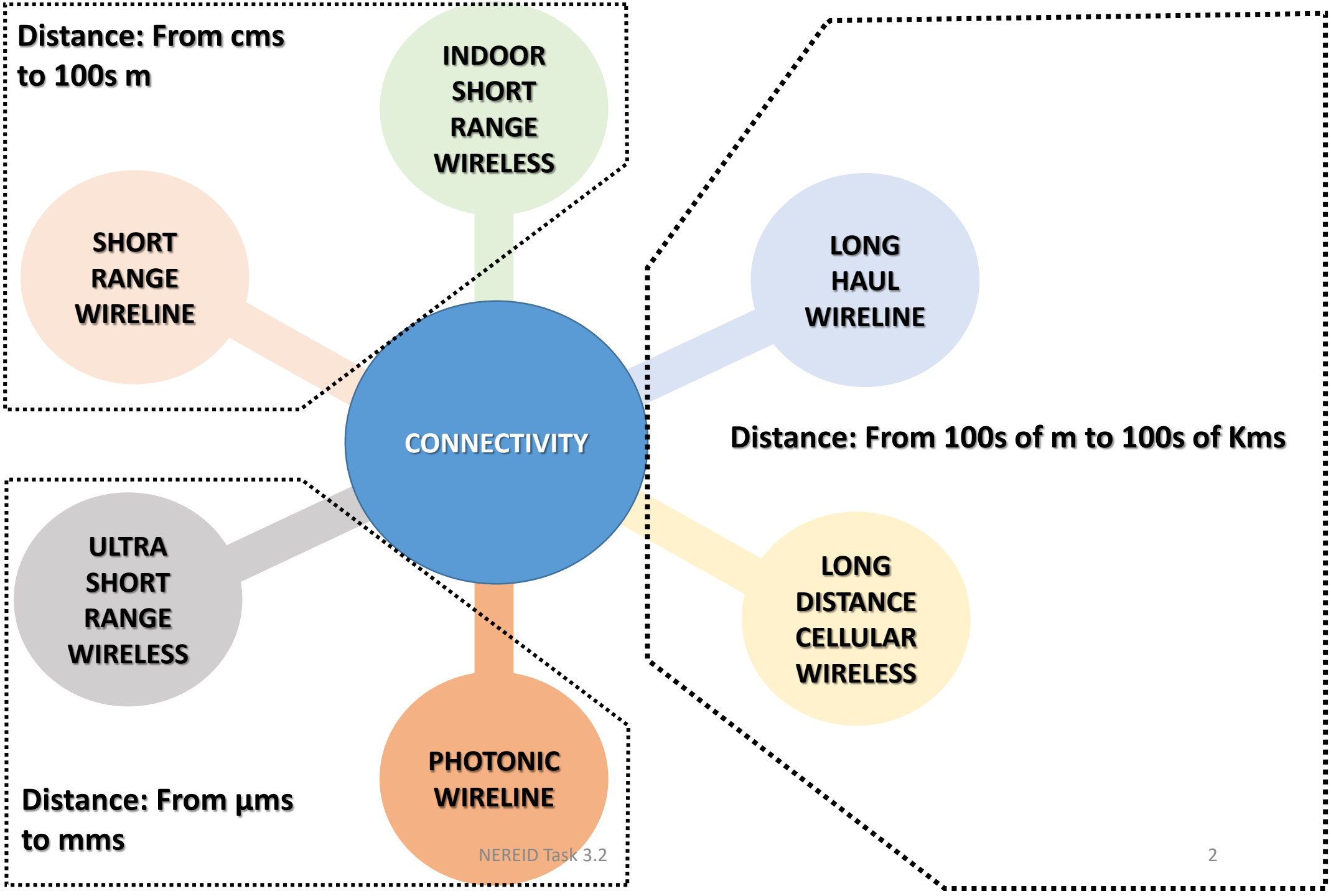
NEREID

3rd General WS

Task 3.2

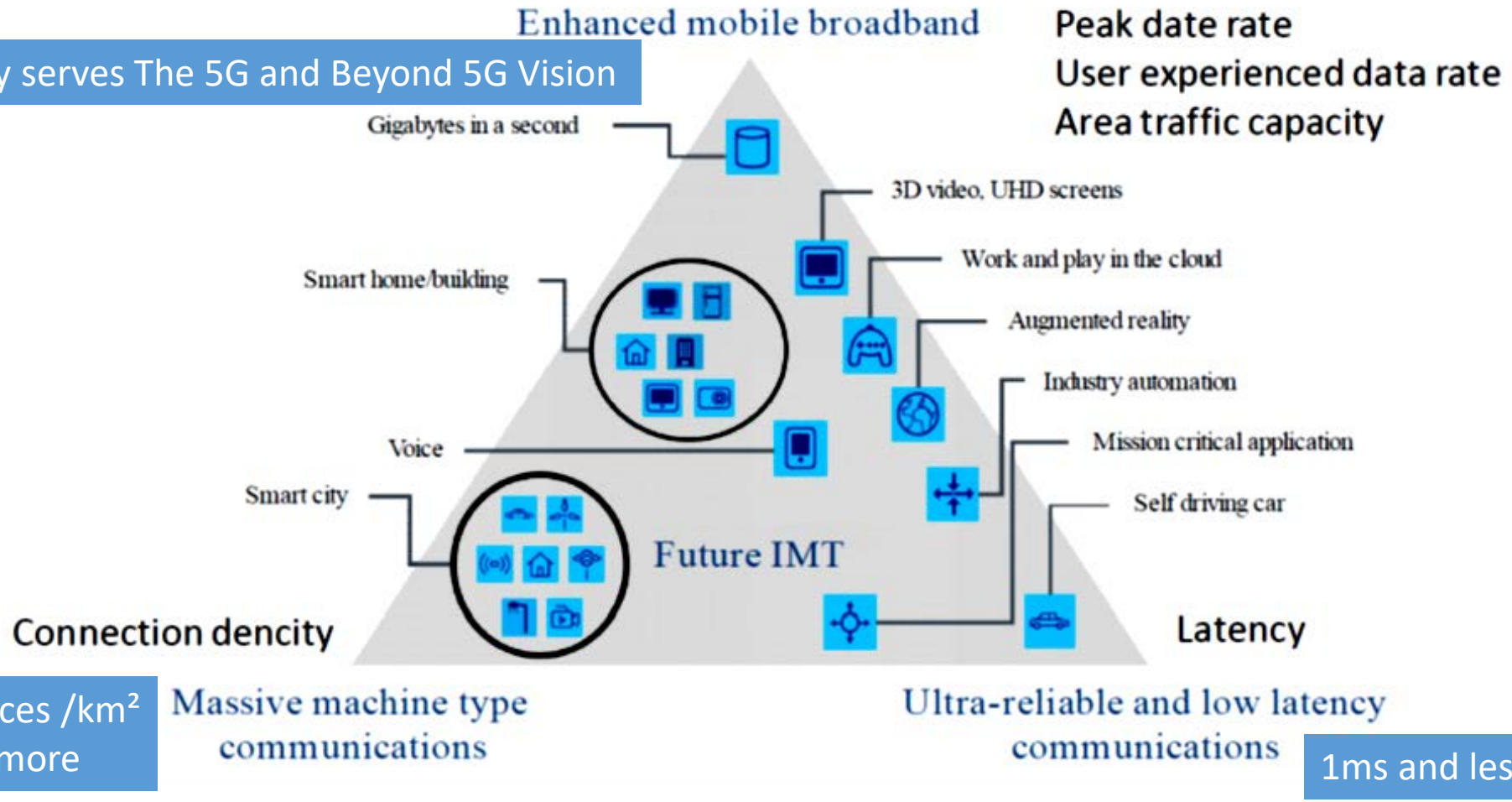
CONNECTIVITY ROADMAP

Didier Belot – Emilio Calvanese Strinati


Distance: From cms to 100s m
INDOOR SHORT RANGE WIRELESS
SHORT RANGE WIRELINE
LONG HAUL WIRELINE
CONNECTIVITY
Distance: From 100s of m to 100s of Kms
ULTRA SHORT RANGE WIRELESS
LONG DISTANCE CELLULAR WIRELESS
PHOTONIC WIRELINE
Distance: From µms to mms

10Gbs / mobile and more

Connectivity serves The 5G and Beyond 5G Vision

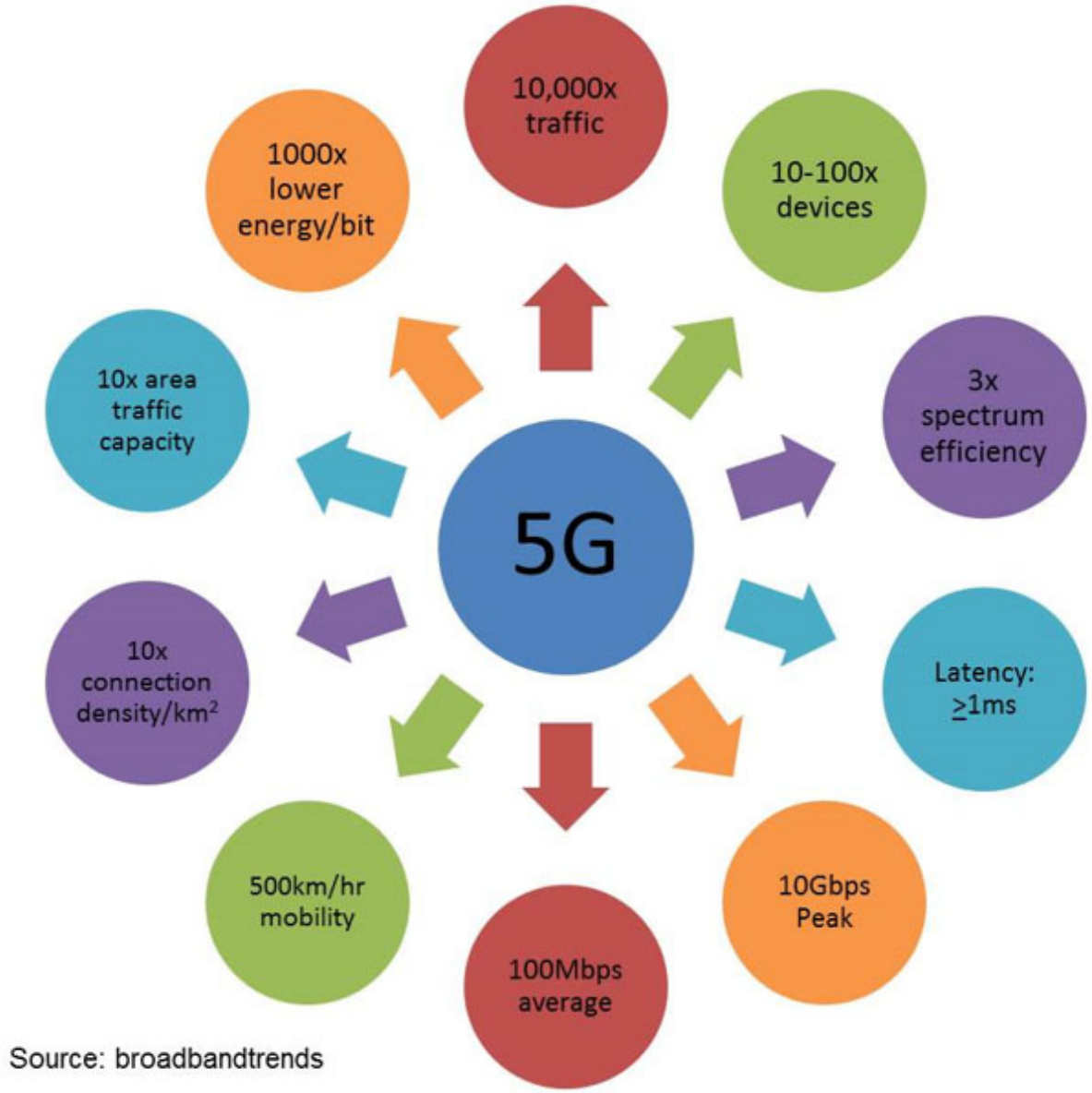


10^6 Devices /km² and more

1ms and less

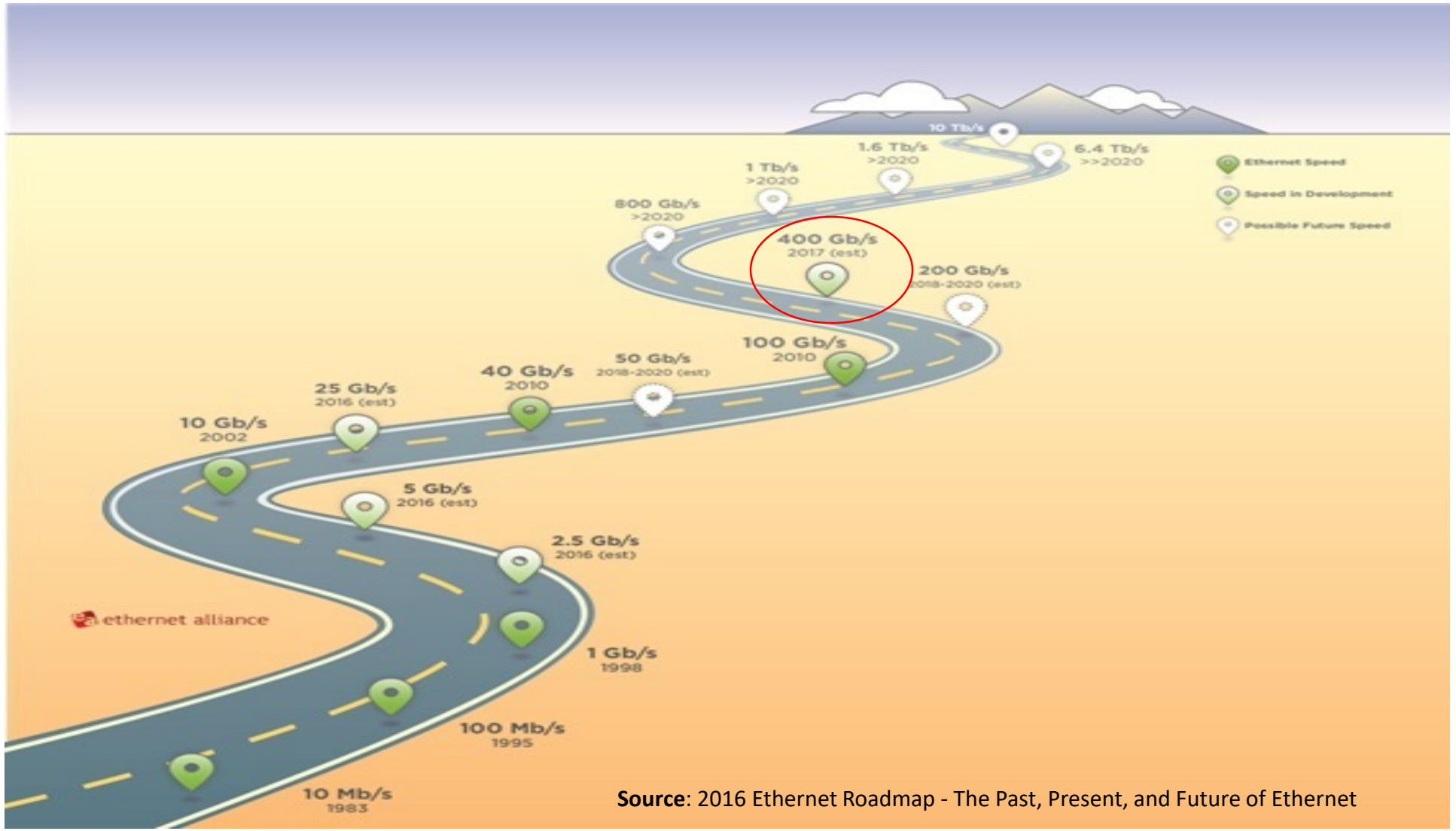
[ITU-R M.2083 : IMT Vision - "Framework and overall objectives of the future development of IMT for 2020 and beyond“].

5G Challenges

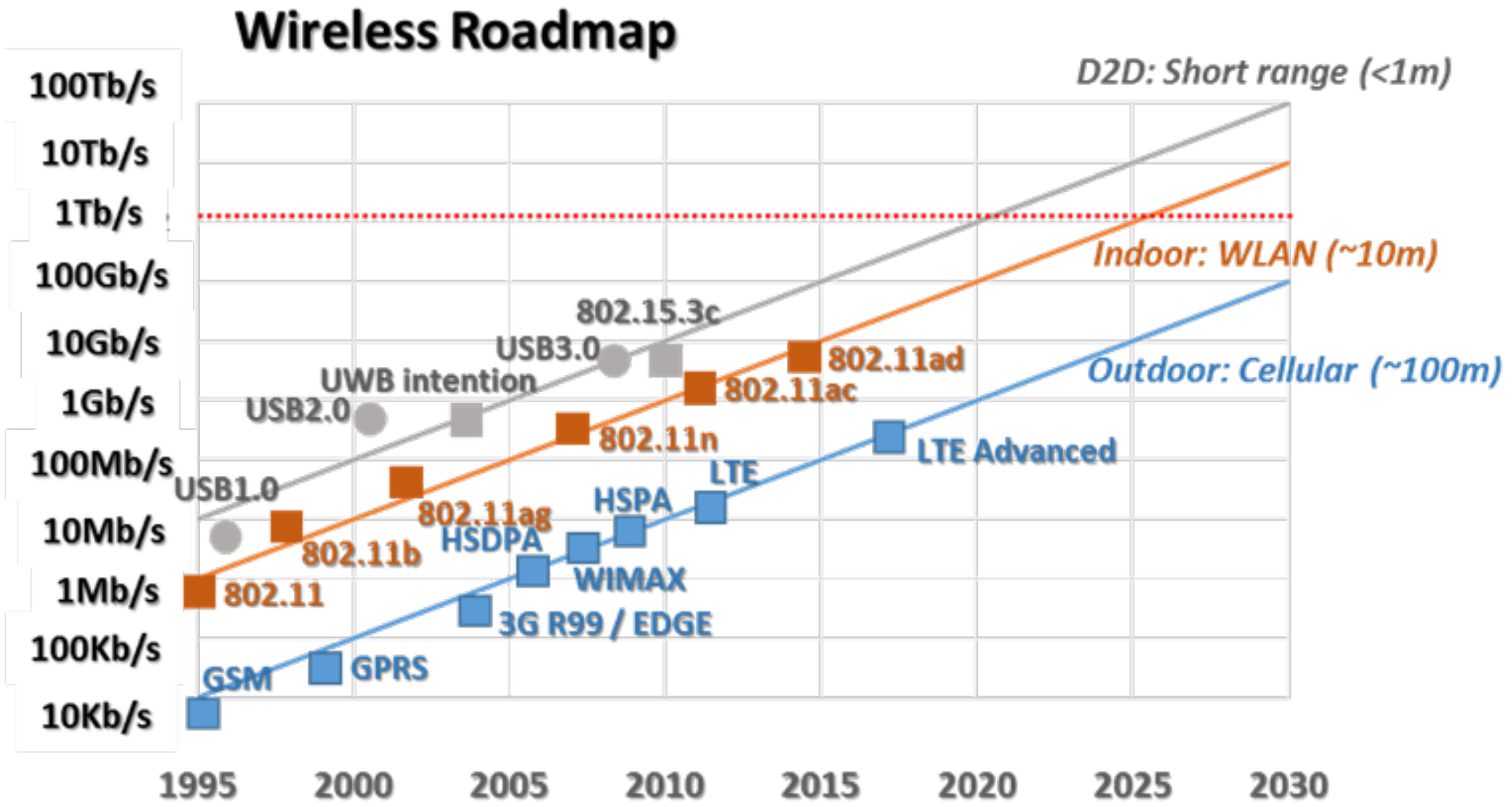


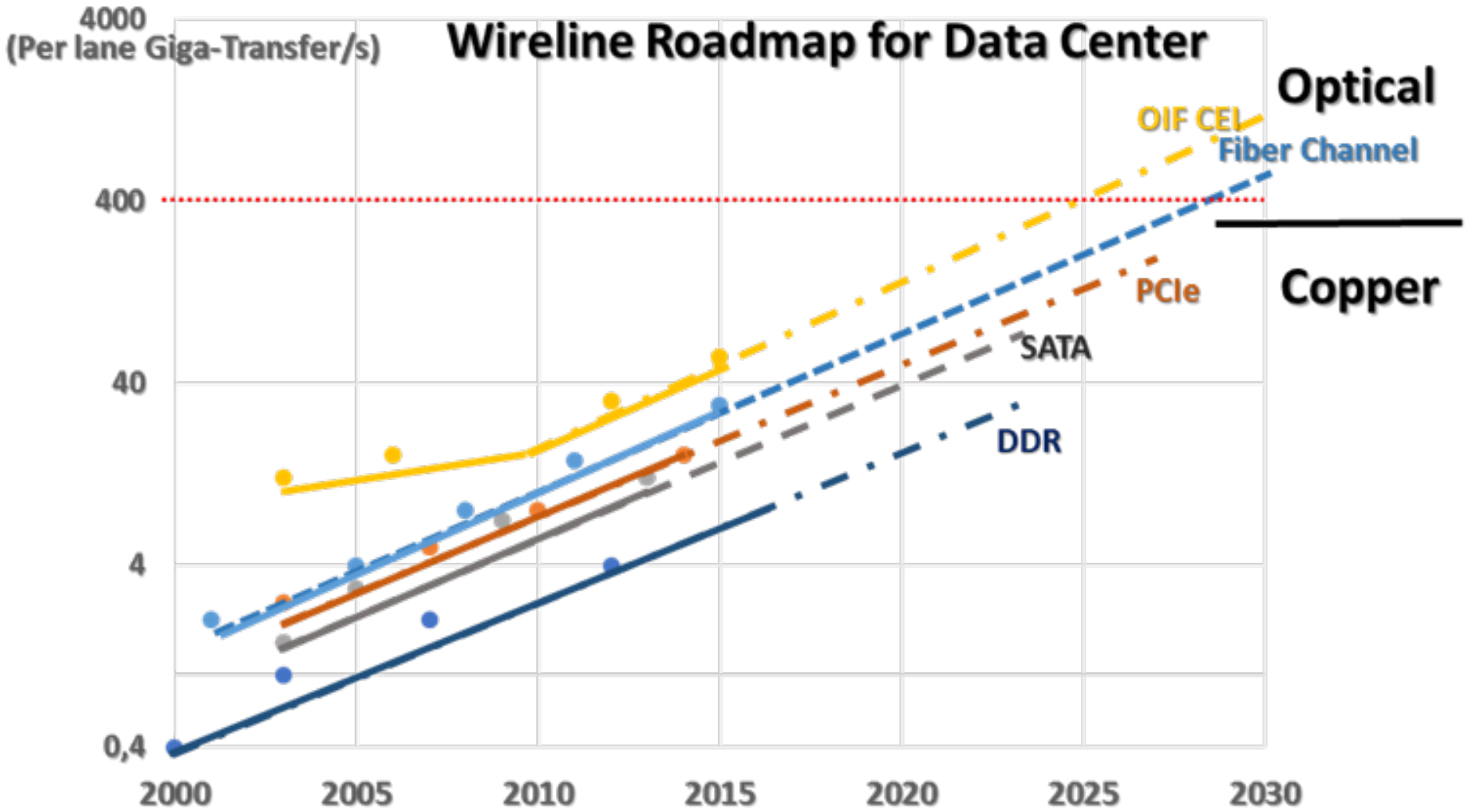
Source: broadbandtrends

Challenges for Connectivity



Source: 2016 Ethernet Roadmap - The Past, Present, and Future of Ethernet

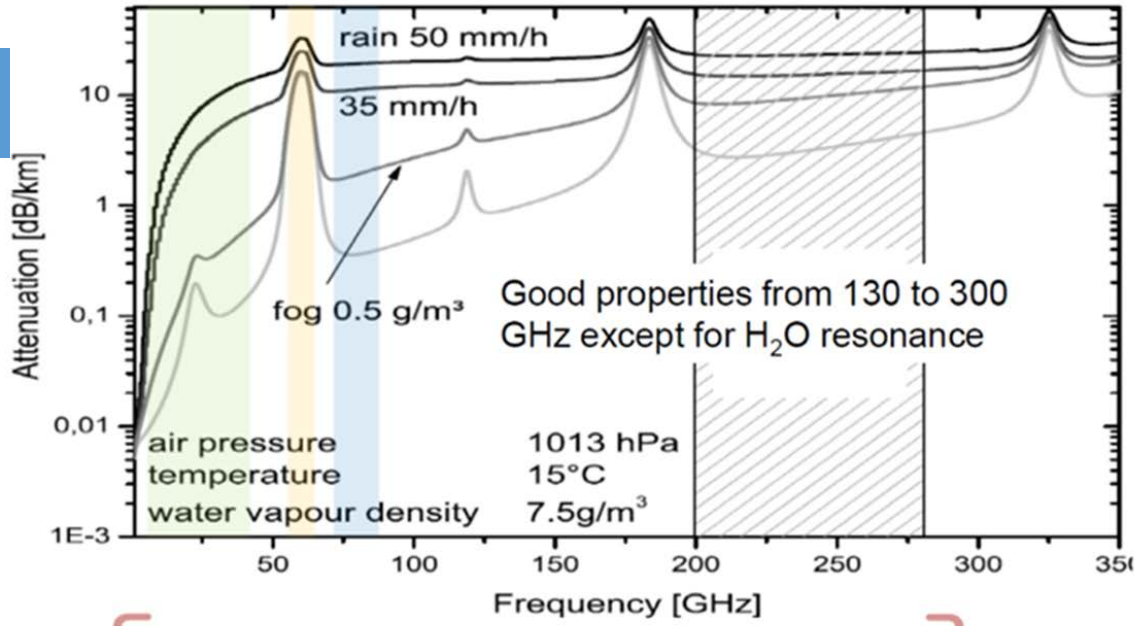

Wireless Roadmap
D2D: Short range (<1m)
Indoor: WLAN (~10m)
Outdoor: Cellular (~100m)
100Tb/s
10Tb/s
1Tb/s
100Gb/s
10Gb/s
1Gb/s
100Mb/s
10Mb/s
1Mb/s
100Kb/s
10Kb/s
1995
2000
2005
2010
2015
2020
2025
2030
802.15.3c
USB3.0
UWB intention
USB2.0
802.11ad
802.11ac
802.11n
802.11ag
802.11b
802.11
USB1.0
LTE Advanced
LTE
HSPA
HSDPA
WIMAX
3G R99 / EDGE
GPRS
GSM



Matteo Bassi - Analog Integrated Circuits, University of Pavia - http://www-3.unipv.it/aic/ - Sinano Summer School 2016

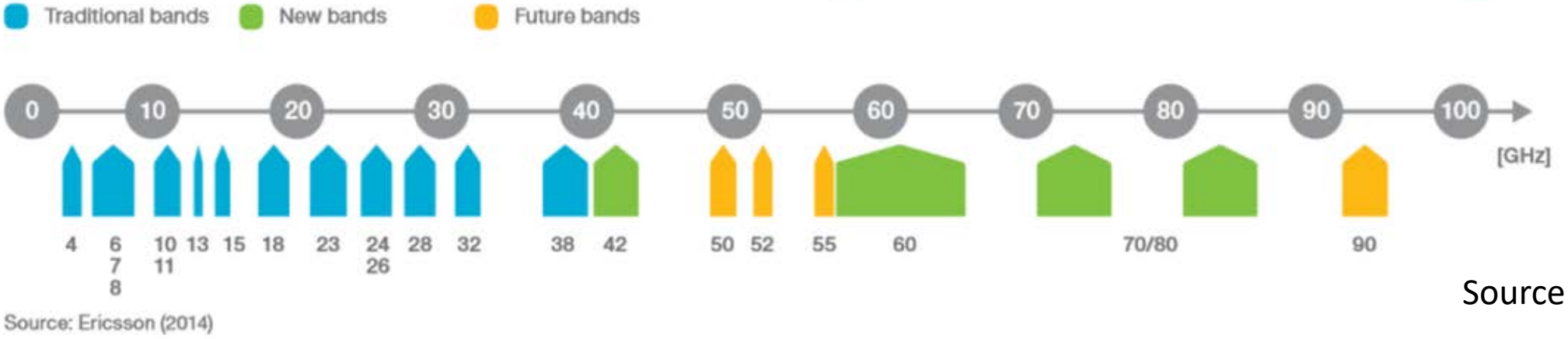
Transmission properties

And Beyond 5G



Attenuation close to constant from E-band and up

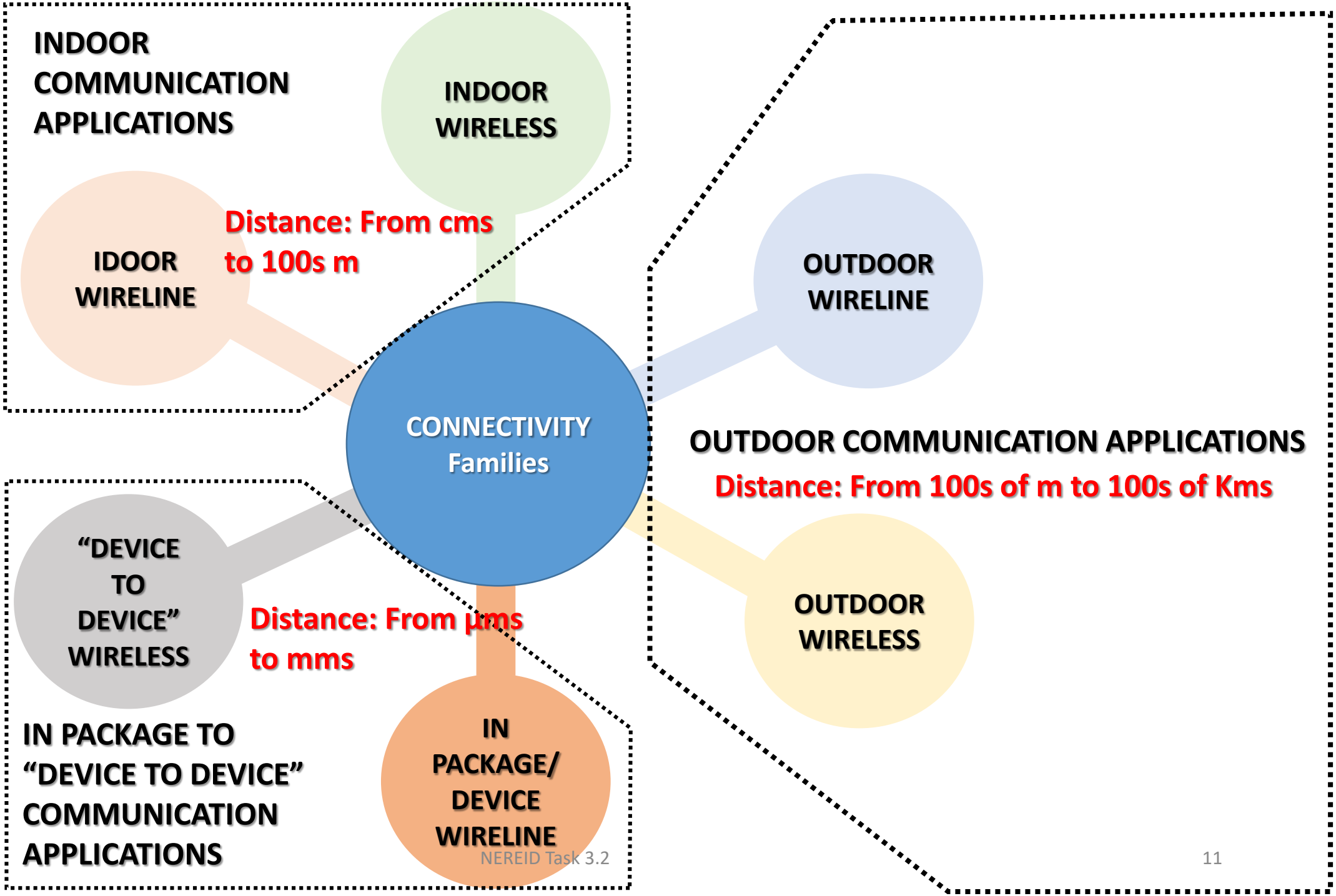
5G



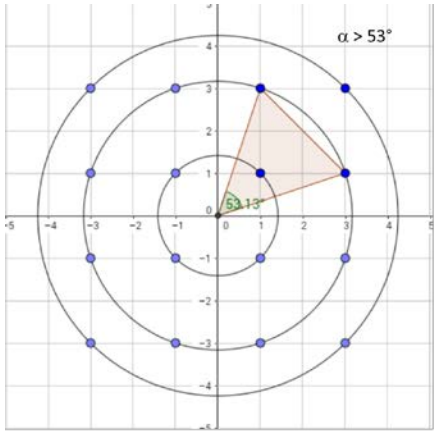
Source: Ericsson (2014)

Source: Ericsson

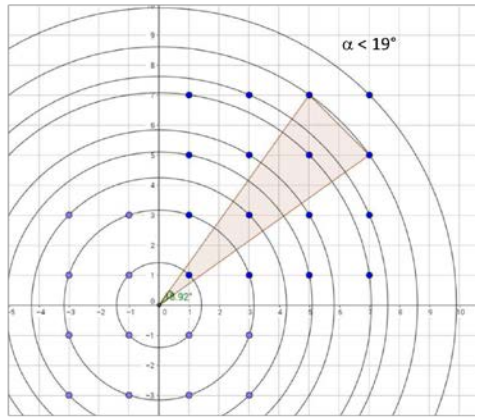
Roadmap Construction


INDOOR COMMUNICATION APPLICATIONS
INDOOR WIRELESS
IDOOR WIRELINE
Distance: From cms to 100s m
CONNECTIVITY Families
OUTDOOR WIRELINE
OUTDOOR COMMUNICATION APPLICATIONS
Distance: From 100s of m to 100s of Kms
OUTDOOR WIRELESS
"DEVICE TO DEVICE" WIRELESS
Distance: From µms to mms
IN PACKAGE TO "DEVICE TO DEVICE" COMMUNICATION APPLICATIONS
IN PACKAGE/ DEVICE WIRELINE

Connectivity Wireless BER example



16 QAM constellation



64 QAM (First quadrant) constellation

BER= f(S/N & Modulation)

ABB - DBB
(S/N= f(Phi N & NF))

DWN Conversion Ampli
(Phi N)
(NF)

Air Interface
GAIN / LOSSES

Air transmission
LOSSES

RX

Multi Chip System

Mixed SOC
DATA
TX – RX

FE Module
PAs-LNAs
Filters
Switches
mmW
Antennas
Array

ANTENNAS

DBB out

DBB in

(S/N)
DBB - ABB

(Phi N)
Up Conversion

(EVM)
Ampli

GAIN / LOSSES
Air Interface

LOSSES
Air transmission

TX

Connectivity Functions Figure Of Merit : Connectivity-FOM

Ideal Figure of Merit Should take into account:

- The Data Rate of the connectivity function
- The distance of the connection
- The quality of the service given by the invert of the Bit Error Rate
- The power efficiency of the connection given by the invert of the power consumption

$$FOM = \frac{Data\_rate(Gbs) \times D(m) \times \frac{1}{BER}}{Psupply(W)}$$

Actual Figure of Merit takes into account:

- The Data Rate of the connectivity function
- The distance of the connection
- **The other parameters will be defined as main challenges**:
  - The quality of the service given by the invert of the Bit Error Rate
  - The power efficiency of the connection given by the invert of the power consumption

$$FOM = Data\_rate(Gbs) \times D(m)$$

OUTDOOR WIRELESS APPLICATIONS (1)

Outdoor & Cellular	Present	5 Years	10 Years
IoT Long Range	Sub GHz (10s Kms, Kbs) ultra low power (mW)	*Sub GHz (100Km, Kbs & 15km, Mbs)* *Ultra low power (<mW)*	*Sub GHz (100Km, few Kbs & 15km, few Mbs)* *Zero power (<100µW)* *Hardware security embedded*
Dwn Links	0.7 to 3GHz (few Mbs)	*0.7 to 100GHz (10 Gbs)* *With dynamic Beam Orientation*	*Up to THz (10s of Gbs)* *With Dynamic Beam Orientation*
Fix Mini Cell to Mini Cell & Fix Mini Cell to Cell **Backhauling**	Research Activities on mmW bands: 28GHz; 40GHz; 60GHz; 70-80GHz.	*mmW to THz bands (10s of Gbs) with Beam Focusing*	*mmW to THz bands (100 Gbs) with Beam Forming*

Potential for Application or Application needs and Impact for Europe	5 Years	10 Years
5G+ Network:	Big Data, Cloudification: European solution for European Business and population.	Full Distributed Cloud; Ad-hoc / opportunistic; local cloud (clustering); multi-cloud: European Independence.
Autonomous objects:	Driving aid, drones automation…: Lifes saved; injured number reduction; travel time reduction; CO2 emission reduction.	Dynamic automated data driven decision & vehicle action: Safe transport system. Sober transport system
Environmental mapping:	Forests, water, snow …. Surveys: Better European Environment control.	Global multi physics environment survey: Better disaster prevent.

OUTDOOR WIRELESS APPLICATIONS (2)

Figure of Merit	2023	2026	2029	2033
FOM=Data_rate(Gbs)×$D(m)$				
IoT Long Range FOM: (15km distance)	15 Gbs.m	30 Gbs.m	60 Gbs.m	120 Gbs.m
Cellular Dwn Links FOM: (100m distance)	50 Gbs.m	100 Gbs.m	800 Gbs.m	5000 Gbs.m
Fix Backhauling FOM: (150m distance)	1500 Gbs.m	3750 Gbs.m	7500 Gbs.m	15000 Gbs.m
Challenges & Potential WPs Collaborations				
IoT Long Range: Standardization harmonisation (WP5); Life duration autonomy (WP4); Embedded security and artificial Intelligence (WP5); Integration (WP5); ultra-low cost (in cents range) **Cellular Dwn Links: Dynamic Beamforming (T3-1; WP2); Privacy (WP5); Minimizing the Power consumption of the mobile (WP4), low cost in mobile (in $ range).** **Fix Backhauling: Up to 300GHz spectrum (T3-1; WP2); Wider Bands; Beamforming (WP5); Low cost solution (1/10 to 1/100 versus existing wireline solutions cell 2 cell)**				

OUTDOOR WIRELINE APPLICATIONS (1)

Cellular, Data Centers long Range, and Long Haul	Present	5 Years	10 Years
Cell to Cell ;	Optical Fibers (10 Gbs / fiber)	*Optical fibers: 100 Gbs / fiber*	*Optic (200 Gbs / fiber)*
Fix Mini Cell to Mini Cell, Fix Mini Cell to Cell	Researches in low cost High Data Rate wireline solutions	*Low cost Optical Fibers (10s of Gbs); Through wall Plastic Waveguide (10 Gbs)*	*Low cost Optical Fibers (100 of Gbs); Through wall Plastic Waveguide (10s of Gbs)*
Cell to Data Centers; Data Centers Long Range	Optical Fibers (10 Gbs / fiber)	*Optical Fibers: 100 Gbs / fiber*	*Optical fibers: 200 Gbs / fiber*
Long haul	Optical fibers (< 10 Gbs / fiber)	*Optical fibers: 40 Gbs / fiber*	*Optical Fibers: 100 Gbs / fiber*

Potential for Application or Application needs and Impact for Europe	5 Years	10 Years
5G+ Network & 5G+ Servers:	Big Data, Claudification: European solution for European Business and population	Full Distributed Cloud; Ad-hoc / opportunistic; local cloud (clustering); multi-cloud: European Independence
WWAN:	Global Network: Web 3.0	Global Network: Web 4.0
FTTx:	Sub-Urban Network deployment: More Citizen will have RAN 2.0 access	Local Rural network deployment: Increasing the citizen number accessing to RAN 3.0.

OUTDOOR WIRELINE APPLICATIONS (2)

Figure of Merit	2023	2026	2029	2033
FOM=Data_rate(Gbs)×$D(m$ or Km)				
Cellular Base Station to Base Station FOM: (1km distance)	100 Gbs.Km	150 Gbs.km	200 Gbs.km	300 Gbs.km
Fix Mini Cell to Mini Cell, Fix Mini Cell to Cell Base Station FOM: (150m distance)	7500 Gbs.m	11000 Gbs.m	15000 Gbs.m	22000 Gbs.m
Cell Base Station to Data Centers & Data Centers Long Range FOM: (10km distance)	1000 Gbs.km	1500 Gbs.km	2000 Gbs.km	3000 Gbs.km
Long haul FOM: (100km distance)	4000 Gbs.km	7000 Gbs.km	10000 Gbs.km	14000 Gbs.km
Challenges & Potential WPs Collaborations				
Cellular Base Station to Base Station: Cost Reduction (WP5); Power consumption Reduction **Fix Mini Cell to Mini Cell, Fix Mini Cell to Cell Base Station: Low cost solution (1/100 of present cell to cell; WP5); Low power solution (1/10 to 1/100 of present cell to cell)** **Cell Base Station to Data Centers & Data Centers Long Range: Data rate per Fiber (T3-1; WP2); Complex modulations (WP5)** **Long haul: Data rate per Fiber (T3-1; WP2); Complex modulations (WP5)**				

INDOOR WIRELESS APPLICATIONS (1)

Indoor communication & Localization	Present	5 Years	10 Years
WLAN/WPAN/WBAN	WiFi (2.4 – 5GHz; <500Mbs) BT (2.4GHz; <10Mbs) DECT (1.9GHz; <100kbs) Infrared (<10m)	*Cognitive Multi Mode Radio 0-6GHz and 60GHz band; LiFi (10s Gbs); P2P over 100GHz bands; New sub-THz band*	*Cognitive Multi Mode WLAN over 100GHz; LiFi (100s Gbs); P2P in sub-THz band*
WSN	Ad-hoc(ISM bands; Kbs) Zigbee (2.4GHz; Kbs) BTLE (2.4GHz; Kbs)	Cooperative sensing, cooperative radio; Toward « Zero Power » Hardware Securtiy embedded	*« Recycling material » for radio* *« Zero power node »; Security / Safety / Privacy Embedded.*
Localization	Radar (RF; < 10m) Infrared (<10m)	*Radar (RF to THz); UWB ; Ultrasound; Impulse light*	*Multi physics fusion*

Potential for application or Application needs and Impact for Europe	5 Years	10 Years
Fitness:	Performance sensing & benchmarks: Consumer Market	Enhanced human performances: Consumer Market
Healthcare:	E-Monitoring: Aging people maintained at home.	E-Hospital: Specialist intervention through the Net. Data Analysis and decision making.
Home safety & security	E-Survey: Domestic accidents and burglaries prevent	Autonomous Home protection: Data Analysis and decision making
Public space safety & security	E-Survey: aggressions, stealing actions, terrorist actions prevent.	Autonomous Public Protection: Multi source data analysis and decision making.
Factory 4.0	Machine automation: reduction of human intervention in product process.	Factory 4.0: No Human intervention.
Autonomous objects	Mono-function autonomous machine: Reducing borrow tasks at home.	CPS: First generation of multi functions robots.

INDOOR WIRELESS APPLICATIONS (2)

	2023	2026	2029	2033
Figure of Merit **FOM=Data_rate(Gbs, Mbs or Kbs)×$D(m)$**				
WLAN FOM: (10m)	250 Gbs.m	500 Gbs.m	1000 Gbs.m	2000 Gbs.m
WPAN FOM: (10m)	50 Mbs.m	100 Mbs.m	150 Mbs.m	200 Mbs.m
WBAN FOM: (1m)	1 Kbs.m	10 Kbs.m	100 Kbs.m	1000 Kbs.m
WSN FOM: (10m)	10 Kbs.m	100 Kbs.m	1000 Kbs.m	10000 Kbs.m
Localization FOM: (10m) FOM is relative accuracy	1%	0.3%	0.05%	0.01%
Challenges & Potential WPs Collaborations				
WLAN: mmW to THz spectrum use (T3.1; WP2) ; Beam forming (WP5); Privacy (WP5); Wide band; Low cost (in $ range); Integration (WP5) **WPAN: Embedded Security (WP5); Low Power (mW range); Integration (WP5); Low cost (in 10s of cents range)** **WBAN: Embedded security(WP5); Privacy (WP5); Ultra low power (100 µW range); Bio-compatible Integration (WP5)** **WSN: Embedded security (WP5); Ultra low power (Life duration Autonomy; WP4); Integration (WP5); Ultra low cost (in cents range)** **Localization : Spectrum compatibility (WP5); data fusion (WP5); Integration (WP5)**				

INDOOR WIRELINE APPLICATIONS (1)

Indoor & Data Center Short Range	Present	5 Years	10 years
WLAN	Copper (100Mbs; <5m) PLC (Power line carrier) (1Mbs; 20m) Optical Fiber (few Gbs; 100m) Plastic Optical Fiber(10s of Mbs; 10m)	*Copper (Low power HDR); PLC (100Mbs; 20m); Optical Fiber (100 Gbs; 100m); GI-POF (1 Gbs; 10m); mmW Plastic Wave Guide (few Gbs; <20m)*	*Copper (ULP HDR); PLC (n x 100Mbs; 20m); Optical Fiber (100s of Gbs; 100m); GI-POF (10 Gbs; 10m); mmW PWG (n x 10Gbs; <20m)*
Data Centers Short Range	Copper (1m; <10 Gbs) Optical Fibers (10m; 40 Gbs / fiber)	*Copper (1m; 10s of Gbs) ; Optical Fiber (10m; 400 Gbs / fiber); GI-POF (1m; 1Gbs)* *mmW PWG(1m; 10Gbs)*	*Copper (1m; 100Gbs) ; Optical Fiber (10m; 1Tbs / fiber); GI-POF (1m; 10 Gbs)* *THz PWG (1m; 10s of Gbs)*

Potential for application or Application needs and Impact for Europe	5 Years	10 Years
Home Automation:	Multi physics Network: Reducing time transfer for data at home.	Multi physics Network: Reducing decision making at home.
Factory Automation:	Multi physics Network: Reducing time transfer for data in Factory	Multi physics Network: for Factory 4.0
5G+ Data Center:	Very high speed Network: for short range transfer.	Very high speed Network: for RAN 3.0

INDOOR WIRELINE APPLICATIONS (2)

Figure of Merit	2023	2026	2029	2033
FOM=Data_rate(Gbs or Mbs)×$D(m)$				
WLAN FOM: (10m)	1000 Gbs.m	1500 Gbs.m	2000 Gbs.m	3000 Gbs.m
Data Centers Short Range FOM: (10m)	4000 Gbs.m	7000 Gbs.m	10000 Gbs.m	15000 Gbs.m
Challenges & Potential WPs Collaborations				
WLAN: Integration (WP5); low cost (in the wireless solutions range: $) Data Centers Short Range: Data Rate per fiber (T3-1 WP2); Integration (WP5); Reliability (WP5)				

DEVICE TO DEVICE WIRELESS APPLICATIONS (1)

Ultra Short Range	Present	5 Years	10 years
Die To Die **Package To Package**	Research on: EM Field (Mbs, mm) ES Field (Mbs, µm) mmW Radio (Gbs, mm)	*Data Rate > 10Gbs; BER 10^{-15}*	*Data Rate > 100Gbs; BER 10^{-18}*
NFC	RF (13MHz; Kbs)	*RF (13MHz; 1Mbs); Hardware Security Embedded*	*Security / Privacy Embedded*
RFID	RF (13MHz; Kbs) RF (2.4GHz; Mbs) Research: in mmW bands	*RF (13MHz; 100Kbs); RF (2.4GHz; 10Mbs); mmW (60GHz; 100Mbs)*	*Security / Safety / Privacy Embedded*

Potential for application or Application needs and Impact for Europe	5 Years	10 Years
High data rate without contact transfer	Multi-media transfer: Consumer market.	Data-Base transfer: Consumer market.
Contact-less Safe Data transfer:	Money transfer: Security of the operation.	Personal and confidential data transfer: Safe and secure.
Traceability and identification:	Goods and animals: safe and secure	People: Privacy.

DEVICE TO DEVICE WIRELESS APPLICATIONS (2)

Figure of Merit	2023	2026	2029	2033
FOM=Data_rate(Gbs, or Mbs)×$D(m)$				
Die To Die & Package To Package FOM: (10cm)	1 Gbs.m	5 Gbs.m	10 Gbs.m	50 Gbs.m
NFC FOM: (10cm)	0.1 Mbs.m	0.5 Mbs.m	1 Mbs.m	5 Mbs.m
RFID FOM: (1m)	100 Mbs.m	500 Mbs.m	1000 Mbs.m	1500 Mbs.m
Challenges & Potential WPs Collaborations				
Die To Die & Package To Package : In the wireline quality: 10E-18 BER; Integration density (WP2); Ultra-low power (WP4) (<mW/link) NFC: Privacy (WP5); Embedded security (WP5); power consumption (WP4) RFID: mmW spectrum use (T3-1 WP2); Embedded security (WP5); Ultra-low power (WP4) (<mW); Integration (WP5)				

IN PACKAGE/DEVICE WIRELINE APPLICATIONS (1)

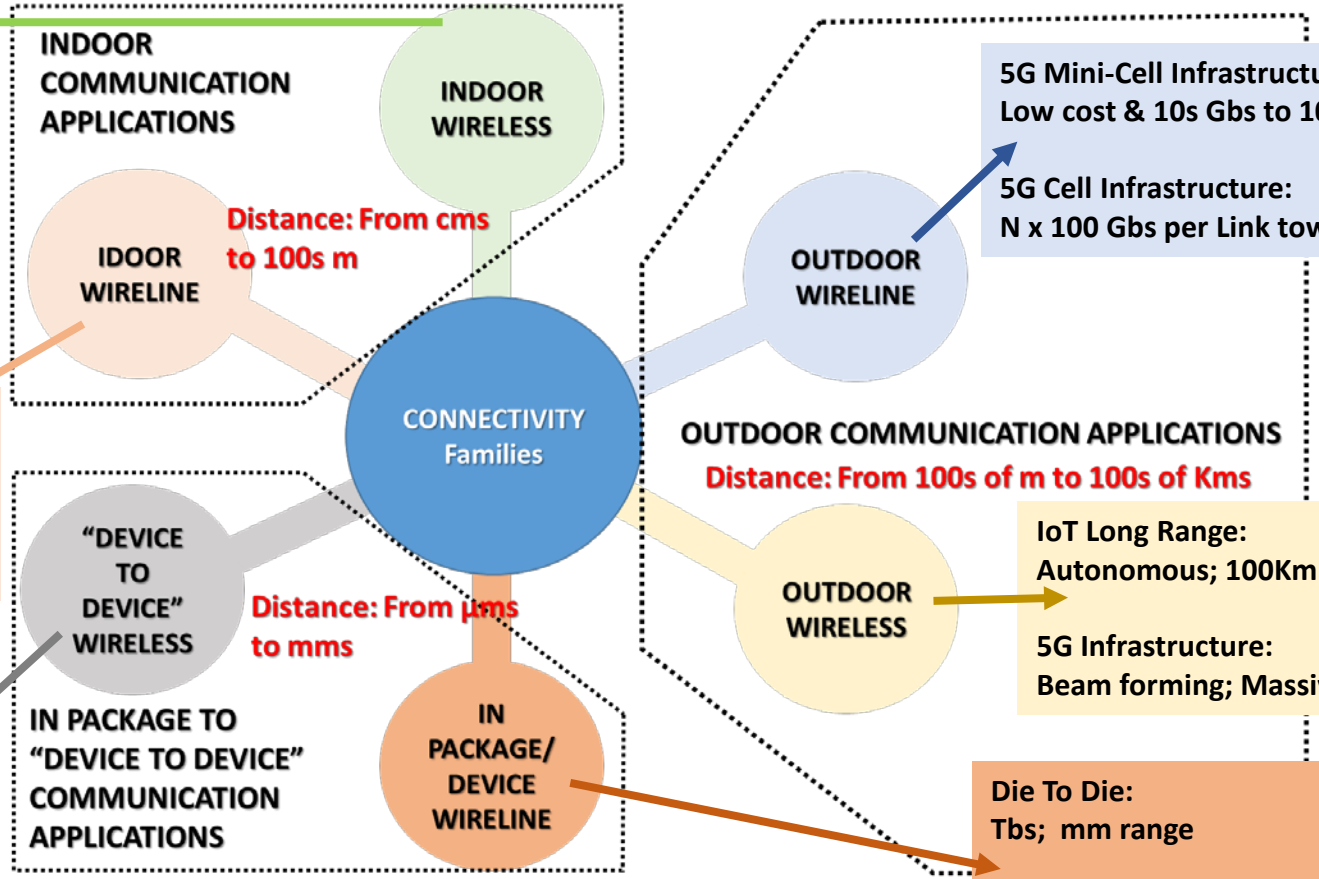
In Package Wireline	Present	5 Years	10 years
Die 2 Die	Copper Pilar (Gbs, 100s µm) Short Bonding (100Mbs, mm) Photonics Silicon Interposer (10s Gbs, mm)	*Copper links (100 Gbs, 100s um);* *Photonics Silicon Interposer (1 Tbs, 10s mms);* *Active Interposers (100Gbs, mm) Flip chipped + Copper (100 Gbs , mm)*	*Photonic Silicon Interposer more than 2 Tbs over 10s mm* *Active Interposers (1Tbs, mm)*
In Module & Module 2 Module	Bonding (10s Mbs, mm) Optical guide on module's substrate (10s Gbs, mms) Flip chipped + Copper (Gbs , mm)	*Optical Waveguide (Tbs, 10 cm), Multifiber connectors, passive alignment*	*Toward 10 Tbs over 10 cm*
Active cable	Optical guide/Fiber (10s Gbs, 10s cms) Copper (Gbs, 10s cms)	*Optical guide/Fiber (toward 2Tbs, 10s cm);* *Copper (100 Gbs, 10s cms);* *GI-POF (10Gbs, 10s cms);* *mmW Plastic Wave Guide (10s Gbs, 10s cm)*	Toward 10 Tbs over 10s cms

Potential for application or Application needs and Impact for Europe	5 Years	10 Years
HPC:	Multicore Processor: European Independence.	Cognitive computing: European Independence.
5G+ Data-center	Big data	Big Data
Intelligent transport; Entertainment; Factory 4.0…	Data transfer	Data transfer

IN PACKAGE/DEVICE WIRELINE APPLICATIONS (2)

Figure of Merit	2023	2026	2029	2033
FOM=Data_rate(Gbs)×$D(m)$				
Die 2 Die FOM: (1cm distance)	10 Gbs.m	15 Gbs.m	20 Gbs.m	30 Gbs.m
Module 2 Module FOM: (10cm distance)	100 Gbs.m	500 Gbs.m	1000 Gbs.m	5000 Gbs.m
Active Cable FOM: (1m distance)	1000 Gbs.m	5000 Gbs.m	10000 Gbs.m	50000 Gbs.m
Challenges & Potential WPs Collaborations				
Die 2 Die : Photonic integration (T3-1 - WP2 – WP5) ; Power consumption (<mW / link) (WP4); Heat management (WP5) Module 2 Module : Photonic integration (T3-1 - WP2 - WP5) ; Power consumption (in the mW range) (WP4) Active Cable : Photonic integration (T3-1- WP2 – WP5) ; Power consumption (in the 10s of mW range) (WP4)				

Next 5 years Connectivity Challenges



WLAN/WPAN/WBAN:
Cognitive; RF-mmW-Light, up to 10s Gbs

WSN:
WuR; µW; Securtiy

Localization:
RF-mmW-THz; µm-cm accurate; cm-100m range

WLAN:
100s Gbs – 100m OF; 1Gbs – 10m GPOF

5G Data Centers Short Range :
10s meters; n x 100Gbs / link, up to Tbs.

Die To Die & Package To Package:
10Gbs & BER 10^{-15}; few mm

NFC:
Security embedded; few cm

RFID:
mmW-100Mbs & Security embedded

5G Mini-Cell Infrastructure:
Low cost & 10s Gbs to 100Gbs

5G Cell Infrastructure:
N x 100 Gbs per Link toward 400Gbs

IoT Long Range:
Autonomous; 100Km range; Security embedded

5G Infrastructure:
Beam forming; Massive MIMO; 10s Gbs to 100Gbs

Die To Die:
Tbs; mm range

In Module:
Tbs; 10s mms range.

IN Device (phones….):
10s Gbs over 10s cms range.

Next 10 years Connectivity Challenges

WLAN/WPAN/WBAN:
Up to 100s Gbs; Sub-THz band

WSN:
Zero Power Node; Securtiy-Safety-Privacy

Localization:
Multi-Physics Radar Fusion

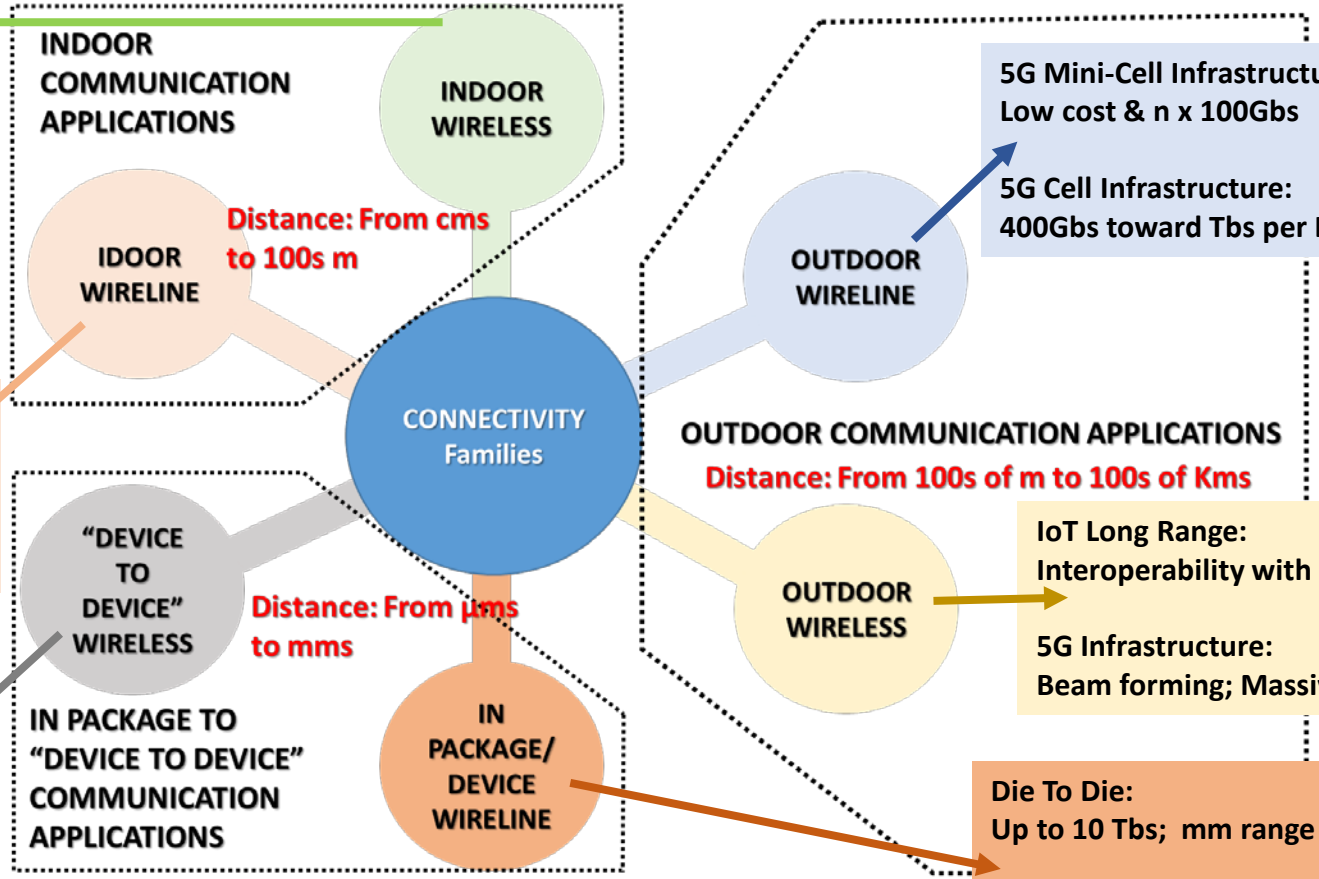
WLAN:
Tbs – 100m OF; 10s Gbs – 10m GPOF (Plastic material)

5G Data Centers Short Range :
10s meters; N x Tbs per links

Die To Die & Package To Package:
100Gbs & BER 10^{-18}; few mm

NFC:
Security-Privacy Embedded; few cm

RFID:
mmW-1Gbs & Security / Safety / Privacy embedded



5G Mini-Cell Infrastructure:
Low cost & n x 100Gbs

5G Cell Infrastructure:
400Gbs toward Tbs per Link

IoT Long Range:
Interoperability with 5G

5G Infrastructure:
Beam forming; Massive MIMO; n x 100Gbs

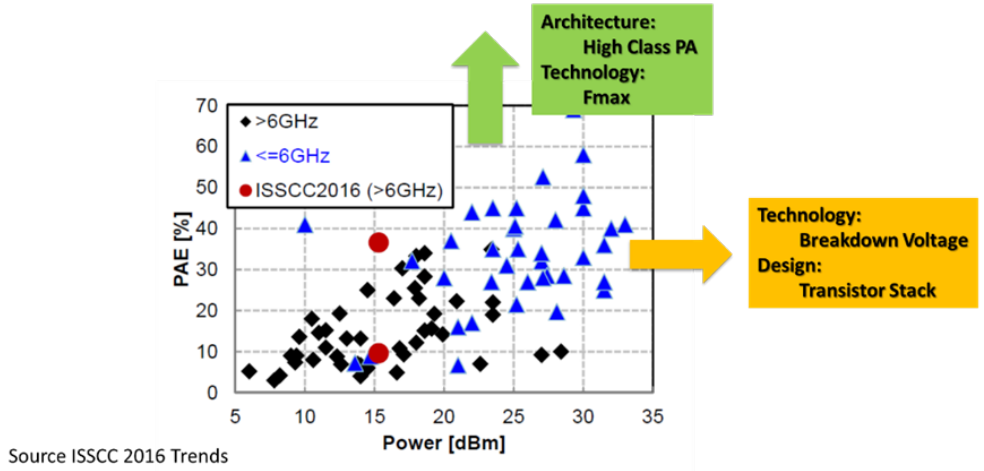
Die To Die:
Up to 10 Tbs; mm range

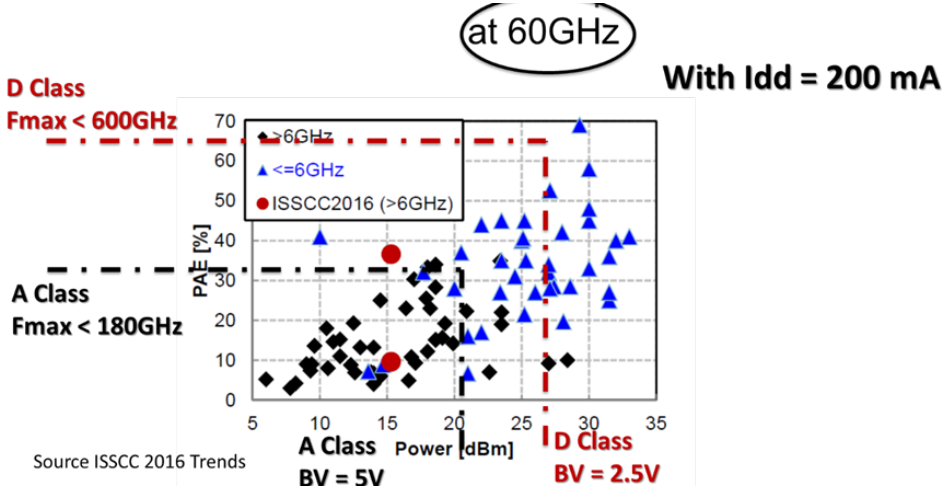
In Module:
Up to 10 Tbs; 10s mms range.

IN Device (phones….):
N x 100s Gbs over 10s cms range.

Silicon for Applications: 60GHz Power Amplifier example

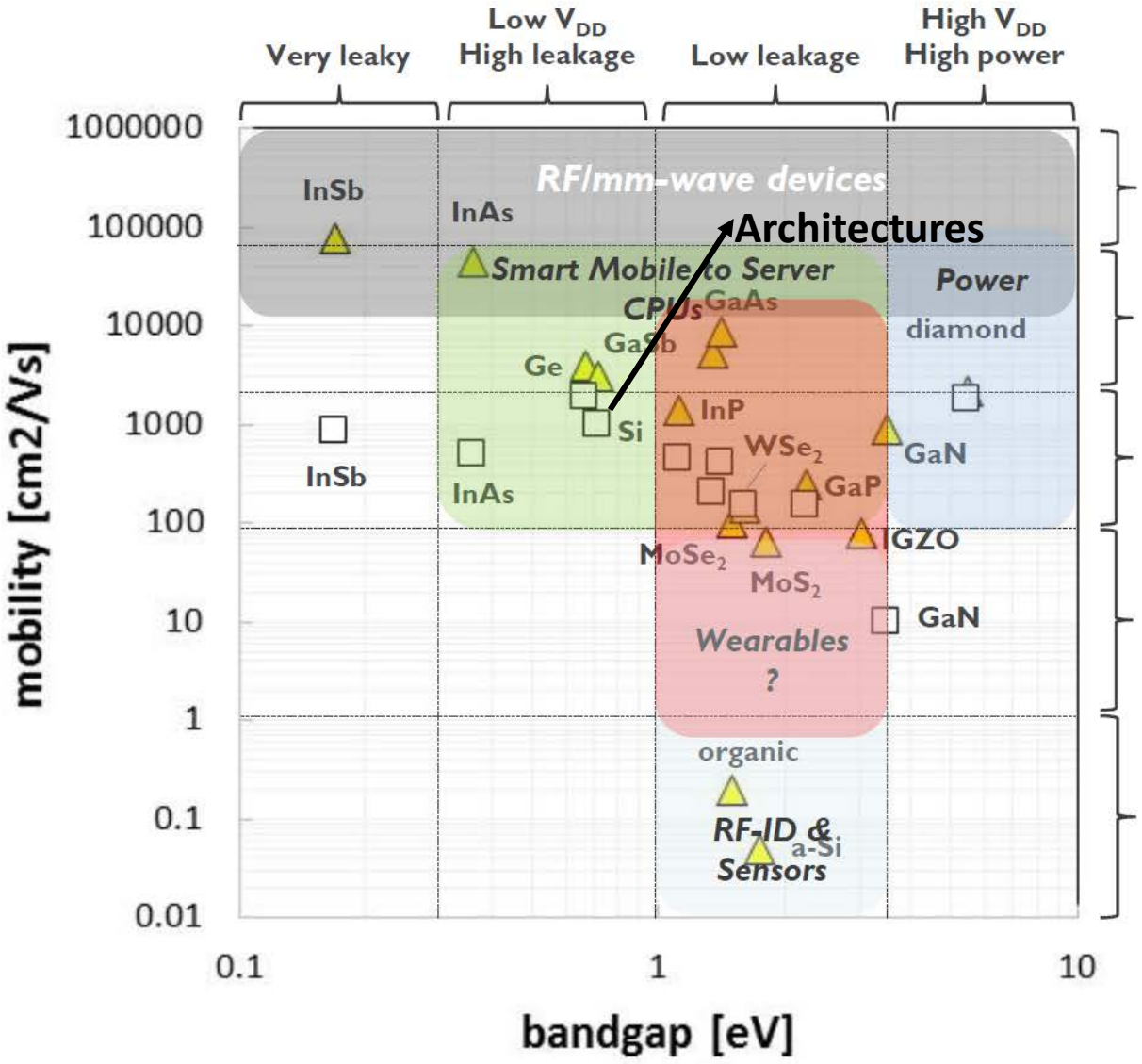
Function Performance = The Technology + The FET Architecture + The Design Architecture + The System Architecture





Class	Active(s)	Theoric Drain efficiency (%)	Theoric PAE (%)	Vdsmax	Idmax
A	1	50	33	BV/2	2*Idd
AB	1	50 - 75	33 - 50	BV/2	2 - Π*Idd
B	1	75	50	BV/2	Π*Idd
C	1	80 - 95	52 - 62	BV/2	3.8*Idd
D	2	100	66	BV	Π*Idd
E	1	100	66	BV/2.8	3.6*Idd
F	1	90	60	BV	Π*Idd

Material for Applications



RF performance (100's GHz)

Very fast electronics (~2-100GHz)

Fast electronics (~500MHz-2GHz)

Slow electronics (~1-100MHz)

Very slow electronics (100's kHz-1MHz)

5G Mini-Cell Infrastructure
5G Cell Infrastructure

5G Infrastructure & Access Points

5G Data Centers Short Range

Die To Die:
In Module & Module 2 Module:
Active Cable

Die To Die & Package To Package

WLAN

WLAN/WPAN/WBAN

Localization

IoT Long Range:

RFID

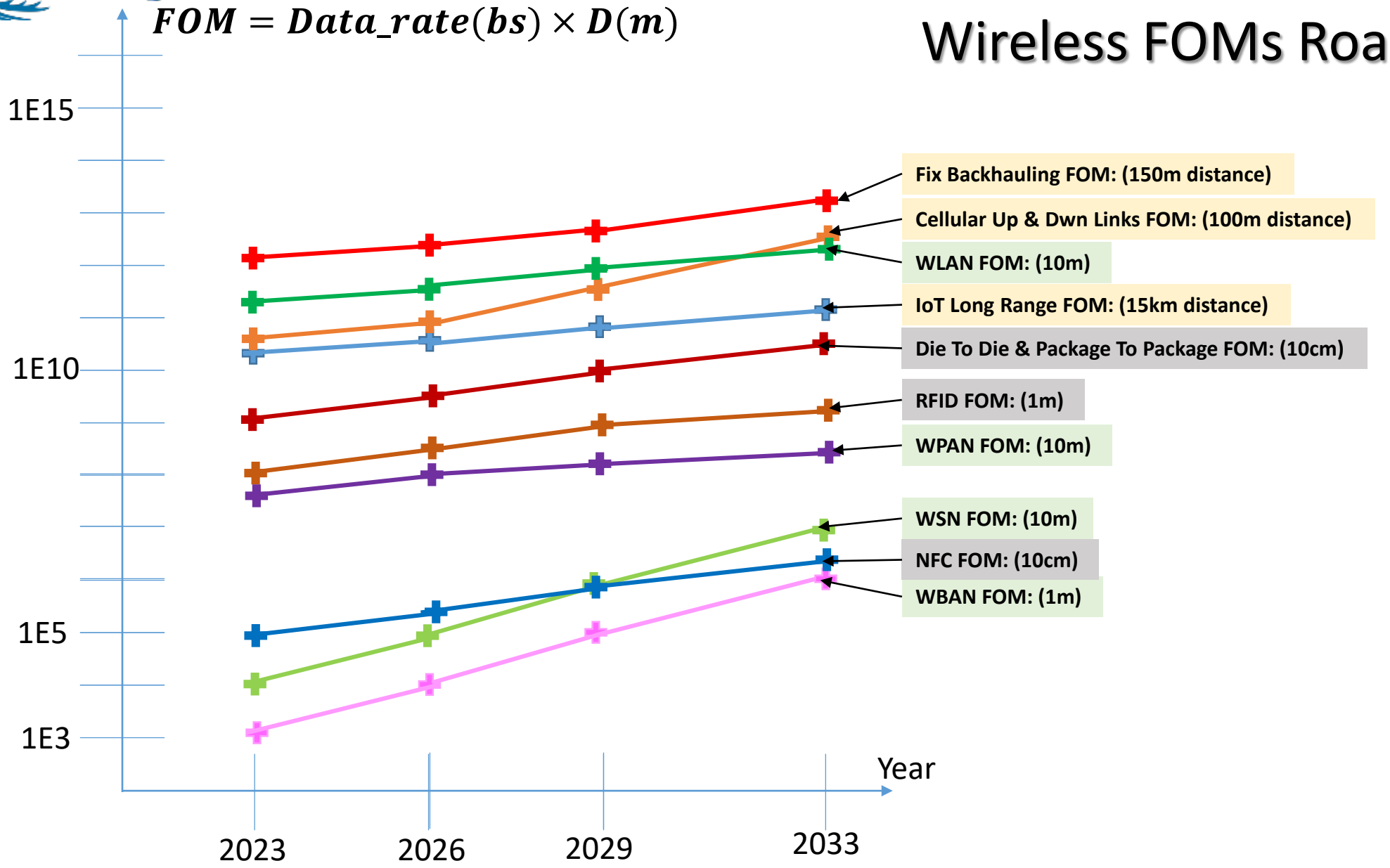
WSN

NFC

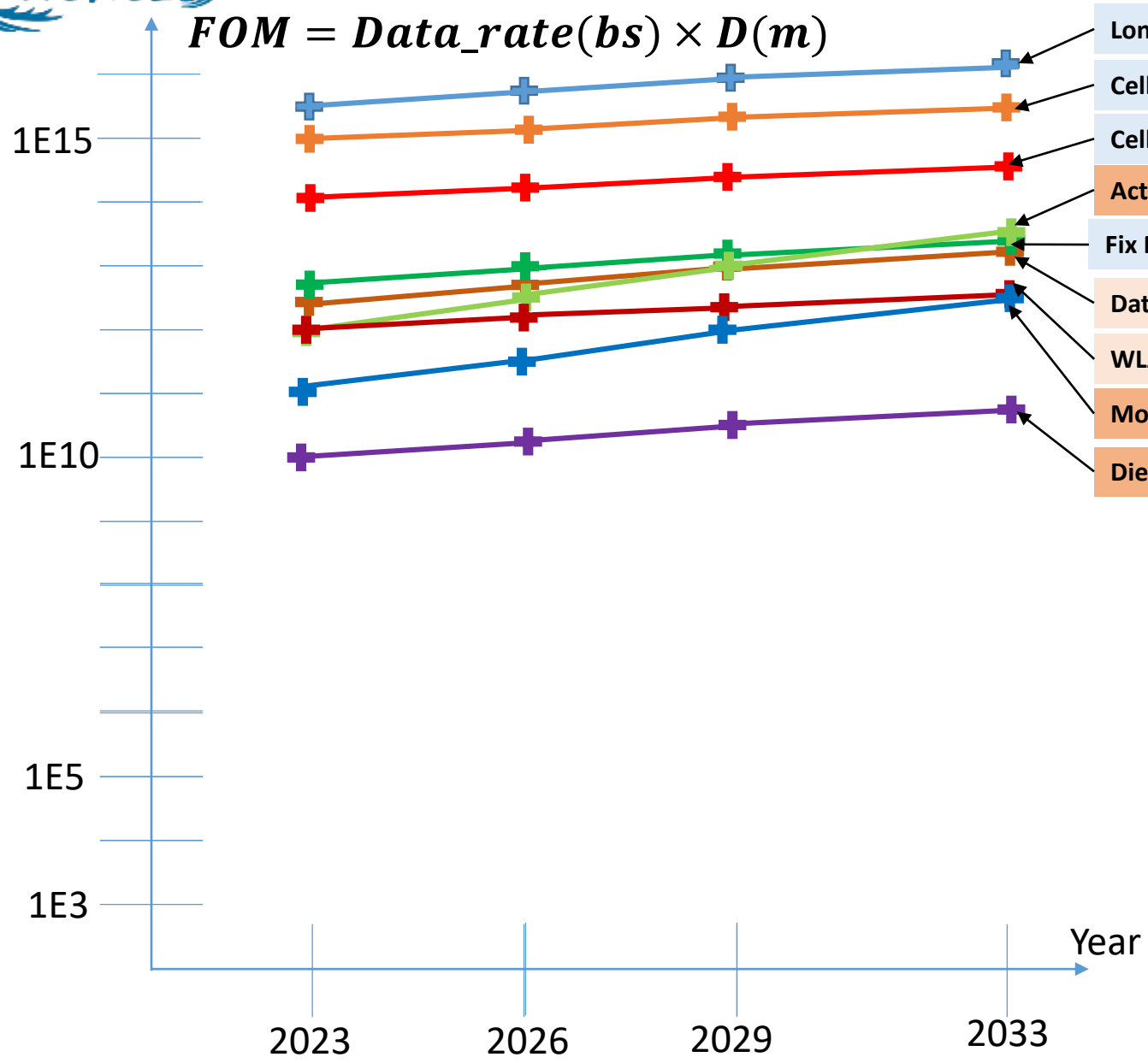
Applications FOM Roadmap

Type	Applications	FOM bs.m 2023	2026	2029	2033
OUTDOOR WLESS	IoT Long Range FOM: (15km distance)	1,50E+10	3,00E+10	6,00E+10	1,20E+11
	LOG	10,17609126	10,47712125	10,77815125	11,07918125
	Cellular Up & Dwn Links FOM: (100m distance)	5,00E+10	1,00E+11	8,00E+11	5,00E+12
	LOG	10,69897	11	11,90308999	12,69897
	Fix Backhauling FOM: (150m distance)	1,50E+12	3,75E+12	7,50E+12	1,50E+13
	LOG	1,27E+01	1,26E+01	1,29E+01	1,32E+01
OUTDOOR WLINE	Cellular Base Station to Base Station FOM: (1km distance)	1,00E+14	1,50E+14	2,00E+14	3,00E+14
	LOG	14	14,17609126	14,30103	14,47712125
	Fix Mini Cell to Mini Cell, Fix Mini Cell to Cell Base Station FOM: (150m distance)	7,50E+12	1,10E+13	1,50E+13	2,20E+13
	LOG	12,87506126	13,04139269	13,17609126	13,34242268
	Cell Base Station to Data Centers & Data Centers Long Range FOM: (10km distance)	1,00E+15	1,50E+15	2,00E+15	3,00E+15
	LOG	15	15,17609126	15,30103	15,47712125
	Long haul FOM: (100km distance)	4E+15	7E+15	1E+16	1,4E+16
	LOG	1,56E+01	1,58E+01	1,60E+01	1,61E+01
INDOOR WLESS	WLAN FOM: (10m)	2,50E+11	5,00E+11	1,00E+12	2,00E+12
	LOG	11,39794001	11,69897	12	12,30103
	WPAN FOM: (10m)	5,00E+07	1,00E+08	1,50E+08	2,00E+08
	LOG	7,698970004	8	8,176091259	8,301029996
	WBAN FOM: (1m)	1,00E+03	1,00E+04	1,00E+05	1,00E+06
	LOG	3	4	5	6
	WSN FOM: (10m)	1,00E+04	1,00E+05	1,00E+06	1,00E+07
	LOG	4	5	6	7
	Localization FOM: (10m) FOM is relative accuracy	1%	0.3%	0.05%	0.01%
INDOOR WLINE	WLAN FOM: (10m)	1,00E+12	1,50E+12	2,00E+12	3,00E+12
	LOG	12	12,17609126	12,30103	12,47712125
	Data Centers Short Range FOM: (10m)	4,00E+12	7,00E+12	1,00E+13	1,50E+13
	LOG	1,26E+01	1,28E+01	1,30E+01	1,32E+01
DEVICE TO DEVICE WLESS	Die To Die & Package To Package FOM: (10cm)	1,00E+09	5,00E+09	1,00E+10	5,00E+10
	LOG	9	9,698970004	10	10,69897
	NFC FOM: (10cm)	1,00E+05	5,00E+05	1,00E+06	5,00E+06
	LOG	5	5,698970004	6	6,698970004
	RFID FOM: (1m)	1,00E+08	5,00E+08	1,00E+09	1,50E+09
	LOG	8,00E+00	8,70E+00	9,00E+00	9,18E+00
IN PACKAGE / DEVICE WLINE	Die 2 Die FOM: (1cm distance)	1,00E+10	1,50E+10	2,00E+10	3,00E+10
	LOG	10	10,17609126	10,30103	10,47712125
	Module 2 Module FOM: (10cm distance)	1,00E+11	5,00E+11	1,00E+12	5,00E+12
	LOG	11	11,69897	12	12,69897
	Active cable	1,00E+12	5,00E+12	1,00E+13	5,00E+13
	LOG	1,20E+01	1,27E+01	1,30E+01	1,37E+01

Wireless FOMs Roadmap



Wireline FOMs Roadmap



- Long haul FOM: (100km distance)
- Cell Base Station to Data Centers & Data Centers Long Range FOM: (10km distance)
- Cellular Base Station to Base Station FOM: (1km distance)
- Active cable
- Fix Mini Cell to Mini Cell, Fix Mini Cell to Cell Base Station FOM: (150m distance)
- Data Centers Short Range FOM: (10m)
- WLAN FOM: (10m)
- Module 2 Module FOM: (10cm distance)
- Die 2 Die FOM: (1cm distance)