

Millimeter Waves Measure them!

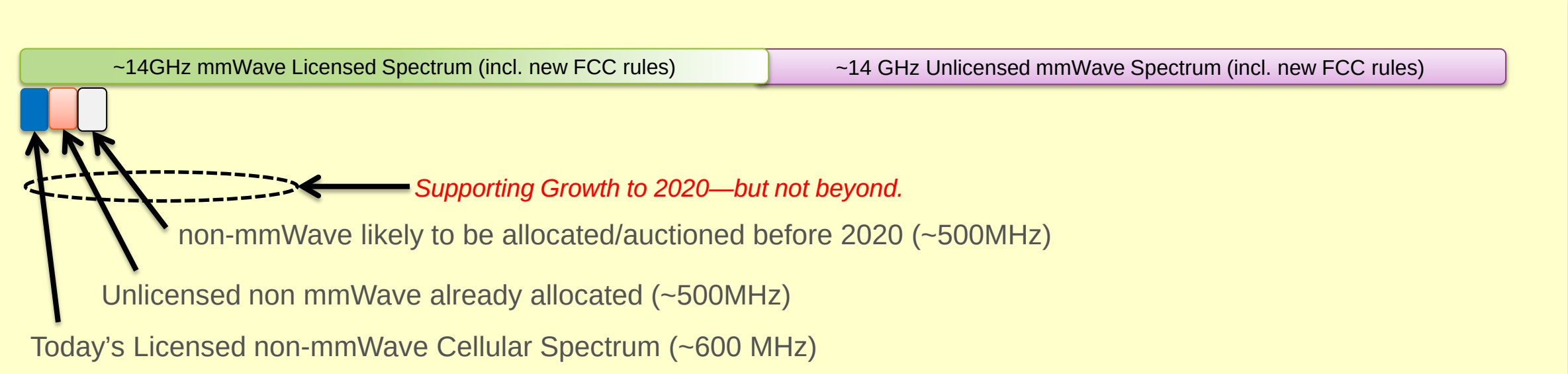
ISART Aug 2017

Roger Nichols
5G Program Manager

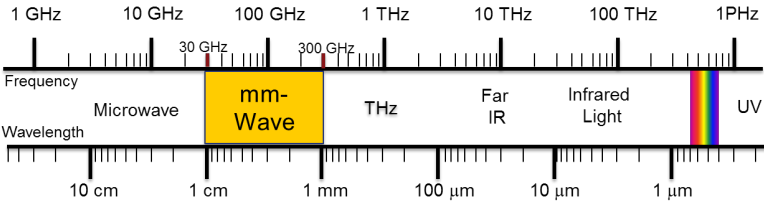
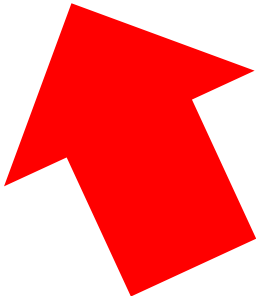


Spectrum Expansion Driving Technology

mmWave—It's all about bandwidth!



$$C = (\text{Bandwidth}) \log_2 \left(1 + \frac{\text{Signal}}{\text{Noise}} \right)$$



Spectrum Expansion Driving Change

mmWave Challenges are Numerous



High Frequency	High Bandwidth	High Path Loss	High Data Rate
Phase Stability	High IF Converters (use 2 nd Nyquist)	Directional Antennas Usually Required	Power consumption
Amplifier Efficiency	I and Q channel match over frequency	Large codebook space for Beam Steering	Algorithm Complexity
Output Power	Integrated Noise Power	Beam forming complexity	Prototyping (FPGA's usually not fast enough)
Antenna Complexity	IF/RF Flatness	Robust Modulation and Coding (MCS)	IO (memory, interfaces to CPU's etc.)
Quadrature Errors (Homodyne)	A/D and D/A Converters (power consumption)	Discovery and Tracking affect MAC and MCS	High sample-rate data to/from converters

*This does not count
system challenges:*

- *Channel Model*
- *Initial Access*
- *Random Access*
- *...the list goes on*

Spectrum Expansion Driving Change

mmWave Challenges are Numerous



High Frequency	High Bandwidth	High Path Loss	High Data Rate
Calibration	IF Flatness	Antenna Codebook	BIG Data
Amplifiers	Noise Power	Modulation	Throughput
Antennas	Fast Data Conversion	Power (RF and BB)	

This does not count system challenges:

- *Channel Model*
- *Initial Access*
- *Random Access*
- *...the list goes on*

On the importance of testing our assumptions

“In physical science a first essential step in the direction of learning any subject is to find principles of numerical reckoning and practicable methods of measuring some quality connected with it. I often say that **when you can *measure* what you are speaking about and express it in numbers you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind**: it may be the beginning of knowledge, but you have scarcely, in your thoughts advanced to the stage of science.”

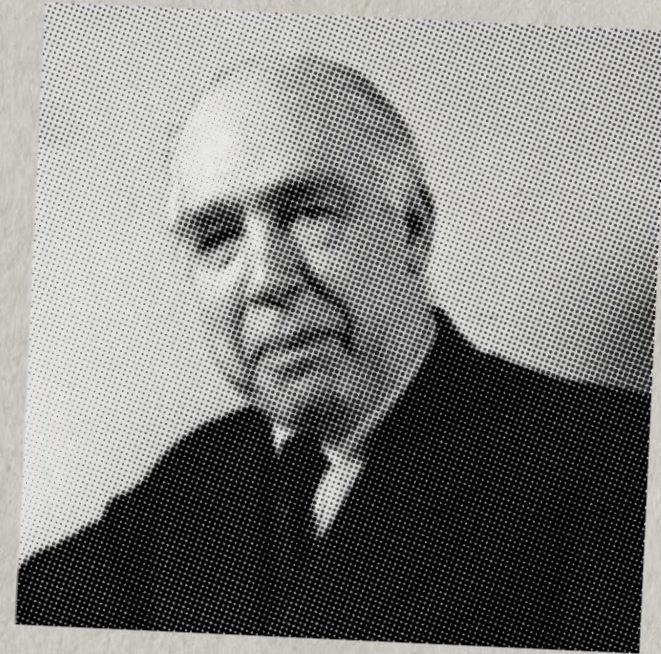
--William Thomson, Lord Kelvin, 1883

Will mmWave Work for 5G?

The Nature of Prediction

I Prediction is
very difficult,
especially about
the future.

Attr: Niels Bohr
20th century



“Go, wondrous creature! mount where Science guides;
Go measure earth, weigh air, and state the tides;
Instruct the planets in what orbs to run,
Correct old Time, and regulate the sun;”

--Alexander Pope, “An Essay on Man” AD 1734

“And figure out how to measure mmWave and spectral
occupation over the air, calibrated, and within budget;
Or your MIMO will be of a meagre and unsatisfactory kind.”

--Roger Nichols, 2016