The Path to 6G: 6 Questions on 6G

Jeffrey G. Andrews
Director, 6G@UT
Dept. of Electrical and Computer Engineering
The University of Texas at Austin

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Outline

- 6G@UT Introduction
- 6 Questions on 6G
  - What is the status of 5G?
  - What are 5G's key limitations?
  - What are the key 6G applications?
  - What are key new technical directions for 6G?
  - What new spectrum will play a role in 6G?
  - Will 6G achieve global coverage?
- Conclusions and More Info
- Q&A

6G ((@)) UT

★ Founding Affiliate (major multiyear commitment)

New New to 6G@UT (joined 2022 or later)

6G@UT Founded July 2021 to:

- Perform fundamental research on the key 6G technologies
- Have transformative impact on the 6G standards and applications
- Educate 6G-era innovators in cutting-edge tools and thinking skills

★ at&t

CROWN CASTLE

ERICSSON New

HONDA Honda R&D Americas, Inc.

intel

★ interdigital

NEXTNAV

NOKIA Bell Labs New

★ NVIDIA

★ QUALCOMM ★

★ SAMSUNG

STELLANTIS New

Tektronix New

VIAVI Solutions New

Western Digital

KEYSIGHT TECHNOLOGIES New

MITRE New

6G@UT FACTS

$20 M

New research funding in last 2 years

25

Renowned Faculty

150

PhD Students

10

IEEE & ACM Fellows

"UT Austin has demonstrated a unique ability to help define advanced wireless technologies and contribute valuable and targeted research."

David Wolter, Asst. VP, Radio Technology, AT&T

NOTABLE AWARDS

National Academy of Engineering

IEEE Edison Medal

IEEE Fourier Award

IEEE Tomiyasu Award

Primetime Emmy Award

Technical/Engineering Emmy Award

IEEE Signal Processing Society Technical Achievement Award

IEEE ComSoc Leonard G. Abraham Prize (2)

IEEE ComSoc Heinrich Hertz Prize (2)

IEEE ComSoc Stephen O. Rice Prize

IEEE ComSoc/Information Theory Society Joint Paper Award (3)

IEEE ComSoc William R. Bennett Prize

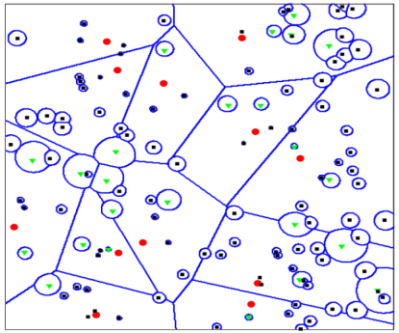
IEEE SPS Best Paper Award

IEEE SPS Sustained Impact Paper Award

IEEE Signal Processing Letters Best Paper Award

Best Paper Awards from conferences such as IEEE GLOBECOM, IEEE ICC, IEEE INFOCOM, IEEE/ION PLANS, IEEE/ACM ICCAD, ACM MSWIM, ACM TODAES, SAMOS, IEEE ISPLC

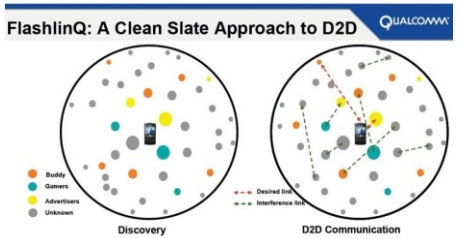
6G@UT & WNCG Impact on LTE and 5G



Landmark cellular and HetNet coverage and capacity results, novel modeling tools

4 ComSoc annual Best Paper Awards (2014 x 2, 2015, 2016)

Collaborative impact on FlashlinQ and D2D/LTE Direct



An Overview of 3GPP Device-to-Device Proximity Services

Xingqin Lin, Jeffrey G. Andrews, Amitabha Ghosh, and Rapeepat Ratasuk

FlashLinQ: A Synchronous Di
for Peer-to-Peer Ad Ho

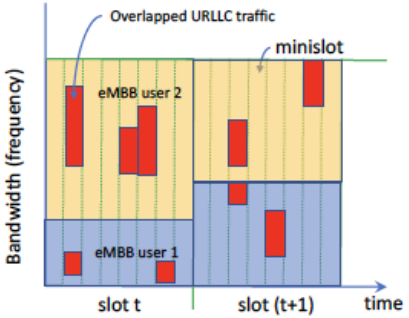
Xinzhou Wu, Saurabh Tavildar, Sanjay Shakkottai, Tom Richardson,

Industry standard – Emmy award winning (twice!) – video quality assessment tools and adaptive streaming algorithms

Controls over ½ of all 5G data traffic (nearly all the video traffic)

URLLC and eMBB traffic in 5G: theoretical fundamentals and optimal joint scheduler

IEEE ComSoc Best Paper in Networking (2021)

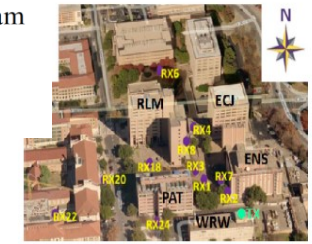


6G@UT & WNCG Impact on LTE and 5G

Broadband Millimeter-Wave Propagation Measurements and Models Using Adaptive-Beam Antennas for Outdoor Urban Cellular Communications

Theodore S. Rappaport, *Fellow, IEEE*, Felix Gutierrez, Jr., *Student Member, IEEE*, Eshar Ben-Dor, *Student Member, IEEE*, James N. Murdock, *Student Member, IEEE*, Yijun Qiao, *Student Member, IEEE*, and Jonathan I. Tamir, *Student Member, IEEE*

First outdoor mmWave channel measurements were done on our buildings at UT Austin



g. 6. Environment of the WRW-A transmitter location. The transmitter posi-n was nearly in line with the western side of ENS, thus reducing the number reflections coming from the receiver's eastern direction (e.g., right side of age).

The most cited paper on 5G, co-authored with two WNCG affiliate board members

What Will 5G Be?

Jeffrey G. Andrews, *Fellow, IEEE*, Stefano Buzzi, *Senior Member, IEEE*, Wan Choi, *Senior Member, IEEE*, Stephen V. Hanly, *Member, IEEE*, Angel Lozano, *Fellow, IEEE*, Anthony C. K. Soong, *Fellow, IEEE*, and Jianzhong Charlie Zhang, *Senior Member, IEEE*

Major advances in full duplex technology, culminating in 5G NR Release 18 work item

Highly adaptive wideband active self interference cancellation, using RF-photonics, 10+ GHz of spectrum simultaneously.

5G/LTE mesh nodes commercialized by GXC (GenXComm) in private LTE and 5GSA networks, a spinout from WNCG.

Samsung-WNCG mmWave research wins Marconi Prize & Globecom awards, influences handset design

Hand Grip Impact on 5G mmWave Mobile Devices

AHMAD ALAMMOURI[1], (Student Member, IEEE), JIANHUA MO[2], (Member, IEEE), BOON LOONG NG[2], (Member, IEEE), JIANZHONG CHARLIE ZHANG[2], (Fellow, IEEE), AND JEFFREY G. ANDREWS[1], (Fellow, IEEE)

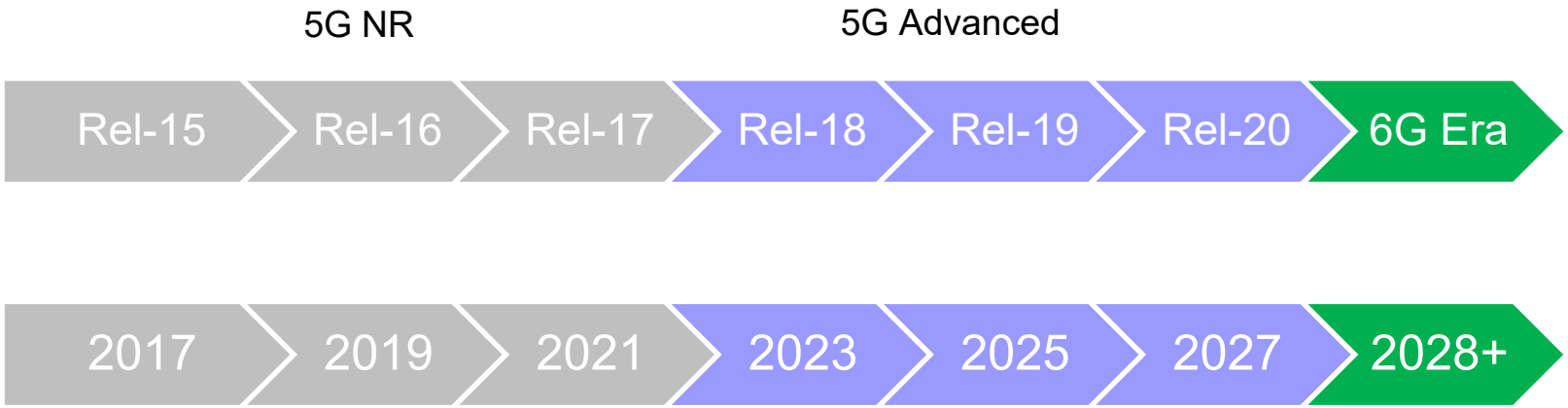
Spatially Sparse Precoding in Millimeter Wave MIMO Systems

ar El Ayach, *Member, IEEE*, Sridhar Rajagopal, *Senior Member, IEEE*, Shadi Abu-Surra, *Me* Zhouyue Pi, *Senior Member, IEEE*, and Robert W. Heath, Jr., *Fellow, IEEE*

On the Initial Access Design in Millimeter Wave Cellular Networks

Yingzhe Li*, Jeffrey G. Andrews*, François Baccelli*, Thomas D. Novlan† and Jianzhong (Charlie) Zhang‡
*Department of ECE, The University of Texas at Austin, Austin, TX 78712
†AT&T Labs, Austin, TX 78759

Question 1: What is the status of 5G?



- 5G deployments continue at pace, but it's a major undertaking to build out a new network!
- So far there is not a major perceived (or objective) difference between LTE-Adv and early 5G.
- We're still relatively early in the 5G era, with the standard just now reaching maturity, mature devices in 2-3 years, network deployments catching up in 3-7 years

Question 2: What are 5G's key limitations?

5G attempted to do 3 major new things at once:

1. Faster smartphone connectivity (eMBB), especially via mmWave spectrum
2. Mission critical IoT, also known as URLLC, for smart factory, robots, driverless cars, etc.
3. Massive IoT, which allows efficient low power low rate access with wide coverage for a high density of cheap IoT devices

All this while preserving most of the key aspects from LTE (unlike any previous G)

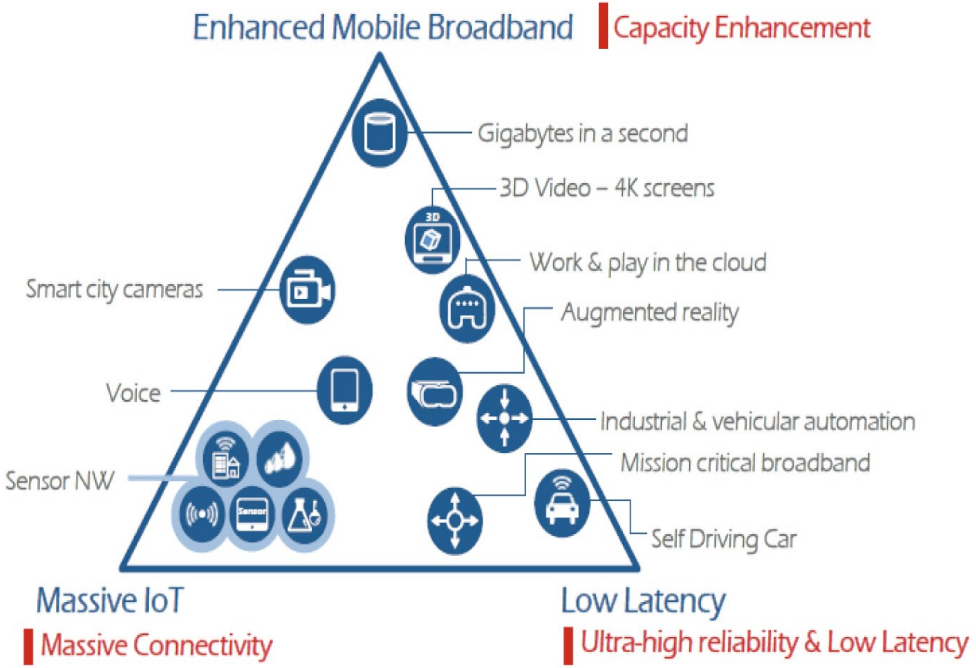


Image courtesy of IEEE

The 5G "Tetris" Waveform

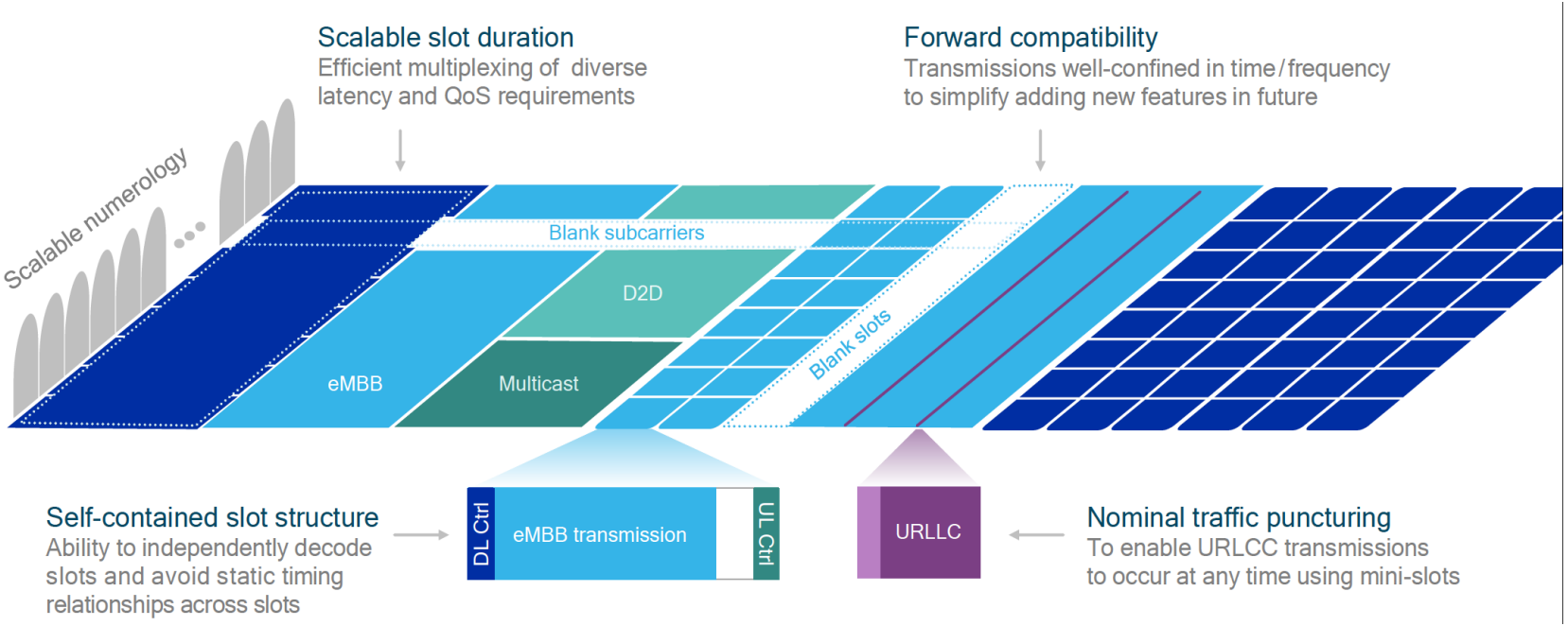


Figure courtesy of Qualcomm

Question 3: What are key 6G applications?

General themes:

- Immersive experiences, namely XR (VR/AR) headsets which may replace the smartphone in 2030s
- Autonomous devices with detailed situational awareness, inc. robots and cars, advanced IoT (similar to 5G)
- Digital twins and supporting the merger of the physical and virtual worlds

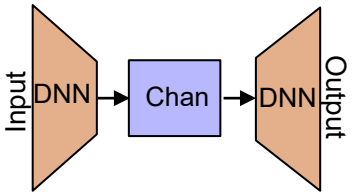
Figure 4.2-1: The XR Market[20]

Source: Next G Alliance: 6G Use cases

Q4: Key new technical directions for 6G?

Deeply Embedded Machine Learning

- End-to-end Deep learning
- ML-based network management
- Site-specific design for mmWave beam alignment
- Learning new codes & algorithms



Data-driven PHY

Raw Sensor Data

Features, Decisions

Pervasive Sensing and Awareness

- Joint communication and sensing
- Cm-level localization & tracking by both BS and UEs
- Multi-modal sensor fusion
- Sensing as a network service
- Urban digital twins

Q5: What new spectrum will play a role in 6G?

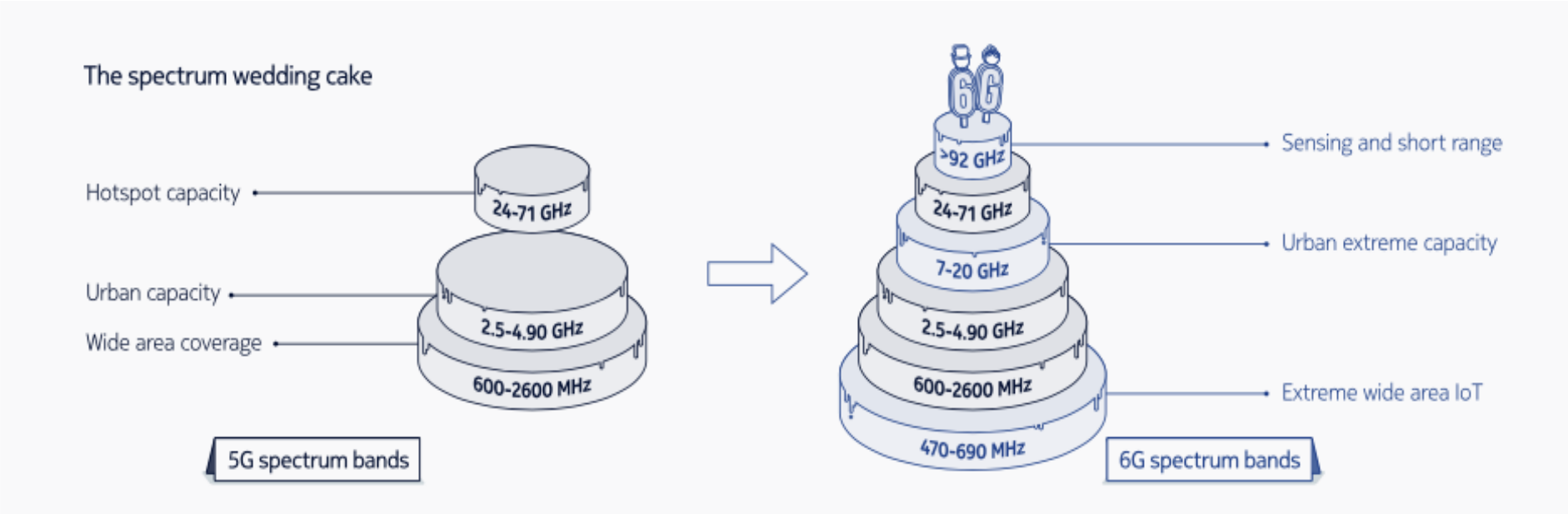


Figure from Nokia Whitepaper

Question 6: Will 6G achieve global coverage?

- 5G did little to improve global coverage: focused instead on higher capacity and new use cases.
- Decent coverage is still lacking in much of the world, and the USA. Why? (physics meets economics).
- LEO to the rescue?
- How will Starlink, Kuiper, Oneweb, etc. fuse with the 6G network?

More Information

- Visit 6g@UT at http://6g-ut.org/
  - Semi-public 6G@UT Forum on March 29: The 6G Mobile Metaverse
  - Co-sponsored by Ericsson, on UT campus.

- Next G Alliance (NGA)
  - https://www.nextgalliance.org/
  - New for 6G, the US ecosystem is being more proactive
  - NGA is trying to drive the requirements, use cases, research, standards, industry-government-academic cooperation
  - Several excellent whitepapers and very active participation