Inclusive Radio Communication Networks for 5G and Beyond

Final Workshop – 28 January 2020, Louvain-la-Neuve, Belgium

Cellular radio mobility standards and future challenges for propagation research and radiated test methods

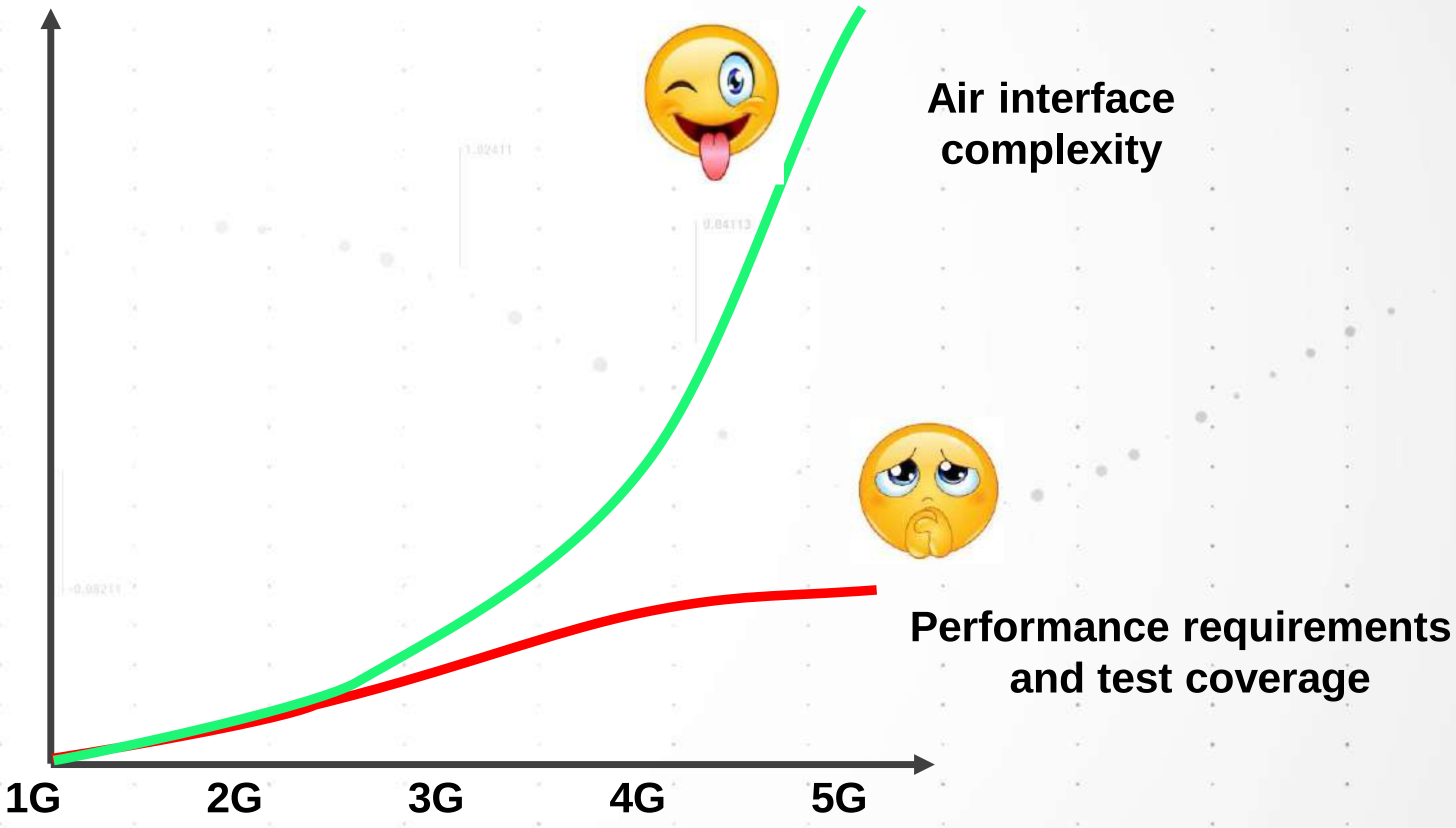
Moray Rumney

Agenda

- EWG-OTA activities
- A quick review of where we have come from and what drives network performance
- The demise of the antenna
- Spherical coverage
- Channel modelling
- Random access
- Safety issues
- Way forward and summary

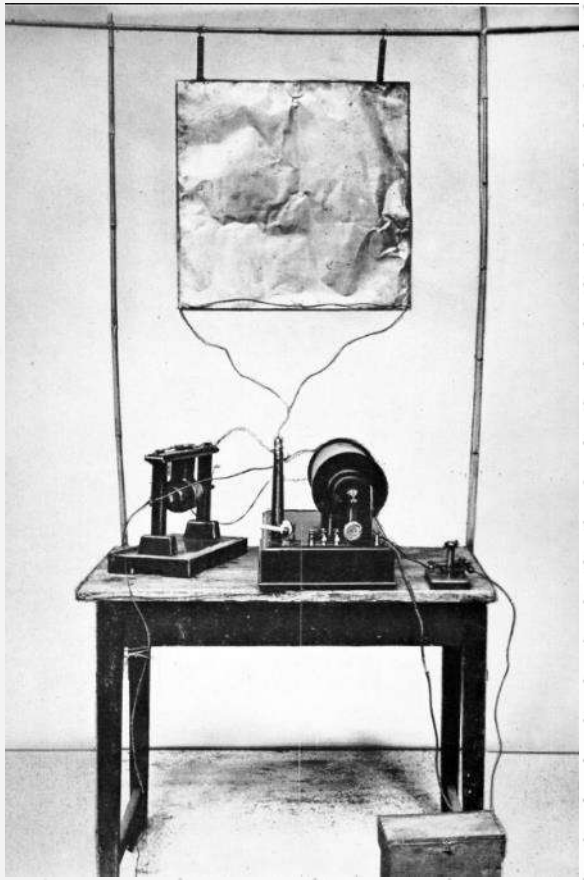
EWG-OTA

- 45 TDs
- Some progress on OTA test methods
- Unlike COST 2100 / COST IC1004, demand for solutions was muted due to lack lack of 3GPP requirements and the rush to specify 5G
- Much still to do but motivation is not coming from the right places

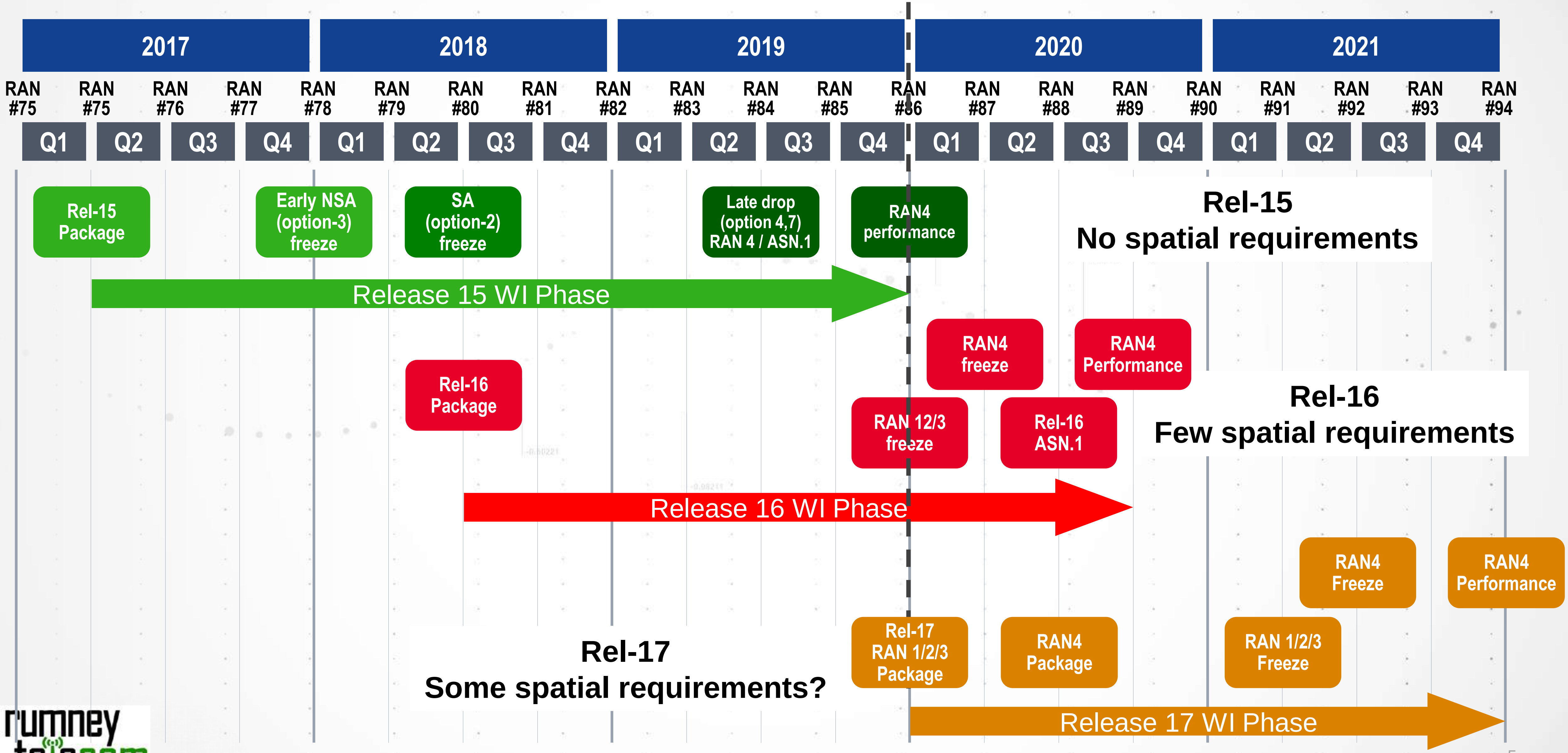


The growing problem with cellular

From spark gaps to Massive MIMO in 125 years!



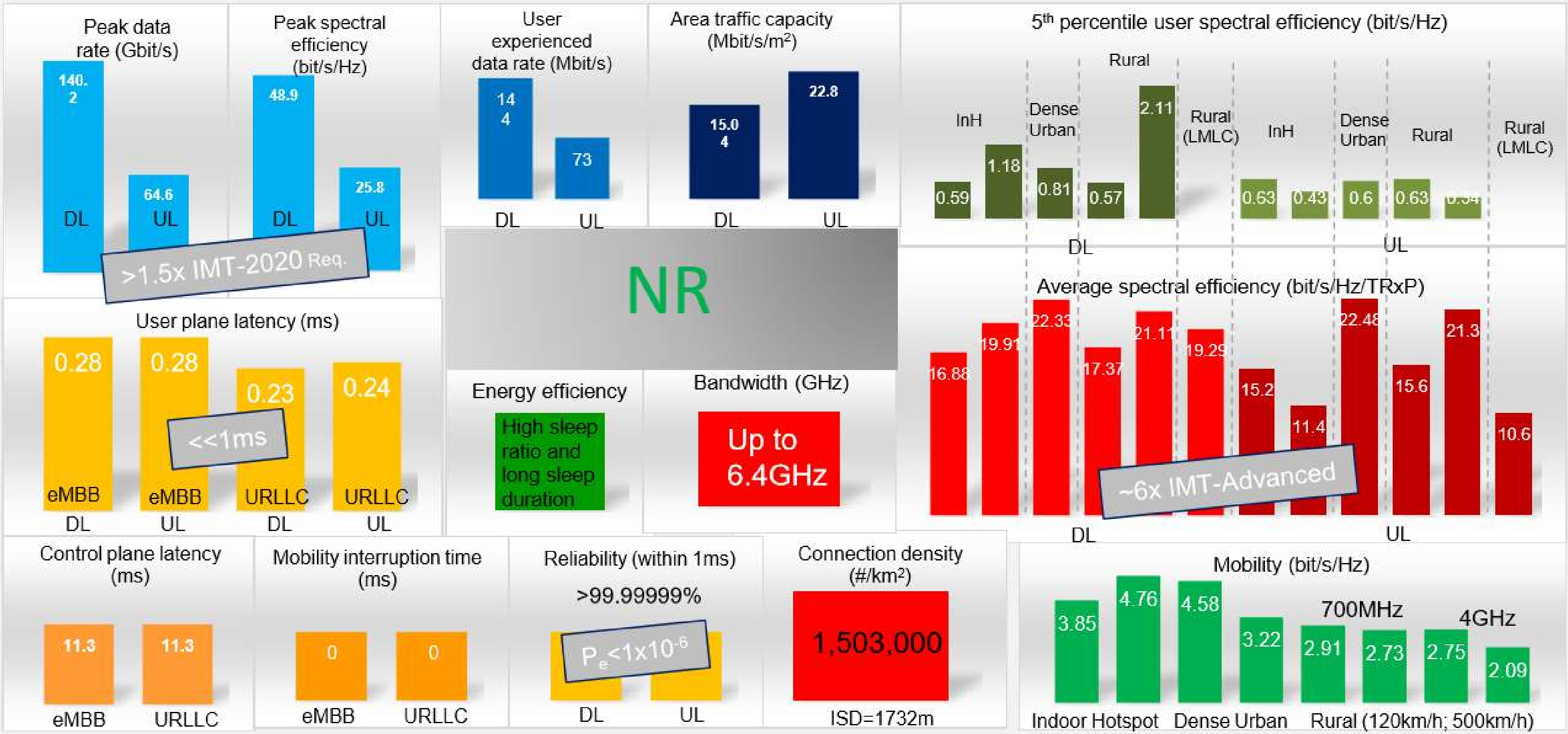
Rel-15/16/17 Timeline



3GPP input to ITU-R workshop on "IMT-2020 terrestrial radio interfaces evaluation”

RP-193058

- 3GPP submitted the presentation in RP-193058 based on the 3GPP self-evaluation report TR 37.910 of its 5G radio interface technology for IMT-2020 to an ITU-R workshop in Geneva in Dec 2019.
- The presentation is full of 5G eye candy including the claim of a peak data rate of 171 Gb/s!



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Poll at first CW 5G debate in London October 2016

Vote for ubiquitous 10 Mbps vs. hotspot peak rates

Sustainability

- Forever pursuing higher peak data rates may be possible but is in sustainable?
- In the 1950s we used to think cars like this were cool

What’s the cellular equivalent of the Smart Car?

And what is the environmental impact of all the resources that go into making a smartphone that has a two-year life?

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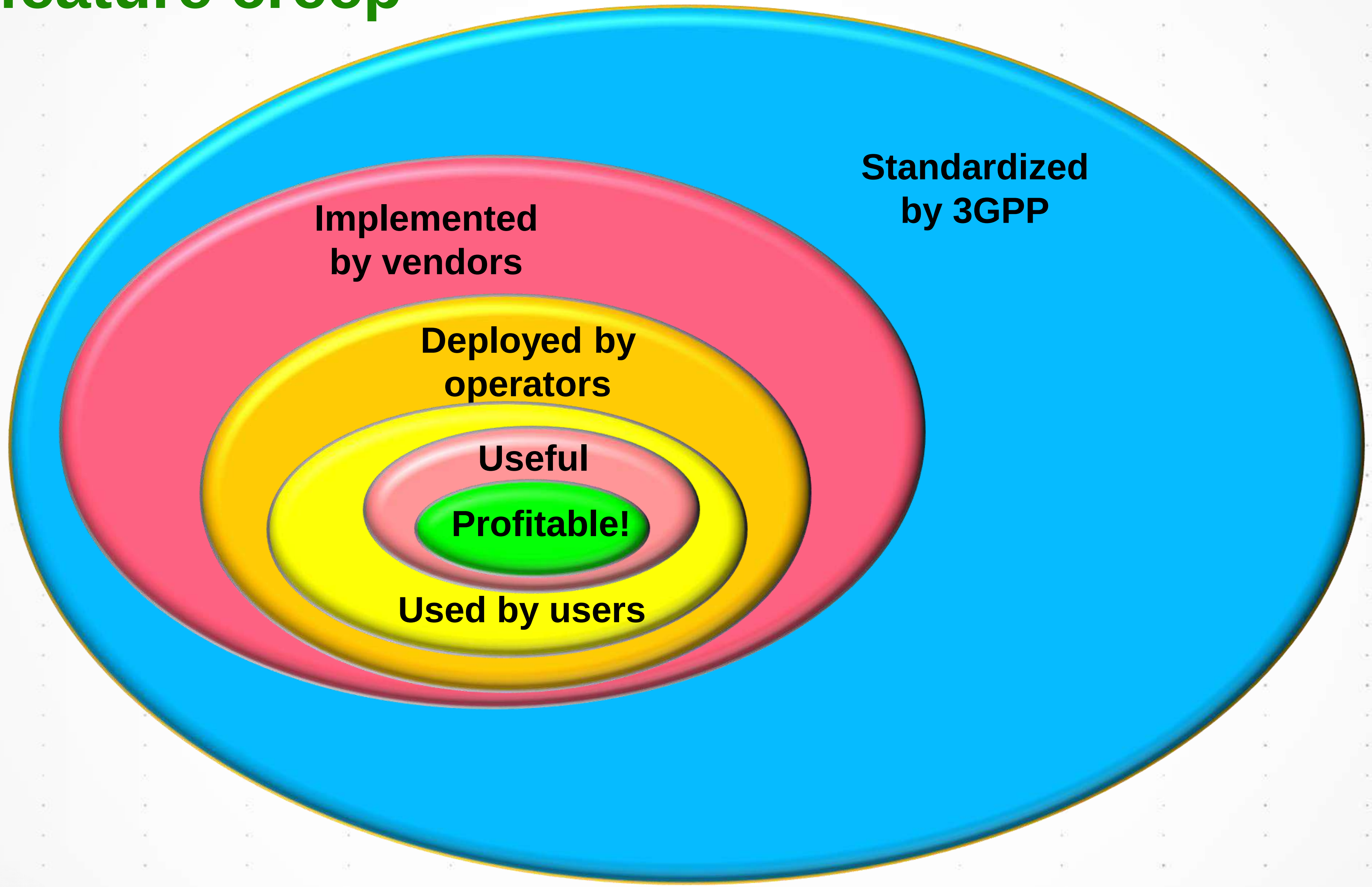
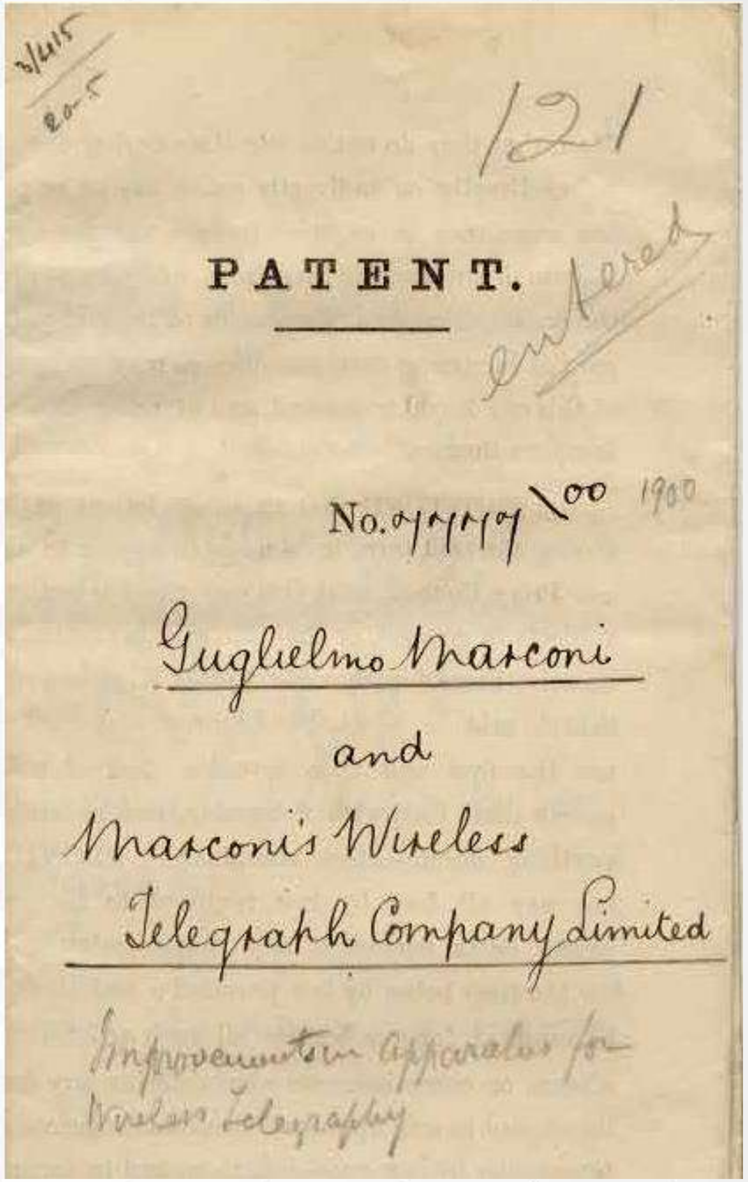
3GPP feature creep



In the beginning…

- By the early 1900s the three essential dimensions of cellular communications systems were identified:
  - Spectral efficiency in b/s/Hz
  - Number of cells (determined by cell size in km^2)
  - Occupied spectrum in Hz
- These three dimensions dating from the Marconi era have been sufficient to predict the capacity of cellular systems ever since
- But not anymore!
- In the last decade or so, the potential to exploit the spatial domain within a cell has become a commercial reality and is at the heart of many of the innovations in air interface technology
- But the potential to fully exploit the spatial domain in practical systems is not fully understood, leading to incomplete specification of radiated “over the air” (OTA) spatial requirements and the associated validation through testing



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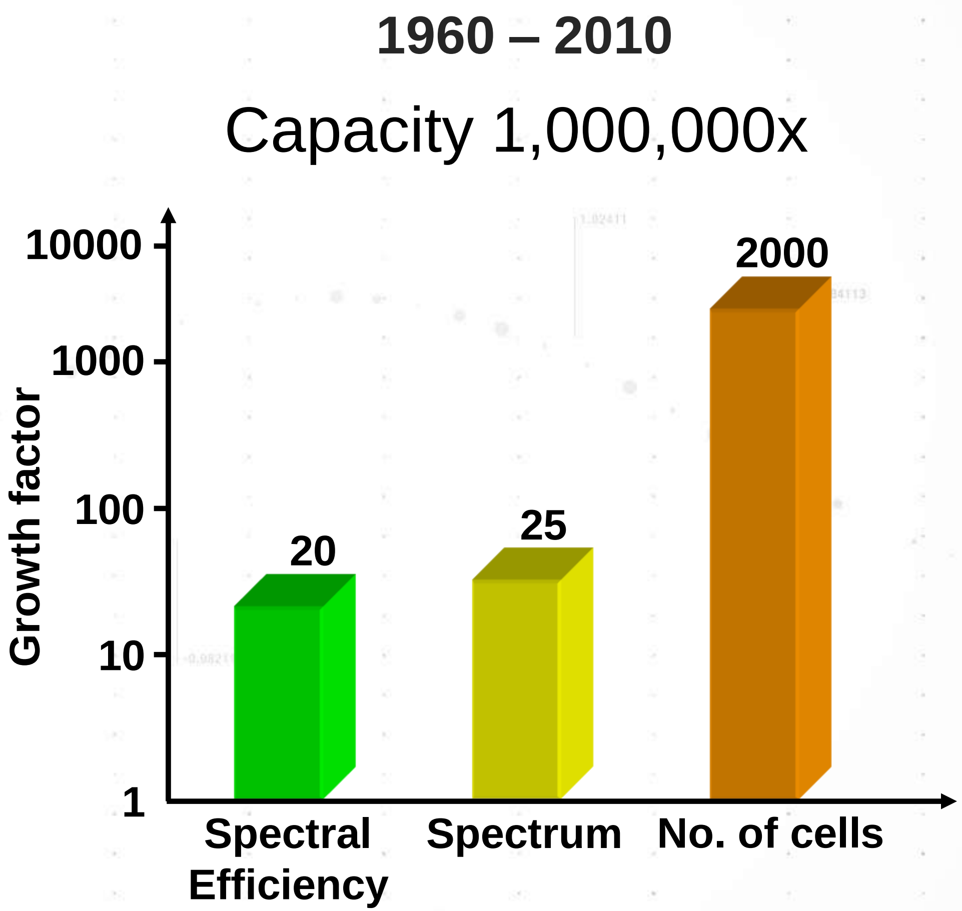
Not all dimensions are equal

- Prior to the advent of the spatial domain, an analysis of the contribution to radio system capacity of the Marconi-era dimensions shows that they are not at all equal
- Although spectral efficiency and spectrum usage dominate the innovation in radio standards, it is the mundane practise of shrinking cell sizes that has completely dominated the growth in system capacity



Principle:
Historically, cell size has dominated the growth of cellular capacity by a factor of ~100:1 over spectrum usage and spectral efficiency

Spectral efficiency vs. data density for different cell sizes

Attribute \ Cell Size	Iridium Satellite	Rural	Urban macro	Urban micro	Pico	Wi-Fi Hotspot	Femto
Coverage	Worldwide (outdoor)	Rural	Urban	Urban	Metro	Home/ Metro	Home/ Metro
Mobility	Perfect	V Good	V Good	Good	Fair	Nomadic	Nomadic
Cell radius	1500 km	30 km	3 km	300 m	30 m	10 m	10 m
Cell area km^2	7,700,000	2826	28	0.28	0.0028	0.0003	0.0003
Total cells	66	500 k	1 M	5 M	50 M	1 B	1 B
Total System capacity/MHz	40 Mbps	500 Gbps	1 Tbps	7.5 Tbps	75 Tbps	2000 Tbps	3000 Tbps
Capex/cell	$5 M	$250 k	$200 k	$50 k	$5 k	$50	$200
Opex/cell/year	$700 k	$25 k	$20 k	$10 k	$5 k	$20	$100
Efficiency bps/Hz	0.6	1	1	1.5	1.5	2	3
Data density $Mbps/km^2/MHz$	0.00000008	0.00035	0.035	5.35	535	6666	10000

Spectral efficiency is essentially constant, data density varies 125 Billion : 1

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What’s changing with 5G?

- Of all the new things with 5G, three stand out as being significant in terms of higher performance
  1. The continued trend towards smaller cells / more dense networks
  2. The increased exploitation of the spatial domain within the cell
  3. The addition of mmWave frequencies
- Number 1 & 2 are relevant to FR1 (<7125 GHz) but are inevitable for mmWave FR2 (> 24.25 GHz)

Exploiting the spatial domain

- The coverage area of a cell has historically been determined based on inter-site distance and any sectoring
- There are two fundamentally different ways in which the space **within** the cell/sector can be further exploited
  - **Beamforming (aka MIMO**) - spatial multiplexing using precoding
  - **Beamsteering** - directing narrow beams towards the user
- Both techniques require use of antenna arrays at one or both ends of the link, but otherwise they are quite different in how they operate and perform

Frequency range		Probability of deployment	
		Beamsteering	Beamforming (at M-MIMO scale)
FR1	< 1 GHz	Unlikely due to antenna array size	Not probable due to antenna size and performance
	2 GHz – 3 GHz	Deployed today with proven 5x gain	Possible, limited/unproven gains outside labs
	3 GHz – 7.125 GHz	More probable than for 2 GHz -3 GHz	Likely, limited/unproven gains outside labs
FR2	24.25 GHz – 52.6 GHz	Essential for realistic operation	Not probable due to cost and limited performance gain over beamsteering due to channel sparseness

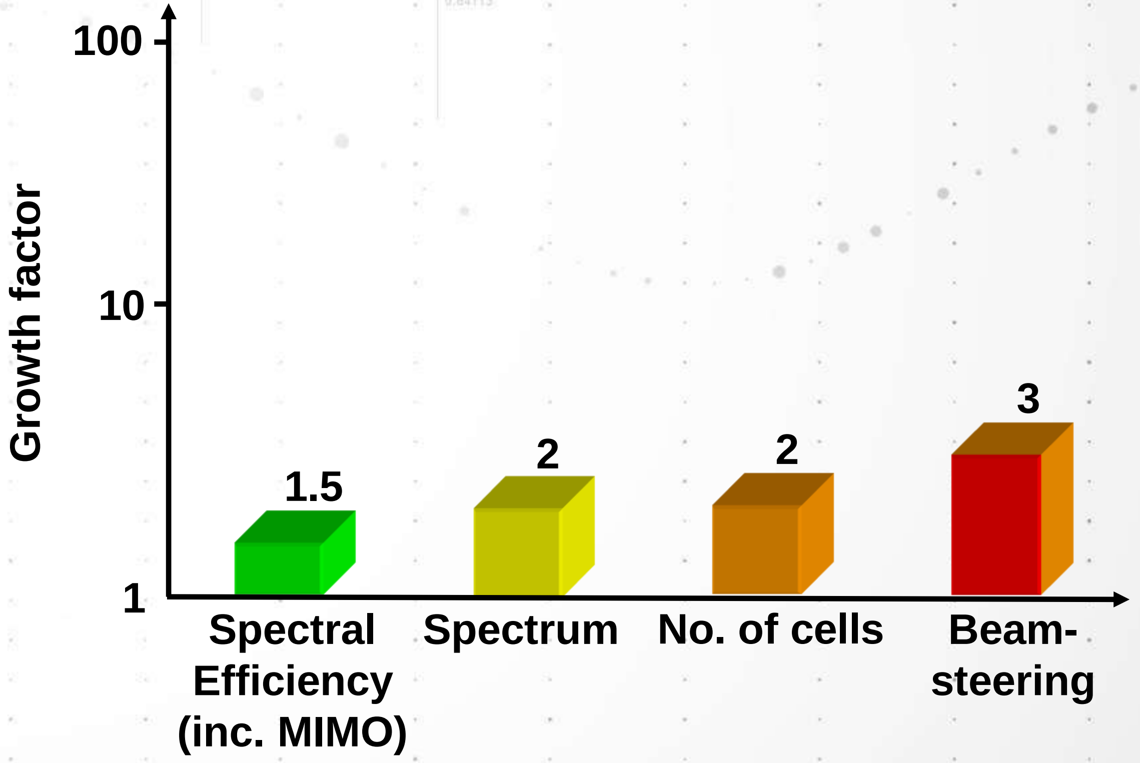
Looking ahead

PREDICTING CAPACITY GROWTH FOR FR1

- Spectral efficiency continues to grow through air interface sophistication: higher order MIMO, interference cancellation, and trunking gains from higher data rates with carrier aggregation. But there is not much blood left in the turnip.
- Significant new FR1 spectrum is newly available from 3.3 GHz to 5 GHz with more above 6 GHz coming
- Cell sizes will continue to shrink but cap-ex, op-ex and zoning will limit this potential
- Beamsteering has a lot of upside in areas where smaller cells are logistically difficult. 3x gains would mean upgrading many legacy macro-cells

2015 – 2025

FR1 Capacity 18x



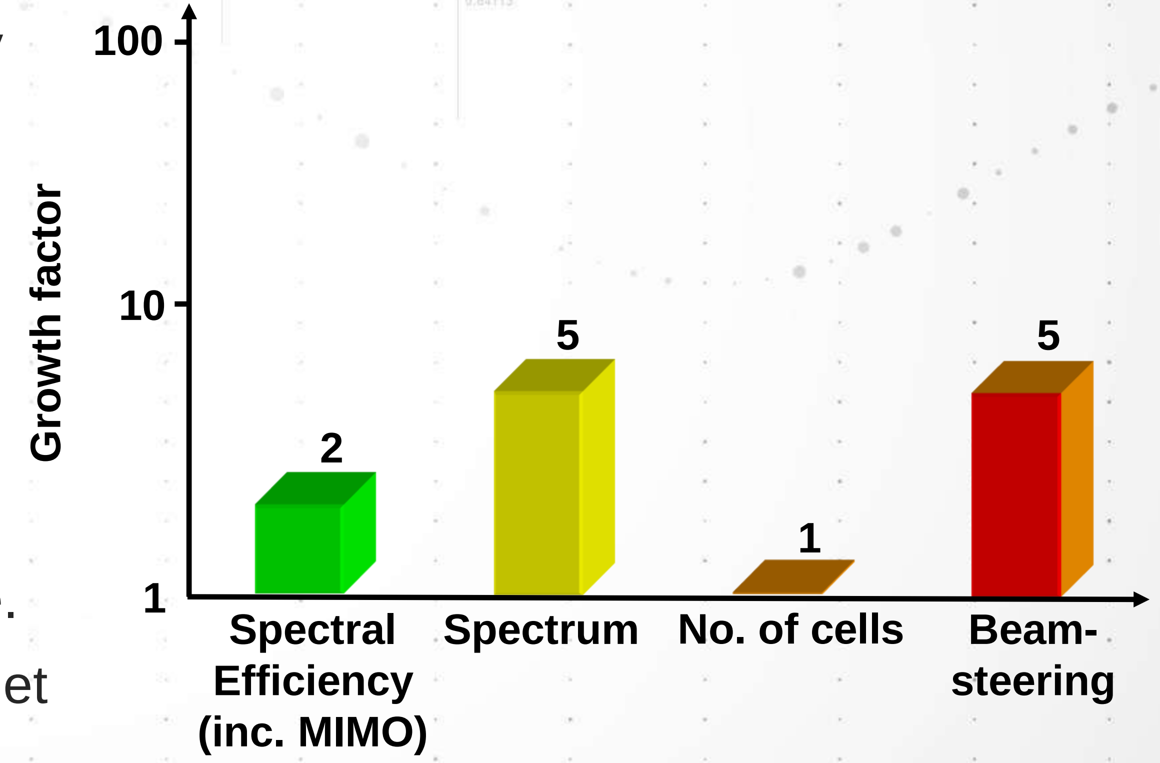
Looking ahead

PREDICTING CAPACITY GROWTH FOR FR2

- There is no baseline FR2 deployment upon which to extrapolate growth, so these estimates are based on the FR1 baseline c. 2015
- Spectral efficiency at mmWave remains to be fully understood. The channel is sparse leading to higher SINR but very limited MIMO, and radio performance is worse due to the physics
- Compared to FR1, there is huge spectrum potential, assume at least 5x by 2025
- Cell sizes will be small but deployment will be patchy so total numbers may be similar to FR1 which is entirely a commercial, not technical issue.
- Beamsteering is essential at FR2 for the link budget

2015 – 2025

FR2 Capacity 50x FR1 in 2015



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Factors affecting performance

Supercar Vs. Smartphone

Car performance attributes

1. Transmission
2. Suspension
3. Tyres / steering
4. Road conditions
5. Traffic
6. Fuel economy

Phone performance attributes

1. Baseband
2. Adaptive modulation & coding
3. Antennas / beamsteering
4. Channel conditions
5. Interference
6. Battery life

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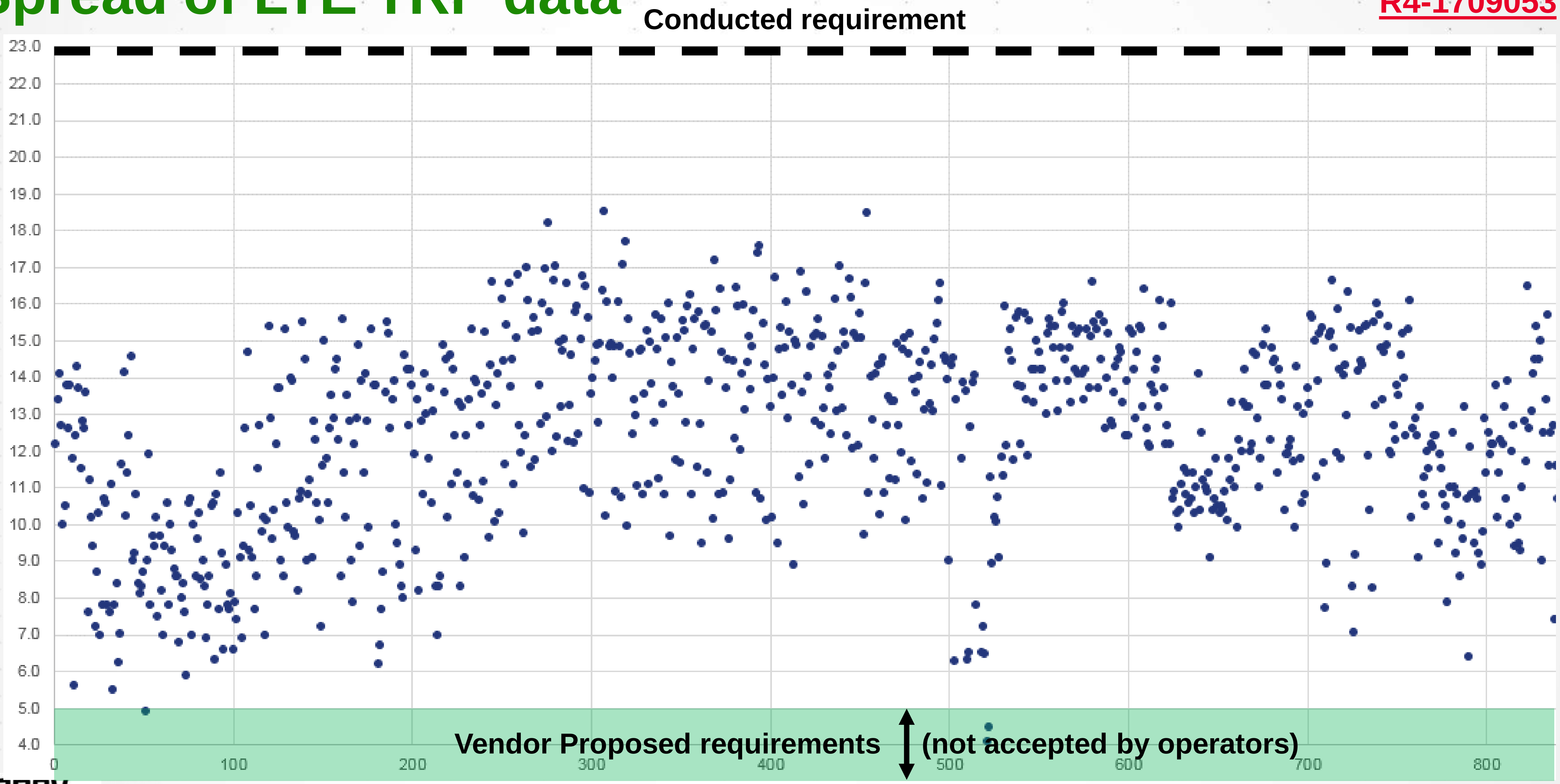
Spread of LTE TRP data

R4-1709053



The OTA performance of 4G LTE smartphones is unspecified and out of control

The consequence of no OTA requirements

Conducted Performance

All UEs pass 23 dBm requirement but this is not relevant to network performance

Radiated Performance

No requirements for 4G and 5G! 4G performance varies from 4 – 18 dBm by product type

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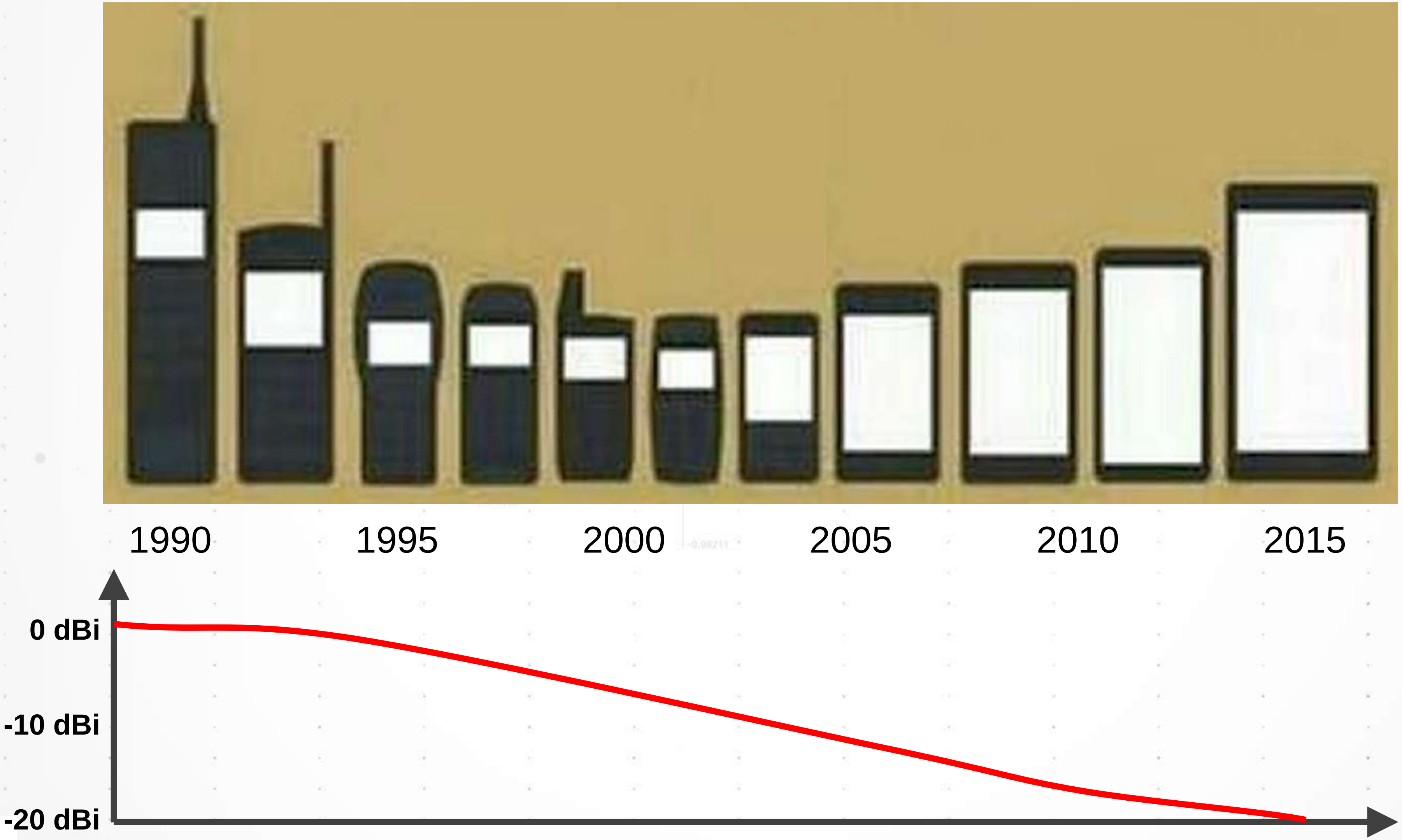
3GPP has not specified significant smartphone SISO OTA requirements since 3G in 2007. Antennas have got worse and there is no easy way to put the performance back in the tube.

Form factor vs. antenna performance



3GPP are considering 5G NR SISO OTA requirements for Rel-17 in 2021 but there is no guarantee the work will be started or successful

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Typical standards development priorities

Step 1 Measure with a micrometer

Features providing a few tenths of a dB of baseband performance are considered worth fighting for

Step 2 Mark with chalk

Once conducted signals reach RF, allowances for implementation margin and test system uncertainty can account for 2 or 3 dB lost performance

Step 3 Cut with an axe

But the **radiated** performance of devices taking into account the antennas can easily vary by 10 dB or more

The antenna <u>really</u> matters but gets ignored!

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Plans for Rel-17

RP-193216

- In Dec 2019 the first batch of Rel-17 study and work items were approved according to **RP-193216**
- The 24 new study / work items can be categorized as New things, fixing things and other things:

New stuff (& verticals)		Fixing things	Other things
NB-IoT/eMTC over NTN	52.6 GHz – 71 GHz	NR Light	NR QoE
NR sidelink relay	IAB	NR MIMO	Dynamic Spectrum sharing
NR Positioning enh.	NR Sidelink enh.	NR Coverage*	Multi-radio dual connectivity
NR XR	NR Multicast broadcast	UE Power saving	Enhanced eNB architecture
RAN slicing	IIoT / URLLC	Multi-SIM	
NR over NTN	NB-IoT/eMTC enh.	Small data	
		SON MDT	

* NR Coverage WI does not mention antennas

The mmWave paradigm shift and 3GPP's response

What we know well	Here be dragons!	The 3GPP response
FR1 Cellular (< 6 GHz)	FR2 Cellular (> 24 GHz)	FR2 Cellular (> 24 GHz)
How **GOOD** is my signal?	**WHERE** is my signal?	**WE HAVE NO TIME!** to define spatial requirements
↓	↓	↓
Non-spatial requirements and cabled testing	3D spatial requirements and OTA testing	Discount the antenna for demod and the dynamics for RRM

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5G NR Outlook

The potential

The long-term reality

Current virtual reality

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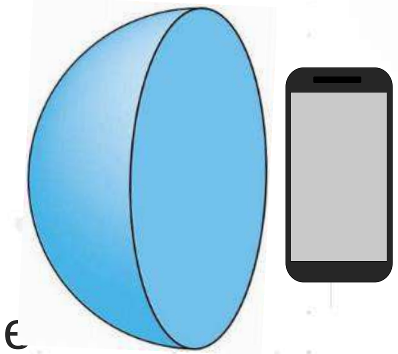
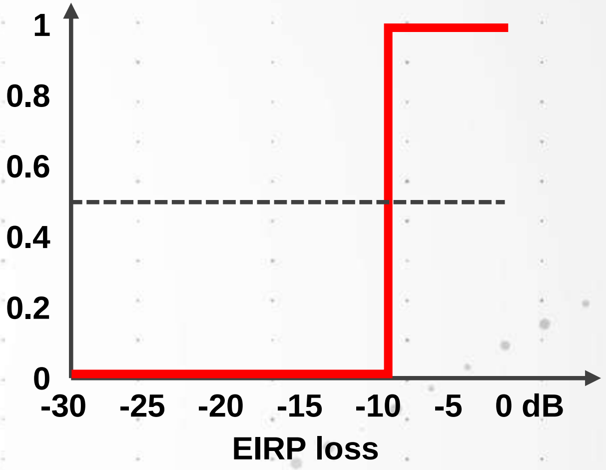
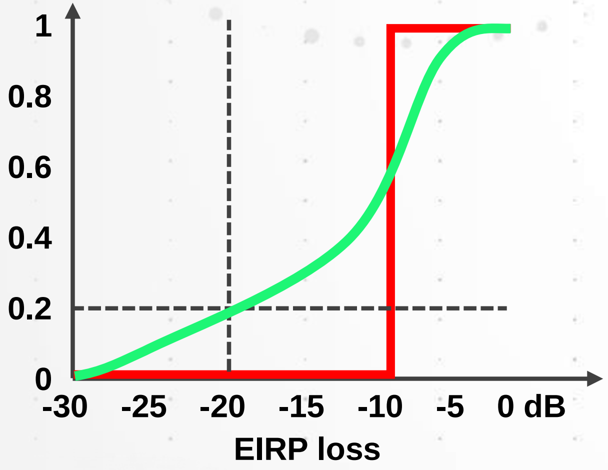
UE FR2 spherical coverage requirements

- Suppose the requirement was set at -10 dB for 50 %
- A UE that could generate peak EIRP for one hemisphere and nothing in the other half would have a CDF like this and would pass the requirement
- Such a passing design would have 50 % network outage







- A more realistic and useful requirement would be one that specified lower performance at a higher probability e.g. -20 dB @ 20 % to ensure some performance at most orientations

If TRP was the OTA battleground for LTE, then EIRP spherical coverage is the equivalent for NR FR2

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Spherical coverage at mmWave

Lower percentile means more directions are specified

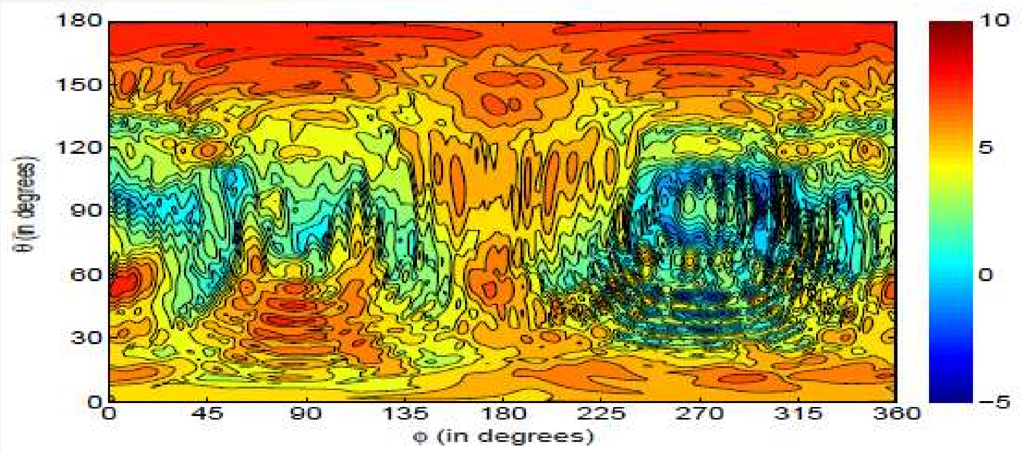
UE Power class	UE type	Max TRP dBm	Min peak EIRP dBm	Max EIRP dBm	Spherical coverage	Spherical coverage percentile
1	Fixed wireless access (FWA) UE	35	40 / 38 (n260)	55	32	85
2	Vehicular UE	23	29	43	18	60
3	Handheld UE	23	22.4 / 20.6 (n260)	43	11.5 / 8 (n260)	50
4	High power non-handheld UE	23	34 / 31 (n260)	43	25 / 19 (n260)	20



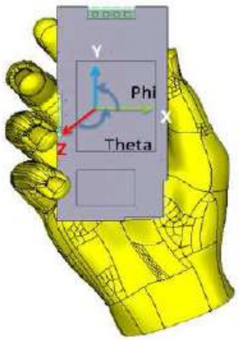
What these specifications mean is that basic radiated performance is only specified in a percentage of directions, even when the antenna is steering

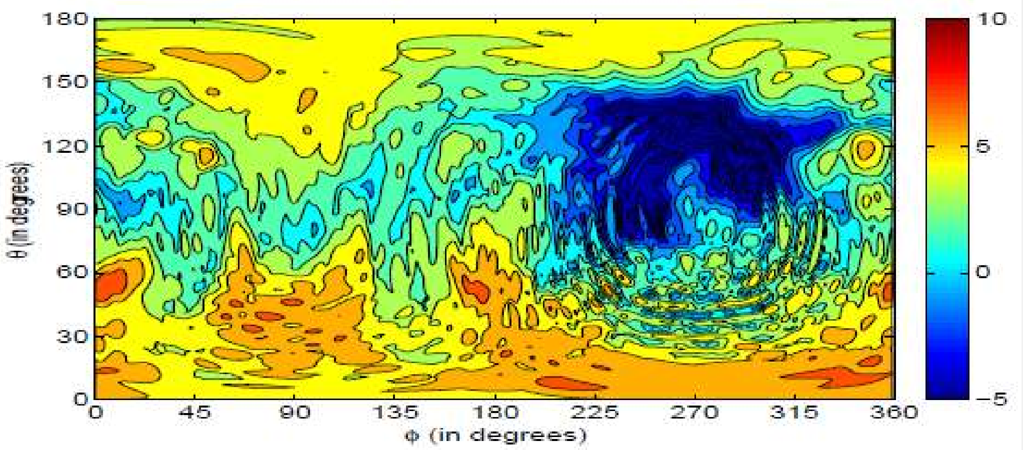
Hand blocking effects

https://arxiv.org/abs/1801.03346 *

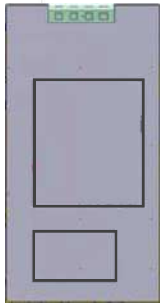


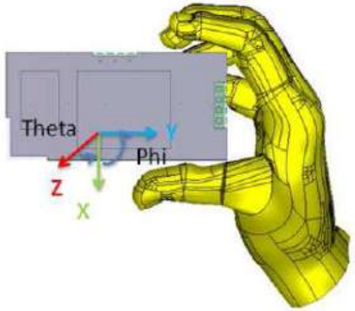
Maximum free space gain of all antennas at 28 GHz

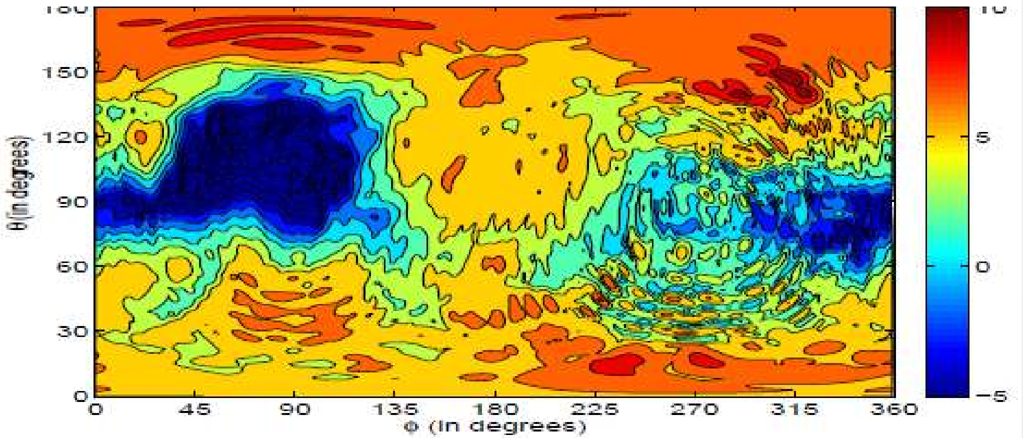




Multi-panel UE showing impact of hand blocking on max antenna gain @ 28 Gz





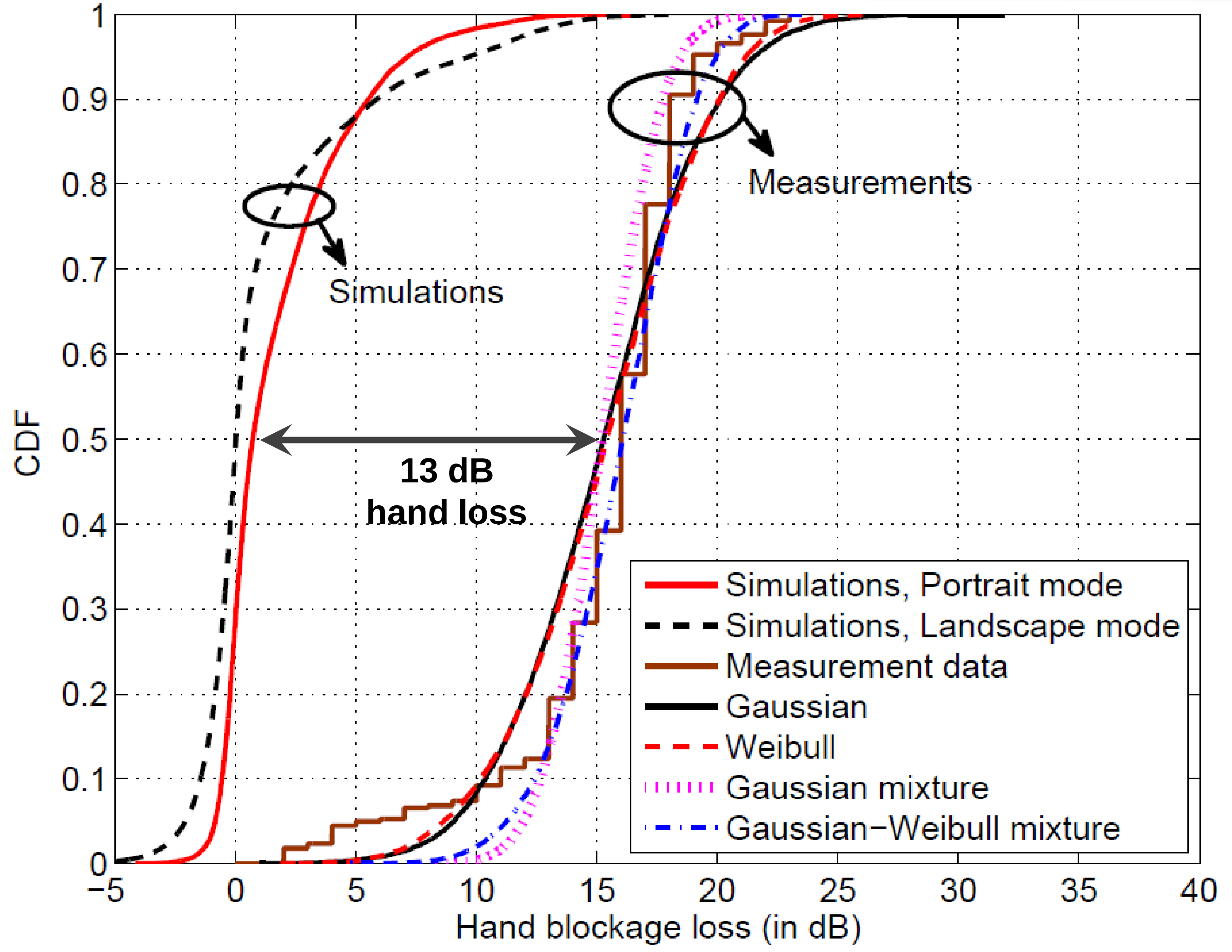


* "Statistical Blockage Modeling and Robustness of Beamforming in Millmeter Wave Systems", Vasanthan Raghavan, Lida Akhoondzadeh-Asl, Vladimir Podshivalov, Joakim Hulten, M. Ali Tassoudji, Ozge Hizir Koymen, Ashwin Sampath, and Junyi Li. Submitted to *IEEE Transactions on Antennas and Propagation*, available at: https://arxiv.org/abs/1801.03346.

Hand blocking effects – impact on CDF

https://arxiv.org/abs/1801.03346

- The CDF derived from the simulations show approximately 13 dB loss due to the hand phantom at 50 % probability
- Measurements aligned closely with the simulations
- Different UE designs and hand grips will give different results but this is good approximation of the impact on EIRP spherical coverage



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Research opportunity: What does a realistic hand phantom look like for 0.5 to 30 GHz?

- In addition to the challenge of correctly modelling human tissue is the increased sensitivity at high frequencies of the phantom/device positioning – very small changes can have a large impact

- Testing with real people may be unavoidable – it is more realistic but is time consuming and not repeatable

Meet “Thing” from the Addams family:

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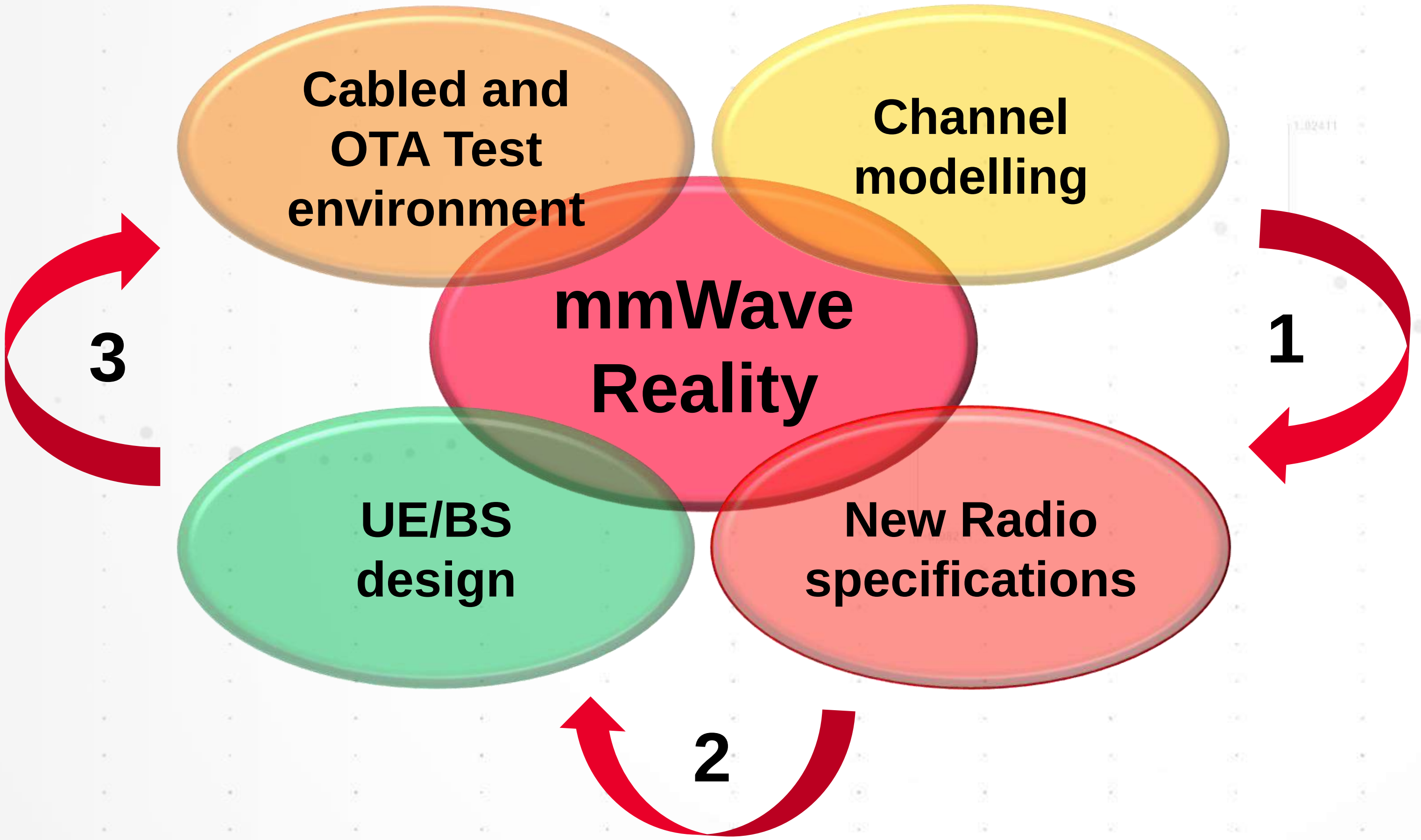
New radio design starts by modelling the radio channel



At FR1 we have good channel understanding and do cabled testing

But for FR2, how well do we really understand the channel. How many beams? How wide? How dynamic – spatial, power, temporal, frequency? 3GPP does not yet have all the answers

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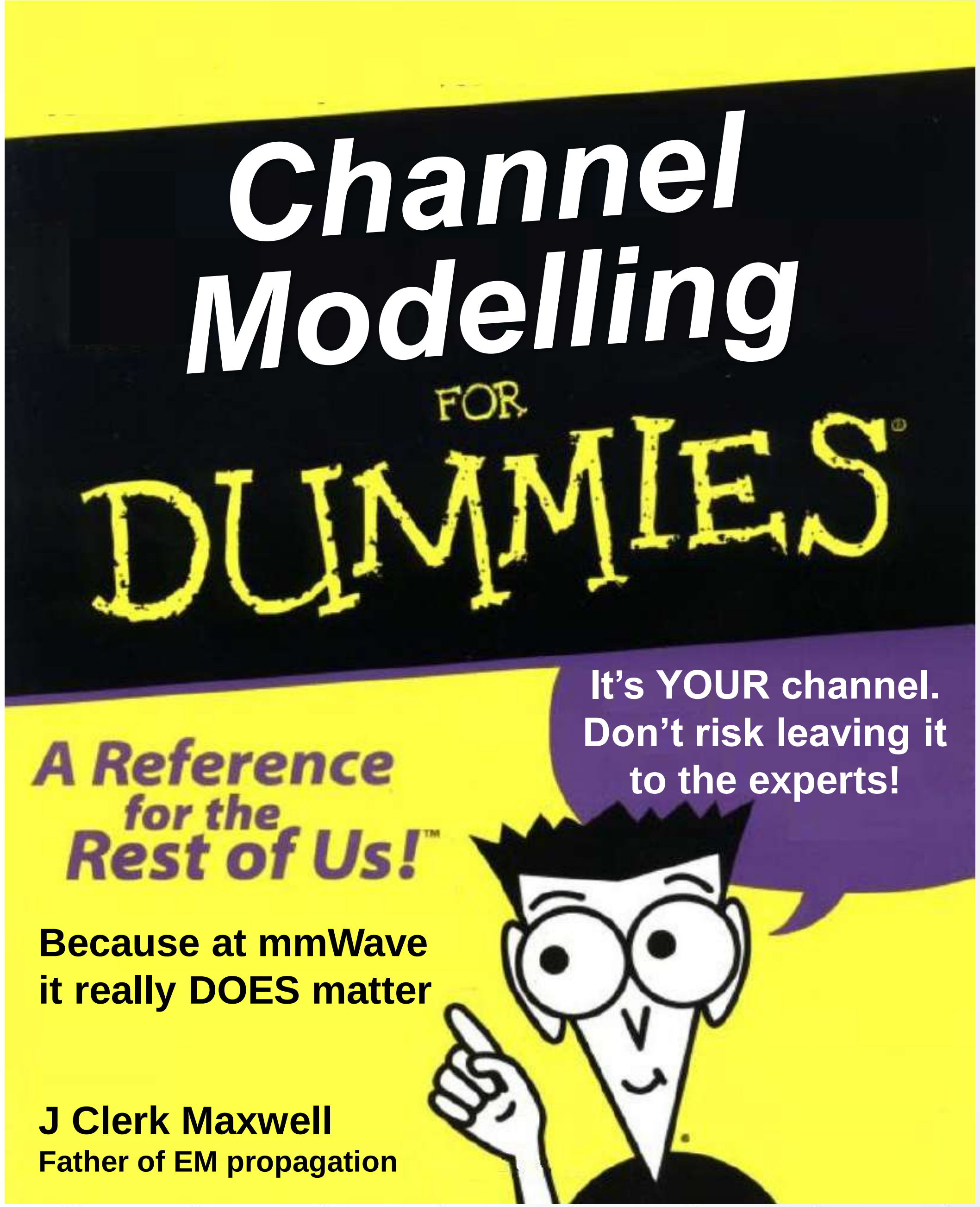
Channel modelling



The NR channel model TR 38.901

- TR 38.901 is an ambitious attempt to provide a unified channel model across a vast frequency and channel bandwidth range 0.45 – 100 GHz
- From this model it should be possible to derive channels for a wide variety of 5G use cases from narrowband mMTC at low frequencies through wideband eMBB in mmWave bands
- TR.38.901 was based on a paper from Globecom* by a channel model special interest group
- The normative model is based on traditional geometric stochastic channel model (GSCM) principles although there is an additional informative hybrid model using deterministic ray tracing
- The Globecom paper reused previous low frequency assumptions regarding cluster density and Doppler modelling and requested 3GPP to refine those assumptions since channel sounding studies suggested a more sparse channel at mmWave frequencies
- Unfortunately 3GPP did not have time to revisit all the assumptions meaning highly scattered low frequency assumptions being applied up to 100 GHz
- There are also no dynamic models to account for large scale parameter evolution due to mobility

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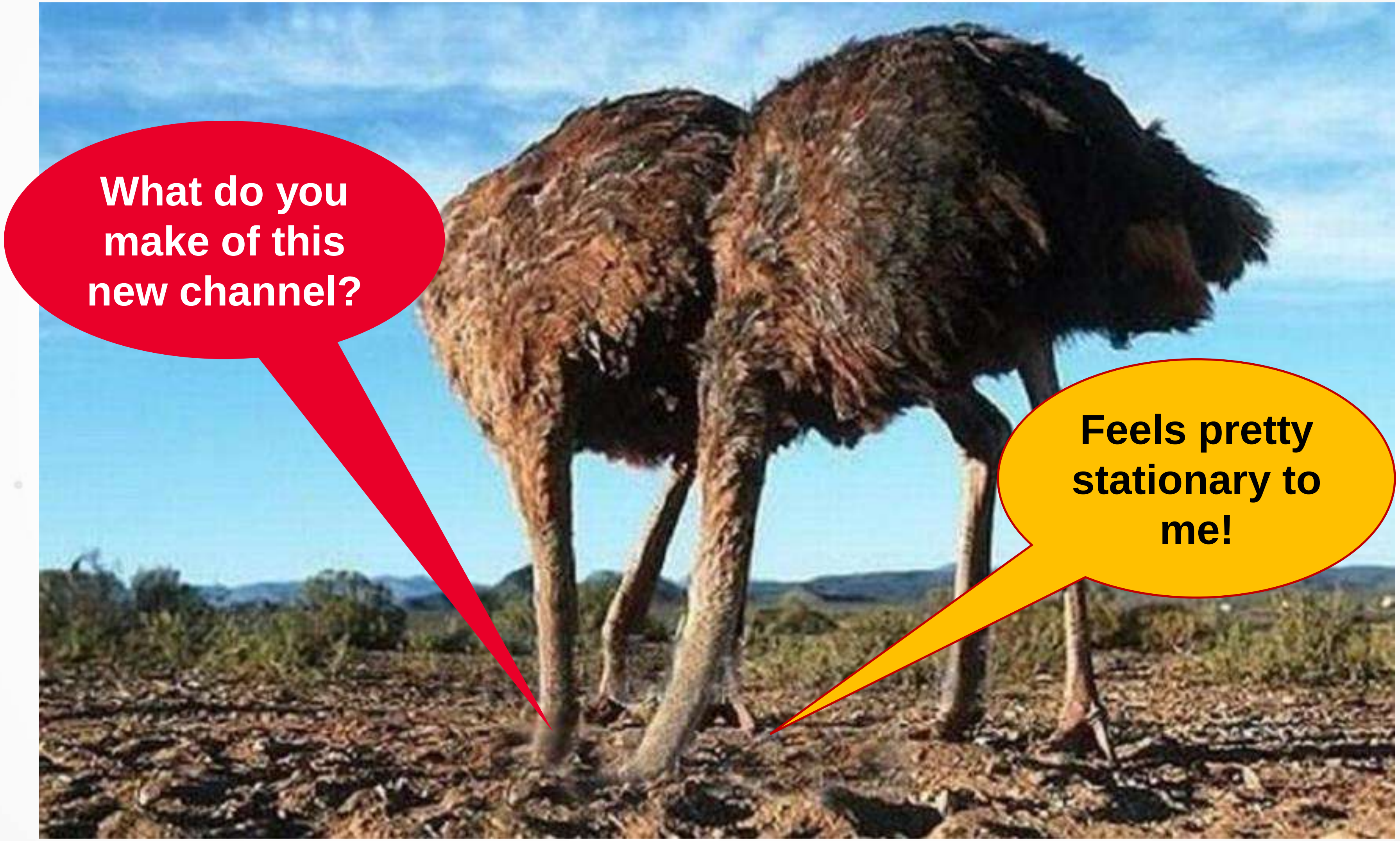
* 5G Channel Model for bands up to 100 GHz, Globecom 2015

Everyone is in agreement



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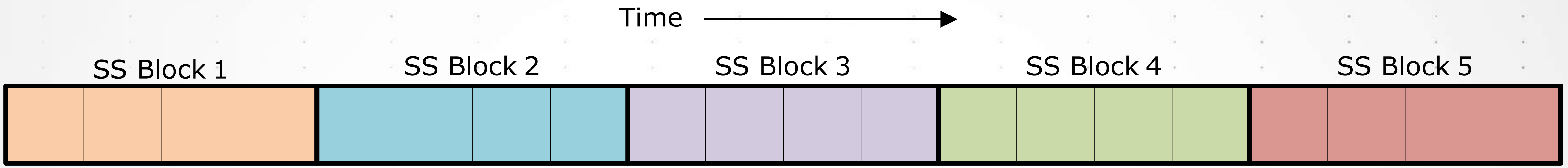
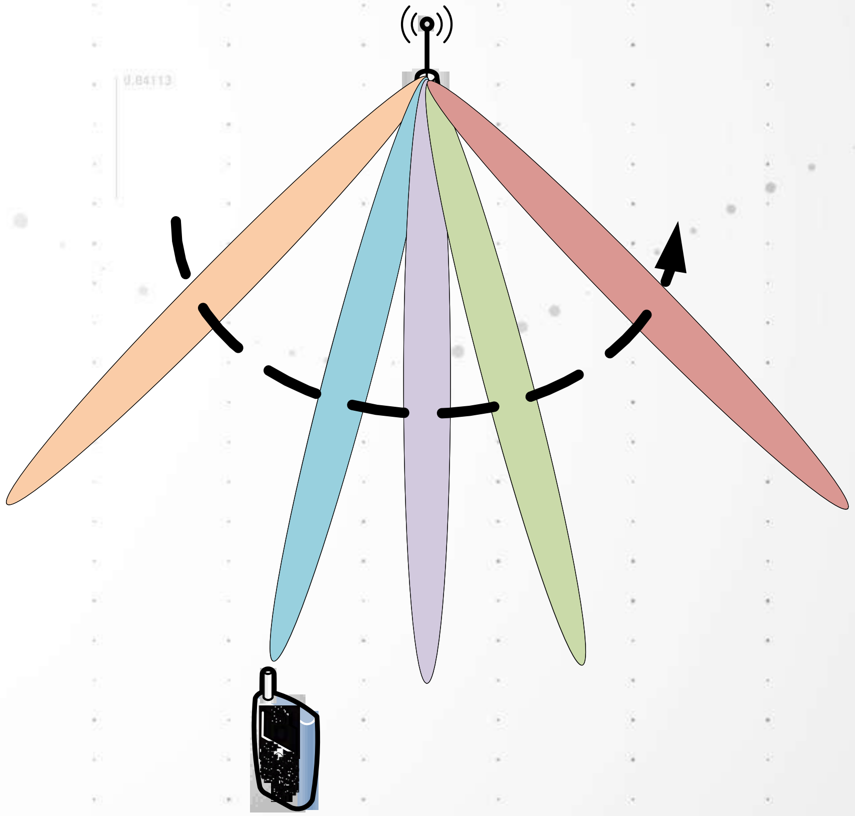
5G New Radio Initial Access



- Each Synchronization Signal Block (SSB) within a SS Burst Set is potentially transmitted in a different beam direction
- Default is 64 beams in 5 ms repeated every 20 ms
- The UE identifies a SSB within the Burst Set by using:
  - The time index carried by the PBCH DMRS
  - The rest of the SSB index carried by the PBCH data
- The UE selects the best SSB to respond with the PRACH to establish a link



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Comparing legacy and mmWave initial access

Legacy/current procedure

Highly predictable,
low complexity,
well understood

mmWave procedure

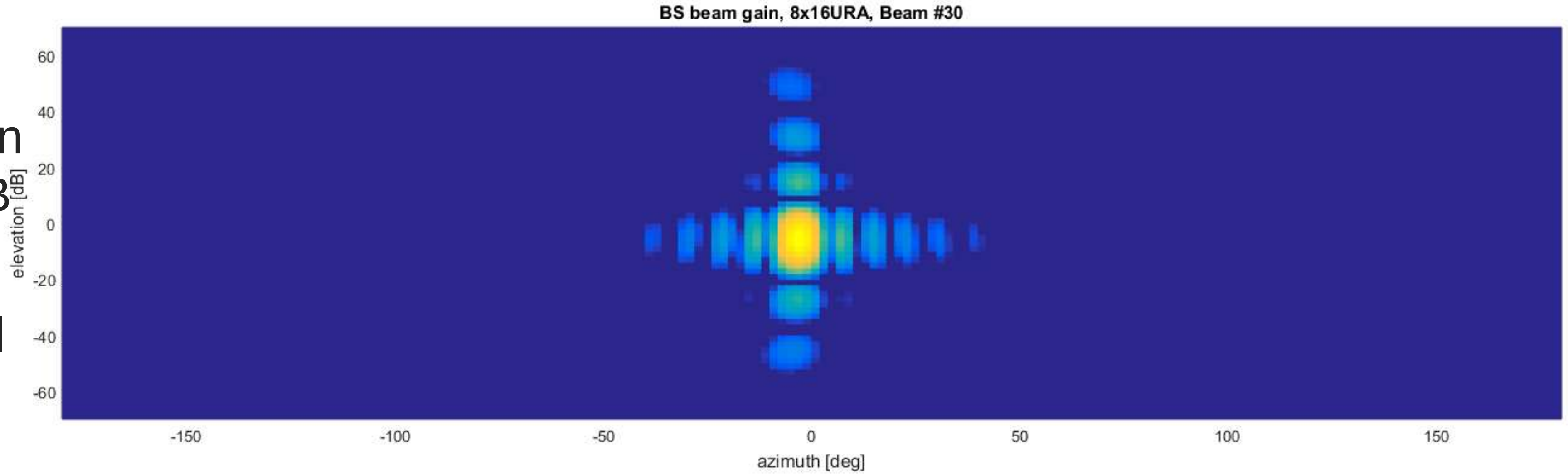
Don’t move!

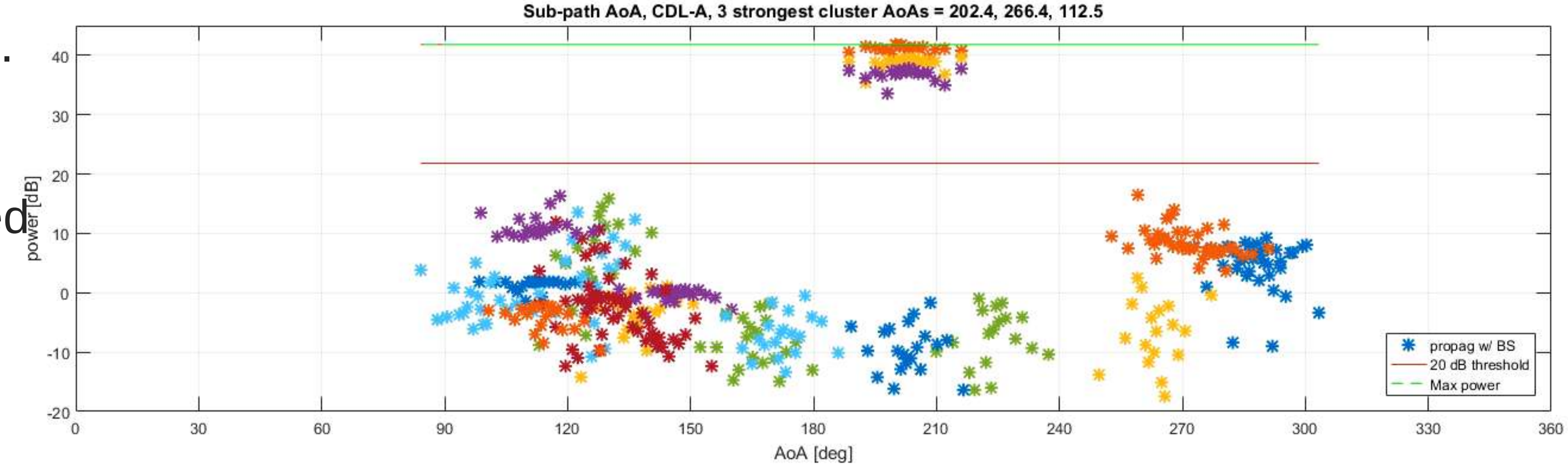
Modelling the dynamics of initial access

- The spatial dynamics of initial access will be determined b the following factors
  - The gNB antenna gain/pattern
  - The gNB beamsweeping direction
  - The spatial properties of the channel model
    - Assumed to be constant during the initial access process
  - The UE antenna pattern[s]
  - The UE orientation
    - Assumed to be constant during the initial access process
  - The UE antenna[s] switching/direction
  - The algorithms at each end and how they interact

CDL-A beamsweeping with gNB antenna assumption*

- This is CDL-A as seen by the UE during gNB beamsweeping
- The isotropic channel model is illuminated based on the gNB pointing direction
- The channel is static. Each dot is an MPC from a cluster which varies in power based on the gNB antenna pattern

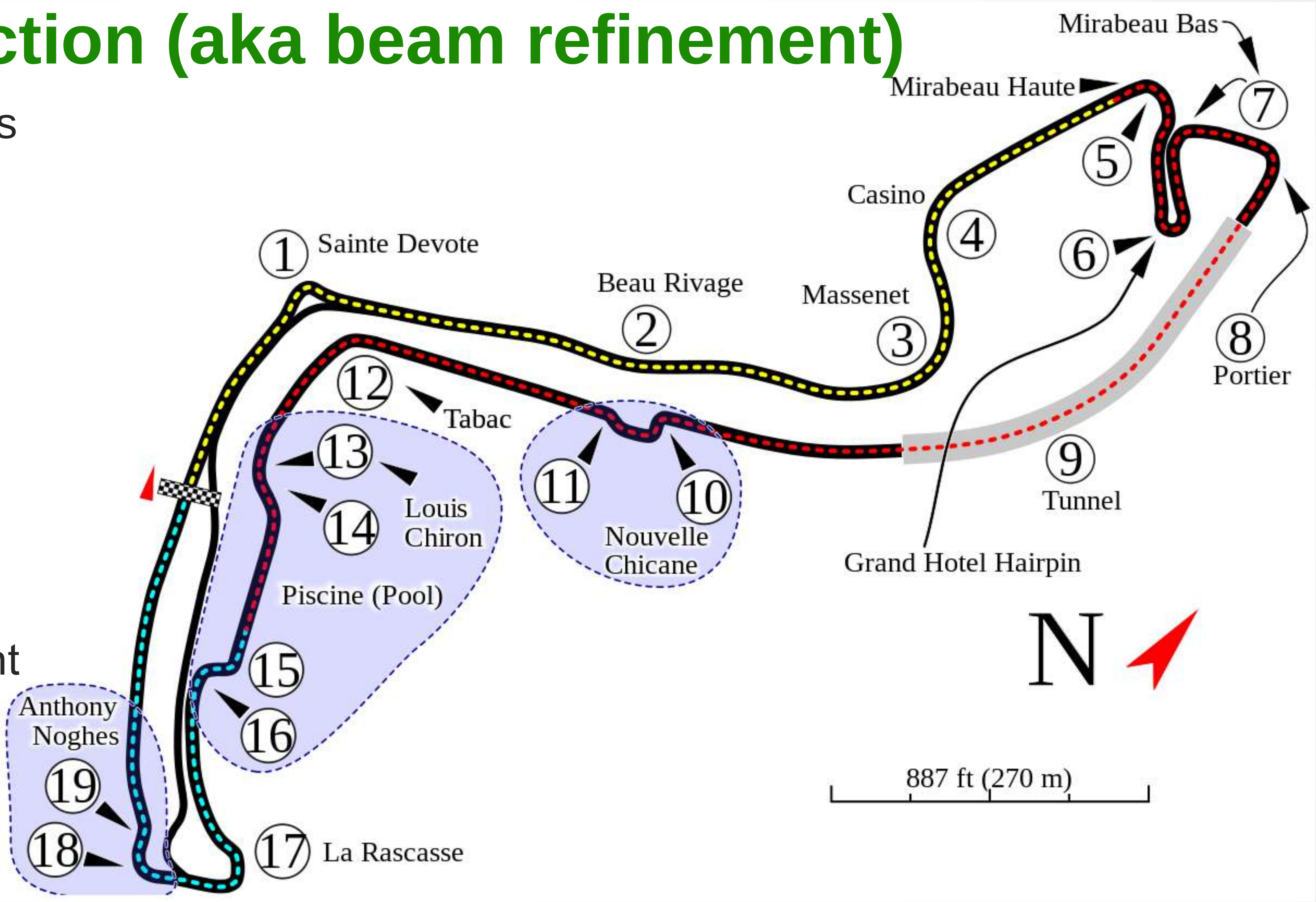




* Uses the original 8 x 16 URA from TR 38.803

Initial access is essential – but so is maintaining the correct beam direction (aka beam refinement)

- Not having beam refinement is like having a race car with no steering wheel
- It can be pointed in one direction at the race start
- If the "circuit" is a drag race with no corners no further steering is needed – like fixed wireless access
- But if it's a mobile environment it could look more like the Monte Carlo F1 circuit and at each corner, without steering, the car crashes.



It's not useful to know the average angle of the steering wheel = 0 degrees

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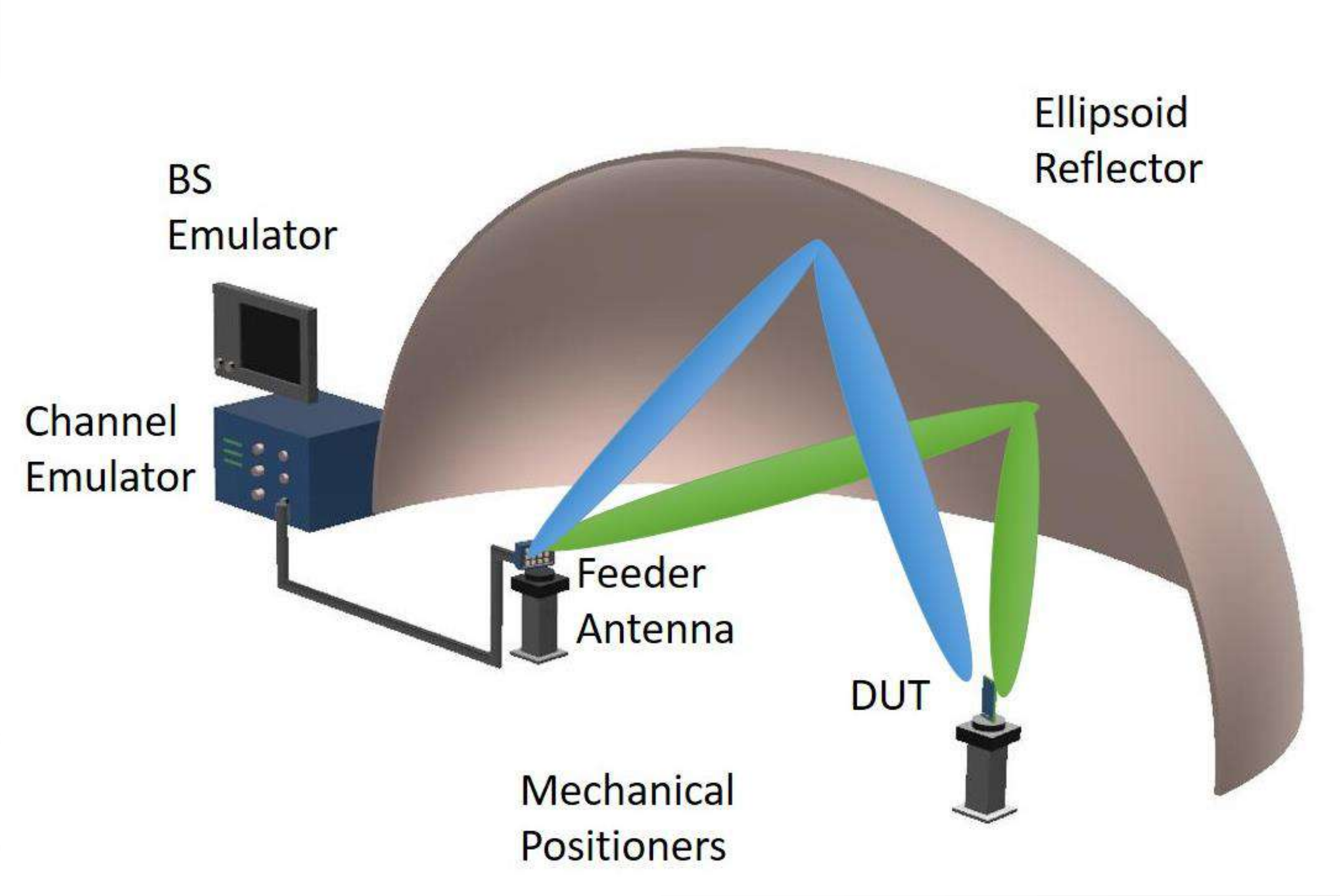
Spatially dynamic testing TD(18)08001



When the steering fails…

Maximum permissible exposure (MPE) @ FR2

Ref. R4-1815953 and R4-1900440

- 3GPP has identified that using the latest design assumptions for a 200 mW mobile phone at mmWave frequencies, putting a finger over the antenna array will exceed MPE limits by around 20 dB
- Solutions involving proximity detectors will b e used to back off the power, or to change the uplink duty cycle to around 2 % so the average power is below the limit
- These solution are not good since they don't include dynamic signalling to the network which may end up in dropped calls with no fallback (e.g. beam switching)

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FCC approval of FR2 UE smartphone

FCC ID:	**A3LSMG977U**
APPLICANT:	**SAMSUNG ELECTRONICS CO., LTD**

DUT Type: Portable Handset
Application Type: Class III Permissive Change
FCC Rule Part(s): CFR §2.1093
Model: SM-G977U
Change Description: Adding 5G NR Band n260

How was this measured?

Band & Mode	Tx Frequency	Power Density mW/cm²
5G NR - n260	37000 - 40000 MHz	0.42
Total Exposure Ratio		**0.99**
VERDICT		**PASS**

Future smart 5G mmWave handset?

FCC approval of 55 dBm (316 W) EIRP CPE

- 3GPP has defined a customer premises equipment (CPE) UE intended for fixed wireless access
- This has maximum EIRP of 55 dBm (316 W) based on a TRP of 25 dBm and a 30 dBi AAS
- FCC recently type approved such a product
  - Samsung SFGAA-110DC 5G Access Unit **https://fccid.io/A3LSFG-AA100DC/Test-Report/Test-Report-1-3758486**
- This product is identified for indoor use where the additional directivity is intended to overcome outdoor to indoor penetration losses
- The safe exposure distance for a 55 dBm EIRP is 1.6 m (10 W/m^2)

It is unclear how such a product can be used indoors with an enforceable exclusion zone of 1.6 m

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Global 5G Protest Day 25 Jan 2020

- https://stop5ginternational.org/5g-protest-day/

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College Green, Bristol, 25/1/2020

Network operator mmWave propagation improvement kit

Bird removal tool

Tree removal tool

E-glass removal tool

Finger removal tool

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5G mmWave user accessory kit

Bamboo
selfie stick

Portable Battery
expansion kit

Eyestrain relief kit

Headsafe kit

Handsafe kit

Wallet expansion kit

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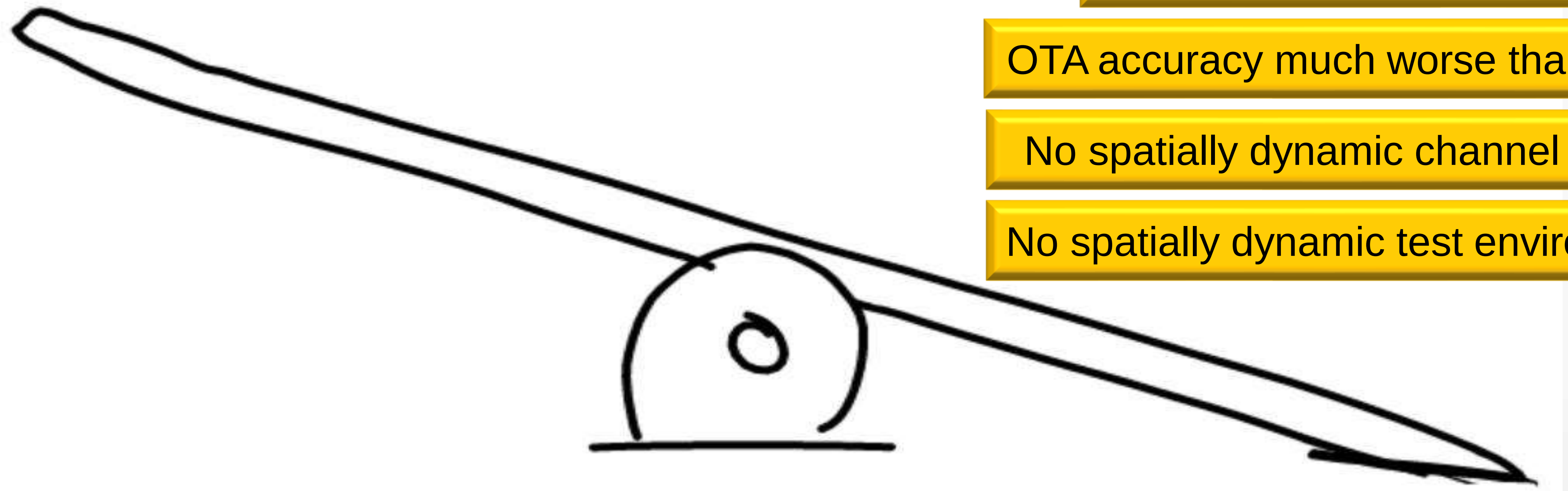
5G Opportunities and challenges

Challenges

- OTA req. / test history is not good
- Active antennas essential and hard
- Spatial tests are slow
- Hand/head/body blocking
- OTA test is large/expensive
- OTA accuracy much worse than cabled
- No spatially dynamic channel models
- No spatially dynamic test environments

Opportunities

- Lots of spectrum
- Very high data rates
- Exploit spatial domain



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Motivation for future OTA research

- Five reasons to be concerned about 5G performance testing and the need for further work:

	4G RF	5G mmWave
What	Cabled test plus 2D spatial channel models with fixed geometry	Yet undefined, much more dynamic and 3D
How	Cabled test plus Lots of choice, MPAC, RTS, Reverb…	No obvious solutions except for line of sight
Importance	Not critical	Critical, no cabled fallback
Difficulty	Hard (OTA part)	Very hard!
Timescales	MIMO OTA took 8 years	Needed urgently!

The need and challenge of 5G spatially dynamic OTA test is not yet widely understood but will become a **showstopper** in the near future so is an urgent research topic

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Wish list - MAGA

3G forgot data
4G forgot voice
5G forgot the antenna

The future is already here, it's just not evenly distributed.
William Gibson

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