IEEE Summit

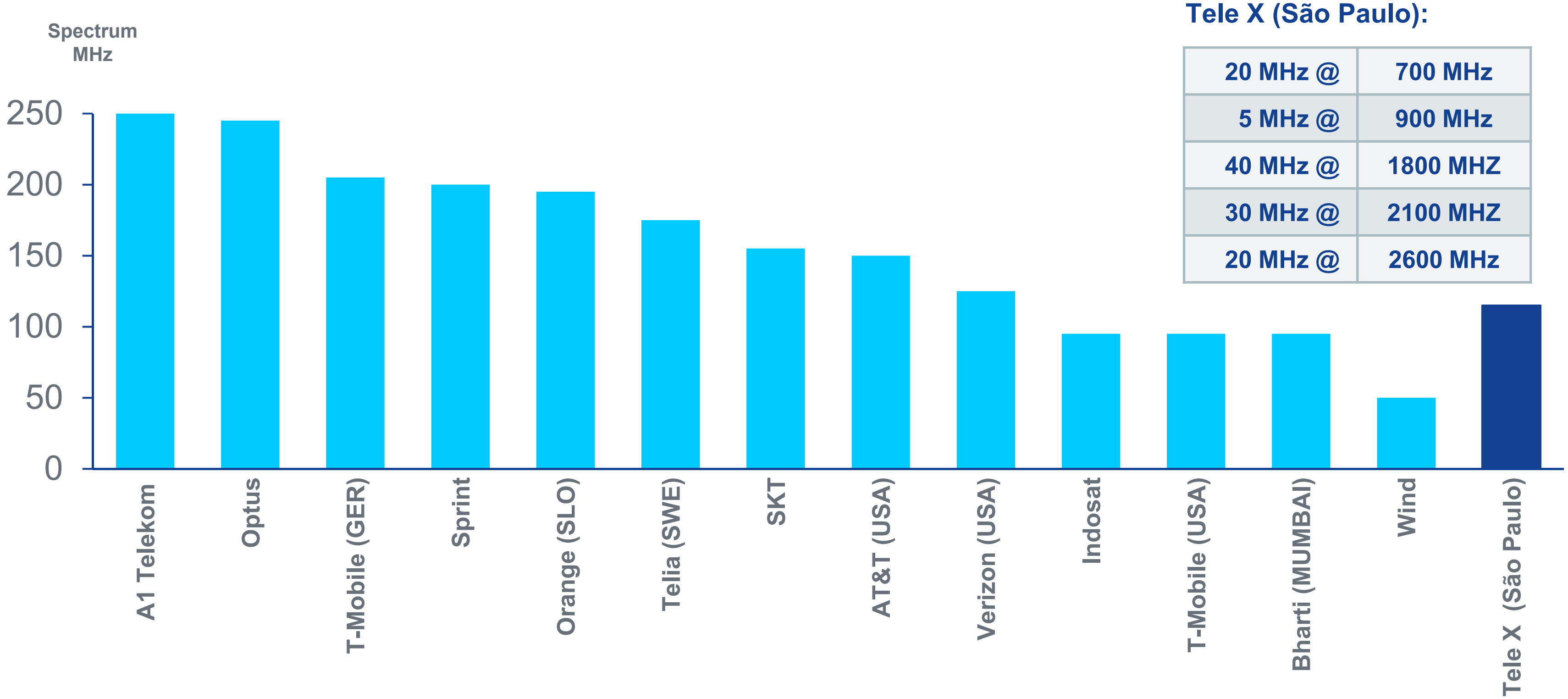
Rio de Janeiro
November 2018

NOKIA

Spectrum assets downlink + uplink from 700 to 3600 MHz (12/2017)

Tele X (São Paulo):

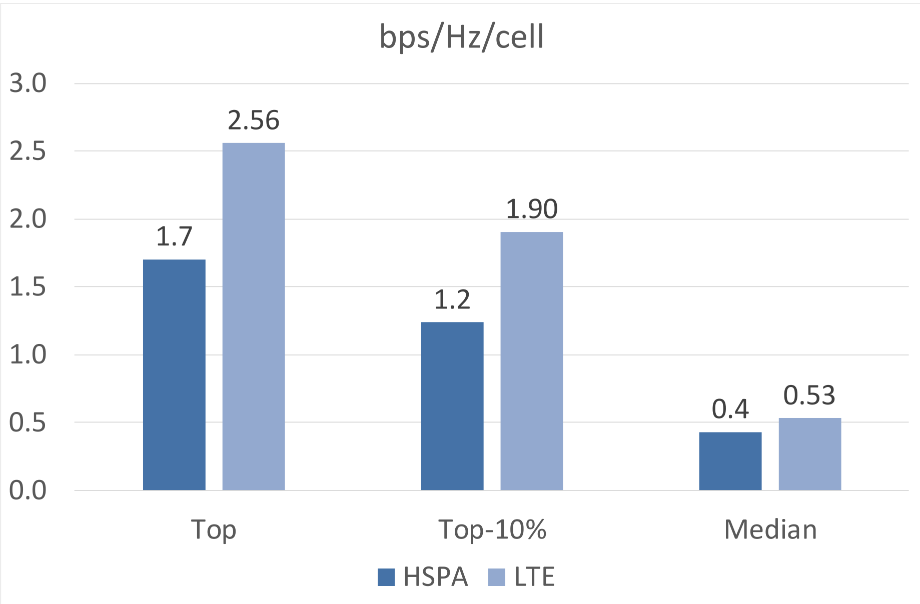
20 MHz @	700 MHz
5 MHz @	900 MHz
40 MHz @	1800 MHZ
30 MHz @	2100 MHZ
20 MHz @	2600 MHz



NOKIA

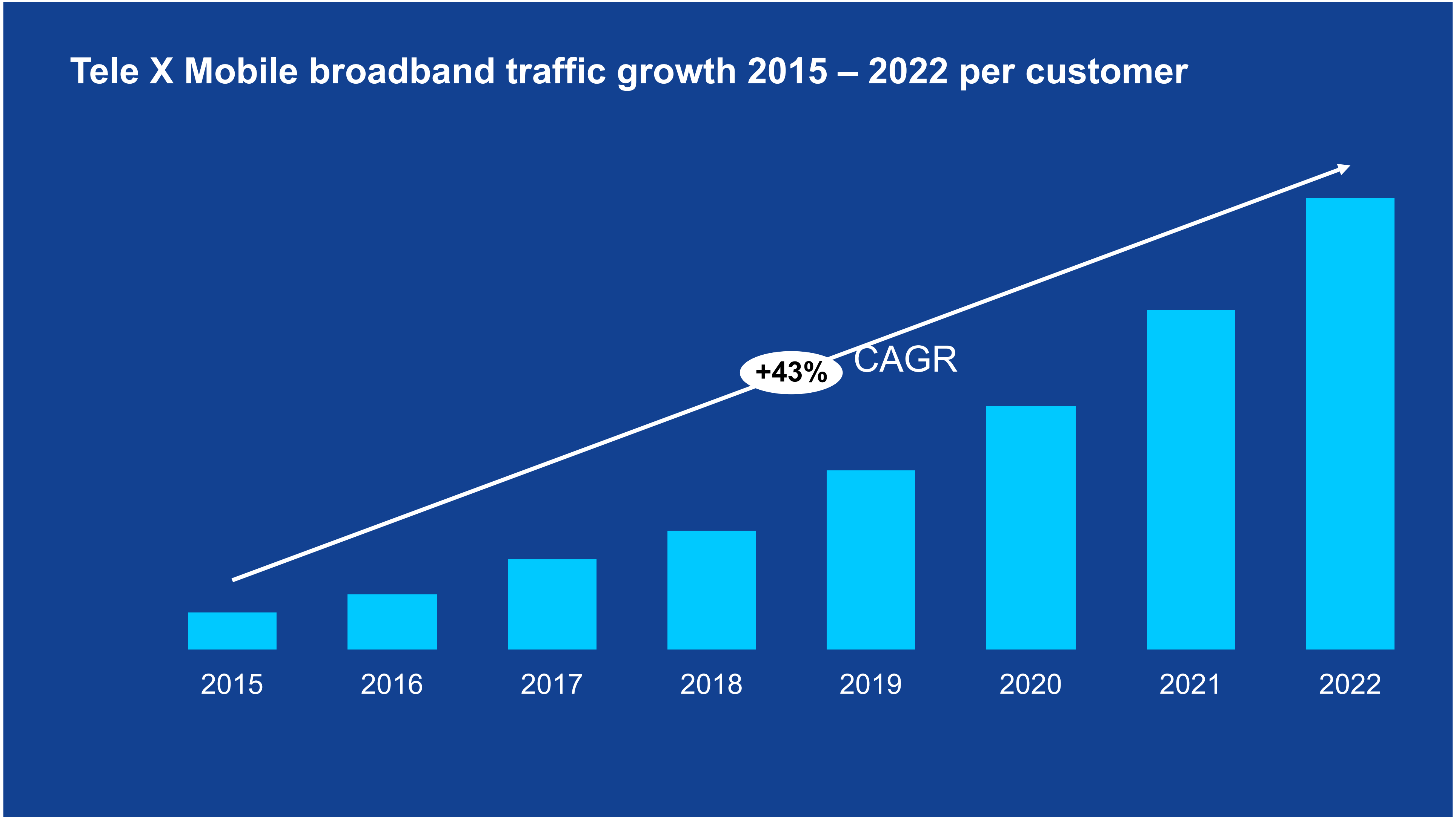
LTE Spectral Efficiency in Live Networks

Large Number of Live Nokia Networks

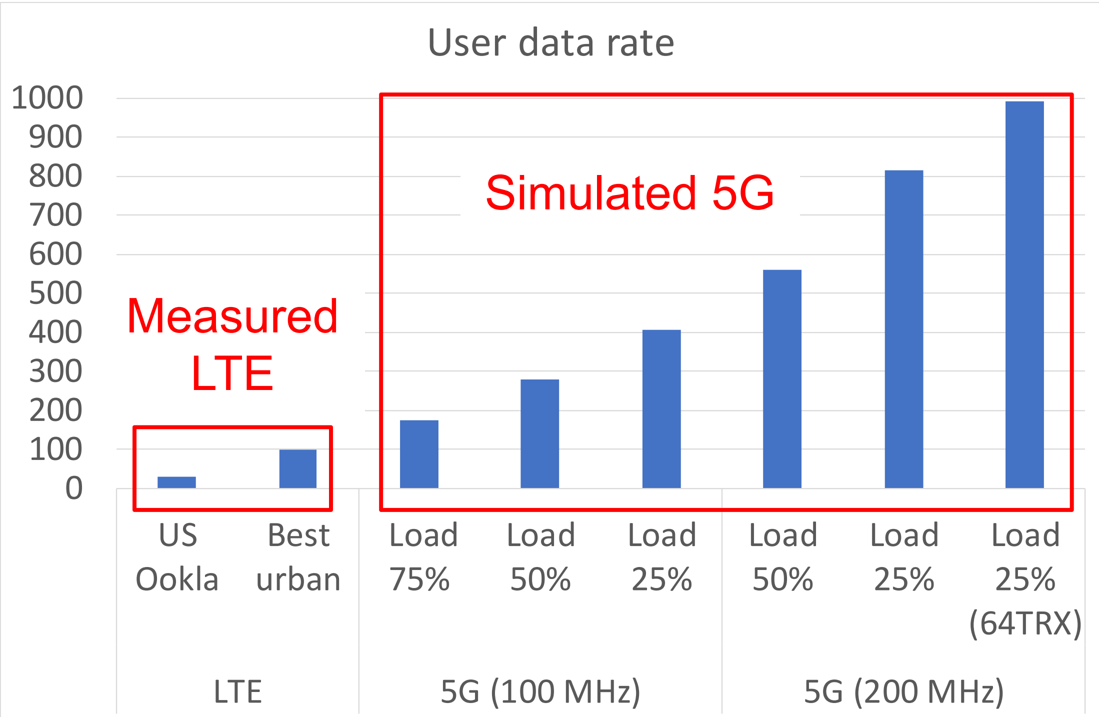


We estimate the spectral efficiency during busy hour in the busy areas from >80 live networks from the carried traffic per cell with a few assumptions

- 20% of BTS makes 50% of traffic
- Busy hour is 7% of daily traffic
- Average busy hour load is 70% of the maximum
- No voice impact considered
- Average LTE bandwidth 15 MHz


Tele X Mobile broadband traffic growth 2015 – 2022 per customer
+43%
CAGR
2015
2016
2017
2018
2019
2020
2021
2022

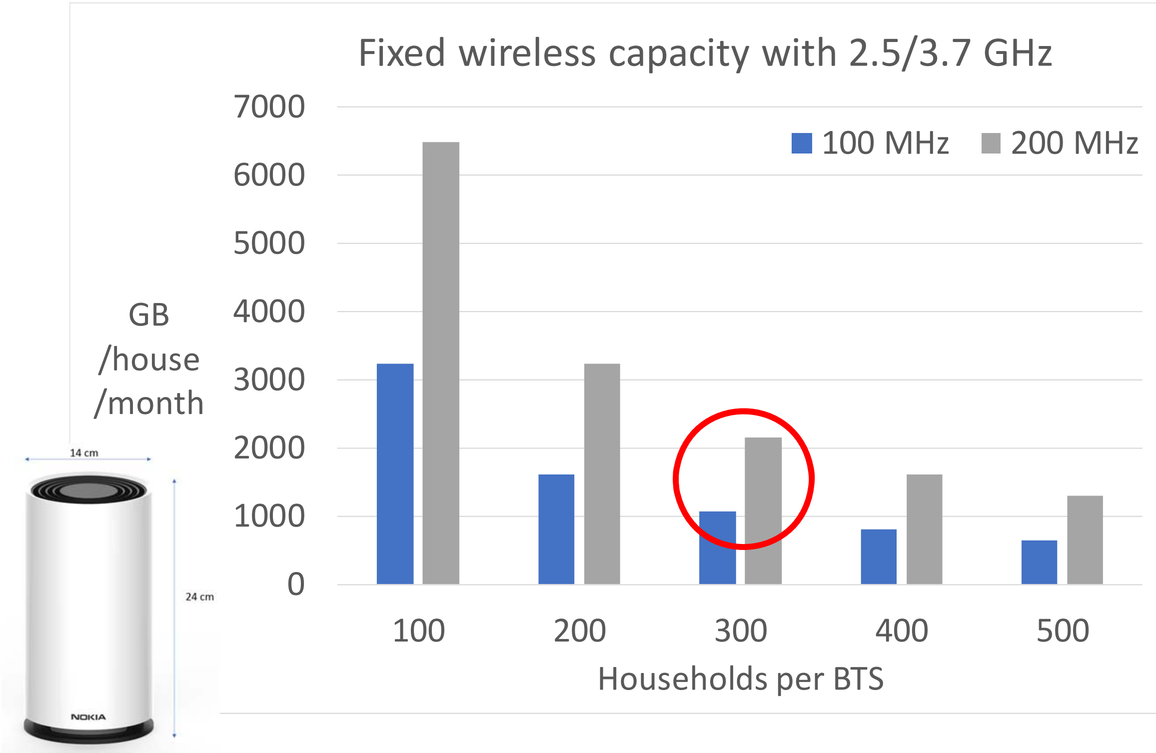
10-20x User Data Rates with 5G up to 1 Gbps



- 200-500 Mbps average user data rates with 100 MHz 5G with mMIMO
- 400-1000 Mbps average user data rates with 200 MHz 5G with mMIMO

NOKIA

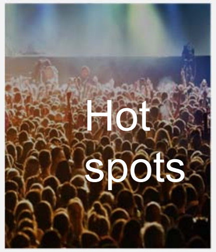
In-Home 5G with 2.5 / 3.7 GHz – Cutting the Cord



- 2.5 / 3.7 GHz brings a lot of capacity – potentially enough for fixed home access
- 1-2 TB per household per month with 300 households per BTS
- No need for directional CPE antenna

NOKIA

5G Motivations per Band

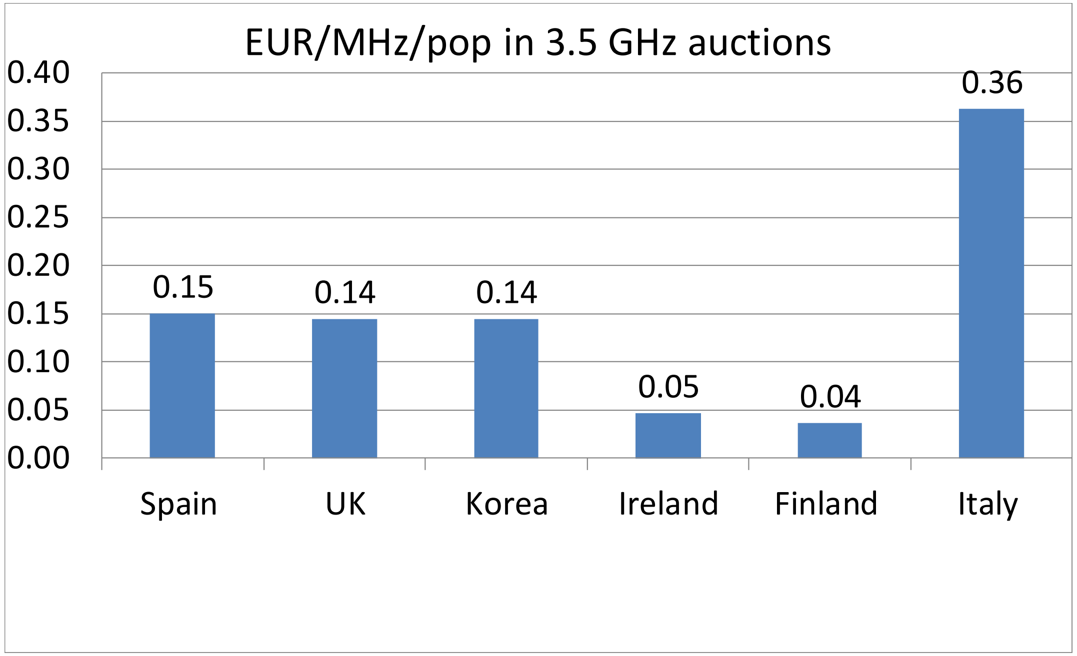


24-39 GHz	• Local solution with spectrum license • Peak rate > 5 Gbps
5 GHz	• Local solution without spectrum license • Improved quality compared to WiFi

3.3-4.9 GHz	• 100 MHz bandwidth for 2 Gbps • 10-20x more capacity than an LTE carrier
1.8 – 2.6 GHz	• 5G brings mMIMO capable eco-system • 2-3x spectrum efficiency compared to LTE
Sub 1 GHz	• Low latency coverage for new services • Improve spectrum and energy efficiency vs LTE

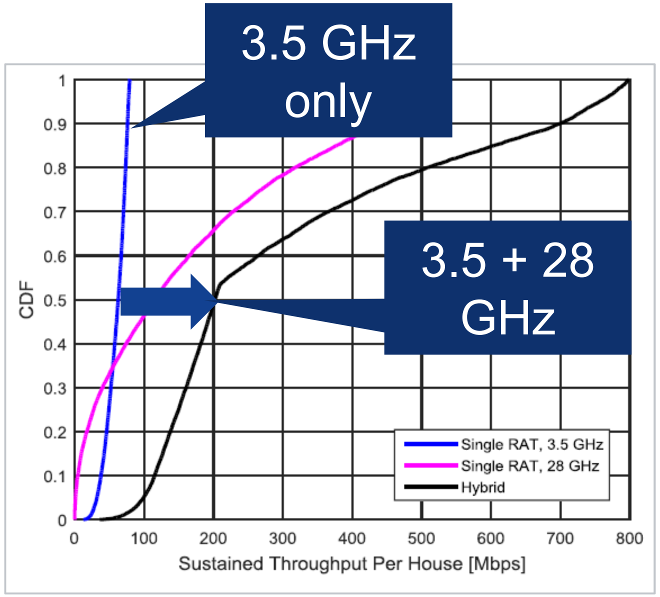
NOKIA

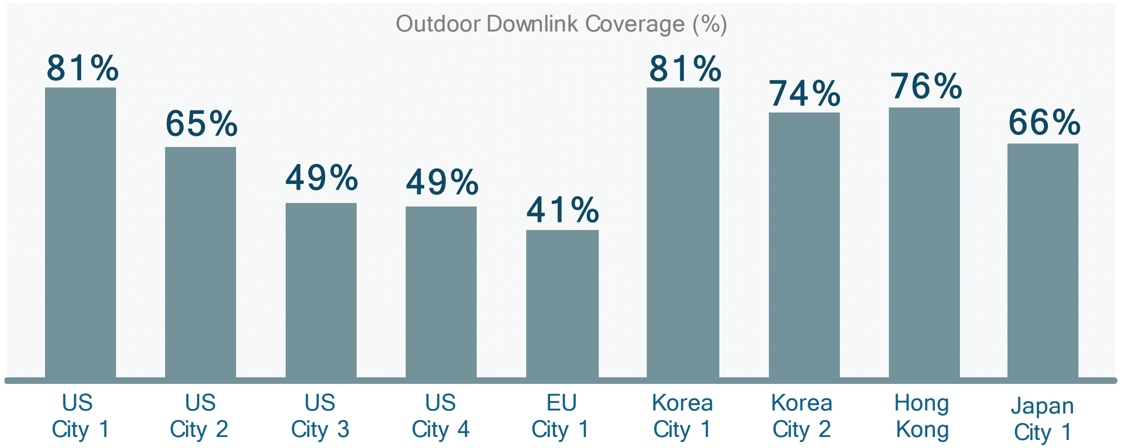
3.5 GHz Spectrum Auctions Results



- Major differences in spectrum prices at 3.5 GHz
- Spectrum price in Italy turned out to be expensive (four operators & high data usage)

28 GHz for Capacity Boost and Offloading



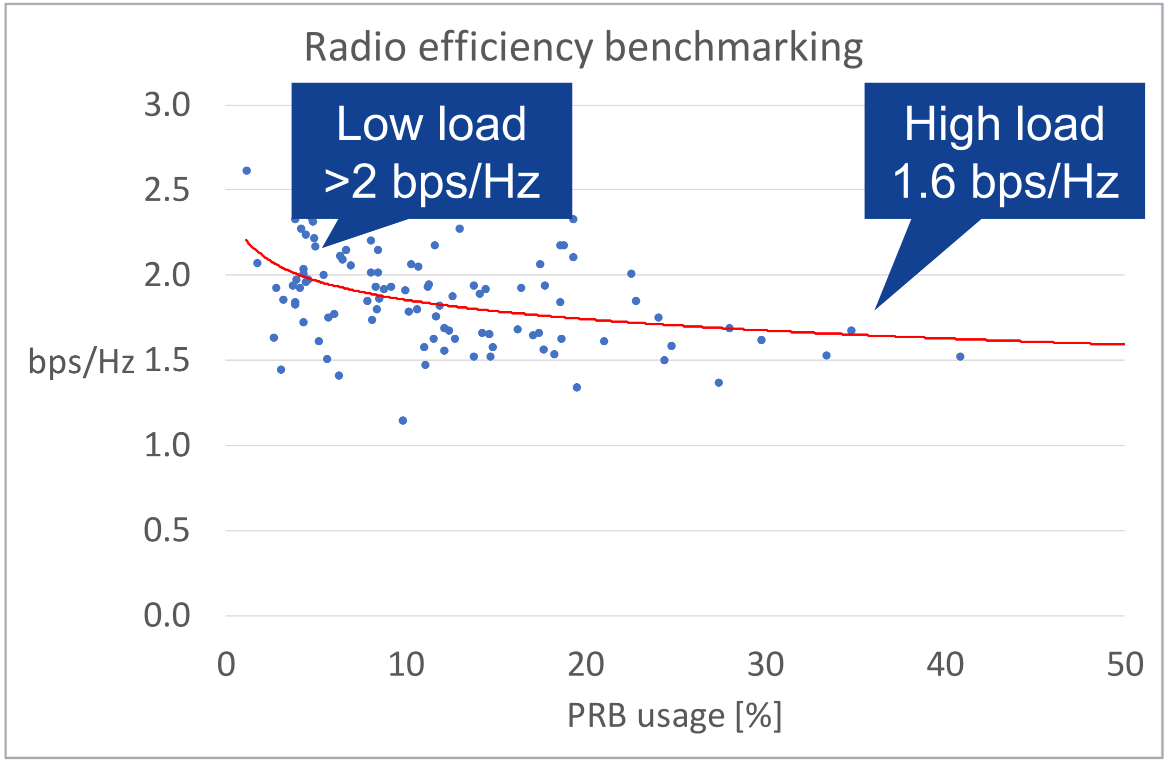


4x data rate with 28 GHz (250 MHz) + 3.5 GHz (40 MHz) vs 3.5 GHz only

Dense urban outdoor coverage 40-80% with existing sites with 28 GHz

NOKIA

LTE Spectral Efficiency – Global Network Wide View



- Low load typically shows >2 bps/Hz
- Very high load shows <1.7 bps/Hz
- High efficiency & high load networks mainly fixed wireless traffic

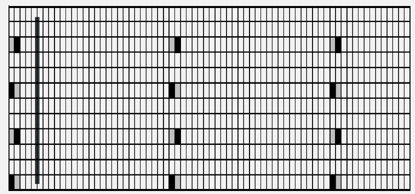
Data collected from network counters
One dot is one complete network

NOKIA

Expected Downlink Spectral Efficiency

			bps/Hz/cell	
Spectrum	**Bandwidth**	**Antennas**	**LTE**	**5G**
<1 GHz	10 MHz	2x2MIMO	1.7	2.2
1.7-2.5 GHz	20 MHz	4x4MIMO[1]	2.5	3.3
2.5/3.5 GHz	100 MHz	mMIMO 64x4[2]	6.3	10.5

Lean carrier



Spectral usage

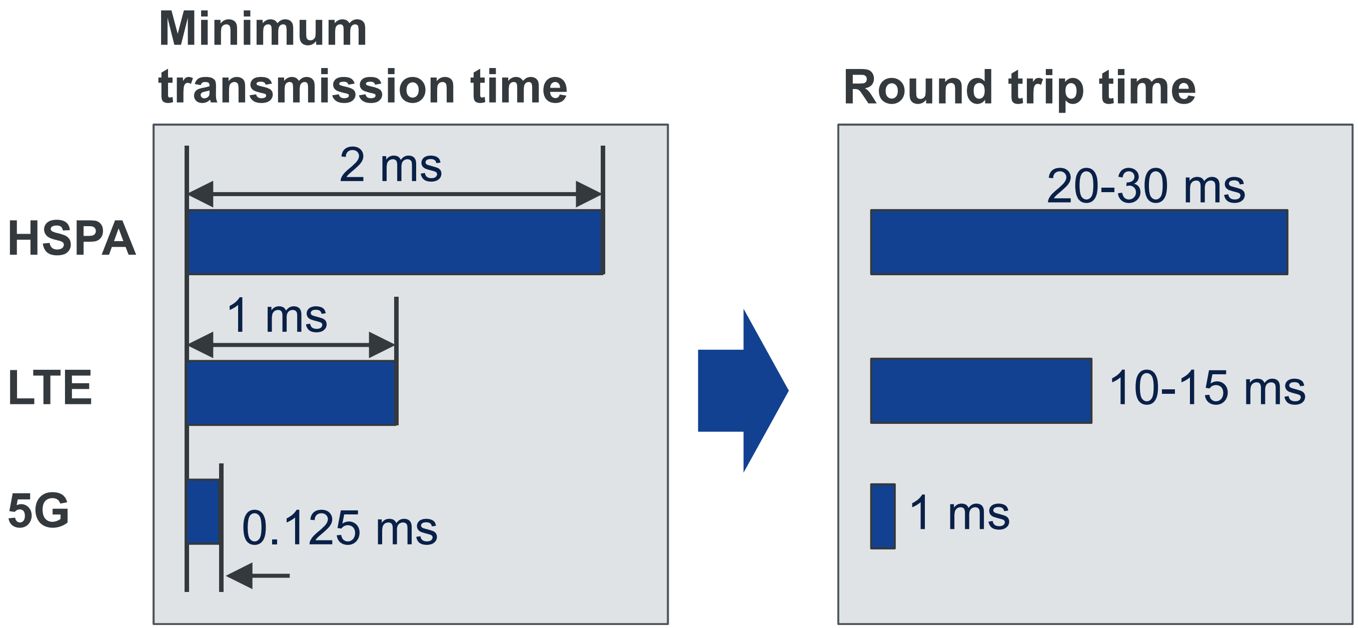
Main factors improving spectral efficiency

- Massive MIMO
- Device antennas
- 5G enhancements

[1]50% gain assumed from 4x4 vs 2x2
[2]mMIMO gives 2.5..3.0x more capacity than 4TX

NOKIA

Low Latency with Short Transmission Time

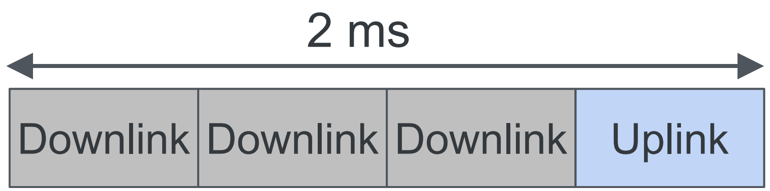


NOKIA

Measured 5G Latency with 3.5 GHz TDD

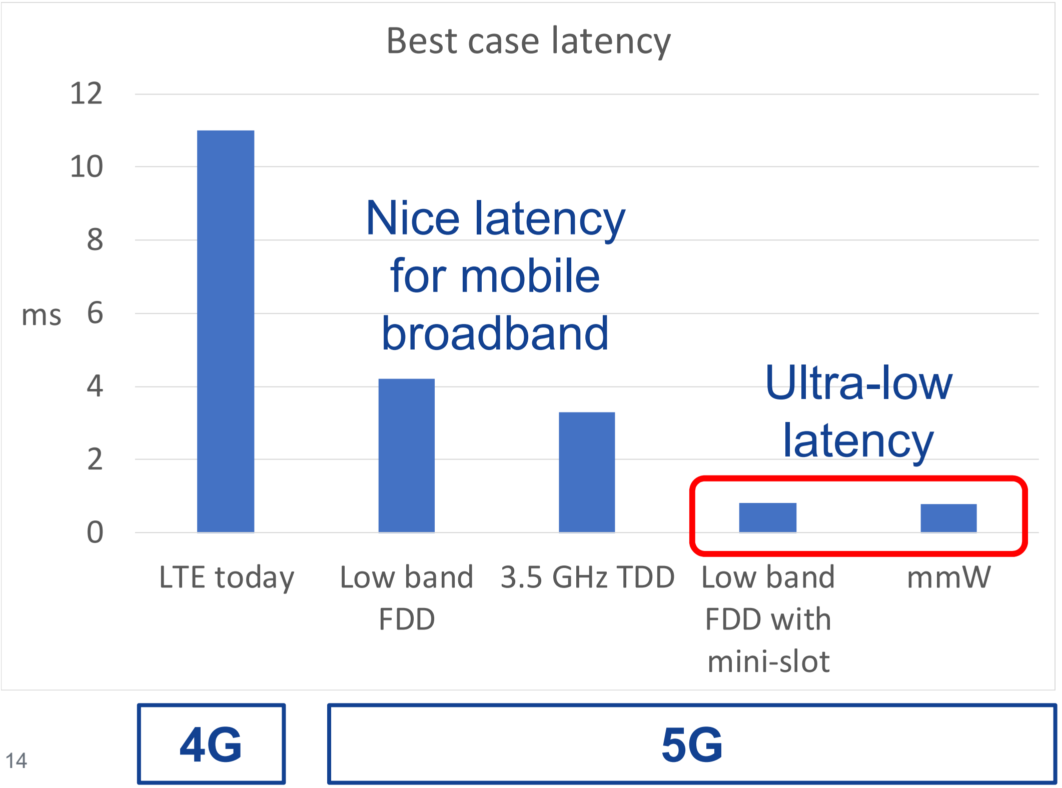
```
PING 192.168.4.50 (192.168.4.50) 56(84) bytes of data.
64 bytes from 192.168.4.50: icmp_seq=1 ttl=127 time=4.18 ms
64 bytes from 192.168.4.50: icmp_seq=2 ttl=127 time=4.91 ms
64 bytes from 192.168.4.50: icmp_seq=3 ttl=127 time=6.37 ms
64 bytes from 192.168.4.50: icmp_seq=4 ttl=127 time=5.37 ms
64 bytes from 192.168.4.50: icmp_seq=5 ttl=127 time=3.86 ms
64 bytes from 192.168.4.50: icmp_seq=6 ttl=127 time=3.88 ms
64 bytes from 192.168.4.50: icmp_seq=7 ttl=127 time=3.87 ms
64 bytes from 192.168.4.50: icmp_seq=8 ttl=127 time=5.88 ms
64 bytes from 192.168.4.50: icmp_seq=9 ttl=127 time=3.87 ms
64 bytes from 192.168.4.50: icmp_seq=10 ttl=127 time=3.89 ms
64 bytes from 192.168.4.50: icmp_seq=11 ttl=127 time=3.87 ms
64 bytes from 192.168.4.50: icmp_seq=12 ttl=127 time=3.87 ms
64 bytes from 192.168.4.50: icmp_seq=13 ttl=127 time=3.87 ms
64 bytes from 192.168.4.50: icmp_seq=14 ttl=127 time=3.85 ms
64 bytes from 192.168.4.50: icmp_seq=15 ttl=127 time=3.87 ms
64 bytes from 192.168.4.50: icmp_seq=16 ttl=127 time=3.88 ms
64 bytes from 192.168.4.50: icmp_seq=17 ttl=127 time=3.87 ms
64 bytes from 192.168.4.50: icmp_seq=18 ttl=127 time=3.87 ms
64 bytes from 192.168.4.50: icmp_seq=19 ttl=127 time=3.88 ms
64 bytes from 192.168.4.50: icmp_seq=20 ttl=127 time=3.87 ms
64 bytes from 192.168.4.50: icmp_seq=21 ttl=127 time=3.87 ms
64 bytes from 192.168.4.50: icmp_seq=22 ttl=127 time=3.88 ms
64 bytes from 192.168.4.50: icmp_seq=23 ttl=127 time=3.86 ms
64 bytes from 192.168.4.50: icmp_seq=24 ttl=127 time=3.88 ms
64 bytes from 192.168.4.50: icmp_seq=25 ttl=127 time=3.88 ms
64 bytes from 192.168.4.50: icmp_seq=26 ttl=127 time=3.86 ms
64 bytes from 192.168.4.50: icmp_seq=27 ttl=127 time=3.88 ms
64 bytes from 192.168.4.50: icmp_seq=28 ttl=127 time=3.88 ms
64 bytes from 192.168.4.50: icmp_seq=29 ttl=127 time=3.88 ms
64 bytes from 192.168.4.50: icmp_seq=30 ttl=127 time=3.88 ms
64 bytes from 192.168.4.50: icmp_seq=31 ttl=127 time=4.38 ms
64 bytes from 192.168.4.50: icmp_seq=32 ttl=127 time=4.36 ms
64 bytes from 192.168.4.50: icmp_seq=33 ttl=127 time=4.87 ms
64 bytes from 192.168.4.50: icmp_seq=34 ttl=127 time=4.87 ms
64 bytes from 192.168.4.50: icmp_seq=35 ttl=127 time=4.88 ms
64 bytes from 192.168.4.50: icmp_seq=36 ttl=127 time=4.87 ms
64 bytes from 192.168.4.50: icmp_seq=37 ttl=127 time=4.88 ms
64 bytes from 192.168.4.50: icmp_seq=38 ttl=127 time=4.88 ms
64 bytes from 192.168.4.50: icmp_seq=39 ttl=127 time=4.88 ms
```

- Measured latency 4-5 ms with 3.5 GHz TDD band with Qualcomm test device
- 3.5 GHz TDD cannot provide <3..4 ms latency due to 2.5 ms TDD frame.
- 2.5 GHz TDD cannot provide <6..10 ms latency if we need to follow TD-LTE frame structure (5 ms)



NOKIA

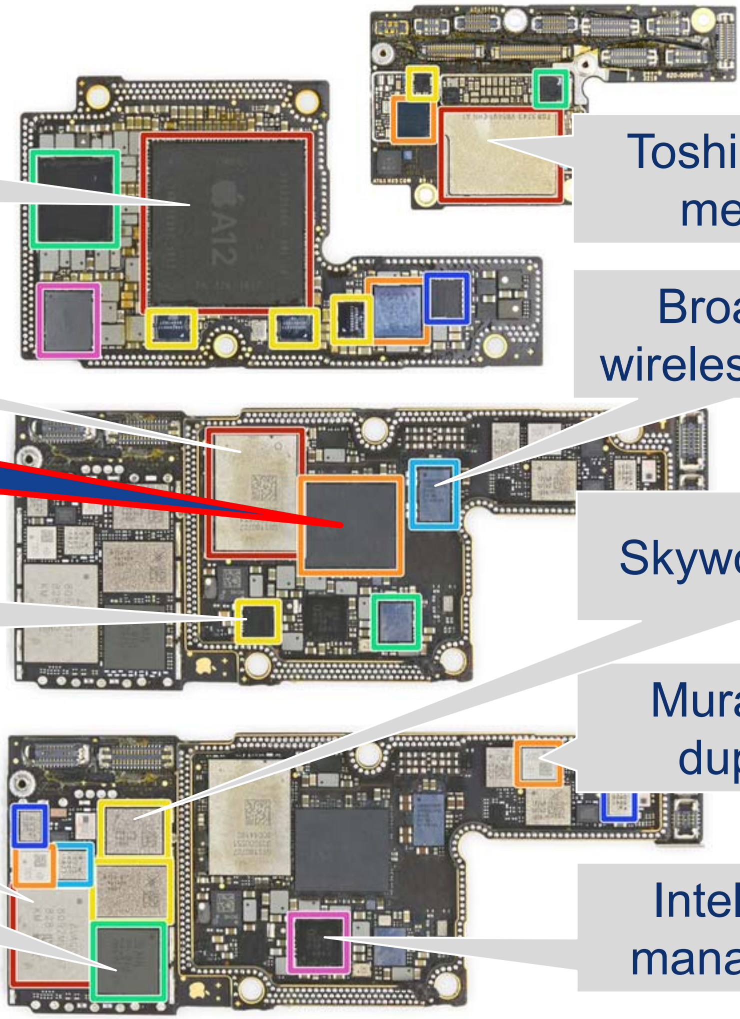
5G Latency and Spectrum



- 5G low latency (1 ms) can be obtained with low band FDD or with mmW TDD
- 2.5/3.5 GHz TDD can provide nice latency (<10 ms) but not ultra-low latency

NOKIA

iPhone XS Teardown



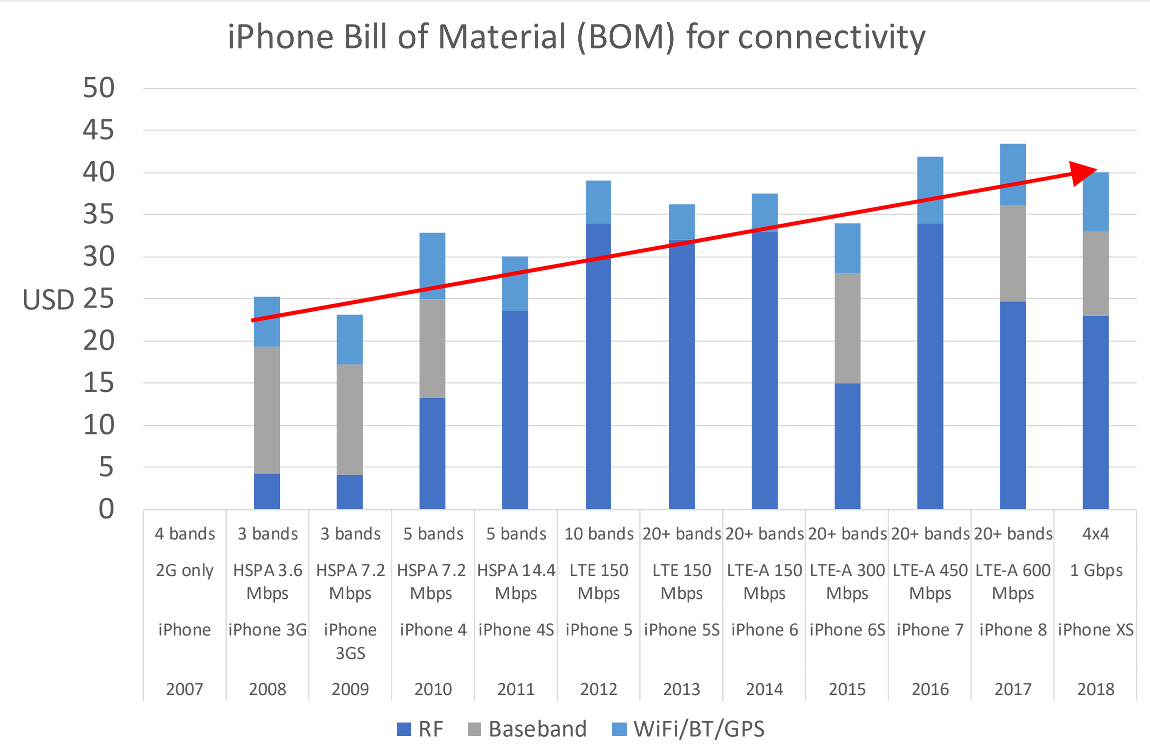
- Application processor A12 (7 nm)
- Apple Bluetooth & Wi-Fi
- Intel baseband XMM7560 (14 nm)
- Embedded SIM micro controller
- Avago high/mid band PA
- Intel RF transceiver
- Toshiba flash memory
- Broadcom wireless charge
- Skyworks PAs
- Murata 4x4 duplexer
- Intel power management

- Apple APL1WB1 A12 Bionic SoC layered over Micron MT53D512M64D4SB-046 4 GB LPDDR4X SDRAM
- STMicroelectronics STB601A0 power management IC (possibly for Face ID)
- 3x Apple 338S00411 audio amplifiers, two for stereo and one for haptics
- Apple 338S00383-A0 power management IC (possibly from Dialog Systems)
- Apple 338S00456 power management IC
- Apple 338S00375 system power management IC (possibly from Dialog Systems)
- TI SN2600B1 battery charger
- Apple/USI 339S00551 (XS) and 338S00540 (XS Max) WIFI/Bluetooth SoC
- Intel PMB9955 (likely XMM7560) baseband processor/modems
  - Sorry, Qualcomm fans.
- ST Microelectronics ST33G1M2 32 bit MCU with ARM SecurCore SC300
  - This is the same embedded SIM (eSIM) that we found in the Apple Watch Series 3 and the Google Pixel 2 XL.
- NXP 100VB27 NFC controller
- Broadcom 59355A2 10646 wireless charging module
- Avago 8092M high/mid PAD
- Murata 500 4x4 MIMO duplexer
- Skyworks 206-15 and 170-21 power amplification modules
- Intel 5762 RF transceiver
- Skyworks 5775 RF Switch
- Skyworks 5941 GPS low-noise amplifiers
- Intel 6829 power management IC

NOKIA

Cost of Connectivity in iPhones Keeps Increasing

Faster speeds, more RF bands and more antennas



- Cost of connectivity parts in iPhones have gradually increased due to faster speeds, more RF bands and more antennas
- iPhone XS has 1 Gbps, 25+ bands and 4x4MIMO
- 5G and mmWs brings again new challenges

NOKIA

5G Device Penetration based on LTE History

LTE

LTE penetration hits 50%

iPhone5 with LTE September 2012

Korea Sep 2013

Japan Dec 2014

USA March 2015

UK Dec 2015

Europe Dec 2016

2012 | 2013 | 2014 | 2015 | 2016

5G

iPhone with 5G

5G penetration hits 50%

2020 | 2021 | 2022 | 2023 | 2024

5G device penetration will hit 50% in most markets during 2023-2024 if we simply follow LTE history. Penetration of 30% typically 1-1.5 year earlier 2022-2023.


NOKIA