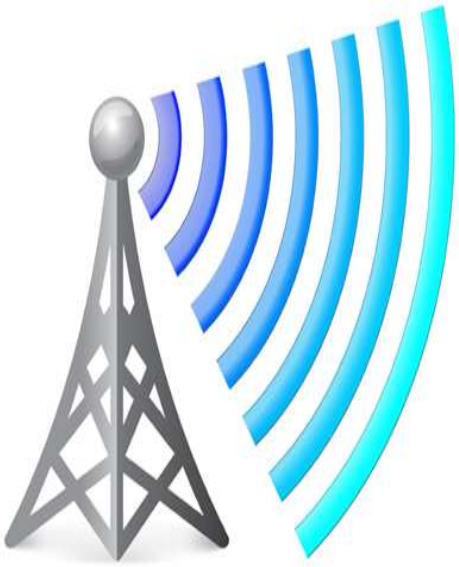


15th Annual
TFI
Technology
Conference

January 23-24, 2020
Austin, Texas

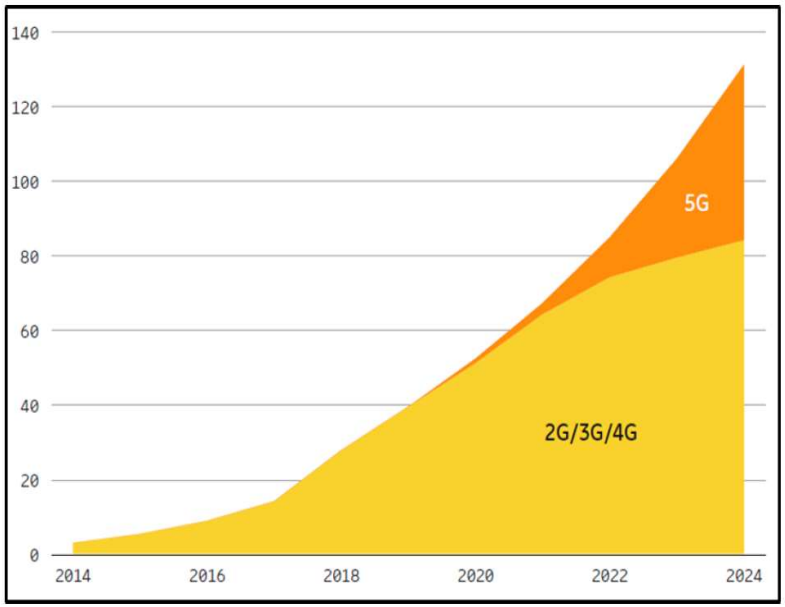
Wireless Industry Panel
Implications for Tax & Valuation

Presenters:
Ruben Miranda, Duff & Phelps (Moderator)
Gary Hunter, AT&T
Steve Yergeau, T-Mobile

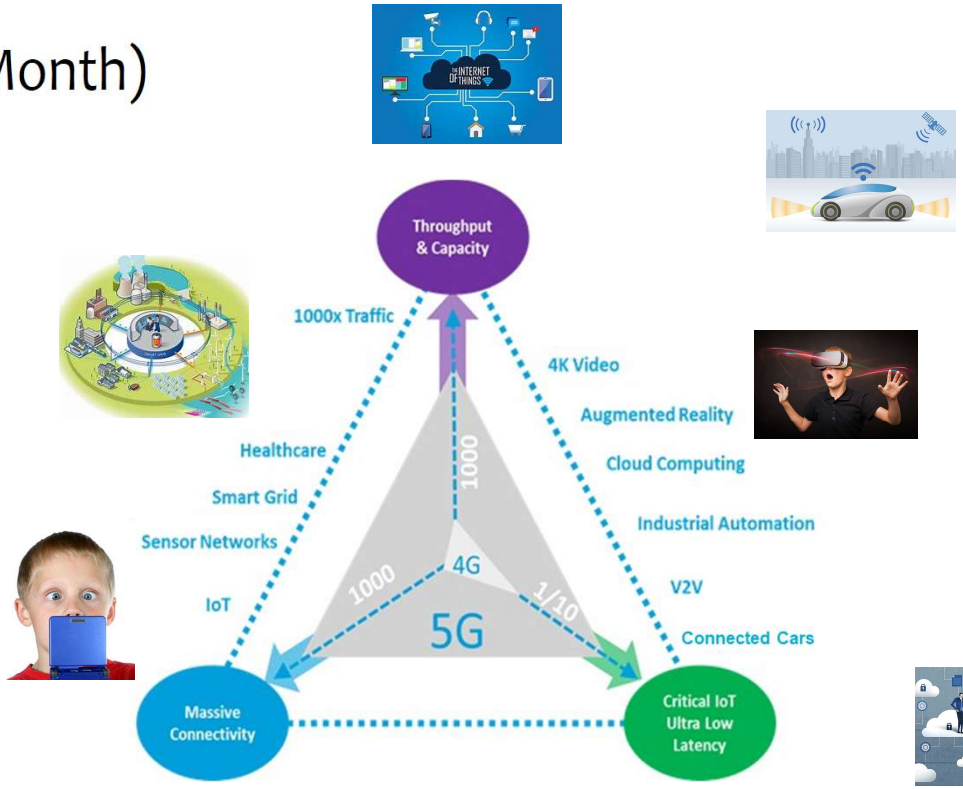
Background - 5G Video

Why 5G and …?

Global Mobile Data Traffic (Exabytes/Month) 2014 to 2024

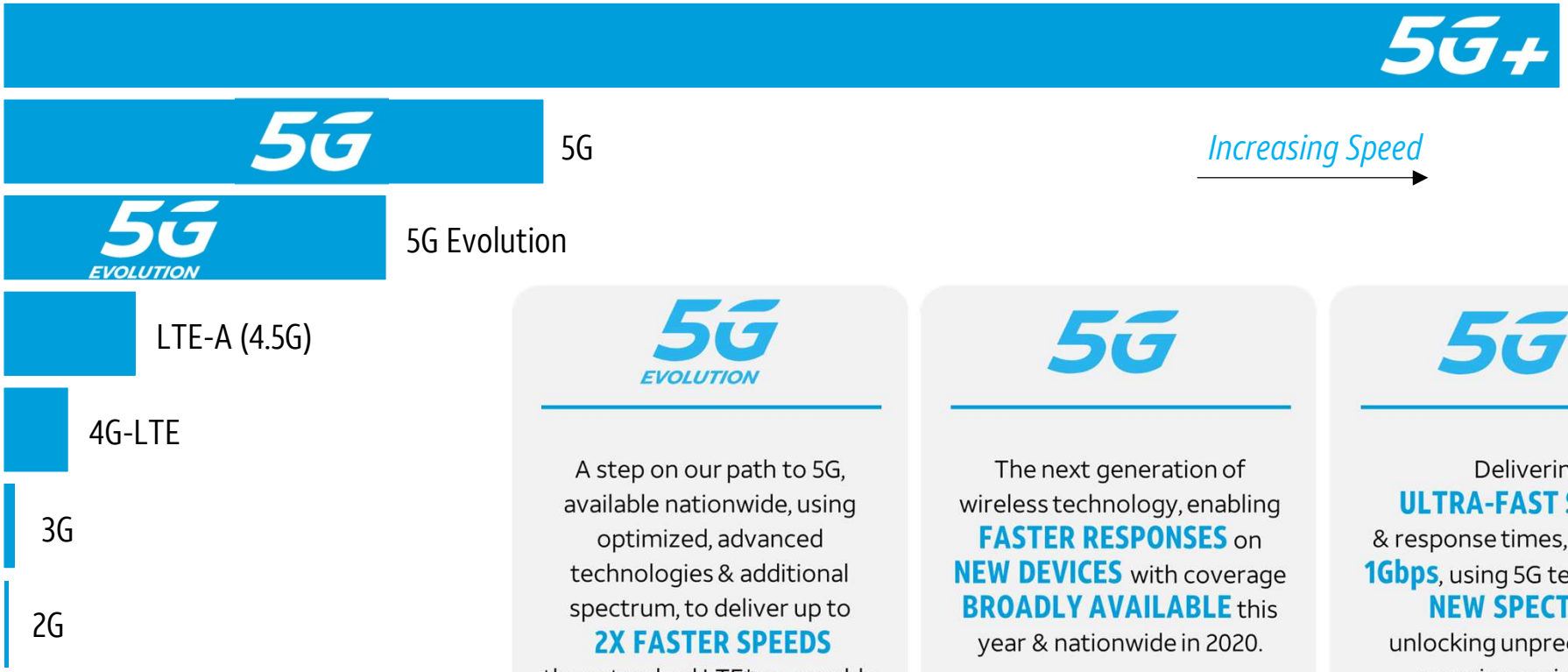


Ericsson Mobility Report, Jun. 2019.



5G is not only about increasing the capacity of networks, but also the need for ultra-reliable, low latency networks necessary to support augmented & virtual reality applications, connected vehicles, AI, advanced IoT applications, etc.

5G Roadmap



5G EVOLUTION

A step on our path to 5G, available nationwide, using optimized, advanced technologies & additional spectrum, to deliver up to **2X FASTER SPEEDS** than standard LTE* on capable **CURRENT & FUTURE DEVICES.**

(*) Claim based on avg AT&T standard LTE versus 5G Evolution download speeds

5G

The next generation of wireless technology, enabling **FASTER RESPONSES** on **NEW DEVICES** with coverage **BROADLY AVAILABLE** this year & nationwide in 2020.

5G+

Delivering **ULTRA-FAST SPEEDS** & response times, capable of **1Gbps**, using 5G technology & **NEW SPECTRUM** unlocking unprecedented experiences in iconic destinations & key venues.

AT&T

Evolution From 4G to Beyond 5G:

	4G	5G	Future Technology Beyond 5G (Speculative)
Peak theoretical throughput	1 Gbps	20 Gbps	1 Tbps (1000 Gbps)
Typical throughputs	10s of megabits per second (Mbps)	100s of Mbps to over 1 Gbps	10s or 100s of Gbps
Wireline broadband replacement	Only viable for small percentage of users	Viable for many users	Viable for nearly all users
Video	Streaming video but with restrictions, HD possible	Fewer restrictions, UHD possible	Super-high resolution
Types of communications	Voice, interactive video	HD interactive, VR	Immersive telepresence and 3D holographic
Reliability	Networks mostly operates on best-effort basis	Designed for mission-critical applications (capable of six nines of reliability 99.9999%)	Nine nines of reliability
Latency (radio network delay)	As low as 10 msec.	As low as 1 msec.	Even greater timing precision

35

Source: *Global 5G: Implications of a Transformational Technology*, 5G Americas Report Provided by Rysavy Research.

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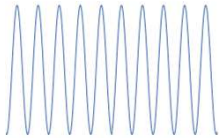
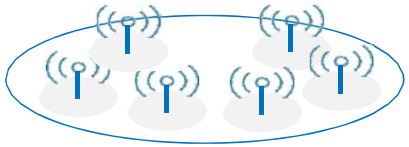
5G Spectrum

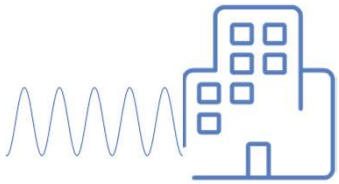
5G will be delivered using different types of spectrum

Speed: mmWave



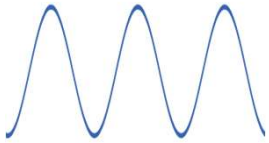


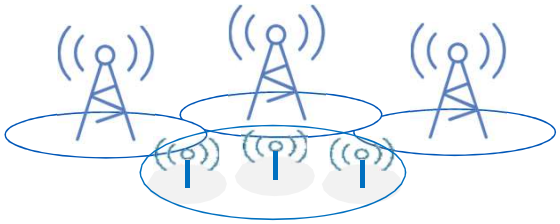
Dense, small cell deployment



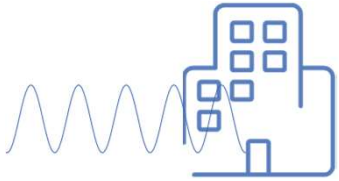
Poor penetration through objects

Mix: Mid-band



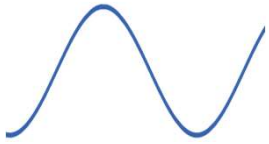


Dense macro tower & small cell deployment



Limited penetration through objects

Coverage: Low Band



Broad, macro tower deployment

Good penetration through objects

AT&T

5G Spectrum – A Visual Representation

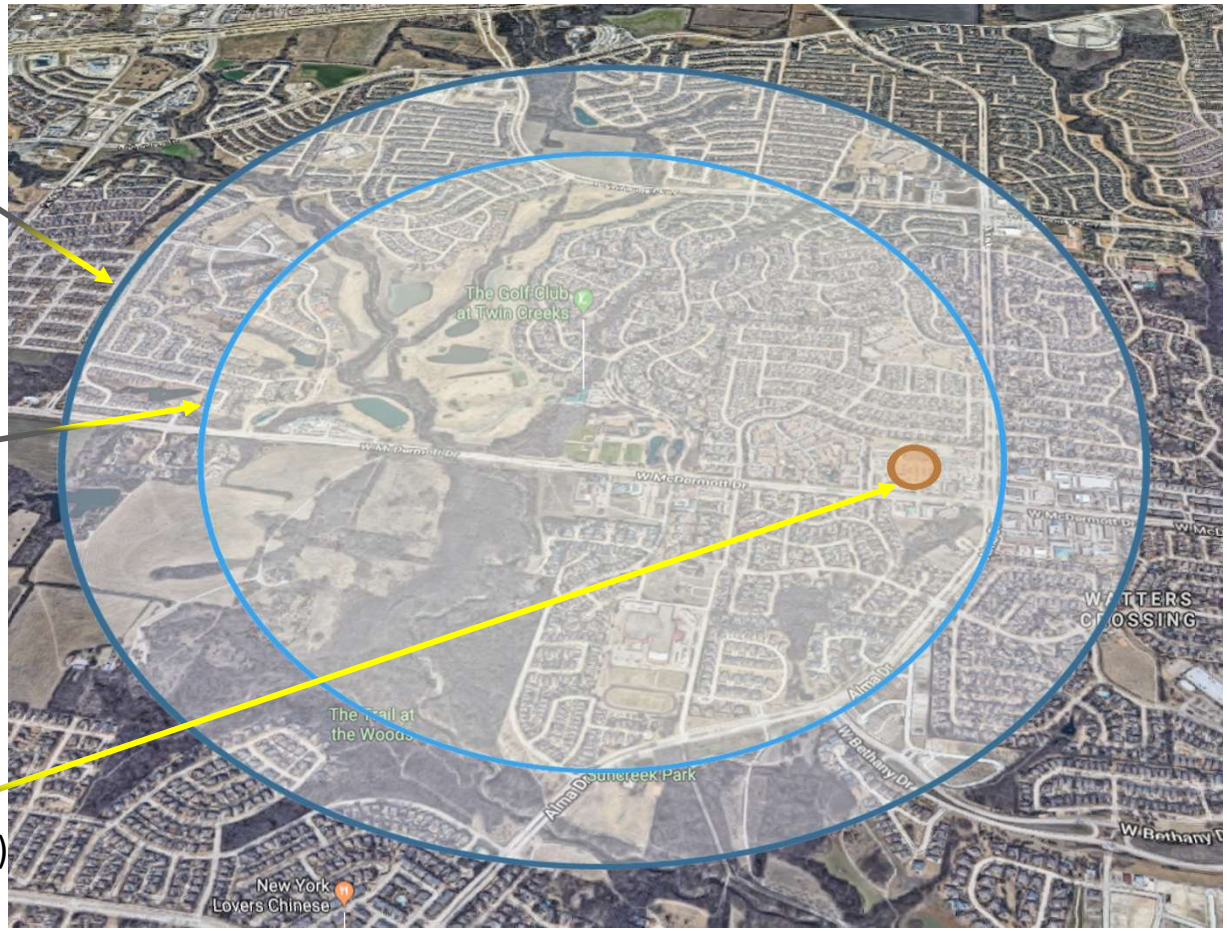
5G

Low Bands
(Coverage)

Mid Bands
(Capacity/ Speed)

5G+

mmWave
(Fiber-like Speeds)



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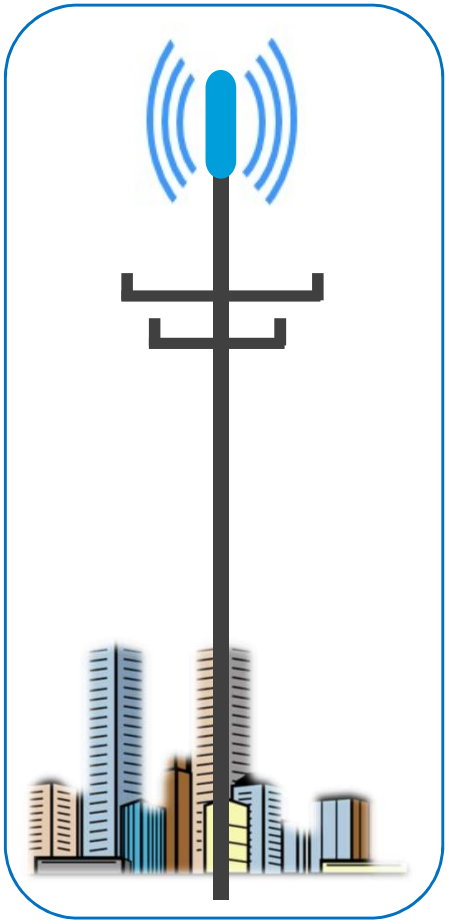
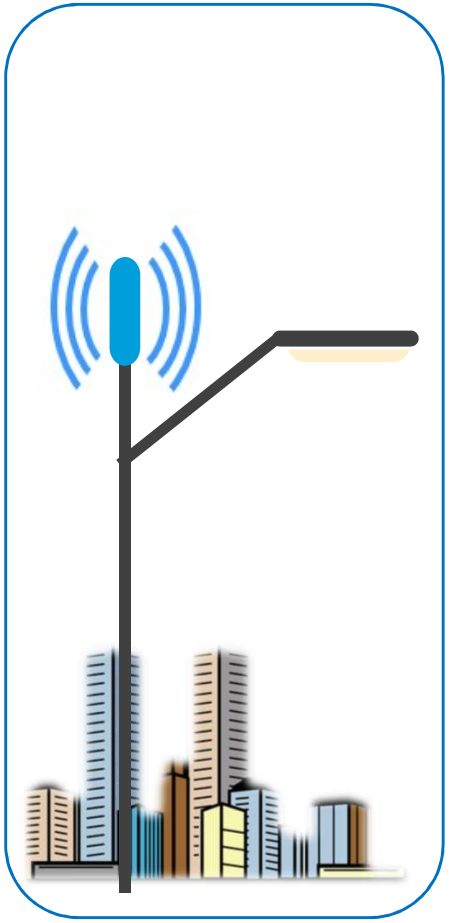
5G Location Deployments May Include:

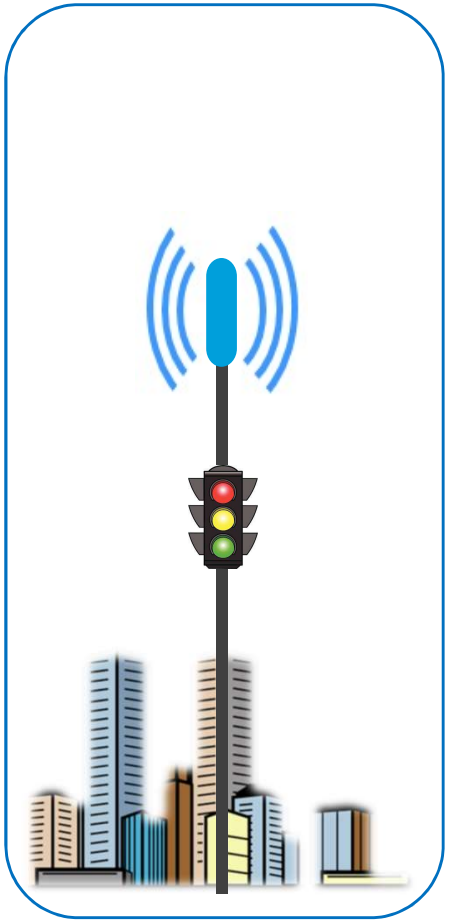
Utility Poles



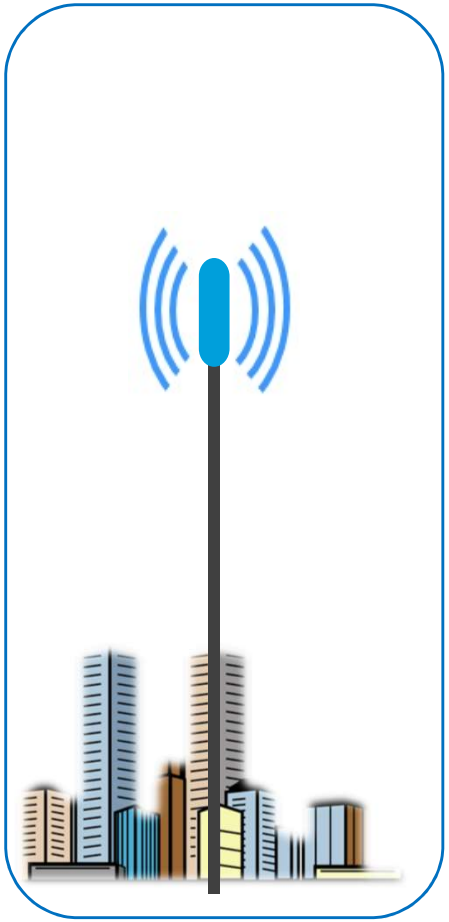
Light Poles



Traffic Poles



Mono Poles



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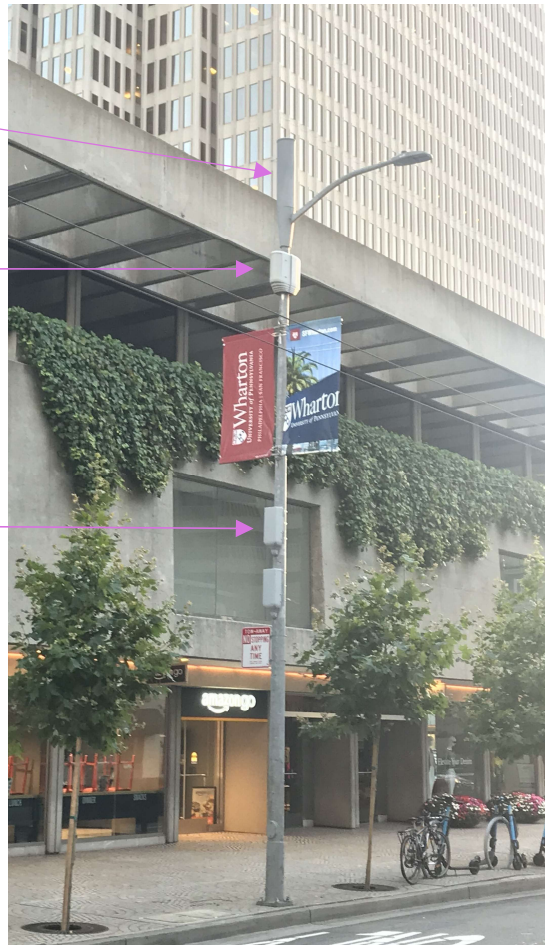
Example - 5G Light Pole Deployment

Antennae

mmWave Radios

LTE Radios



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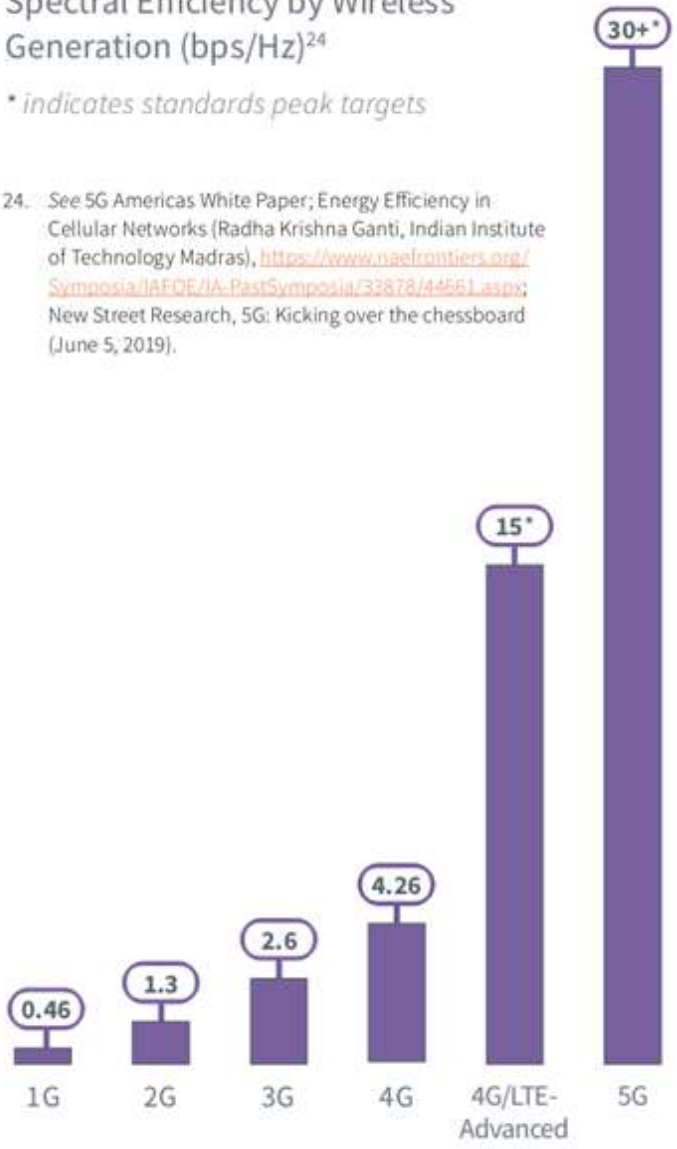
Spectrum

T-Mobile's Layer Cake Analogy

Spectral Efficiency by Wireless Generation (bps/Hz)[24]

* *indicates standards peak targets*

24. *See* 5G Americas White Paper; Energy Efficiency in Cellular Networks (Radha Krishna Ganti, Indian Institute of Technology Madras), https://www.naefrontiers.org/Symposia/IAFOE/IA-PastSymposia/33878/44661.aspx; New Street Research, 5G: Kicking over the chessboard (June 5, 2019).



5G Will Drive Even Greater Spectral Efficiencies In Key Bands[33]

33. T-Mobile US, Inc. & Sprint Corporation Public Interest Statement Attachment, WT Docket No. 18-197 (June 18, 2018), https://ecfsapi.fcc.gov/file/10618281006240/Public%20Interest%20Statement%20and%20Appendices-%20A-%20Public%20Redacted%20.pdf.

19%

increase in low-band spectral efficiency.

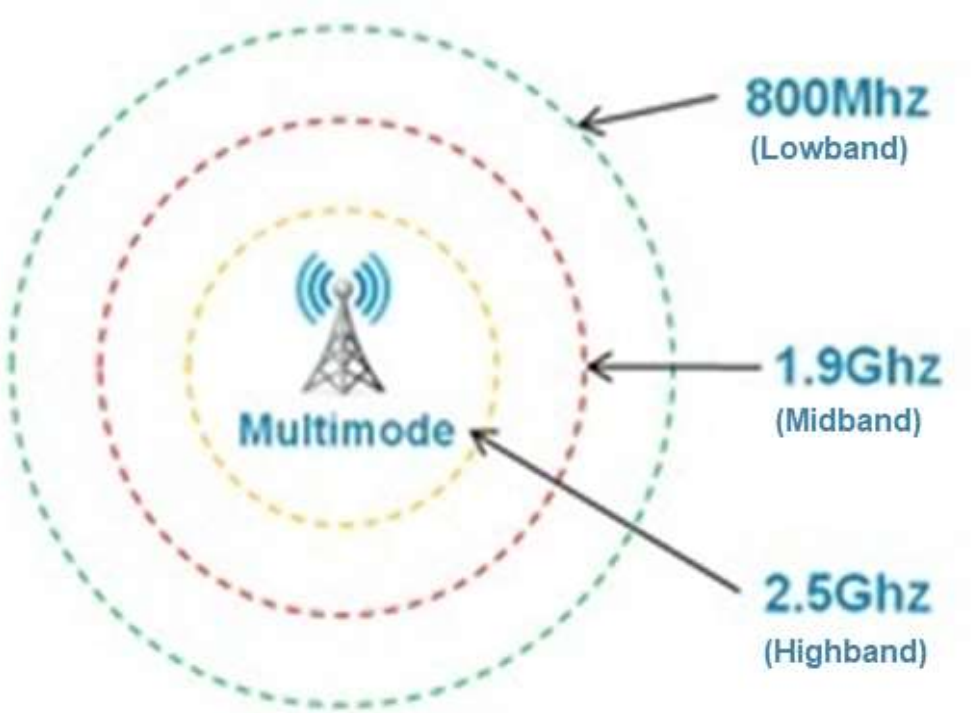
52%

increase in mid-band spectral efficiency.

Source: "Smarter and More Efficient: How America's Wireless Industry Maximizes Its Spectrum." CTIA, July 9, 2019. https://www.ctia.org/news/smarter-and-more-efficient-how-americas-wireless-industry-maximizes-its-spectrum

Spectrum

5G Runs Better on Higher Frequencies



Per MHz channel

800Mhz
(Lowband)

19% faster on 5G
(vs 4G LTE)

1.9Ghz
(Midband)

2.5Ghz
(Highband)

52% faster on 5G
(vs 4G LTE)

30 to 300 GHz
(mmWave)

>100% faster on 5G
(vs 4G LTE)

Spectrum

Example Speed Benefits of 5G by Frequency

Type	Frequency (MHz)	Channel Width (MHz) [1]	4G LTE Spectral Eff. (Mbps/MHz)	4G LTE Speed (Mbps) [2]	5G Spectral Eff. (Mbps/MHz) [3]	5G Speed (Mbps) [2]
low	700	10	15.0	56.3	18.0	67.5
mid	1,700	10	15.0	56.3	22.5	84.4
high	2,500	10	15.0	56.3	22.5	84.4
mmwave	43,000	100	15.0	112.5	30.0	1,125.0

[1] Assumes max channel width for LTE of 20 MHz
[2] Assumes 50% allocated for download & 25% overhead
[3] Assume 19% increase for low-band, 50% increase for mid- and high-band, 100% for mmwave

- Speed Bump
  - 4G LTE (existing bands): 56.3 Mbps
  - 5G on mmWave: **1,125 Mbps**
  - **10x** increase in channel size, **19x** increase in speed!