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shaping tomorrow with you

# An approach to 5G

**Thailand-Japan joint workshop on**
**5th Generation Mobile Communication System**
Bangkok, Thailand
Feb. 20, 2018

**FUJITSU LIMITED**

# Market demands and Mobile Communication systems

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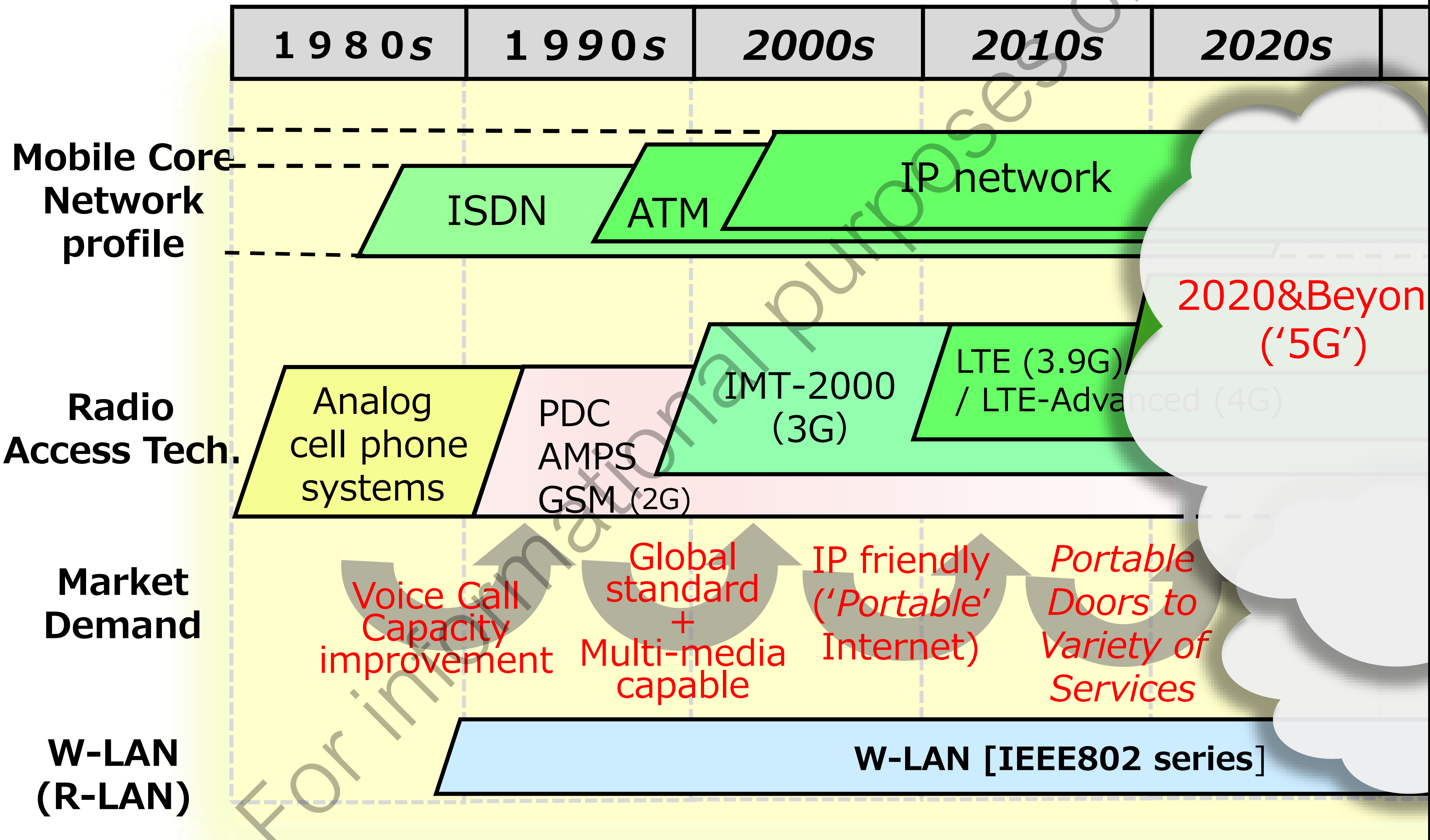

# ‘5G’ role: Bridging Digital World and Physical World

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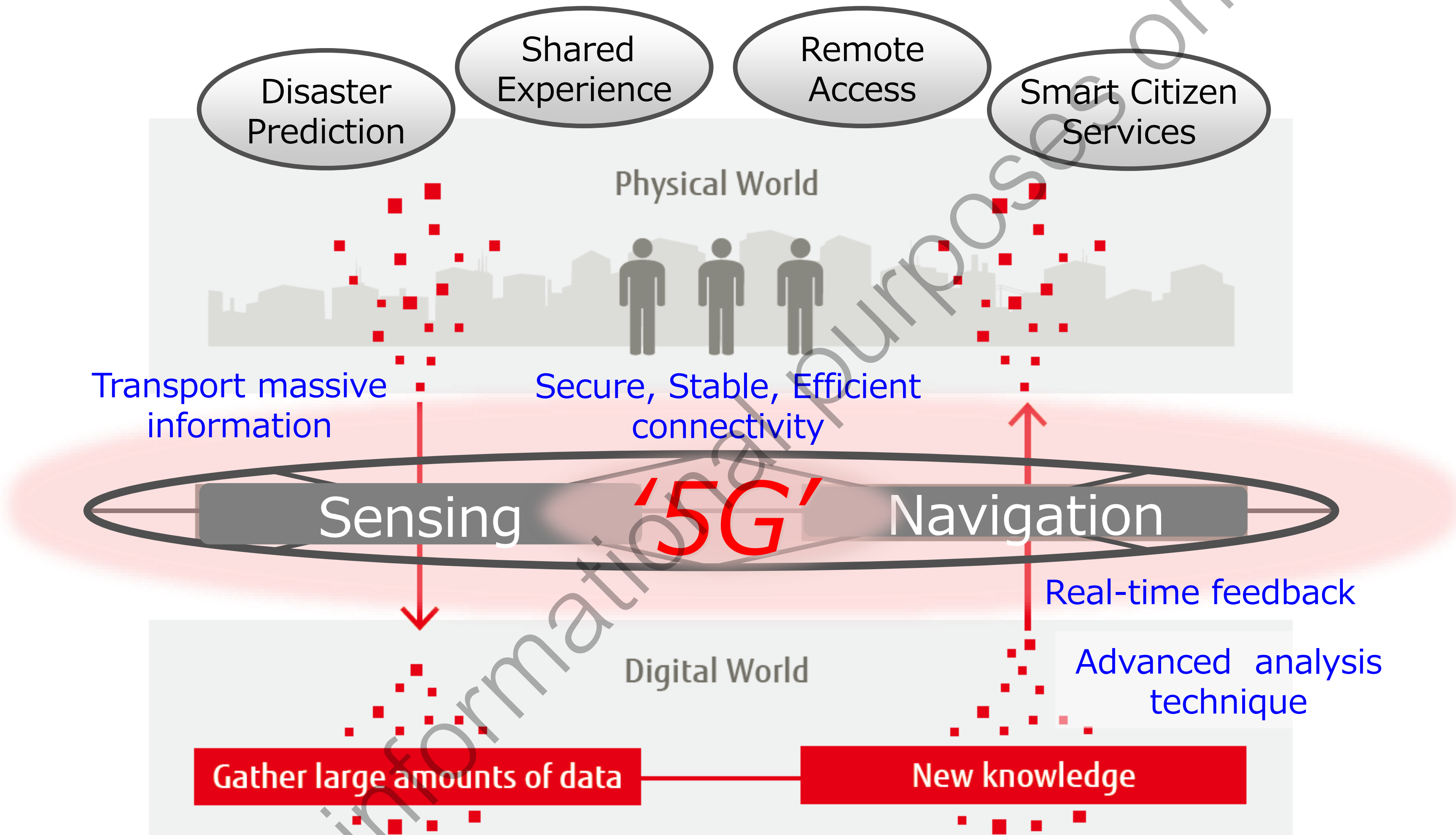


5G ICT creates new knowledge and supports activity of humans and machines in real time, by analyzing large amounts of data in physical world.

# Requirements for 5G NR(New Radio)

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| Use-case | Key performance indicator | New Radio | | LTE-Advanced | | LTE (Rel-8) | |
|---|---|---|---|---|---|---|---|
| | | DL | UL | DL | UL | DL | UL |
| eMBB | Peak data rate | 20 Gbps | 10 Gbps | 1 Gbps | 500 Mbps | 100 Mbps | 50 Mbps |
| | Peak spectral efficiency | 30 bps/Hz | 15 bps/Hz | 30 bps/Hz | 15 bps/Hz | 3~4 × HSDPA (Rel-6) | 2~3 × HSUPA (Rel-6) |
| | C-plane latency | 10 ms | | Less than 50 ms | | Less than 100 ms | |
| | U-plane latency | 4 ms | | reduced U-plane latency compared to Rel-8 | | Less than 5 ms | |
| | Celll/TRxP spectral efficiency [bit/s/Hz/TRxP] | 3 times higher than IMT-A※<br>※ ITU-R Rep. M. 2134 | | - | | - | |
| | Area traffic capacity [bit/s/m²] | | | - | | - | |
| | User experienced data rate [bit/s] | | | - | | - | |
| | 5% user spectrum efficiency [bit/s/Hz/user] | | | Cell edge user throughput [bit/s/Hz/cell/user] | | User throughput | |
| | | | | 0. 12 (2×2 ANT) | 0. 04 (1×2 ANT) | 2~3 × HSDPA (Rel-6) | 2~3 × HSUPA (Rel-6) |
| | Target mobility speed (URLLC, mMTCも関連) | 500 km/h | | 350 km/h | | 350 km/h | |
| | Mobility interruption time (URLLC, mMTCも関連) | 0 ms | | - | | - | |
| URLLC | U-plane latency | 0. 5 ms | | - | | - | |
| | Reliability | $10^{-5}$ for 32 Bytes with U-plane latency of 1 ms | | - | | - | |
| mMTC | Coverage | Max coupling loss 164 dB | | Max coupling loss 164 dB (NB1) | | - | |
| | UE battery life | Beyond 10 years | | Up to 10 years | | - | |
| | Connection density | 1,000,000 devices/km² | | 60,680 devices/km² | | - | |

Ref: "Report of the Next Generation Mobile Communications system committee," MIC (Sep. 2017).
(Derived from original information in 3GPP TR 38.913, "Study on scenarios and requirements for next generation access technologies," (Aug. 2017))

# 3GPP NR (New Radio) specifications

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| | |
|---|---|
| TS 38.101-1 | NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone |
| TS 38.101-2 | NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone |
| TS 38.101-3 | NR; User Equipment (UE) radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios |
| TS 38.101-4 | NR; User Equipment (UE) radio transmission and reception; Part 4: Performance requirements |
| TS 38.104 | NR; Base Station (BS) radio transmission and reception |
| TS 38.113 | NR; Base Station (BS) and repeater ElectroMagnetic Compatibility (EMC) |
| TS 38.124 | NR; Electromagnetic compatibility (EMC) requirements for mobile terminals and ancillary equipment |
| TS 38.133 | NR; Requirements for support of radio resource management |
| TS 38.141 | NR; Base Station (BS) conformance testing |
| TS 38.141-1 | NR; Base Station (BS) conformance testing Part 1: Conducted conformance testing |
| TS 38.141-2 | NR; Base Station (BS) conformance testing Part 2: Radiated conformance testing |
| TS 38.201 | NR; Physical layer; General description |
| TS 38.202 | NR; Services provided by the physical layer |
| TS 38.211 | NR; Physical channels and modulation |
| TS 38.212 | NR; Multiplexing and channel coding |
| TS 38.213 | NR; Physical layer procedures for control |
| TS 38.214 | NR; Physical layer procedures for data |
| TS 38.215 | NR; Physical layer measurements |
| TS 38.300 | NR; Overall description; Stage-2 |
| TS 38.304 | NR; User Equipment (UE) procedures in idle mode and in RRC Inactive state |
| TS 38.305 | NG Radio Access Network (NG-RAN); Stage 2 functional specification of User Equipment (UE) positioning in NG-RAN |
| TS 38.306 | NR; User Equipment (UE) radio access capabilities |
| TS 38.307 | NR; Requirements on User Equipments (UEs) supporting a release-independent frequency band |
| TS 38.321 | NR; Medium Access Control (MAC) protocol specification |
| TS 38.322 | NR; Radio Link Control (RLC) protocol specification |
| TS 38.323 | NR; Packet Data Convergence Protocol (PDCP) specification |
| TS 38.331 | NR; Radio Resource Control (RRC); Protocol specification |

| | |
|---|---|
| TS 38.508-1 | 5GS; User Equipment (UE) conformance specification; Part 1: Common test environment |
| TS 38.508-2 | 5GS; User Equipment (UE) conformance specification; Part 2: Common Implementation Conformance Statement (ICS) proforma |
| TS 38.509 | 5GS; Special conformance testing functions for User Equipment (UE) |
| TS 38.521-1 | NR; User Equipment (UE) conformance specification; Radio transmission and reception; Part 1: Range 1 Standalone |
| TS 38.521-2 | NR; User Equipment (UE) conformance specification; Radio transmission and reception; Part 2: Range 2 Standalone |
| TS 38.521-3 | NR; User Equipment (UE) conformance specification; Radio transmission and reception; Part 3: NR interworking between NR range1 and NR range2; and between NR and LTE |
| TS 38.521-4 | NR; User Equipment (UE) conformance specification; Radio transmission and reception; Part 4: Performance |
| TS 38.522 | NR; User Equipment (UE) conformance specification; Applicability of RF and RRM test cases |
| TS 38.523-1 | 5GS; UE conformance specification; Part 1: Protocol conformance specification |
| TS 38.523-2 | 5GS; UE conformance specification; Part 2: Implementation Conformance Statement (ICS) proforma specification |
| TS 38.523-3 | 5GS; UE conformance specification; Part 3: Test Suites |
| TS 38.533 | NR; User Equipment (UE) conformance specification; Radio Resource Management (RRM) |

# 5G RAT and LTE Evolution (Fujitsu's view)

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- **5G Phase-1 (To be deployed in 2020)**
  - New RAT (up to 30GHz)
    - Mainly for eMBB
    - Massive MTC, Ultra reliable MTC
  - E2E latency reduction
  - Flexible TDD
  - Enhancements for UDN

Forward/ Backward compatibility

- **5G Phase-2 (To be deployed in 2022~2023)**
  - Extension of BW using new spectrum above 6GHz (New RAT up to 100GHz, BF/MIMO)
  - Support of full-duplex operation
  - (mmWave) wireless back/fronthaul

Tight interworking

- **LTE Evolution**
  - eMBB
    - eLAA for 5GHz unlicensed
    - Flexible duplex (FDD)
    - WiGig aggregation
    - MUST
  - Latency reduction, V2X, …

**LTE Evolution continues**

- Technologies for LTE evolution can also be used also for 5G new RAT. So, the above classification may not be strictly followed.

Ref: "R&D activities towards 5G in Fujitsu," Multimedia Promotion Forum, presentation #678, (Oct. 2015)

# ‘Expansion’ of data traffic

- Either in volume or in its behaviour -

# New traffic types from possible new fields

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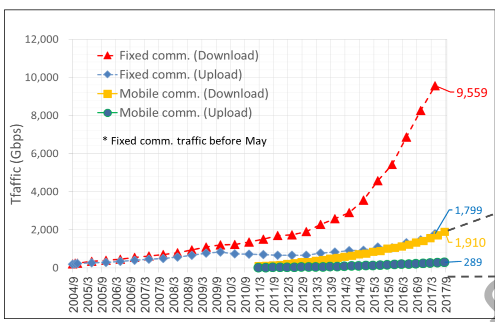
Urgent: Cope with enormously increasing traffic (on going story in '4G' systems)
Foreseen: Handling of genuine new type, genuine mobile specific traffic.

**X 10 within 7 years!**
**X 100 within 14 years?**
**X 1000 in 21 years ???**

Depending on
Cost vs. Value provided




| 2017 | 202x |
|---|---|
| | Mobile specific traffic (Mobile specific applications) |
| | Replacement of fixed (wired) communications |
| 1910Gbps | 1910Gbps |

Genuine new Type Traffic

**Wired comm. alike traffic**


Refs:
"Status of the mobile communications traffic of Japan (Sep. 2017)," Information and Communications Statistics Database, Ministry of Internal Affairs and Communications of Japan, Nov. 2017.
"Aggregation and Provisional Calculation of Internet Traffic in Japan (as of May 2017)," Ministry of Internal Affairs and Communications of Japan, Aug. 2017.

# Profile of communication traffics

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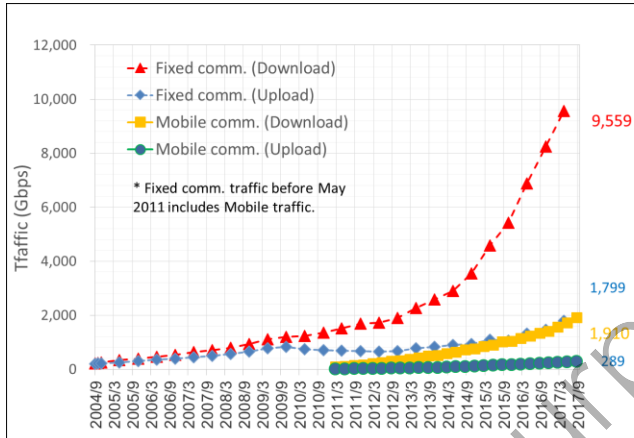
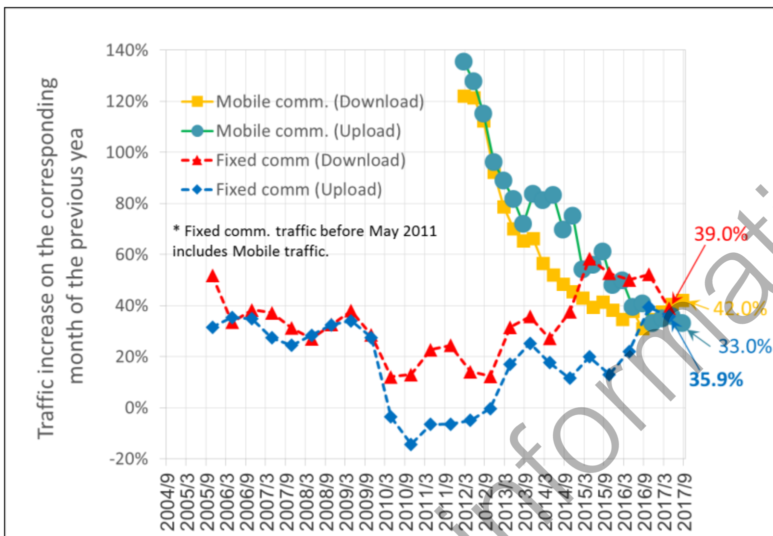
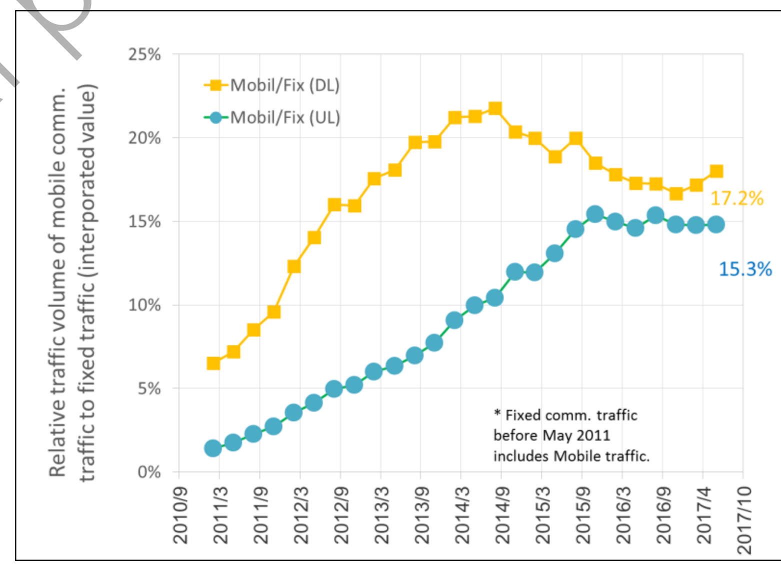


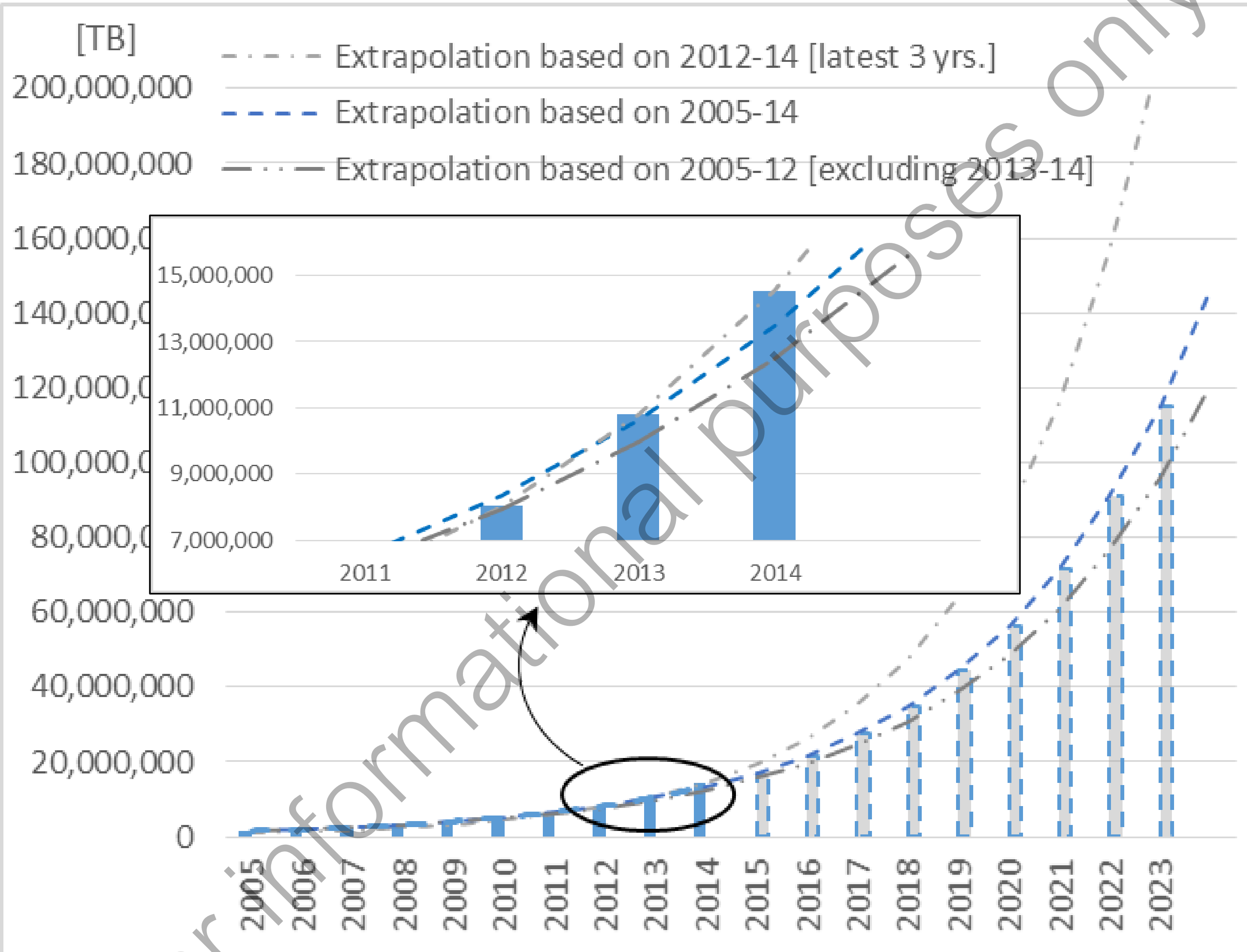

Annual growth ratio of communications traffic




Relative ratio of traffic volume (mobile / fixed)

Ref: "Status of the mobile communications traffic of Japan (Sep. 2017)," Information and Communications Statistics Database, Ministry of Internal Affairs and Communications of Japan, Nov. 2017.
Ref: "Aggregation and Provisional Calculation of Internet Traffic in Japan (as of May 2017)," Ministry of Internal Affairs and Communications of Japan, Aug. 2017.

# Data traffic* and its extrapolations**




*Service industry, ICT, transport, real estate, money & securities, commercial services, utilities, construction and manufacturing
**: Extracted based on data up to year of 2014 in the reference below.

Ref:" "Traffic of big data flow estimation and investigations on usage of the big data," Ministry of Internal Affairs and Communications of Japan, 2015.

# Flexible frame structure (NR)

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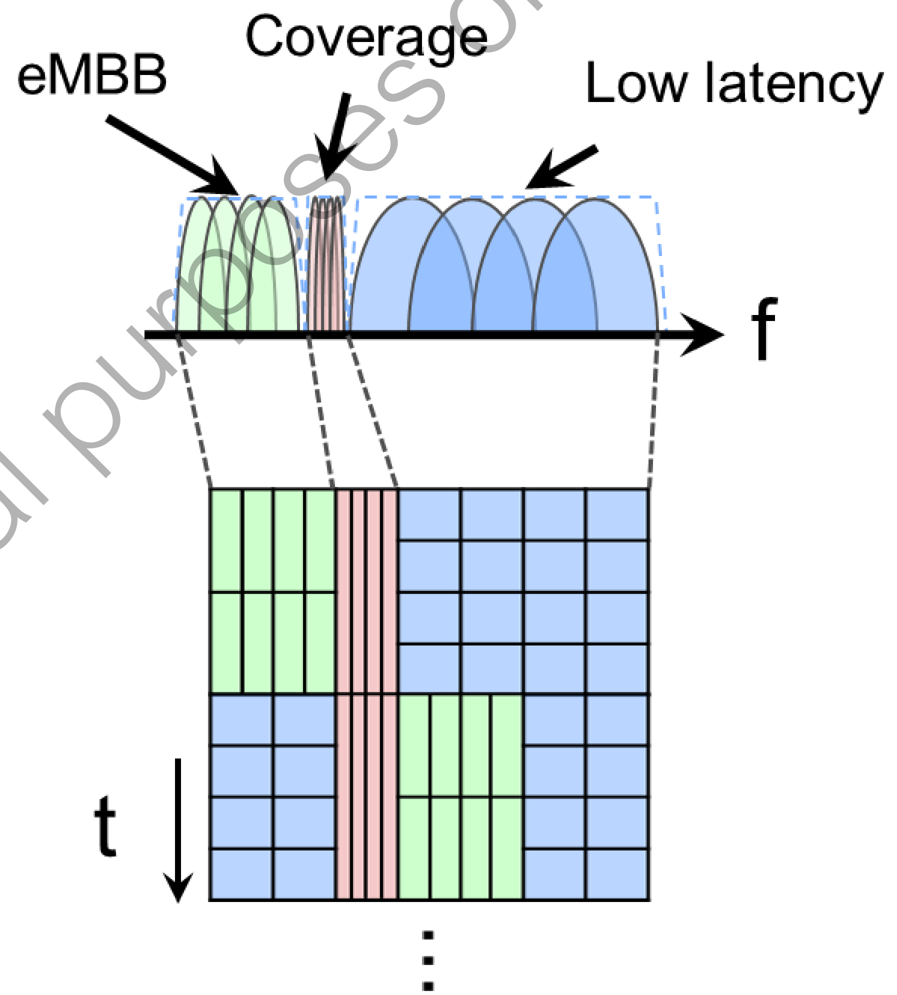
### 4.2 Numerologies

Multiple OFDM numerologies are supported as given by Table 4.2-1 where μ and the cyclic prefix for a carrier bandwidth part are given by the higher-layer parameters *DL-BWP-mu* and *DL-BWP-cp* for the downlink and *UL-BWP-mu* and *UL-BWP-cp* for the uplink.

**Table 4.2-1: Supported transmission numerologies.**

| **μ** | $\Delta f = 2^{\mu} \cdot 15\,[\text{kHz}]$ | **Cyclic prefix** |
|---|---|---|
| **0** | 15 | Normal |
| **1** | 30 | Normal |
| **2** | 60 | Normal, Extended |
| **3** | 120 | Normal |
| **4** | 240 | Normal |

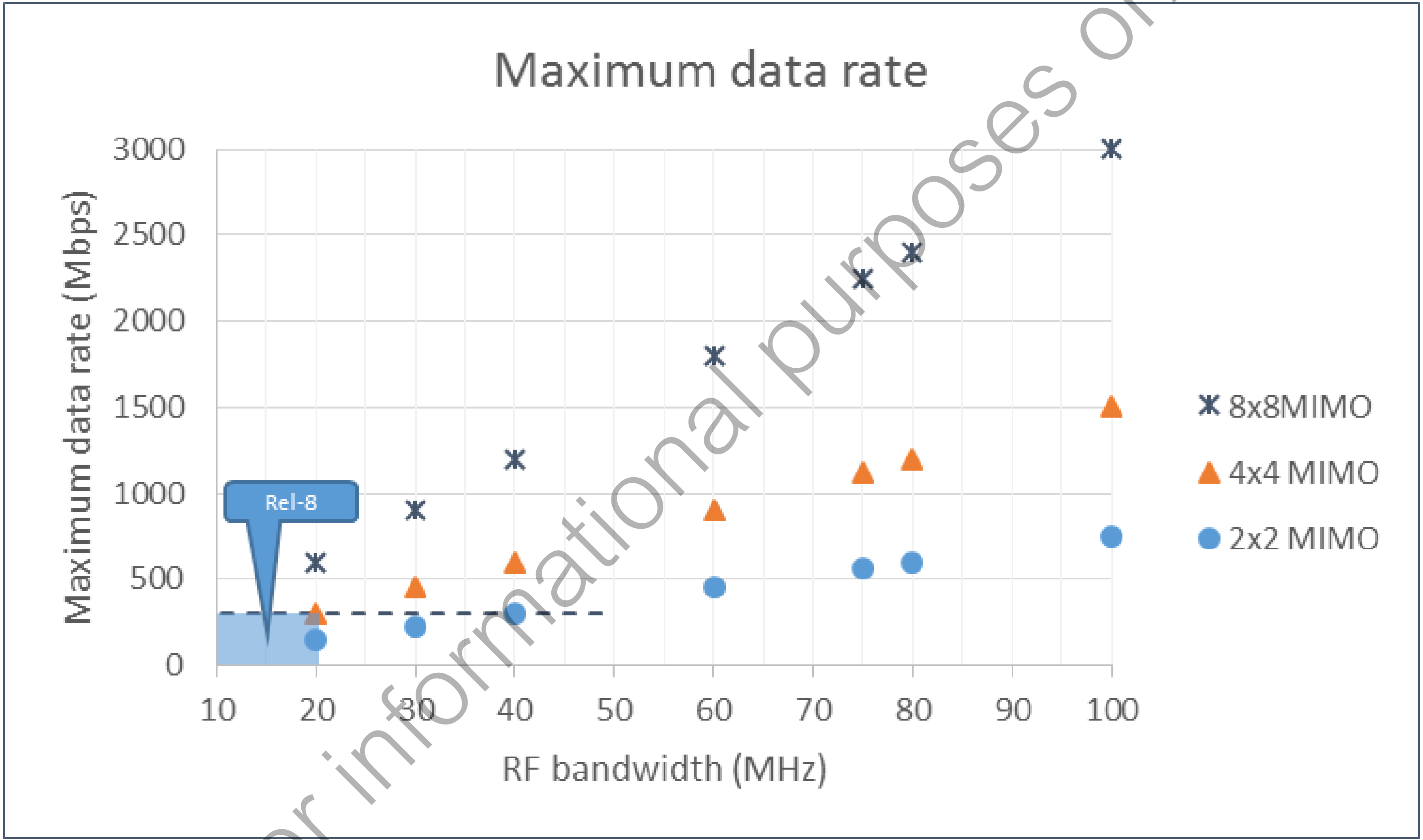
Ref: 3GPP TS38.211 “NR; Physical channels and modulation (V.15.0.0).” Dec. 2017



# Higher data rate

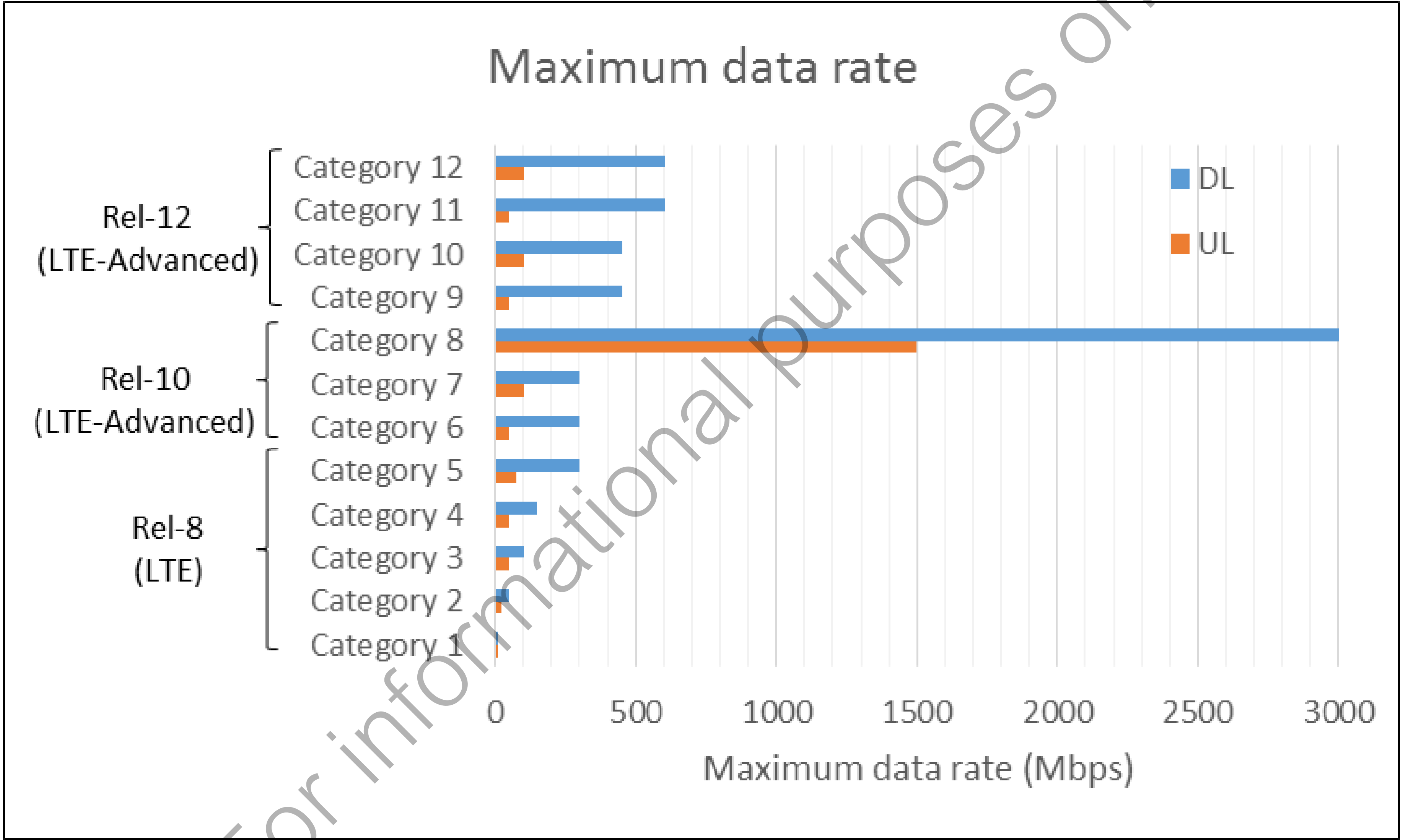
- w.r.t. LTE/LTE-Advanced per 3GPP release -

# Peak data rates in LTE FDD (DL)




Ref: "E-UTRAN UE radio access capabilities," 3GPP TS36.306

# Maximum data rates specified for LTE (per 3GPP release)




Ref: "E-UTRAN UE radio access capabilities," 3GPP TS36.306

# Utilization of higher and wider spectrum

- implementation aspects -

# Number of frequency bands in 3GPP

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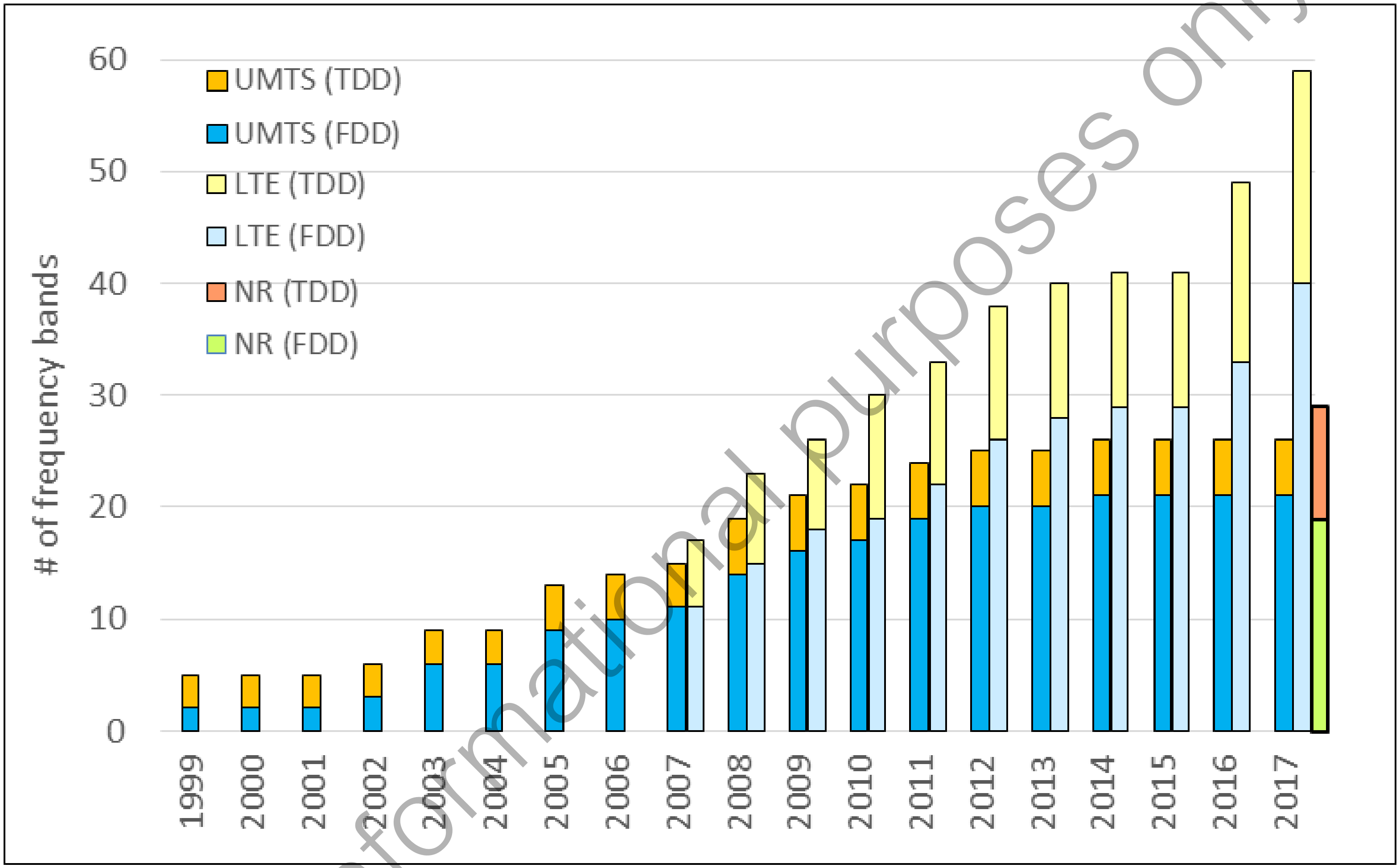
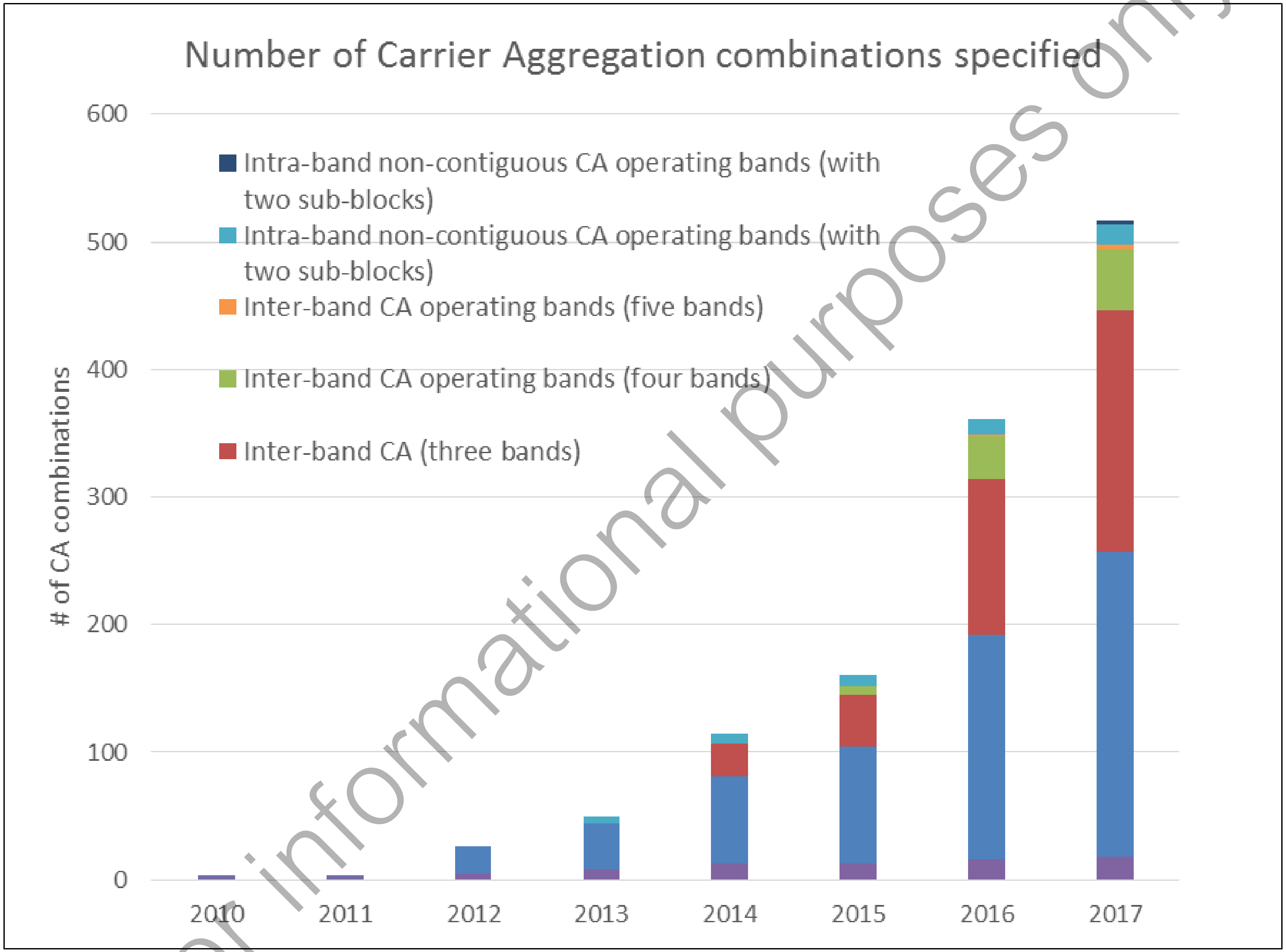




Refs:
3GPP TS25.101, "User Equipment (UE) radio transmission and reception (FDD)," (Dec. 1999-Dec. 2017).
3GPP TS25.102, "User Equipment (UE) radio transmission and reception (TDD)," (Dec. 1999- Dec. 2017).
3GPP TS 36.101, "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception", (Oct. 2010-Dec. 2017).
3GPP TS 38.101-1, "NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone," (Dec. 2017).
3GPP TS 38.101-2, "NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone," (Dec. 2017).

# Number of combinations specified for LTE-Advanced






Ref: 3GPP TS 36.101, “Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception”, (Oct. 2010-Dec. 2017).

# Utilization of single contiguous wide bandwidth spectrum

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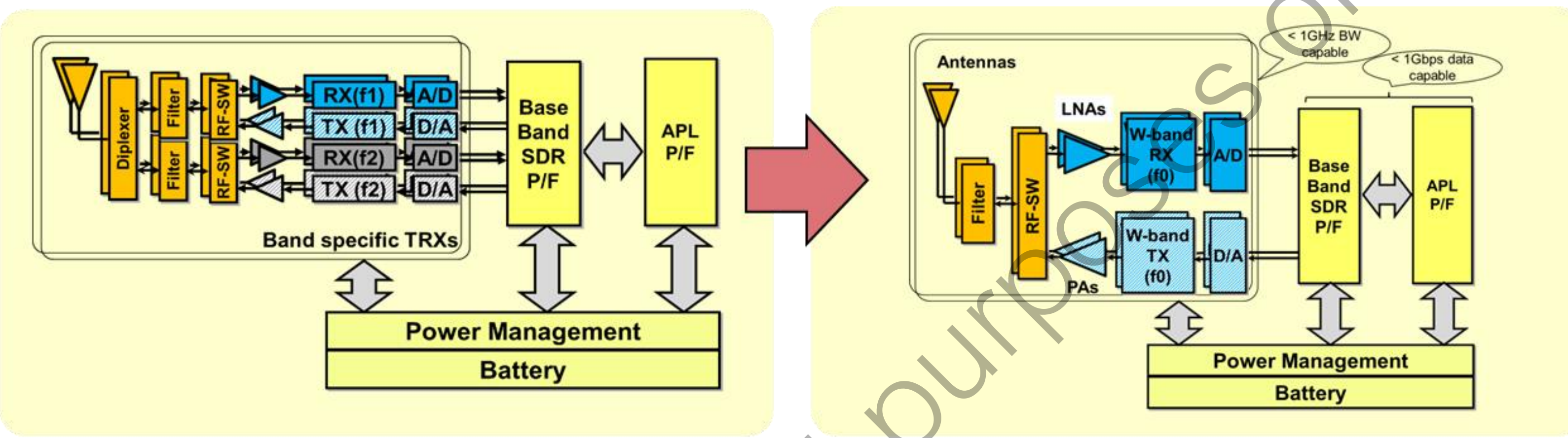


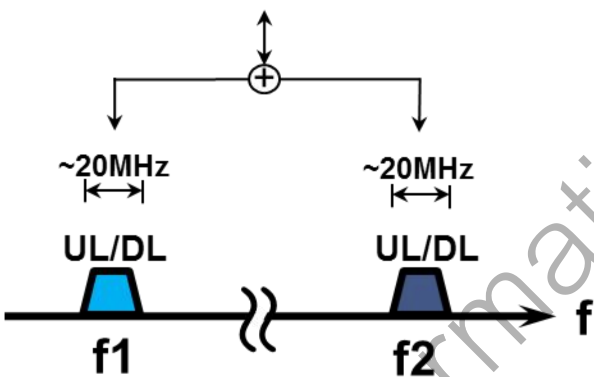


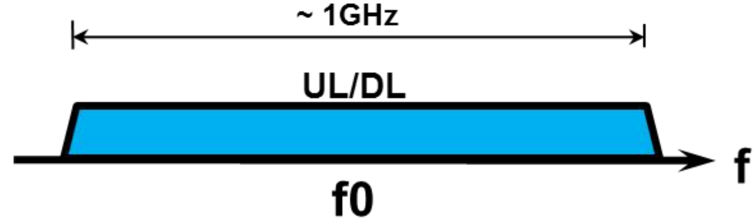


Carrier Aggregation (LTE-Advanced)
(Combining multiple component carriers)

Single contiguous wide bandwidth carrier

# (Ref) Radio propagation properties in EHF and SHF band

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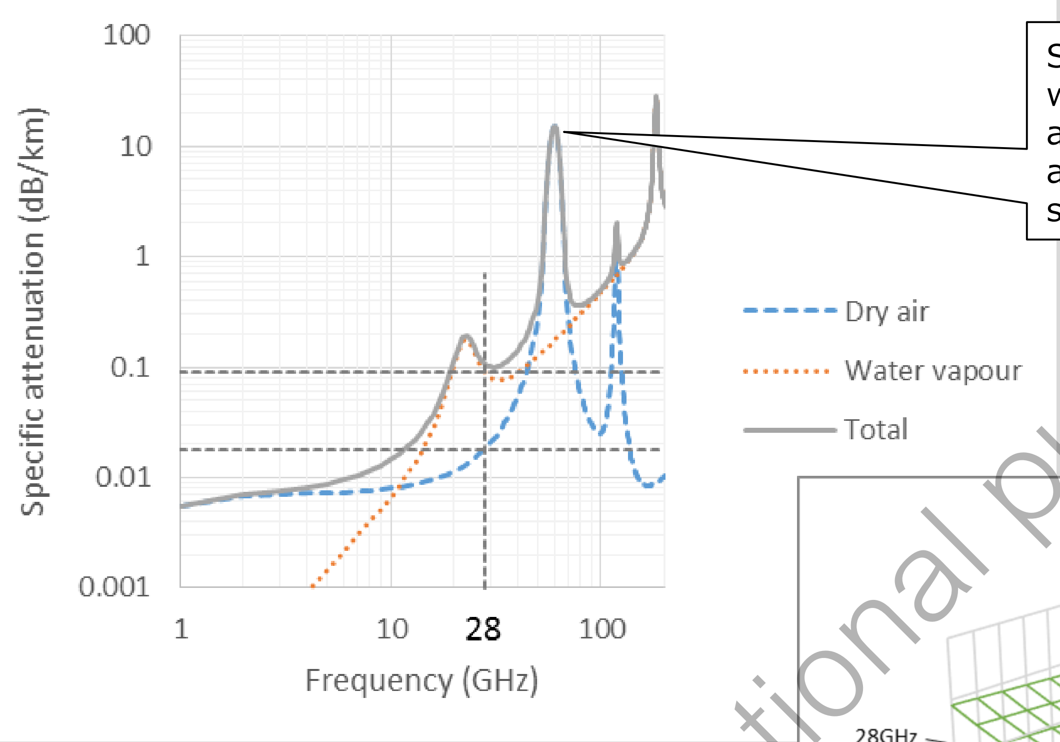
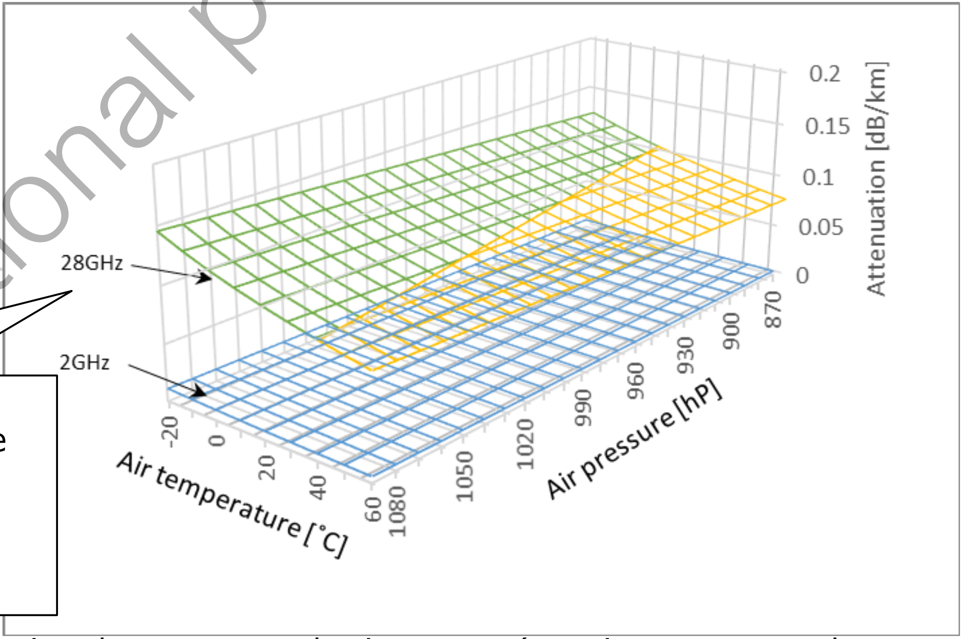



Attenuation due to atmospheric gasses

Several peak attenuation points, caused by water vapor etc., are observed as 60GHz as an example. These bands may suffer additional attenuation in some conditions such as rain or snow.




Compared to UHF(eg. 2GHz), relatively large but marginal dependency to air temperature as well as humidity is observed.
(Note: The chart does not capture …)

Attenuation due to atmospheric gasses (vs. air pressure and temperature)

Ref: "Attenuation by atmospheric gasses," Recommendation ITU-R P.676-10, pp.13-16, Sep. 2013, ITU-R.

# Carrier frequency vs. bandwidth specified for LTE/LTE-Advanced

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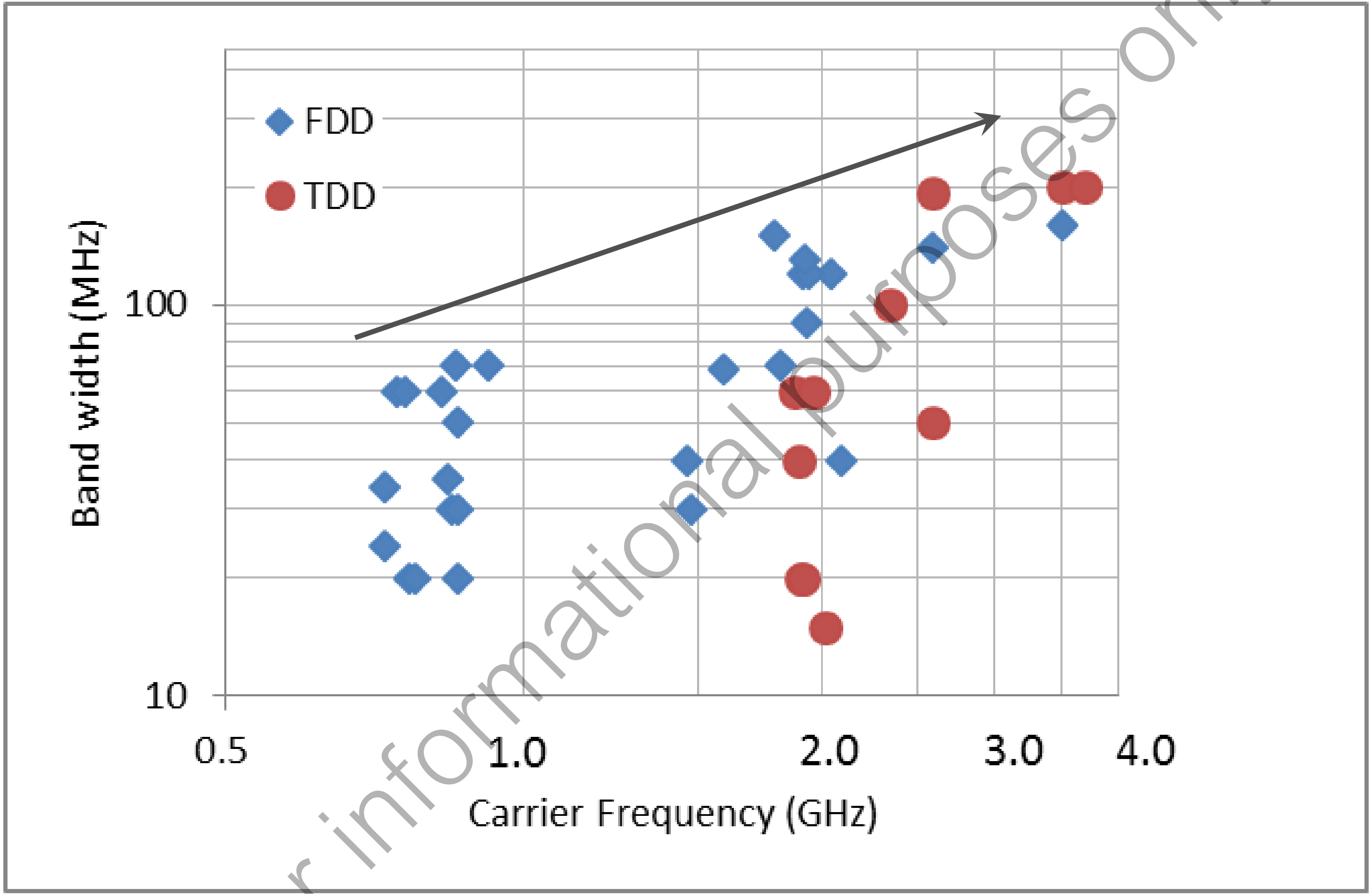


Ref: "Mobile Communications Systems for 2020 and beyond", ARIB 2020 and Beyond Ad Hoc Group White Paper, Oct. 2014.
(Derived from original information in 3GPP TS36.101 "E-UTRA UE radio transmission and reception,")

# Fractional bandwidth of 3GPP bands vs. Reference sensitivity

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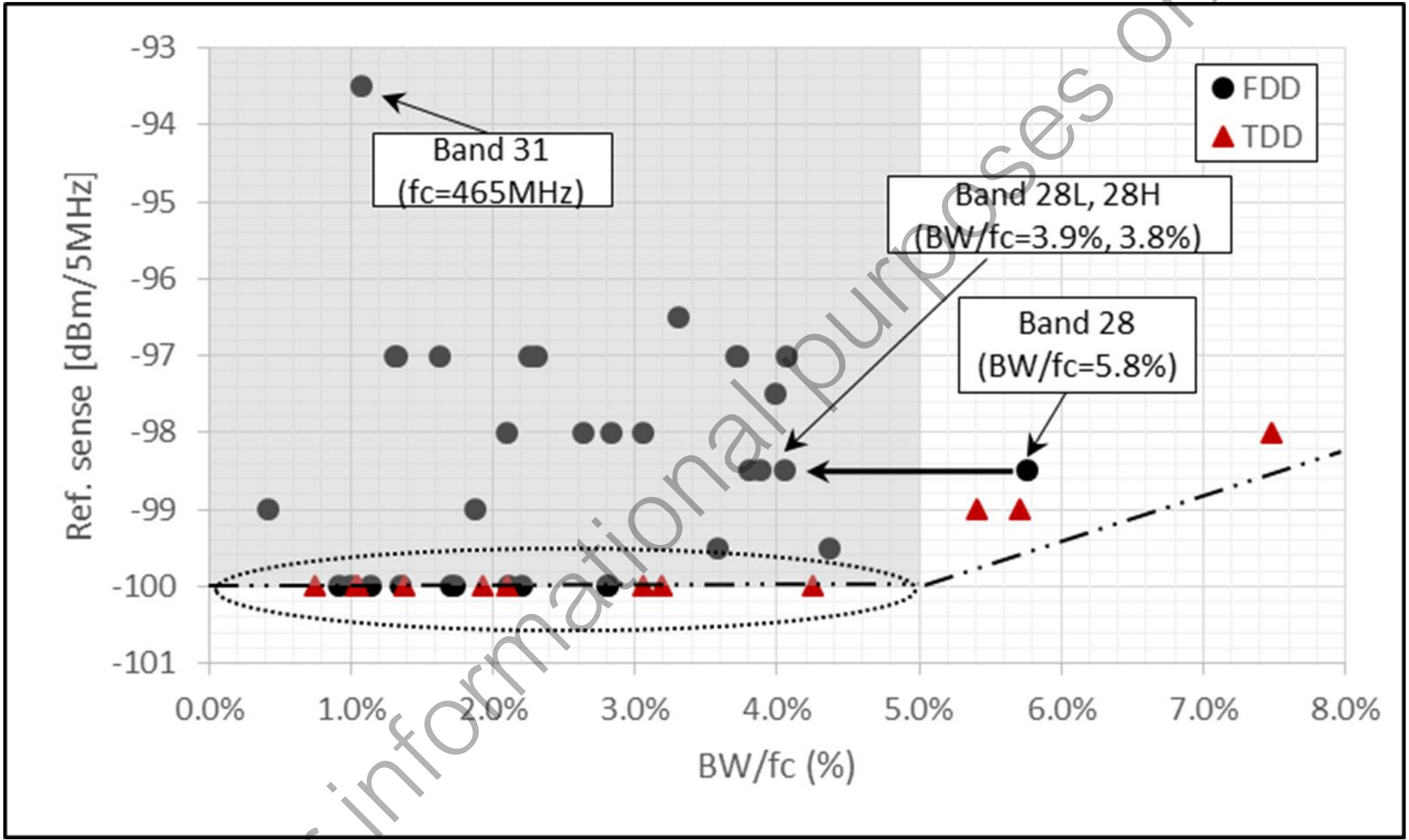


Ref: "Research Progress of the Fifth Generation Mobile Communications Promotion Forum," IEEE VTS APWCS2016, Aug. 2016. (Derived from original information in 3GPP TS36.101 "E-UTRA UE radio transmission and reception,")

# Operation of New RAT above 6GHz

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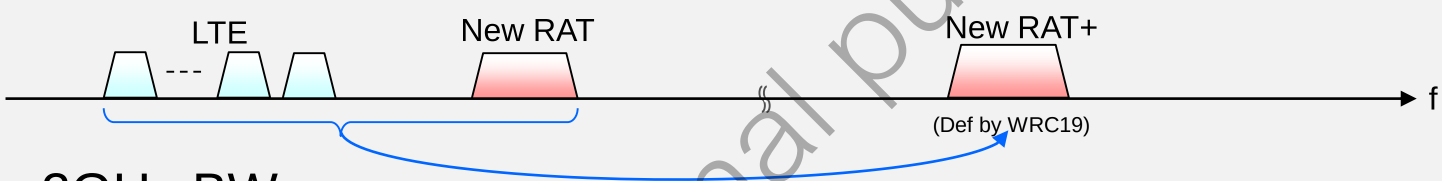
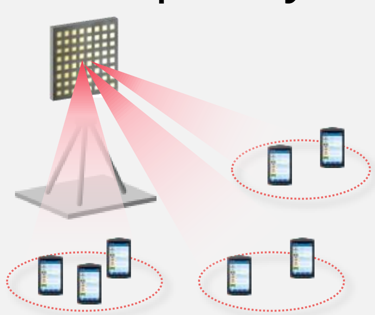
- **Channel susceptible to shadowing, large penetration loss**
- **Beamforming gain and diversity to compensate the large path loss**
  - **→ Potentially high device cost/complexity and power consumption**
  - **→ Limited mobility and cell/beam discovery/tracking**

- **Features for above 6GHz (up to 100GHz)**

• Dual connectivity SCell (First priority)
• Standalone operation should also be supported




  - ~2GHz BW
  - Support of multiple radio interface parameters for future proofing and optimization for different scenarios (e.g. Indoor/outdoor, frequency bands, fronthaul/backhaul applications)
- **Beam-space multiplexing of multiple TX signals**
  - Analog/digital hybrid beamforming
    - Low power consumption & cost
    - One analog beam serves multiple UEs



- **Beam-space + site diversity to compensate shadowing**

# Ultra low latency data transmisson

- You can’t go beyond the speed of light -

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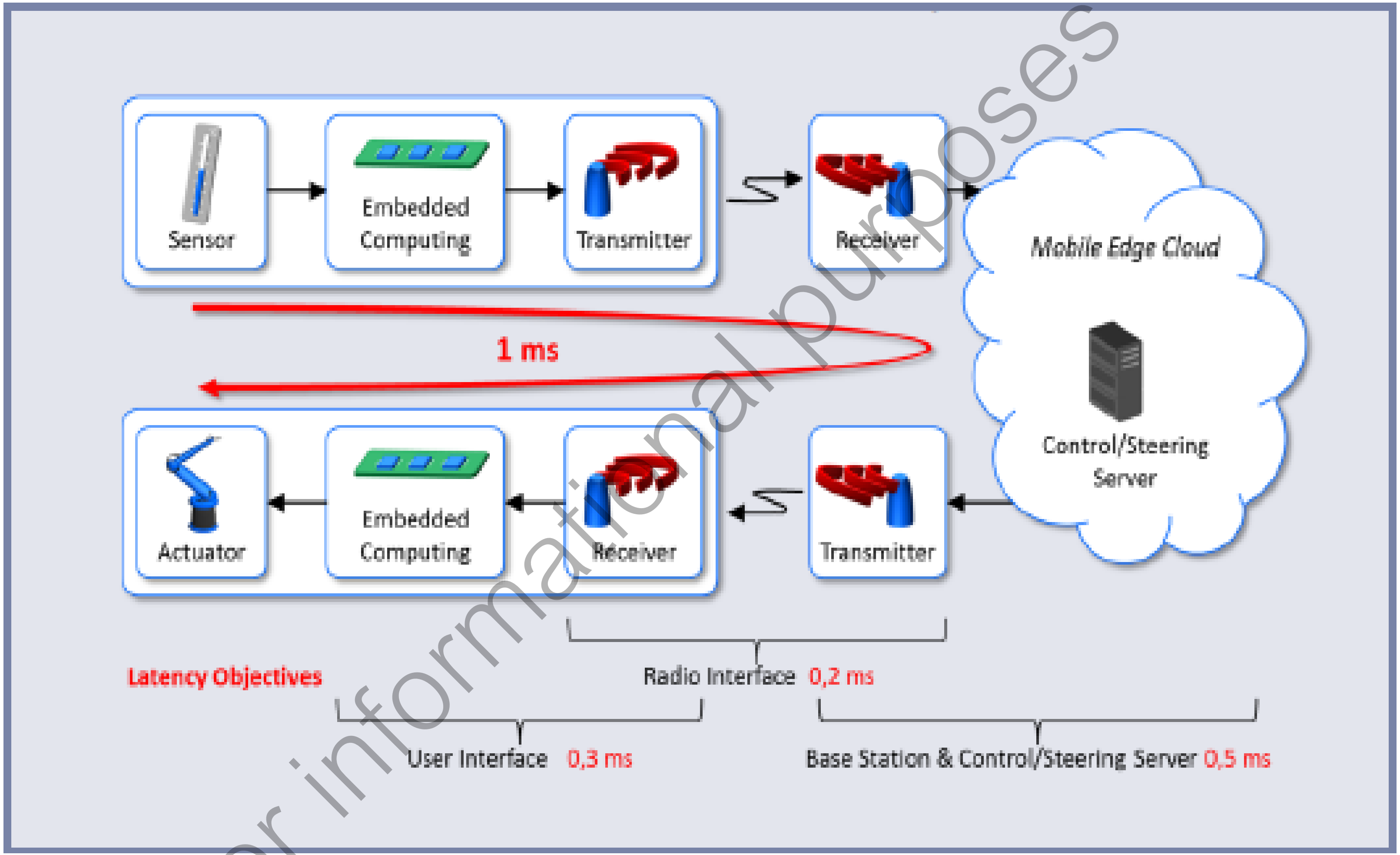
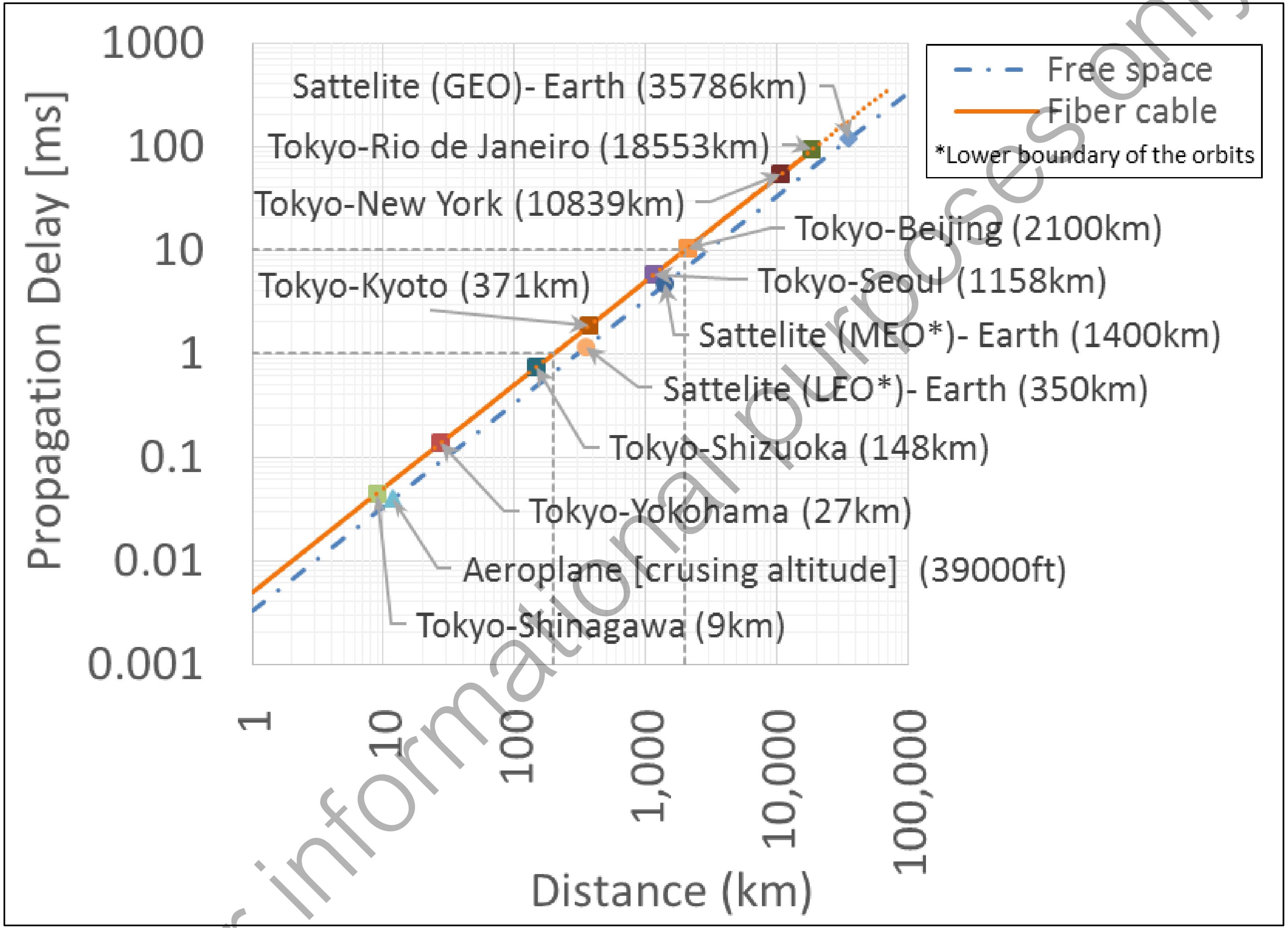
## Exemplary latency budget of a system of the Tactile Internet [16]




[16] The Tactile Internet, ITU-T Technology Watch Report, Aug. 2014

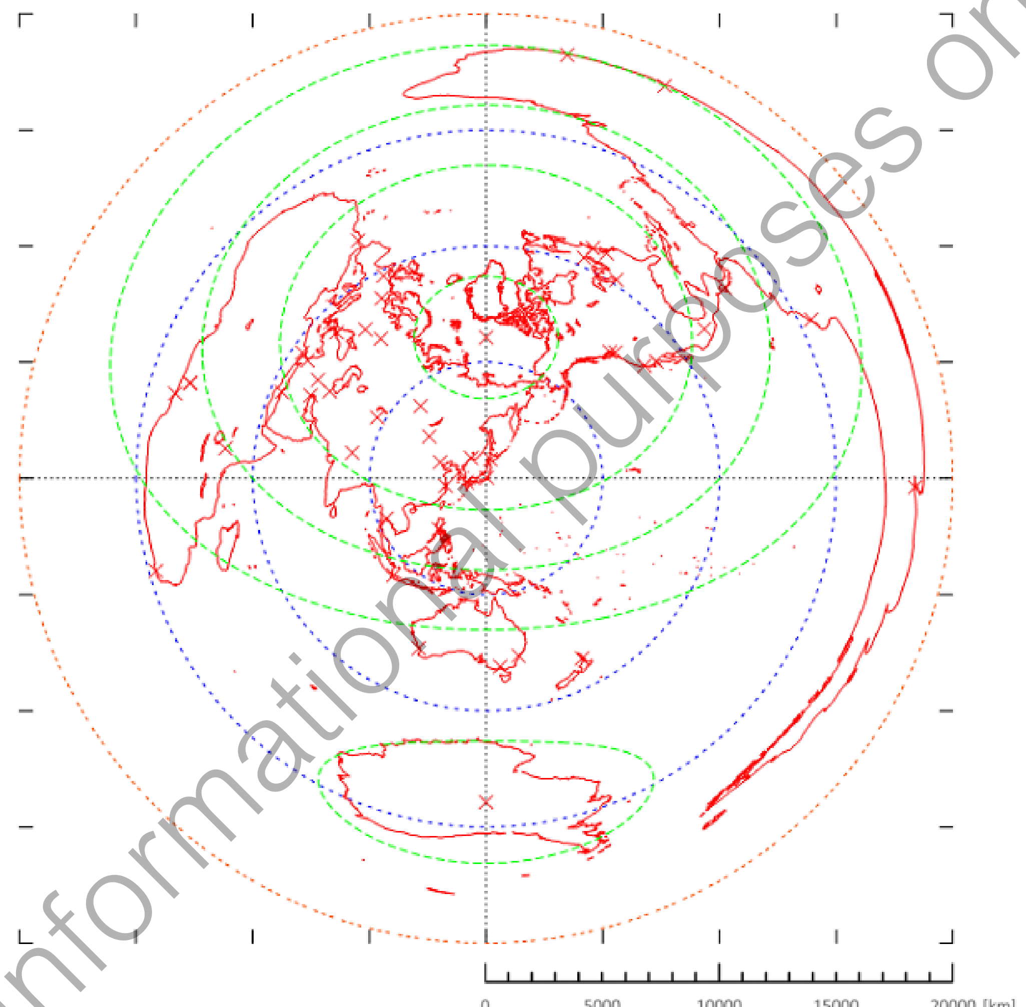
# Lower bound of propagation delay vs. distance




**Propagation delay at speed of light [6]**

[6] "Embarking on Mobile Communications systems for 2020 and beyond," Proc. 2016 IEICE General Conference, TK-3-4, SSS-9, Mar. 2016 (in Japanese).)

# Consideration: Geological localized network services




Azimuthal equidistant projection



Ref: Nakamura. T, “Radio Access Network Technologies for ‘5G’”,IEICE Soc. conf. 2015 (Sep. 2015),
P. Wessel, W. Smith, “A global self-consistent, hierarchical, high-resolution shoreline database”, Journal of geophysical research, Vol. 101, No. B4, pp.8741-8743 (Apr. 1996)

# 対数等距離・正方位図(東京中心)による距離圏表示

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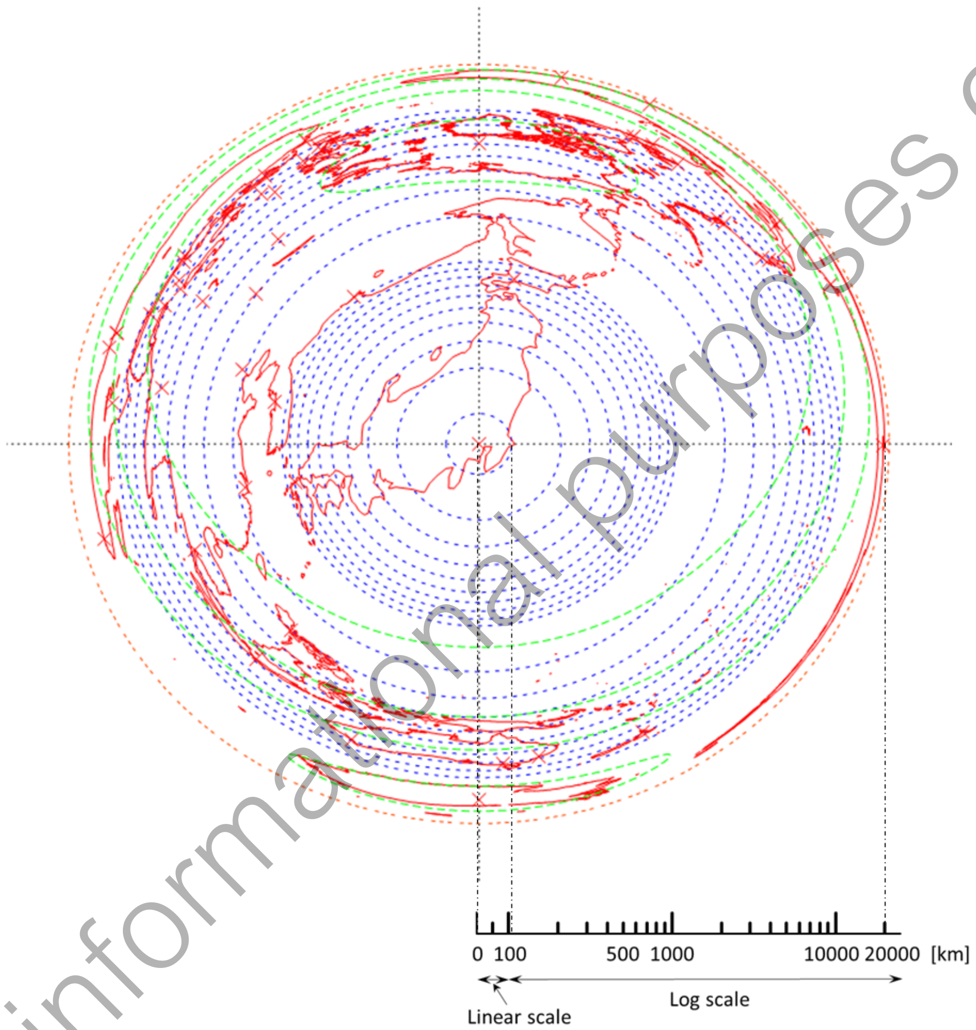


Azimuthal equidistant map (Tokyo centered) [6][17]


[6] "Embarking on Mobile Communications systems for 2020 and beyond," Proc. 2016 IEICE General Conference, TK-3-4, SSS-9, Mar. 2016 (in Japanese).)

[17] P. Wessel, W. Smith, “A global self-consistent, hierarchical, high-resolution shoreline database”, Journal of geophysical research, Vol. 101, No. B4, pp.8741-8743 (Apr. 1996)

# An enabling technology

**Ultra High-Density Distributed Smart Antenna Systems**

# Ways to improve system capacity

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1. Improved spectral efficiency:
   - Peak spectral efficiency: 30bps/Hz (UL), 15bps/Hz(DL)
2. Wider spectrum
   - Utilization of SHF or EHF (up to bandwidth of several hundreds MHz)
3. Smaller cells
   - Area traffic capacity (bps/$m^2$) should be 3 times higher than IMT-Advanced (ITU-R Rep. M.2134)

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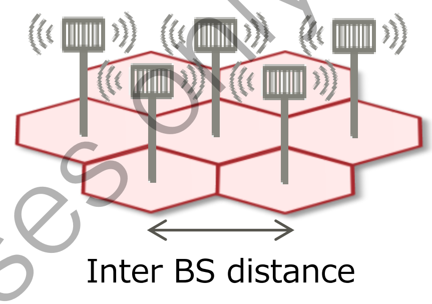
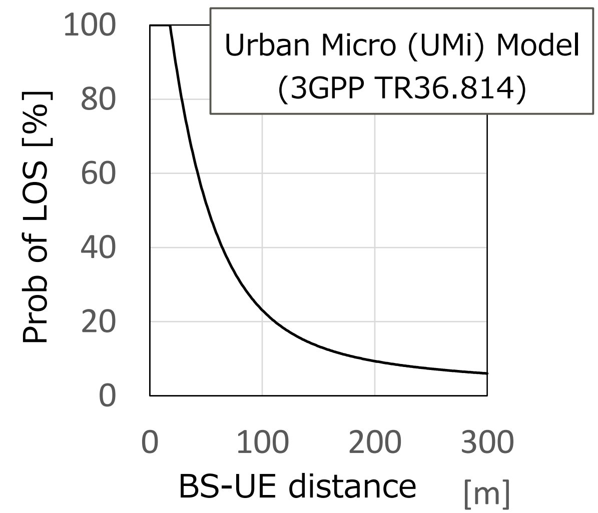
- **Ultra High-Density Distributed Smart Antenna Systems**
  - BS-BS distance < 100m
    (Outdoor: ~several 10m,
    Indoor: ~ Several meters)
- **Propagation characteristics**
  - Line of sight propagations
    ⇒ Stable and high quality communications
  - **Higher inter-cell interference**
    Utilizing inter BS **coordinated transmission at cell edge areas**
- **Enabling technologies**
  - Inter cell coordinated beam forming
  - Combination of distributed and concentrated antenna deployment




| Inter BS distance [m] | # of BSs [BSs/km²] |
|---|---|
| 500 | 5 |
| 200 | 29 |
| 100 | 116 |
| 50 | 462 |
| 35 | 943 |



# Prob. of LOS vs. ISD (Inter Site Dist.)

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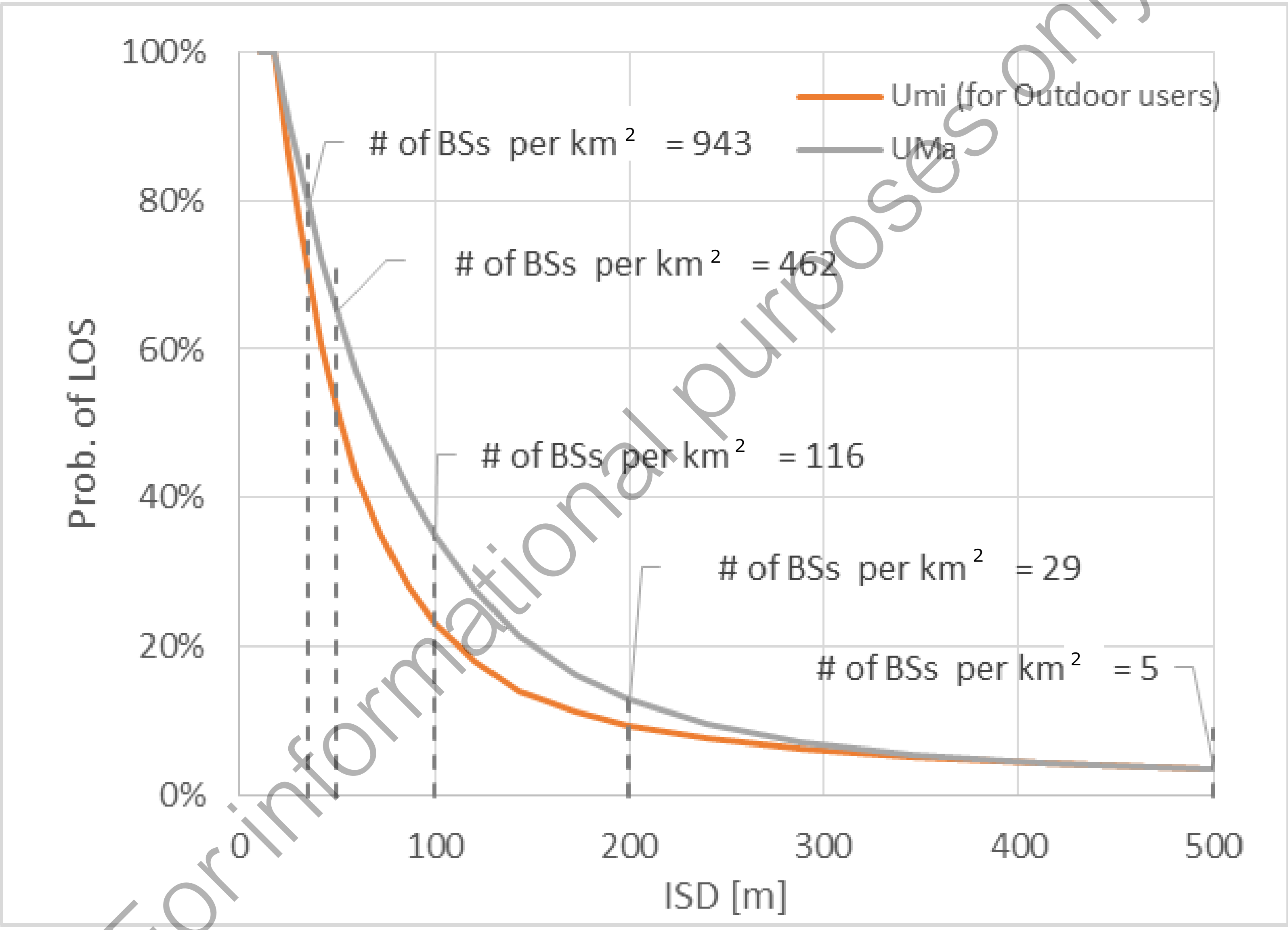


(Ref: 3GPP TR36.814 (V.9.2.0) for 2-6HGz spectrum)

# Ultra Dense Network (UDN)

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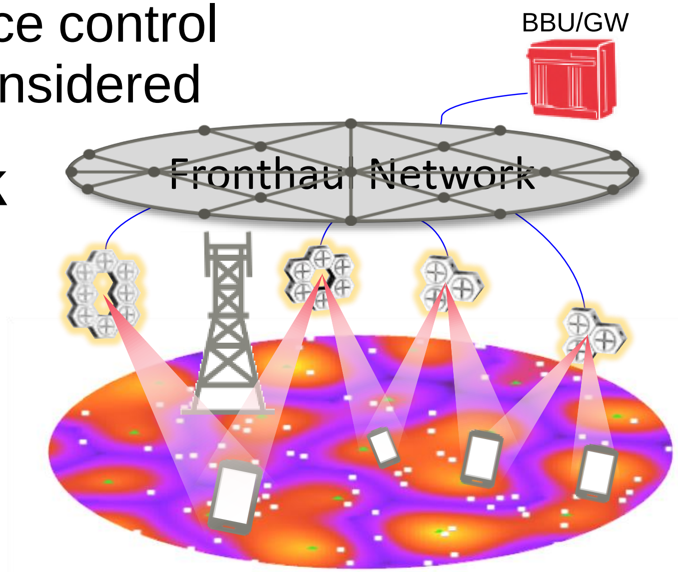
- **Dense deployment of small cells improves bps/Hz/m²**
  - Increased inter-cell interference limits the area throughput
  - Increased requirements (bandwidth, scalability, cost) for backhaul/fronthaul networks
- **Dynamic virtual cell configuration based on traffic distribution**
  - UE-centric virtual cell configuration via large scale cooperation among distributed small cells for interference control
  - Excessive lean carrier design should be considered
- **Flexible backhaul/fronthaul network**
  - Reconfigurable MP-to-MP, Packet-based
    - Architectural design and functional splitting
    - Heterogeneous transmission links (Optical, wireless, DSL)
  - Study RAN specification impacts



Dynamic virtual cell configuration

# Population density vs. Transmission Point (TP) density, subscribers per TP

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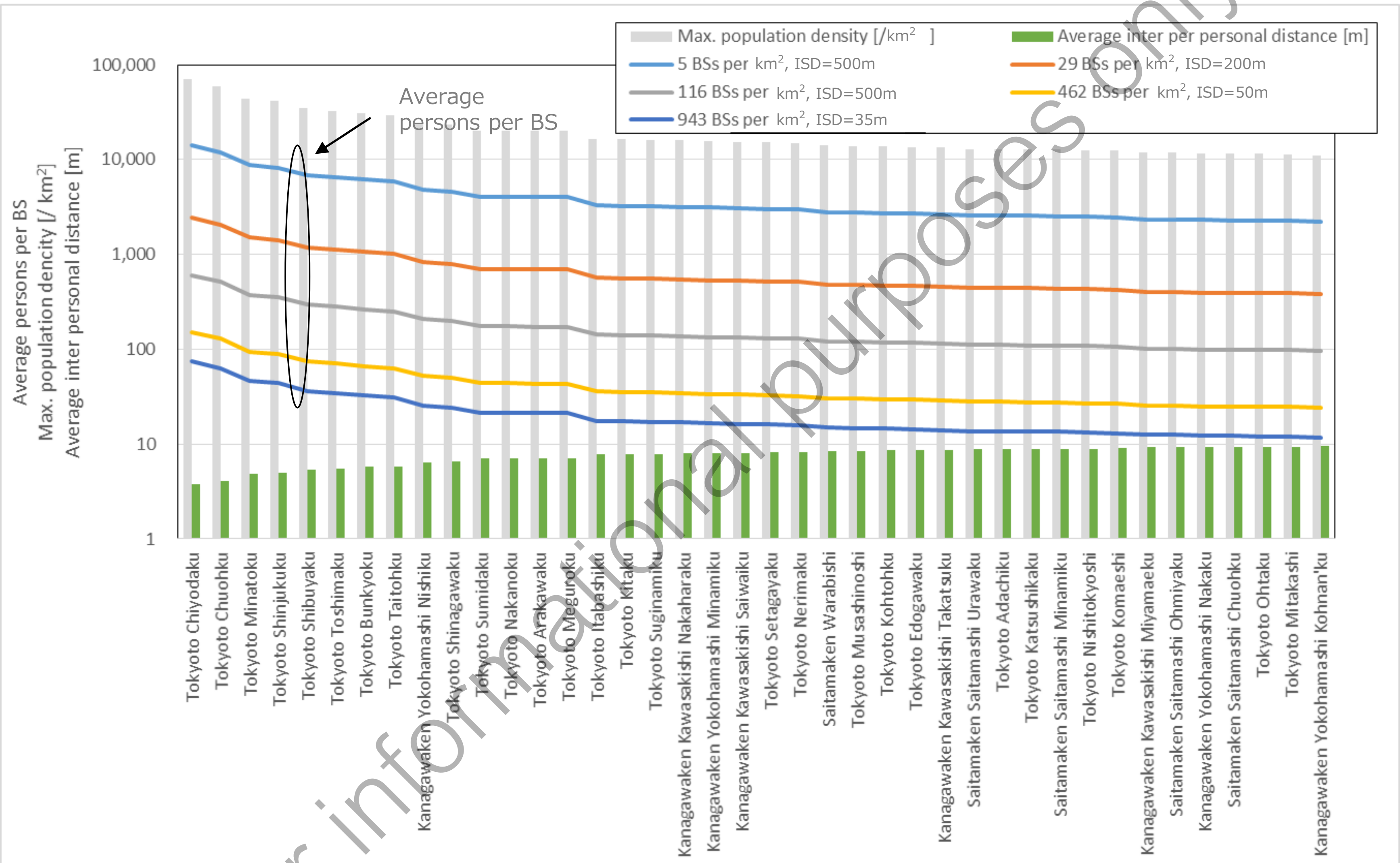
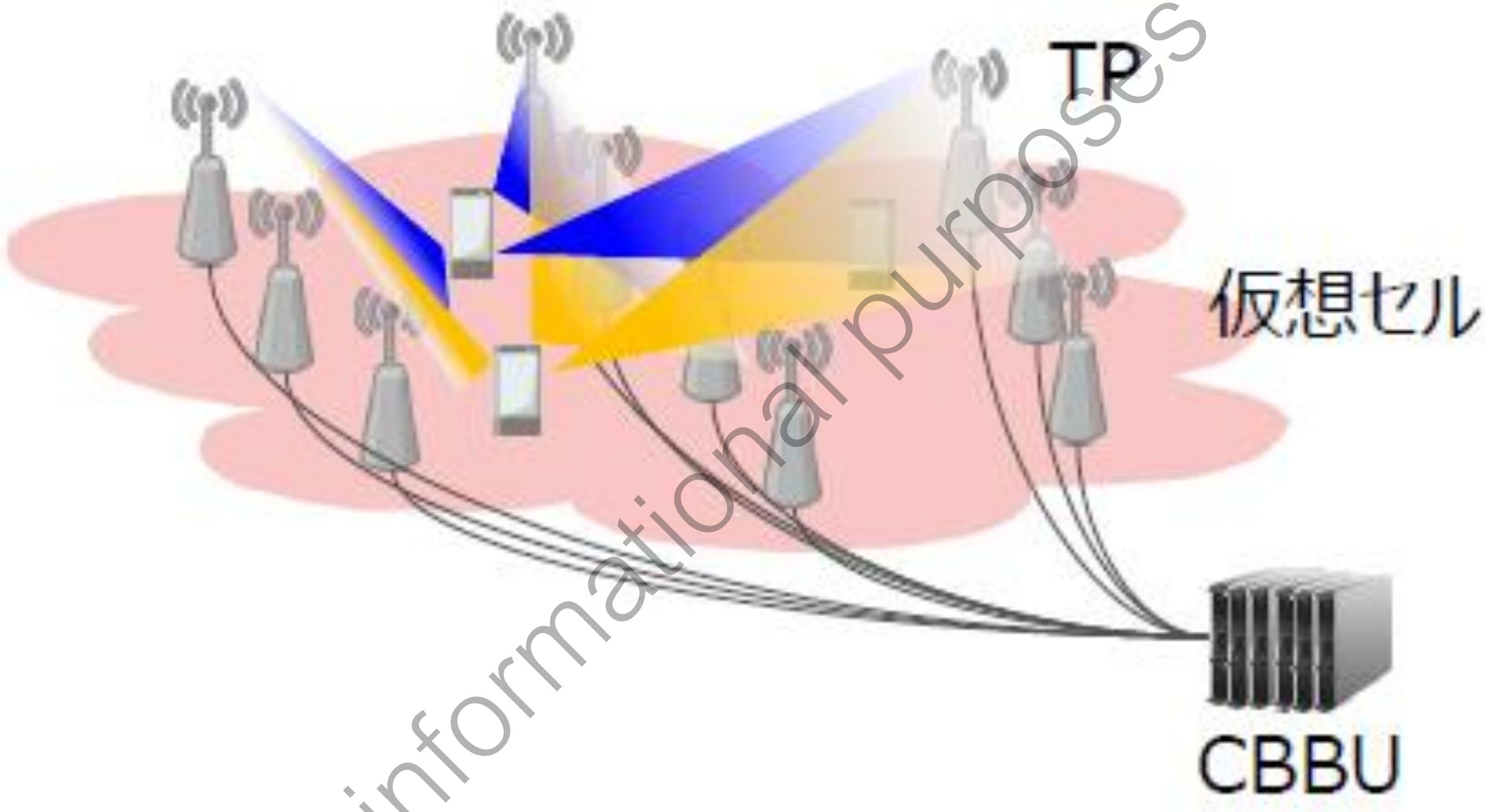



Ref: Derived from “5GMF White Paper (5G Mobile Communications Systems for 2020 and beyond) Ver.1.01,” The Fifth Generation Mobile Communications Systems Forum, Jul.2016. Original in “Population based on place of working or schooling (Daytime population), Population based on place of usual residence (Nighttime population), Rate of daytime population to Nighttime population - Shi, Ku, Machi and Mura (2010),” Statistics Bureau of Japan, 2010-2015 (In Japanese) (URL: http://www.stat.go.jp/data/kokusei/2010/kihon4/zuhyou/syuyou.xls), Area of Shi, Ku, Machi and Mura in each Ken,” Geospatial Information Authority of Japan.

# Ultra Dense Network (2/2)



**Fujitsu Launches Field Trial of Ultra High-Density Distributed Antenna Systems for 5G**

**Fujitsu establishes a 5G testing site at one of its network business locations, conducts trials of the simultaneous, high-speed transmission of high resolution video**

**Fujitsu Limited, Fujitsu Laboratories Ltd.**

**Tokyo and Kawasaki, Japan, November 07, 2017**

Fujitsu Limited and Fujitsu Laboratories Ltd. have today commenced field trials of an ultra high-density distributed antenna(1), a technology aimed at increasing capacity for fifth generation mobile communications, or 5G. The trials, conducted jointly with NTT DOCOMO, Inc., are being conducted at a testing site established to trial 5G, located at the Fujitsu Shin-Kawasaki Technology Square, a central base for Fujitsu's network business.

This trial will utilize a testing system designed for the newly developed ultra high-density distributed antenna technology. In addition to testing that technology, trials will also be conducted on the simultaneous transmission of high resolution video using the distributed antennas. Fujitsu will evaluate application behavior on this testing system, verifying the effectiveness of this 5G technology for a variety of use cases, such as live video transmission in stadiums. Fujitsu and Fujitsu Laboratories will be conducting this trial jointly with DOCOMO, with the goal of commercializing 5G technology from 2020.

Fujitsu Shin-Kawasaki Technology Square (lobby)


Ref: “Fujitsu Launches Field Trial of Ultra High-Density Distributed Antenna Systems for 5G,” Press release of Fujitsu, (Nov. 2017) [http://www.fujitsu.com/global/about/resources/news/press-releases/2017/1107-01.html]

# Conclusion

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1. **Role of ‘5G’, demanded features to the system**
   Bridging Digital World and Physical World
   in secure, stable and efficient manner

2. **Phased approach and candidate features**
   Phase 1: Flexible radio interface specification
   - May meet a sub set of 5G requirements
   - Forwards compatibility to Phase 2 and beyond

   Phase 2: Extended frequency bands above 6GHz
   - Has to meet all ITU-R IMT-2020 requirements
   - Backwards compatibility to Phase 1

3. **Enabling technology**(ies)
   - Ultra High-Density Distributed Smart Antenna Systems
   - mmWave beamforming
   - Space-division full duplex（SDFD）

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