5G: Enabled by technology, with Public Policy Assist

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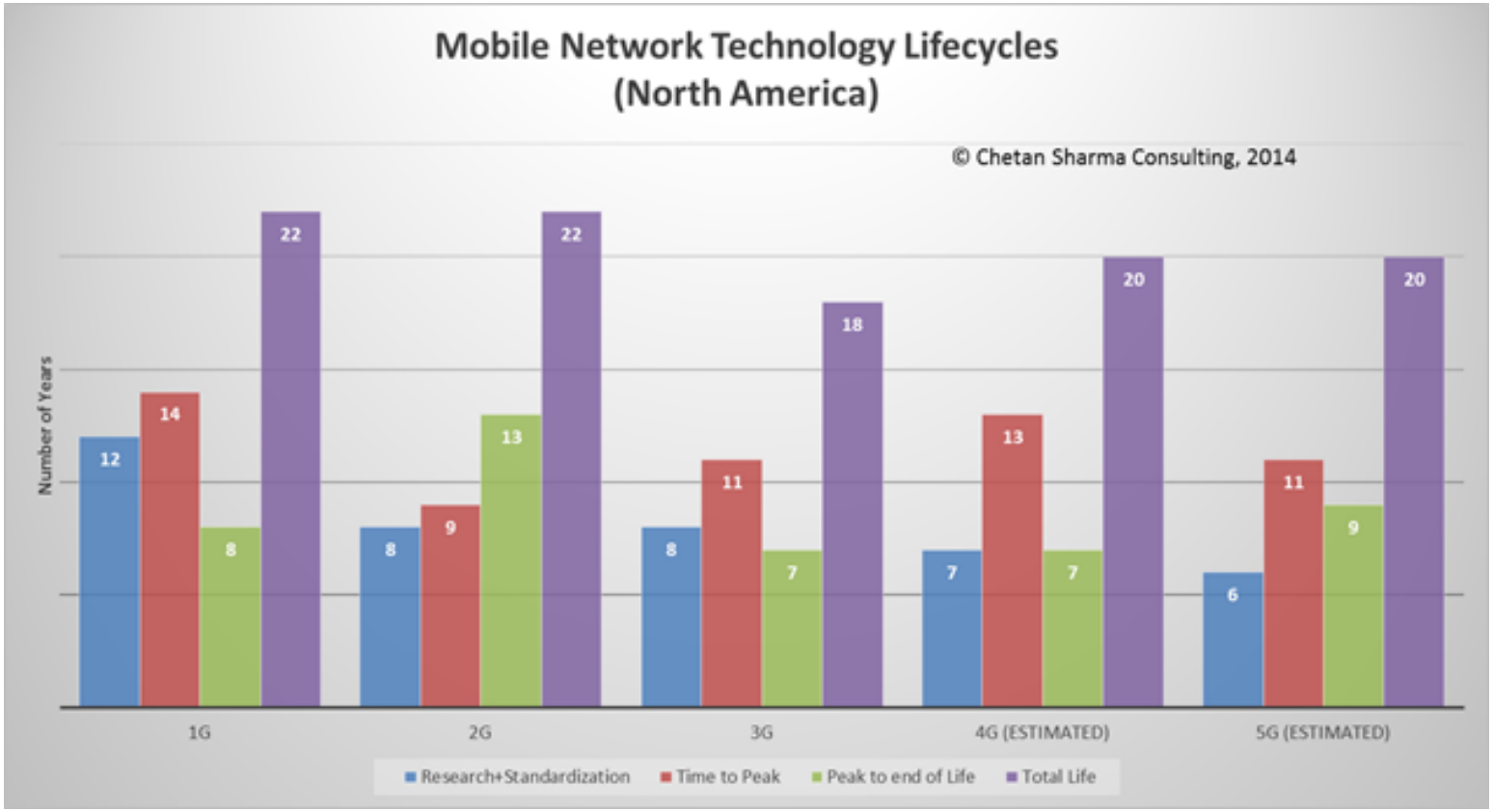
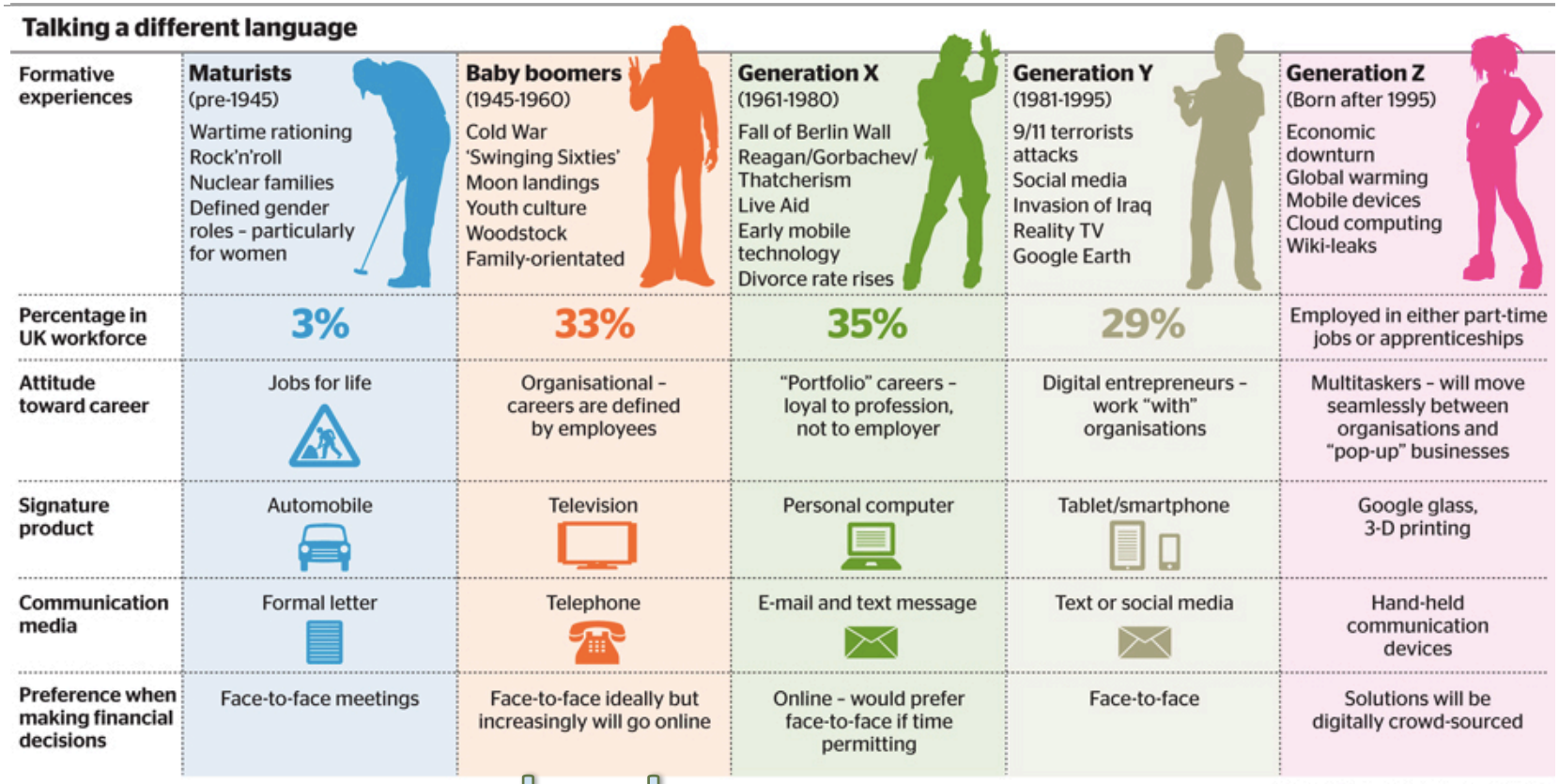
Design for 20 years



Generations are distinct



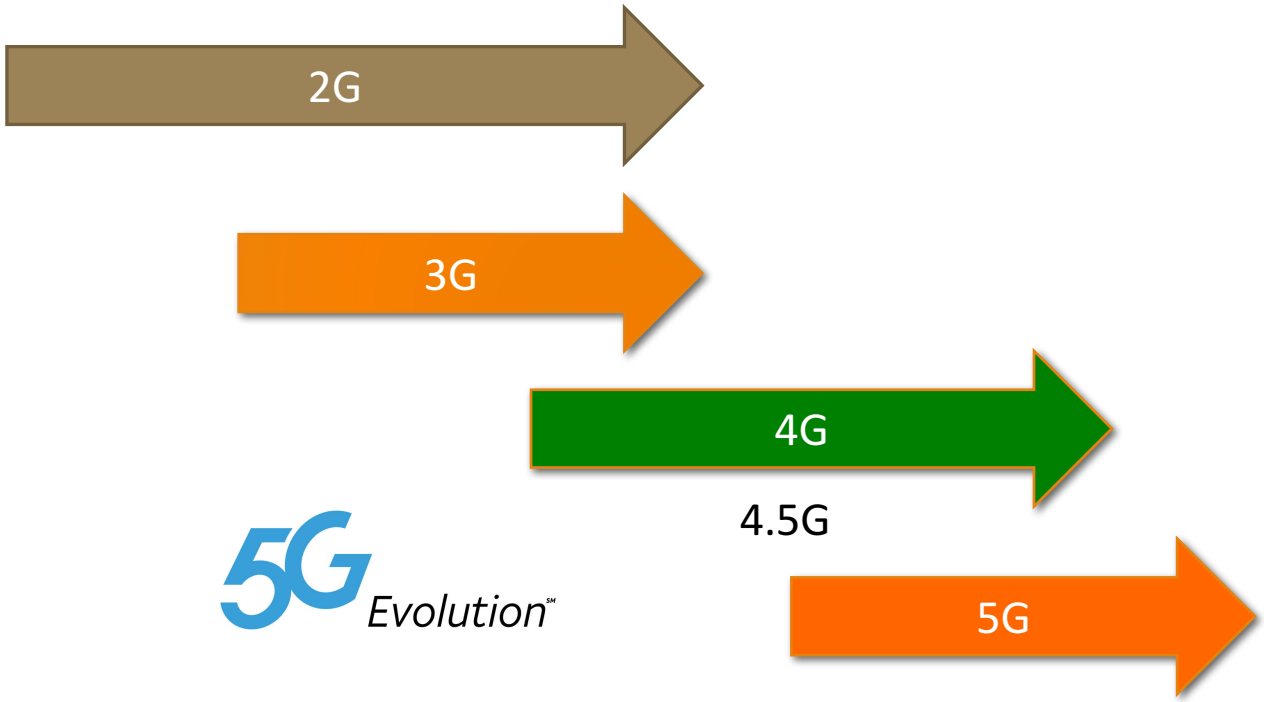
land line

2G

3G

4G

Generations overlap



Generational surprises

Generation	Expectation	Surprise
2G	better voice quality (“digital!”)	SMS
3G	WAP	web
4G	IMS	YouTube, WhatsApp, notifications
5G	IoT (low latency)	?

underestimated cost and fixed-equivalence as drivers

Lessons, in brief

Experience	Lessons
VoLTE, IMS	avoid complexity avoid entanglement plan intercarrier interfaces
Wi-Fi	don't trust the RAN/AP
disaggregation of functions	clear & simple interfaces don't assume trust between elements
app stores	keep it application-neutral
FTTH, backhaul cost	re-use backhaul where you can find it

2G → 3G → 4G → 5G ➔ increasing number of technology components

5G is a systems standard

Technology component	Proposed application	Less exciting, but likely
mmWave	10 Gb/s user rates	capacity in stadiums fixed wireless?
edge computing	IoT	video caching
M2M	billions & billions of devices! autonomous vehicles!	electric meters
1 ms latency	autonomous vehicles!	keep it application-neutral
slicing	QoS	test networks, VPNs

Changing spectrum environment

Except at highest frequencies, all new spectrum likely to be shared

- e.g., 3.5 GHz
- in time & space

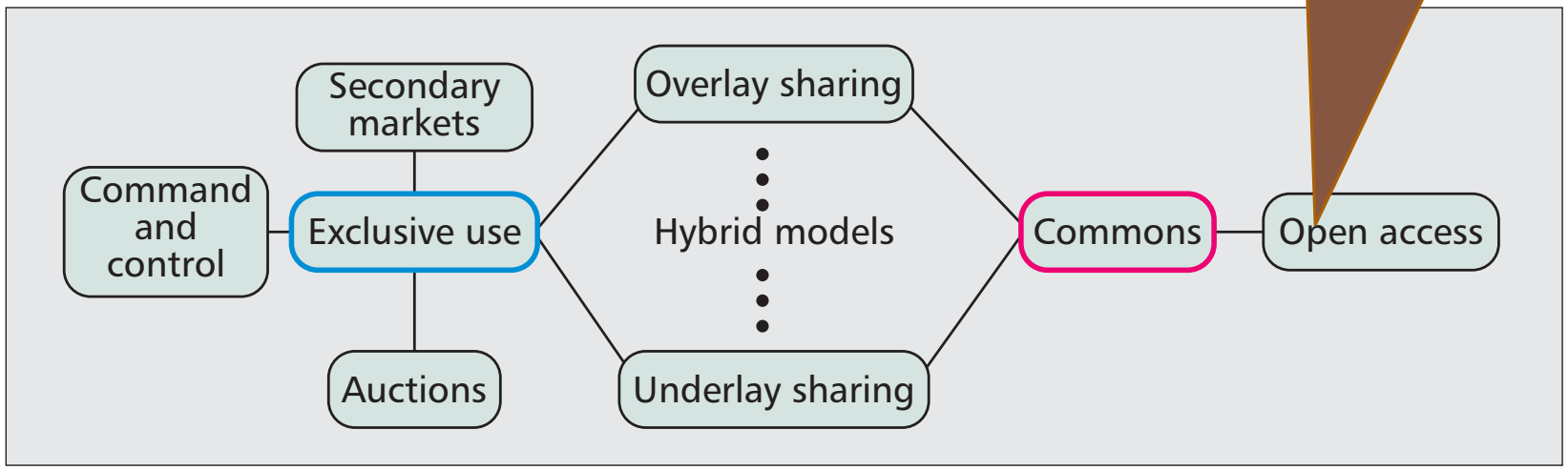
→ need frequency-agile systems that can shift capacity to different bands, quickly

→ few common bands for consulting spectrum database

- **now**: scan, pray & wait
- **5G**: shared band → database

Spectrum sharing

How much politeness & fairness is required?
→ LTE-U & LTE-LAA (license-assisted, listen-before-talk)



Ideal spectrum

Unused or cheap

A ilable globally rtant for consu ize)
- rably un sing

No

Propag

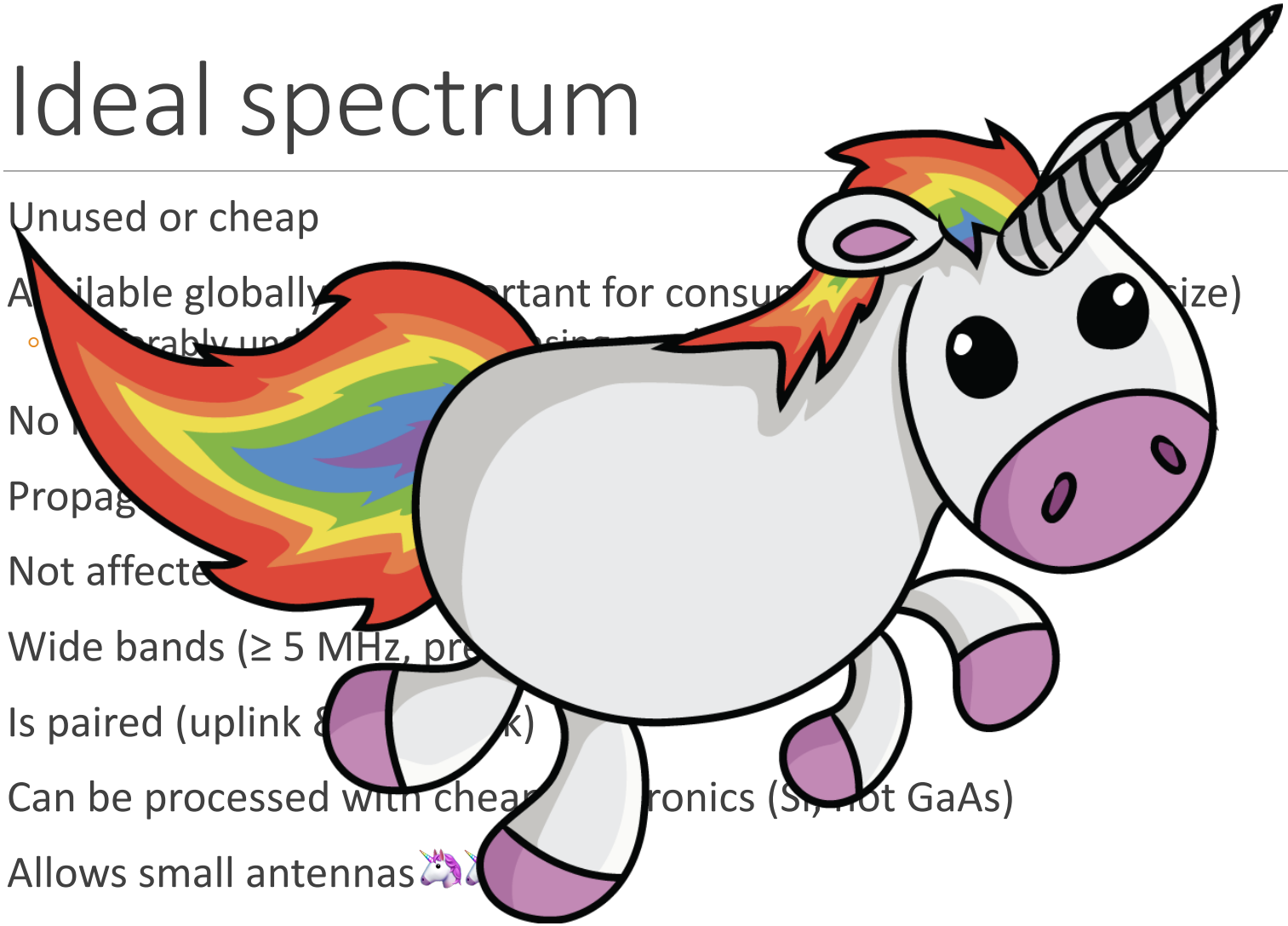
Not affecte

Wide bands (≥ 5 MHz, pr

Is paired (uplink & k)

Can be processed with chea ronics (Si, not GaAs)

Allows small antennas



Spectrum management

UNTIL THE 2000S	"MODERN"
Single purpose	Flexible use
Fixed technology (modulation)	Flexible technology
Exclusive use	Shared, over/underlay
Narrow bands (except TV)	At least 5 MHz, preferably 100
Assume single radio per device	Multiple (> 4) XTR/RCV
Worry mostly about OOB to like	Receiver requirements?
Spectral efficiency secondary	Spectral efficiency matters
Single-country	International coordination

Challenges for spectrum sharing

Unlicensed ~2000

- indoor home
- indoor enterprise
- campus
- --> natural separation
- only power rules (no listen-before-talk (CS) required)

Unlicensed now

- secondary public SSID
  - e.g., CableWiFi
- re-use HFC/FTTH backhaul
- One band, one channel

Unlicensed emerging

- LTE-U, LAA
- what are the "kindergarten" rules?

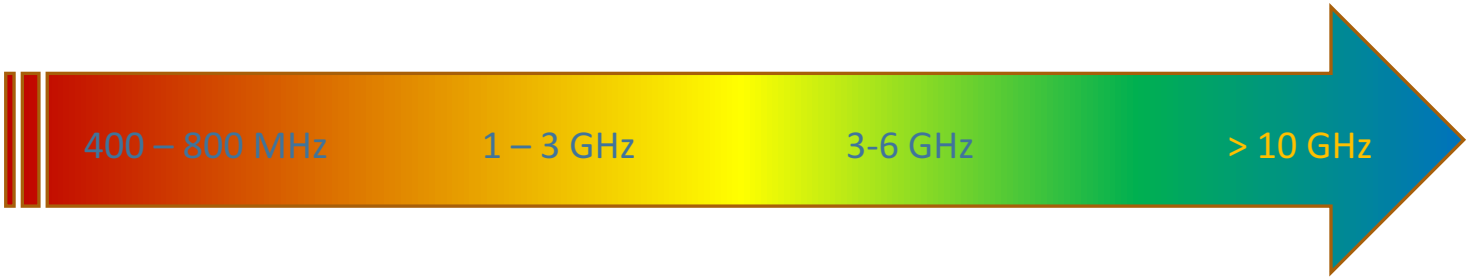
Spectrum co-existence

"high tower, high power"
(TV, cellular downlink, radar transmitter)

vs.

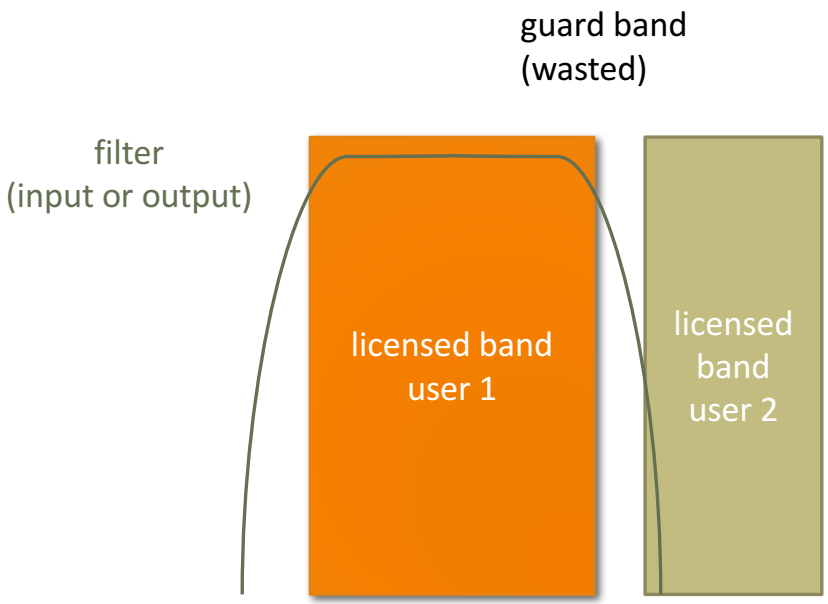
- cellular uplink
- radar receiver
- GPS receiver

Spectrum roles



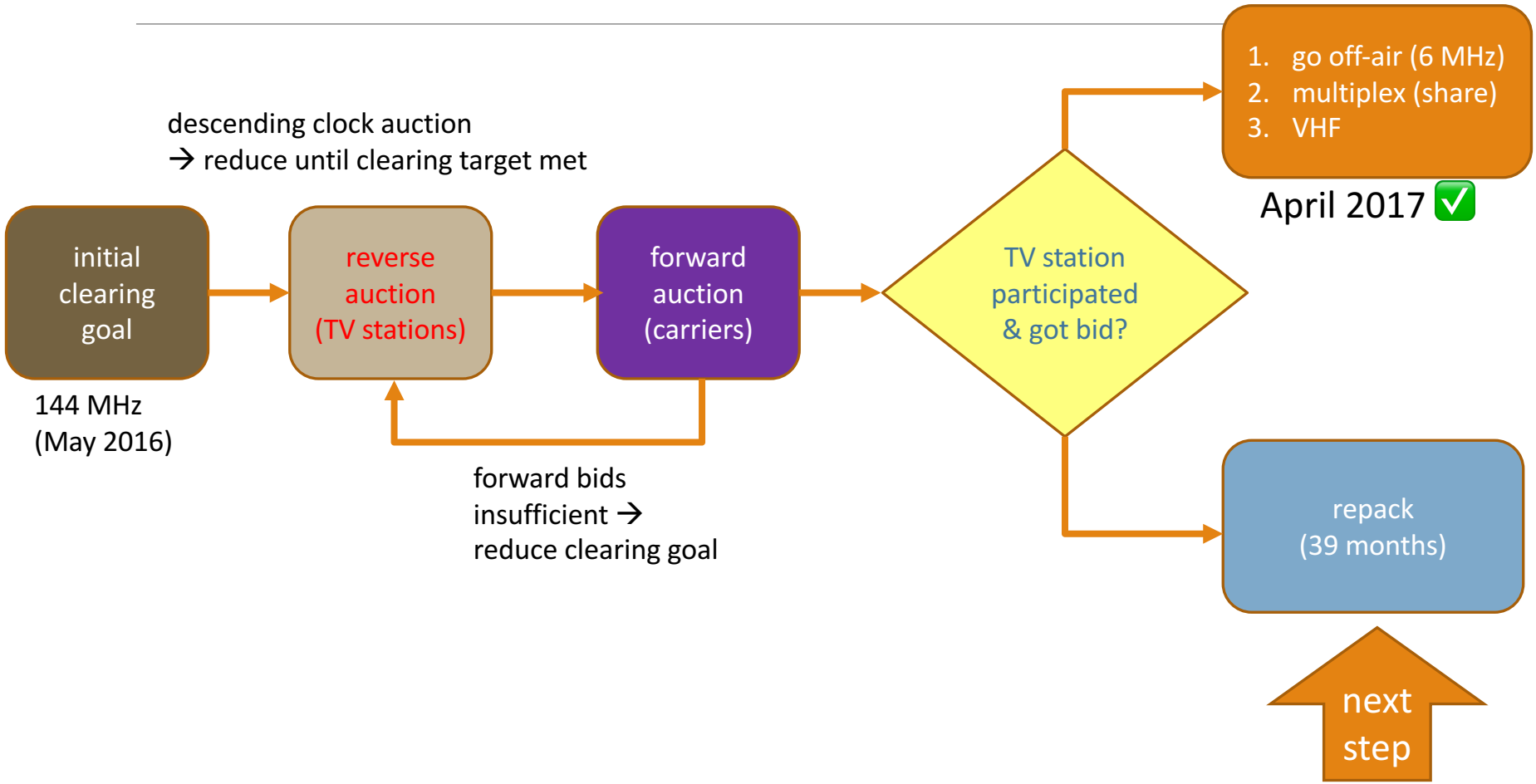
base-level coverage (particularly rural)	urban capacity	indoor & capacity	directional capacity
Digital dividend TV incentive auction	AWS-3	3.5 GHz	mmWave R&O

The filter problem



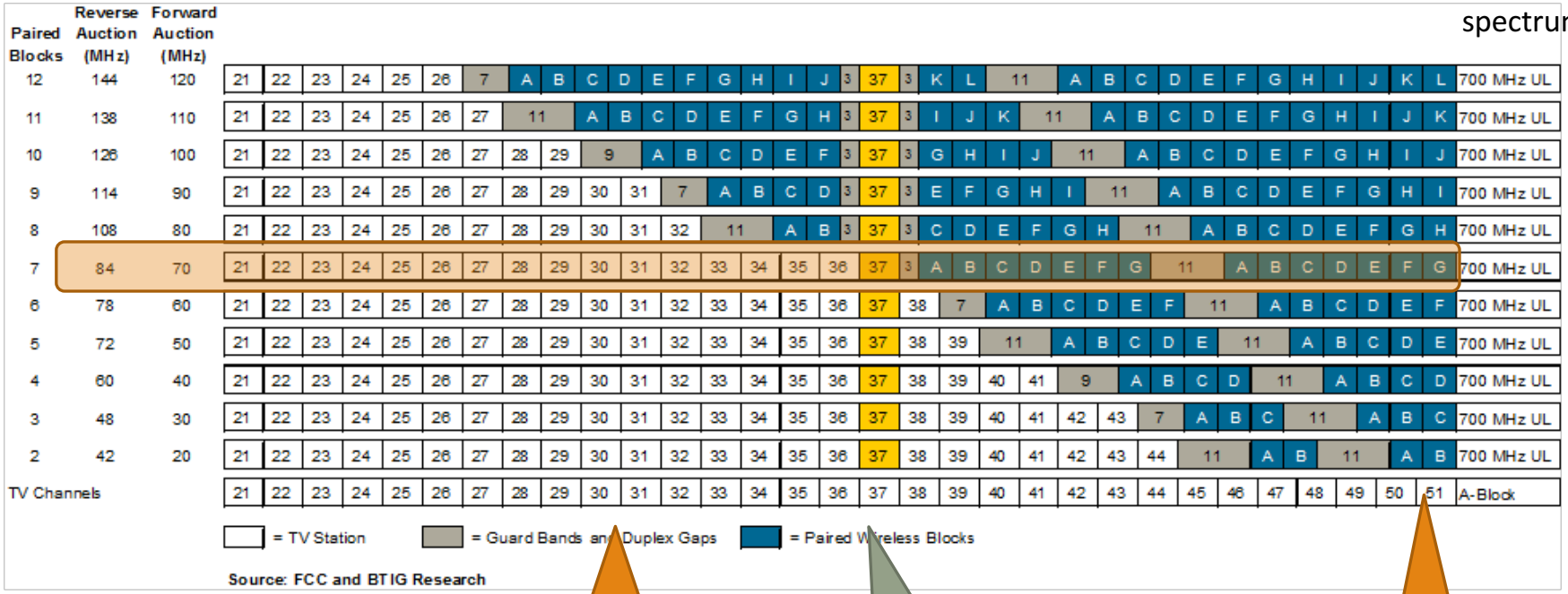
Power imbalance:
- cell downlink: 100 W ERP
- cell uplink: 0.05 – 2 W

TV incentive auction



600 MHz incentive auction

FirstNet spectrum



5 MHz downlink blocks

radio astronomy, medical monitoring

5 MHz uplink blocks

Incentive auction facts

Forward Auction

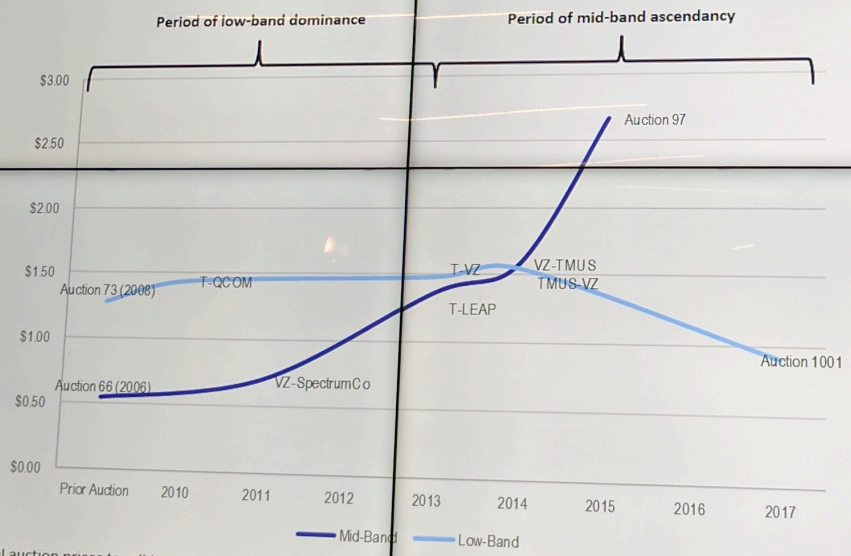
$19.8 billion	Gross revenues (2nd largest in FCC auction history)
$19.3 billion	Revenues net of requested bidding credits
$7.3 billion	Auction proceeds for federal deficit reduction
70 MHz	Largest amount of licensed low-band spectrum ever made available at auction
14 MHz	Spectrum available for wireless mics and unlicensed use
2,776	License blocks sold (out of total of 2,912 offered)
$1.31	Average price/MHz-pop *sold* in Top 40 PEAs
$.93	Average price/MHz-pop *sold* nationwide

Spectrum Needs And Values Are Changing

Prior to 2013, low-band routinely fetched 2x the amount of mid-band. The perceived value of mid-band vs low-band started to shift after VZ deployed LTE on 700MHz. By the AWS-3 auction in 2015, mid-band sold for more than 2x the last significant low-band transaction. The incentive auction was conceived in an era when low-band was the most valuable spectrum, and executed in an era when focus had shifted to higher bands.

Mid-Band Vs. Low-Band Values - Selected Transactions [1]

$ / MHz-POP

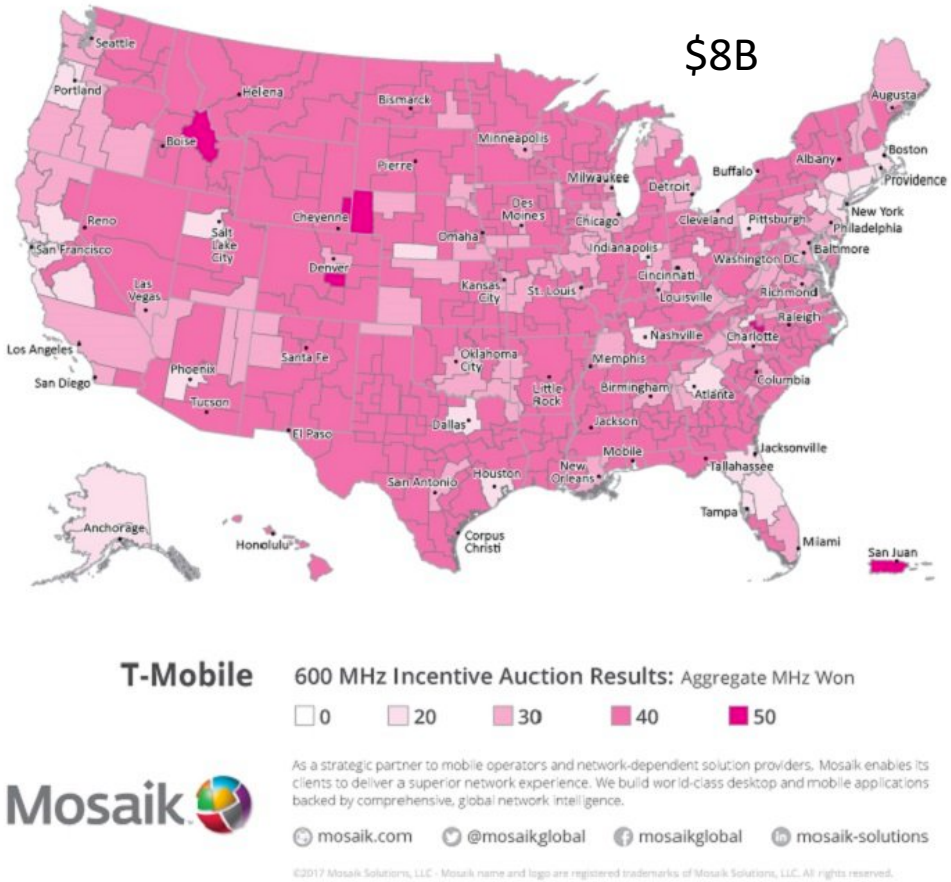


1) Indexes reported values to national auction prices for all transactions, save VZ-SpectrumCo and auctions themselves.
Source: Company data, FCC, New Street Research estimates

new|street RESEARCH
Jonathan Chaplin | 212 921 9876 | jonathan.chaplin@newstreetresearch.com

https://law.duke.edu/innovationpolicy/spectrum-incentive-auction/

Forward auction: T-Mobile & others



dish
$6.2B
486 licenses

COMCAST
$1.7B
145M POPS

at&t
$1B
18 PEAs
(has 700 MHz spectrum)
FirstNet spectrum

TV white spaces (US)

First large-scale spectrum database

But limited use in the US

- number of channels
- power levels
- equipment
- available mostly in rural areas, not urban
- change after incentive auction

Channel Number	Frequency Range (MHz)	Allowable Antenna Height (meters AGL)
2	54-60	30
7	174-180	30
8	180-186	30
9	186-192	30
13	210-216	30
18	494-500	30
24	530-536	30
25	536-542	30
26	542-548	30

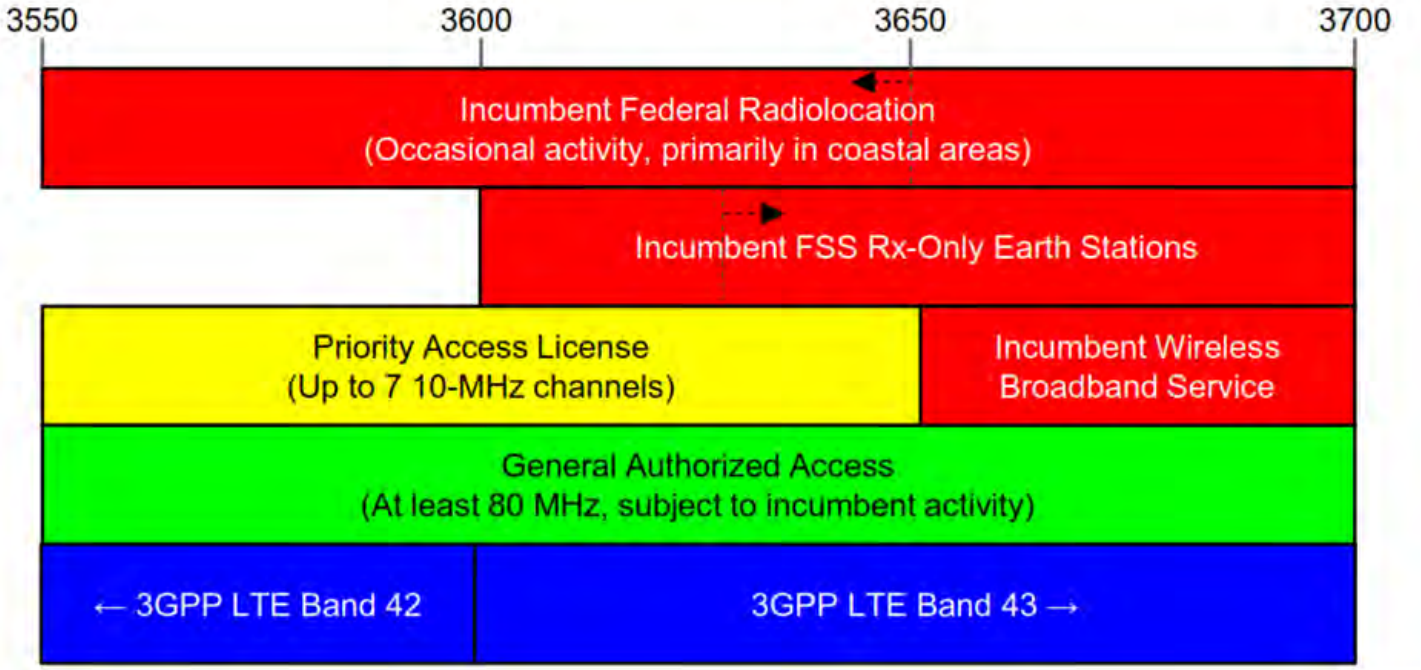
Leonia, NJ

Channel Number	Frequency Range (MHz)	Allowable TX Power (mW)
42	638-644	40

Amherst, MA

Channel Number	Frequency Range (MHz)	Allowable TX Power (mW)
23	524-530	40
24	530-536	100
25	536-542	100
26	542-548	100
27	548-554	40
41	632-638	40
42	638-644	40
44	650-656	40
47	668-674	40
48	674-680	40
50	686-692	40

3.5 GHz band



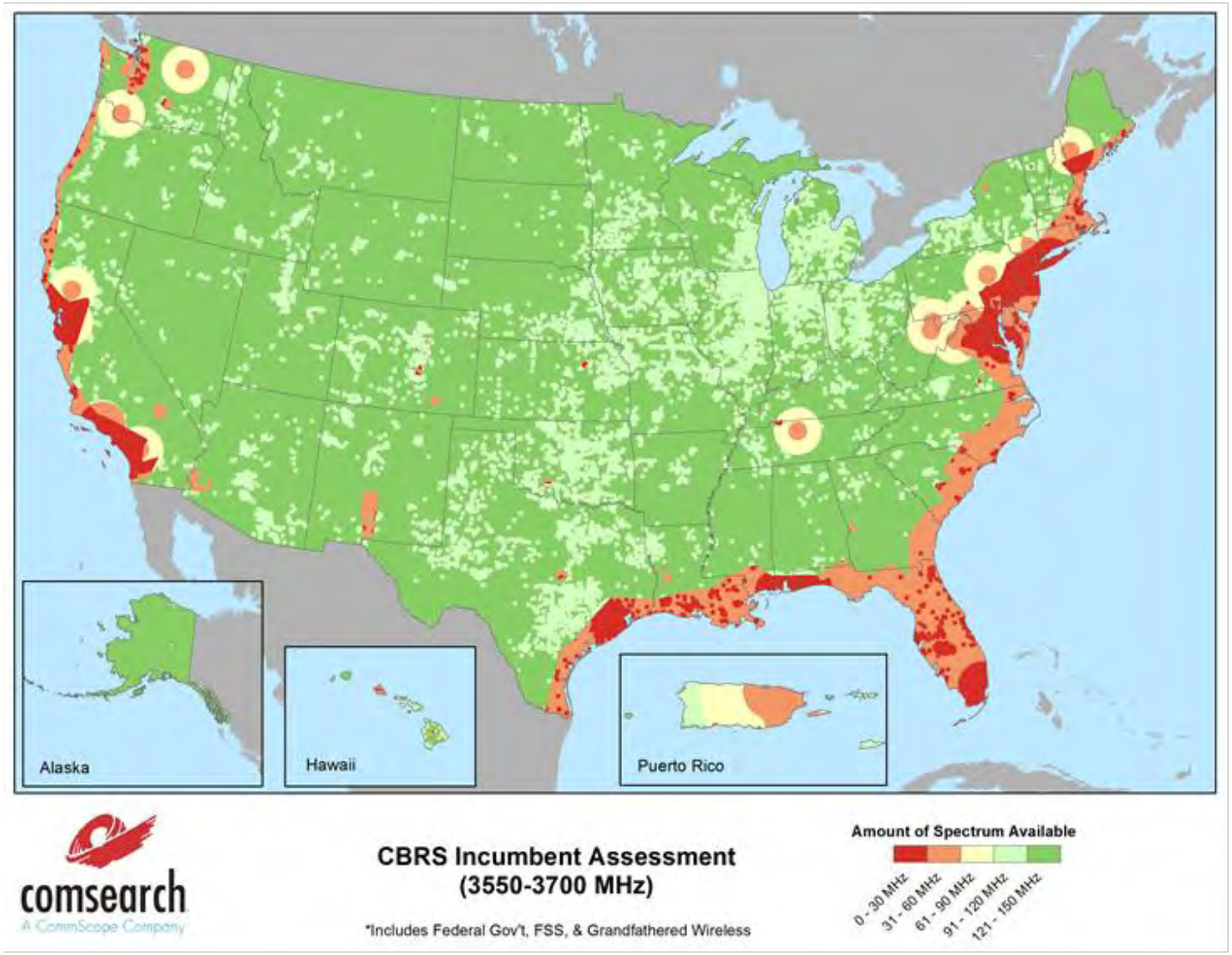
Band 42: TDD, 3.4-3.5 GHz

Band 43: TDD, 3.6-3.65 GHz

Source: Google

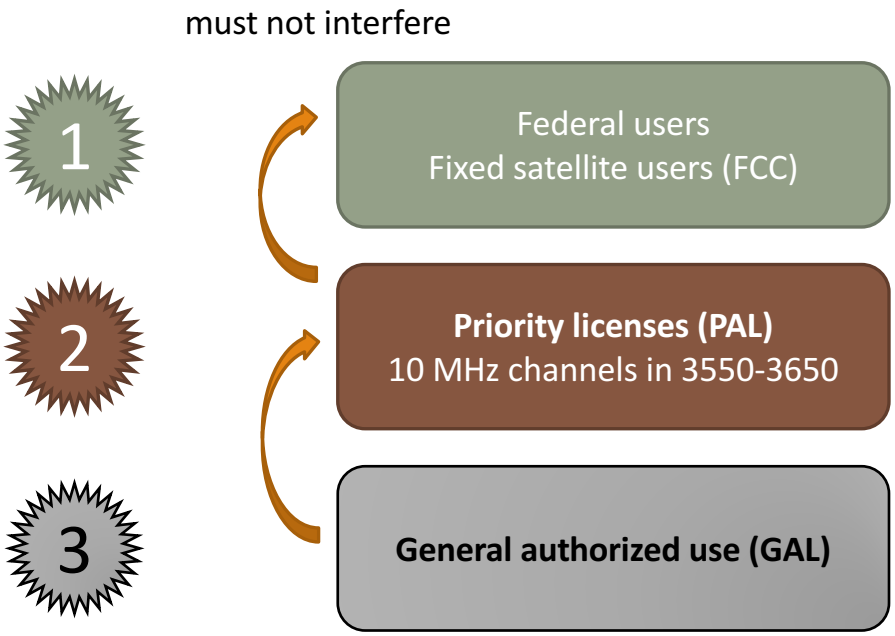
FSS: C Band (3.625–4.200)

CBRS availability



Source: CommScope

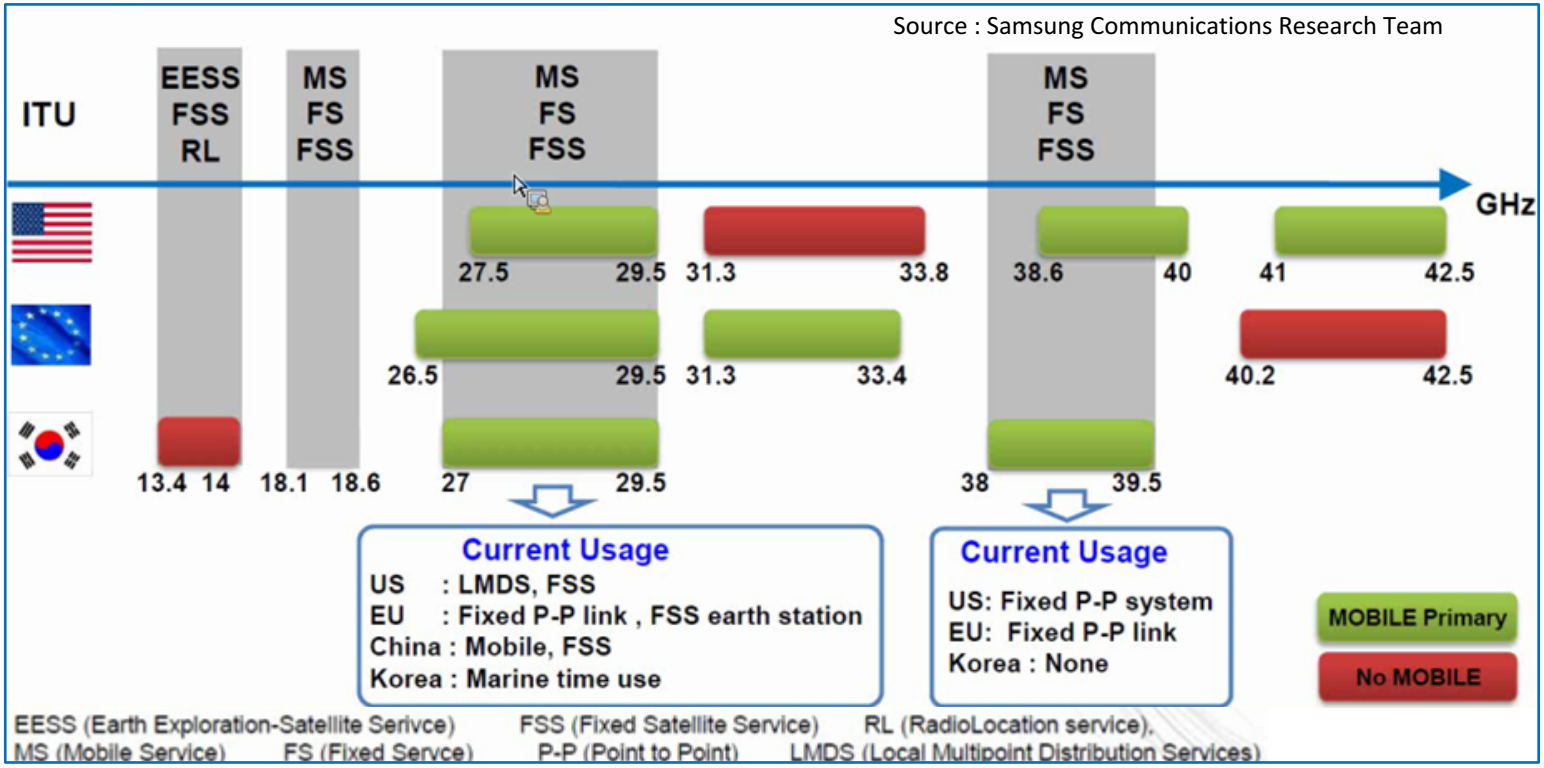
3.5 GHz user classes



census tract
≤ 70 MHz
3-year licenses
assigned via SAS

ESC (environmental sensing capability) allows commercial use in coastal and Great Lakes region

30-40 GHz mmW overview



- Note: The Commission's Fixed Microwave (Part 101) and Satellite Communications (Part 25) service rules govern most of US mobile allocations shown above

MMW: Spectrum Frontiers R&O

Core Principles

- Identify substantial spectrum in MMW bands for new services
- Protect incumbent services against interference
- Flexible use: enable market to determine highest valued use
- Overlay auctions where no existing assignments
- Provide spectrum for both licensed and unlicensed use

R&O – 10.85 GHz added for mobile service (July 2016)

- Licensed bands (3.85 GHz): 27.5-28.35 GHz; 37-38.6 GHz; 38.6-40 GHz
- Unlicensed bands (7 GHz): 64-71 GHz

FNPRM – seeks comment on another 18 GHz & above 95 GHz

- 24.25-24.45 GHz; 24.75-25.25 GHz; 31.8-33.4 GHz; 42-42.5 GHz; 47.2-50.2 GHz; 50.4-52.6 GHz; 71-76 GHz; 81-86 GHz; bands above 95 GHz

Licensing, operating and regulatory rules

- Part 30: Upper Microwave Flexible Use Service (UMFUS)
- Geographic area licensing, area size, band plan, license term

Conclusions

5G is no one thing

- and some of the “things” may be secondary
- but reducing the cost per

New spectrum is one key differentiator for 5G

New bands may take 10+ years: policy negotiation + clearing/sharing + deployment

Each band has unique challenges, but some tools emerging

- reverse auctions for clearing
- spectrum databases, enabled by multiple radios and GPS