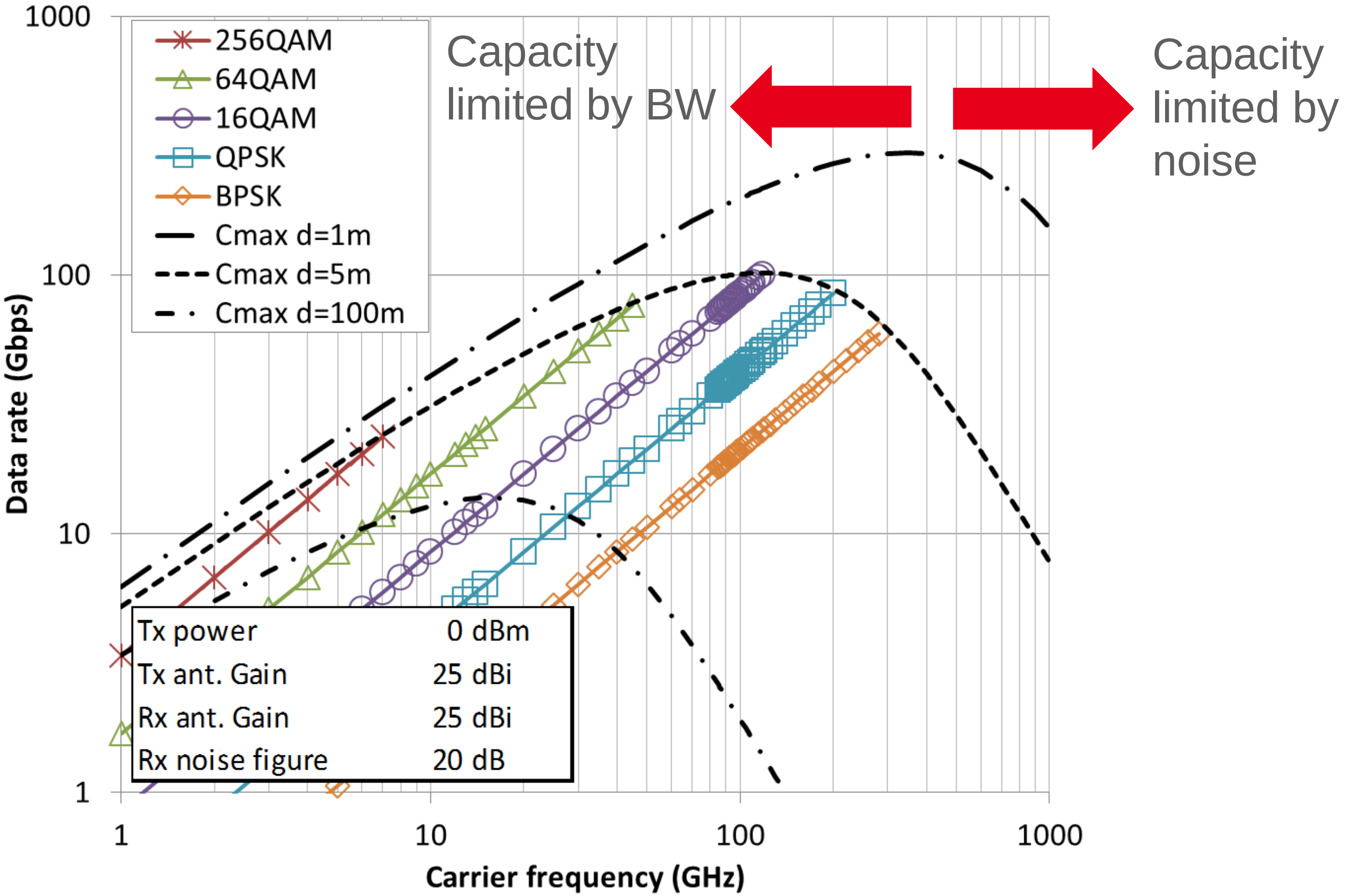
signal-to-noise ratio

The Shannon theorem

$$C = B \log_2 (1+S/N)$$



The Shannon theorem: example BW = 20% Carrier frequency



SOMMAIRE

RF COMMUNICATIONS FUNDAMENTALS

LARGE BW RADIOS

How to achieve a high data-rate to exploit the available channel capacity?

Challenges: limited range, gain, emitted power

High frequency
High bandwidth > 100GHz

Multiple channels
Spatial and/or frequency multiplexing

Multiple levels modulation
QAM, M-ASK

20-40Gbps, 5pJ/bit

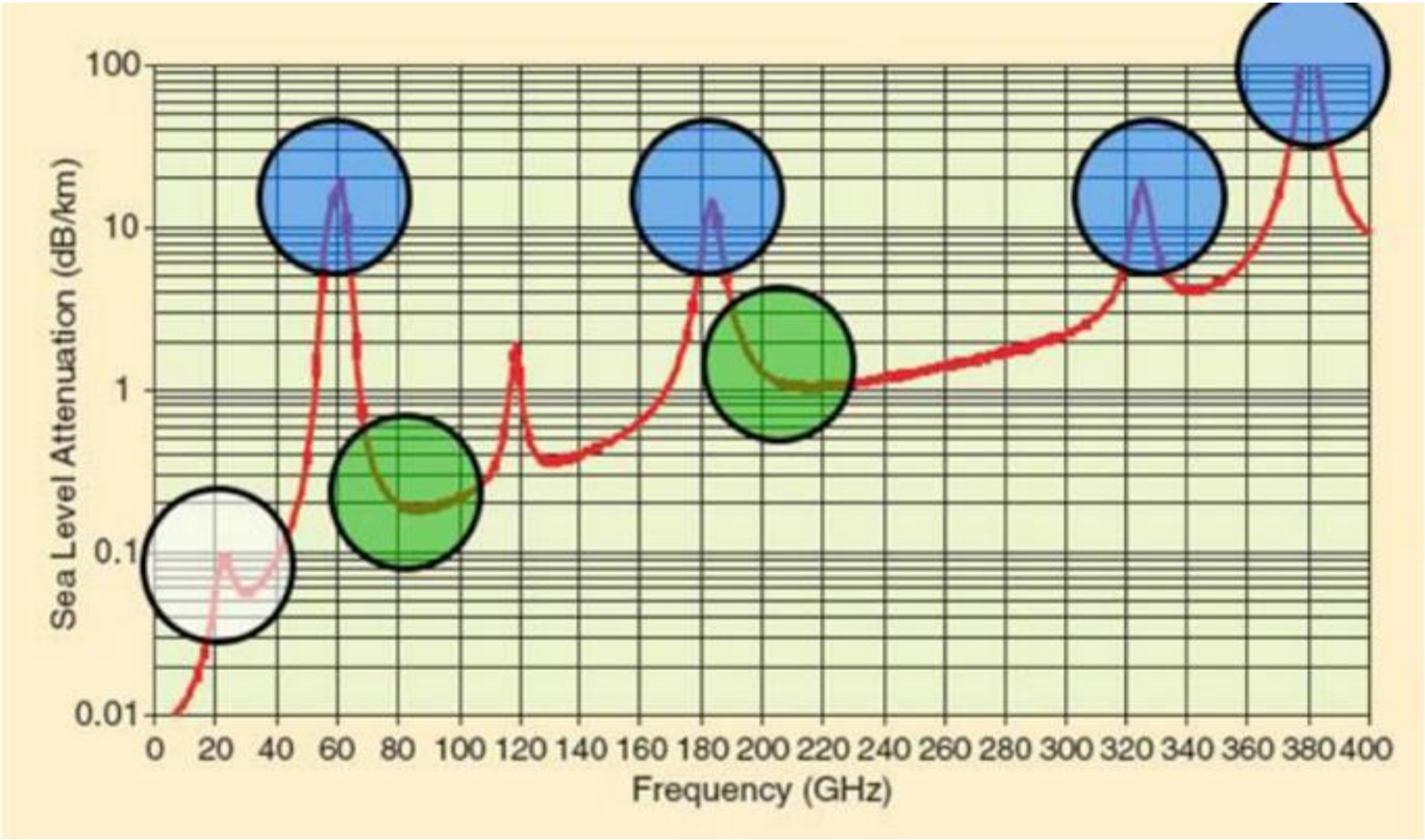
Challenges: RF architecture, bandwidth, channel filtering, multi tone frequency synthesis, antenna coupling, silicon area and antenna form factor

Challenges: RF architecture, linearity, carrier synchronization (phase & frequency)

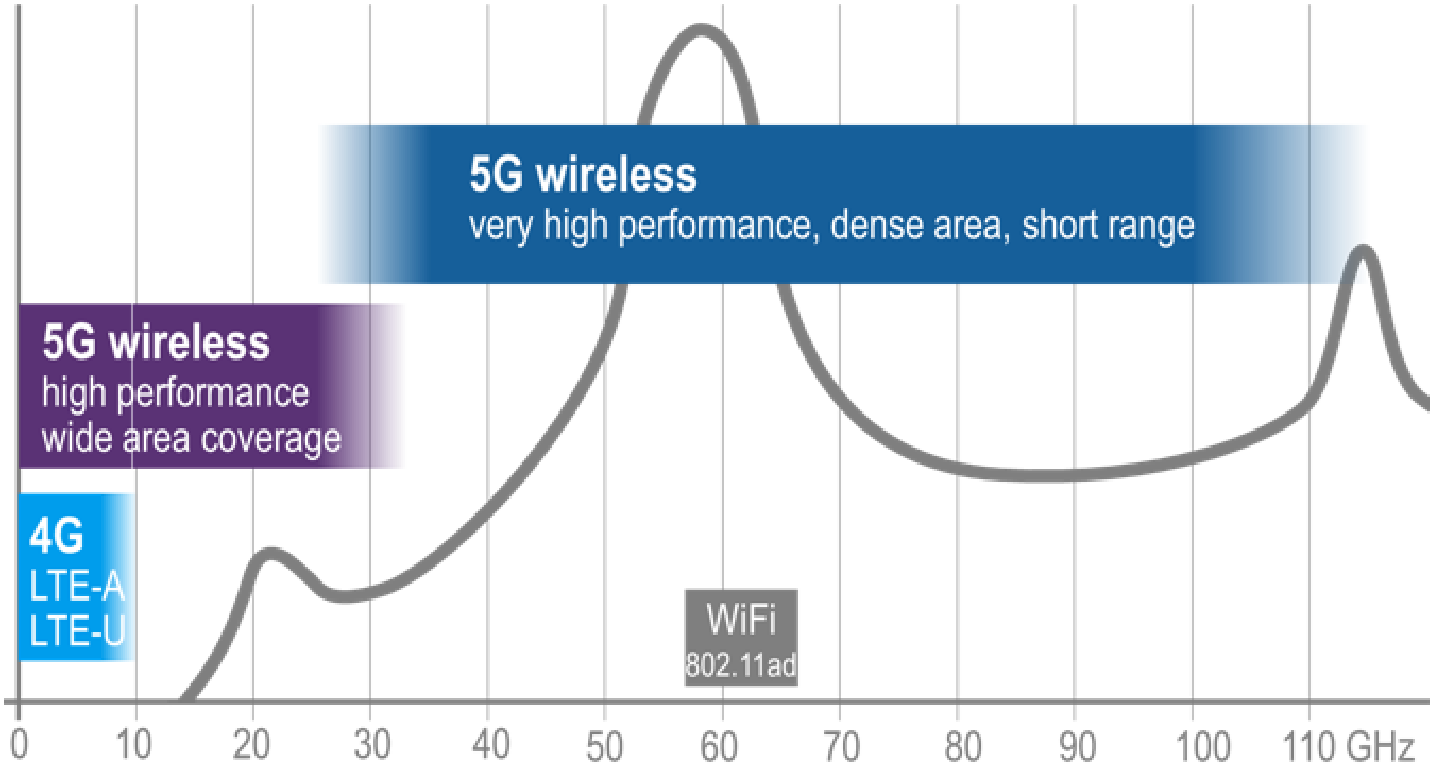
Advanced technology

Challenges: RF/mmw modeling

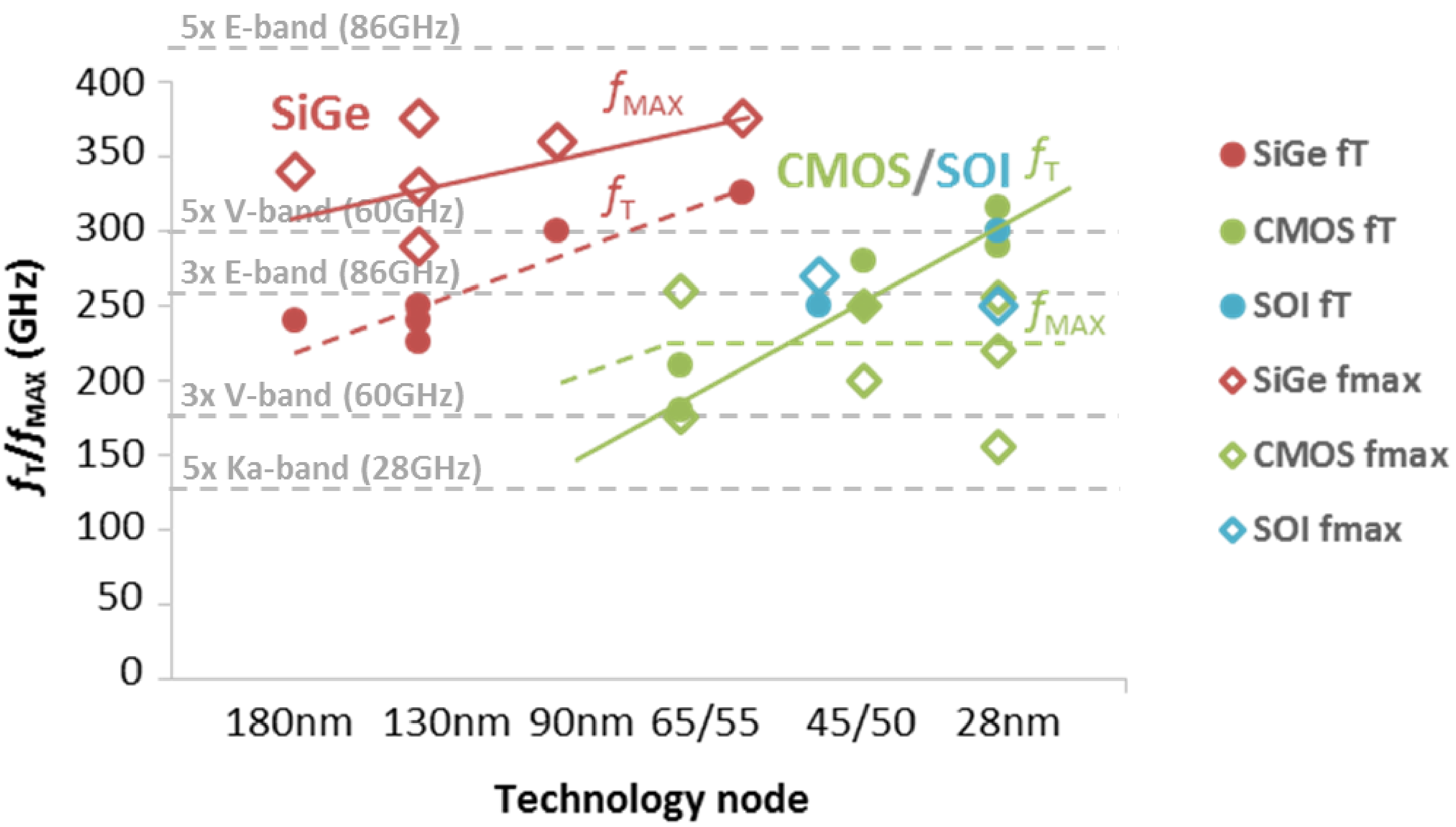
Link attenuation increases with frequency…



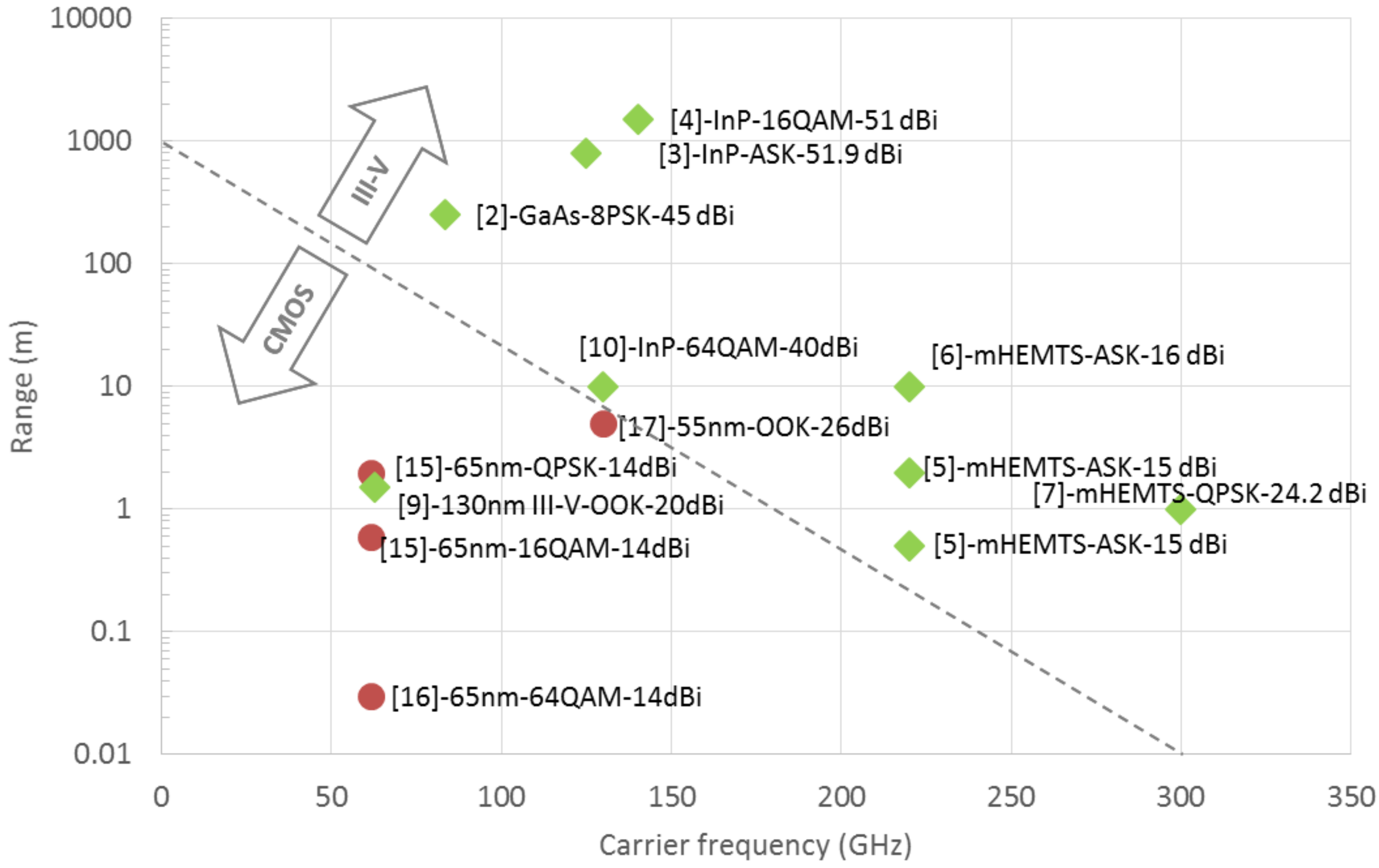
mmW in consideration for mobile communications



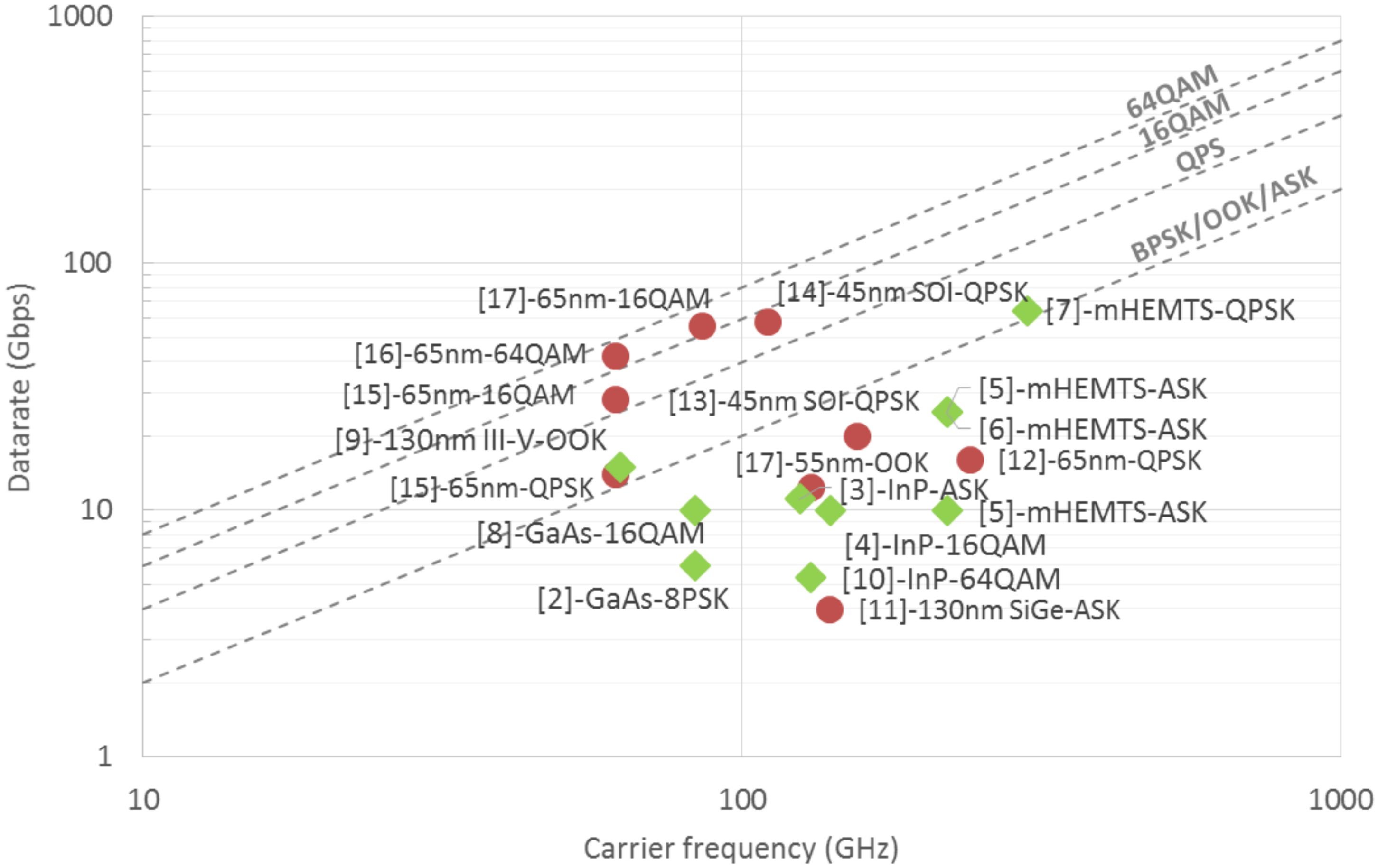
Comparison of Silicon processes for mmW applications



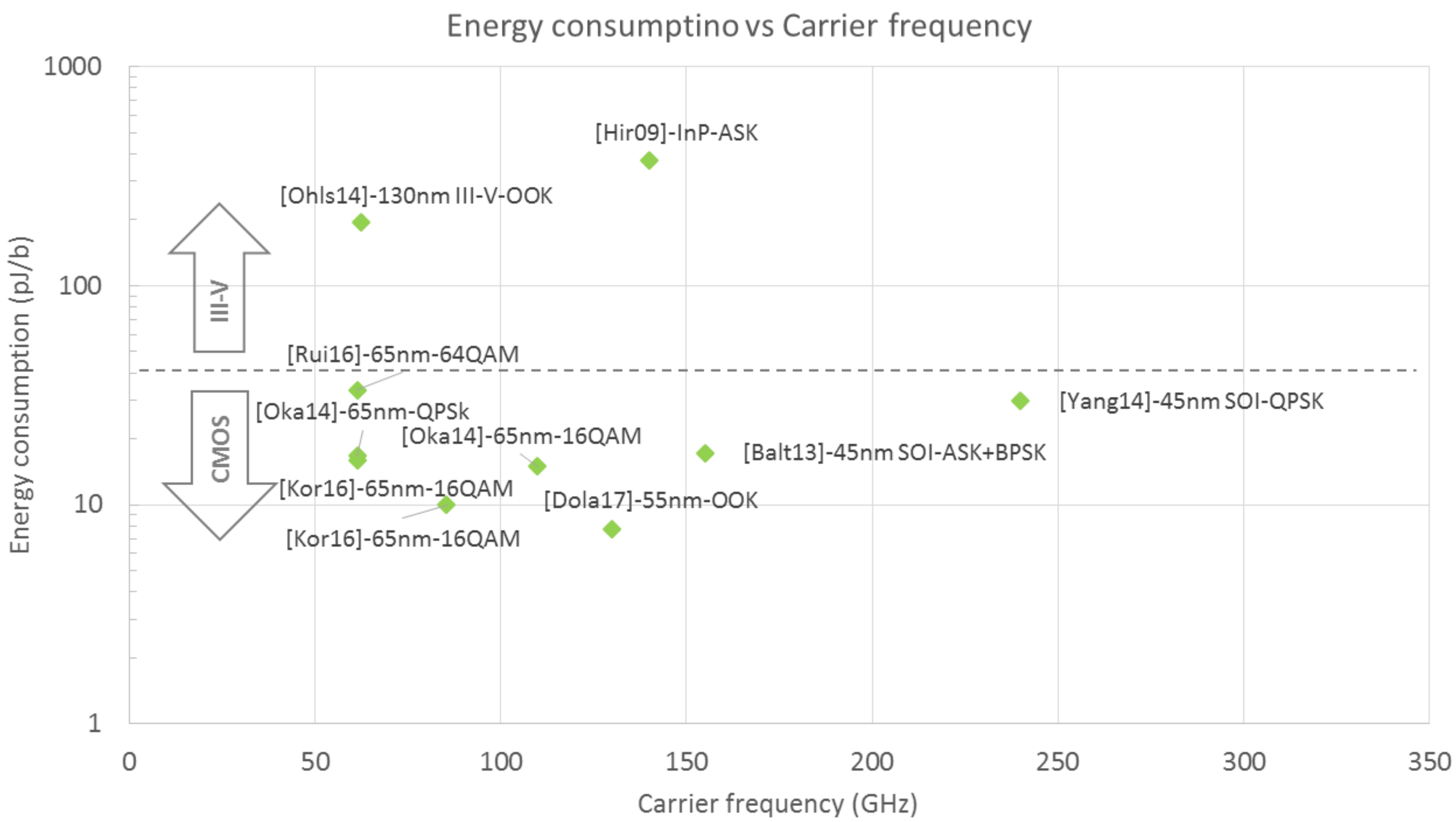
State of the art multi-Gbps radios



State of the art multi-Gbps radios



State of the art multi-Gbps radios



Leti, technology research institute
Commissariat à l'énergie atomique et aux énergies alternatives
Minatec Campus | 17 rue des Martyrs | 38054 Grenoble Cedex | France
www.leti.fr