BCG

5G Spectrum Roadmap & Challenges

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THE BOSTON CONSULTING GROUP

Future mobile networks combine 5G with existing 4G/Wi-Fi – spectrum for 5G both in frequency ranges <6 GHz and >6 GHz

Technology	Network deployment	User benefit
LTE Advanced Pro **in bands <6 GHz**	• Macro and small cells	• Coverage • Wide-area capacity
5G **in bands <6 GHz**	• Macro and small cells	• Coverage • Low latency • Wide-area capacity
5G **in bands >6 GHz**	• Small cells	• Local area capacity • Extreme low latency
Wi-Fi, LTE, sigfox, LoRa **in unlicensed bands[1]**	• Macro and small cells	• Local area capacity • Low Power Wide Area network for IoT

Spectrum used for legacy access technologies today will also be used for 5G

1. E.g., 863-865 MHz, 2.4 GHz, 5 GHz and 57-64 GHz
Source: 3GPP, Wi-Fi Alliance, BCG

It is a longer road towards 5G radio spectrum

Overview spectrum allocation, standardization & approval, and trials & deployments

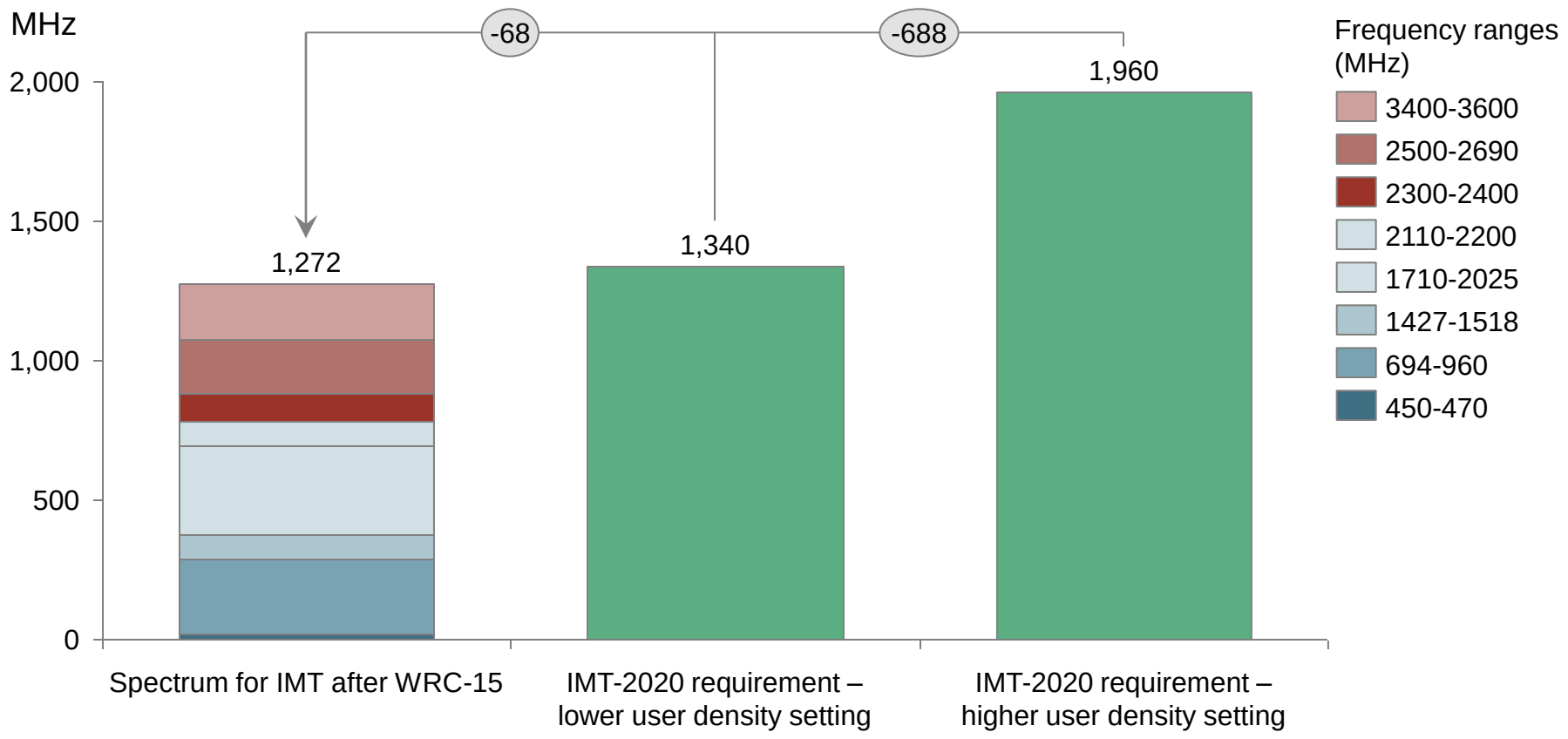
Year	ITU-R (Radiocommunication Sector)	3GPP	MNOs & suppliers
2015	IMT-2020 vision WRC-15[1]	Requirements	Requirements (NGMN[2])
2016	Requirements and evaluation criteria	Requirements	Technology trials
2017	Call for IMT-2020 proposals Workshop for explanation of evaluation criteria and methodology	Release 14 – 5G study items Architecture evolution Radio technology selection	
2018	Start of evaluation process	Release 15 – 5G work items New radio (NR) interface for 5G ITU-R submission	Customer trials (e.g. South Korea for Olympics, pre-standard 5G fixed wireless in the US
2019	WRC-19	Release 16 – 5G work items	
2020	IMT-2020 recommendations	Release 17+ – 5G enhancements	Start of commercial service (Japan, South Korea, USA)
2021+			Wider deployment (Europe)

>6GHz spectrum for 5G will be allocated at WRC-19

1. WRC-15 considered spectrum allocations up to 6 GHz; 2. The Next Generation Mobile Networks (NGMN) Alliance is a mobile telecommunications association of mobile operators, vendors, manufacturers and research institutes; 3. WRC-19 considers spectrum allocations above 6 GHz; Source: ITU-R, 3GPP, NGMN Alliance, Alcatel Lucent, BCG

New frequency ranges required for IMT-2020 and 5G

Spectrum available and required for IMT-2020



Nearly 700 MHz additional spectrum required until 2020 in higher user density setting

Note: IMT = International mobile telecommunications
Source: ITU-R (M.2290-0; 12/2013), BCG

Consensus on new frequency ranges for IMT is difficult

Overview of bands under consideration and allocated at ITU's WRC-15

Frequency ranges under consideration at ITU's WRC-15

470 – 694 MHz[1]	★	**3400 – 3600 MHz[4]**	★
694 – 790 MHz[2]		3600 – 3700 MHz[4]	★
1350 – 1400 MHz	★	3700 – 3800 MHz[4]	★
1427 – 1452 MHz[3]	★	3800 – 4200 MHz[4]	★
1452 – 1492 MHz[3]	★	4400 – 4500 MHz	
1492 – 1518 MHz[3]	★	4500 – 4800 MHz	
1518 – 1525 MHz		4800 – 4990 MHz	
1695 – 1710 MHz		5350 – 5470 MHz	
2700 – 2900 MHz	★	5725 – 5850 MHz	
3300 – 3400 MHz		5925 – 6425 MHz	

★ Frequency ranges recommended by GSMA

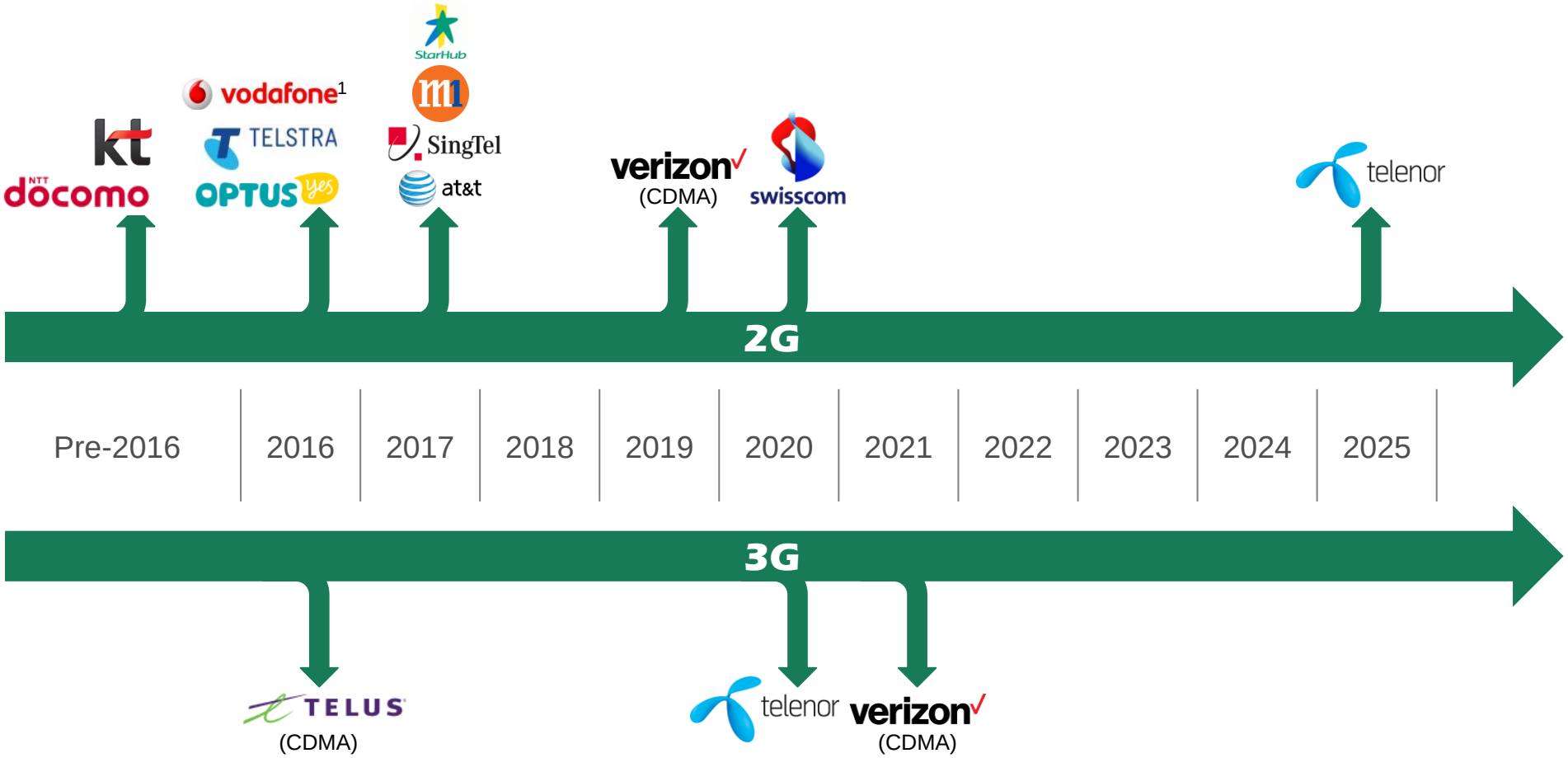
New frequency ranges allocated for IMT

Relatively little additional spectrum allocated to IMT

1. IMT in ITU regions 2 (Americas) and 3 (Asia-Pacific); 2. ITU region 1 (Europe, Africa, the Middle East and Central Asia); 3. Allocated to IMT worldwide except parts of Africa and Asia; 4. 3500 – 4200 MHz already allocated to IMT in ITU regions 2 and 3; Note: IMT = International mobile telecommunications; Source: ITU (2016), GSMA (2015), BCG analysis

2G and 3G shutdown accelerating – but not enough

2G and CDMA are first networks to go offline – some advocates of switching off 3G/WCDMA first



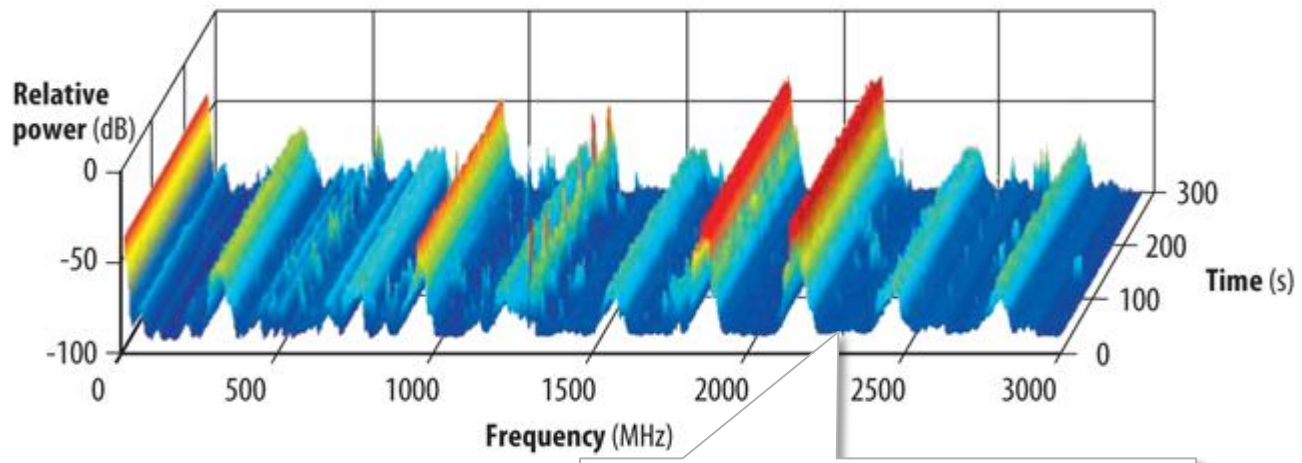
Operators are very cautious and are protecting today's still significant customer base on legacy access technology

1. Vodafone Australia

Source: Operators' press releases, BCG press research and analysis

Current efforts in license sharing are not sufficient to meet demands of 5G mobile networks – new spectrum required

Spectrum measurement showing high, constant utilization at mobile frequencies



Opportunity, e.g., in 2300-2400 MHz

Source: Ericsson

Regulators promoting ASA[1]

FCC	Ofcom	ARCEP	European Commission
3550 MHz to 3700 MHz	3800 MHz to 4200 MHz	2300 MHz to 2400 MHz	2300 MHz to 2400 MHz

Operators need to prepare for technical and business implications of shared spectrum

1. ASA = Authorized Shared Access (shared licensed spectrum use)
Source: Ericsson, FCC, ARCEP, European Commission, BCG research

Various frequency ranges are being considered for IMT-2020 and 5G

FCC	Ofcom	RSPG
24.25 GHz to 24.45 GHz	10.5 GHz to 10.68 GHz	700 MHz[2]
25.05 GHz to 25.25 GHz	10.7 GHz to 11.7 GHz	3.4 GHz to 3.8 GHz[2]
27.5 GHz to 28.35 GHz	14.4 GHz to 15.35 GHz	24.5 GHz to 27.5 GHz
29.1 GHz to 29.25 GHz	17.8 GHz to 19.7 GHz	31.8 GHz to 33.4 GHz
31.0 GHz to 31.3 GHz	21.2 GHz to 23.6 GHz	37.0 GHz to 40.5 GHz
37.0 GHz to 38.6 GHz	24.5 GHz to 27.5 GHz	40.5 GHz to 42.5 GHz
38.6 GHz to 40.0 GHz	27.5 GHz to 29.5 GHz[1]	42.5 GHz to 43.5 GHz
42.0 GHz to 42.5 GHz	31.8 GHz to 33.4 GHz	45.5 GHz to 47.0 GHz
57 – 64 GHz	36.0 GHz to 40.5 GHz	47.0 GHz to 47.2 GHz
64 – 71 GHz	42.5 GHz to 50.2 GHZ	47.2 GHz to 50.2 GHz
71 – 76 GHz	50.4 GHz to 52.6 GHz	50.4 GHz to 52.6 GHz
81 – 86 GHz	55.78 GHz to 76 GHz	66 GHz to 76 GHz
	81 GHz to 86 GHz	81 GHz to 86 GHz
	92 GHz to 100 GHz	

Frequencies **made available** by FCC

Frequencies **in focus** of Ofcom's latest spectrum strategy

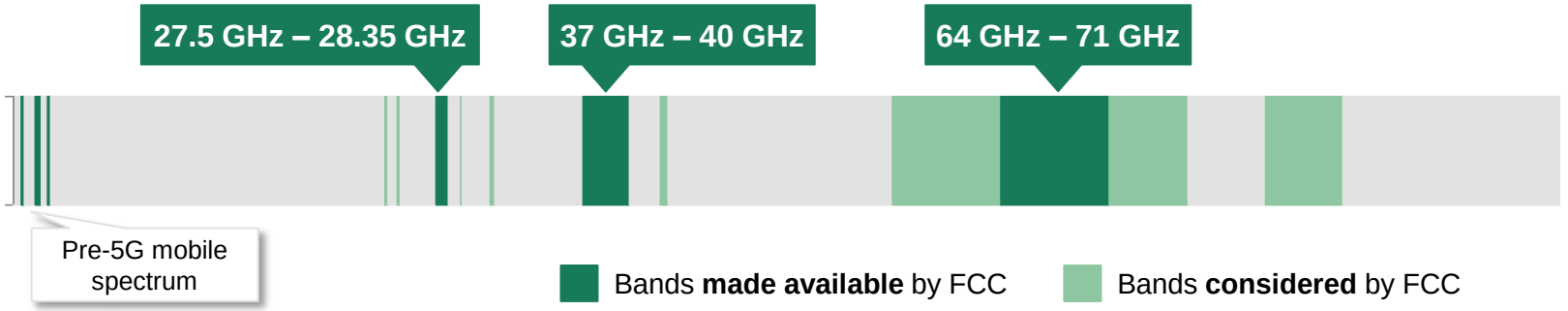
Frequencies **recommended** by RSPG

Global harmonization of 5G spectrum will be challenging

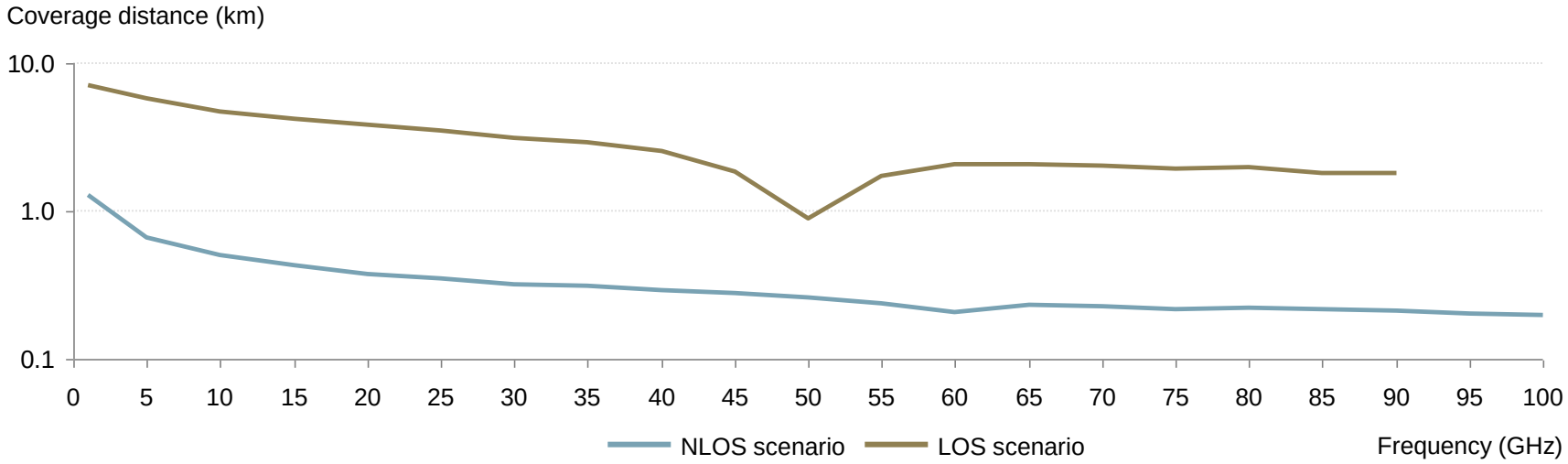
1. Original frequency range recommended was 25.25-29.5 GHz; 2. 700 MHz and 3.4 to 3.8 GHz considered by ITU in addition to WRC-19 studies; Note: IMT = International mobile telecommunications; Source: FCC (Notice of Inquire, 2014; Notice of Proposed Ruling, 2015; Notice of New Rules, 2016), Ofcom, (2015/2016), ITU (2016), RSPG (2016), GSA (2016), BCG analysis

Large amount of 5G spectrum available above 20 GHz

Pre-5G and new spectrum (FCC)



Estimated coverage distance[1] (km)

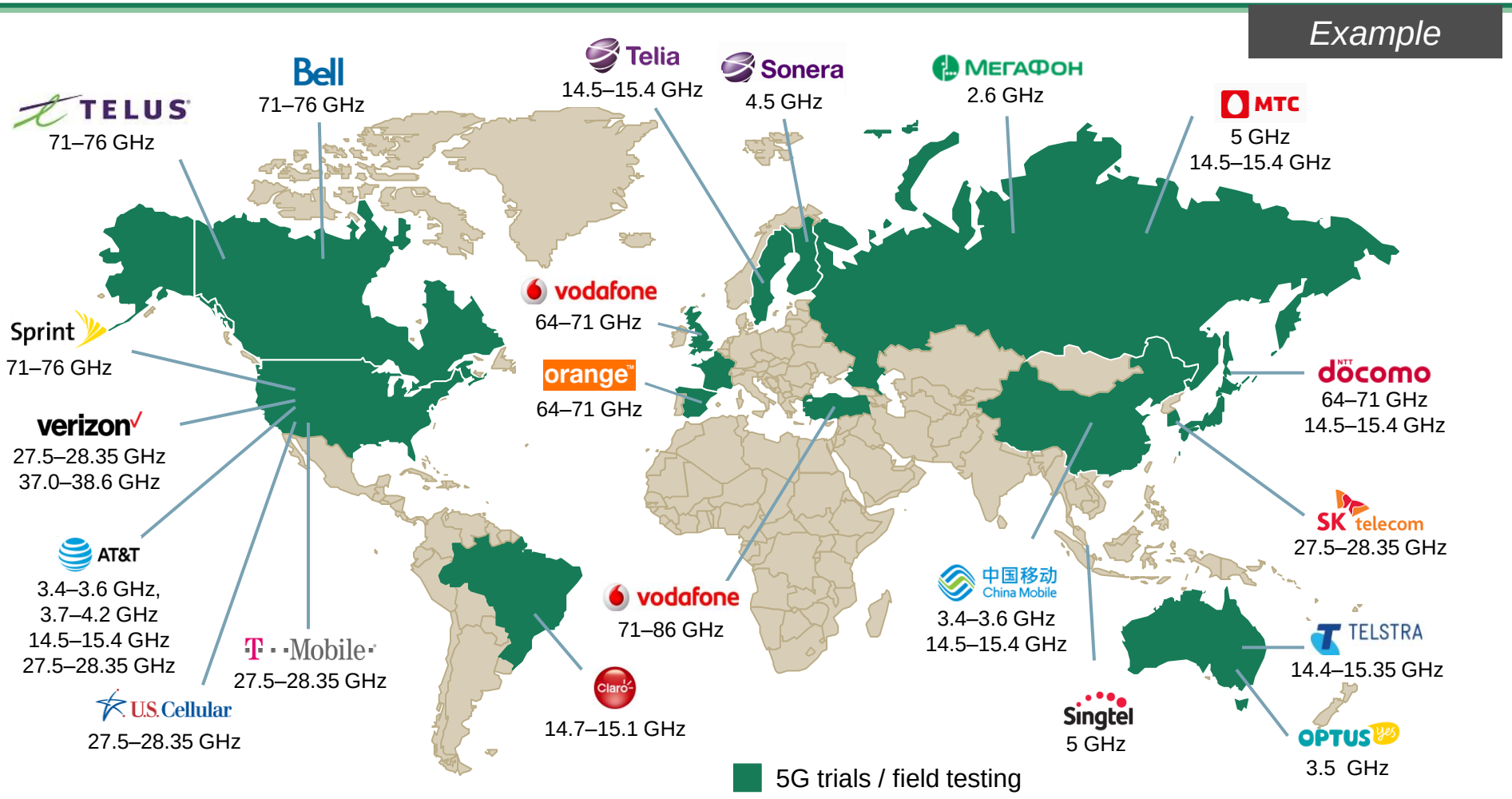


1. Maximum coverage distance with 70 dB maximum path loss dynamic range and 10 dB SNR, as a function of transmitter and receiver distance; loss model assumes path loss with exponent 3.5 or 5 (LOS or NLOS measurements in urban setting for 28 GHz) and atmospheric attenuation

Source: Rappaport et al. "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!", BCG analysis

Operators are trialing 5G on numerous spectrum bands

Overview 5G trials and used spectrum bands[1]



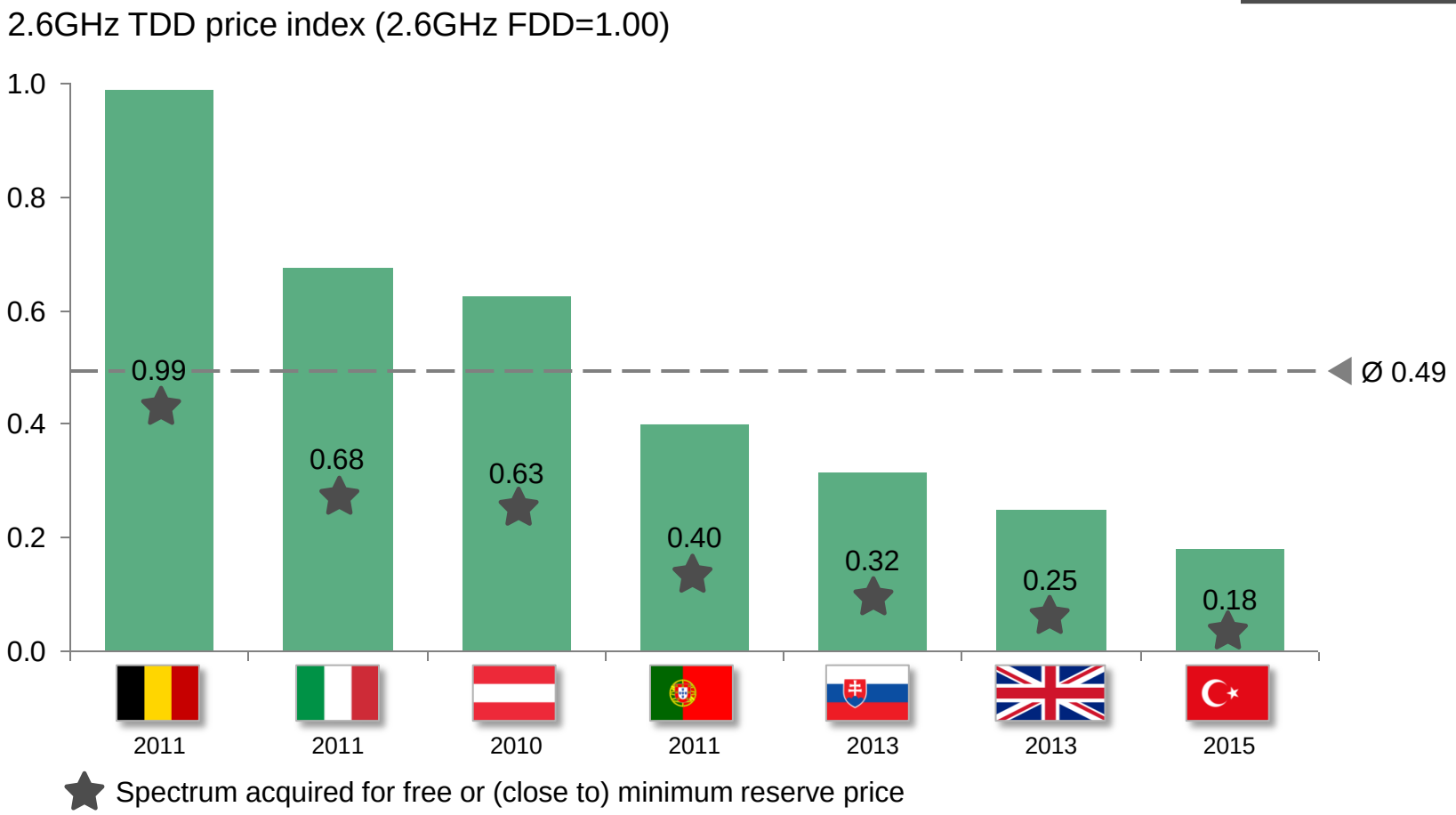
Preferred 5G spectrum bands start to crystallize, e.g. around 3 GHz and 28 GHz, but also 15 GHz and multiple frequency ranges in 24-29 GHz

1. Bandwidths of several 100 MHz typically used in 5G trials
Source: Company press releases, BCG press research, GSA (2016)

Ecosystem uncertainty is a big challenge for operators

Price comparison of 2600 MHz FDD vs. 2600 MHz TDD

Example

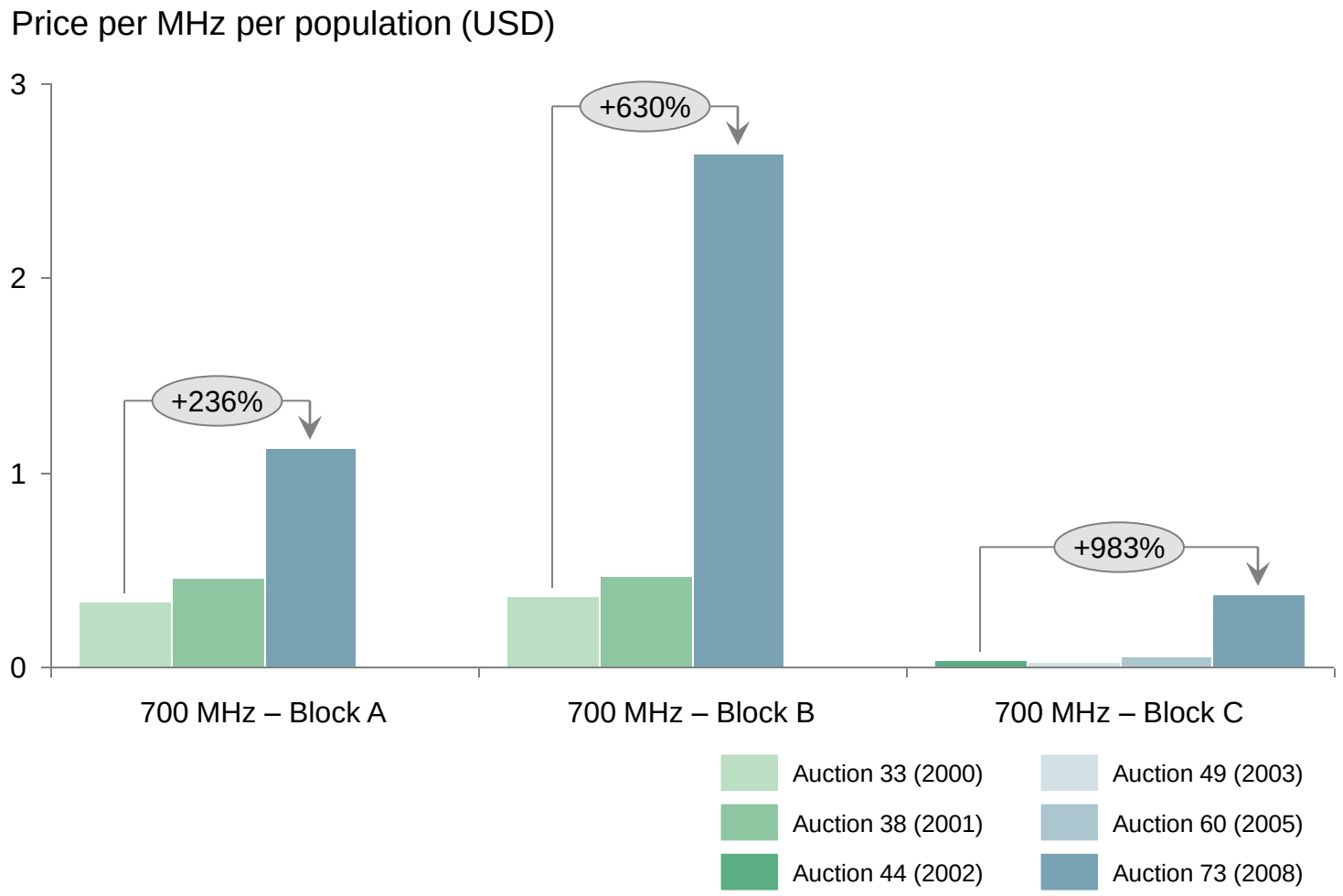


High frequency and TDD spectrum can be acquired at substantial discounts

Note: Comparison of price of 1 MHz of TDD spectrum vs. 2x0.5 MHz of FDD spectrum
Source: BCG spectrum benchmark database and analysis

Not just a European phenomenon: Steep price increase of 700 MHz in US with improving ecosystem certainty

Example



Note: Excluding blocks D and E
Source: FCC; BCG analysis

5G spectrum challenges – and opportunities – for operators

1 There is still a lot of uncertainty on the additional spectrum bands that will play an important role for 5G deployments[1]

2 Despite this uncertainty, operators need to develop robust spectrum strategies for 5G and be prepared to actively push ecosystem development

3 The ones who actively shape the playing-field can acquire spectrum at much lower prices than what is paid for established bands

1. Typically 5-10+ years between identification and monetization of new spectrum bands
Source: BCG

Thank you