

IEEE 5G Summit

University of Strathclyde,
Glasgow, Scotland, UK.

Monday 14th May, 2018.

Gold sponsors:





15/05/2018

Gold Sponsors:



Glasgow, Scotland, UK

www.5GSummit.orgMonday 14th of May 2018Technology and Innovation Centre,
University of Strathclyde, Glasgow, G1 1RD, Scotland UK**Plenary Track 1: 940am to 1245pm - 5G Innovations** (Chair – Bob Stewart, Strathclyde)

915am Registration Opens & Exhibits

940 am **Welcome to University of Strathclyde**
Sir Jim McDonald, Principal & Vice Chancellor, University of Strathclyde**950 am** **Glasgow 5G Summit Overview: Plenary, IoT and Rural Tracks**
IEEE 5G Summit Chair: James Irvine, University of Strathclyde**1000 am** **5G Connectivity – Embracing the New Business Opportunities**
Tony Gribben, Head of Cisco (Scotland) & Dez O'Connor, Bus Dev. Manager**1015 am** **5G New Radio (NR) Standards – What are the Technologies?**
Iain Stirling, Principal Communications Engineer, MathWorks Ltd**1030 am** **New Technologies, New Applications and 5G Future**
Rahim Tafazolli, Director, 5G Innovation Centre (5GIC), Univ of Surrey**1045 am** **Slicing the 5G Business Cases**
Mansoor Hanif, 5GUK Advisory Board Member**1100 am** **UK DCMS: 5G Testbed and Trials**
Andrew Smith, 5G Testbed and Trials Policy Advisor, DCMS (UK Govt)**1115am** **Break and Exhibits / Networking****1140 am** **Enabling 5G in the UK - the Role of Spectrum**
Cristina Data, Director of Spectrum Policy and Analysis, Ofcom.**1155 am** **5G – Maximising use of Licensed, Unlicensed & Shared Spectrum**
Dean Brenner, Senior Vice President, Qualcomm Inc**1210 pm** **Panel Session: What are the Barriers to Deployment?** Moderator - Ian Birleson, WHP**1245 pm** **Lunch, Networking and Exhibits/Displays/Demonstrations**

Event Co-Sponsors



Track 2: 5G IoT, 2pm – 445pm (Chair – Federico Coffele, PNDC)

200pm	Operator Perspectives on 5G Mike Fitch, Chief Wireless Research, British Telecom	
210pm	NB IoT Service Provision for the Utility Sector Andy Haig, Vodafone	
220pm	The Global IoT Service Provision Opportunity Charlie Swan, Nokia	
230pm	5G Equipment Challenges Wenbing Yao, Huawei	
240pm	Spectrum Management and Coverage Raj Sivalingam, Julian Stafford, WHP Telecoms	
250pm	IoT and Connectivity Monitoring Requirements for Health and Wellbeing Andy Todman, Chief Executive, Age UK West Cumbria	
300pm	5G Security and Trust for IoT in Mission Critical Systems Greig Paul, University of Strathclyde	
310pm	How Might 5G and IoT Contribute to Scotland's Connectivity Vision? Richard Parkinson, Neil Watt, Farrpoint Ltd	
330pm	Break and Exhibits / Networking	
400pm	Chaired Discussion Session on 5G IoT and Utility Sector: Moderator - James Irvine, Strathclyde	

Track 3: 5G Rural, 2pm – 445pm (Chair – Stephen Speirs, Cisco Systems)

200pm	5GRuralFirst Project: Shared and Dynamic Spectrum for Rural Connectivity David Crawford, Centre for White Space Communication	
210pm	5G for Agricultural Technologies: Drones, V2X, 4k Video and IoT Dave Ross, Agri-Epi Centre	
220pm	Next Generation Media Broadcast for Radio & TV Rural Broadcast David Hemingway, Senior Policy Advisor, BBC R&D	
230pm	Remote Rural – Don't leave us to last again!! Donnie Morrison, MBE, Highlands and Islands Enterprise	
240pm	The Real-5G vision for Rural & Remote areas Zahid Ghadialy, Parallel Wireless Ltd	
250pm	Self-organised networks for coverage in Events, Disaster Areas & Rural Areas Muhammad Imran, University of Glasgow	
300pm	LiFi for 5G and Beyond Harald Haas, pureLiFi Ltd	
310pm	5G Rural Integrated Testbed Michael Armitage, Broadway Partners Ltd	
330pm	Break and Exhibits / Networking	
400pm	Chaired Discussion Session on 5G Rural Opportunities: Moderator - Ivan Andonovic, Strathclyde	
445pm	5G Summit Key Takeaways and Close: Moderator and Chair: Bob Stewart, Strathclyde	

Social Networking

5pm – 6pm	Reception in TIC
700pm	Optional Networking Dinner in Glasgow (Tickets can be ordered on-line)

IEEE 5G Summit

Professor Sir Jim McDonald

Principal and Vice Chancellor Uni. Strathclyde



The background is a dark blue network diagram with white lines connecting various nodes. Each node is represented by a different icon, including a laptop, desktop monitor, VR headset, drone with a medical bag, antenna tower, tractor, wind turbine, cow with a collar, wheat stalks, fish, houses, cars, bus, family group, and city skyline. The text is centered in white.

IEEE 5G Summit

Professor Bob Stewart

Technical Programme Chair



IEEE 5G Summit

Dr James Irvine

General Chair



Glasgow IEEE 5G Summit Overview

James Irvine

General Chair, University of Strathclyde



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**POWER NETWORKS
DEMONSTRATION CENTRE**



IEEE 5G



IEEE 5G Summits:

The Promise of 5G



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IEEE 5G



**First in UK
First in Scotland**



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Rural First



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Okay then,
not Rural Last



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IEEE 5G



IEEE 5G Summits: Industry Focused Open & Discursive

Morning on Foundations

Technology, Economics, Trails

Afternoon on Applications

Rural / Industry & Utilities

Panels after each session

Hold questions until then

Morning on Foundations

Technology, Economics, Trails

Afternoon on Applications

Rural / Industry & Utilities

Panels after each session

Hold questions until then



The Promise of 5G

High Bandwidth
Resilience
Device to Device



Something to think about

High Bandwidth
Resilience
Device to Device



Something to think about

Speed sells, but

Speed has a limited impact on satisfaction. ... For video, we saw that once speeds reach 1.5 Mbps, further increases have little or no impact on users' perception of performance.

Boston Consulting Group, Nov 2015



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IEEE 5G



University of
Strathclyde
Engineering





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IEEE 5G



IEEE 5G Initiative



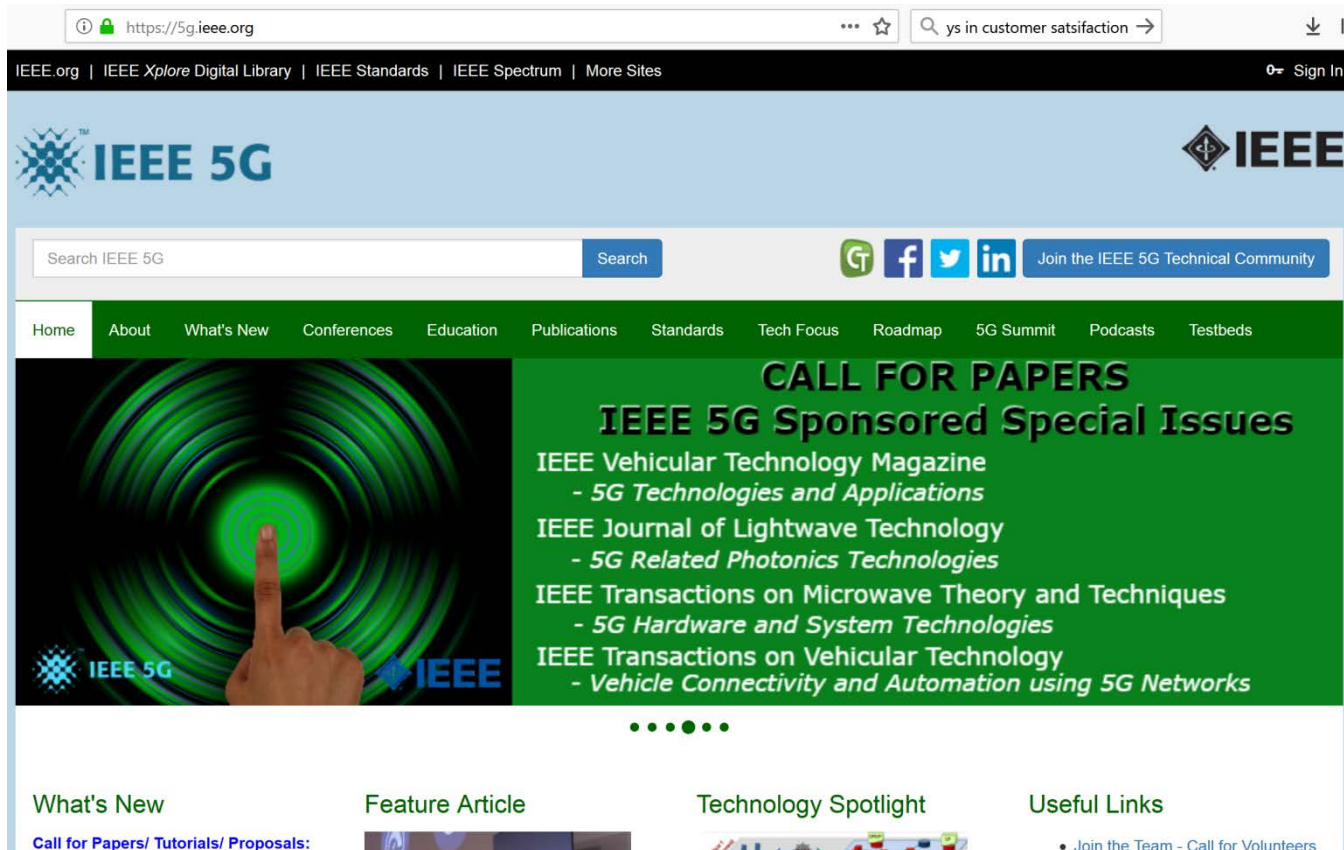
IEEE 5G

Technology, standards, education,
publication and conferences

Roadmapping technologies for massive
communication beyond 5G



5g.ieee.org



The screenshot shows the homepage of the IEEE 5G website. The browser address bar displays 'https://5g.ieee.org'. The page header includes navigation links: 'IEEE.org | IEEE Xplore Digital Library | IEEE Standards | IEEE Spectrum | More Sites' and a 'Sign In' button. The main header features the 'IEEE 5G' logo on the left and the 'IEEE' logo on the right. Below the header is a search bar with the placeholder text 'Search IEEE 5G' and a 'Search' button. To the right of the search bar are social media icons for GitHub, Facebook, Twitter, and LinkedIn, followed by a button that says 'Join the IEEE 5G Technical Community'. A red arrow points to this button. Below the search bar is a green navigation bar with links: 'Home', 'About', 'What's New', 'Conferences', 'Education', 'Publications', 'Standards', 'Tech Focus', 'Roadmap', '5G Summit', 'Podcasts', and 'Testbeds'. The main content area has a green background. On the left is a large image of a hand pointing at a glowing green circular pattern. To the right of this image is a 'CALL FOR PAPERS' section titled 'IEEE 5G Sponsored Special Issues'. This section lists four IEEE publications with their respective 5G-related topics: 'IEEE Vehicular Technology Magazine - 5G Technologies and Applications', 'IEEE Journal of Lightwave Technology - 5G Related Photonics Technologies', 'IEEE Transactions on Microwave Theory and Techniques - 5G Hardware and System Technologies', and 'IEEE Transactions on Vehicular Technology - Vehicle Connectivity and Automation using 5G Networks'. Below this list are five dots. At the bottom of the page, there are four sections: 'What's New' with a link to 'Call for Papers/ Tutorials/ Proposals:', 'Feature Article', 'Technology Spotlight', and 'Useful Links' with a link to 'Join the Team - Call for Volunteers'.



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IEEE 5G



Thanks!



Kenny Barlee

Local Arrangements
University of Strathclyde



Louise Crockett

Registration Coordinator
University of Strathclyde



Mischa Dohler

IEEE 5G Initiative
King's College London



Ashutosh Dutta

IEEE 5G Initiative
IEEE ComSoc



Oliver Holland

IEEE UK VTS Chapter Chair
King's College London



Steve Hunt

Civic Engagement



Muhammad Imran

Academic Liaison
University of Glasgow



Ivan Marjanovic

5G Rural Track
Scottish Futures Trust



Andrew Muir

Publicity
FarrPoint Ltd



Raj Sivalingam

5G Utilities Track
WHP Telecomms



Rahim Tafazolli

Director of 5GIC



Greig Paul

Exhibits Coordinator
University of Strathclyde

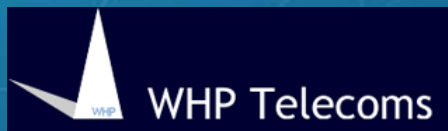
The background is a dark blue network diagram with white nodes and connecting lines. Various white icons representing different industries and IoT applications are scattered around the network. These include a laptop, a desktop monitor, a VR headset, a drone carrying a medical bag, a radio tower, a tractor, a wind turbine, a cow with a collar, wheat stalks, two fish, a city skyline with a factory, a family walking, a bus, a car, and a house with a Wi-Fi symbol.

IEEE 5G Summit

Dr Oliver Holland

IEEE Comsoc

Parallel
Wireless



IEEE Vehicular Technology Society Welcome to the IEEE 5G Summit Glasgow

Oliver Holland
King's College London
IEEE VTS UK and Ireland Chapter Chair and
IEEE VTS Chapters Committee Chair

www.vts-ukri.org



The IEEE VTS

- The IEEE: World's largest professional organization for the advancement of technology (paraphrased from website)
- Encompasses a number of technical “societies”, overseeing particular topics within the IEEE
- VTS – “Vehicular Technology Society”, covers aspects such as electronic vehicles, vehicular communications, and (the biggest part of it by far, perhaps from the early days of car phones and the link with “mobility” in mobile communications) mobile and wireless communications
- Along with Computer Society and Communications Society, one of the biggest societies in the IEEE

5G and This Summit

- 5G is ground-breaking in terms of capabilities: Reliability, latency, availability, number of connections, of course massive increases in capacity among other aspects
- The VTS recognises the importance of 5G; is proudly a leading society sponsoring the IEEE 5G initiative
- The local VTS UK and Ireland Chapter is therefore strongly supporting the IEEE 5G Summit Glasgow; delighted to have this key colloquium of the IEEE 5G Initiative taking place in one of the countries of the UK/Ireland
- Deeply impressive event, bringing key stakeholders and imparting invaluable experience in 5G tech and potentials

Welcome!

- ...enjoy the event!



(...and other IEEE VTS events – next slide)

IEEE VTS Vehicular Technology Conferences (VTCs)

- Two VTC's per year, in the Spring and Fall (Autumn)
- IEEE VTC2018-Spring, Porto, Portugal, 3-6 June 2018
 - Technical program: 12 tracks, 12 workshops, several tutorials, ~428 peer-reviewed papers and a series of world-class invited speakers; IEEE 5G Initiative workshop focussing on 5G testbeds
 - Porto: UNESCO World Heritage City; breathtaking sights
 - Registration still possible: www.vtc2018spring.org
- IEEE VTC2018-Fall, Chicago, IL, USA, 27-30 August 2018
 - Keynotes from: Developer first mobile phone Martin Cooper (also “Cooper’s Law”), Chief of US FCC Office of Engineering and Technology Julius Knapp, CIO/Commissioner of Chicago's Dept. of Innovation and Technology Danielle Dumerer
 - Rich technical program, demos, etc., under development
 - Paper (recent results) submission still possible: www.vtc2018fall.org

IEEE VTS Vehicular Technology Conferences (VTCs)



Porto

Martin Cooper,
Julius Knapp



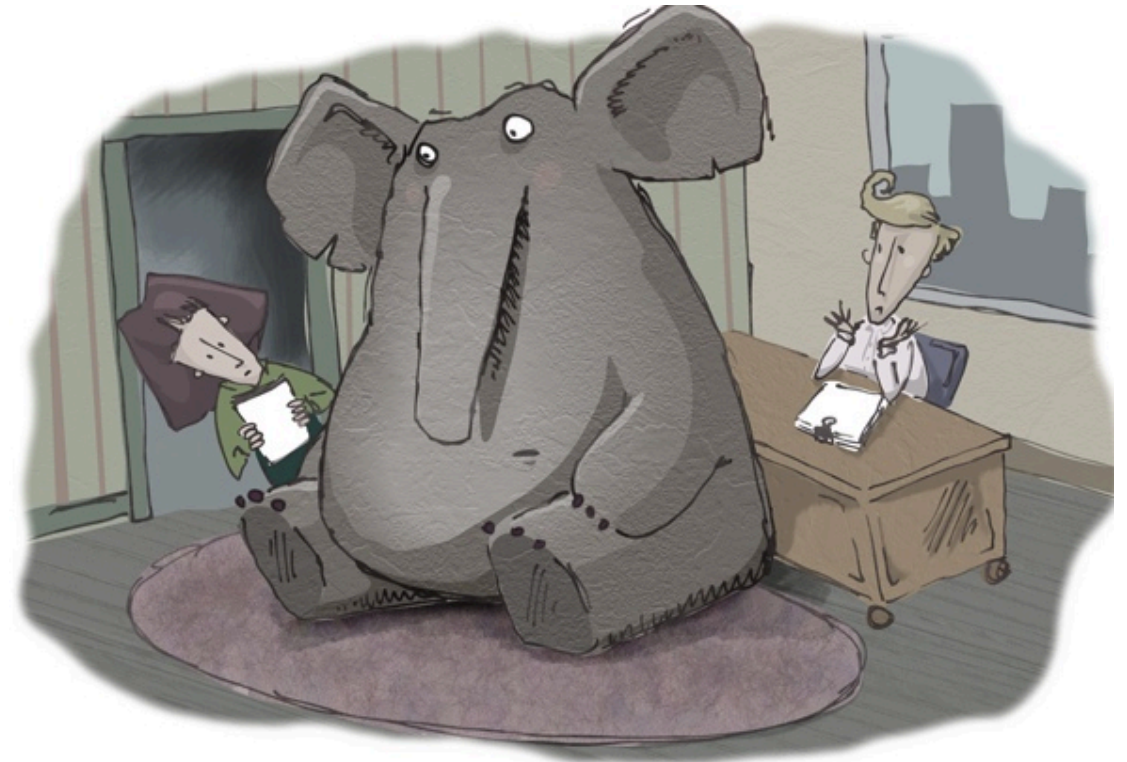
Plenary Track: 5G Innovations



5G Challenges

- **Cost.** mmW, densification
- **Payoff.** Consumer wallet, B2B(2C)
- **UK Coverage.** 5G like every other G does not fix coverage

..



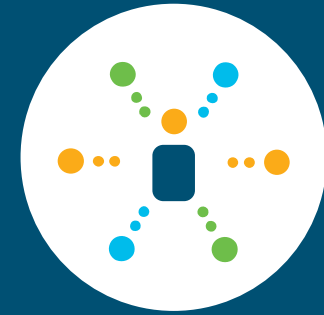
5G | Navigate The Opportunity



Value



Efficiency



Business Models

“[5G is] more than just putting radios on roofs.

-Timotheus Höttges, CEO, DT

”

Cisco 5G Redefining Your Network



Converged
Core



Network
Slicing



Service
Automation



Edge
Distribution



Virtual
Scaling










Security



Services

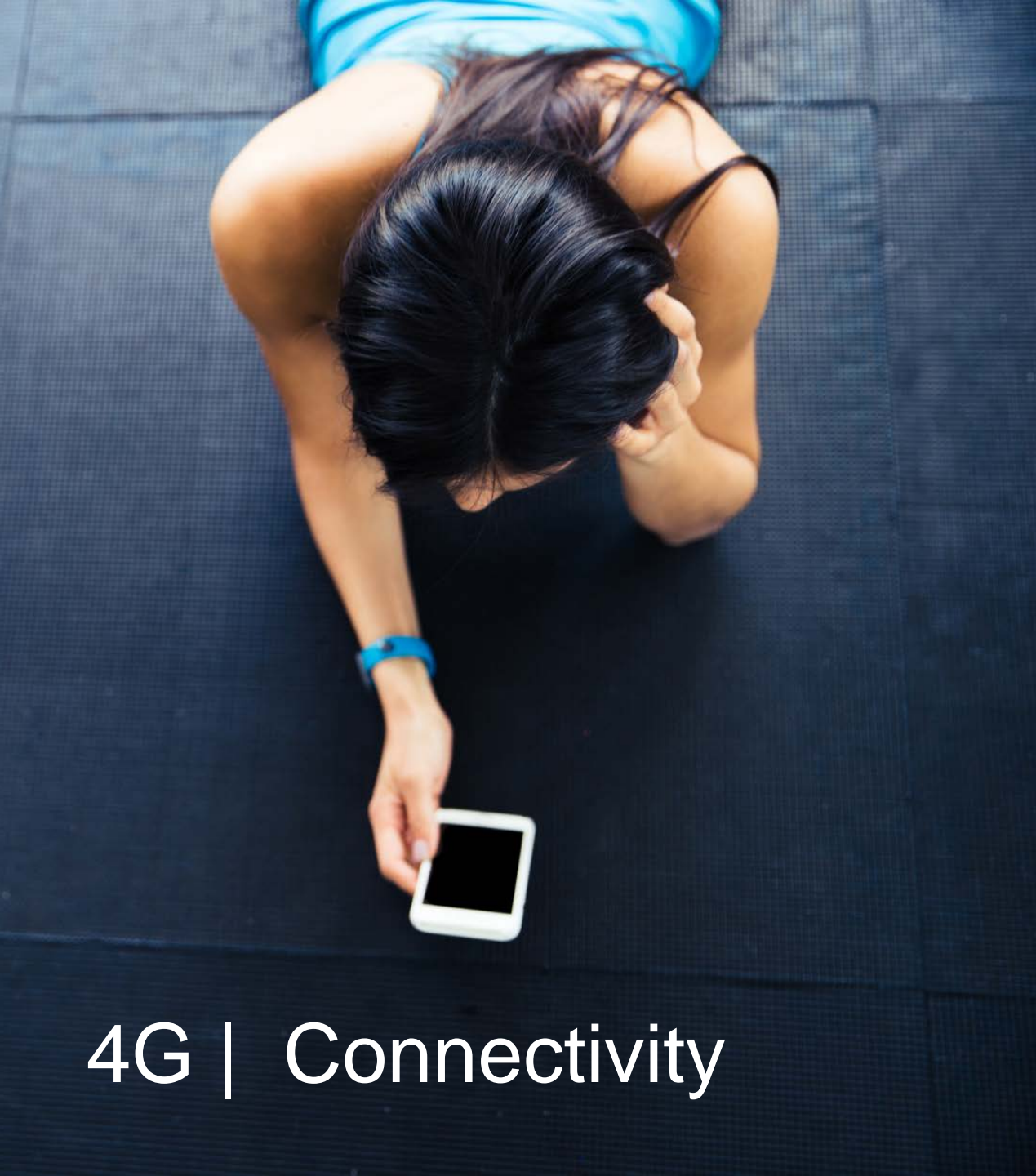
Key transitions and Cisco initiatives driving innovation in 5G Era



						
HW/SW Disaggregation <ul style="list-style-type: none">• Software-only offers available• Hardware can be COTS BIG or small, 5G can fit anywhere	Edge Computing <ul style="list-style-type: none">• Multi-access edge computing (MEC)• Cisco cloudlets, SDN, Network Fabric and Edge DC Network edges blur	Evolved Packet Core (SLICES) <ul style="list-style-type: none">• CUPS de-composed mobile core• VPP-based Cloud Native• Multi GB capable at Edge• 5G<>Ent API's SLICES for ALL	Open Roaming <ul style="list-style-type: none">• Federation of "WiFi" access networks and identity providers• Zero touch global wifi onboarding. SOMEBODY has a reason..	Open vRAN <ul style="list-style-type: none">• Creating an ecosystem of emerging RAN vendors to lead industry transformation• Any Access Take out cost, drive innovation	Automation <ul style="list-style-type: none">• Open APIs and controllers• Dedicated automation team for• CNAAP Integrations• Network Slicing SIMPLE for anyone to use	IP Transport <ul style="list-style-type: none">• High bandwidth and high density FH/BH/MH product portfolio• Bandwidth aware programmable transport• Segment Routing IP An ecosystem enabler

...Innovate for another wave of Disruptions..

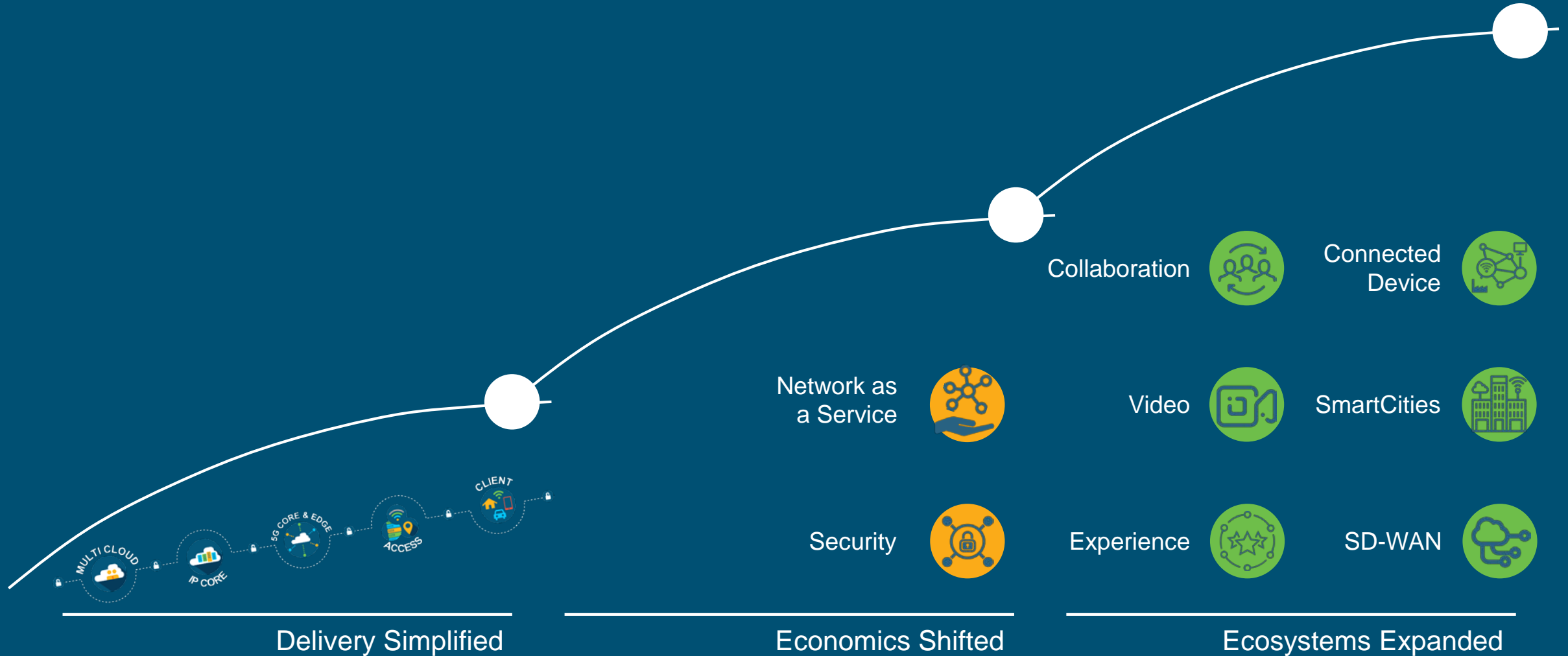
4G | Connectivity



5G | Experiences



Cisco 5G Power^X | Cloud-Scale Platform

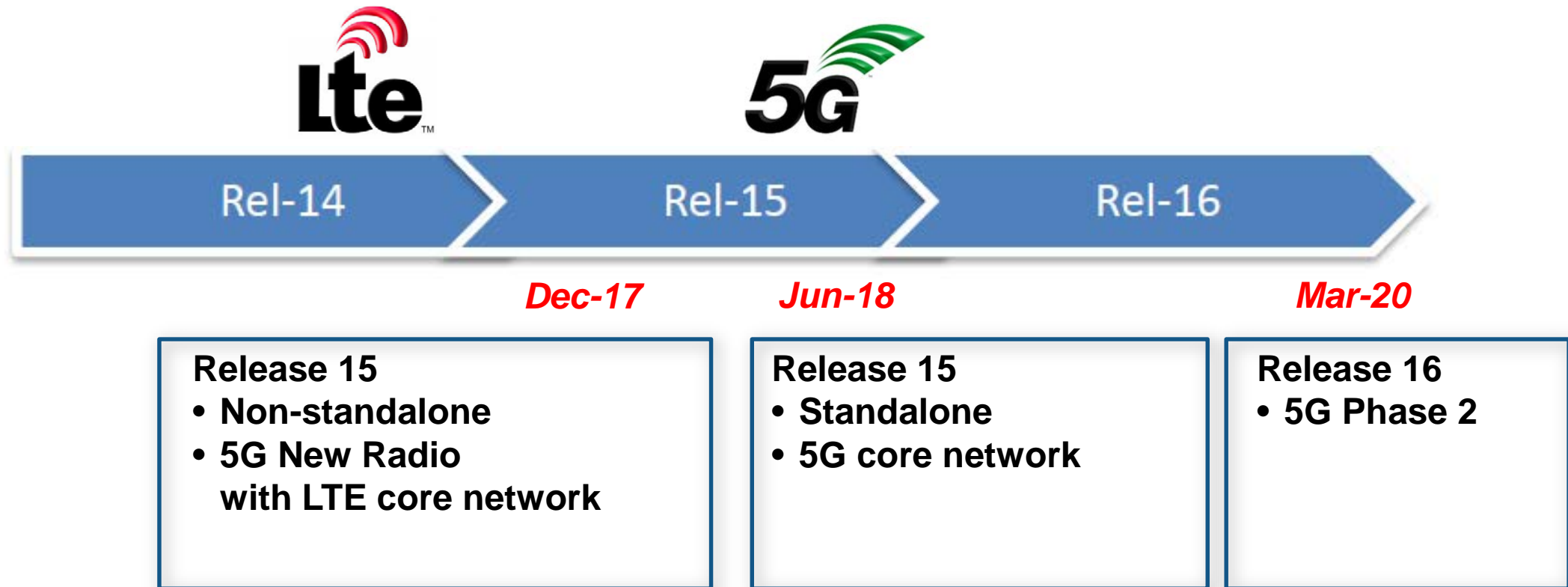


5G New Radio (NR) standards

What are the technologies?

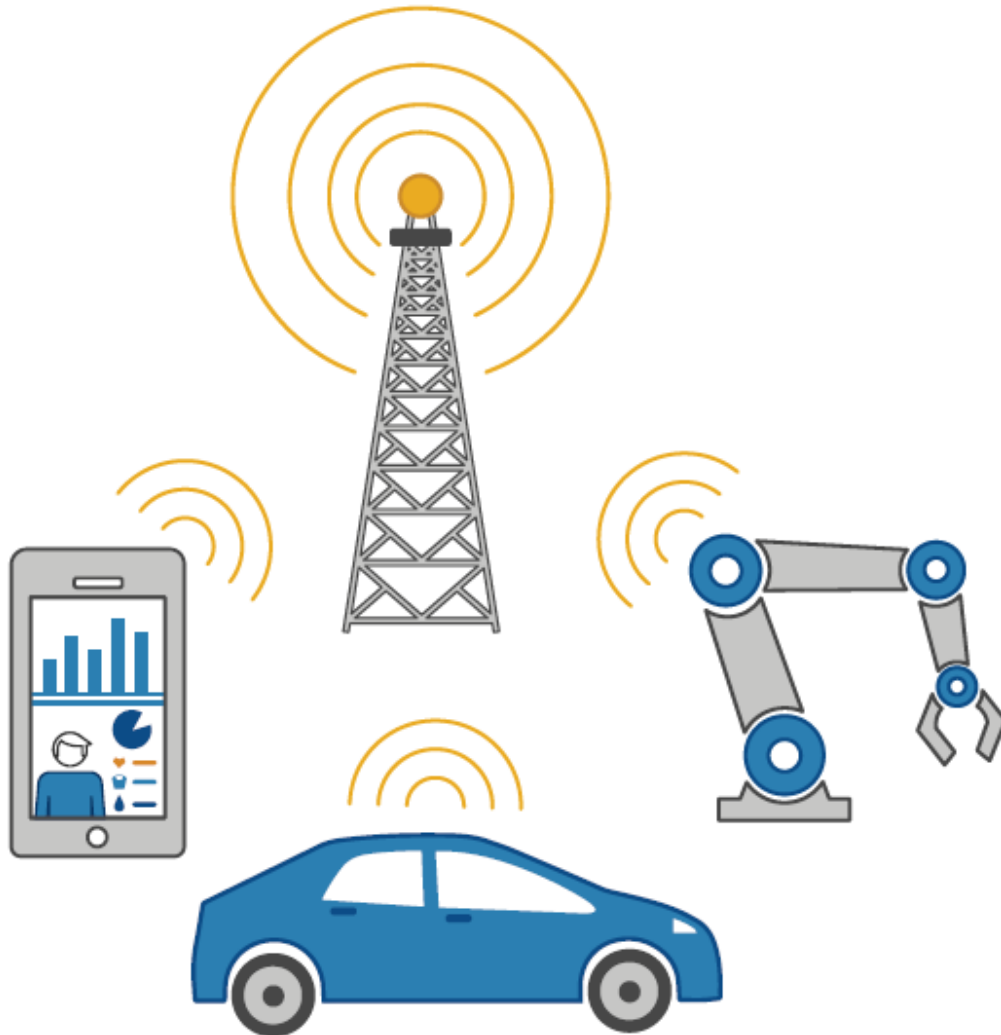
Iain Stirling
MathWorks

3GPP Standardization Timeline



- Development of LTE continues
- 3GPP 5G for IMT-2020 includes LTE and NR

5G Applications and Requirements



New Applications

4K, 8K, 360° Video
Virtual Reality
Connected Vehicles
Internet of Things



5G Requirements / Use Cases

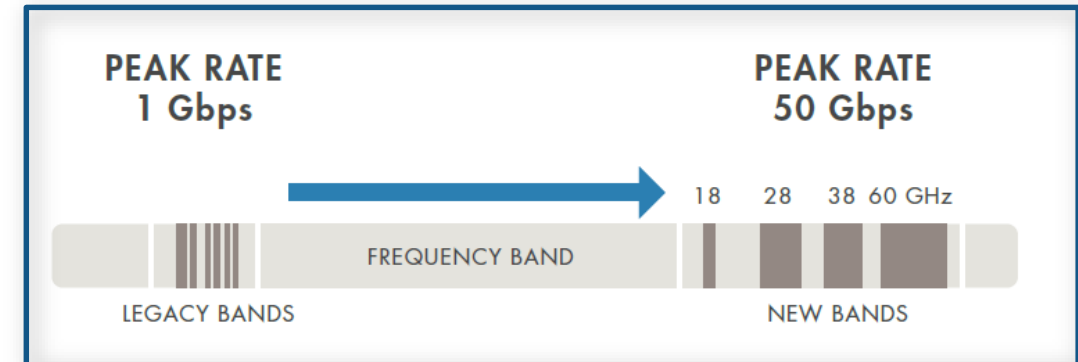
Enhanced mobile broadband (>10 Gbps)
Ultra low latency (<1 ms)
Massive machine-type communication (>1e5 devices)

Achieving Higher 5G Broadband Data Rates

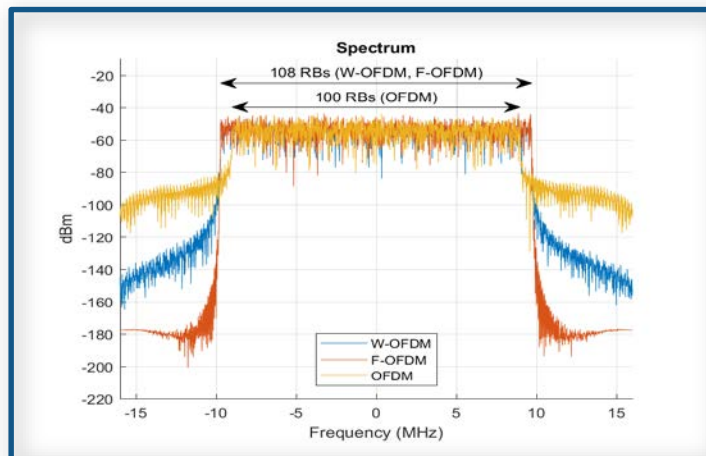
Technical Solutions

Increased bandwidth
Better spectral efficiency
Flexible air interface
Densification

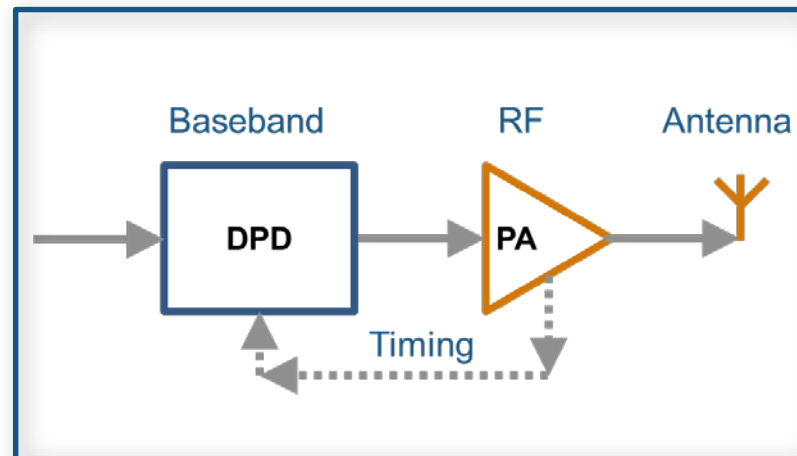
Higher Frequency Bands



New Physical Layer



New RF Architectures



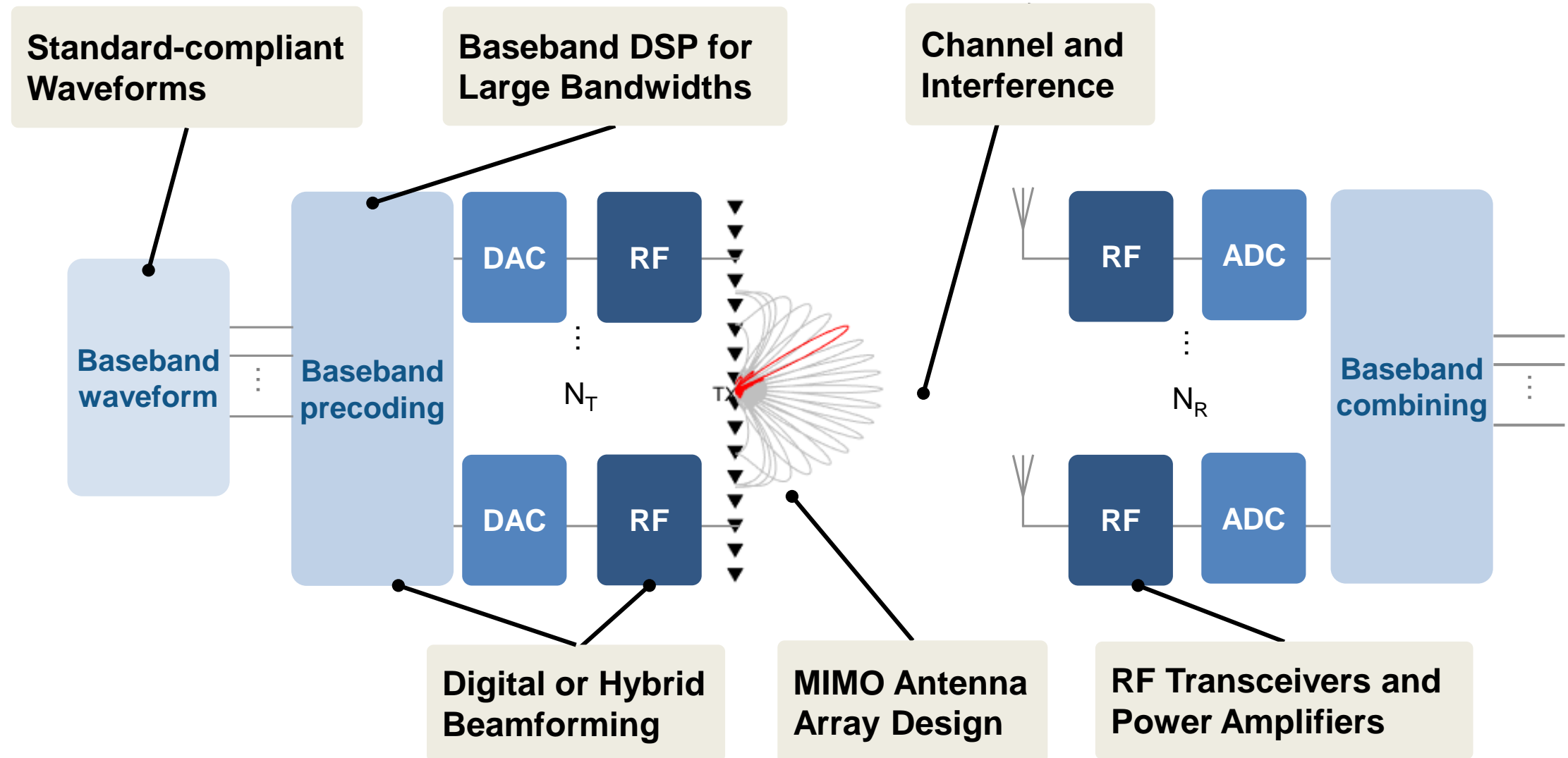
Massive MIMO



Massive MIMO antenna array for a Huawei 5G field trial.

Multi-Domain Engineering for 5G

Subsystems must be designed and tested together

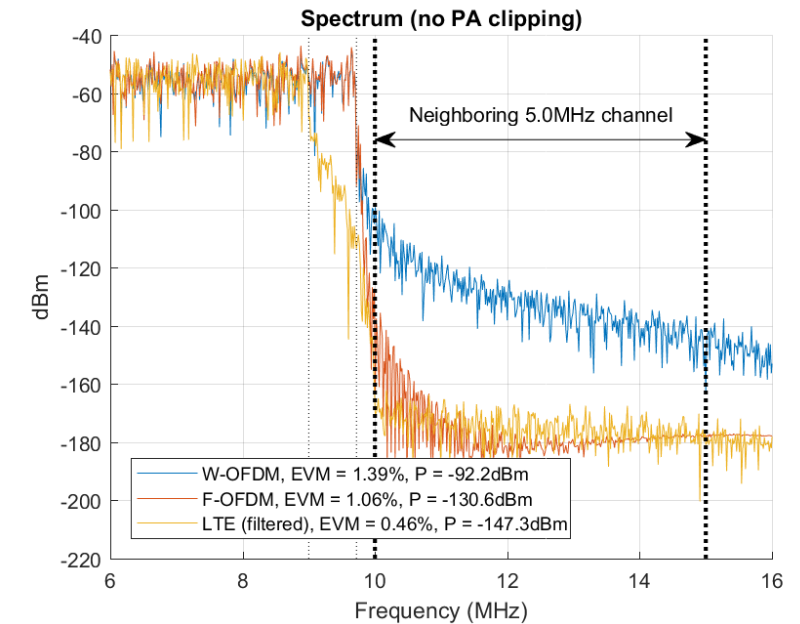
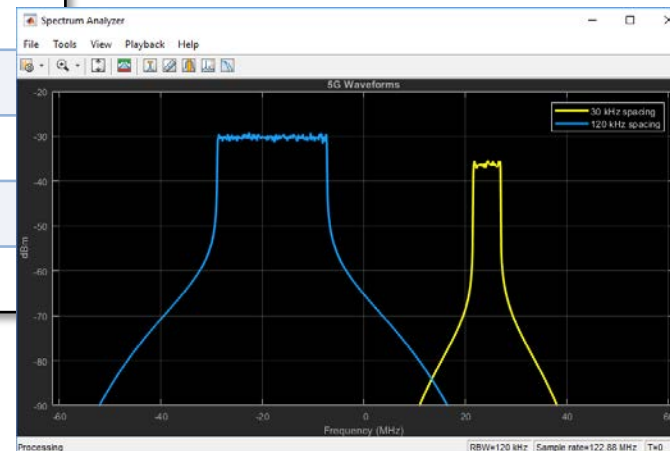


Baseband DSP for Large Bandwidths

- 5G waveform same as LTE: Cyclic-Prefix OFDM (CP-OFDM)
- New baseband techniques for higher capacity

μ	Subcarrier Spacing $\Delta f = 2^\mu * 15\text{kHz}$	Bandwidth (MHz)
0	15	49.50
1	30	99
2	60	198
3	120	396
4	240	397.44
5	480	397.44

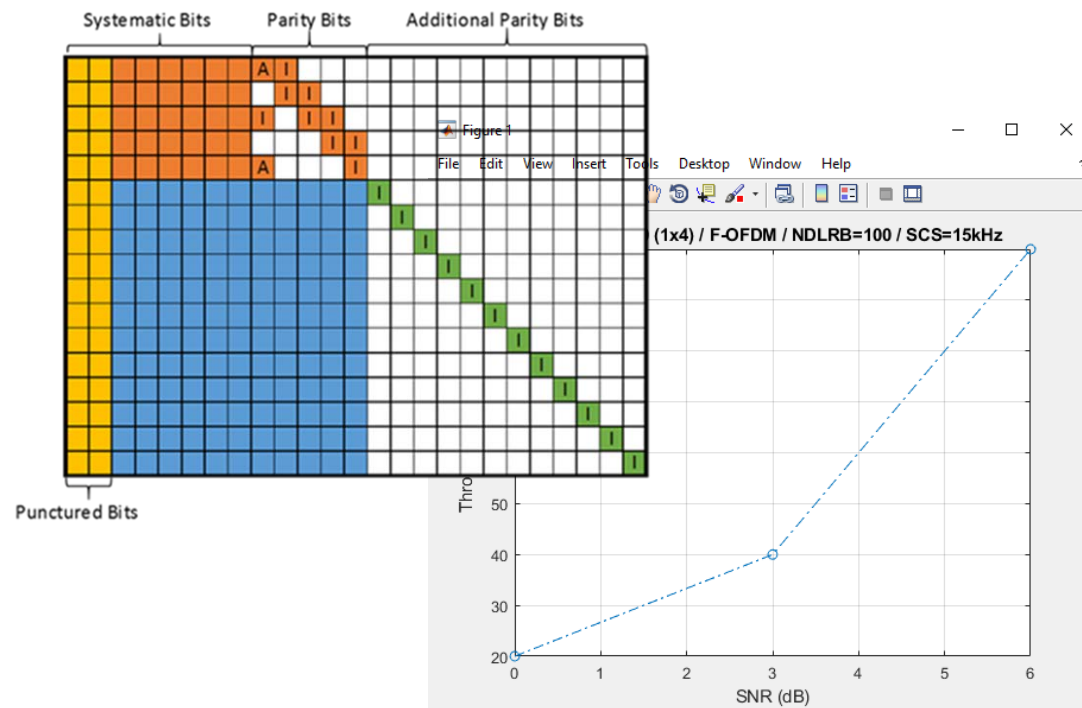
Increase bandwidth and reduce latency with flexible subcarrier spacing



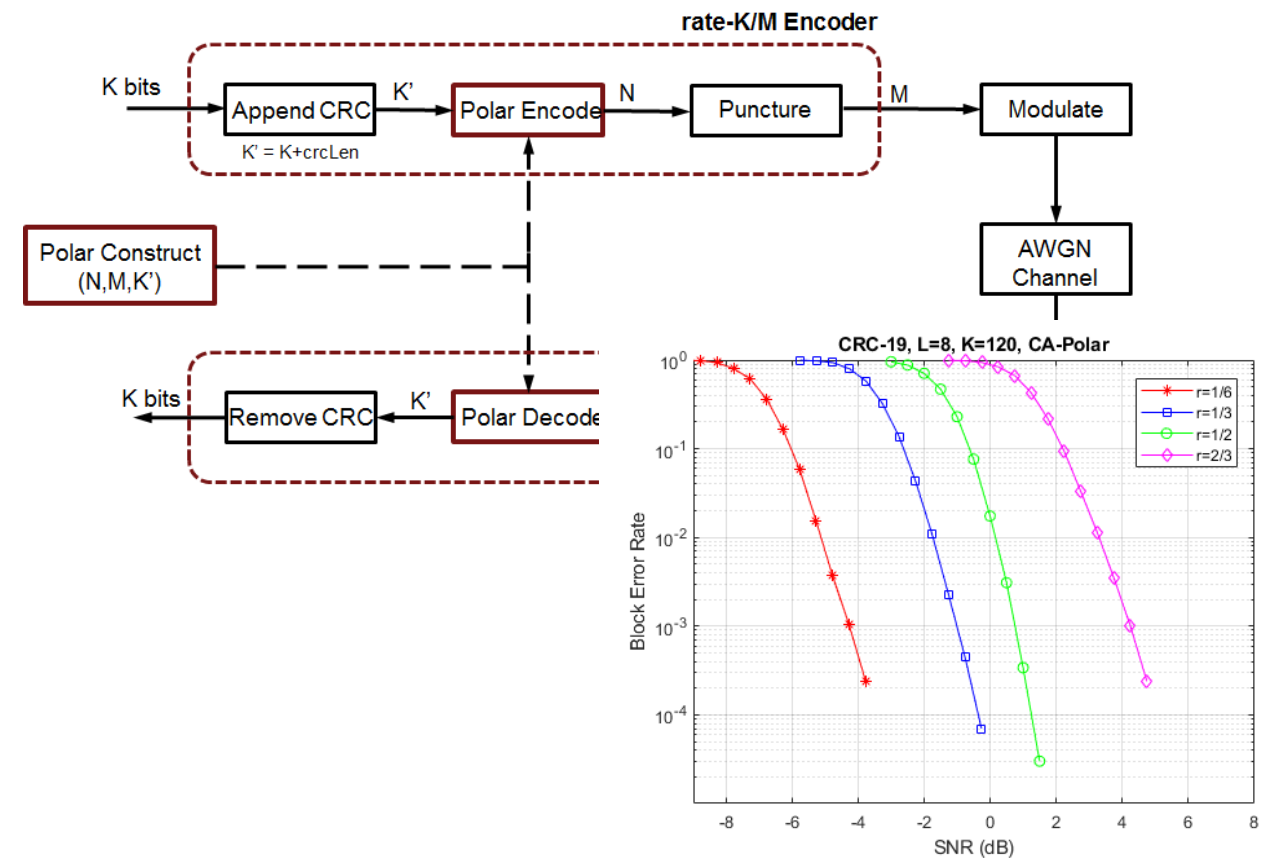
Reduce spectral leakage with filtering or windowing

Efficient Channel Coding Methods

- Low-Density Parity Check (LDPC) for data channel: memoryless block coding



- Polar Codes for control channel: achieve channel capacity

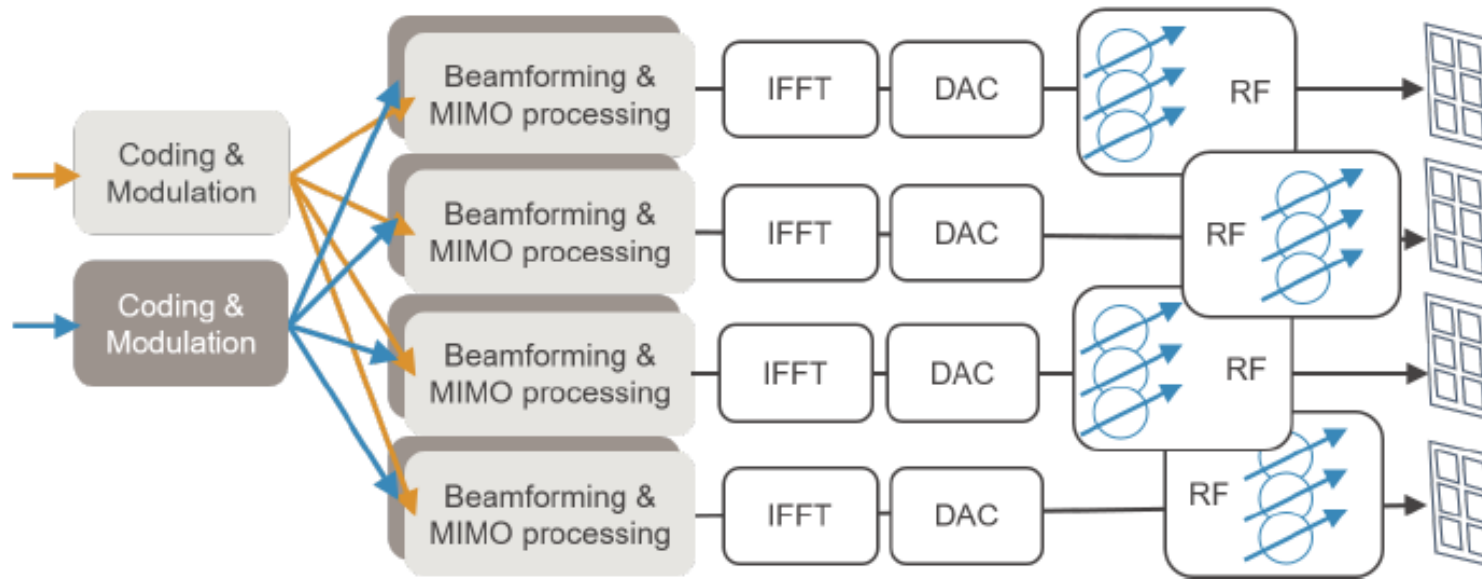
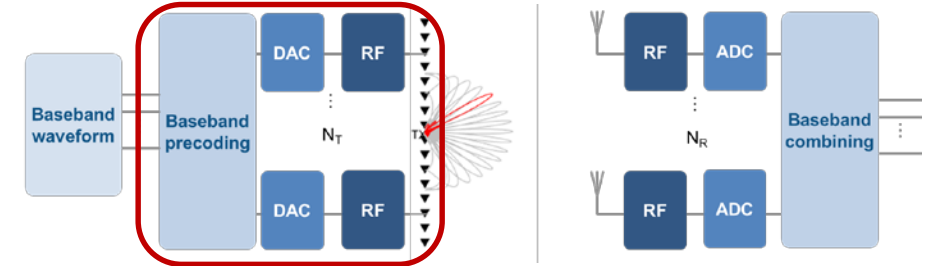


Hybrid Beamforming for Massive MIMO

- Beamforming partitioned between digital and RF
 - Each Tx and Rx element has phase control
 - Subarrays handle amplitude and additional phase
 - Number of transmit antennas can be $\gg N_S$
- Model and optimize beamforming architecture
- Model imperfections in the signal chain

Why Hybrid Beamforming?

- Massive MIMO reduces mmWave propagation loss
- Hybrid beamforming reduces implementation cost



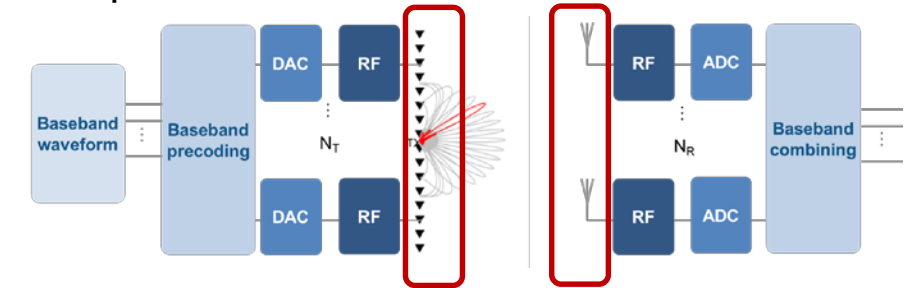
Different realizations have different complexity tradeoffs

Massive MIMO Antenna Arrays

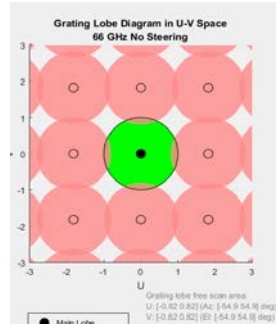
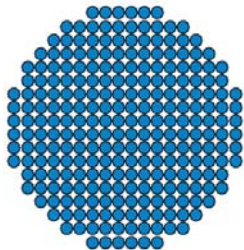
- Model antenna and array beam patterns
- Model antenna element failures
- Optimize tradeoffs between antenna gain and channel capacity
- Simulate with 3D channel model

Antenna array design considerations

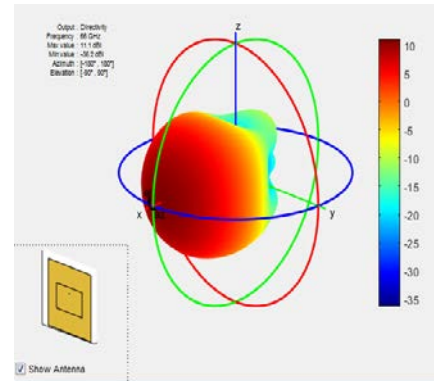
- Element coupling
- Imperfections



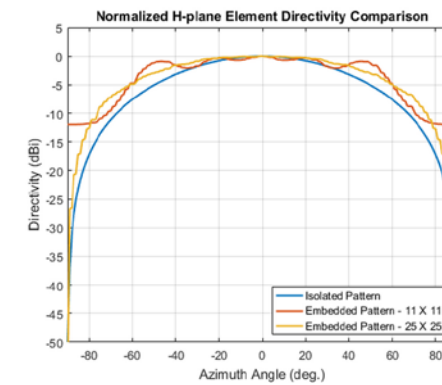
Design an array



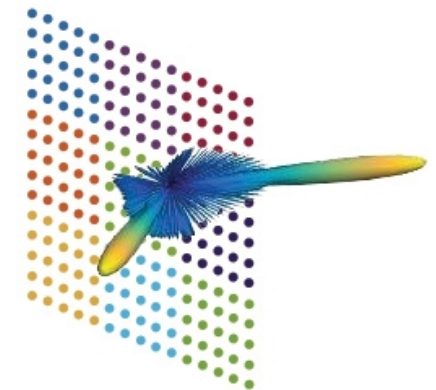
Import antenna patterns



Model mutual coupling

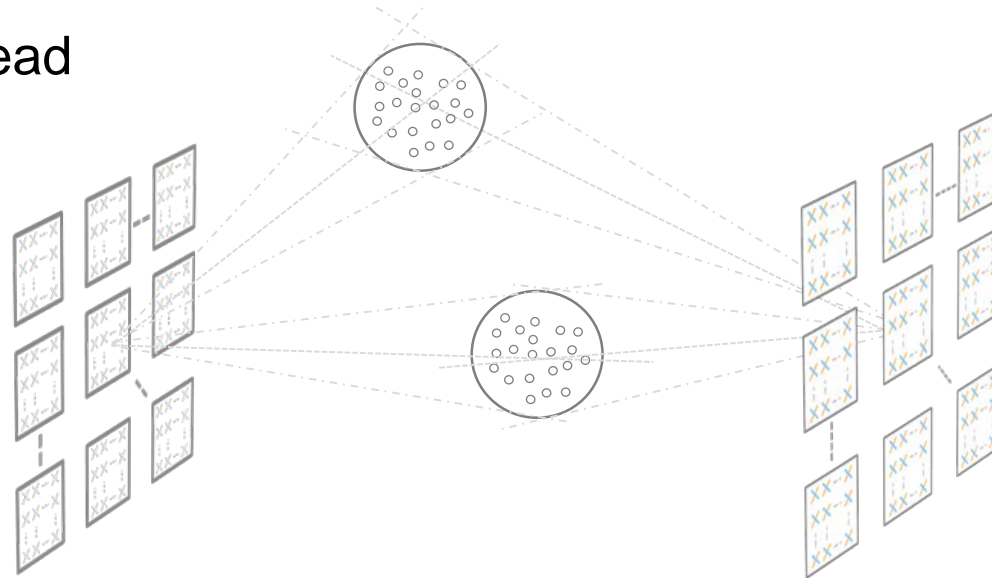


Array beam pattern

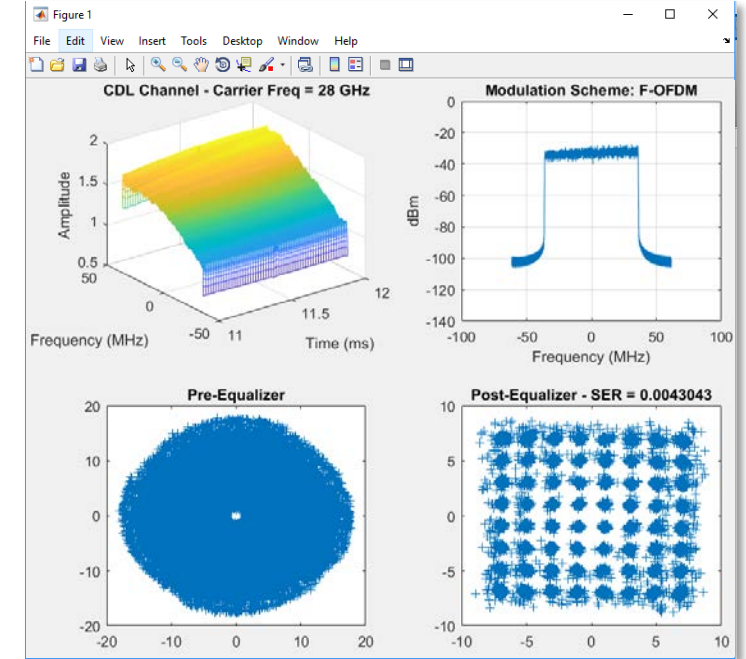


5G Channel Model

- 3GPP TR 38.901: 500 MHz - 100 GHz (mmWave)
- For massive MIMO arrays (up to 1024 elements)
- Delay profiles:
 - Cluster delay line (CDL): Full 3D model
 - Tapped delay line (TDL): Simplified for faster simulation
- Control key parameters
 - Channel delay spread
 - Doppler shift
 - MIMO correlation



Cluster Delay Line: 3D model

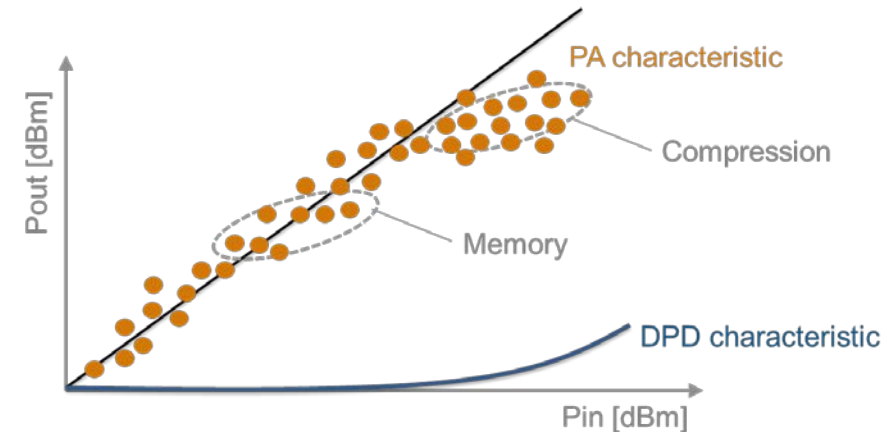
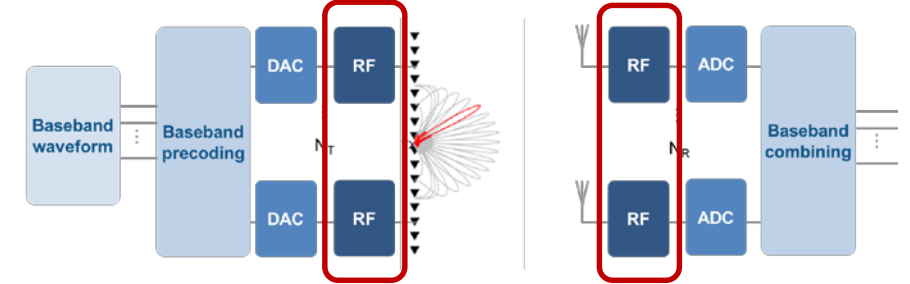


RF Power Amplifier (PA) Linearization

- 5G frequencies and bandwidth put greater requirements on RF transmitter efficiency
- 5G PAs are difficult to model
 - Non-linearity
 - Memory effects
- Solution: Linearization using adaptive digital pre-distortion (DPD)

RF challenges in 5G

- Frequency dependent behavior
- Highly integrated RF + digital devices



MATLAB & Simulink Wireless Design Environment

for baseband, RF, and antenna modeling and simulation

Algorithms, Waveforms, Measurements

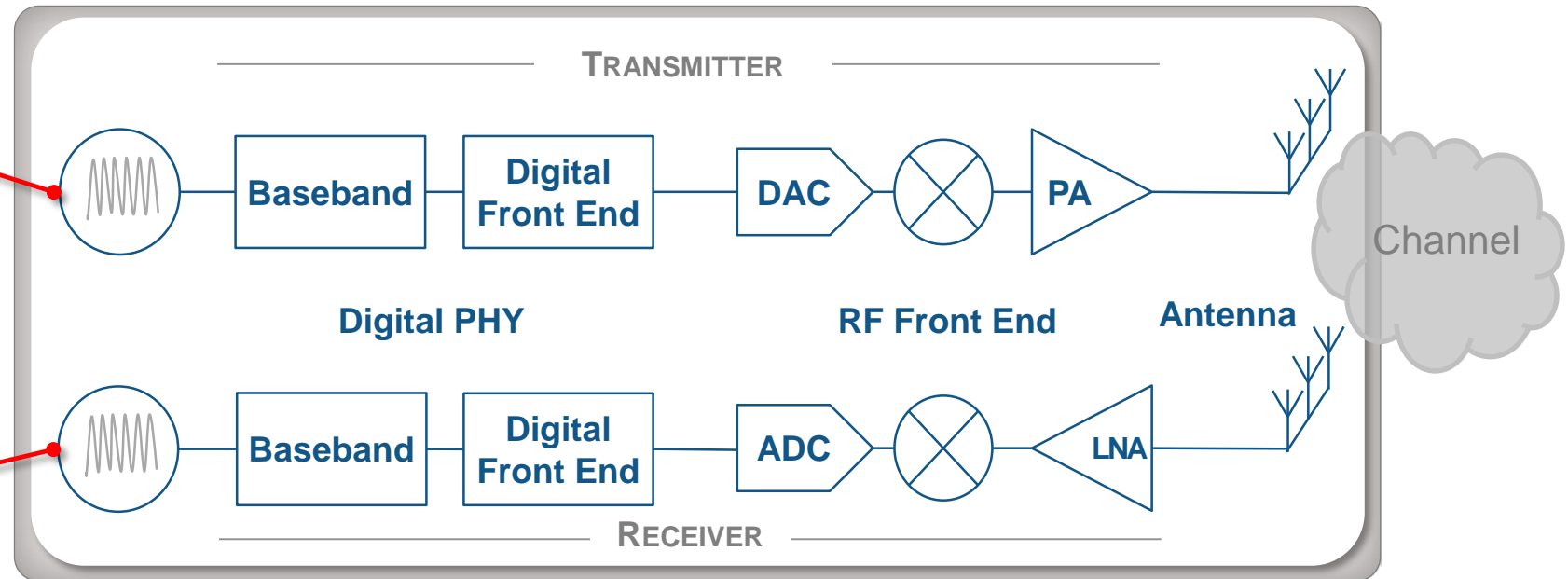
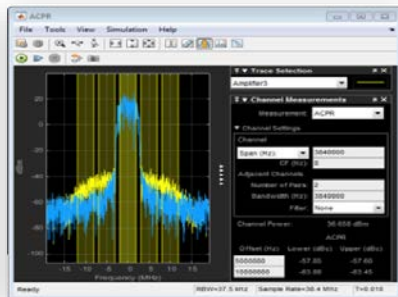
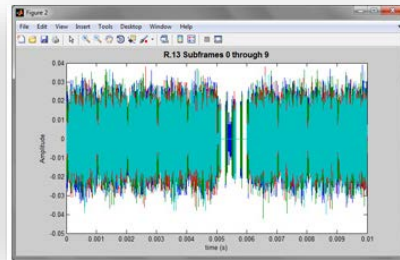
- Communications System Toolbox
- LTE System Toolbox (5G Library)
- WLAN System Toolbox

RF Front End

- RF Toolbox
- RF Blockset

Antennas, Beamforming

- Antenna Toolbox
- Phased Array System Toolbox



- Simulink
- DSP System Toolbox
- Control System Toolbox

Mixed-signal

- Communications System Toolbox
- Antenna Toolbox
- LTE System Toolbox
- WLAN System Toolbox

Channel and Propagation

5G, SPECIAL GENERATION

NEW TECHNOLOGIES, NEW APPLICATIONS AND 5G FUTURE

IEEE 5G SUMMIT, GLASGOW, SCOTLAND, UK
14TH MAY

Professor Rahim Tafazolli
Director Institute for Communication Systems (ICS), 5GIC

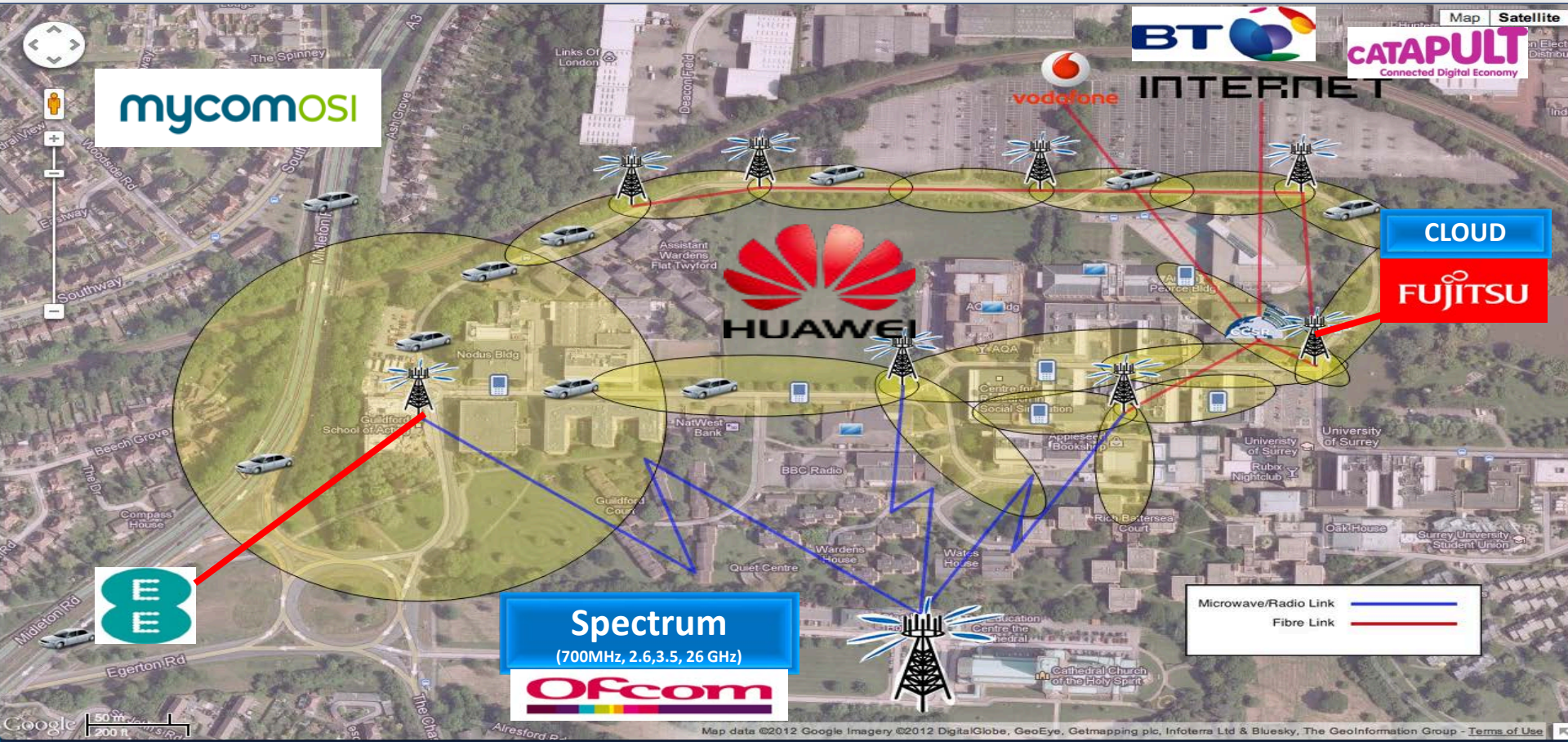
5G INNOVATION CENTRE

LARGEST OPEN INNOVATION CENTRE ON 5G

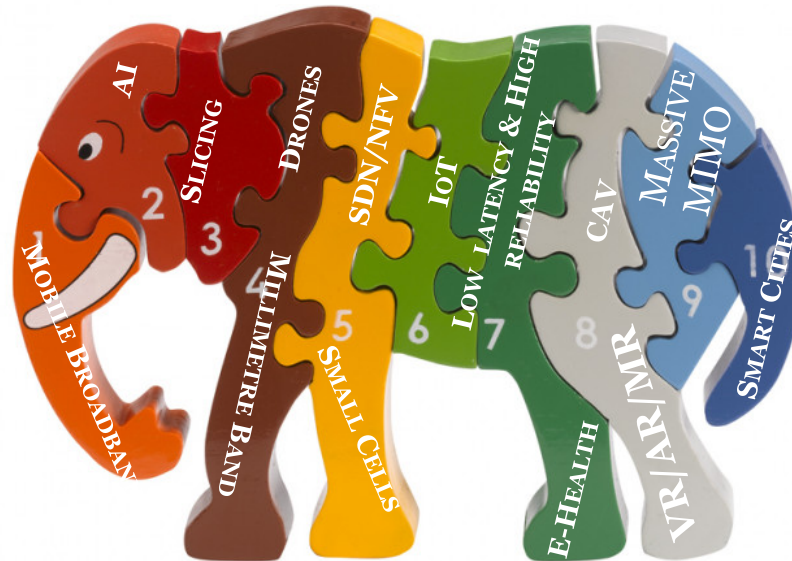
University of Surrey, 5GIC



ART OF POSSIBILITIES?



WHAT IS 5G?



COMMUNICATIONS & AUTOMATION

Connectivity + Intelligence (AI and Machine Learning)

Automation

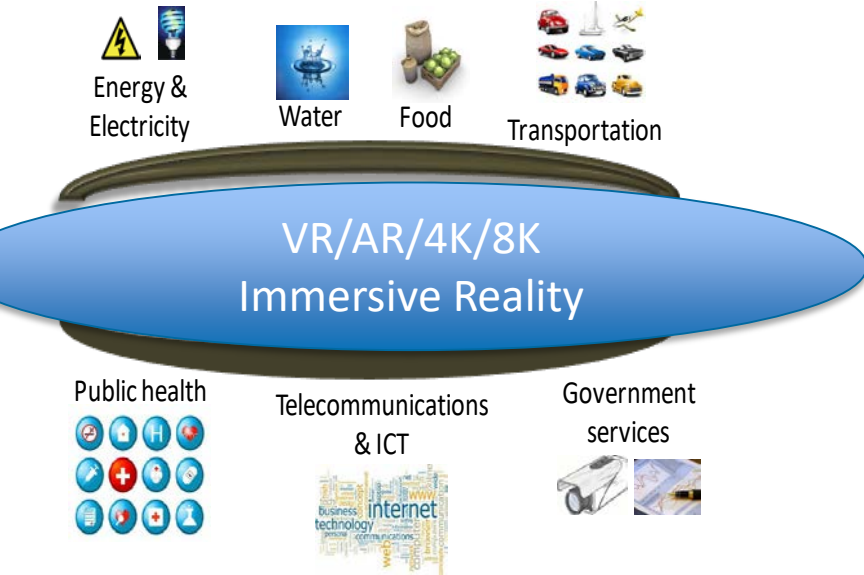
Data to information transformation

Blurring boundaries between real and cyber worlds



Connected Devices of small and large sizes and capabilities
(robots, cars, sensors, actuators, smart phones driverless cars)

ONE NETWORK INFRASTRUCTURE SERVING ALL INDUSTRY SECTORS



- Programmable
- Resilient
- Low delay, high reliability
- 1000x more capacity than 4G
- One Million connections per km²

5G DEPLOYMENT

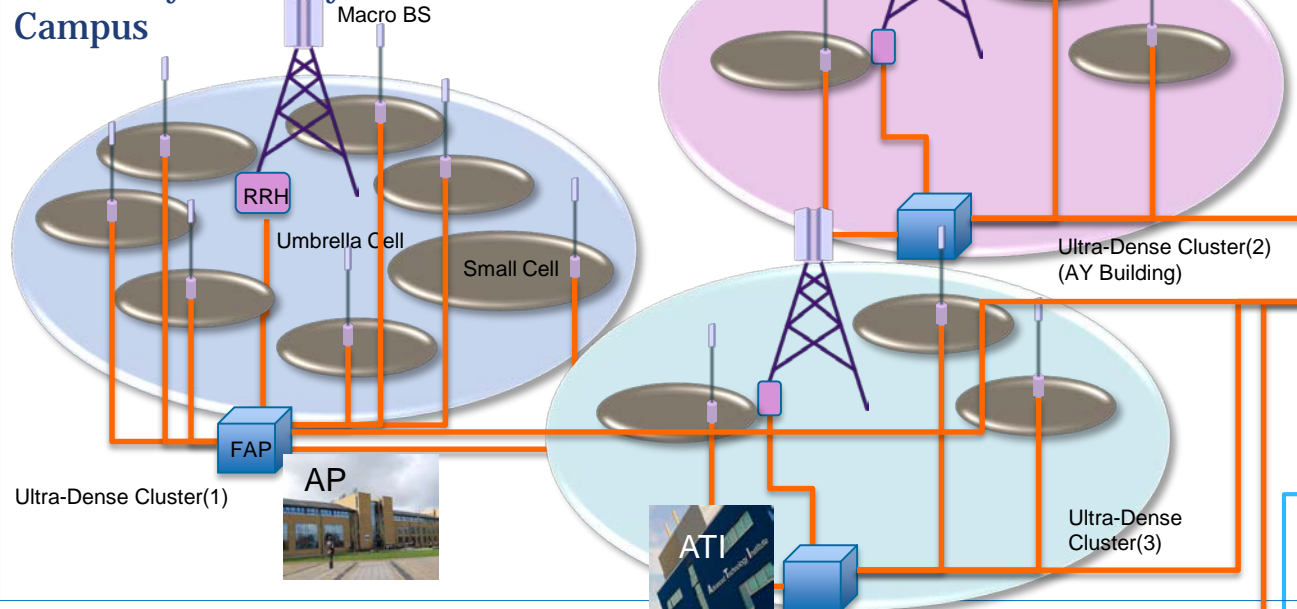
FIBRE + WIRELESS

- **LOW+ MEDIUM+ HIGH DENSE CELLS**
 - **CAPACITY LIMITED**
 - **COVERAGE LIMITED**

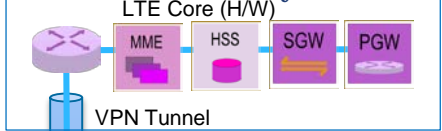
- **5G DEPLOYED WITH 4G AND WiFi**
 - **PIONEER FREQUENCY BANDS**
 - **700MHz → COVERAGE**
 - **3.5 GHz → CAPACITY AND COST**
 - **26 GHz, MILLIMETRE BAND → ULTRA HIGH CAPACITY**

5GIC TEST-BED: ULTRA-DENSE CAMPUS TEST-BED

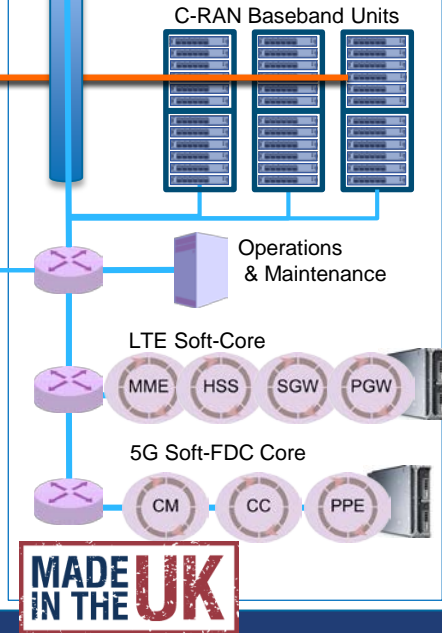
University of Surrey Outdoor Campus



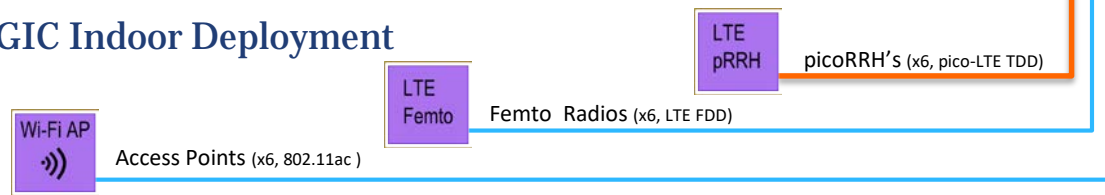
Vodafone Newbury Test Centre



5GIC Comm's Room



5GIC Indoor Deployment

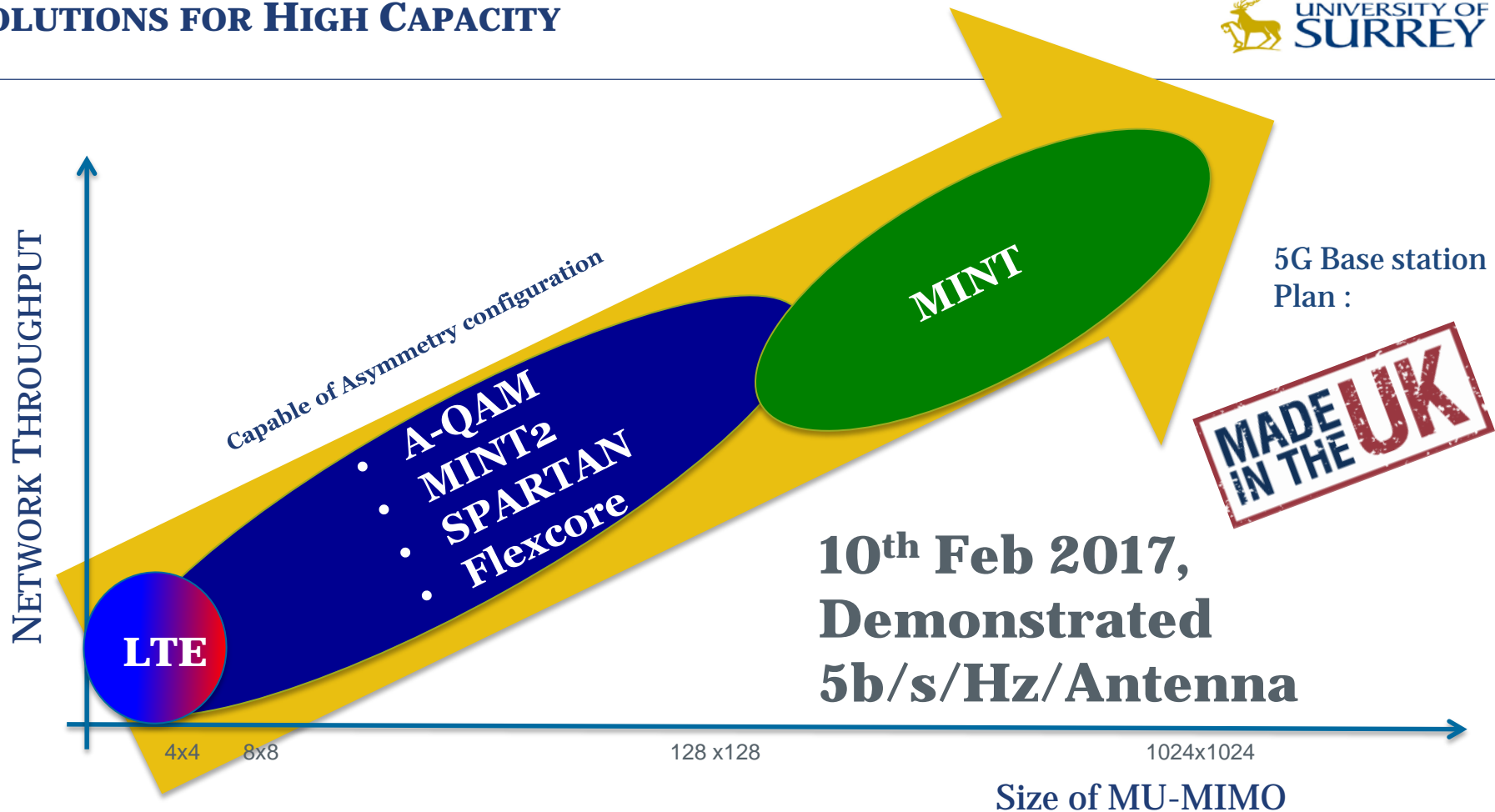


5GIC ADVANCES

- TRANSMISSION OF 4K (ULTRA HIGH DEFINITION) VIDEO ON A MOBILE NETWORK
 - 1st in the world, Sep 2015
- NOVEL SCMA TECHNIQUE OF FOR SUPPORT OF massive connectivity OF IOT DEVICES
 - 300% more connectivity than 4G
 - 1st in the world, Sep 2015



SOLUTIONS FOR HIGH CAPACITY



WHERE IS NEW MONEY?

AUTOMATION

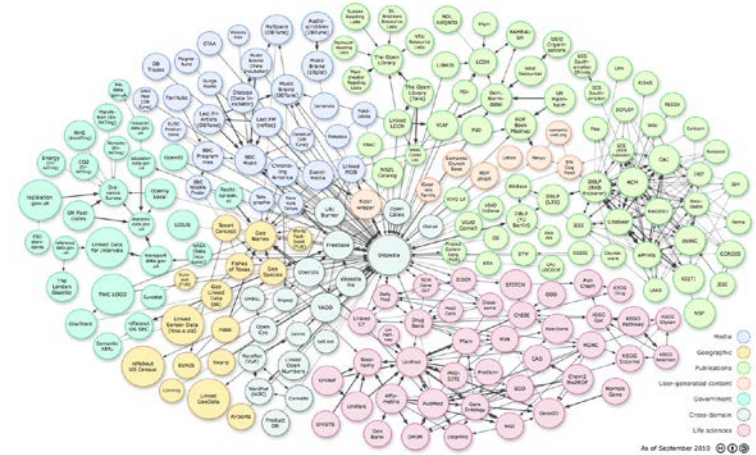
POWERED BY:

AI
&

ULTRA LOW LATENCY AND RELIABLE COMMUNICATIONS

&

MASS CONNECTIVITY



What is the order ?

2019-5G WILL START WITH:

- EMBB WITH NEW SPECTRUM TO ADDRESS CAPACITY CRUNCH
- USING MAINLY 3.5GHZ BAND AND 4G

2020 ONWARDS – GAME CHANGER:

- URLLC (WITH GUARANTEED LOW LATENCY)
- WILL OPEN UP NEW BUSINESS OPPORTUNITIES AND HENCE NEW MONEY

STANDARDS AND WIN-WIN BUSINESS MODELS BETWEEN TELCOS AND VERTICALS
WILL HOPEFULLY BE IN PLACE

THANK YOU

Rahim Tafazolli

5GIC/The University of Surrey

r.tafazolli@surrey.ac.uk

IEEE 5G Summit Glasgow 14th May Technology Innovation Centre University of Strathclyde

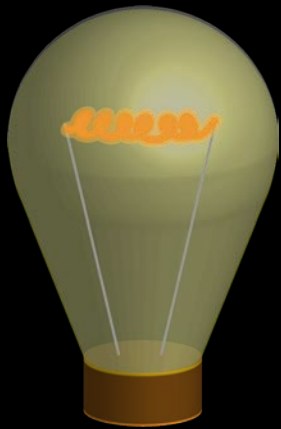
Slicing the 5G Business Case

Mansoor Hanif
Board Member
UK5G Innovation Network

Join us in shaping 5G for the UK at www.UK5G.org

Why is Network Slicing key to 5G Business Case?

UK
5G

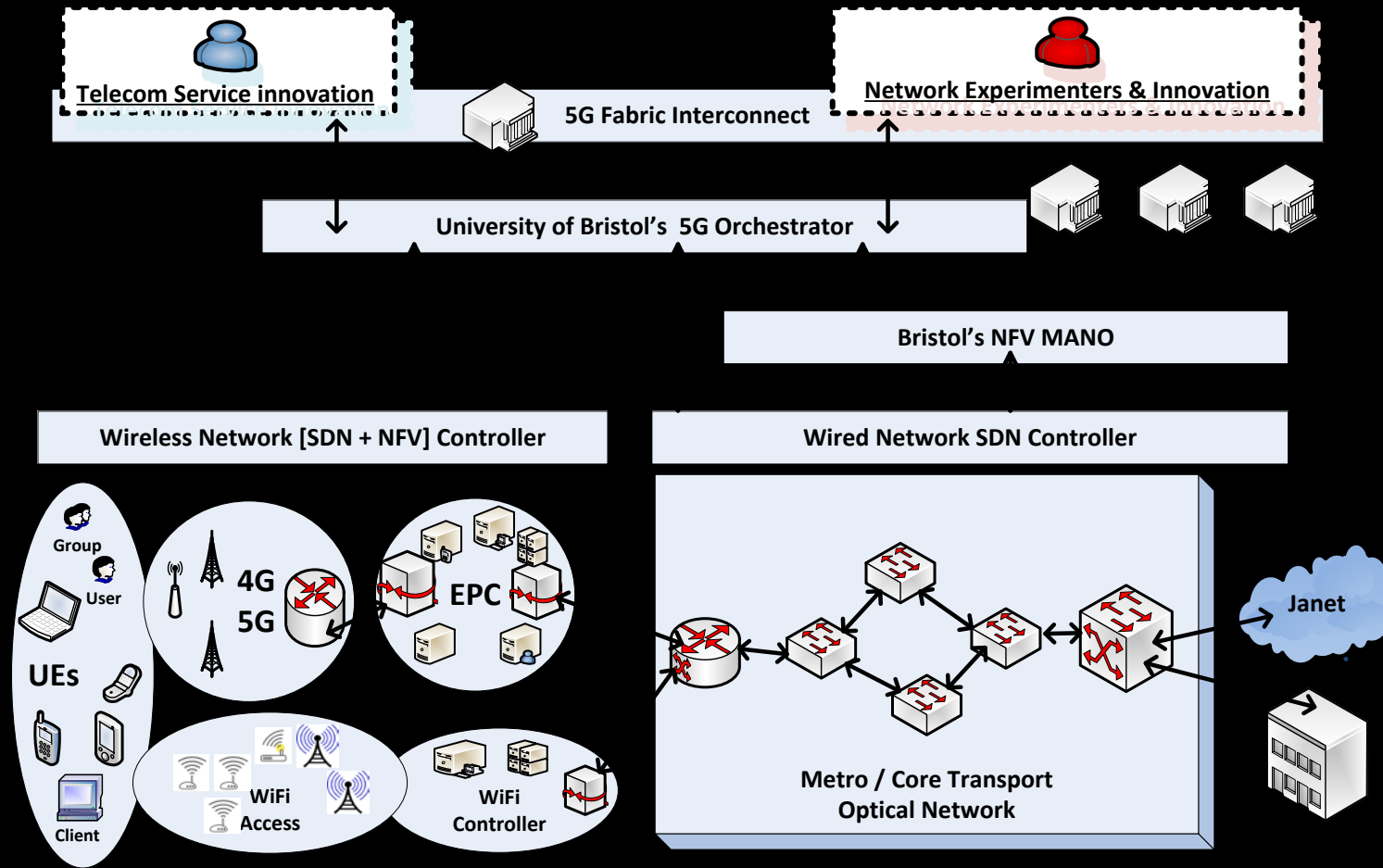


- Network Slicing (NS) offers dynamic virtual network capabilities over shared infrastructure
- NS Efficiency is multiplied through malleable network capabilities and scaled through automation – perfect fit for 5G!
- **5G can offer more for consumers but NS can generate new sources of revenue from a common 5G Investment**
- NS enables 5G to encompass and integrate **licensed** (MNOs), **licence-exempt** (Wi-Fi, visible light, etc.) and **shared** (primary, secondary, database driven) spectrum.
- **NS empowers new models** for infrastructure ownership, competition and partnerships – including **5G Community Networks**
- **New technology + New Operating Model + New Business Models + New Ecosystem = Very Slow gestationunless?**

UK 5G DCMS Trials – An open architecture to explore Slicing

UK
5G

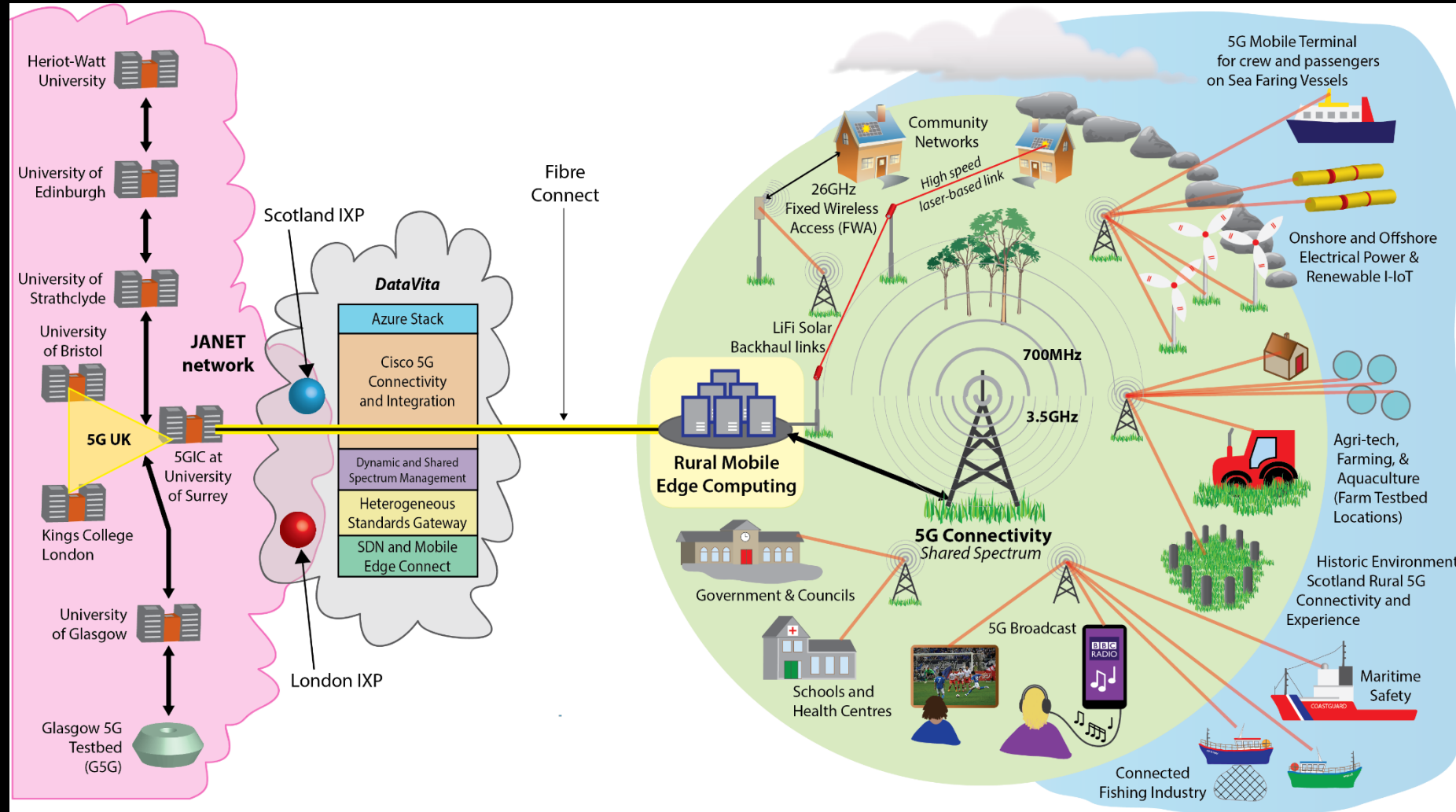
- World-leading National-scale public-funded test-bed infrastructure
- Multi-vendor and Multi-Access
- 5G UK Exchange allows unique opportunities to interconnect to any testbed from any trial location
- Consortia based approach with active encouragement for vertical partners, start-ups and academic spinoffs
- Direct inputs from end customers to trial scopes and use cases
- Many use cases focus on Network Slicing
- Experimenters are offered:
 - Manageability
 - Common standardized API
 - Testbed privacy preservation
 - Sustainability



Example shown: UoB 5GUK Overview & Opportunities - Ref: H.R. Falaki

UK 5G DCMS example trial architecture – Rural First

UK
5G



UK 5G DCMS Trial Use Cases – Examples from Worcestershire Consortium

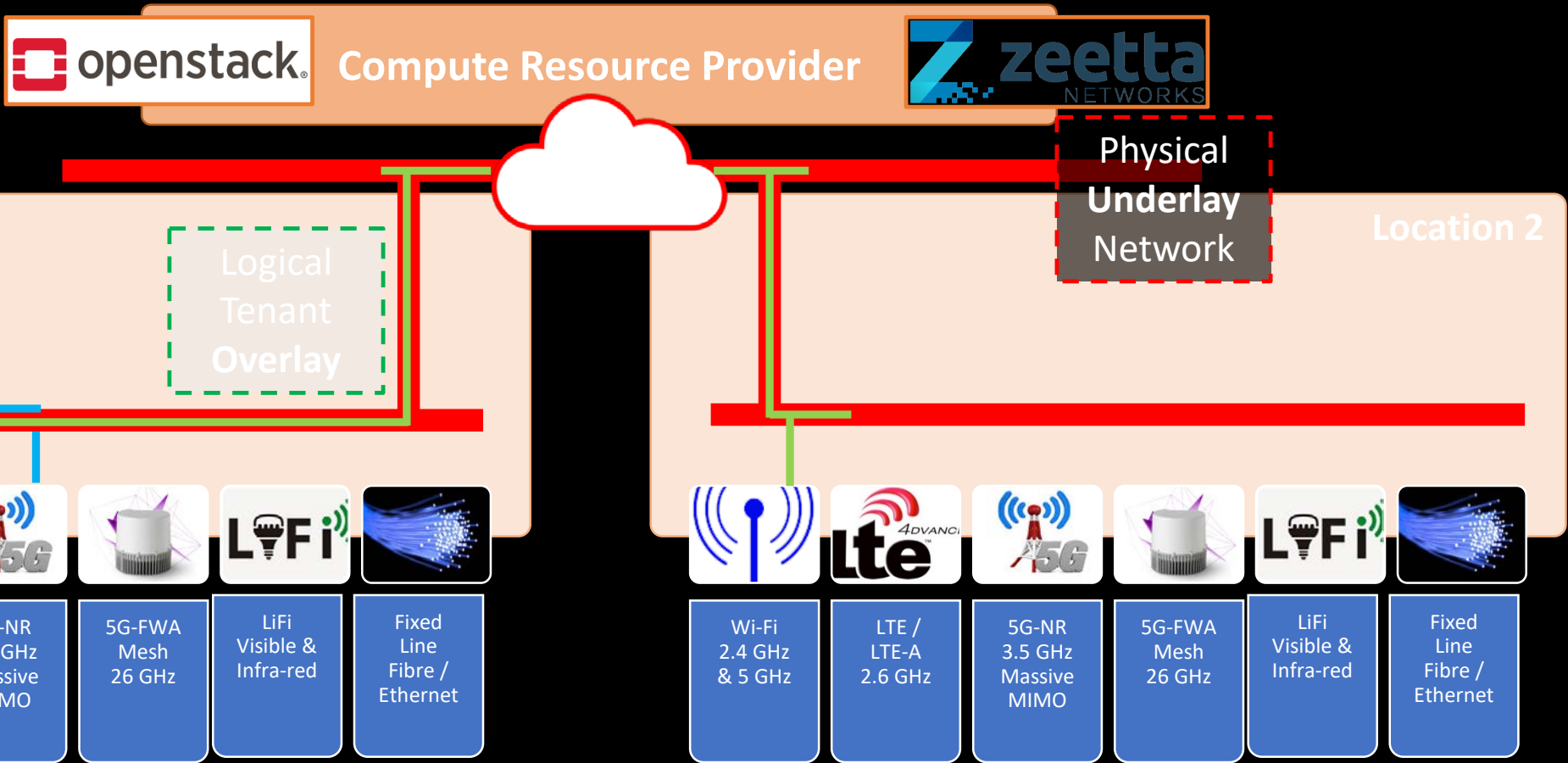


Innovation - 3GPP Compliant 5G Architecture from the outset – 5GIC core with Huawei gNBs

Use Case	URLLC	mMTC	eMBB	Strategic Direction
Preventative Maintenance x 2	Low Latency Availability 99.999%	1 sensor per sq.m equates to 1m devices per sq.km	5+Mbyte/Sensor/ per second Across hundreds of sensors	New Business Models – selling service Inter-company collaboration International collaboration Underpinned by dynamic Network Slicing
Robotics	Low Latency Availability 99.999%		Multiple 4K Cameras	Assembly line automation with significant Edge Computing
Assisted Maintenance	99.999% Availability		10Gbs per second	International deployment underpinned by dynamic Network Slicing

Security by Design – ever more important as technology becomes mission critical

Network Slicing – A view from inside a test bed (Bristol example)



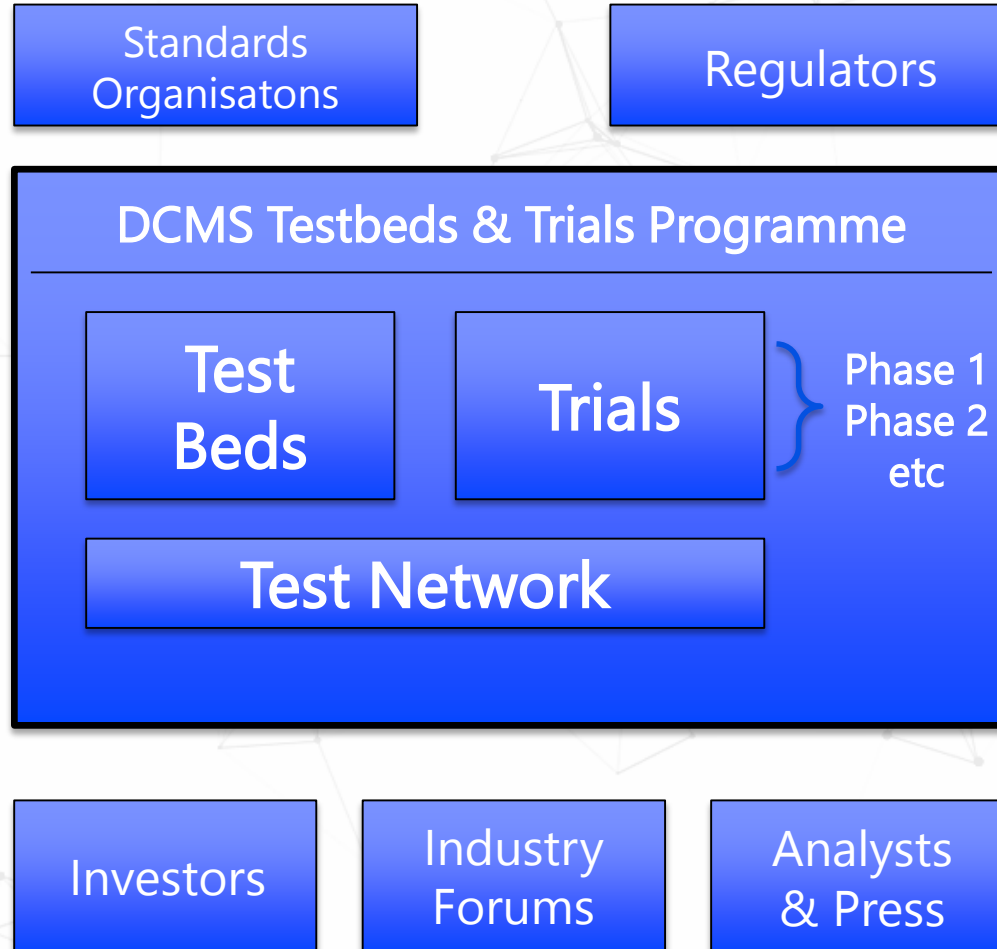
Empowering an expanding ecosystem

**UK
5G**

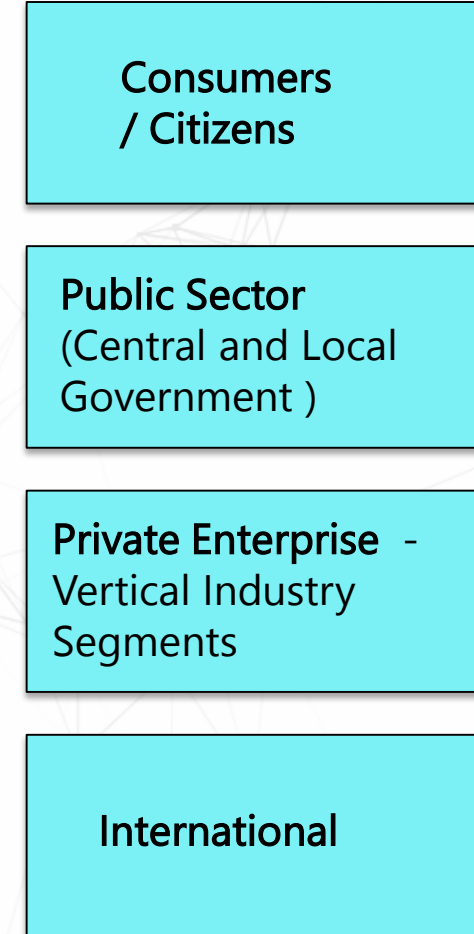
Sellers



Enablers



Buyers



UK5G Innovation Network: maximising the UK 5G Opportunity

Key Principles

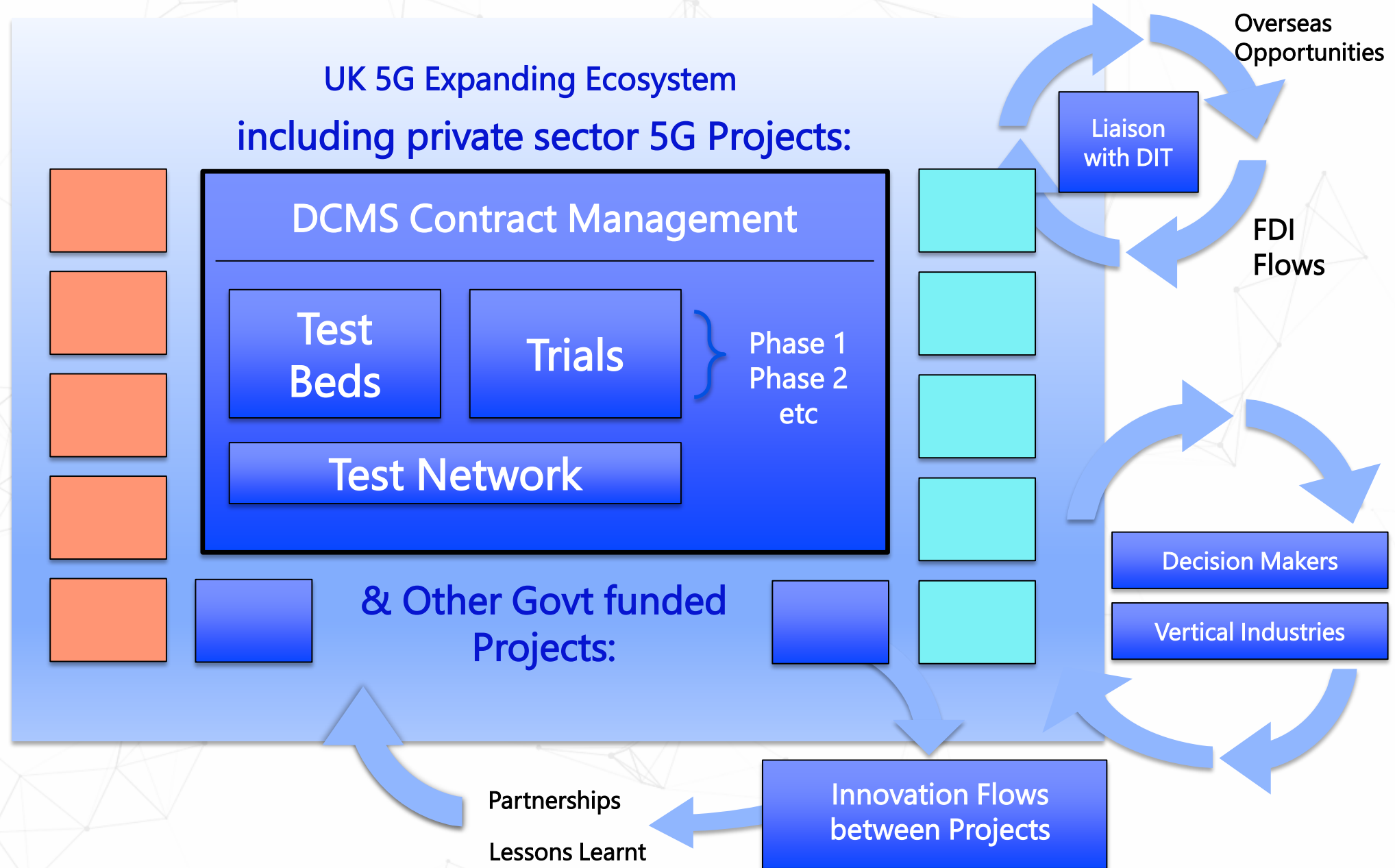
- Impartiality
- Enthusiasm
- Sustainability

Key Aims

- Preparing the market
- Connecting supply and demand

Key Activities

- Advisory Board
- Marketing plan
- Content Coordination
- Events
- Introductions
- Inward Investment



Conclusion – get involved!

- Network slicing is key to the success of 5G but we need technical trials to support a holistic end-to-end slicing architecture and simplify operational complexity:
 - Multi-domain e2e orchestration => **Beyond the Network and into the B2B customer domain**
 - Service assurance for slices to support stringent application needs => **Foundation of the NS Business Models**
 - Converged multi-access slices => **A 5G Framework embracing all access technologies**
 - Multi-operator federated slicing => **The future of Roaming and MVNOs**
- UK Collaborative trials: best opportunity to accelerate adoption of 5G NS Business Models:
 - Do the use cases work in a real scenario?
 - Economics of setting up and running slices?
 - Slice provisioning and packaging for diverse customers?
 - Slice value and pricing models?
- You are invited to:
 - register www.UK5G.org and ask your contacts to register as individuals, organisations and projects
 - provide and upload relevant content using the back office.
 - Send any queries to hello@UK5G.org

**UK
5G**

Join us in
shaping 5G
for the UK

www.UK5G.org
[@UK_5G](#)
[linkedin.com/company/uk5g/](https://www.linkedin.com/company/uk5g/)
hello@UK5G.org

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Update on DCMS 5G Testbeds & Trials Programme

14th May 2018
IEEE 5G Glasgow Summit

Dr Andrew Smith



Department for
Digital, Culture,
Media & Sport

The evolution of 5G policy

Future Communications Challenge Group (FCCG)

UK strategy and plan for 5G &
Digitisation - driving economic
growth and productivity

January 2017 Interim report

1. FCCG Jan 2017

Proposes the “UK seizes the real chance to be a world leader in the development of 5G”



2. UK Digital Strategy - March 2017

- Ambition “to create a world-leading digital economy that works for everyone”
- Prioritises “Building world-class digital infrastructure for the UK”

3. 5G Strategy - March 2017

- Launches the 5G Testbeds and Trials Programme
- Aim: “the UK should be a global leader in 5G so that we can take early advantage of its potential”
- £16M for leading UK research institutions to cooperate on a new 5G capability → 5GUK

The evolution of 5G policy – cont.

4. Industrial Strategy - November 2017

- £25M initial competition for projects across industries
- £10M to create facilities for testing security
- £5M to test 5G applications and deployment on roads
- up to £35M to trial technical and commercial solutions on trains via trackside infrastructure


Department for
Digital, Culture
Media & Sport

Next Generation Mobile Technologies: An
update to the 5G strategy for the UK

December 2017

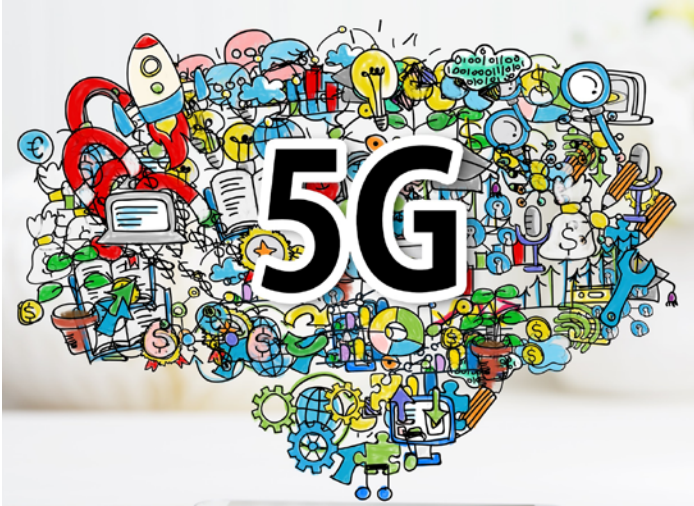


5. 5G Strategy Update - December 2017

- Reports on progress made over the course of the year
- Announces UK5G as winners of the competition to establish a 5G Innovation Network

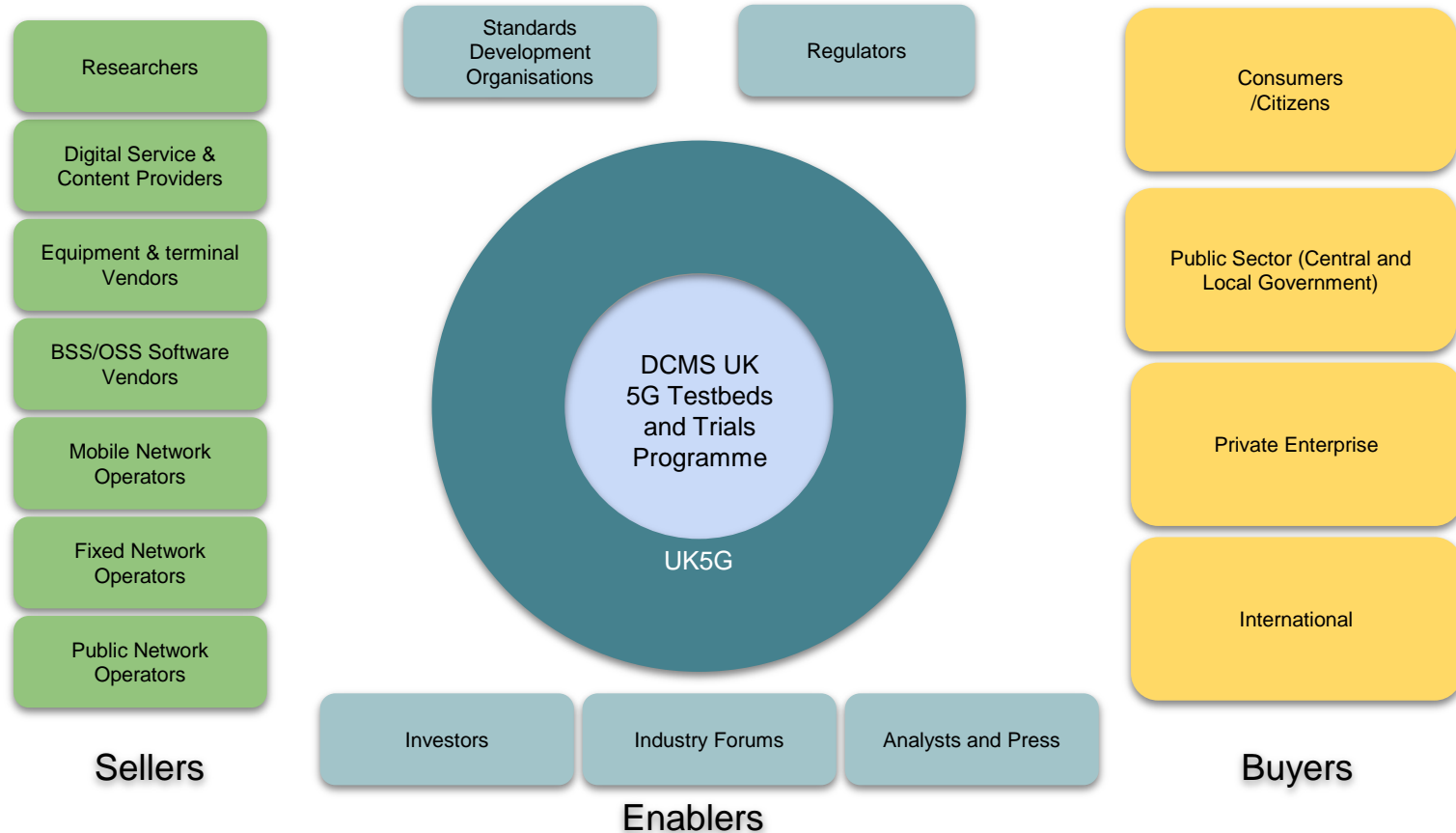
The programme in focus...

Our Objectives

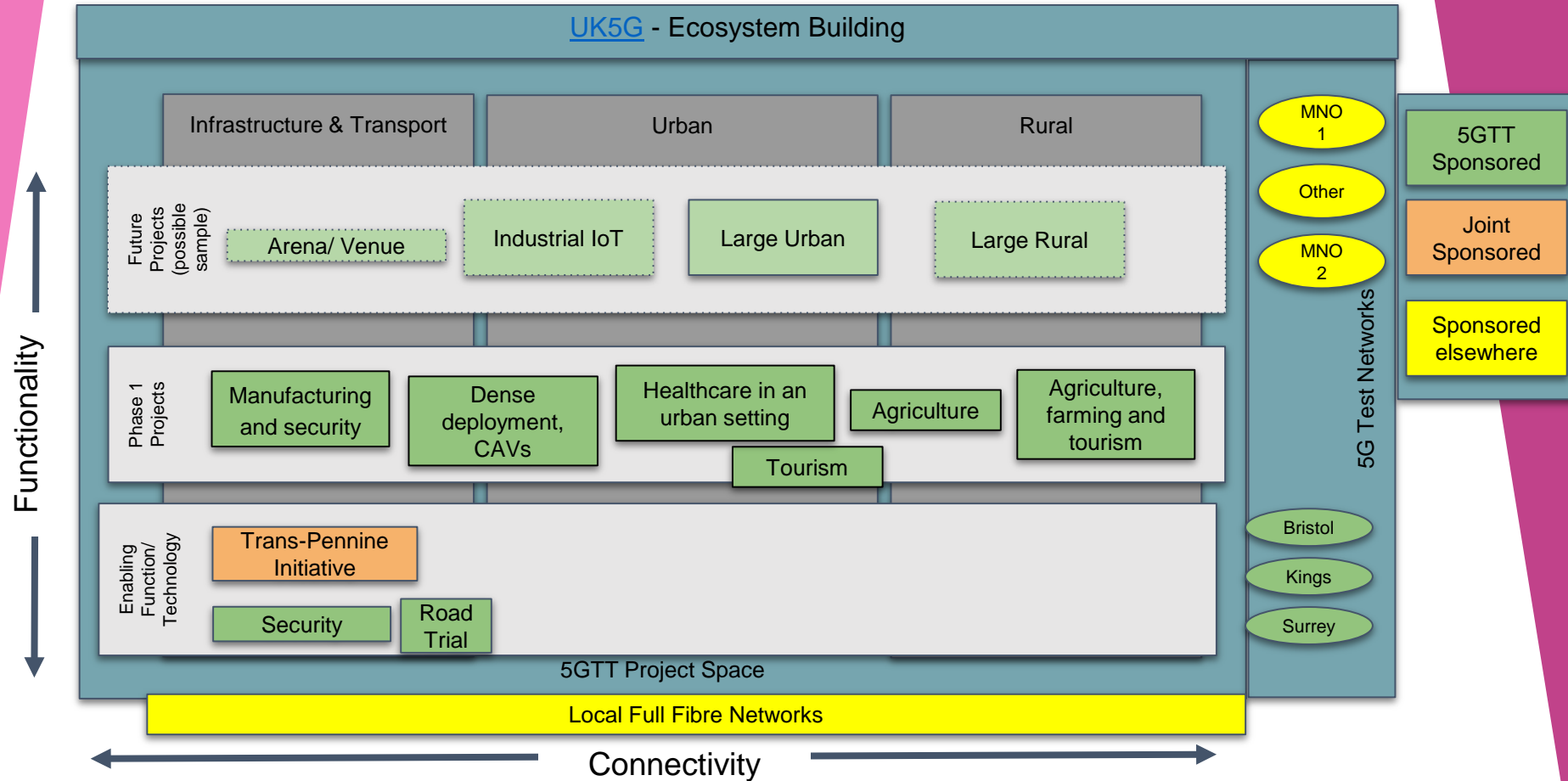


- Establish the conditions under which the deployment of 5G can be accelerated
 - ▶ drive efficiency and productivity
 - ▶ maximise the chances of the UK being a world-leader
- Foster the development of the UK's 5G ecosystem
- Creating new opportunities for UK businesses
- Encourage inward investment

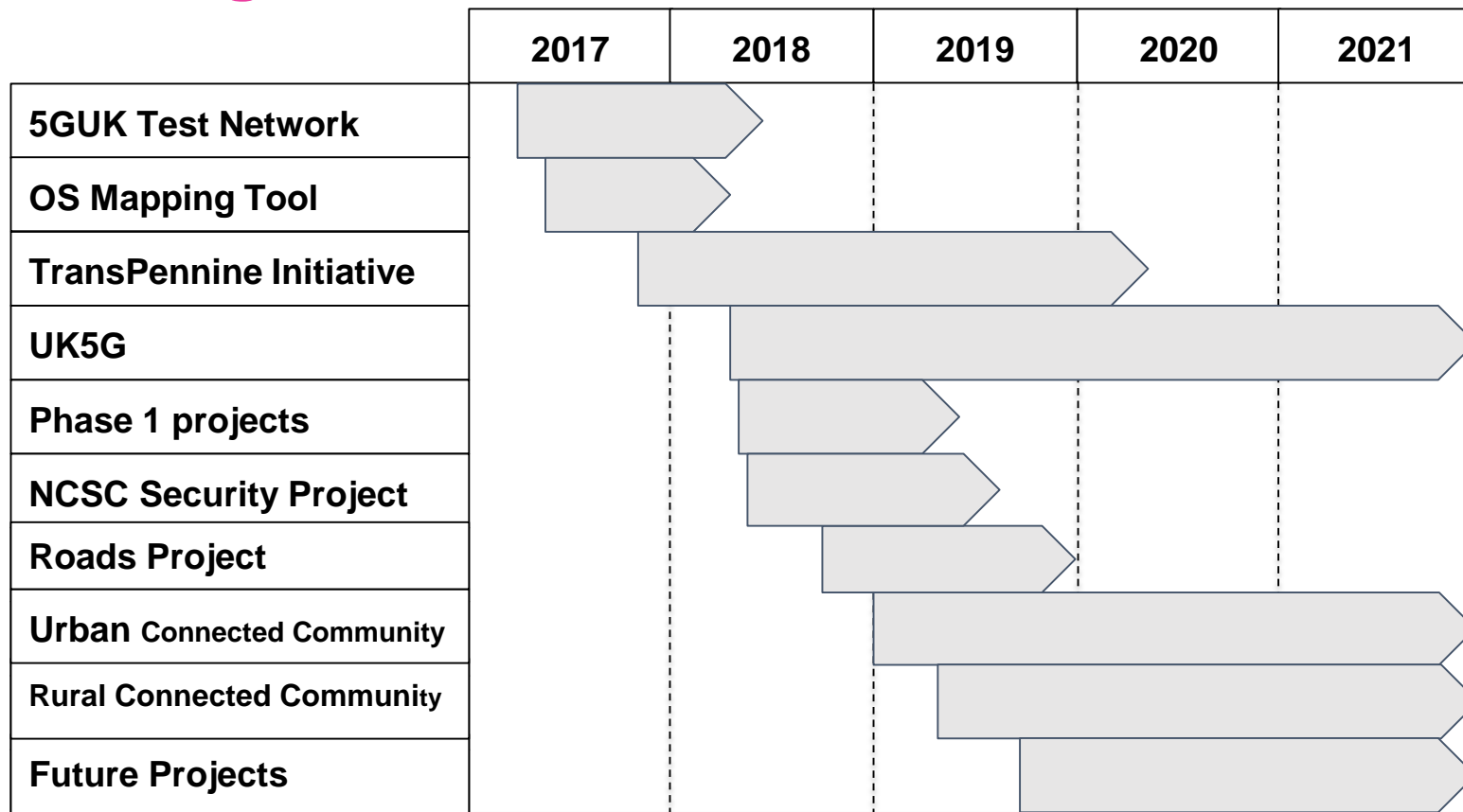
The 5G ecosystem



Developing 5GTT Programme: delivery approach

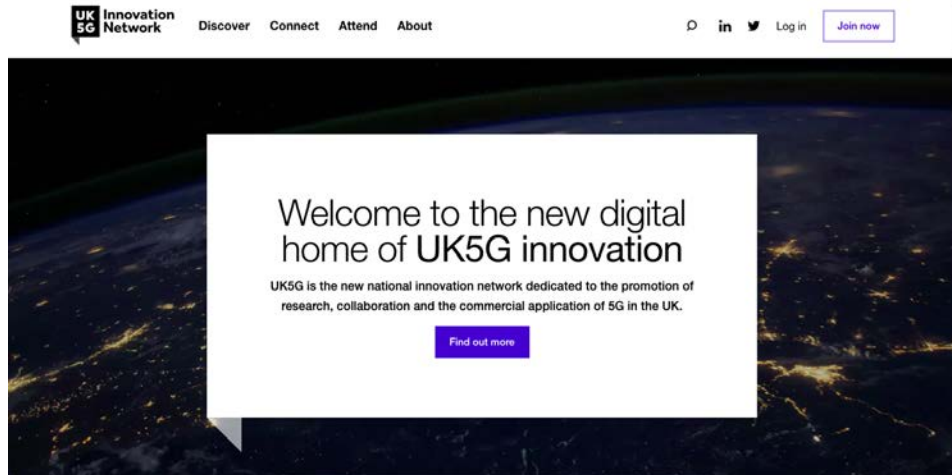


Programme Activities and Timeline



UK5G

- Comprised of Cambridge Wireless, TM Forum and Knowledge Transfer Network



- Funded and endorsed by DCMS
- Enabling knowledge sharing
- Keen to engage

Phase 1 projects

- **£23.8 million investment in six 5G projects**
- Wide-range of sectors
- Focused on collaboration
- Led by industry, SMEs, universities and local authorities
- Over 90 different institutions involved
- To run from April 2018 to the end of March 2019



Phase 1 projects cont.

5G Rural Integrated Testbed (5GRIT)

Sector: Rural, including farming and tourism.

Location: Cumbria, Northumberland, North Yorkshire, Lincolnshire, Invernessshire, Perthshire) and Monmouthshire.

Worcestershire 5G Consortium

Sector: Manufacturing and security

Location: Worcester

5G Smart Tourism

Sector: Tourism

Location: West of England, Bristol, Bath



5G RuralFirst: Rural Coverage and Dynamic Spectrum Access Testbed and Trial

Sector: Rural, agriculture and various

Location: Orkney, Shropshire, and Somerset

Liverpool 5G Testbed

Sector: Healthcare in an urban setting

Location: Liverpool

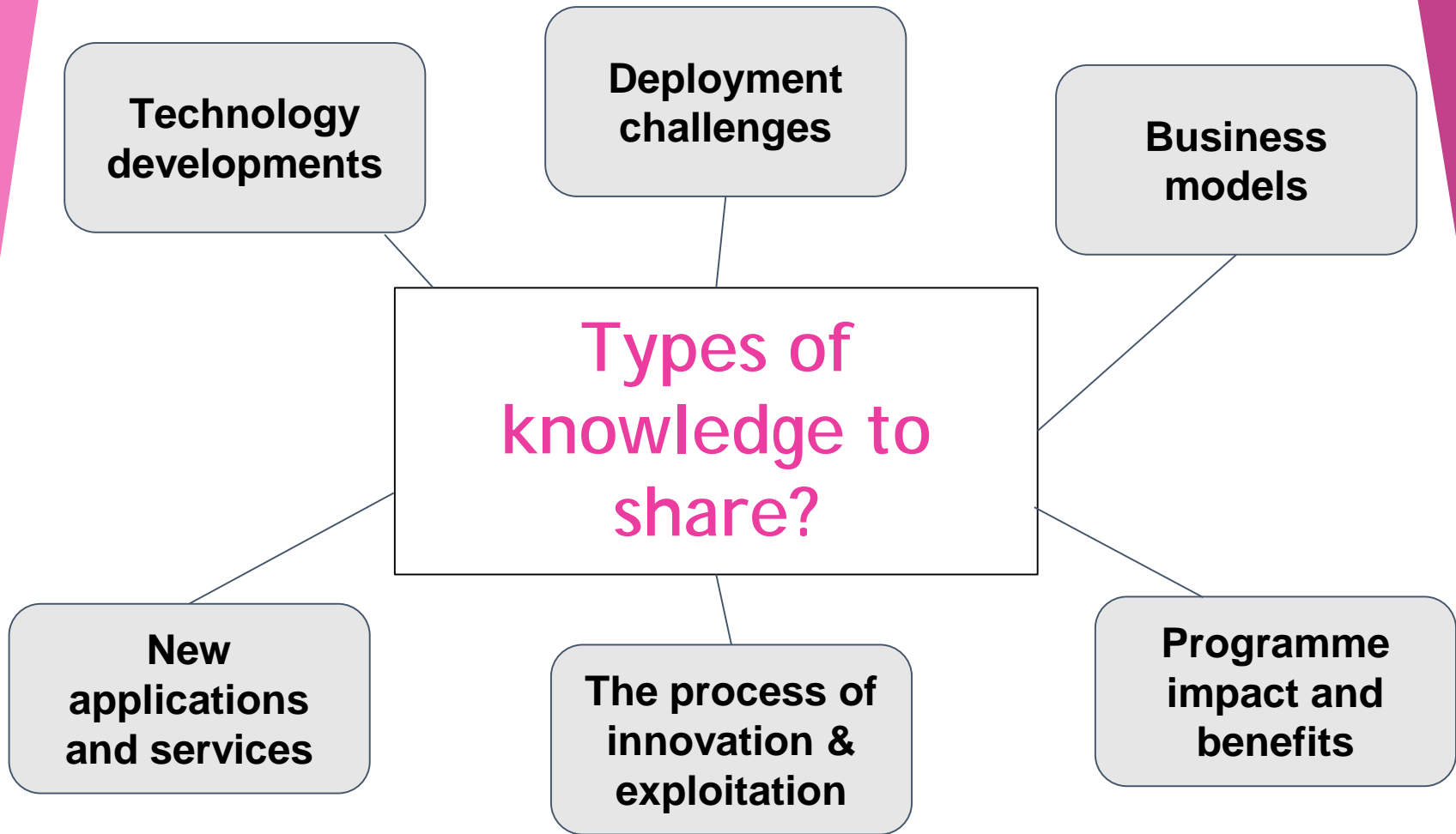
AutoAir

Sector: Dense deployment, CAVs

Location: Milbrook and 5GIC



Phase 1 Onboarding and Collaboration Event at the Oval



Continue to support Phase 1 projects

Work with UK5G to develop the ecosystem

Reach out across government and internationally

Push forward with the development of future projects

Thank you

(Questions over coffee!)

Dr Andrew Smith
andy.smith@culture.gov.uk



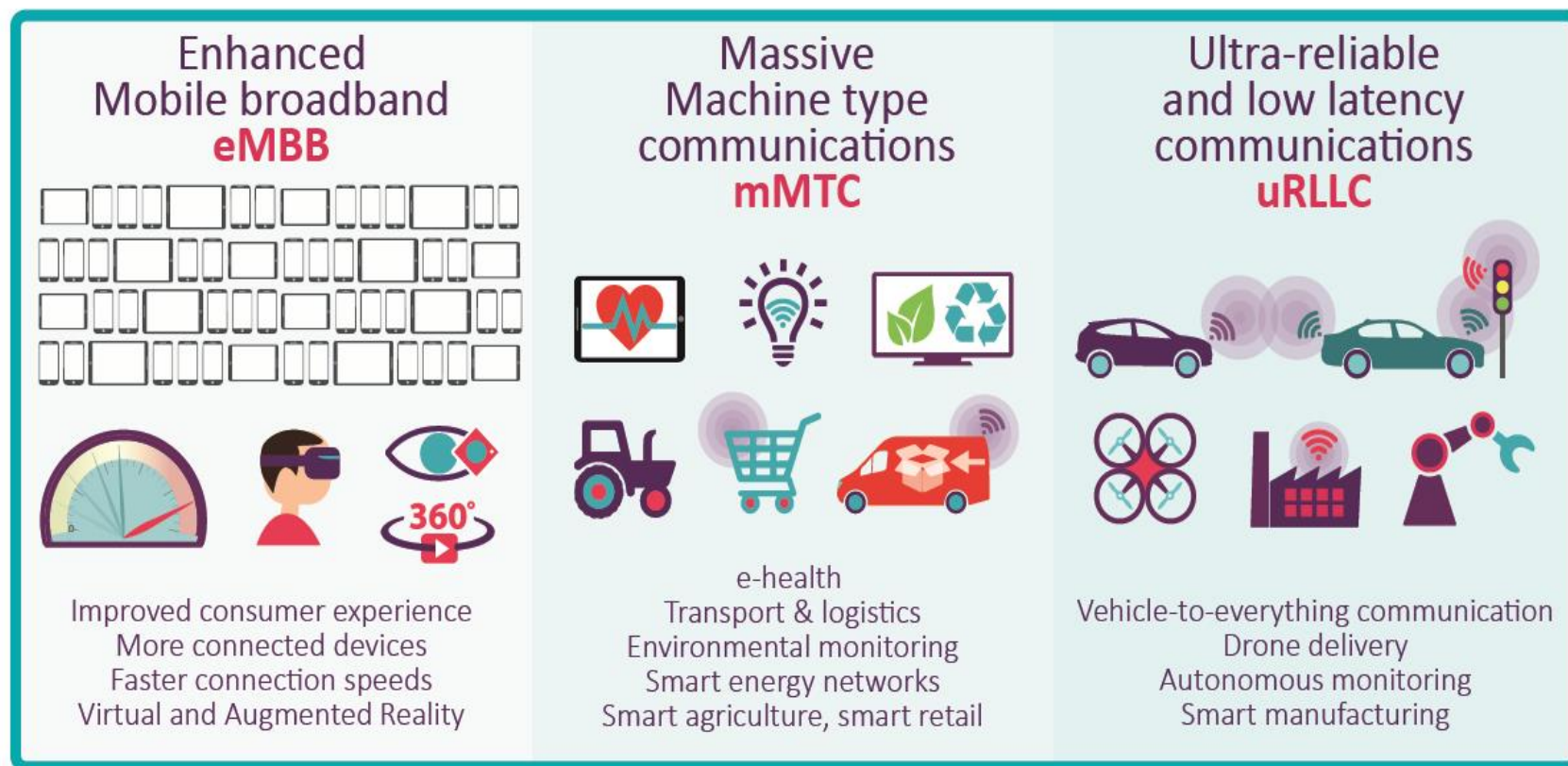
Department for
Digital, Culture,
Media & Sport

Enabling 5G in the UK- the role of spectrum

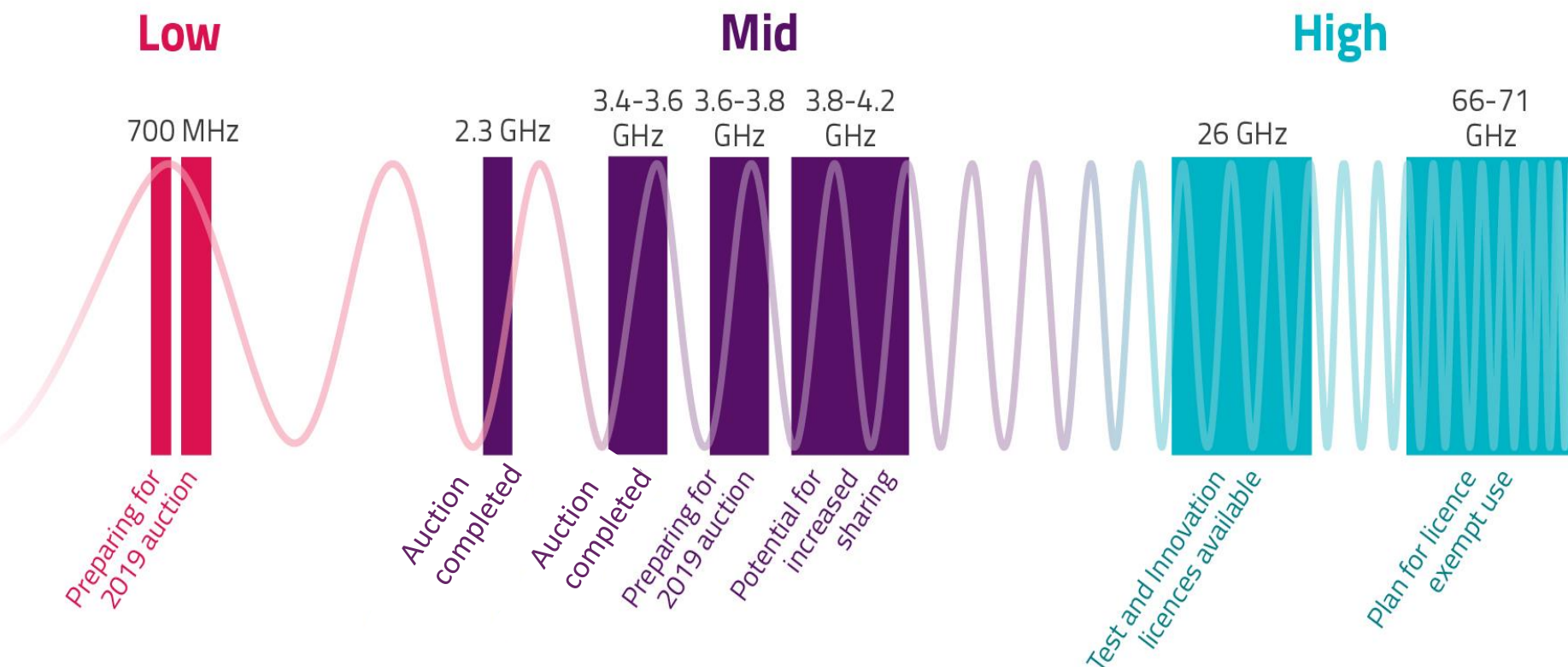
Cristina Data, Director Spectrum Policy And Analysis - Ofcom

14 May 2018

5G will enable different use cases across a broad range of industry sectors



Our objective: making sure spectrum is not an inhibitor of 5G



Different authorisation methods may be needed

Low and mid range spectrum for 5G

700 MHz

- Provide wide area coverage
- Clearance well under way
- **Award in 2019**



3.4-3.8 GHz – “primary” band for 5G

- Large bandwidth can support higher data rates, provide increased capacity, and enable higher speeds
- **3.4-3.6 GHz - awarded**
- **Intention to award 3.6-3.8 GHz in 2019**

Our roadmap for 5G mmWave spectrum

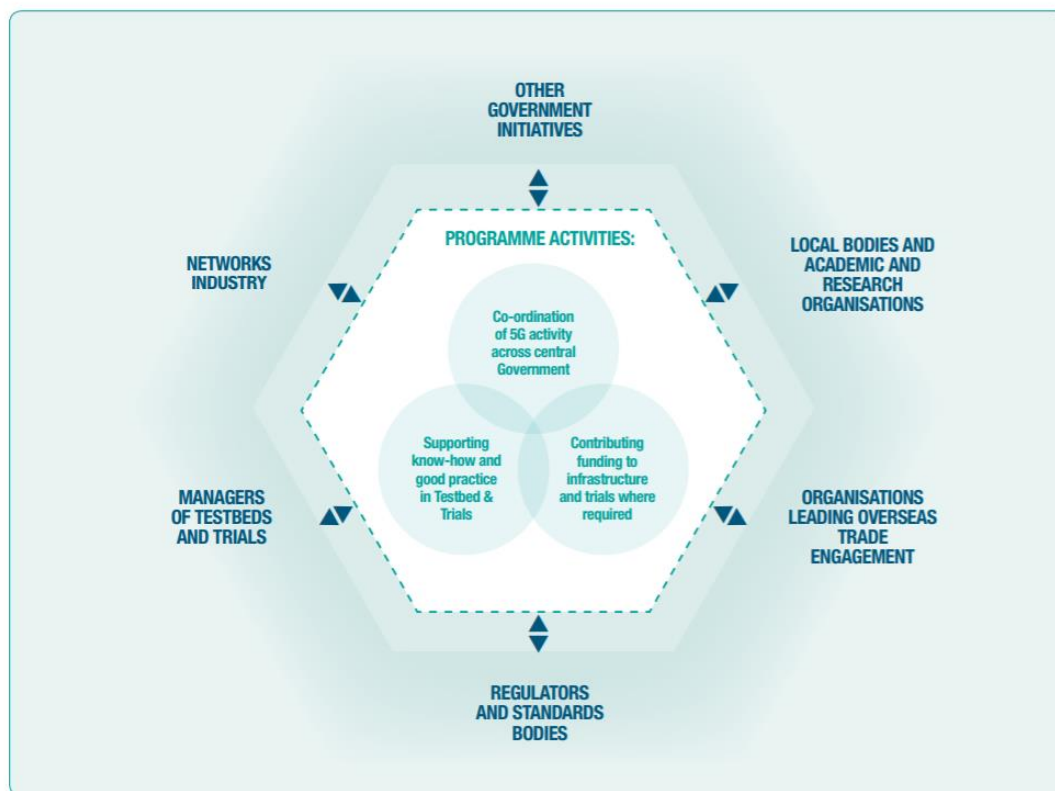
- **26 GHz:** Trial and Innovation licences available.
- **66-71 GHz:** We are working to make this band available on licence exempt basis for 5G
- **40 GHz:** Support internationally as part of wider band for harmonisation of equipment (37-43.5 GHz)



UK 5G Test beds and trials programme

UK Government has committed **£160m** to 5G test beds and trials programme

- £16m test network
- £25m phase 1 trials (trials include: rural connectivity, connected autonomous cars, connected cars).



Ofcom's role in supporting trials

We recently launched our **Innovation and Trial portal** to help applicants access spectrum for innovative uses

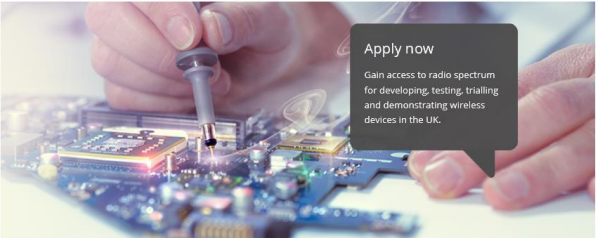
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- Phones, telecoms and internet >
- TV, radio and on-demand >
- Postal services >
- < Return to main menu
- Spectrum**
- Spectrum management
- Protecting and managing the airwaves
- Radio spectrum and the law
- Spectrum information

Innovation licensing including 5G

09 March 2018



Apply now
Gain access to radio spectrum for developing, testing, trialling and demonstrating wireless devices in the UK.

We make spectrum available to stimulate innovation in the UK, including to help facilitate the development of 5G.

What is 5G?

5G is the next generation of mobile technology.

See also...

- [Award of 2.3 and 3.4 GHz spectrum by auction](#)
- [Spectrum information](#)

innovation and trial licensing

Ofcom aims to make it as simple as possible to gain fast access to radio spectrum for you to conduct research, development and trial innovative wireless technologies.

Enabling 5G in the UK

In this document we provide an update on the actions we will be taking to facilitate 5G rollout in the UK.

Placing radio equipment on the market

A person manufacturing, importing or supplying any radio or electrical apparatus is responsible for ensuring that it complies with all relevant legislation before it can be placed on the market or put into service in the UK (or in the European Economic Area).

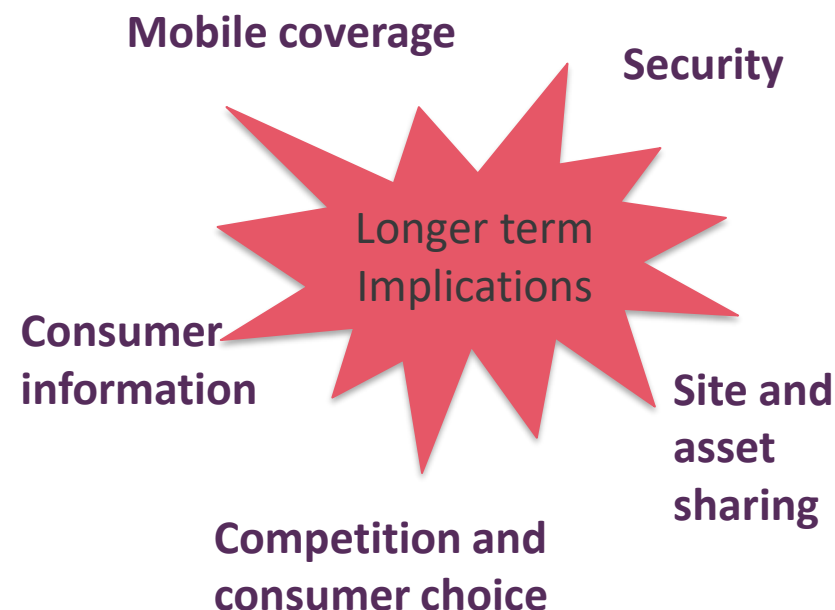
Spectrum demand requests

This information is for those interested in gaining access to spectrum, on a commercial basis, where there are no existing suitable licences.

Enabling 5G in the UK – wider enablers

What we are doing to make 5G available in the UK:

- making **spectrum** available for 5G and other wireless services;
- working with Government and policy-makers to **ensure access to sites** is not a barrier to 5G;
- ensuring access to appropriate **backhaul** connectivity;
- ensuring **net neutrality** regulation is not a barrier to deployment;
- **acting as a facilitator**, working with Government, different industry sectors and other countries to further understand potential applications of 5G.



May 14, 2018

@qualcomm_tech

IEEE 5G Summit
Glasgow, Scotland, UK

Qualcomm

5G - Maximising use of Licensed, Unlicensed & Shared Spectrum

Dean Brenner

SVP, Spectrum Strategy & Tech. Policy
Qualcomm Incorporated

Yongbin Wei

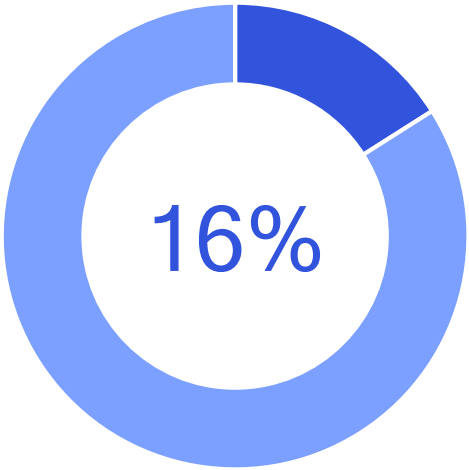
Sr. Director, Engineering
Qualcomm Technologies, Inc.



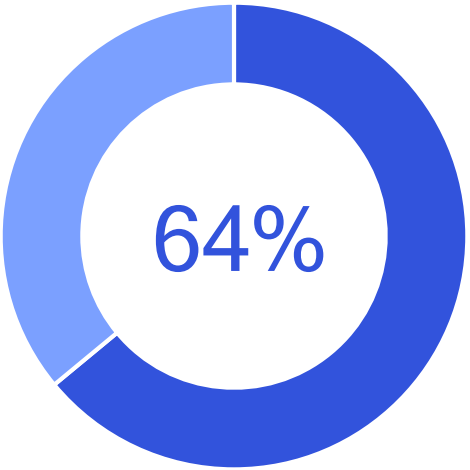
Enabling Gigabit LTE all over the world by using LAA

More operators can deliver Gigabit LTE using LAA in 5 GHz unlicensed spectrum

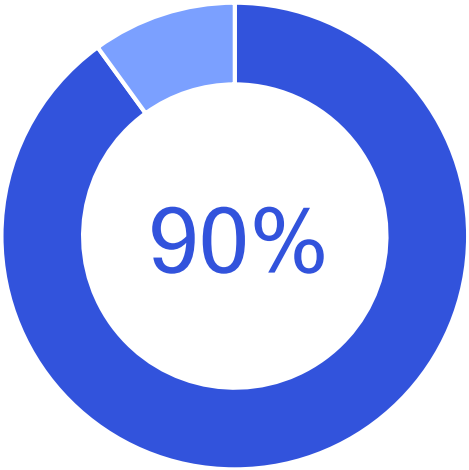
■ Share of operators who can deploy Gigabit LTE



60 MHz licensed¹



X16 LTE Modem
20 MHz licensed + LAA



X20 LTE Modem
10 MHz licensed + LAA



20 commercial Gigabit LTE devices, including smartphones, always connected PCs, ...

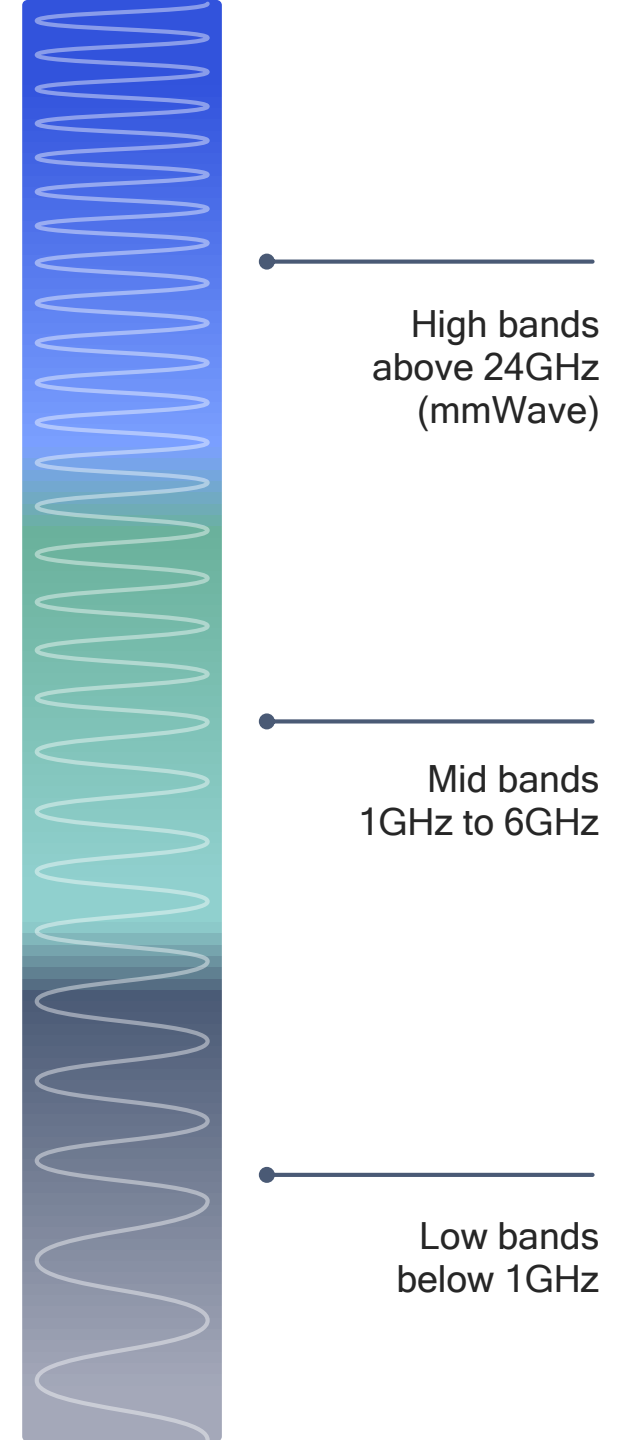
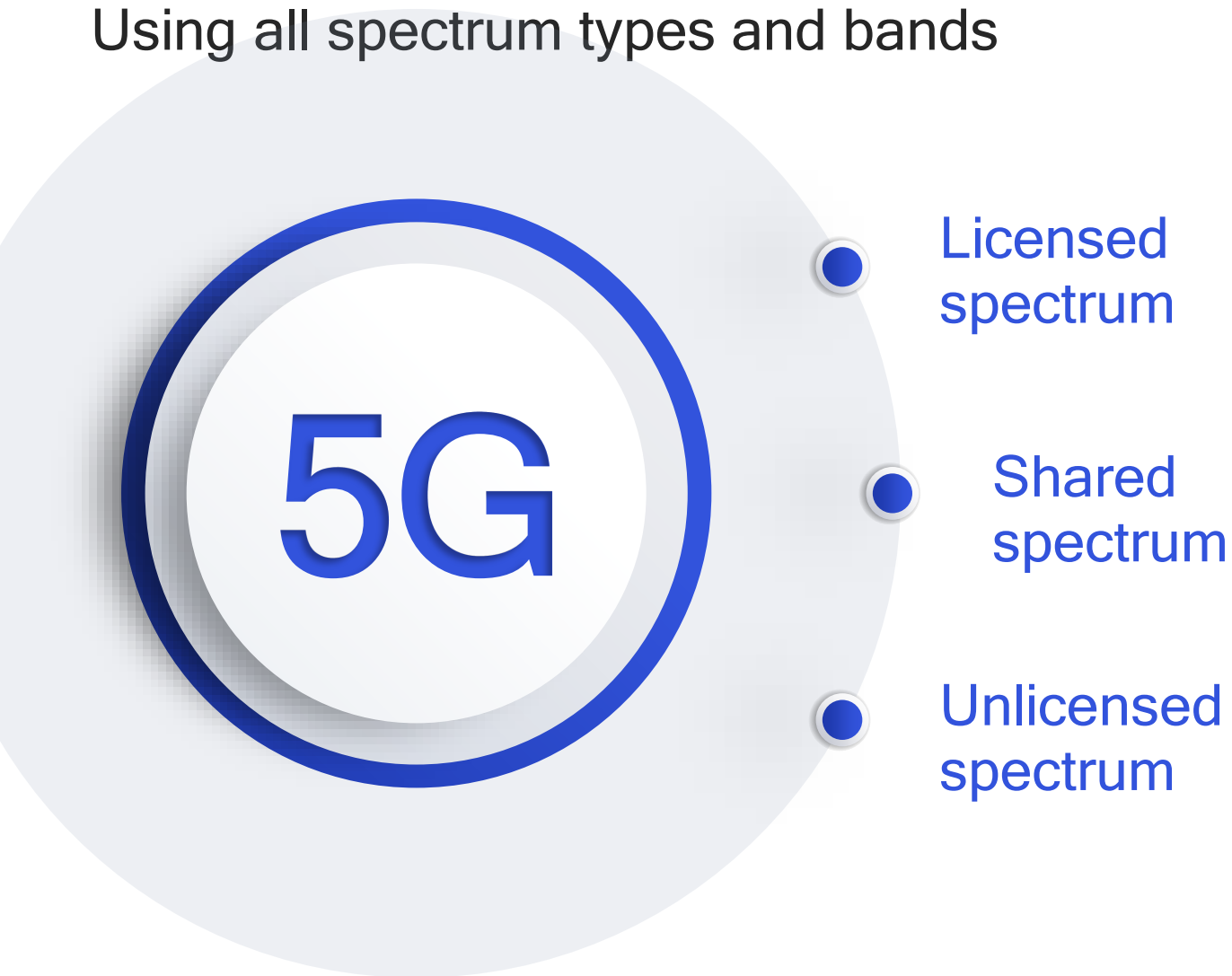


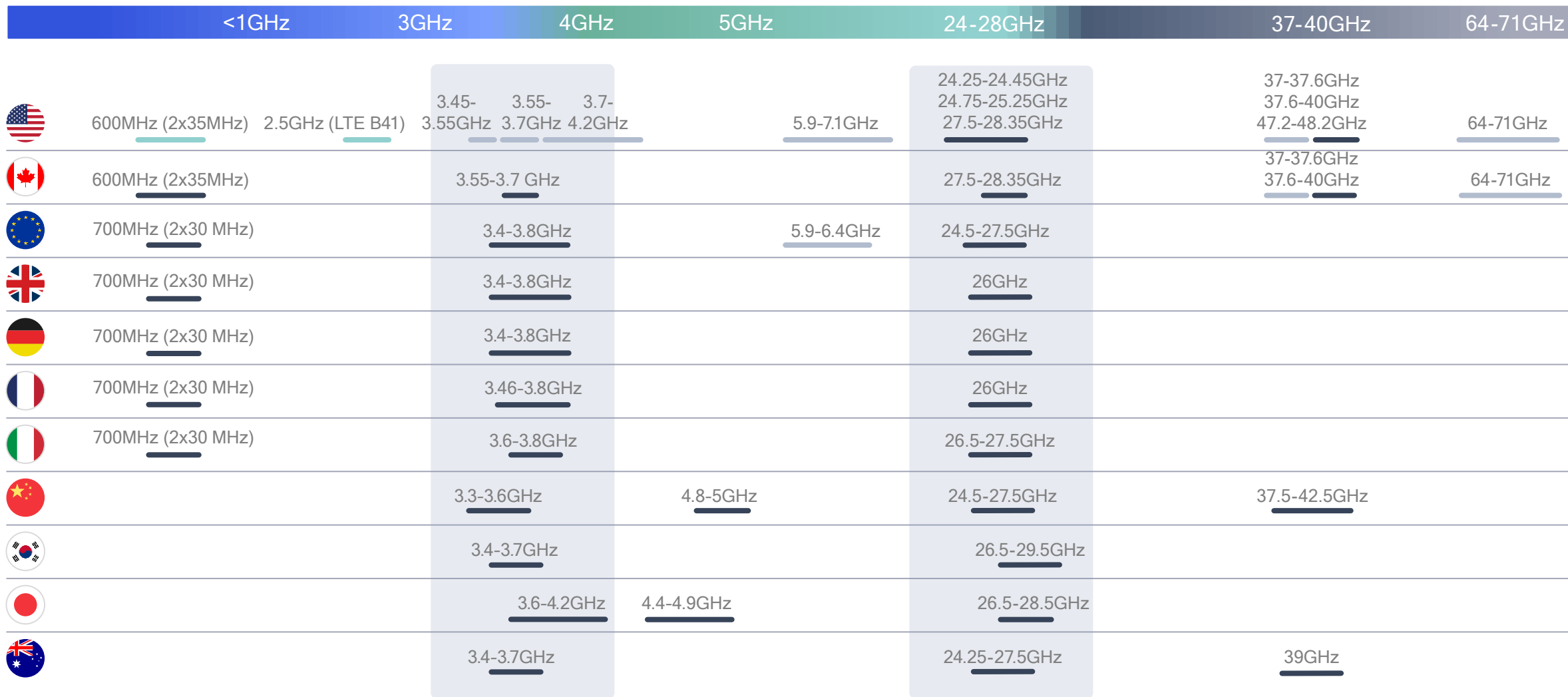
45

Operators in 26 countries with Gigabit LTE planned or trialed

Spectrum is critical for 5G success

Using all spectrum types and bands

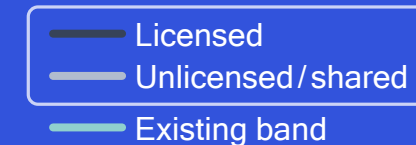




Designed for diverse spectrum bands/types

Global snapshot of 5G spectrum bands allocated or targeted

New 5G band



Spectrum sharing valuable for wide range of deployments

Licensed spectrum aggregation

Better user experience with higher speeds



Enhanced local broadband

Neutral host, neighborhood network



Private 5G networks

Industrial IoT, Enterprise



Enhancing existing
deployments

Examples today: Gigabit LTE with LAA¹

New types of deployments

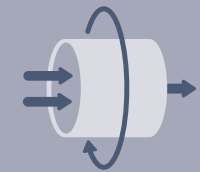
Examples today: Private LTE networks

1. Licensed-Assisted Access (LAA);

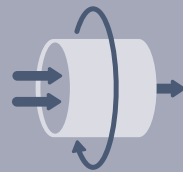
5G NR – opportunity for new spectrum sharing paradigms

Building on spectrum sharing technologies that we are pioneering today for LTE

Evolution path



LTE-U / LAA



LWA



MulteFire



CBRS / LSA

5G NR Spectrum Sharing

Revolution path



Flexible NR
framework



Time synch
and coordinated
sharing



Guaranteed
QoS



Exploiting
spatial domain



Vertical and
horizontal sharing

What is revolutionary from previous sharing solutions?

New sharing paradigms



New 5G NR framework is friendly for efficient sharing from the **beginning**



Coordination and time **synchronization** among sharing entities to improve efficiency and robustness



Elevate support of **guaranteed QoS** services when sharing spectrum and greatly improve upon simple best-effort practice



Exploit **spatial domain**: High frequency bands and MIMO with many antennas naturally suitable for sharing and CoMP



Support **flexible spectrum sharing**, both vertical and horizontal spectrum sharing

Private 5G networks for Industrial IoT use cases

Optimizing LTE for the Industrial IoT today

New opportunities with 5G NR capabilities



Ultra-reliable
low-latency



Time-sensitive
networking



mmWave and
sub-6GHz eMBB



NR in unlicensed
spectrum

Optimized

Tailored for industrial applications,
e.g., QoS, latency

Dedicated

Local network, easy to deploy,
independently managed

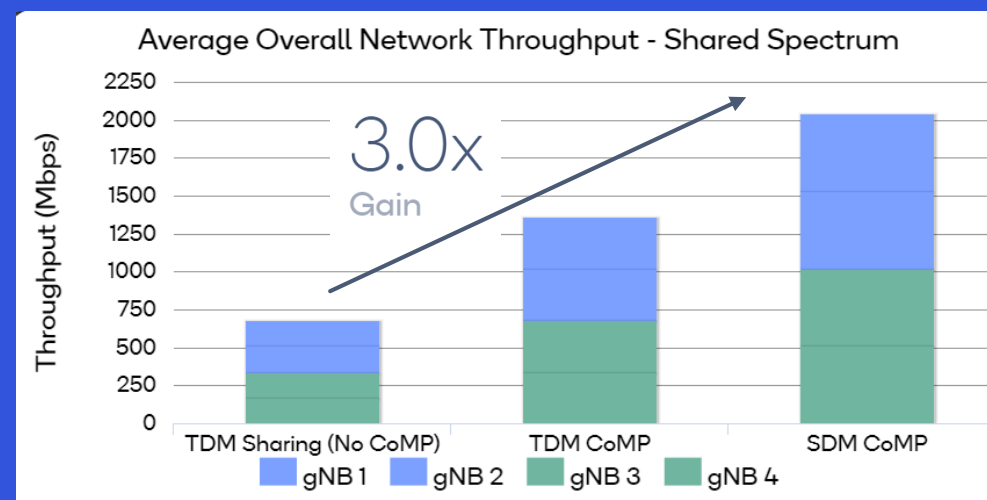
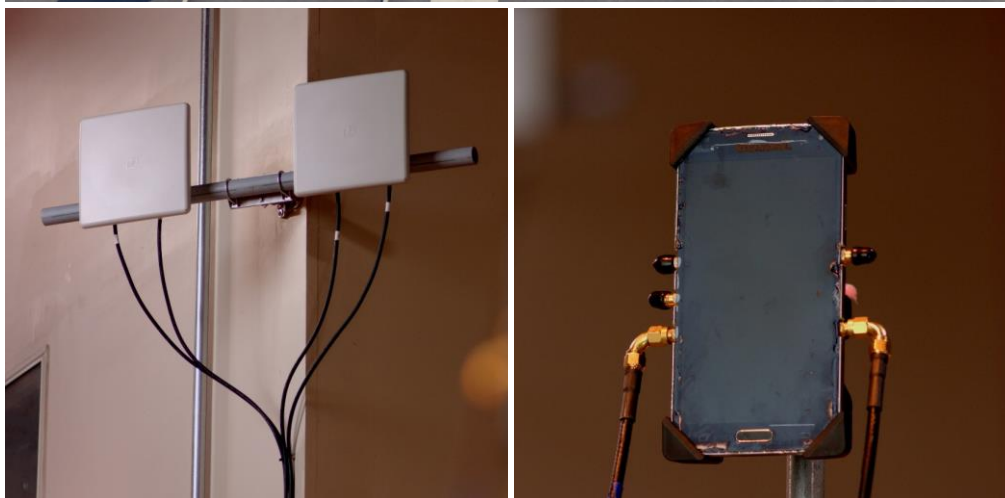
Secure

Industrial grade security with
LTE and 5G NR

Demonstrating the potential new 5G NR spectrum sharing paradigms

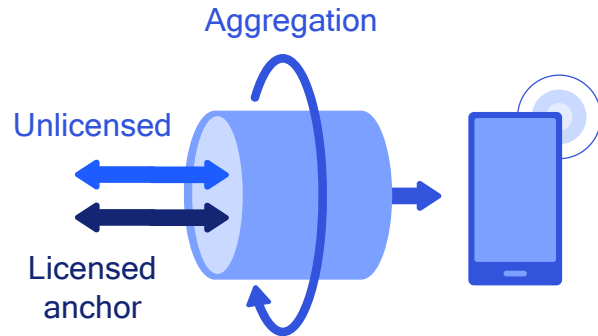
Utilizes 5G NR spectrum sharing prototype – designed to also support testing of 5G NR in unlicensed spectrum

Significant performance gains utilizing advanced intra-operator CoMP and inter-operator SDM techniques



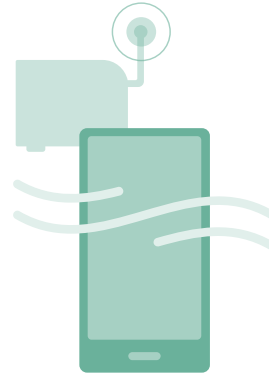
COMP = Coordinated Multi-Point
SDM = Spatial Domain Multiplexing

3GPP study on 5G NR operation in unlicensed spectrum



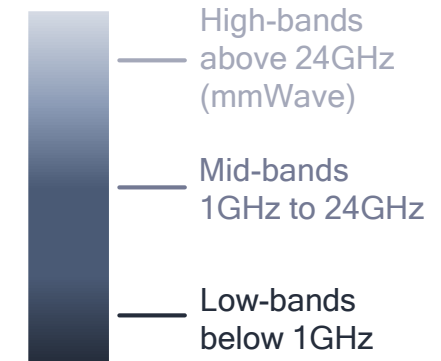
NR-based LAA

NR in unlicensed aggregated with LTE (dual connectivity) or NR (carrier-aggregation) in licensed spectrum



Standalone unlicensed

NR operating standalone in unlicensed spectrum. This will become the MulteFire™ evolution path to 5G.



Across spectrum bands


Both below and above 6 GHz, e.g., 5GHz, 37GHz, 60GHz* (*assuming no change to waveform)

1 Study item in Rel. 15 (RP-170828), which could be followed by a work item that is completed in Rel. 16.

Designing with fair co-existence in any unlicensed spectrum:
NR/NR, NR/LTE, NR/Wi-Fi



Thank you!

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For more information, visit us at:

www.qualcomm.com & www.qualcomm.com/blog

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WHP Telecoms

IEEE 5G SUMMIT – Glasgow 14th May 2018

Panel session– “Barriers to deployment”



WHP - Introduction



- **Infrastructure support partner** to the telecommunications industry for 30 years
- **Recognised market leader** and largest provider in our field
- **We provide end to end services** to enable the deployment, upgrade, improvement and densification of networks across all technologies
- **Deeply embedded relationships** with customers, long term partnerships
- **Track record of success**, delivering **high quality solutions** consistently, to the industry



WHP's turnkey services for network deployment



Advisory Services Project & Programme Management

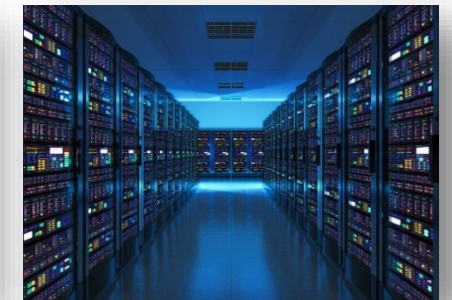
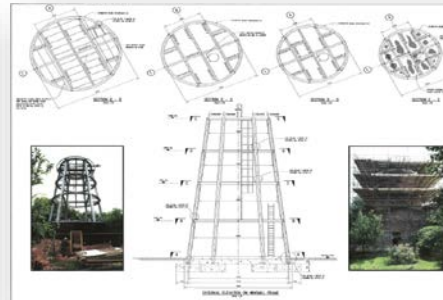
Acquisition

Planning

Design

Implementation

Integration



Property & Estates Work, Inspection & Maintenance

Barriers to deployment - background



DCMS has already committed more than £1Bn to supporting a business case for fibre and 5G networks through investment programmes and initiatives such as the DCMS Barrier Busting Taskforce

“by removing future barriers before they arise and ensuring that market and policy conditions are as good as they can be to maximise investment in new technologies”

- Matt Hancock, Minister of State for Digital

The Scottish Government have also announced £600M of gap funding for their R100 Project.

“This is the biggest public investment ever made in a UK broadband project. It is a truly transformative moment for our broadband infrastructure and a statement of our intent to make Scotland a world-class digital nation”

- Fergus Ewing, Rural Economy and Connectivity Secretary

Barriers to deployment



- **Rural barriers to deployment?**
- **Urban barriers to deployment?**
- **Other**
 - Rail
 - Motorway

5G IoT Track

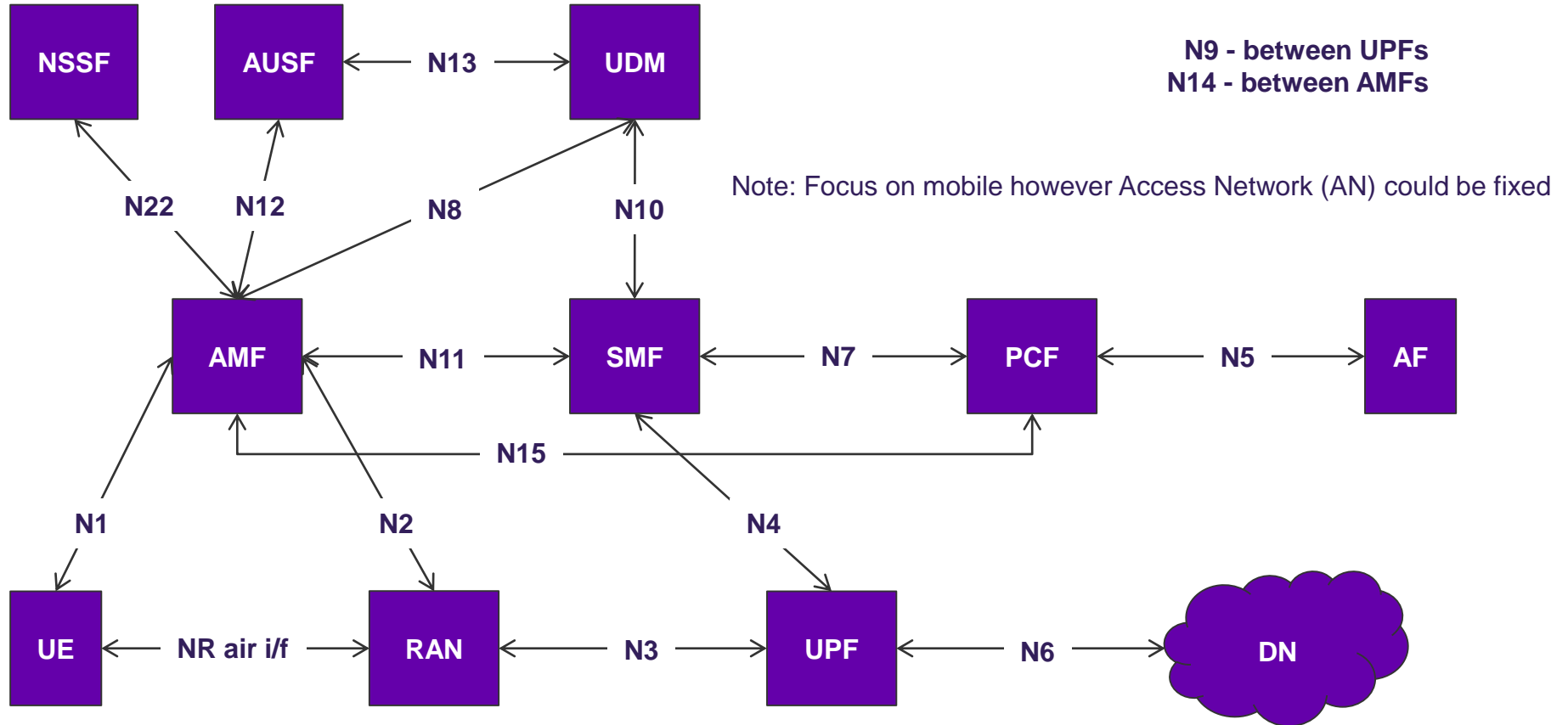




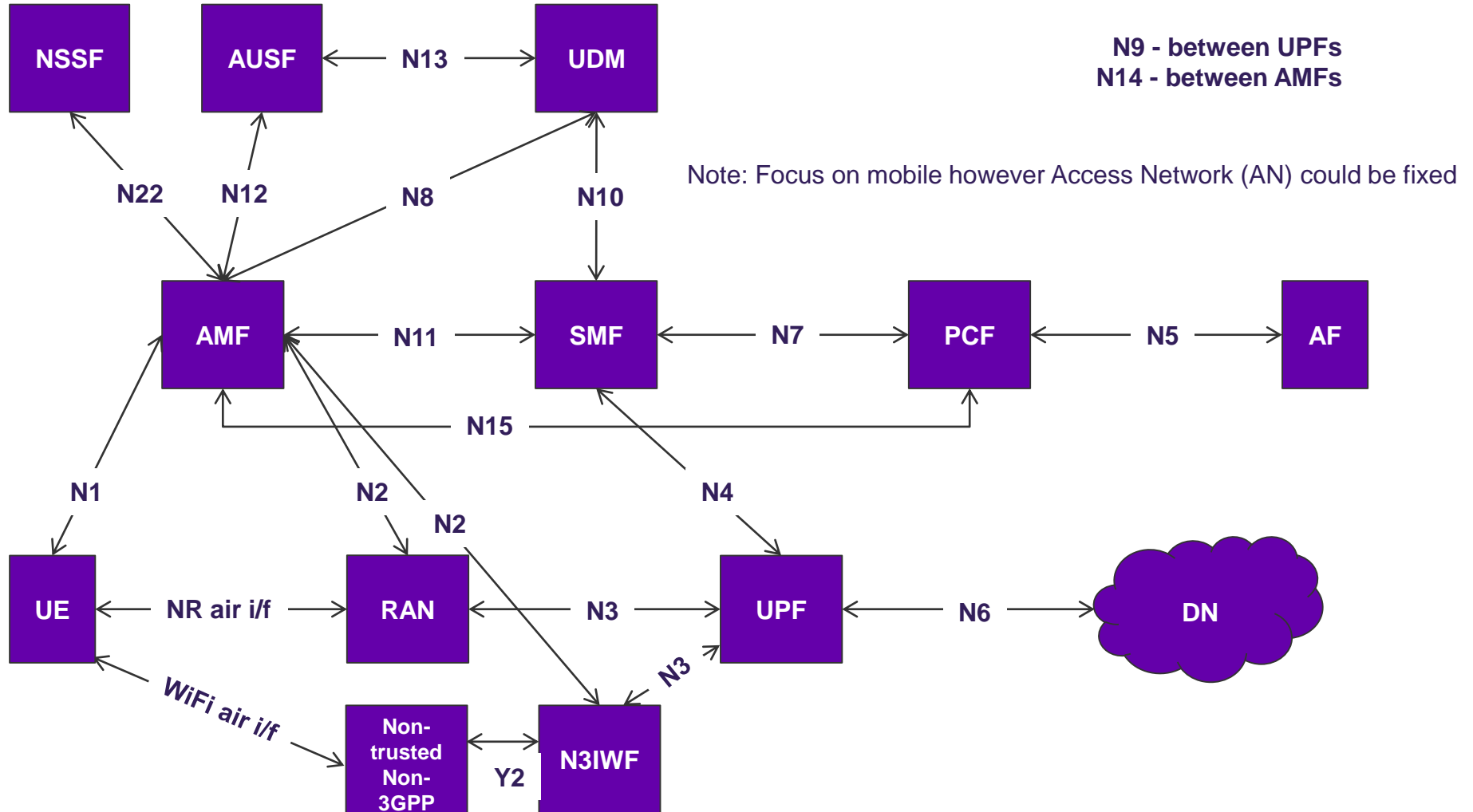
Developing a 5G Network Architecture

Michael Fitch and Andy Sutton
BT Technology Service and Operations
May 2018

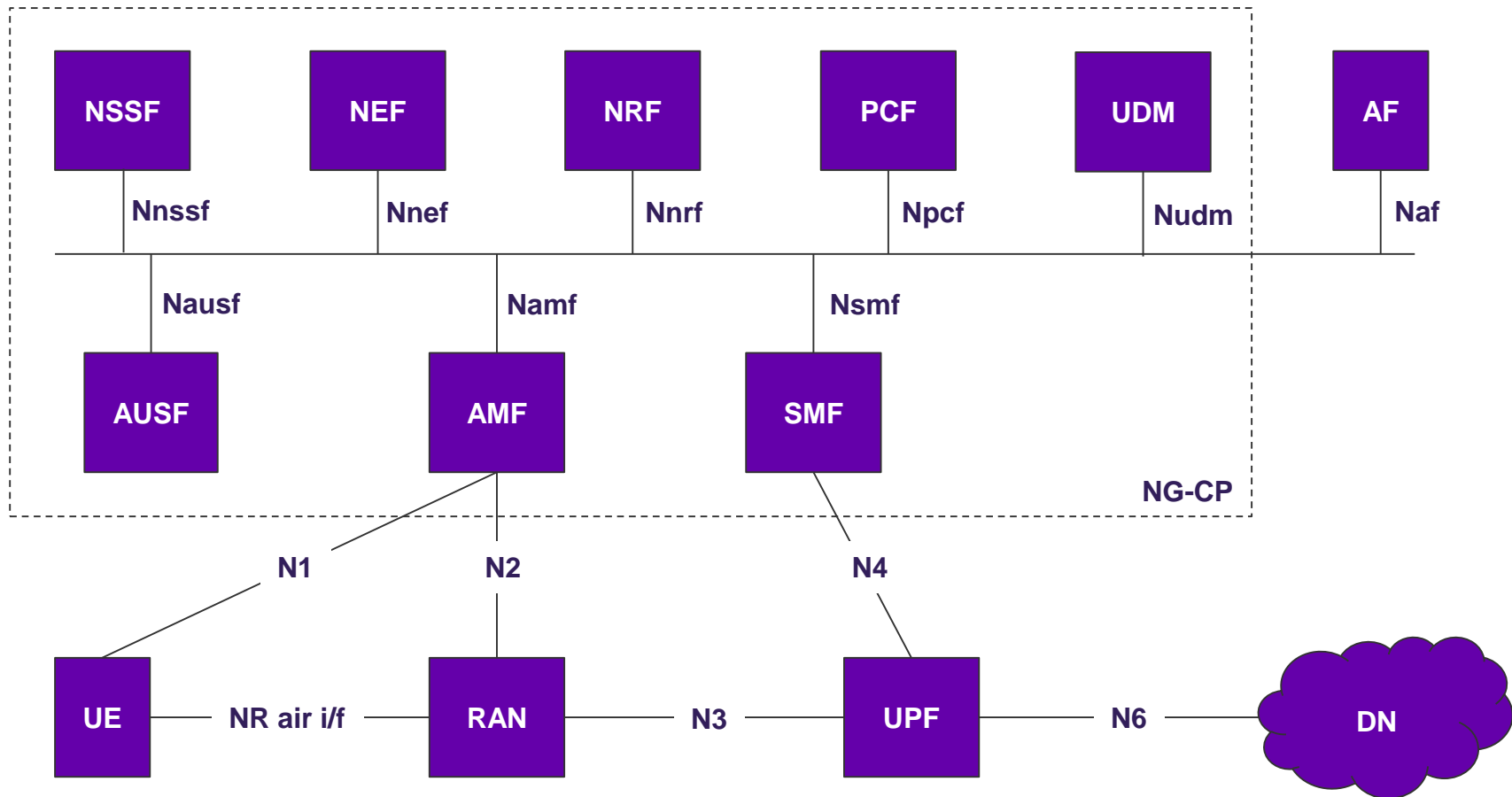
3GPP 5G network architecture



3GPP 5G network architecture



3GPP 5G Service Based Architecture



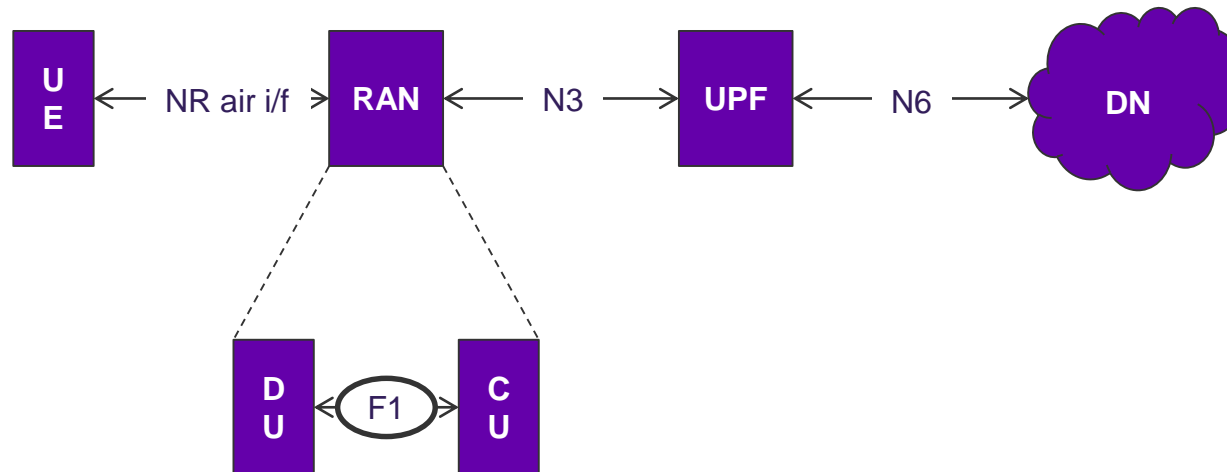
Functional blocks within 5G network architecture

1. AUSF = Authentication Server Function
2. UDM = Unified Data Management
3. NSSF = Network Slice Selection Function
4. NEF = Network Exposure Function
5. NRF = Network Repository Function
6. AMF = Core Access and Mobility Management Function
7. SMF = Session Management Function
8. PCF = Policy Control Function
9. AF = Application Function
10. UE = User Equipment
11. RAN = Radio Access Network
12. CU = Centralised Unit
13. DU = Distributed Unit
14. UPF = User Plane Function
15. DN = Data Network, e.g. operator services, Internet or 3rd party services

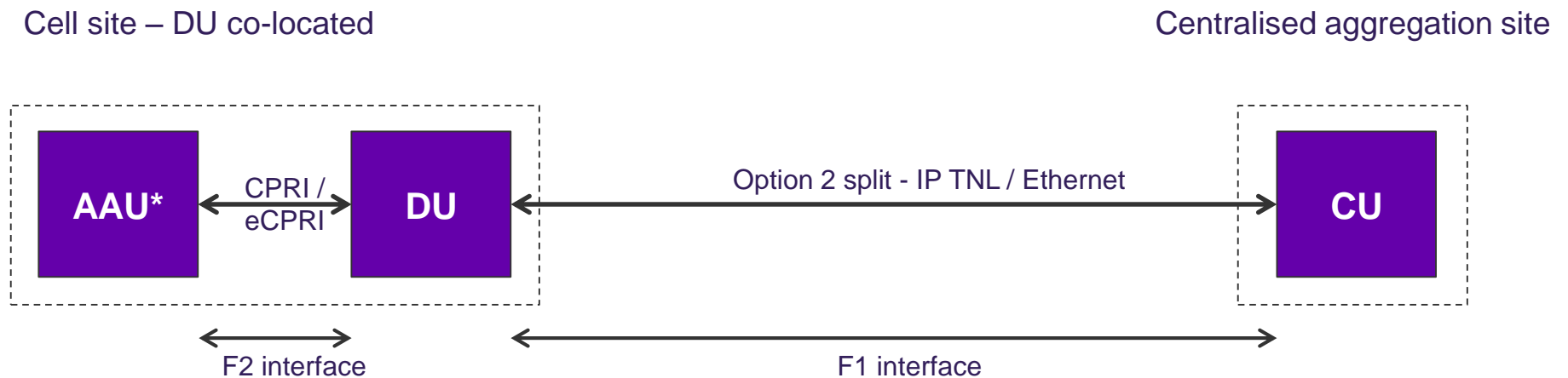
5G interfaces (reference points)

- N1: Reference point between the UE and the Access and Mobility Management function (AMF).
- N2: Reference point between the (R)AN and the Access and Mobility Management function.
- N3: Reference point between the (R)AN and the User plane function (UPF).
- N4: Reference point between the Session Management function (SMF) and the User plane function (UPF).
- N5: Reference point between the Policy Function (PCF) and an Application Function (AF).
- N6: Reference point between the UP function (UPF) and a Data Network (DN).
- N7: Reference point between the Session Management function (SMF) and the Policy Control function (PCF).
- N7r: Reference point between the vPCF and the hPCF.
- N8: Reference point between Unified Data Management and AMF.
- N9: Reference point between two Core User plane functions (UPFs).
- N10: Reference point between UDM and SMF.
- N11: Reference point between Access and Mobility Management function (AMF) and Session Management function (SMF).
- N12: Reference point between Access and Mobility Management function (AMF) and Authentication Server function (AUSF).
- N13: Reference point between UDM and Authentication Server function (AUSF).
- N14: Reference point between 2 Access and Mobility Management function (AMF).
- N15: Reference point between the PCF and the AMF in case of non-roaming scenario, V-PCF and AMF in case of roaming scenario.
- N16: Reference point between two SMFs, (in roaming case between V-SMF and the H-SMF).
- N22: Reference point between AMF and Network Slice Selection Function (NSSF).

Functional decomposition of the 5G RAN

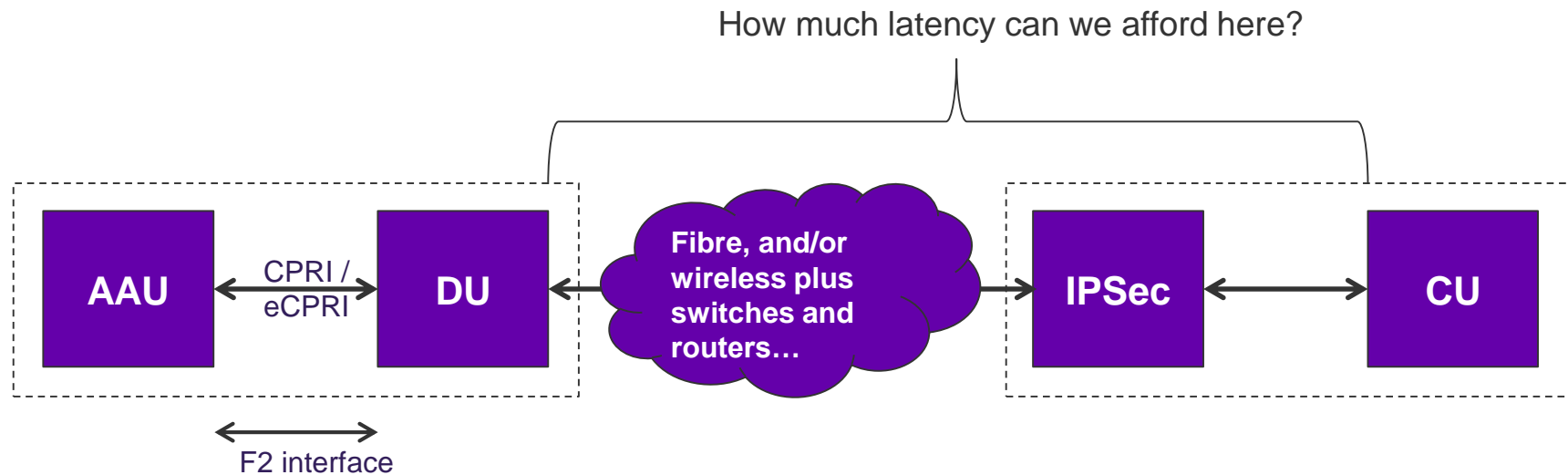


5G RAN architecture – DU co-located with RF



*AAU illustrated, actual implementation could be AAU or passive antenna with RRU

Latency requirements



How will this scale to support other split options? Does it need to?

Alternative splits in uplink/downlink?

Alternative splits as subs move from cell centre to cell edge?

...

5G Latency Requirements – Industry Targets

NGMN 5G Requirements

- 5G E2E Latency (eMBB) = **10ms** (i.e. RTT from UE-Application-UE)
- 5G E2E Latency (URLLC) = **1ms** (i.e. RTT from UE-Application-UE – or just UE-UE)

In both cases, the values are defined as capabilities that should be supported by the 5G System.

GSMA 5G Requirements

- 5G E2E Latency = **1ms** (again, defined as a capability target, not as a universal requirement)

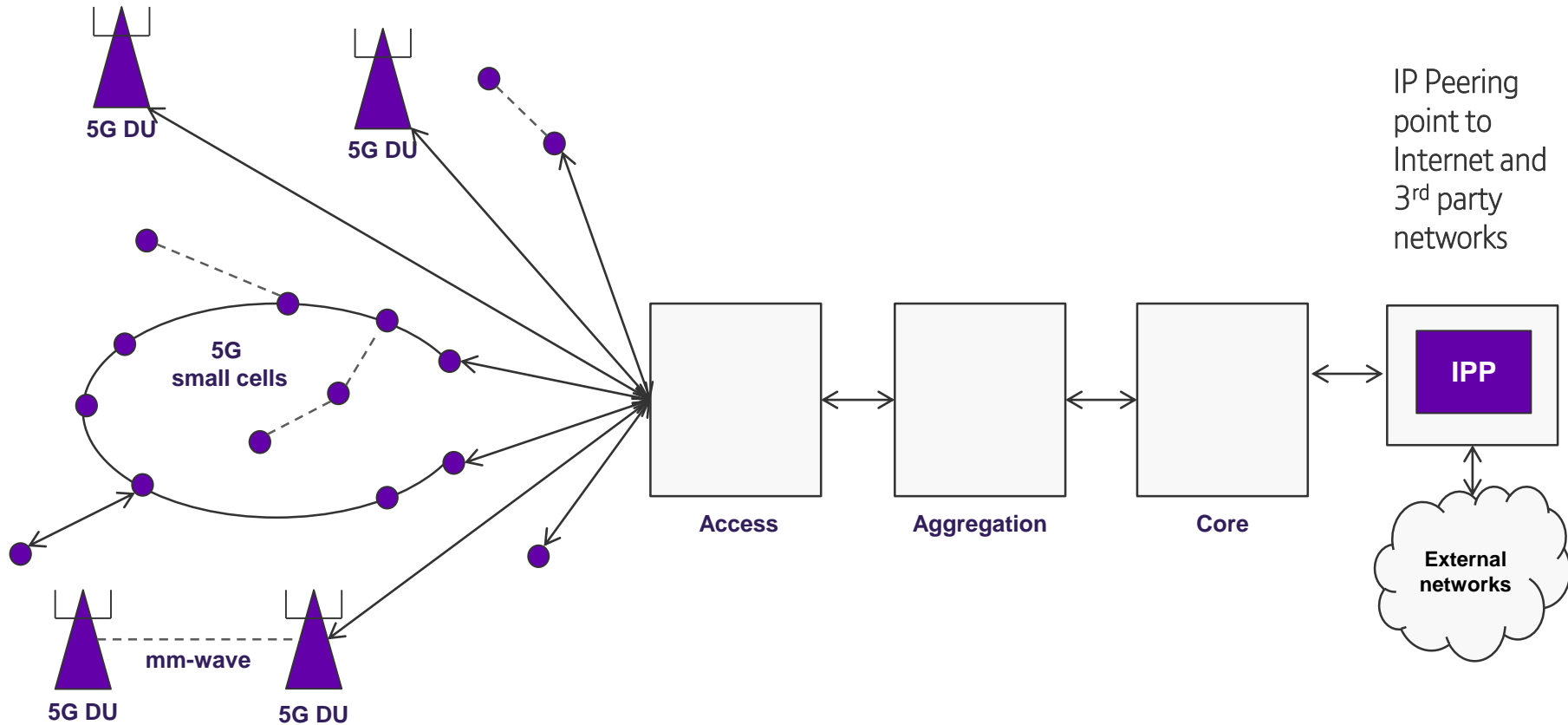
ITU-R IMT-2020 Requirements

- eMBB User Plane Latency (one-way) = **4ms** [radio network contribution]
- URLLC User Plane Latency (one-way) = **1ms** [radio network contribution]
- Control Plane Latency = **20ms (10ms target)** [UE transition from Idle to Active via network]

Low Latency Use Case Requirements (various sources)

- Virtual Reality & Augmented Reality: **7-12ms**
- Tactile Internet (e.g. Remote Surgery, Remote Diagnosis, Remote Sales): **< 10ms**
- Vehicle-to-Vehicle (Co-operative Driving, Platooning, Collision Avoidance): **< 10ms**
- Manufacturing & Robotic Control / Safety Systems: **1-10ms**

Developing a 5G Network Architecture



5G Network Latency modelling

We have done significant analysis of network latency and cost to underpin the 5G Architecture (this work is ongoing but the figures below provide initial results).

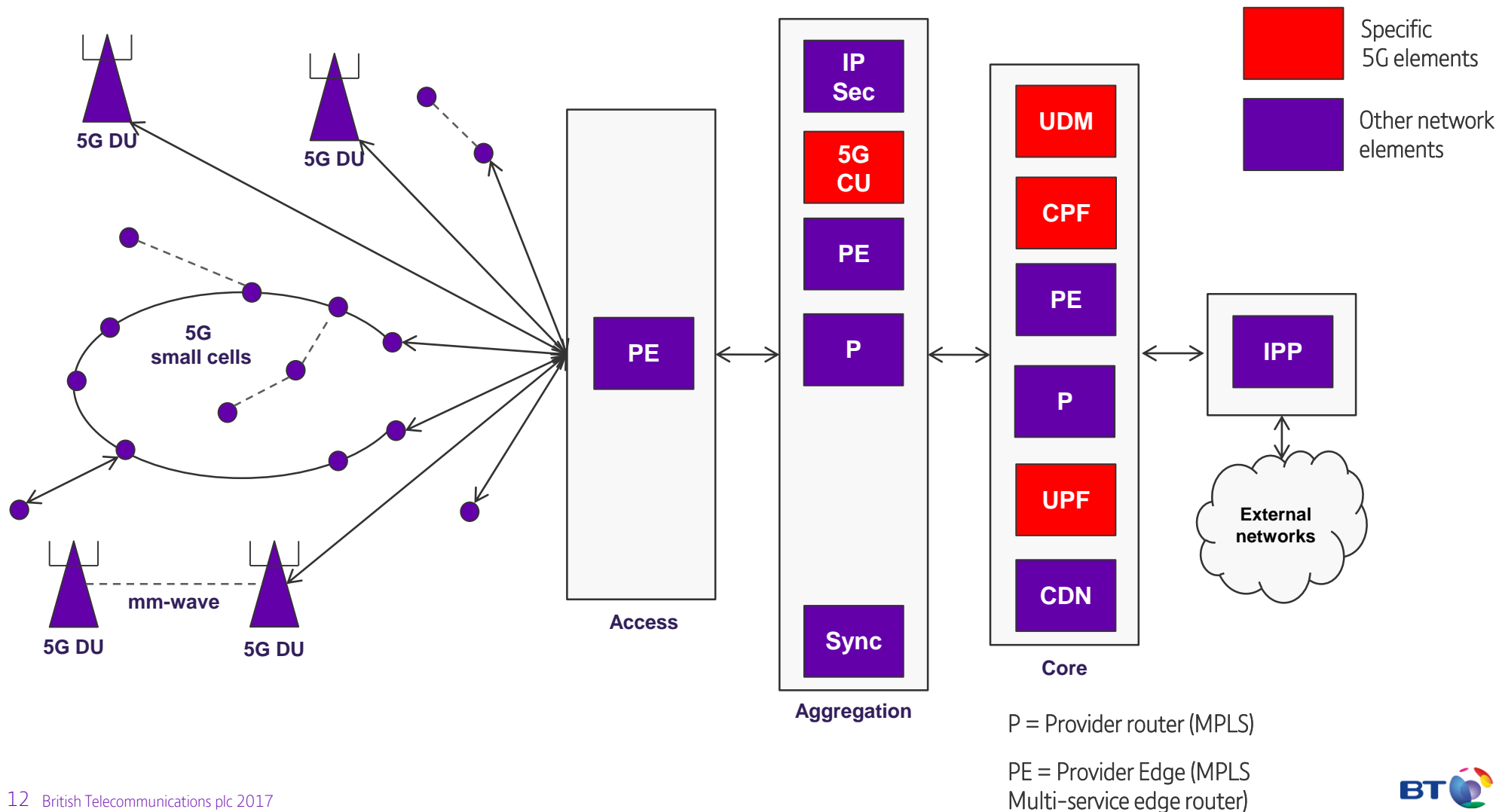
The following figures relate to content served from the same location as the UPF node:

UPF Location	Access	Aggregation	Core
Number of sites	12000	106	10
Transport Latency (1-way)*	0.6ms	1.2ms	4.2ms
Estimated 5G Latency (RTT)*	9.2ms [eMBB]	10.4ms [eMBB]	16.4ms [eMBB]
	2.2ms [URLLC]	3.4ms [URLLC]	9.4ms [URLLC]

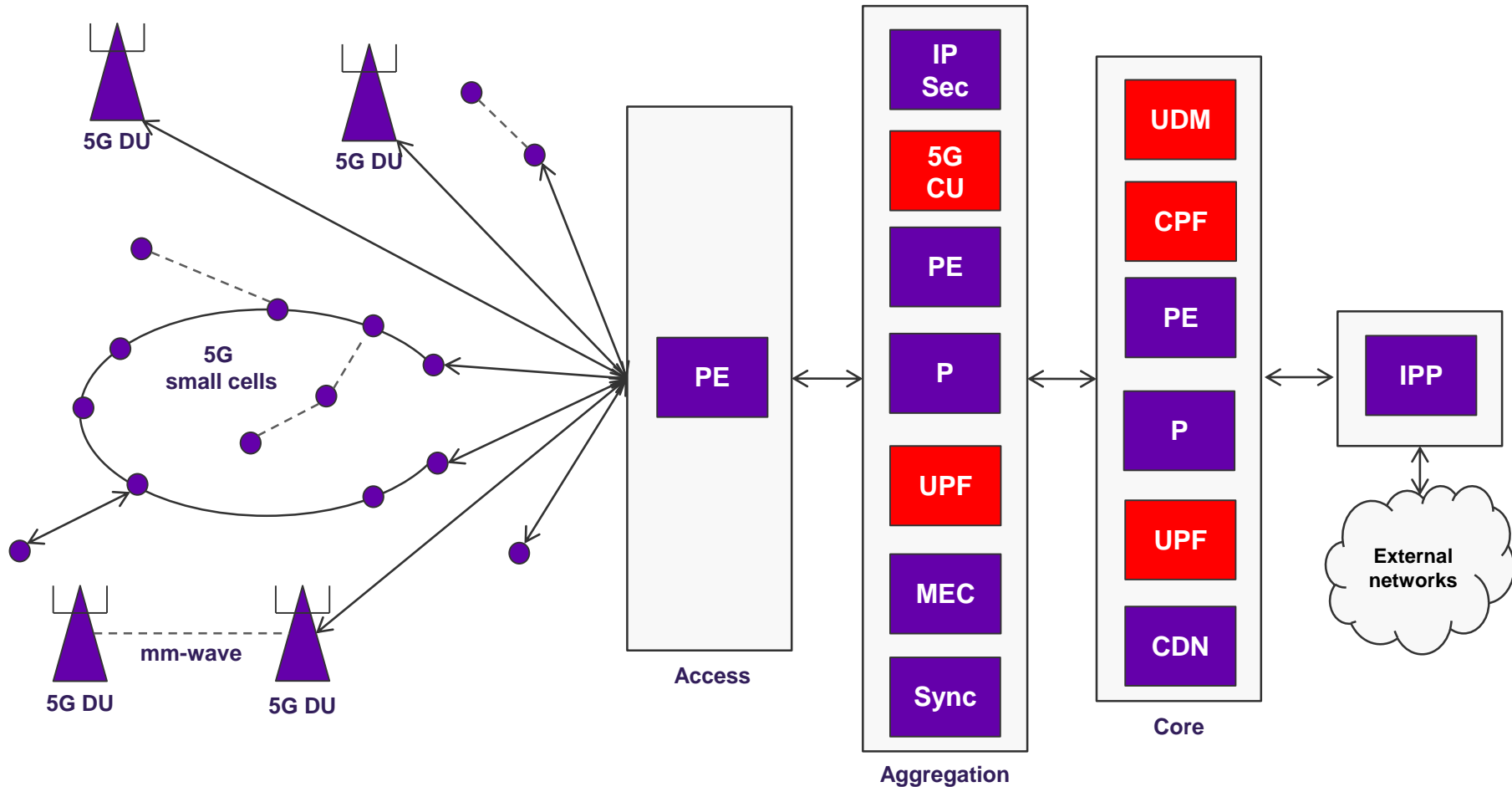
* Assumptions:

- Latency figures based on 95th-percentile of transmission delay (i.e. 95% of cell sites are within this) + overhead for IP
- 5G RTT assumes 8ms overhead for 5G New Radio & Next-Gen Core (eMBB case) - 1ms for URLLC (as per 3GPP 5G)

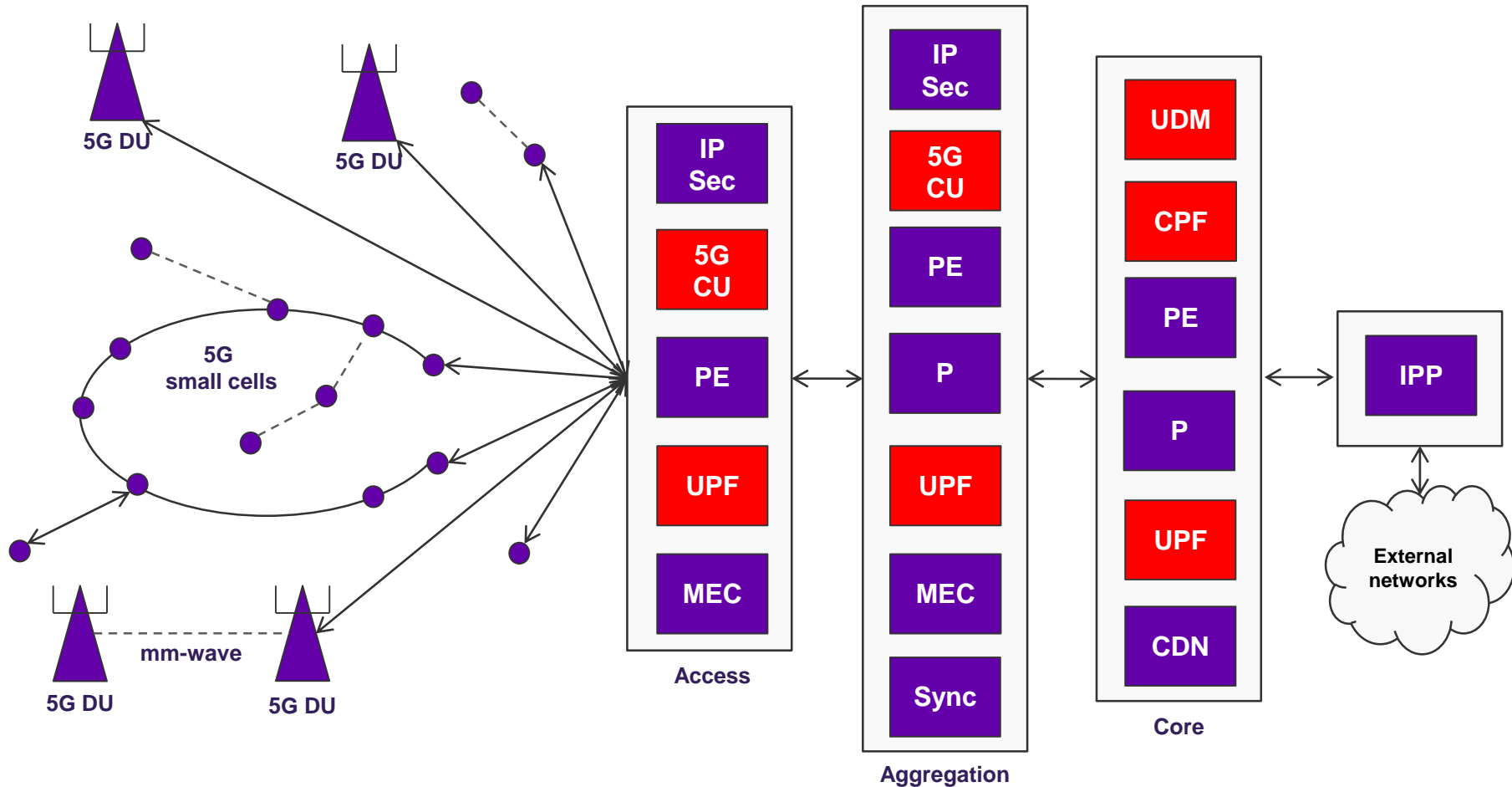
Conceptual 5G Network Architecture (1)



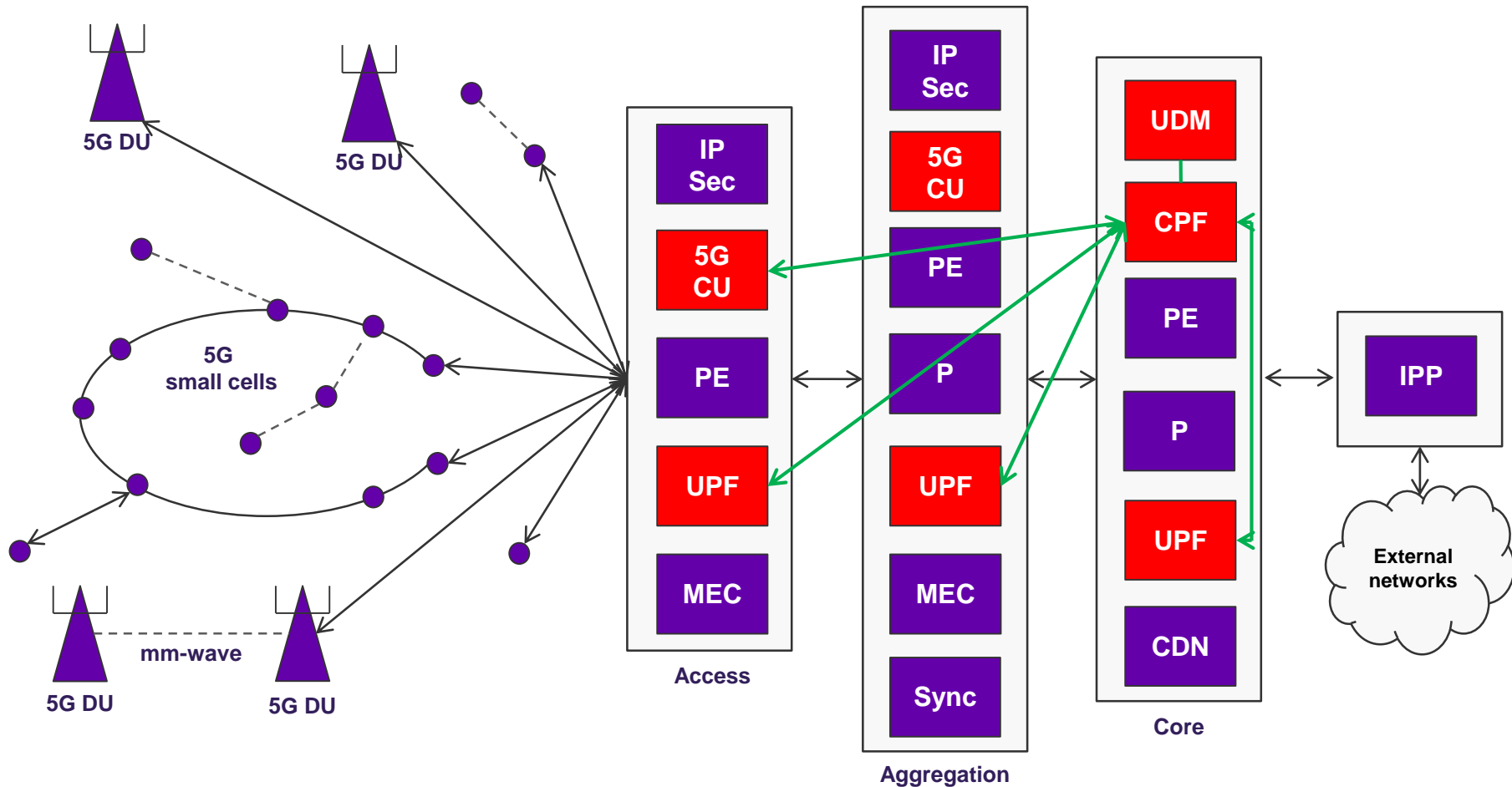
Conceptual 5G Network Architecture (3)



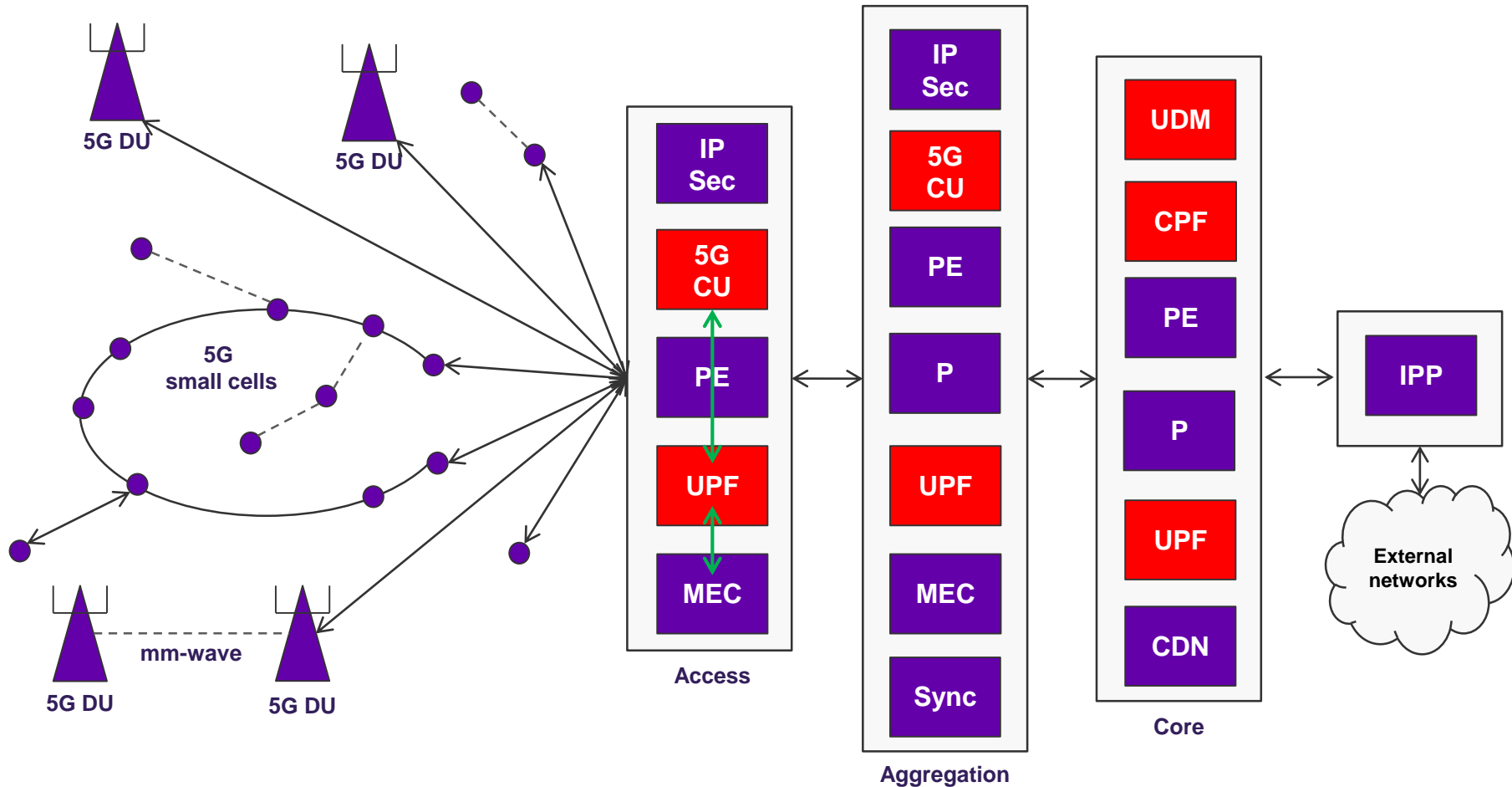
Conceptual 5G Network Architecture (5)



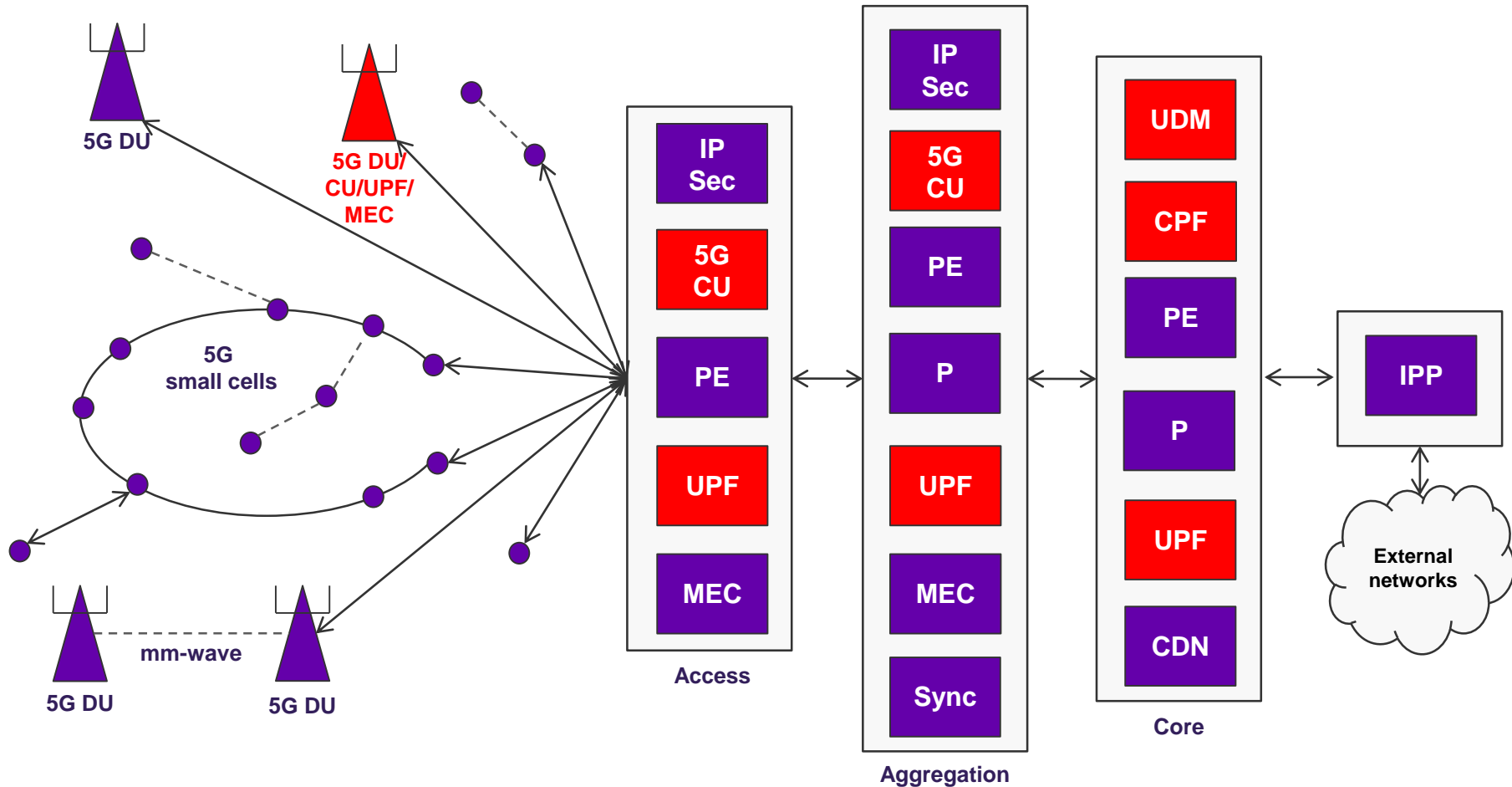
Consider control plane latency – potential for distribution?



Low-latency access to apps, content and compute

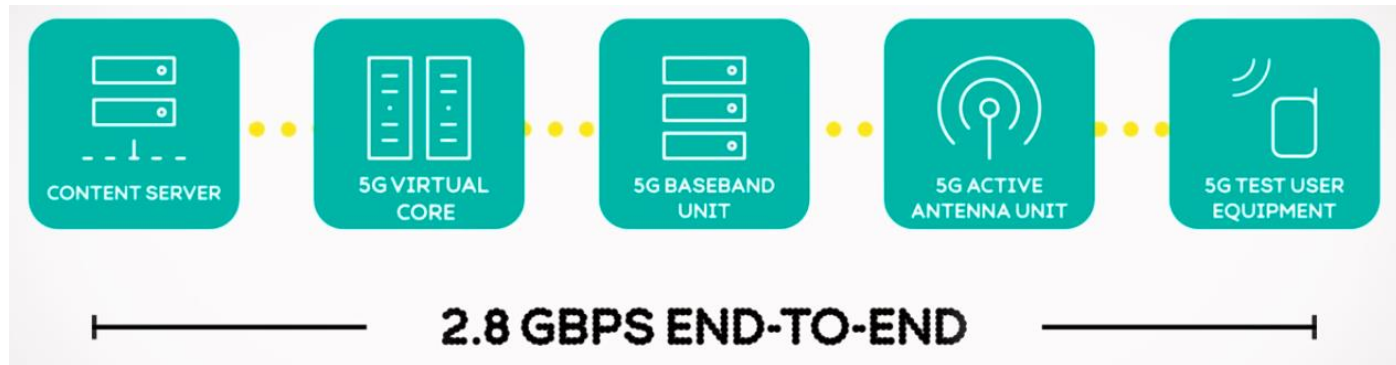


Ultra-low latency service optimisation



BT/EE trials

EE hits 2.8Gbps download speeds in UK-first 5G trial

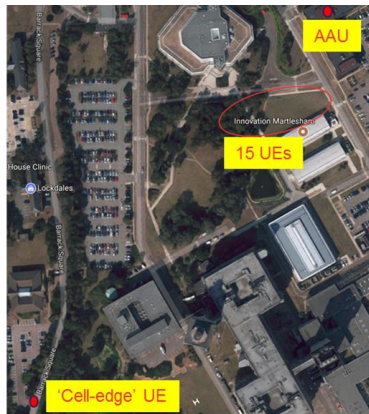


University, BT and Nokia to conduct joint research into 5G mobile networks in Bristol

<http://www.bristol.ac.uk/news/2017/november/5g-mobile-networks.html>

<http://newsroom.ee.co.uk/ee-showcases-end-to-end-5g-network-architecture-with-28gbps-speeds/>

Massive MIMO testing @Adastral Park



Huawei and EE Showcase 5G Uplink and Downlink Decoupling PoC in London



Summary

- 5G will address enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC), use cases
- 5G requires a new network architecture
- The functional decomposition of the RAN results in DU and CU network elements
- Next Generation Core network can be grouped into two functional blocks, CPF and UPF
- Some RAN functionality will move towards the core whilst the core will move towards the RAN
- Small cells are an essential component of 5G
- URLLC is an overlay and requirements will vary based on use cases
- URLLC use cases, UR use cases and LL use cases...
- Initial MTC use cases will be addressed by NB-IoT (4G)



Thank You!
Any questions?

Andy Haig - Vodafone



NOKIA

The Global IoT Service Provision Opportunity

Charlie Swan

charlie.swan@nokia.com

May 2018

8.4 billion connected things will be in use worldwide in 2017, up 31 percent from 2016, and will reach 20.4 billion by 2020. Total spending on endpoints and services will reach almost \$2 trillion in 2017.

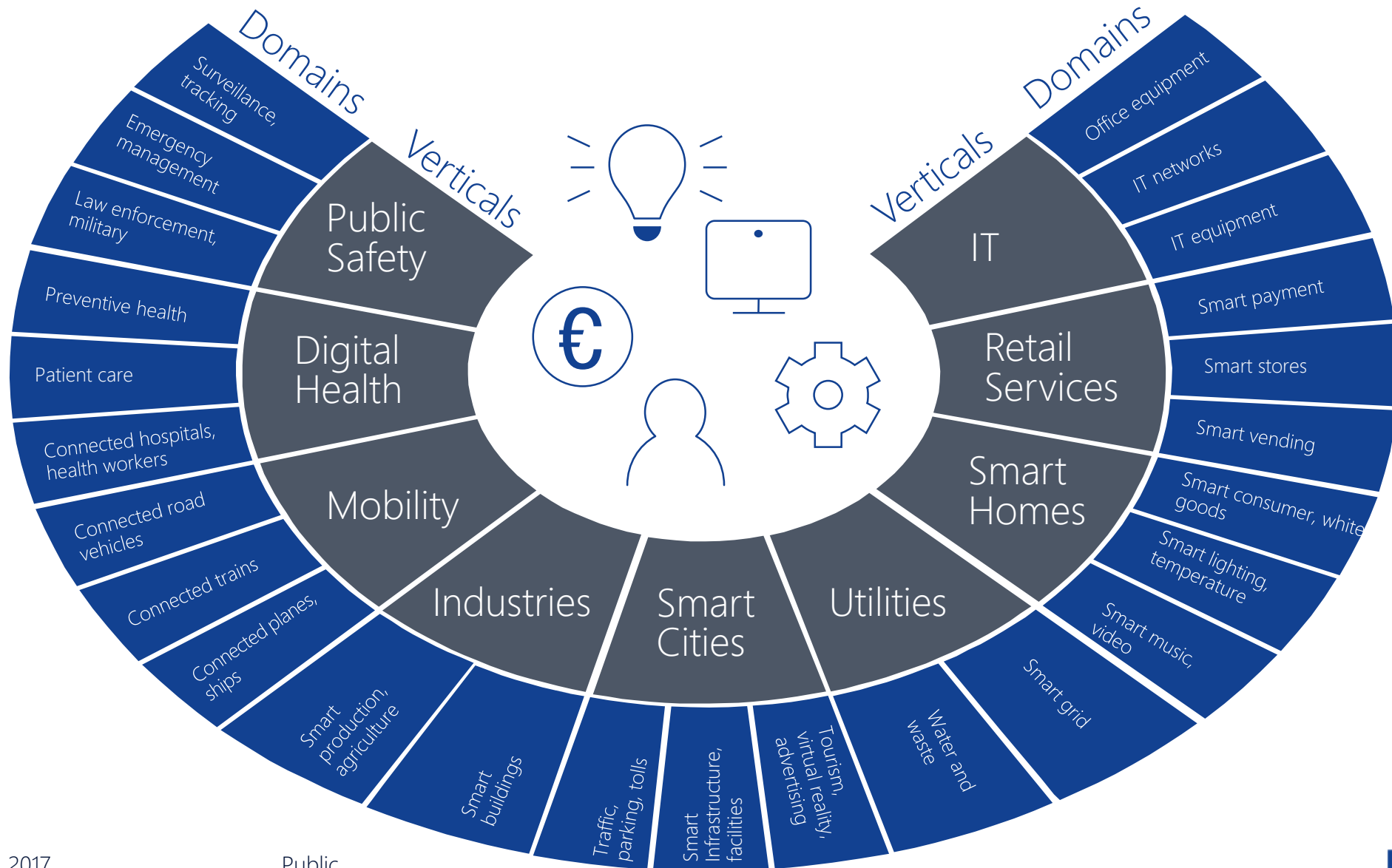
– Gartner, January 2017

A service provider's opportunity in the service delivery value chain

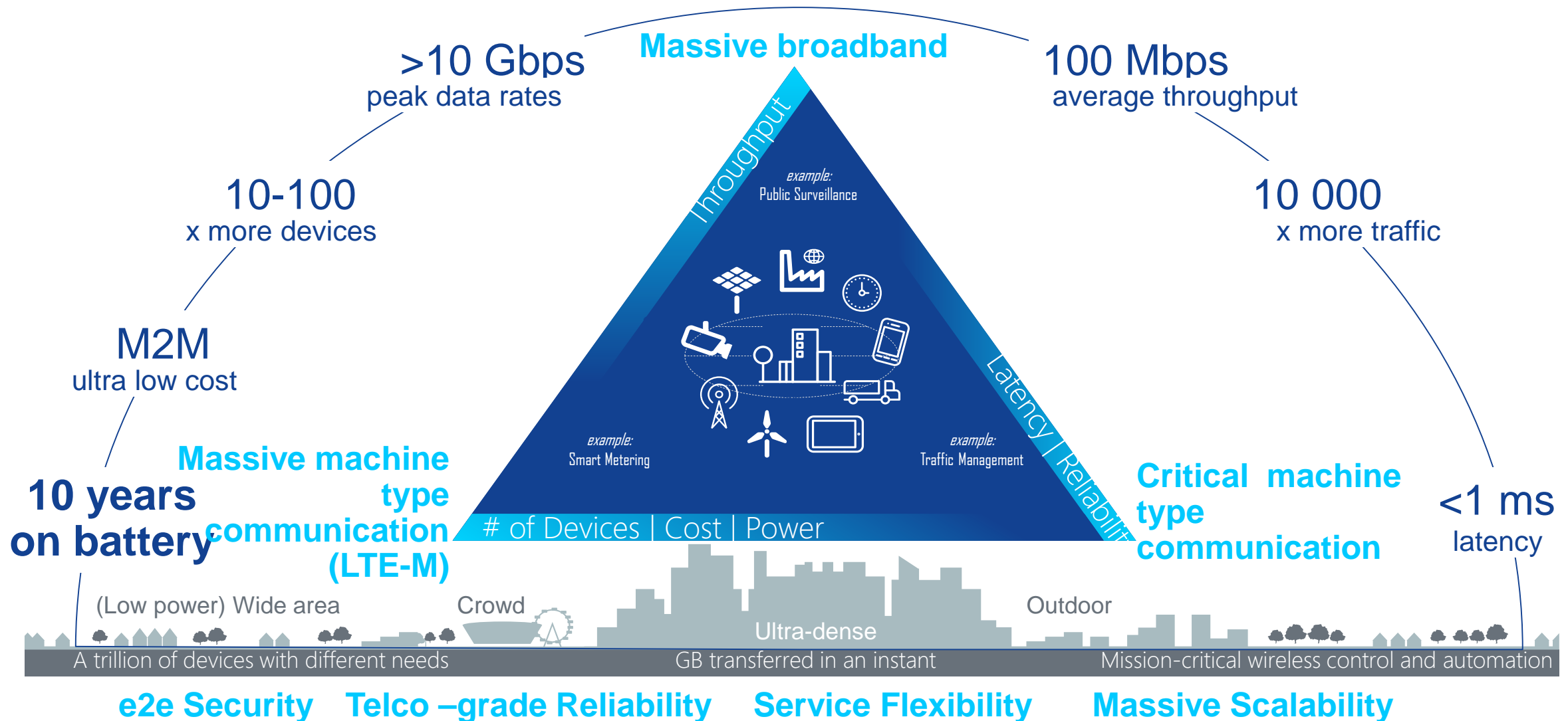
	Connectivity	Device	Application	Service provision	System integration
Description	Offer the network for transmission of data from IoT devices	Offer the end user module, with an embedded M2M chipset	Provide the actual applications that manage the data collected by the device	Manage the distribution, supply chain, fulfilment, billing and support	Provide system integration services; Design/develop systems
Approximate share of value	5-30%	5-20%	30-60%	20-30%	<20%
Approximate EBIT margin	~10%	<5%	0-30%	0-10%	~ 0%

Source: Analysys Mason, 2015

The IoT has a transformational impact on (almost) all sectors



IoT is a major driver for the evolution towards 5G



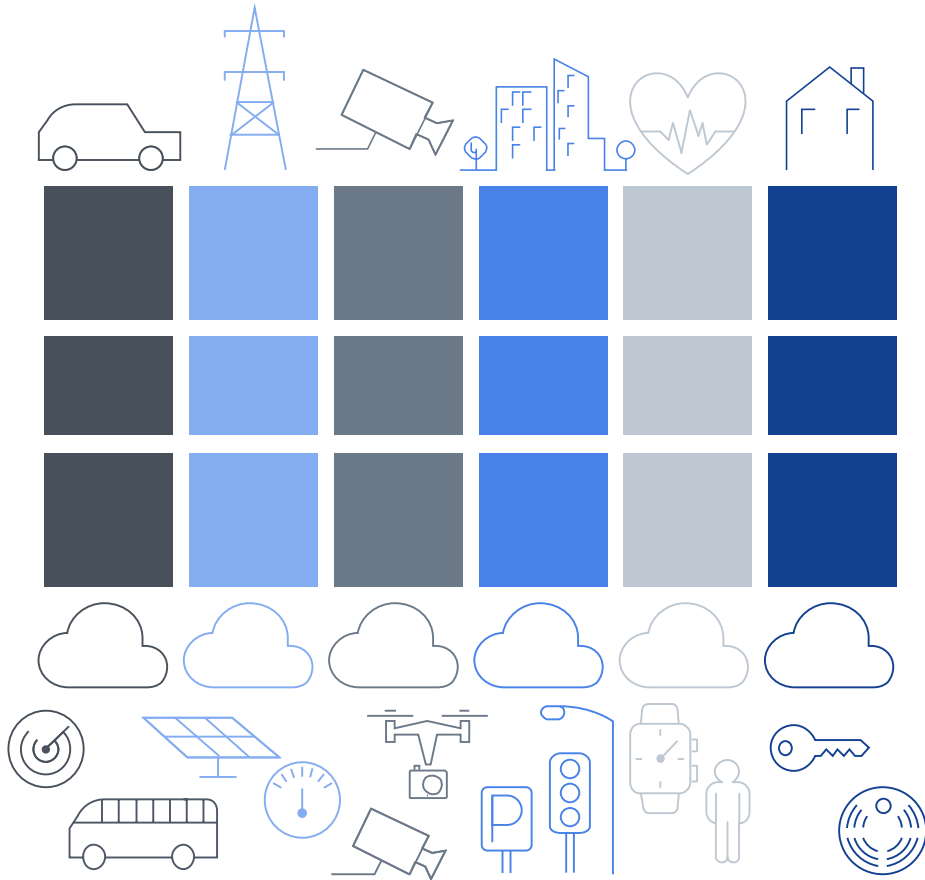
Until now, most service providers have focused on M2M vertical applications



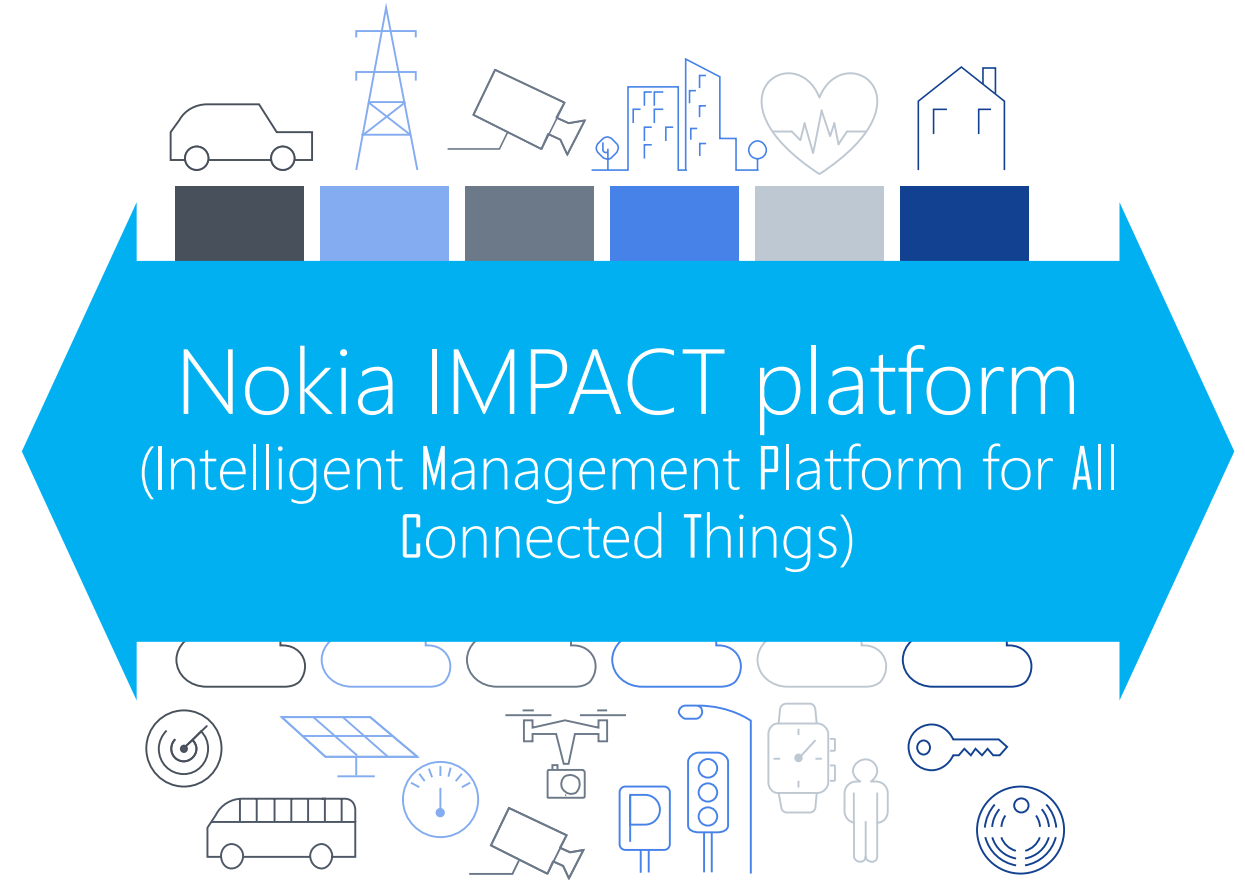
Siloed systems,
lack of
standards
and no
interoperability

- Limited business value
- High cost for integration
- Duplication of effort
- Underutilized resources
- No economies of scale

A horizontal platform approach to enable mass adoption



- Under-utilized resources
- High integration cost
- No economies of scale



Horizontal approach

- Streamline ops & reduce costs
- Mix & match devices, apps & data
- Start small, scale fast, grow big

Opportunity for service providers
to deliver
IOT/Smart City/Smart Utilities
“as a Service”.

NOKIA

5G is Now, from eMBB to Digital Society

Dr. Wenbing Yao

VP, Business Development and Partnerships



IEEE 5G Summit, May 2018, Glasgow

5G is Now the Reality

R15, a milestone for enhanced MBB experience; R16, a platform serving all industries

Rel - 15		Rel - 16
NSA NR	SA NR	Full IMT 2020 NR
eMBB		eMBB/uRLLC/mMTC

1'st 5G Trial

Pre-Commercial 5G

5G Commercial deployment



Global 5G User

400_M

Forecast: Ovum

Global Massive 5G Deployment

2017

2018

2019

2020

2022

Standard

Phase 1

NR Framework

- Waveform & Channel Coding
- Frame Structure, Numerology
- Native MIMO & Flexible Duplex

Others: uRLLC

Architecture

- UL&DL Decoupling
- CU-DU Split
- NSA / SA

Phase 2

NR Improvement

- New Multiple Access
- eMBB Sub6G Enhancement
- Self-Backhaul

Vertical Digitalization

- uRLLC Enhancement
- mMTC
- D2D
- V2X
- Unlicensed

Devices

CPE

NSA
F-OFDM/SCMA
Massive MIMO

SmartPhone

SA; NR based LAA/LWA



SmartPhone/ IoT Modules




























NSA and SA
IoT-5G (mMTC); V2x (uRLLC)

5G Population Coverage

22%

Forecast: GSMA

Latest Protocol Terminals for Accelerated 5G Deployment

	2018	2019~
4R, TM9	   High-end & Middle-end Smartphone	     Most of Smartphone
Short TTI		  Smartphone
IoT	    (NB-IoT) (NB-IoT) (NB-IoT, eMTC) (NB-IoT, eMTC)	    (NB-IoT) (NB-IoT) (NB-IoT, eMTC) (NB-IoT, eMTC)
5G	  C-Band CPE1.0 (Commercial) mmWave CPE1.0 (Commercial)	       C-Band CPE2.0 (Commercial) mmWave CPE2.0 (Commercial) Smartphone

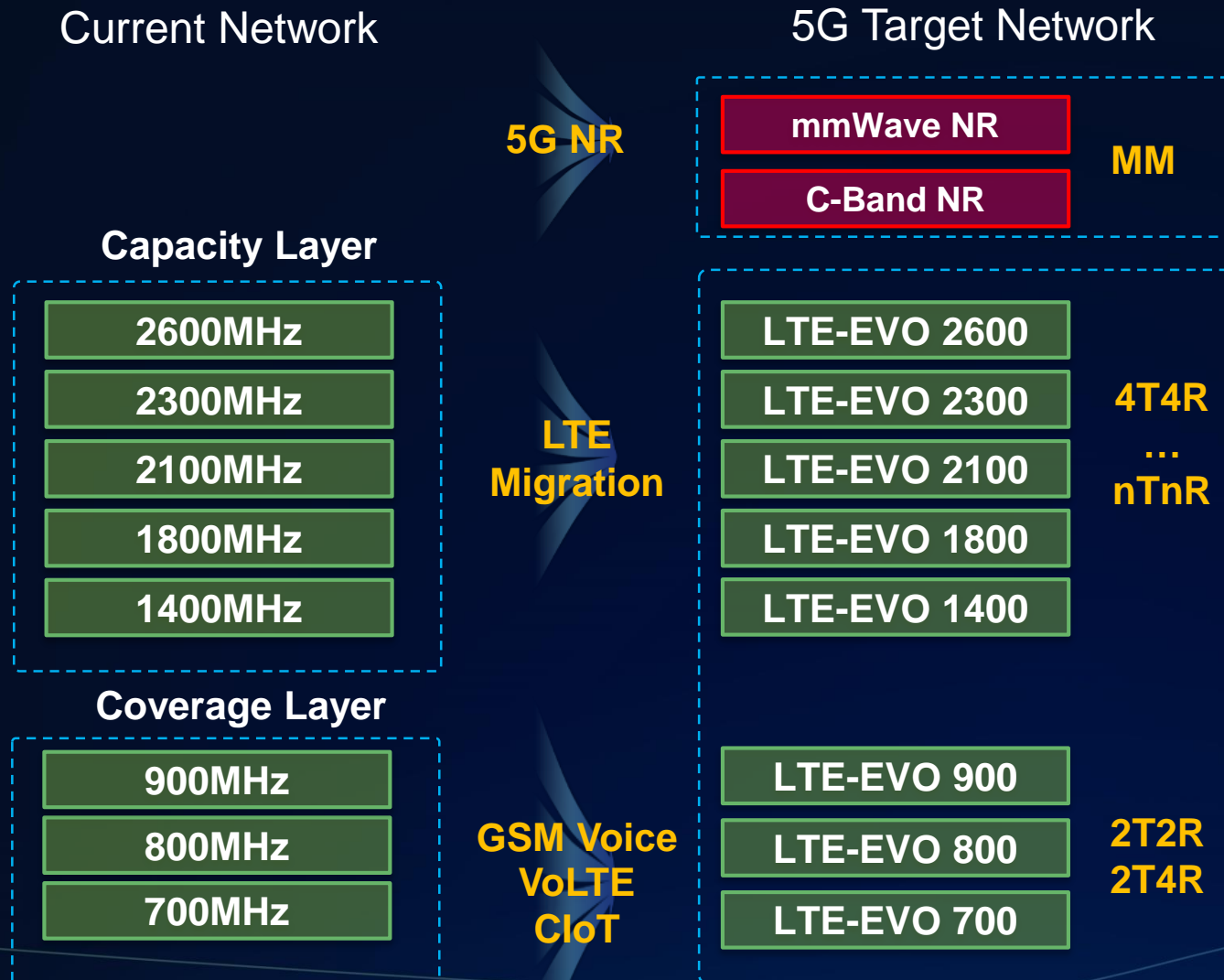
- ✓ More and more terminals can support the latest features and technology
- ✓ More 5G chipset development, more 5G terminals



Mobile Network 2020s

One Network for All Bands, All RATs, All Industries

Target Network Evolution towards 5G with Investment Protection



- Complementary Bands for Capacity, such as WTTx
- **3.5 GHz , first 5G target band**
- Scaled out 4T4R
- Massive MIMO for hotspots
- All Bands deployed by LTE Evolution to nTnR
- Hardware ready for 5G NR

**Low Band for
Building a Fundamental Network**
Spectrum Refarming + CloudAIR 2.0

Scenario-oriented 5G Era SingleRAN Deployment

5G NR Continuous Deployment
in Traffic Highland

LTE Foundation Layer
for Full Services

GULN@900M Builds Ubiquitous Coverage
for Voice, Data, & NB-IoT

Indoor
Digitization
in 5G Era

Scenario-
oriented
Site



One OSS +
Wireless AI

5G NR Continuous Deployment in Traffic Highland



- 1 C-band M-MIMO to match 1.8 GHz LTE coverage
- 2 3D Beamforming adding 2~3dB Downlink coverage
- 3 DL/UL Decoupling enable co-coverage in Uplink
- 4 L/NR spectrum cloudification to maximize spectrum utilization

Scenario Oriented Sites: Simplified, Drop & Play

Green Field

- 2m² footprint
- All in-one, non-cabin
- 7 Bands

Street

Situational Sites, On-demand Coverage

- Nlos Backhaul
- Reuse Pole

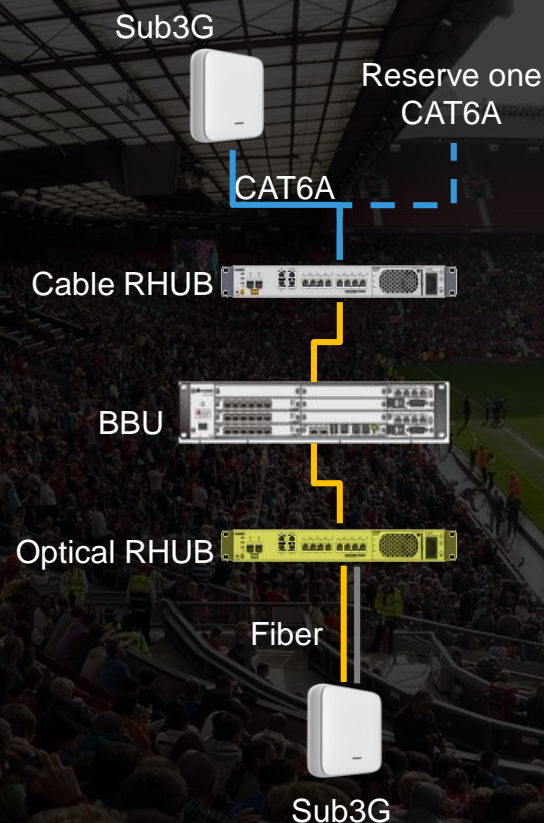
Rural

- ROI 3~5 years@2000 population



LampSite Indoor Digitalization Enables 5G-oriented Evolution

Indoor Digitalization



Full Scenario Support

LampSite Pro



2*250mW



Huge Capacity & Wide Coverage



Campus



Sport Center



Traffic Center



Shopping Mall



Hospital



Metro

LampSite Grid



2*250mW



Multi Wall scenario



Office



Hotel

LampSite Sharing



Multi-operator sharing



2*40W



2*5W



2*250mW

Flexible Capacity

5G Smooth Evolution

Opening Network Capabilities

5G Lampsite - The World's 1st 4/5G Digital Indoor System

The World's 1st 4/5G Digital Indoor System



**4G+5G
Lampsite**

Unified Digital Architecture for

4G/5G

Wideband (100MHz @ C-band)

Multi-bands @ Sub3G

4T4R & v8T8R @ C-band

Sub-6G @ One Box



Multi-Play @ One Box

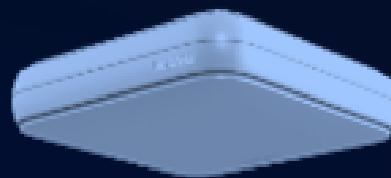
Meter-Level position



IoT + eMBB



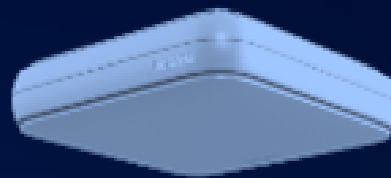
Single Operator 5G overlay



C-band NR module

- B42/43
- 4×4 MIMO
- IBW 100MHz

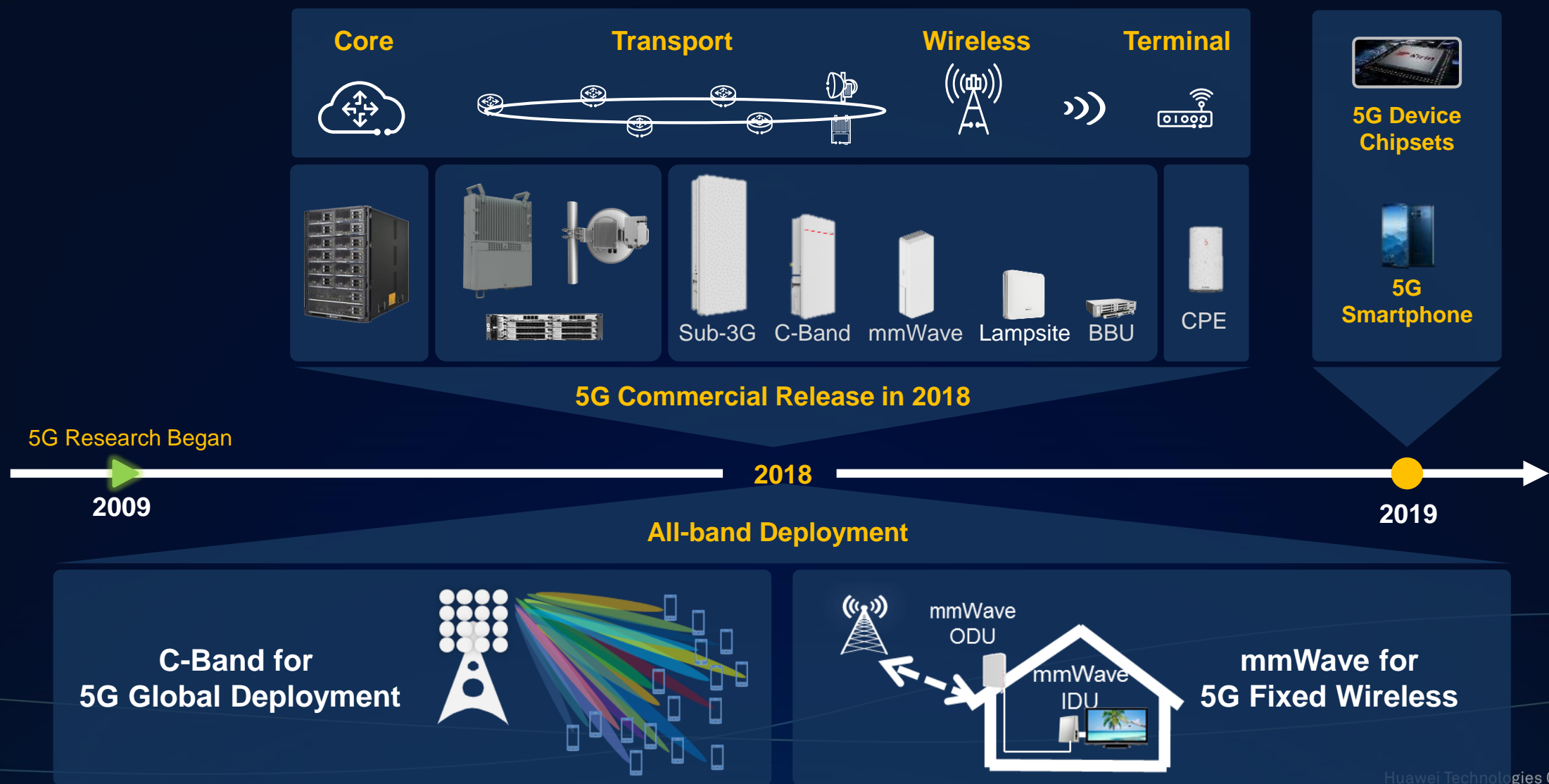
Multi Operator 5G overlay



C-band NR module

- B42/43
- 4×4 MIMO
- IBW 200MHz

Huawei End-to-End Full Series 5G Solution in 2018



Keep Innovation for Industry Digitalization

Cloud VR



Connected Car



Wireless Factory



Digital Sky



Wireless eHealth



Creating New Ecosystem with



283 Partners

49 Projects

4 SIGs



PHILIPS



Tencent 腾讯

FESTO

KUKA



BOSCH

YouTube

TUM



dji



...



Thank You.

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WHP Telecoms

IEEE 5G SUMMIT – Glasgow 14th May 2018

Achieving fit-for-purpose infrastructure - the need for collaboration

Raj Sivalingam
WHP Telecoms

WHP - Introduction



- **Infrastructure support partner** to the telecommunications industry for 30 years
- **Recognised market leader** and largest provider in our field
- **We provide end to end services** to enable the deployment, upgrade, improvement and densification of networks across all technologies
- **Deeply embedded relationships** with customers, long term partnerships
- **Track record of success**, delivering **high quality solutions** consistently, to the industry



Fit for purpose communications infrastructure



Key infrastructure opportunities and challenges:

- 5G: “Building UK leadership and capacity”
- Extending fibre: deeper into the network
- Utilities: enabling connectivity for smart grid
- Rail and road corridors

To summarise, to enable fit for purpose UK connectivity needed for the 2020s.....



We need more 'collaboration' in,

- business models to incentivise investment
 - eg. neutral hosting models
- enabling standardised approach to regulation
 - planning permissions, access to public assets
- proactive approach to spectrum
 - by end users and regulators
- leadership and knowledge sharing (in a complex and interdependent value chain)



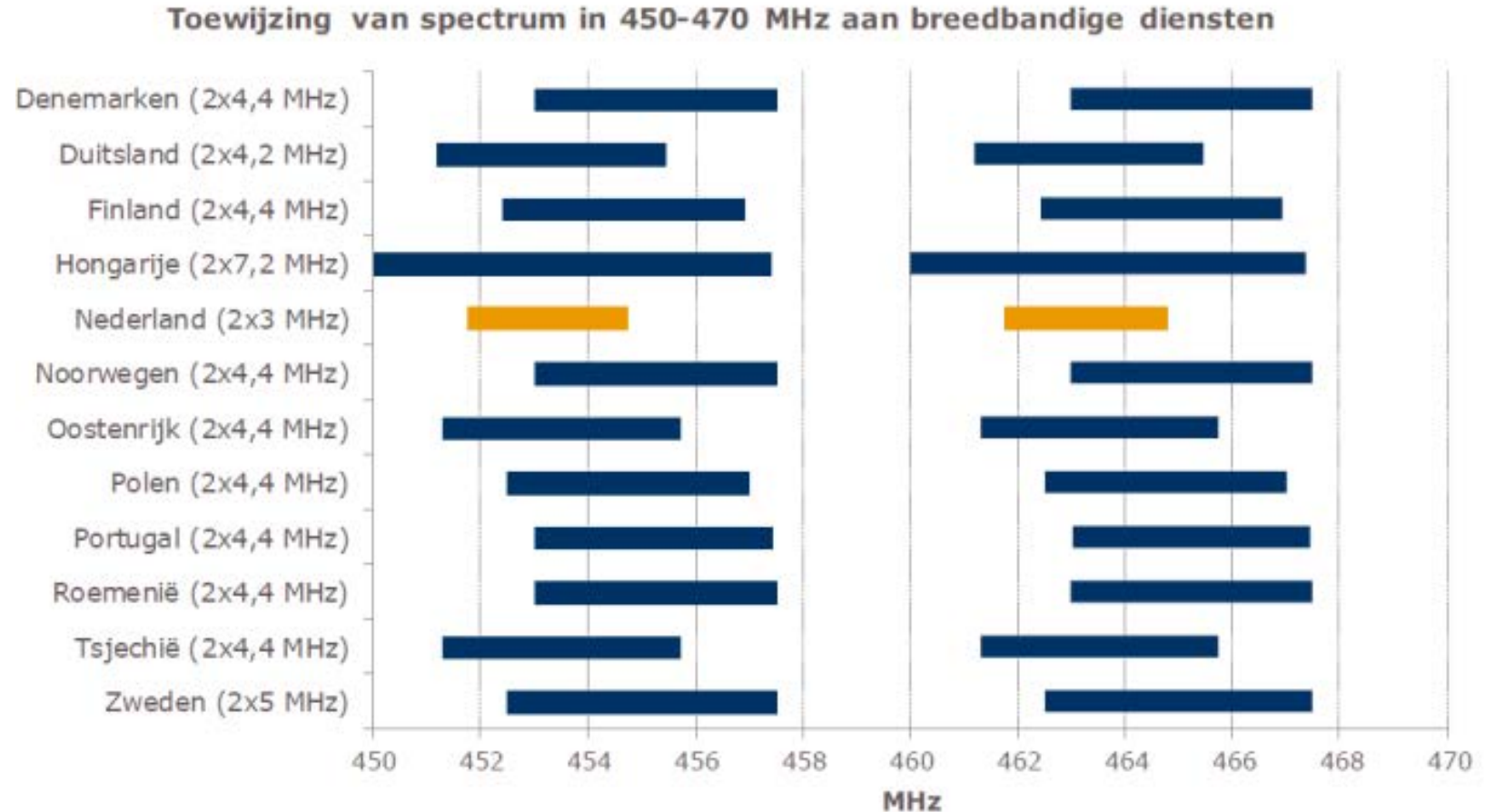
Raj Sivalingam

R.Sivalingam@whptelecoms.com

Supplementary slides



7. European developments









EUTC and JRC currently responding to consultations about release of spectrum in 400 MHz bands in Ireland, Netherlands and Portugal.

7. European developments

450MHz wireless networks providing solutions to utilities in several EU countries



<p>ArgoNET </p> <ul style="list-style-type: none"> ➤ Technology: CDMA ➤ Public companies and large enterprises, with initial focus on energy market ➤ Power utility references: Energie AG Oberösterreich & Energie Steiermark 	<p>UTILITY CONNECT </p> <ul style="list-style-type: none"> ➤ Technology: CDMA ➤ (Semi-)public companies with critical demands, initial focus on energy market ➤ Power utility references: Alliander, Stedin 	<p>450connect </p> <ul style="list-style-type: none"> ➤ Technology: CDMA ➤ Critical users among companies and organizations with initial focus on power utilities ➤ Power utility references: Stadtwerke Düsseldorf, EWE
<p>net </p> <ul style="list-style-type: none"> ➤ Technology: LTE (in addition to fixed network) ➤ Originating from Utility, initial focus on energy market, also other business customers acquired ➤ Power utility references: MVM 	<p>Ukkomobile </p> <ul style="list-style-type: none"> ➤ Technology: LTE ➤ B2B (enterprises and government) with initial focus on moving vehicles and consumer (nationwide coverage in rural areas) 	<p>ice.net </p> <ul style="list-style-type: none"> ➤ Technology: LTE ➤ B2B and consumer (nationwide coverage in rural areas) ➤ Power utility references: Vattenfall & EON
Hungary	Finland	Iceland, Denmark & Norway

IoT & Connectivity Monitoring Requirements for Health & Wellbeing

Millom CAMPUS

Independent Living Centre &
Community Services Hub
“5G Rural First Test” Site?



“5G” Helps With “5D”

5D

- Dementia
- Diabetes
- Disability
- Discrimination
- Death

What if?

Why?



How?



What?

The Why?

- “Super Aging” population living with multiple long term conditions that need to be actively self managed.
- 80% +65’s private home owners. Want to live and die at home.
- Carers – formal and informal: need help and respite.
- The digital divide: Digital by default –
We should be Human by default!

The What?

- Millom CAMPUS proposal.
- Independent Living Centre.
- Community Services Hub.
- Cyber Café.
- Linked by a walkway/corridor to the Millom Community Hospital.
- The CAMPUS: Provides the Infrastructure.

The How?

- Millom CAMPUS as a “5G Rural First” Test Site.
- Living Lab:
 - Work with Universities & Communities.
- Citizen Scientists:
 - Retired NHS Staff.
 - Intergenerational Opportunities.
- Rural Digital Health Economy Primer
- Workforce Development – Economic Regen

The What If?

- Proof of Concept: National Exemplar.
- Scalable and Transferrable.
- Share the learning: “5G Rural First”.
- Extend the operational reach of our health and social care systems and local services.
- Improved quality of life and death.
- Resilience in our communities.



Contact Details



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5G SECURITY & TRUST

DR GREIG PAUL – UNIVERSITY OF STRATHCLYDE

THE LAST YEAR?

New Adventures in Spying 3G & 4G Users: Locate, Track, Monitor

**Ravishankar Borgaonkar, Lucca Hirshi, Shinjo Park, Altaf
Shaik, Andrew Martin and Jean-Pierre Seifert**

**BLACKHAT USA 2017
Las Vegas
26 July 2017**

AN LTE IMSI CATCHER!

BUT THAT'S NOT ALL!

WiFi-Based IMSI Catcher

Piers O'Hanlon

Ravishankar Borgaonkar

BlackHat, London, 3rd November 2016

NOW WE DON'T EVEN NEED A CELL SIGNAL!

“EE Wifi_Auto”



Who cares?

Uhhhh... Drivers of mobile-connected cars!

Utilities providers running CNI

Users of IoT devices

Businesses using mobile calls/data

CELLULAR TRENDS?

- More ways to connect/integrate (VoLTE/VoWiFi)
- Recognition of untrusted bearers (IKE/IPSec VPNs)
- Increasingly complex authentication protocols (!)
- Multiple independent routes/ways to authenticate
- Often we forget the basics of security though...

SOME THINGS NEVER CHANGE

- Trust “the network”, even when roaming
- Handset + user are blind - trusting the network
- Backwards compatibility (all the way to 2G!)
- And lots of legacy stuff still in use (CHAP in 2017???)

WHAT COULD WE DO BETTER?

- Let's adopt good, modern standards, and aim for algorithm agility to build a strong cryptographic base
- Algorithm agility – let's prepare for post-quantum
- Let's stop “invisible” attacks on users or their devices!
- Think about (and remember) user privacy

ROAMING

- If your phone “sees” a strong foreign MCC/MNC it will connect onto it – see SE England, NI border
- Simple solution – ask the user if they are in France?
- Rogue state IMSI catcher, anyone?
- Roaming networks get trusted a fair bit...

BROADER SOCIETAL TRENDS

- The rise of ephemerality (Snapchat, etc.)
- Mobiles as an identity broker (SMS 2FA etc!)
- The handset now holds valuable data!
- Business case – companies are starting to use cellular networks as a simple replacement for corporate VPN for non-technical users!
- We need to preserve trust and avoid headlines!

How I stalked my girlfriend

For the past week I've been tracking my girlfriend through her mobile phone. I can see exactly where she is, at any time of day or night, within 150 yards, as long as her phone is on. It has been very interesting to find out about her day. Now I'm going to tell you how I did it.

THE GUARDIAN

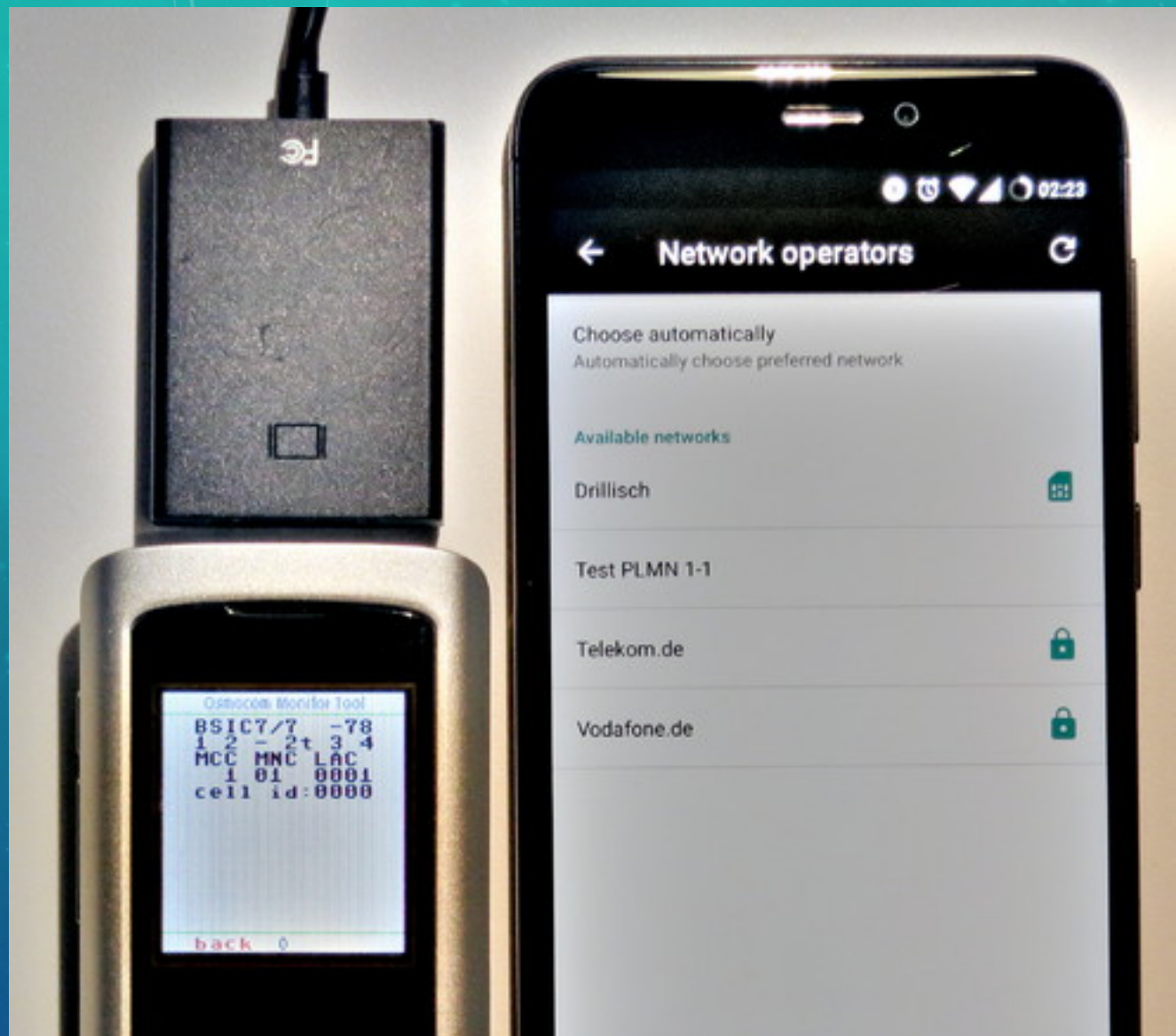
FEBRUARY 2006

IT'S NOT ALL JUST HANDSETS!

- IoT and utilities will be big users of modern cellular
- They may interoperate (or be) CNI (as are you!)
- We can't have SS7 access into power networks!
- Vehicle-to-vehicle; interesting security challenges
- End-to-end is the way to go! We even have a SIM!

WHERE NOW?

- Remove “null” cipher/integrity checks in 5G!
 - Yes, that means you, NEA0 & NIA0!
- Be “secure by default”, not by option
- Assume active RF-adversaries are operating
- Remember slicing is logical, not physical!
- Encrypt + authenticate everything possible (and impossible) – preferably E2E (why not?!)



- 1x USB3 to VGA cable required (~£25)



GREIG.PAUL@STRATH.AC.UK

How might 5G and IoT contribute to Scotland's Connectivity Vision?

Richard Parkinson & Neil Watt

From Connectivity to Enterprise IT



We lead our clients through the complex decisions underpinning the need for investment in digital connectivity...

...and help organisations plan, source, implement, and optimise digital technology to maximise their business benefit

Example Clients



Highlands and Islands Enterprise
Iomairt na Gàidhealtachd 's nan Eilean

intelligentpos



ConocoPhillips



WEST OF ENGLAND
Combined Authority

Clarks

ICAS



• EDINBURGH •
YOUR COUNCIL - YOUR FUTURE



SWAN

GMCA
GREATER MANCHESTER
COMBINED AUTHORITY

SCOTLAND
NETWORKING
TOGETHER



Department for
Digital, Culture
Media & Sport



ROYAL borough of
GREENWICH



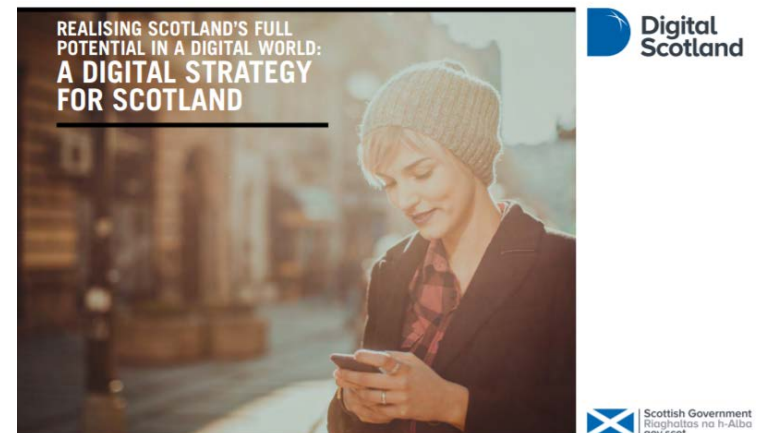
nexen

NHS
Highland

Vetsnow

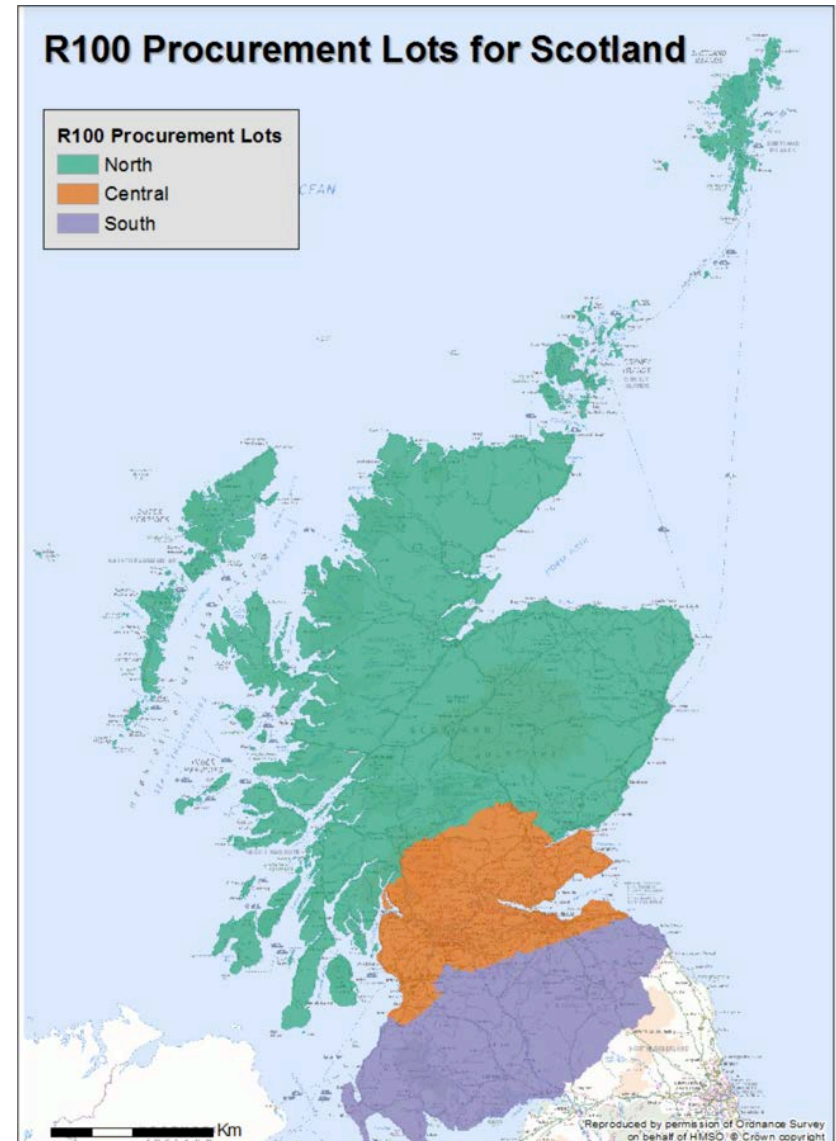
What is the Digital Strategy?

1. Improving and extending our broadband and mobile networks to benefit communities and businesses across Scotland
2. Help businesses develop and use digital technologies effectively
3. Increasing digital participation by developing digital skills and confidence
4. Creating digital public services and making better use of data to make the public sector more efficient



Reaching 100% (R100)

- State Aid compliant solution:
 - Technical compliance
 - Wholesale Access compliance
- 30Mbps to all premises
- £600m public funding
- Delivery by 2021
- 3 geographical Lots
- Gap funded model



“Fixed Wireless Access may be eligible for State aid provided that the technology is capable of delivering reliable high speeds per subscriber”

- capable of providing access speeds in excess of 30Mbps download, by evidence;
- provides at least a doubling of download speeds and substantially higher upload speeds in the target area;
- must be designed in anticipation of providing at least 15Mbps download speed to end users for 90% of the time during peak times in the target area;
- must show how the solution would adapt to maintain capability and end user experience in changes to key parameters such as increased takeup and increased demand for capacity;
- must have characteristics (e.g. latency, jitter) that enable advanced services to be delivered e.g. videoconferencing and High Definition video streaming;
- Must have longevity such that one might reasonably expect increases in performance within the next 7 years.

- All publicly funded infrastructure must be open access through passive and active services
 - Passive mast/ duct/ pole/ enclosure access
 - Active wholesale access
- R100 can help future 5G through the build of more fibre backhaul
- Site access and planning may be challenging in sensitive rural areas

Some questions:

- 700MHz – what coverage obligations will be applied?
- 3.4GHz – how will this be used by spectrum winners?
- Might spectrum sharing be introduced to help rural areas?

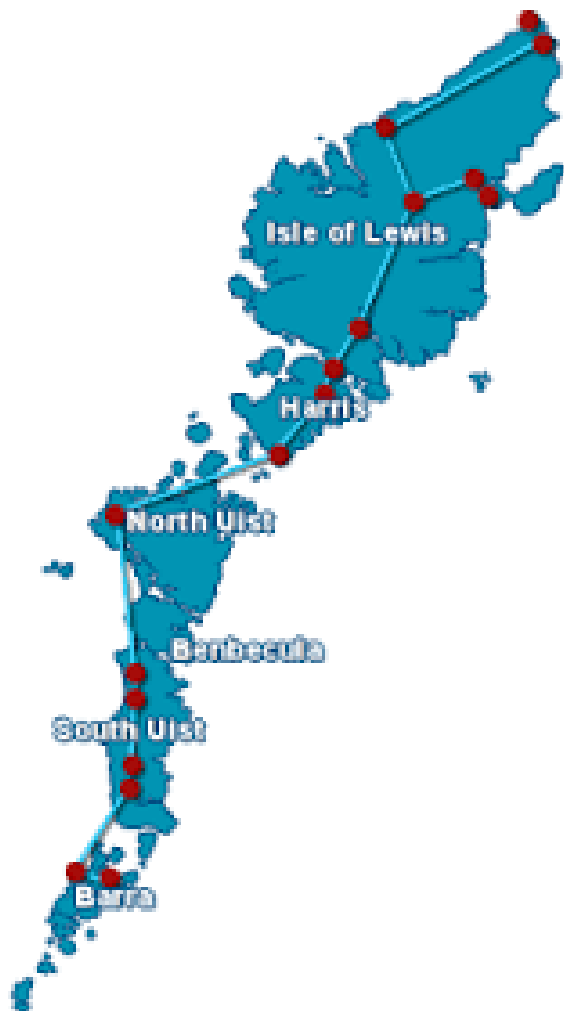
IoT in rural island communities

IoT trial in the Western Isles enabling business and public sector to develop innovative application solutions

A number of Gateways installed at Stornoway and Carloway

Sensors deployed:

- Digital Health and Care
- Monitoring fuel dumps
- Environmental controls at Connected Communities mast sites.



Connectivity:

- Connectivity is improving and there is a lot of work happening which means this trend will continue.
- We need to continue to develop plans for developing 5G and IoT.
- 5G FWA may have a place in delivering R100.

End User Applications:

- We see exciting developments using 5G and IoT, for example Digital Health & Care.
- Development of applications needs to happen in parallel with the connectivity.

We need to promote our success and remain ambitious.

5G Rural Track





5G RuralFirst: Shared and Dynamic Spectrum for Rural Connectivity

David H Crawford

Who Are We?And What Do We Do?

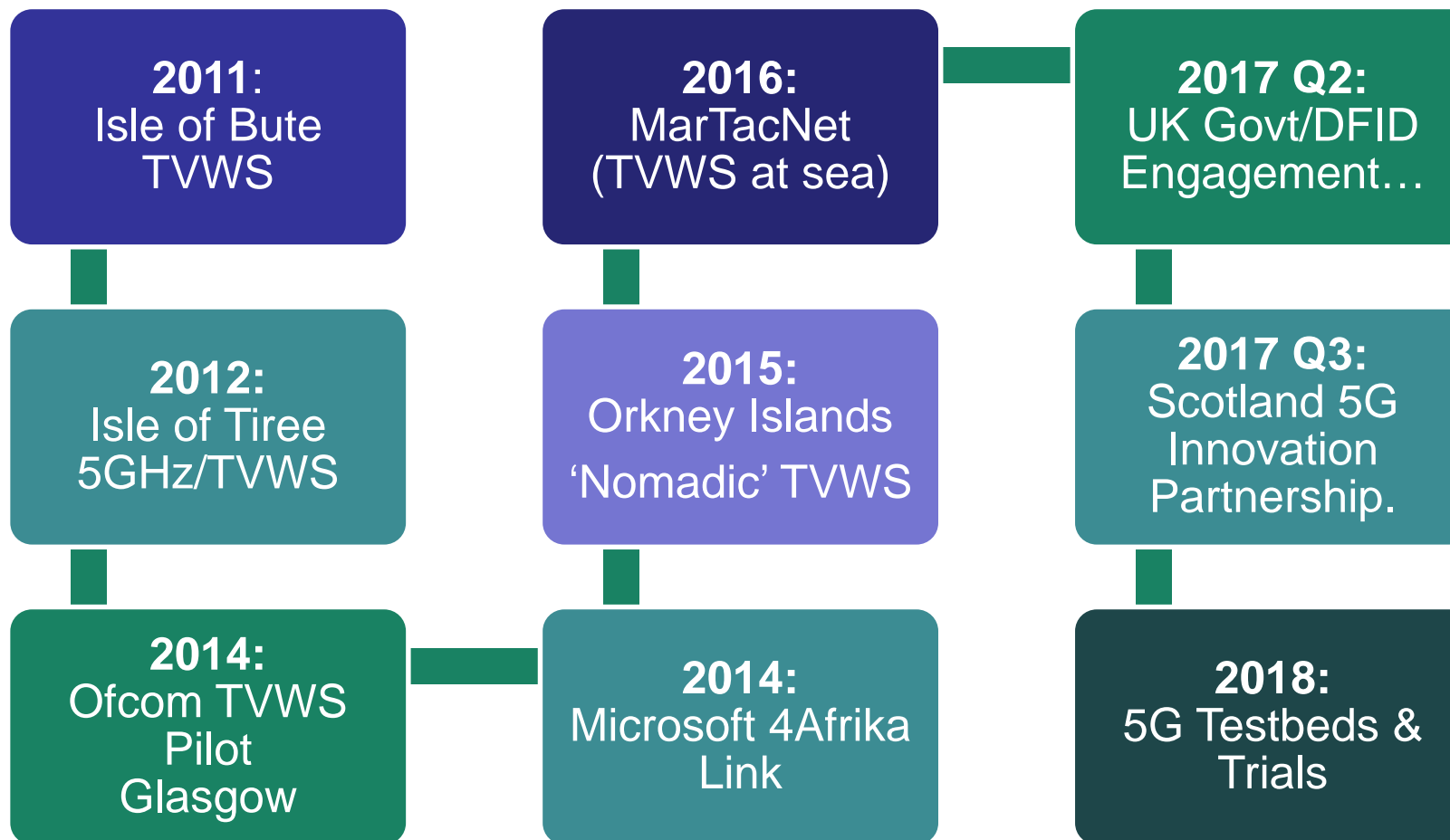
A multi-disciplinary international centre working with industry, government, and academic partners to undertake R&D on Dynamic Spectrum and related areas

- Started in 2011 and led by the University of Strathclyde
- Builds on over 30 years of experience in mobile/wireless communications and signal processing
- Investigating technological and socio-economic aspects of Dynamic Spectrum Access and related topics
- Academically-led, Industry-focused, Government-engaged
- Working closely with business, social enterprise groups, government offices, and industry

Ed Vaizey, UK Govt Minister,
meets Colin McGuire during the
Centre's opening ceremony

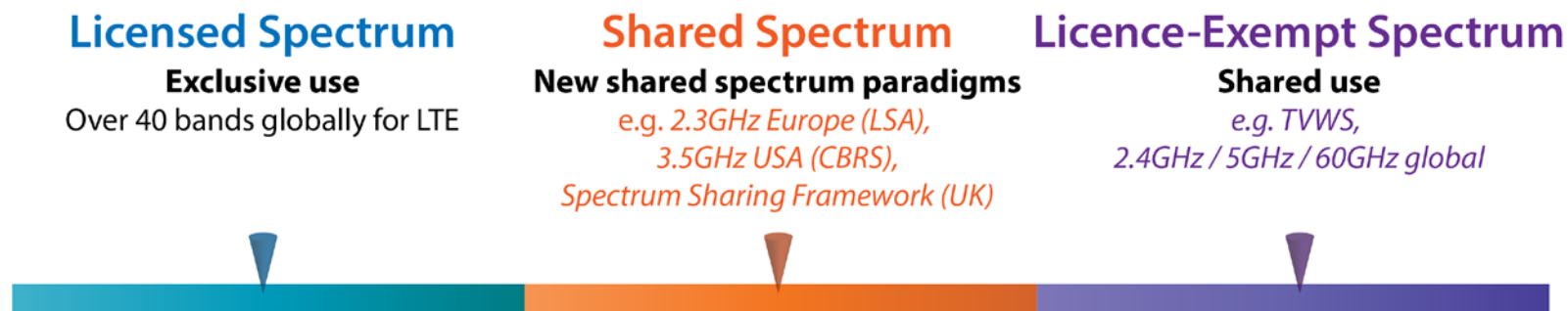


Core Projects Timeline

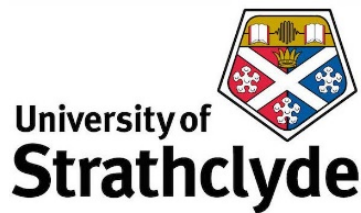


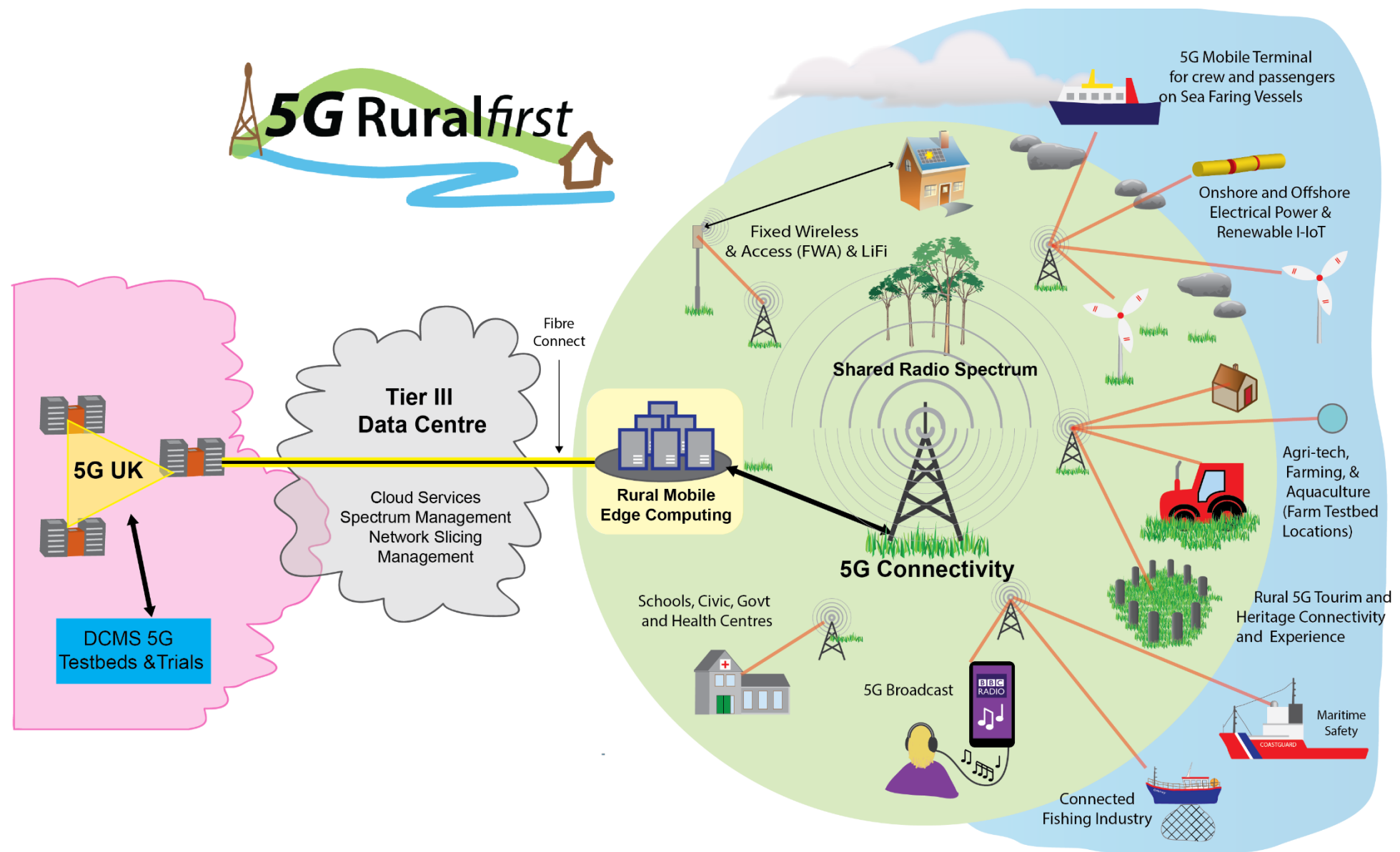


- End-to-end testbed system comprising rural 5G testbed locations across the UK, linked to a 5G edge facility connected to 5G core in Surrey.
- Supported by DCMS 5G Testbeds & Trials Programme.
- Will facilitate trials of innovative **technology**, **applications**, and **business models** aimed at improving the overall potential of the UK's 5G eco-system to deliver cost-effective connectivity for a range of applications and usage scenarios in hard-to-reach rural locations.



5G RuralFirst Project Partners





Thank You!

Dr David H Crawford
david.crawford@strath.ac.uk



Innovate UK



Department for
Business, Energy
& Industrial Strategy

Agri-EPI Centre - *and “5G RuralFirst”*

5G for Agricultural Technologies

Dave Ross
Chief Executive Officer

Dave.ross@agri-epicentre.com

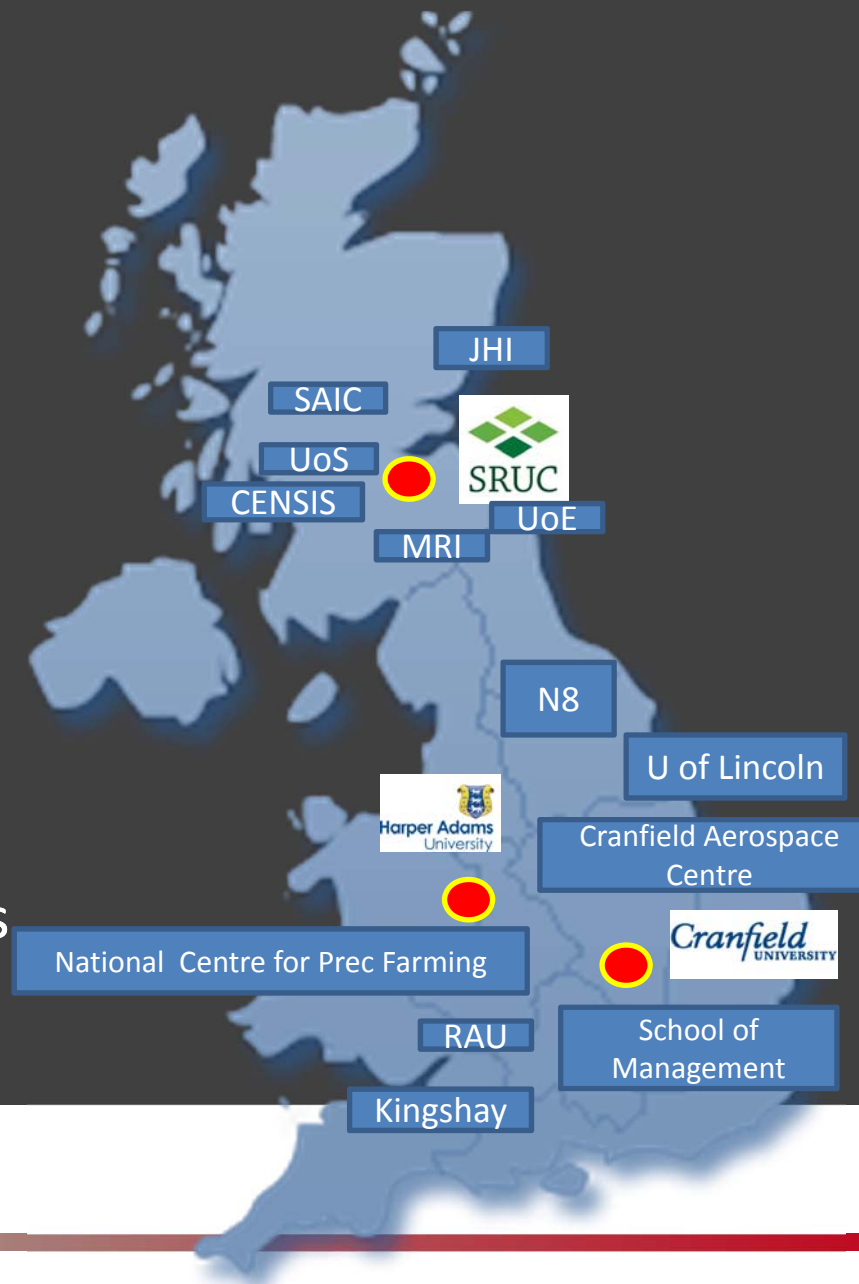


AGRIEPICENTRE

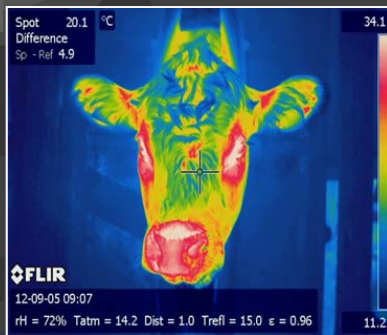
Engineering • Precision • Innovation

Agri-EPI Centre – a network of excellence

- National coverage
- Dynamic and flexible links
- The Hubs
- Aligned organisations
- Satellite Innovation facilities
- Mobile laboratory facilities
- Incubation Facilities
- Training and dissemination facilities



Transformational Technology

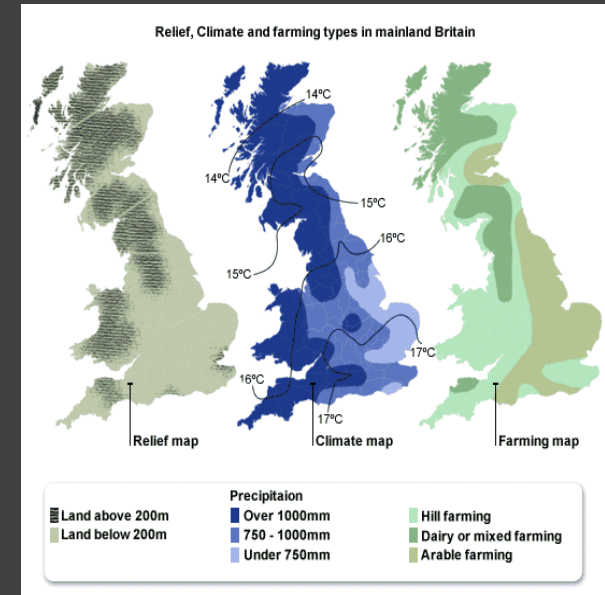


5G in agriculture – In future, 100% coverage is critical

Agricultural covers all regions and landscapes

Agri-Tech requires reliable communication

- Data transfer from farm office to the field (rate maps etc.)
- IOT sensors for remote monitoring of crops and livestock
- Vehicles telemetry: ground based and airborne
- Real time control of autonomous machines



5G in agriculture – Low latency high data rates

Remote monitoring:

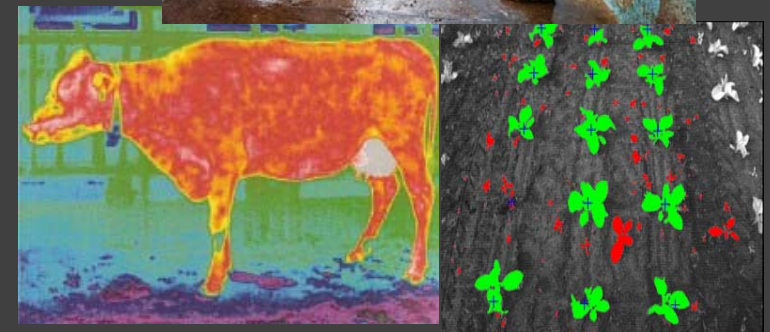
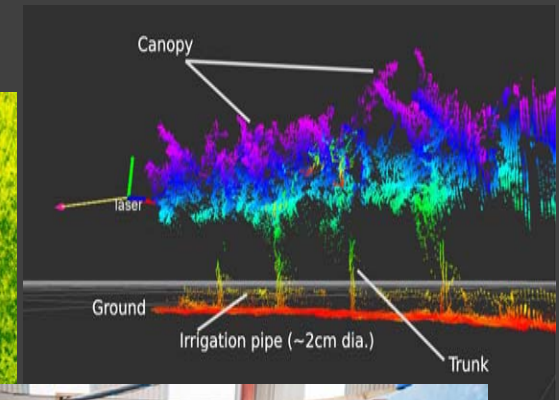
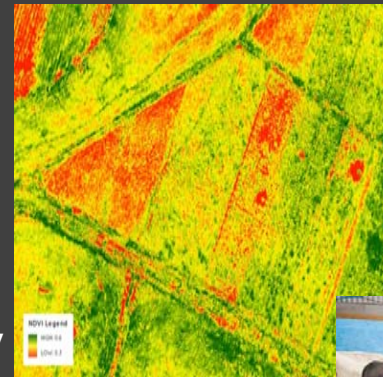
- IOT field and animal sensors
- Swarm vehicle telemetry

Server based analysis of:

- High-Res multi/hyperspectral field imagery
- Canopy 3D point clouds
- Animal behaviour/location/health
- HD video streams (multiple simultaneously)

Server based real time control of:

- Targeted applications e.g. spot spraying
- Swarm vehicle navigation



5G for remote health diagnosis



The Use Case

- *Utilising 5G infrastructure*
- *User-centric approach to data integration :*
 - *AR - Microsoft Hololens*
 - *Speech synthesis and recognition*
 - *training and diagnostic videos*
- *To provide near-real-time, animal side health information to Vets and technicians*

Visualisation

- *Animal Identification*
- *Age*
- *Breed*
- *Drugs used*
- *Specific info:*
 - *Dry Off Date*
 - *Lactating Duration*
- *Treatment relevant video content*

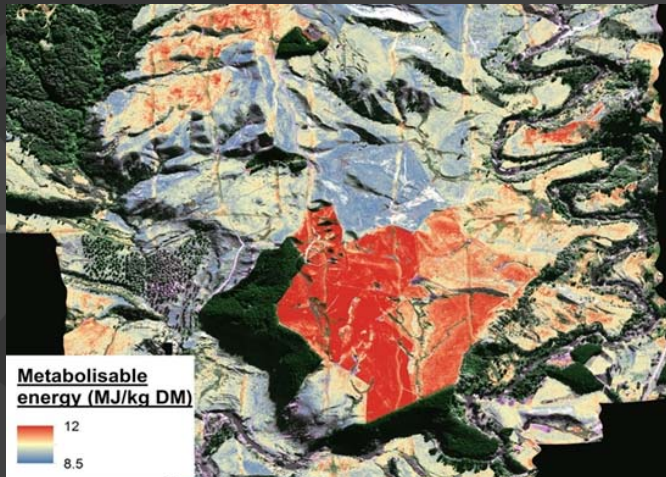
“Hands Free Hectare”

- Worlds first...
- Real time sensor and treatment.
- Remote processing
- UHD cameras (multiple streams) for intelligent control)
- Remote Command and control of multiple robotic systems



Real time imagery (inc multi/hyperspectral)

- Remote server processing of UAV acquired data (and control)
- Ditto hyperspectral data





Thank you for listening

Dave.ross@agri-epicentre.com



Next Generation Media Broadcast for Radio & TV

David Hemingway
BBC Distribution & Business Development



People TV and Radio



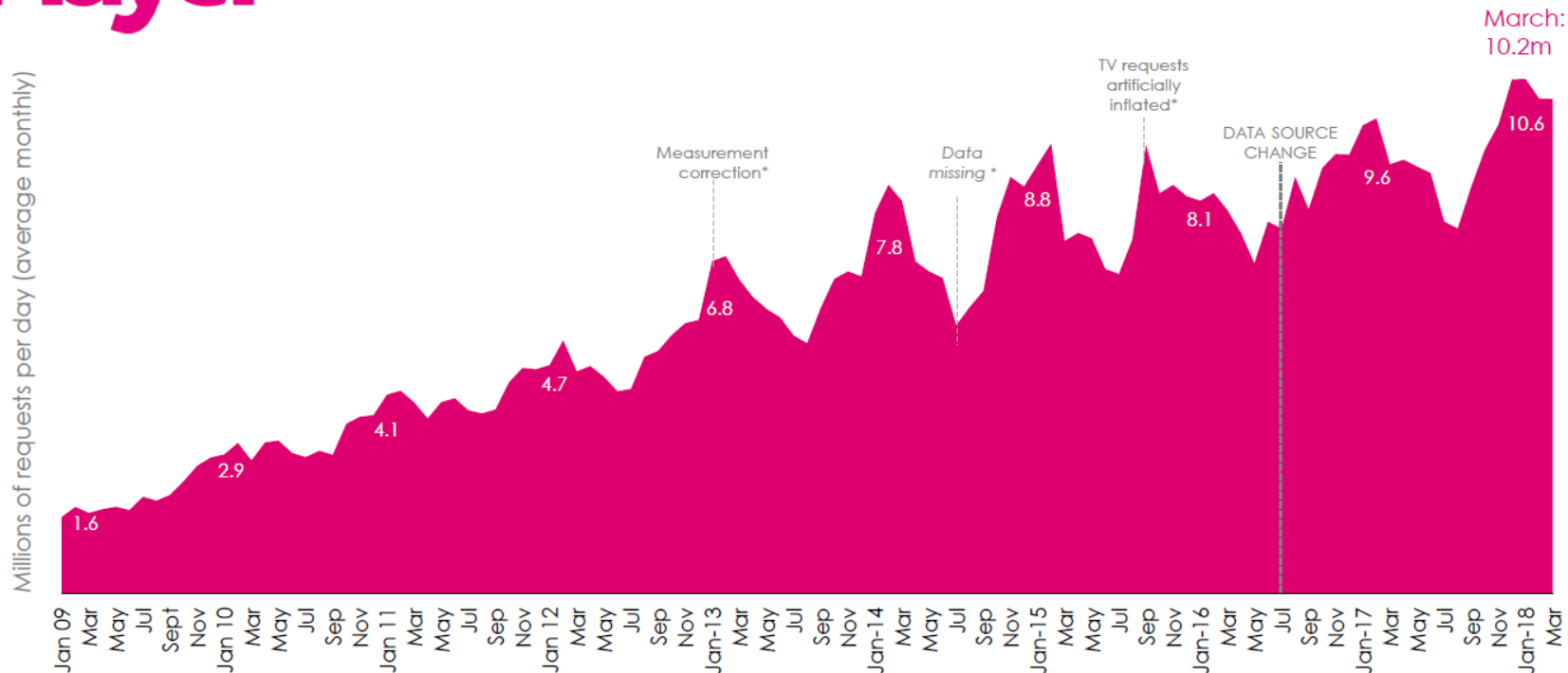
Total – 252 mins/day
35 mins/day SVoD etc
91% watch TV every week
51% have connected TVs
Broadcaster VoD = 4%



Total – 183 mins/day
Reaches 89.6% each week
7.8% listening online

Total TV + Radio consumption – 7¼ hours per day!

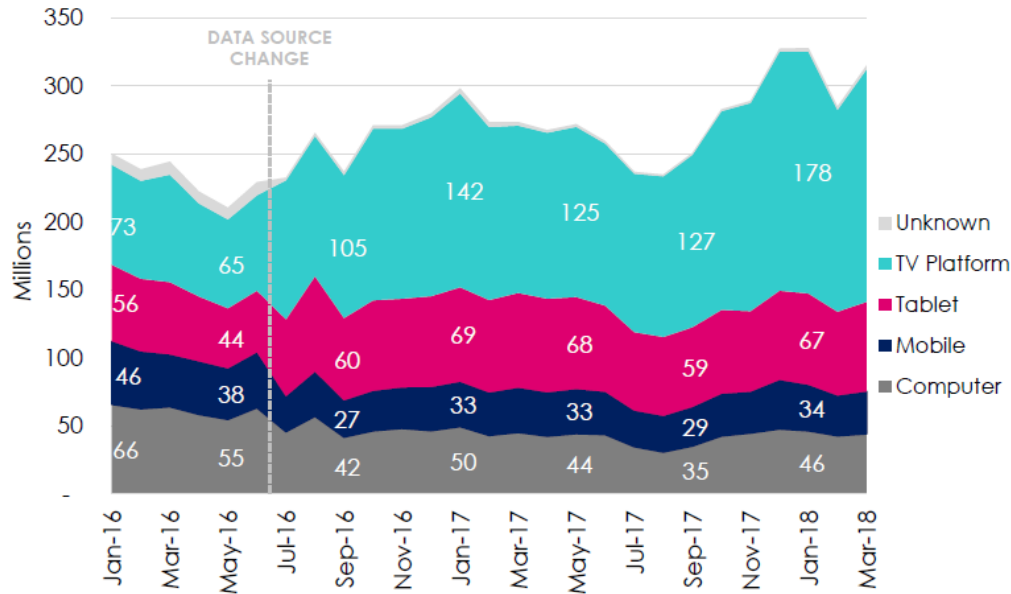
Online Viewing



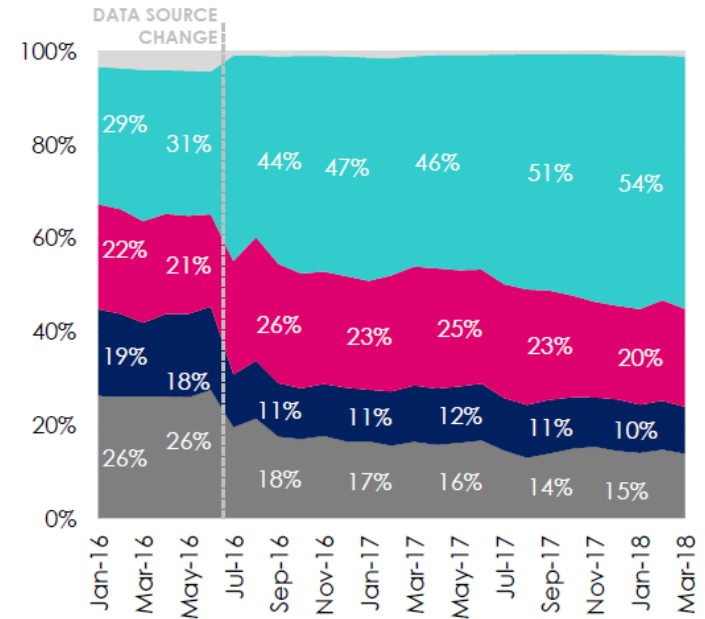
January figures shown on graph

Online Viewing

Number of requests (millions)



% of requests



Benefits of IP delivery to audiences



On-demand
services: what you
want, when you
want it



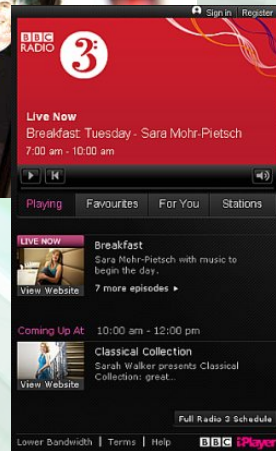
Mobility: what
you want,
where you want
it



Personalisation:
Content tailored for
your interests

What does 5G offer broadcasters?

- Mobility
 - Particularly important for radio
 - But also for TV in the future of autonomous cars
- Ubiquity
 - Commercial MNO networks
 - “Community” networks
 - Private networks
- Economies of Scale
 - Cross-sector use (“Verticals”)
 - Integration into consumer devices
- Broadcast/Unicast



Thank you!



@HemingwayDM

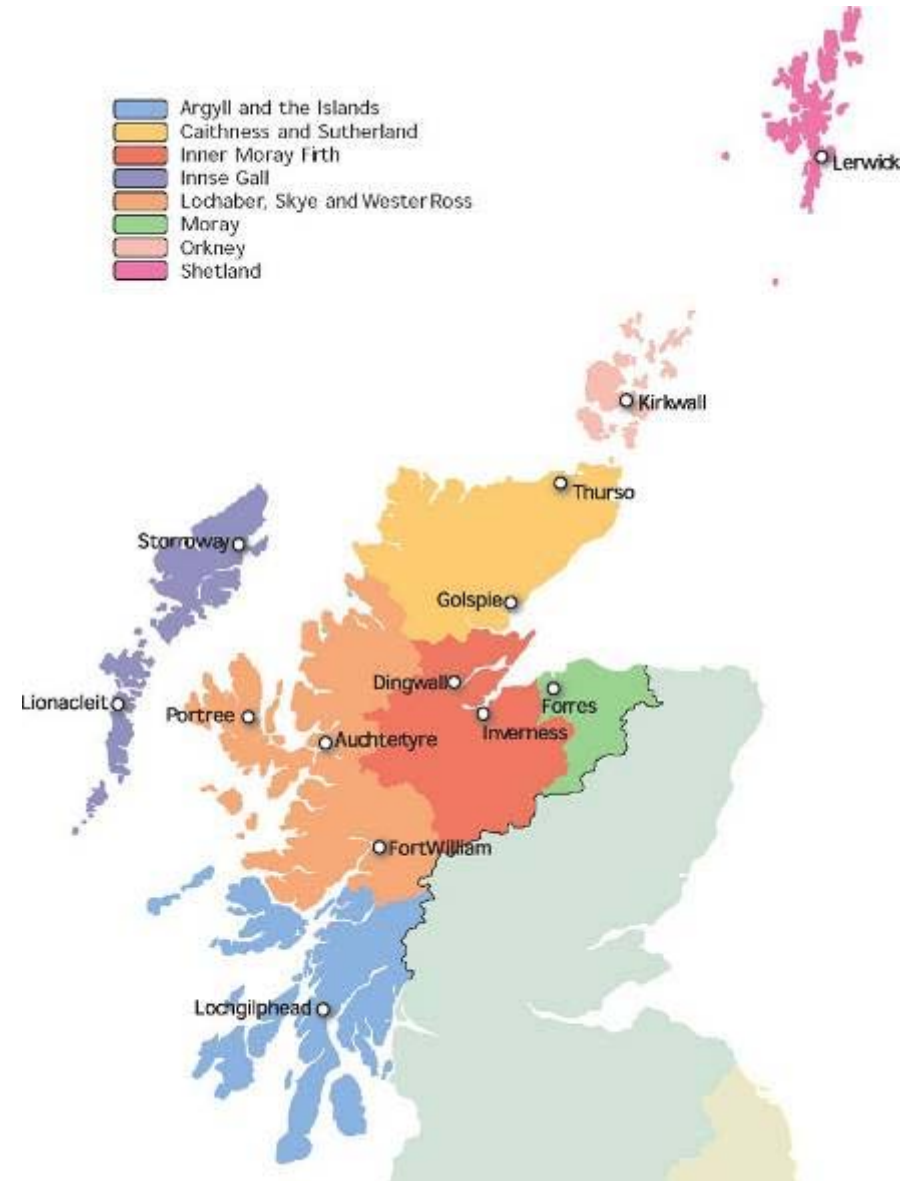


Remote Rural – Don't leave us to last again!

Donnie Morrison

Background

- Economic Development Agency covering all of Highlands and Islands
- HIE serves a challenging geography
- % population coverage obligations doesn't always work for us



4G only reaching many parts of the Highlands and Islands this year!

That's 6 years later than many urban areas.

Some areas don't even have 2G yet!

There is a business case for remote rural locations
In many ways our need is greater due to our peripherality!!

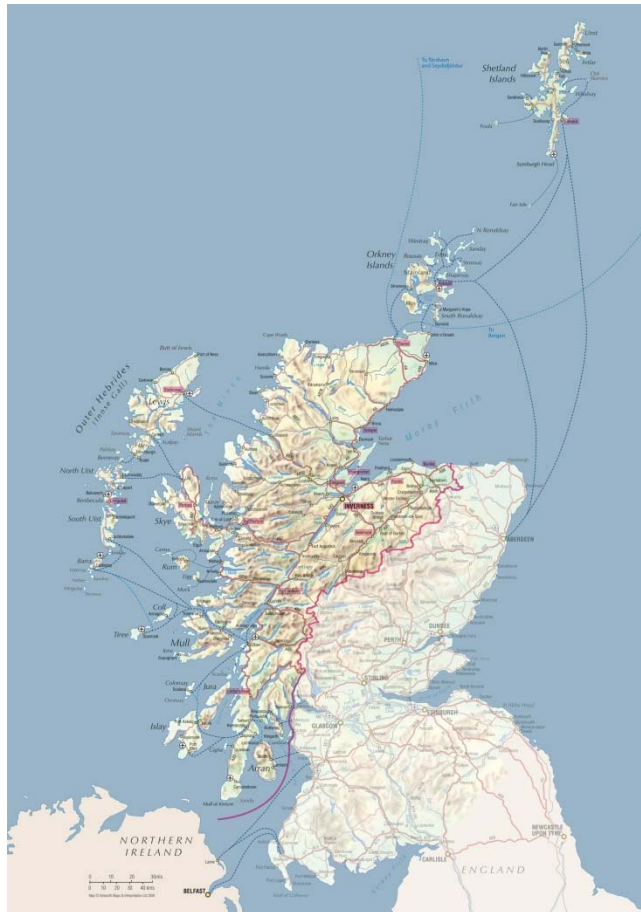
Applications

- Aquaculture
- Connected Health
- Telemedicine
- Education
- Creative industries
- Tourism
- Environmental
- Augmented reality

We have history

- First mast sharing project in the UK in late 90s
£45M – Cellnet and Vodafone provided a step change and mast sharing is now the norm
- Orkney, Shetland and Western Isles have local broadband networks
- Ideal locations for testbed trials
- Fibre backhaul now reaches into many remote island locations
- Some examples of testing already undertaken

Superfast Broadband Infrastructure



This is the most challenging and complex telecoms project in the UK

Cost : £146m

£126m Public Money + £19.4m BT

Our 'intervention area' covers all the premises across the Highlands and Islands where there was no NGB planned commercially

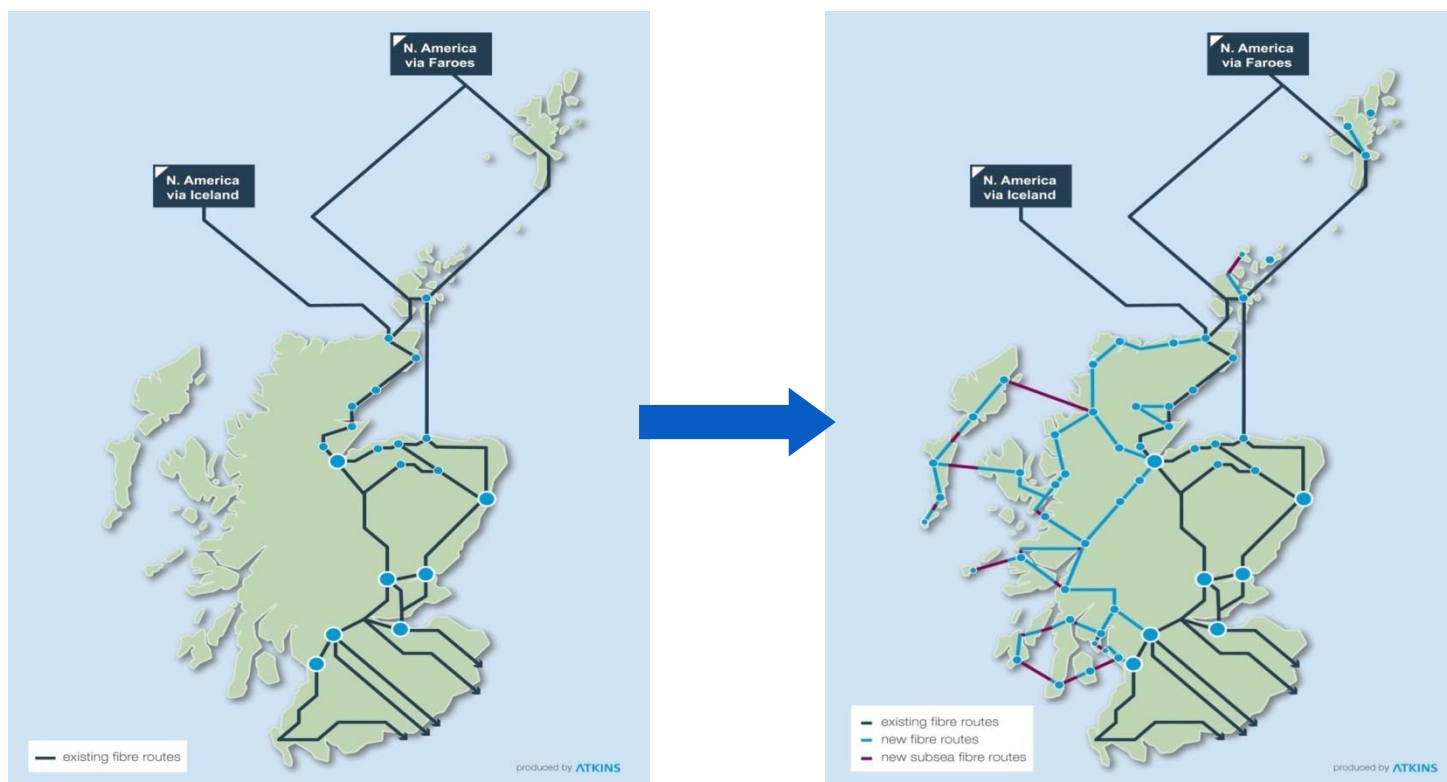
NGB would cover less than 21% premises in the H&I if left to the market

This project will take NGB to over 84% by the end 2018 across the Highlands and Islands

New procurement currently in progress by Scottish Government to reach 100% by 2021

What Have We Delivered?

Building a robust, future-proofed backhaul infrastructure



This infrastructure already existed in the rest of the country

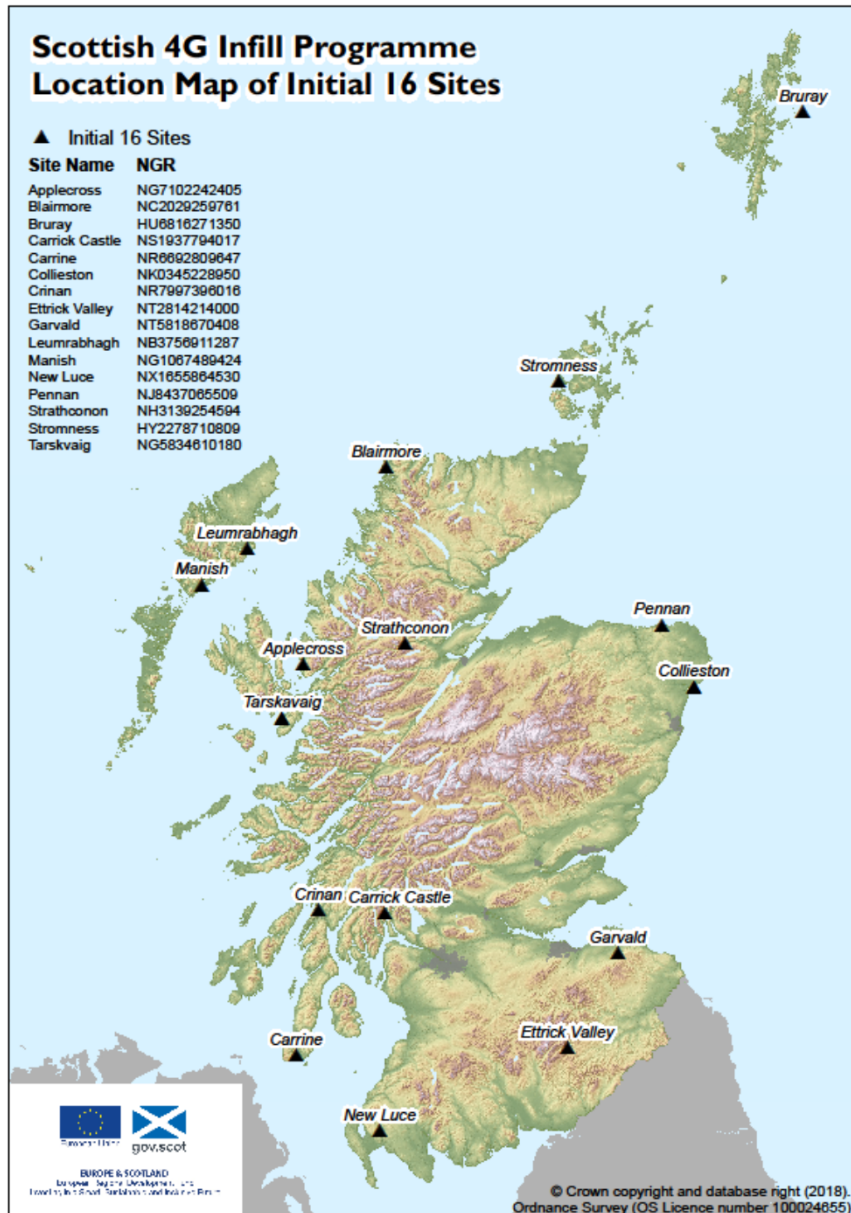
4G Mobile progress

Industry currently building new sites

Home Office building additional sites for Emergency Services

Scottish Government 4G Infill tackling 'Not Spots'

Scottish 4G Infill Programme



- Addressing 'not spots' where there is no mobile coverage from any provider.
- Currently out to tender
- Expectation that this will also bring fibre backhaul further into some rural communities
- Initial 16 sites identified and will be subject to further review
- Further work commissioned looking at an additional list of locations

Test Bed Opportunities

Existing infrastructure allows rapid access to mast sites for testing purposes

- Key areas of interest:
 - Access for testing quickly facilitated
 - Robust equipment for our environment
 - Fast deployment utilising existing skills base
 - Software upgradeable equipment?

Trials Case Studies

- Droneway from West of Scotland to Isle of Lewis
- Nokia Plug and Play 4G small cell.

General Area of the Droneway Trial

Isle of Lewis

Access Information

There is an Airport on the Isle of Lewis
Flights go from Inverness, Glasgow, Edinburgh
and Aberdeen to Stornoway, Isle of Lewis
Flights go from London Airports to Inverness
There is a Ferry (Boat) from Ullapool
to Stornoway



Backhaul Performance at Trumpian Head

Backhaul Donor - North Tolsta

LIVE_SITES.CELL_ID	16662
LIVE_SITES.OLK_CELL_ID	1647012
LIVE_SITES.MBNL_CELL_ID	EIS012
LIVE_SITES.DEPENDENT_CELL_ID	72498
LIVE_SITES.SITE_ID	1216873
LIVE_SITES.SITE_NAME	TOLSA(PEAT ROAD)
LIVE_SITES.LABEL	TOLSA
LIVE_SITES.NGC_EASTING	152785
LIVE_SITES.NGC_NORTHING	946241
LIVE_SITES.PROJECT_AREA_v3a	Darwin
LIVE_SITES.Overall_Integration_Decision	Shared Integrate
LIVE_SITES.flag	1

Directions: [To here](#) - [From here](#)

PING	38 ms	DOWNLOAD SPEED	46.44 Mbps	UPLOAD SPEED	40.53 Mbps
Wireless Status					
PLMN:	23430				
Service status:	Valid service				
RSSI (dBm):	-77				
RSRP (dBm):	-103				
RSRQ (dB):	-6				
Roaming:	No				

Light House - Tiumpian Head
Antenna Elevation - 62m ASL
Lat N58.2608, Long W6.1388
2 Antenna Fitted
In Band LTE Backhaul

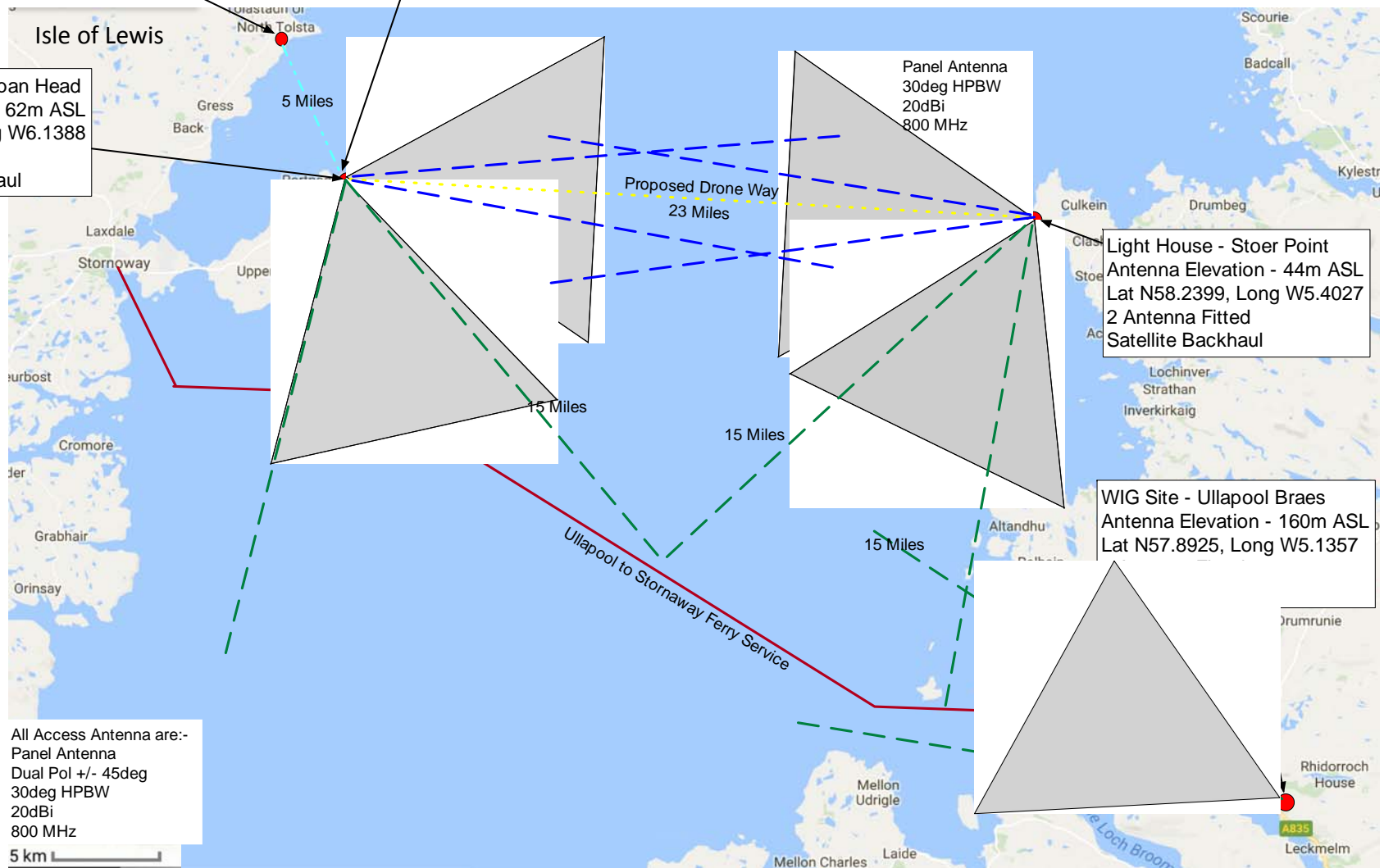
Panel Antenna
30deg HPBW
20dBi
800 MHz

Light House - Stoer Point
Antenna Elevation - 44m ASL
Lat N58.2399, Long W5.4027
2 Antenna Fitted
Satellite Backhaul

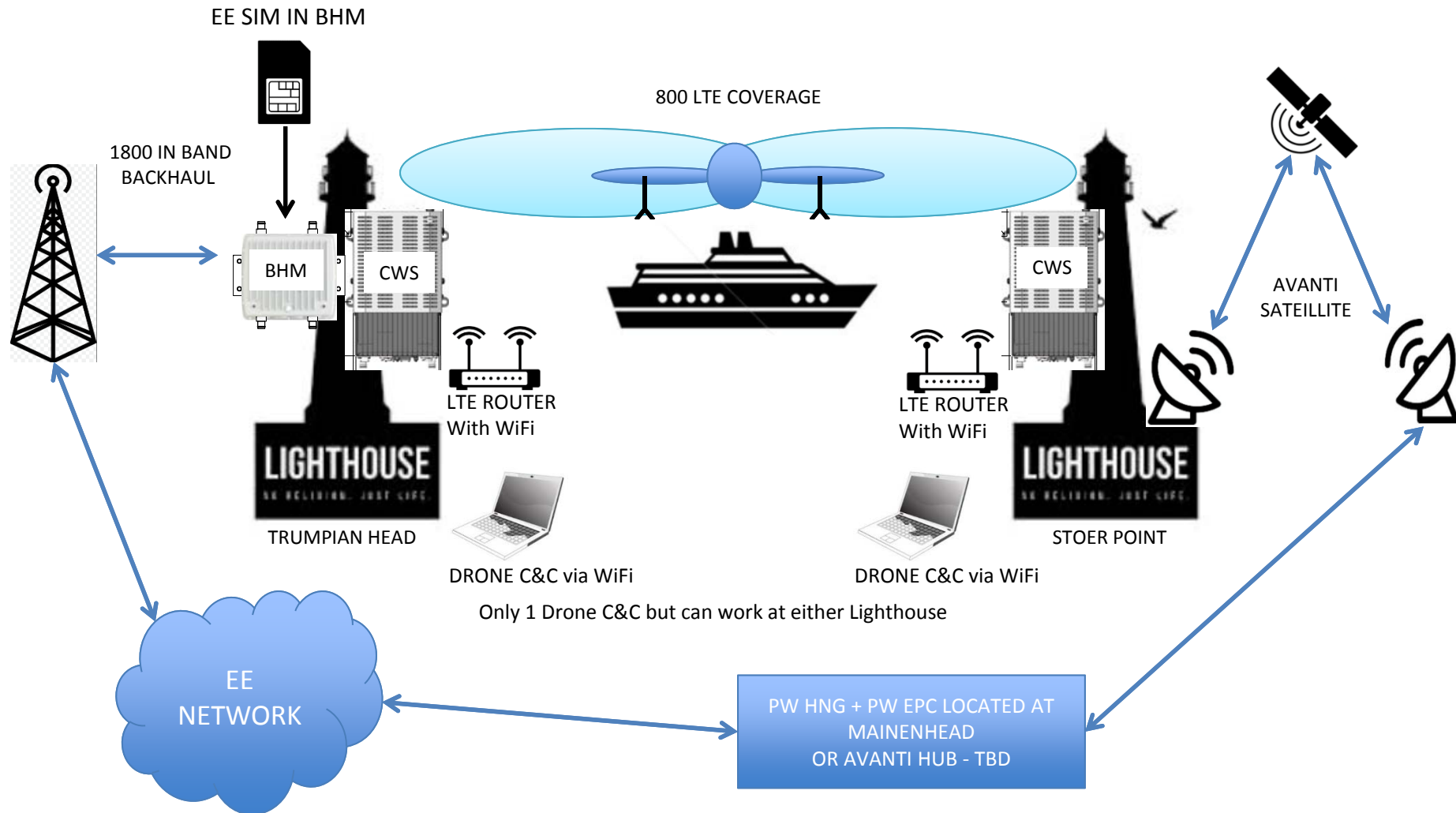
WIG Site - Ullapool Braes
Antenna Elevation - 160m ASL
Lat N57.8925, Long W5.1357

All Access Antenna are:-
Panel Antenna
Dual Pol +/- 45deg
30deg HPBW
20dBi
800 MHz

5 km

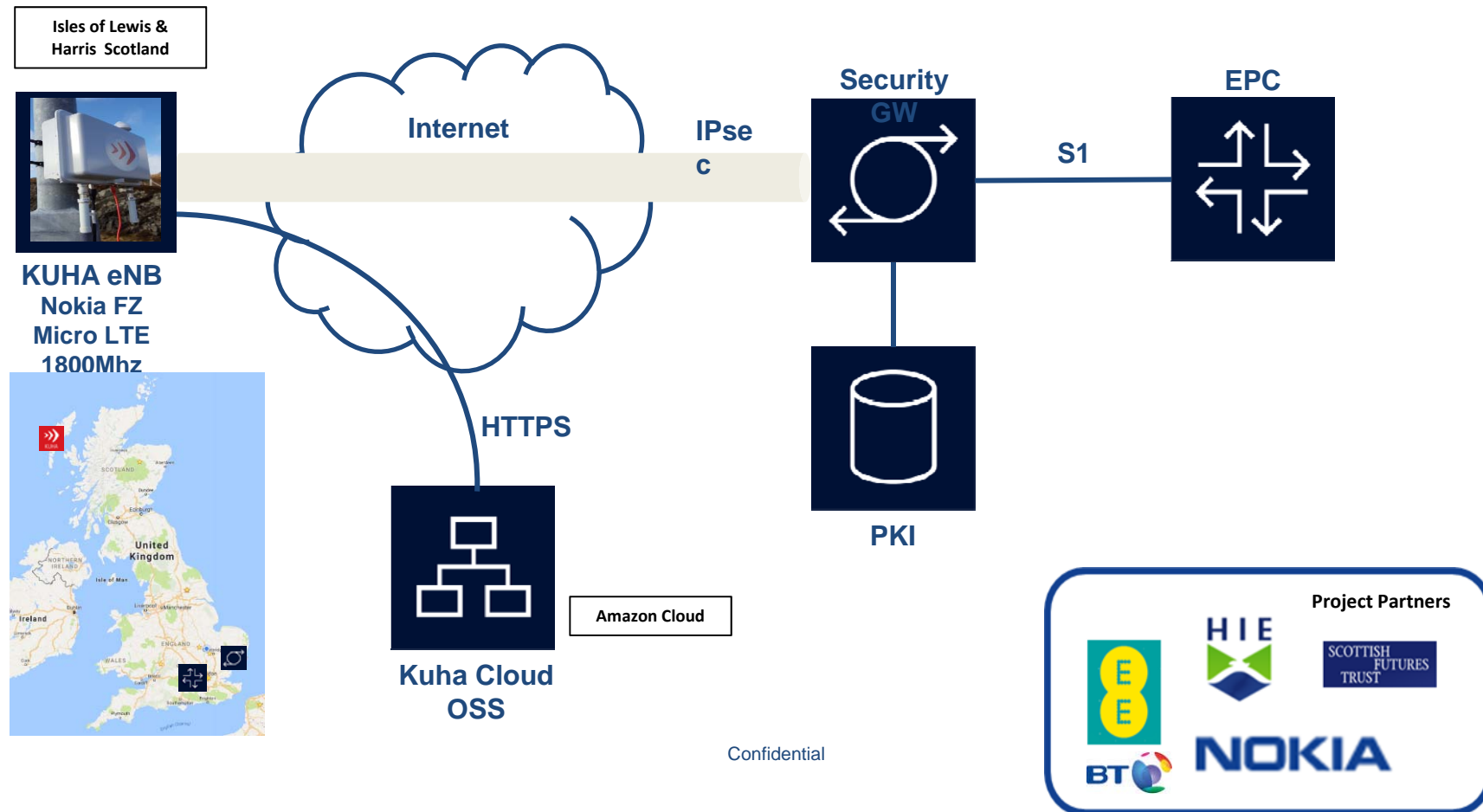


End to End Droneway



Nokia Kuha small cell trials in Outer Hebrides

Proof of Concept Architecture



Nokia Kuha trials in Outer Hebrides



Habost Site
Isle of Lewis

The Place



The Router



One Man



The Cell



Trial results



- Proposition to trial only took one week
- Nokia Kuha Cell installation time 15 minutes – No 'big' telco skills needed on site
- Cell Integration process from “**power on**” to “**on-air**”: 20 minutes
- Plug & Play.
- IPSec Tunnel setup and configuration included in the Plug & Play
- Services tested: Video streaming, Web browsing, OTT voice/video call (Skype), SMS



To summarise

- *We have a unique asset owned by the public sector which allows rapid deployment of test and trial equipment*
- *Successful testing in our environment would suggest that if you can do it here you can do it anywhere.*
- *Trialling faster routes to deployment of new technologies including working with local service providers has many benefits:*
 - *Lower deployment costs*
 - *Easier maintenance provision*
 - *Access to fibre backhaul even in our most remote communities*
- *We believe that there is a business case in rural communities!*

Don't leave us till last !

Donnie Morrison

Broadband, Mobile and Wireless Networks

donnie.morrison@hient.co.uk



The Real-5G vision for Rural & Remote areas

Zahid Ghadialy
Senior Director, Strategic Marketing

About myself

- Senior Director, Strategic Marketing at Parallel Wireless
 - Previously Solution Architect
- Founder & Blogger at 3G4G
- Member of Board of Directors at CW (Cambridge Wireless)
- SIG Champion at CW:
 - Future Devices & Technologies (present)
 - Smart & Intelligent Cities (past)
 - Small Cells (past)
- Previously Programme Manager at techUK
 - Communications Infrastructure
 - Spectrum Policy Forum
 - Satellite Applications & Services
 - CTO Council leader
- Previously MD & CTO of eXplanoTech



Disclaimer

This presentation is intended to stimulate discussion on some of the exciting current and future developments in digital communications technology and networks.

It also contains some forward looking statements, research and speculation that may never become part of standards.

It would not be prudent to make any financial or investment decisions based on this presentation.

Company Introduction

Founded in 2012



MISSION

Reimagine the RAN

Make *ANY* cellular deployment as easy and cost-effective as Wi-Fi



INNOVATION

- World's only sw enabled multi-technology 2G/3G/4G fully orchestrated via HetNet Gateway solution
- World's **SMALLEST** with **lowest power consumption** base stations
- World's **ONLY** complete end-to-end public safety LTE solution



STRONG
CUSTOMER
MOMENTUM

- Engaged with **30 operators** on **6 continents**
 - Rural, urban/dense urban, enterprise, public safety, smart cities
 - Public references: EMEA (**BT/EE, Vodafone**), LATAM (**Telefonica**), APAC (**Optus**), NA (**Ice**)
- **Most band 14 public safety LTE deployments in US**
 - Public References:
 - (US) Super Bowl 50, NYC Marathon, LA-RICS, Harris County

5G is coming...

Simple Definition of 5G (IMT-2020)

Enhanced Mobile Broadband (eMBB)

- 5G Phase 1 (Rel-15) – initially as NSA (Non Standalone) followed by SA (Standalone)

eMBB

Ultra-Reliable & Low-Latency Communications (URLLC)

- 5G Phase 2 (Rel-16)
- Enabler of new use-cases (verticals)
- Potential source of new revenue

URLLC

Massive Machine Type Communications (mMTC)

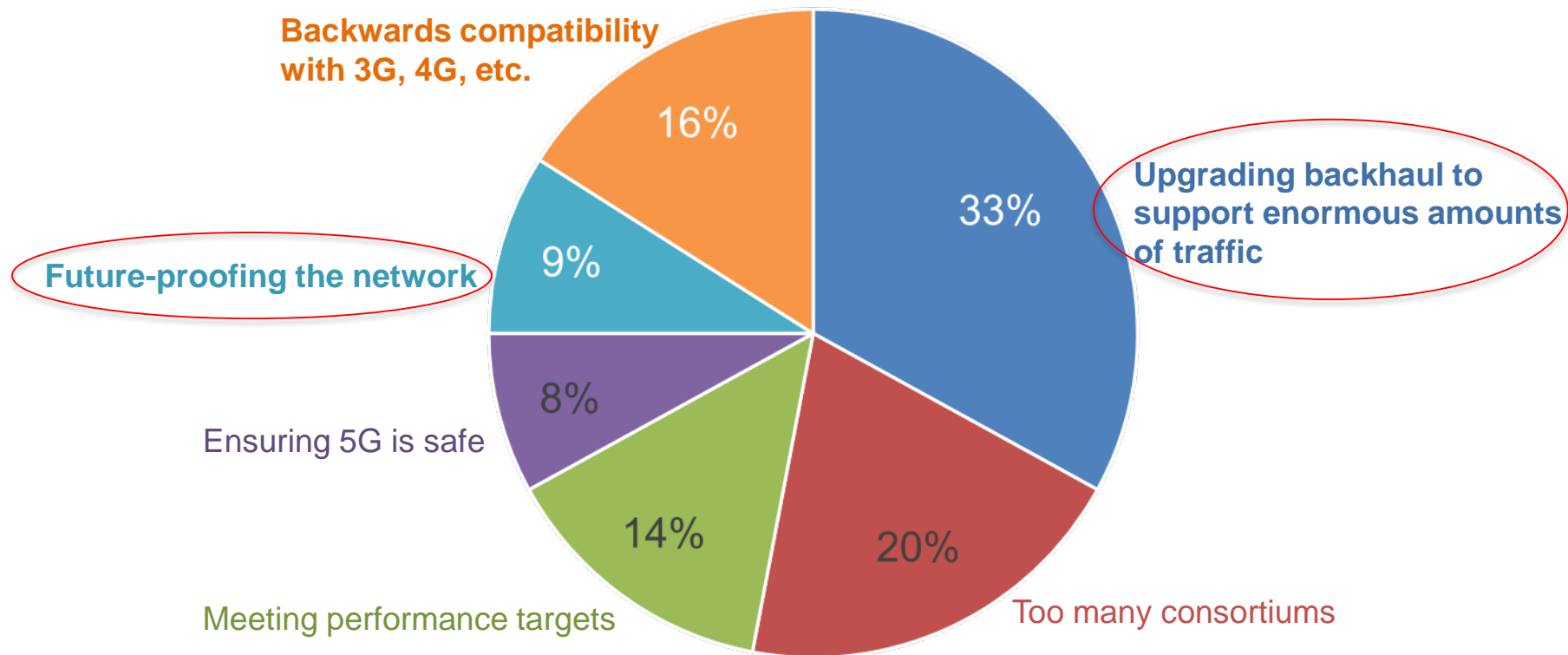
- Not on radar just yet but probably 5G Phase 2 (Rel-16)
- Backward compatible for LTE-M & NB-IoT

mMTC

5G (IMT-2020)

Biggest Challenges in Implementing 5G

Old but still applicable



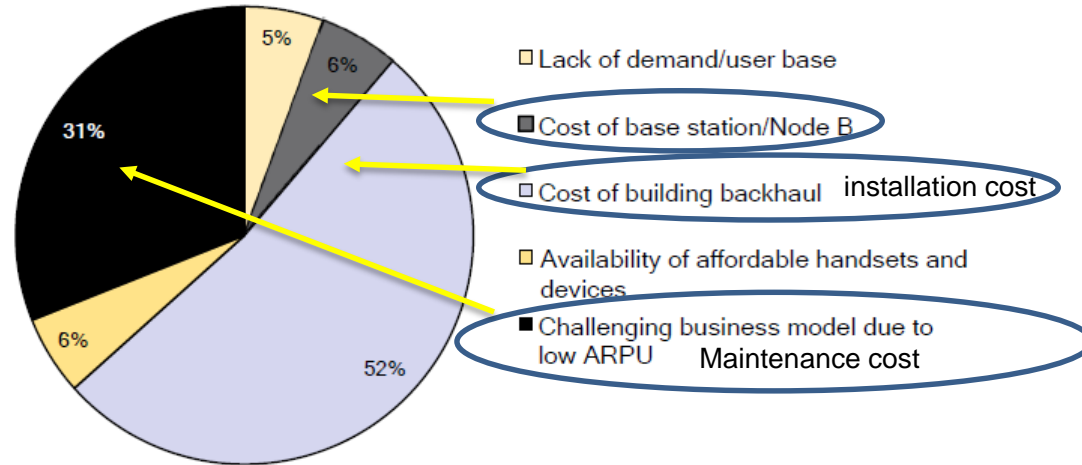
Source: Light Reading Poll, April 2015

What are the Rural Coverage Challenges?

Complexity and Cost

What Do Operators Think?

Which of the following do you think represents the greatest challenge in providing rural connectivity?



Source: Informa

Key Requirements and how PW Meets Them

Innovative, Cost-effective, Flexible, Future-proofed



Cost-effective

Cost-effective Integrated Wired & Wireless Backhaul, all in-one
Low power consumption → OPEX savings
Self-configuration, self-optimization with SON



Plug-n-Play

4 hours to install and commission one CWS
Under 3 days to light up a rural community with cluster of 4 CWS
Planning “Lite” – designed to be within notification rules



Flexible and Open

Eliminates backhaul challenge – can integrate capacity as becomes available
Interoperates with any vendor core, any type of backhaul
Software defined Nodes – can be re-configured UMTS & LTE



Future-proofed

Supporting 2G, 3G, 4G right now.
Gateway is a key element for future 5G networks.

Problems for Rural 5G

Enhanced Mobile Boardband (eMBB)

- Not enough backhaul capacity
- Not enough masts
- Not enough coverage

eMBB

Massive Machine Type Communications (mMTC)

- Many use-cases but not enough:
 - IoT devices and products
 - Cheap connectivity options

mMTC

Ultra-Reliable & Low-Latency Communications (URLLC)

- Needs new core
- Probably mmWave too

URLLC

5G (IMT-2020)

Urban Mobile Network Philosophy



Photo Source: Prof. Andy Sutton

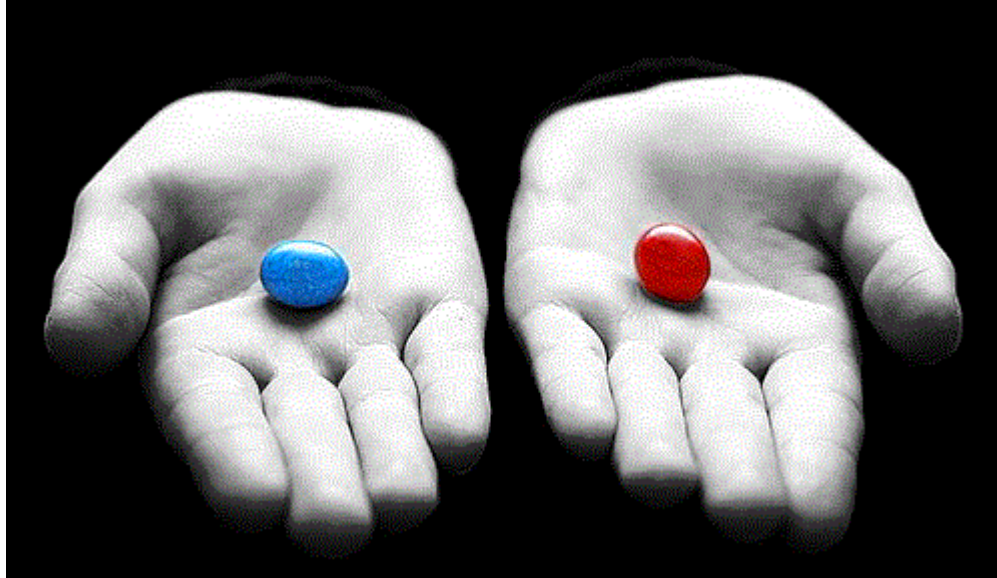
Rural Mobile Network Philosophy

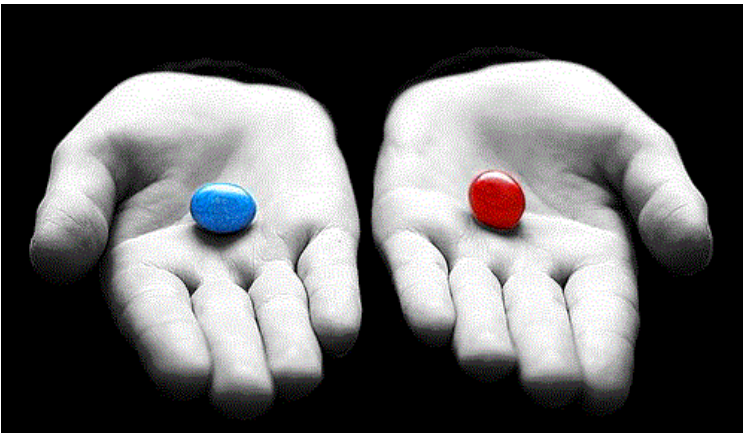
If you don't build it, they
will build it themselves



© Cortes de la Maesta

‘Blue pill or Red pill’: It’s the operators choice





The Rise of the Alternatives

The 'Blue pill' scenario

Satellite Broadband Megaconstellations on the Rise

- Satellites can provide ubiquitous coverage globally
- Geostationary High Throughput Satellite market is already saturated and wholesale prices are dropping as much as 50% yoy.
- Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellites provide much better latency than GEO satellites
- At least 15 companies have declared their intent to develop LEO and MEO broadband satellites
- Most popular megaconstellations: Oneweb, SpaceX & Telesat
- PointView, a new subsidiary of Facebook launched multi-million dollar experimental satellite in February. The satellite, named Athena, will deliver data 10 times faster than SpaceX's Starlink Internet satellites

LEO & MEO Broadband Constellations

At least 15 companies have declared their intent to develop broadband satellite constellations in low Earth orbit (LEO) or medium Earth orbit (MEO), according to Northern Sky Research. Most of these companies intend to have their first-generation systems deployed within five years. O3b, which is nearing completion of a 20-satellite constellation begun in 2013, will add seven mPower second-generation broadband satellites starting in 2021.

PROGRESS KEY

- Constellation builder selected
- Launcher(s) identified
- Prototype satellite(s) launched
- Operational satellite(s) in orbit

Source: Northern Sky Research

Laser Light
Satellites: 12
Altitude (km): 10,000

LeoSat
Satellites: 100
Altitude (km): 1,432

Samsung
Satellites: 4,600
Altitude (km): 1,500-2,000

Lucky Star
Satellites: 136
Altitude (km): 1,000

Hongyan
Satellites: 300
Altitude (km): 1,100

SpaceX Starlink
Satellites: 4,425
Altitude (km): 1,100-1,325

O3b
Satellites: 27
Altitude (km): 8,000

Yaliny
Satellites: 135
Altitude (km): 600

Telesat LEO
Satellites: 117
Altitude (km): 1,000

OneWeb
Satellites: 900
Altitude (km): 1,200

Viasat
Satellites: 24
Altitude (km): 8,200

Xinwei
Satellites: 32
Altitude (km): N/A

Astrome Technologies
Satellites: 600
Altitude (km): 1,400

Boeing V-band
Satellites: 2,956
Altitude (km): 1,050-1,080

Comsat
Satellites: 800
Altitude (km): 600

SPACE NEWS

B&B | SPACE NEWS | 17.02.18

SPACE NEWS | 18

Source:
Spacenews

Other Solutions: Facebook Drone & Google Loon

AQUILA

To help bring internet connectivity to more people, Facebook is designing solar-powered airplanes that will beam internet signal to people in remote, underserved regions within a 60-mile diameter. Each aircraft is designed to be in the air for up to 90 days at a time.

FLIGHT ALTITUDE
Aquila is designed to fly at altitudes between 60,000 and 90,000 feet.

60-MILE COMMUNICATION DIAMETER

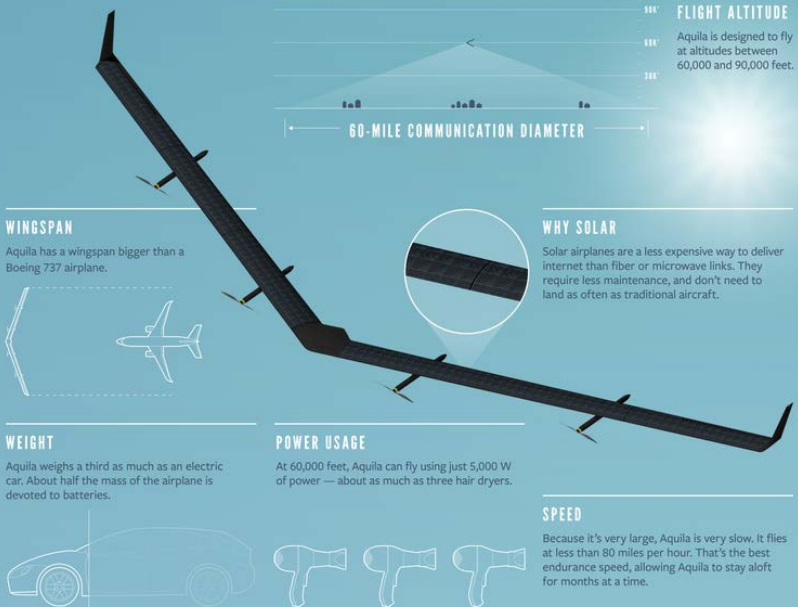
WINGSPAN
Aquila has a wingspan bigger than a Boeing 737 airplane.

WHY SOLAR
Solar airplanes are a less expensive way to deliver internet than fiber or microwave links. They require less maintenance, and don't need to land as often as traditional aircraft.

POWER USAGE
At 60,000 feet, Aquila can fly using just 5,000 W of power — about as much as three hair dryers.


WEIGHT
Aquila weighs a third as much as an electric car. About half the mass of the airplane is devoted to batteries.

SPEED
Because it's very large, Aquila is very slow. It flies at less than 80 miles per hour. That's the best endurance speed, allowing Aquila to stay aloft for months at a time.



How the balloons work

The balloons are sent up 20km (12 miles) into the stratosphere	Software moves them up or down to find the right winds to direct them into position	Each balloon beams an internet connection down to antennas on the ground
--	---	--



Google

BBC

Facebook’s Telecom Infra Project (TIP)

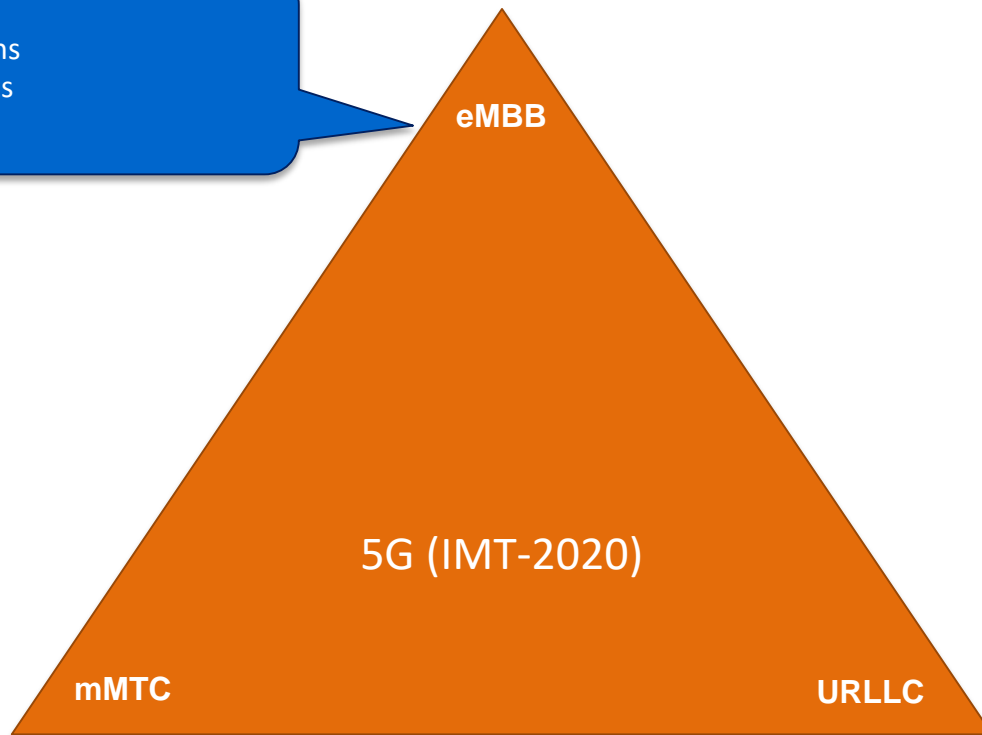
(Parallel Wireless is a member of TIP)

Access Projects	Backhaul Projects	Core & Management Projects
Edge Computing	Millimeter Wave (mmWave) Networks	Artificial Intelligence and Applied Machine Learning
Power and Connectivity	Open Optical Packet Transport	End-to-End Network Slicing (E2E-NS)
System Integration and Site Optimization		People and Process
OpenCellular – Wireless Access Platform Design		
Solutions Integration		
OpenRAN		
CrowdCell		
vRAN Fronthaul		
TIP Community Labs		
TEAC (TIP Ecosystem Acceleration Centers)		

Rural 5G Alternatives

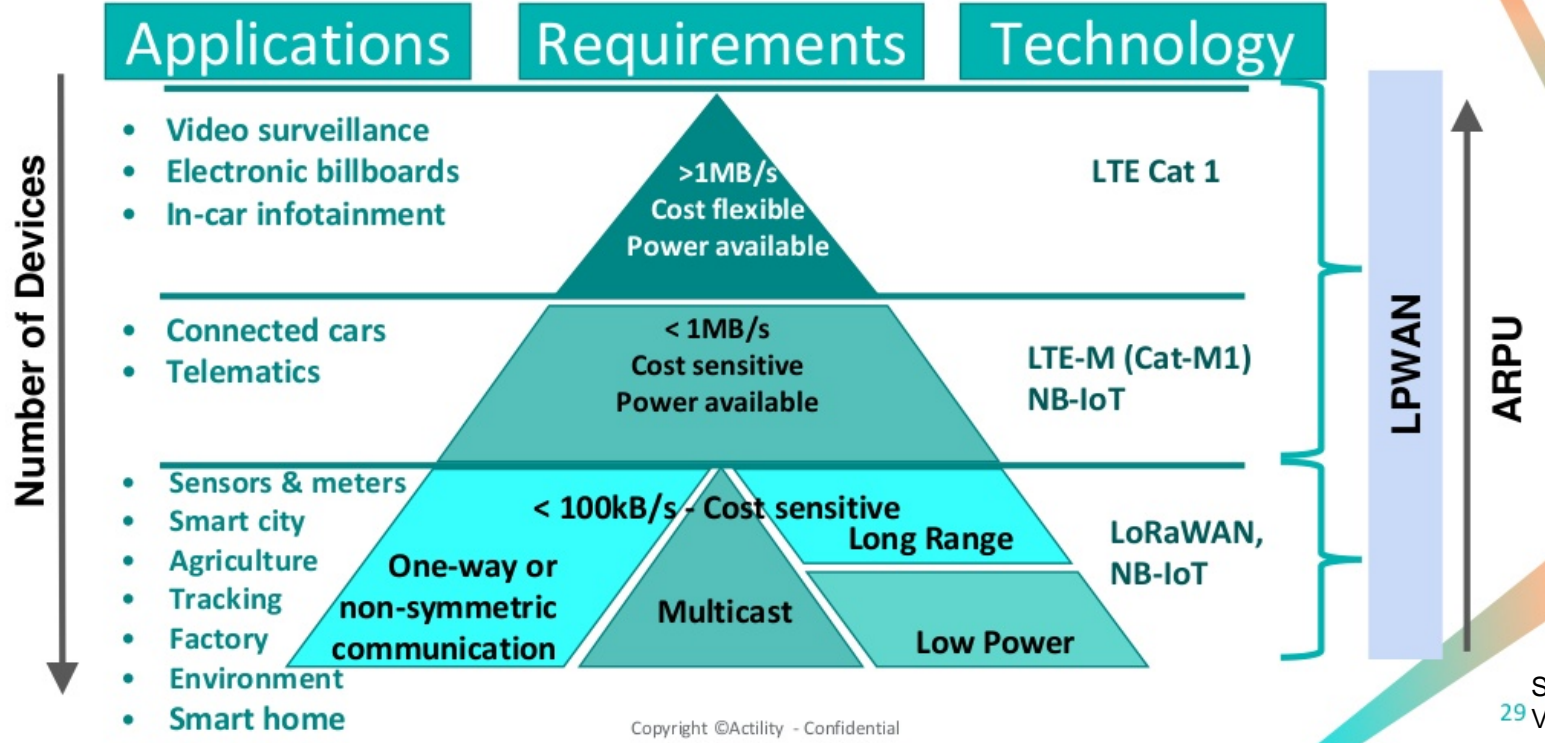
eMBB Alternatives

- LEO / MEO Satellite solutions
- Drones / Balloons / Airmasts
- Wi-Fi & Mesh Links



LoRaWAN: A cheaper alternative than cellular IoT

LoRaWAN and Cellular IoT are complementary



Copyright ©Activity - Confidential

Source: Activity
29 Via [3G4G Blog](#)

LoRaWAN: A cheaper alternative than cellular IoT



LoRaWAN: A cheaper alternative than cellular IoT



Source: [Ben Wood](#)

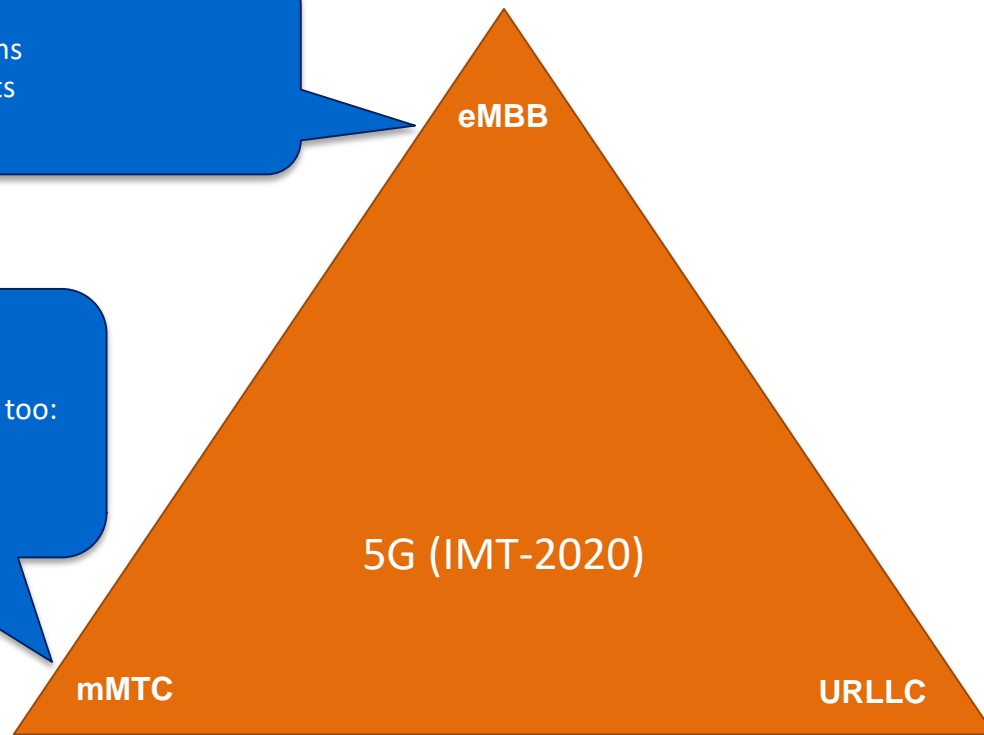
Rural 5G Alternatives

eMBB Alternatives

- LEO / MEO Satellite solutions
- Drones / Balloons / Airmasts
- Wi-Fi & Mesh Links

mMTC Alternatives

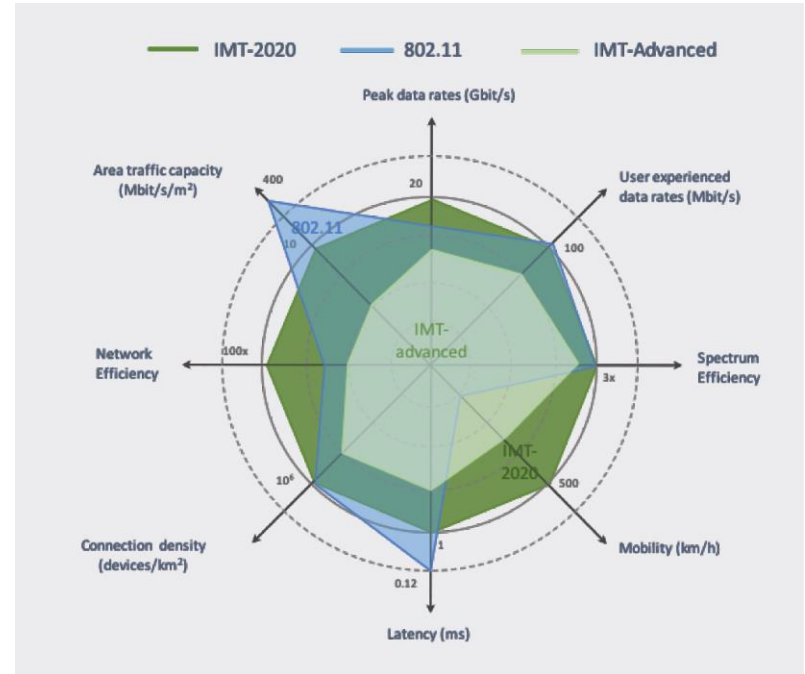
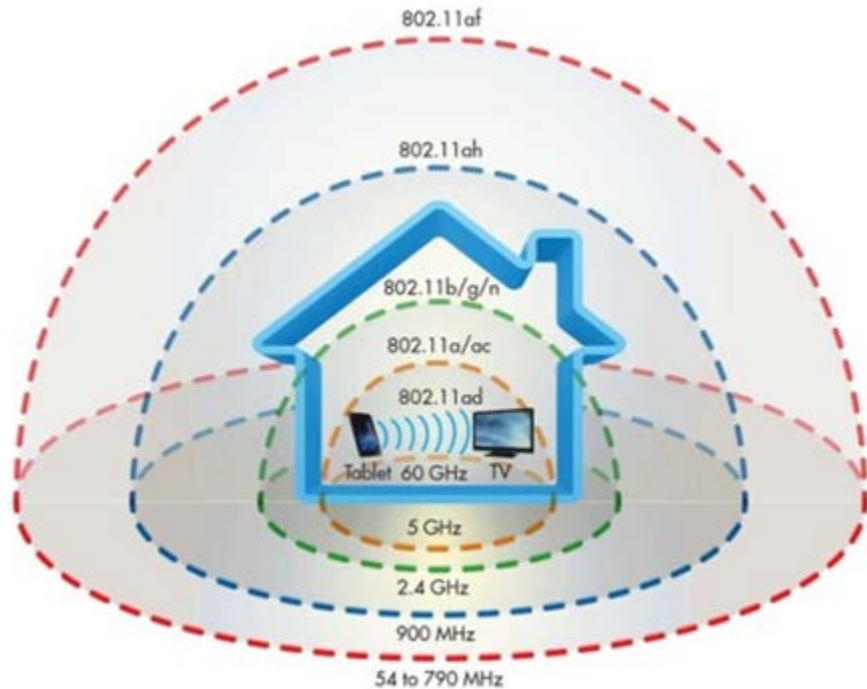
- LoRaWAN
- But there are other options too:
 - 802.11af (White-Fi)
 - 802.11ah (HaLow)
 - Bluetooth 5 Mesh



802.11 Technologies (a.k.a. Wi-Fi)

Standard	Year Adopted	Frequency (GHz)	BW (MHz)	Modulation	Max Data Rate	Max Range
802.11b	1999	2.4	22	DSSS	11 Mbps	450 feet
802.11a	1999	5	20	OFDM	54 Mbps	400 feet
802.11g	2003	2.4	20	OFDM	54 Mbps	450 feet
802.11n	2009	2.4, 5	20, 40	MIMO-OFDM	600 Mbps	825 feet
802.11ac	2015	5	20, 40, 80, 160	MIMO-OFDM	7 Gbps	35 meters
802.11ax	2019	2.4, 5	20, 40, 80, 160	MIMO-OFDM	10 Gbps	1000 feet
802.11ad	2016	60	2160	OFDM, SC	7 Gbps	30 feet
802.11ay	2019	60	(2160) x2, x3, x4	OFDM, SC	20 Gbps	300-500 meters

802.11 Technologies: Use-cases and Latency



Source: [RCR](#)

Rural 5G Alternatives

eMBB Alternatives

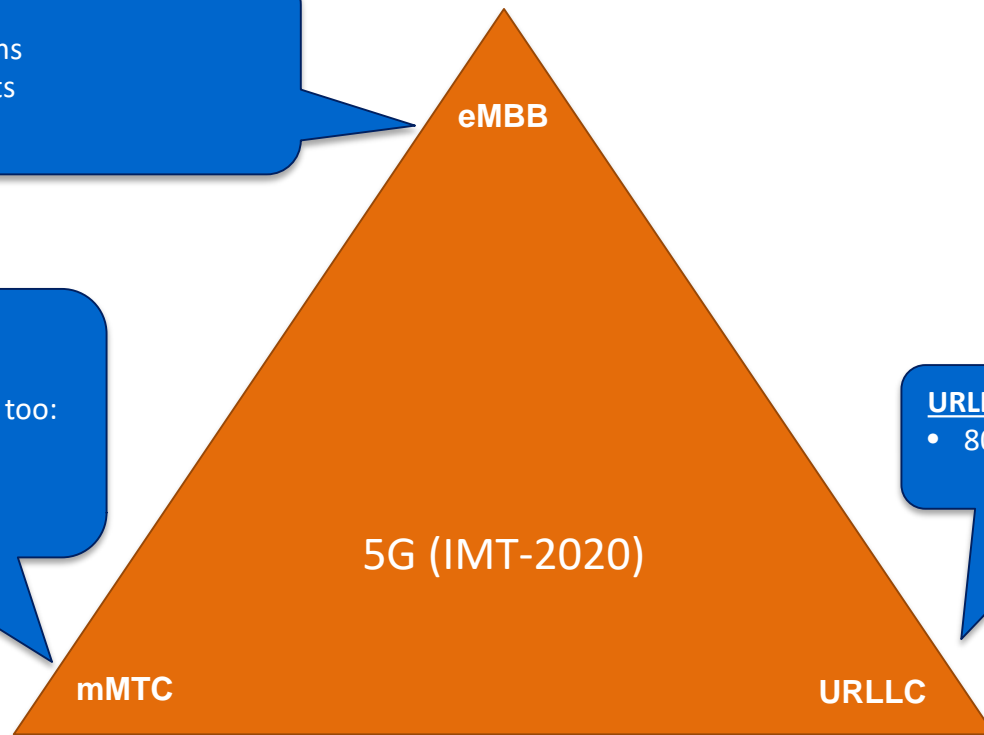
- LEO / MEO Satellite solutions
- Drones / Balloons / Airmasts
- Wi-Fi & Mesh Links

mMTC Alternatives

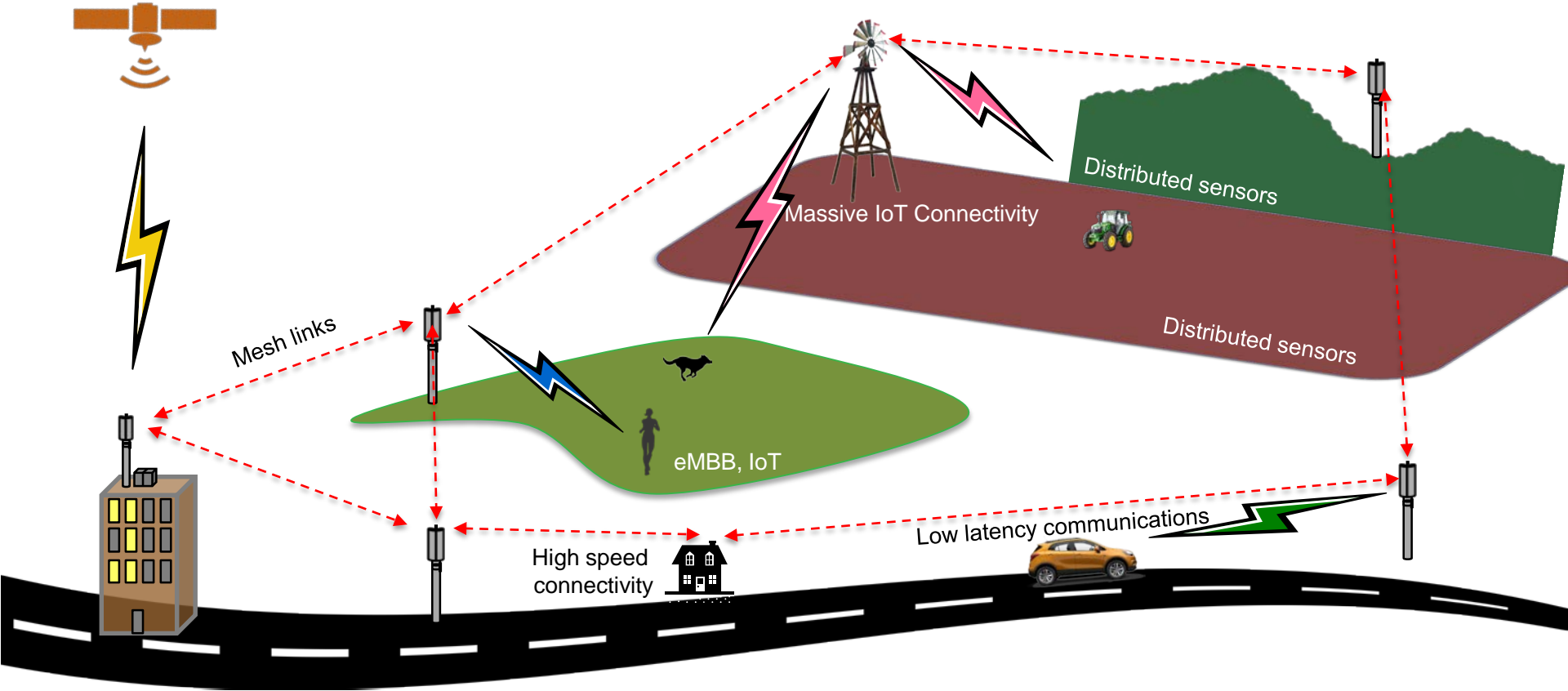
- LoRaWAN
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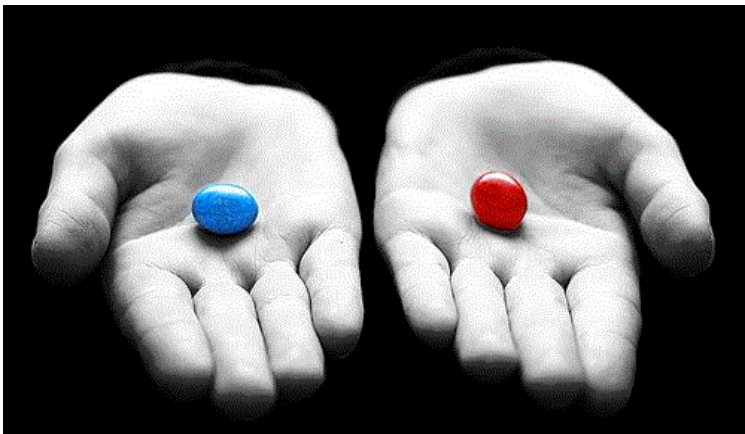
URLLC Alternatives

- 802.11 technologies



An Alternative Rural 5G of 2025



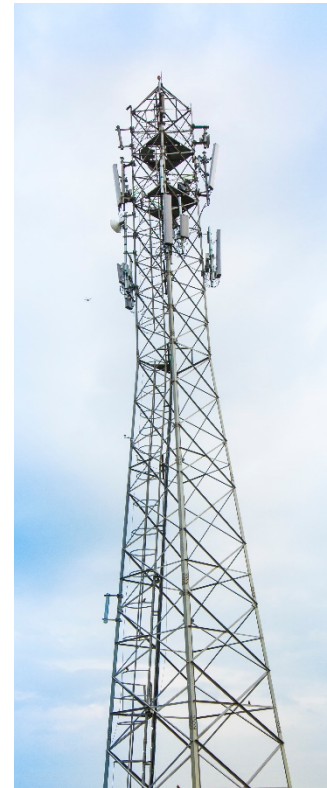


How can Parallel Wireless help?

The 'Red pill' scenario

Parallel Wireless Converged Wireless System (CWS)

Small Form Factor – can be easily deployed in trickiest of locations



Telefonica Press Announcement

Telefónica presents “Internet para todos”, a collaborative project to connect the unconnected in Latin America

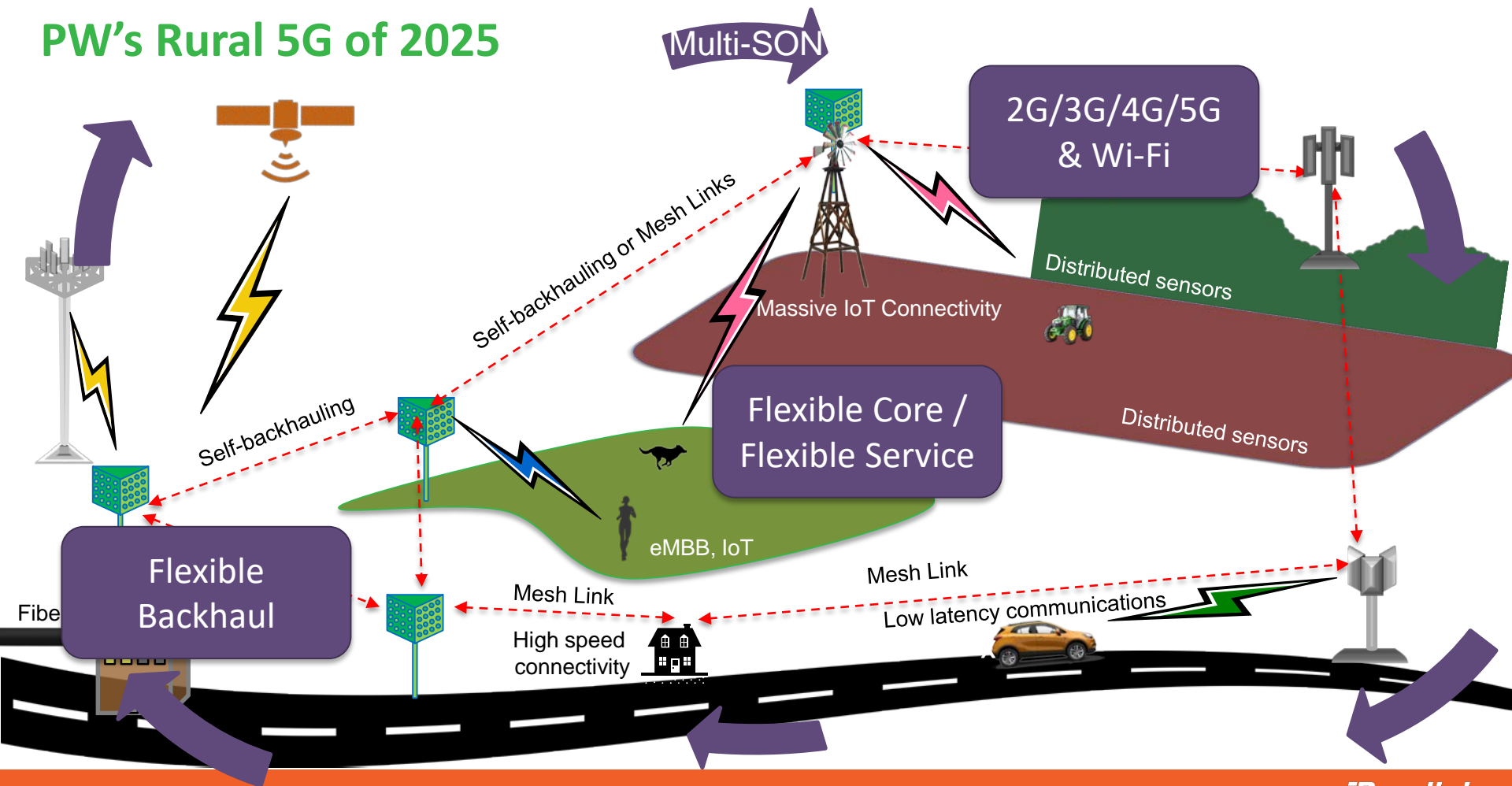
- Initiative is aimed at connecting the more than 100 million people in Latin America with no internet access
- Telefónica expands its collaboration with Facebook on key technological and commercial innovations and collaborates with multiple stakeholders: rural operators, technology firms and regulators.



[Link](#)

Recently, the team began testing the ability to stretch the capabilities of existing technologies, such as microwave, and exploring new Radio Access Network (RAN) solutions such as Parallel Wireless programmable Open RAN technologies to connect remote communities in Peru with 3G and 4G wireless based on General Purpose Processing Platforms. The pilot demonstrates the maturity of the technologies to provide cost-effective connectivity in low-density areas. Telefonica is also testing Facebook's OpenCellular LTE RAN platform.

PW's Rural 5G of 2025



Parallel *Wireless*

 *Reimagine Your Network*



Self-organised networks for coverage in Events, Disaster Areas & Rural Areas

Muhammad Ali Imran

Popup Networks for Events, Disasters and Rural areas

- Challenges of popup networks

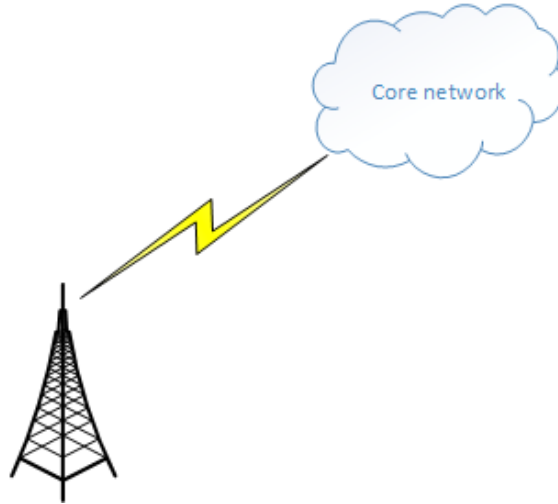
- Quick deployment
- Fronthaul/backhaul
- Power requirement

- UofG proposed solutions

Challenged for popup networks



Quick deployment

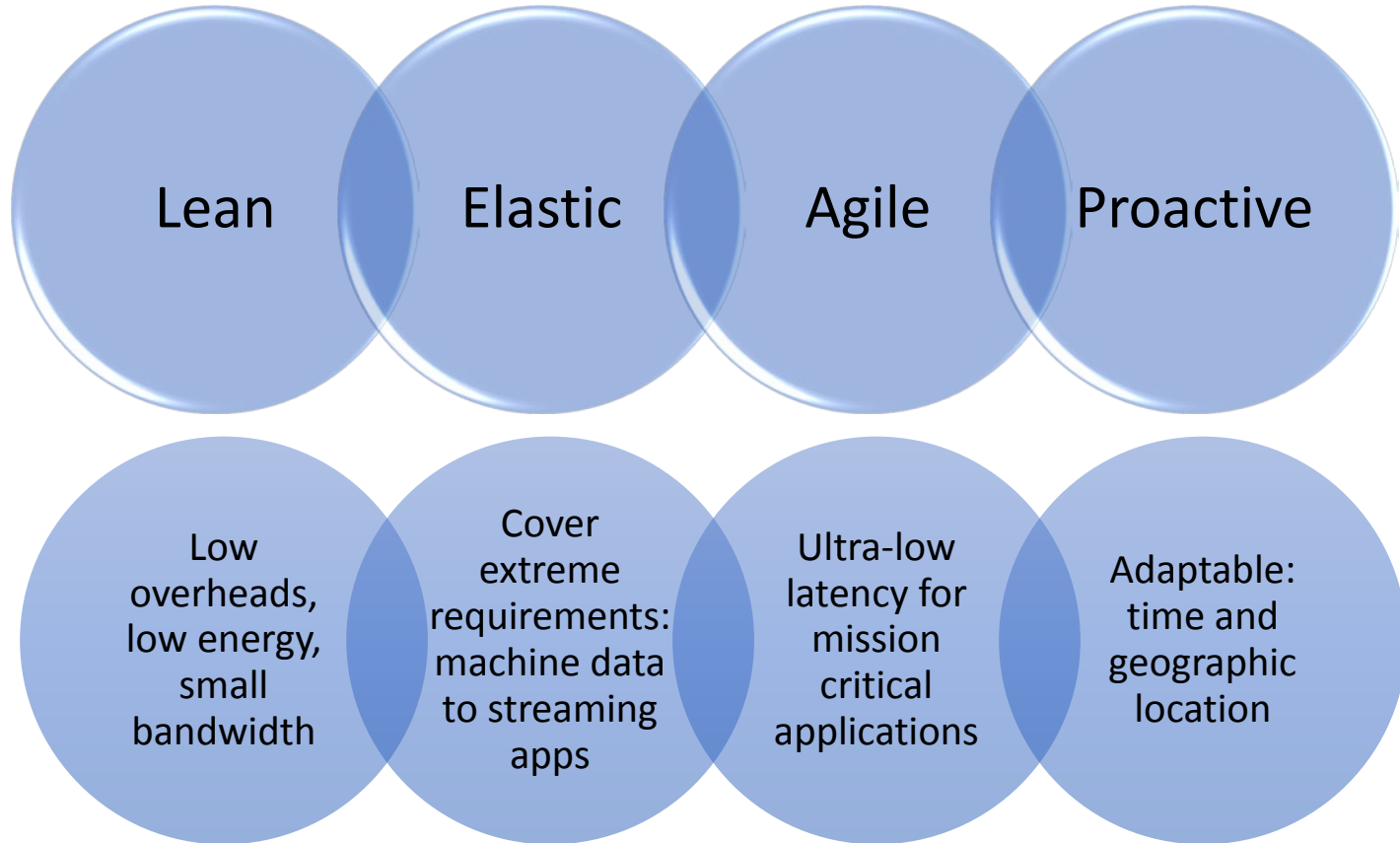


Fronthaul/backhaul

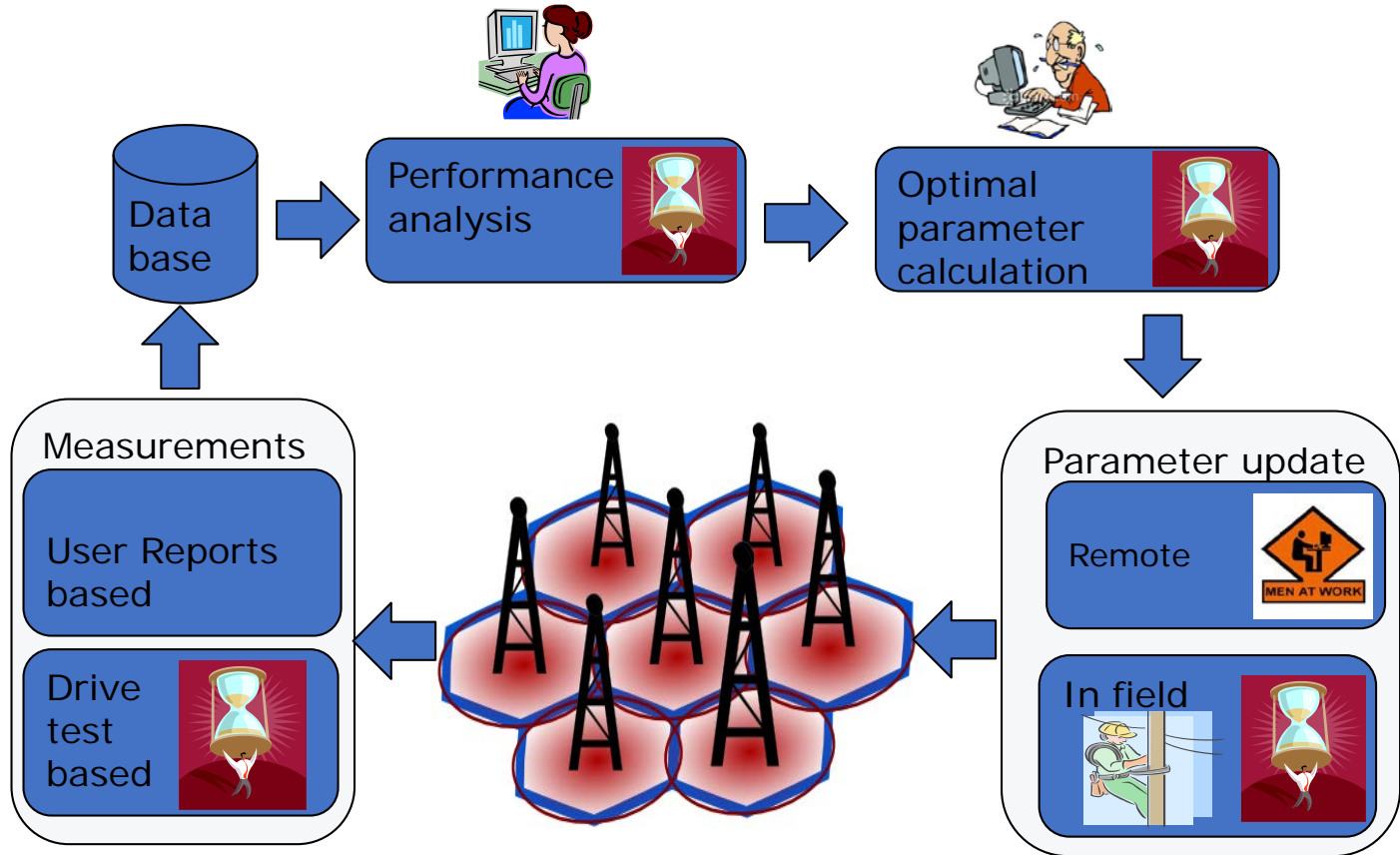


Power requirement

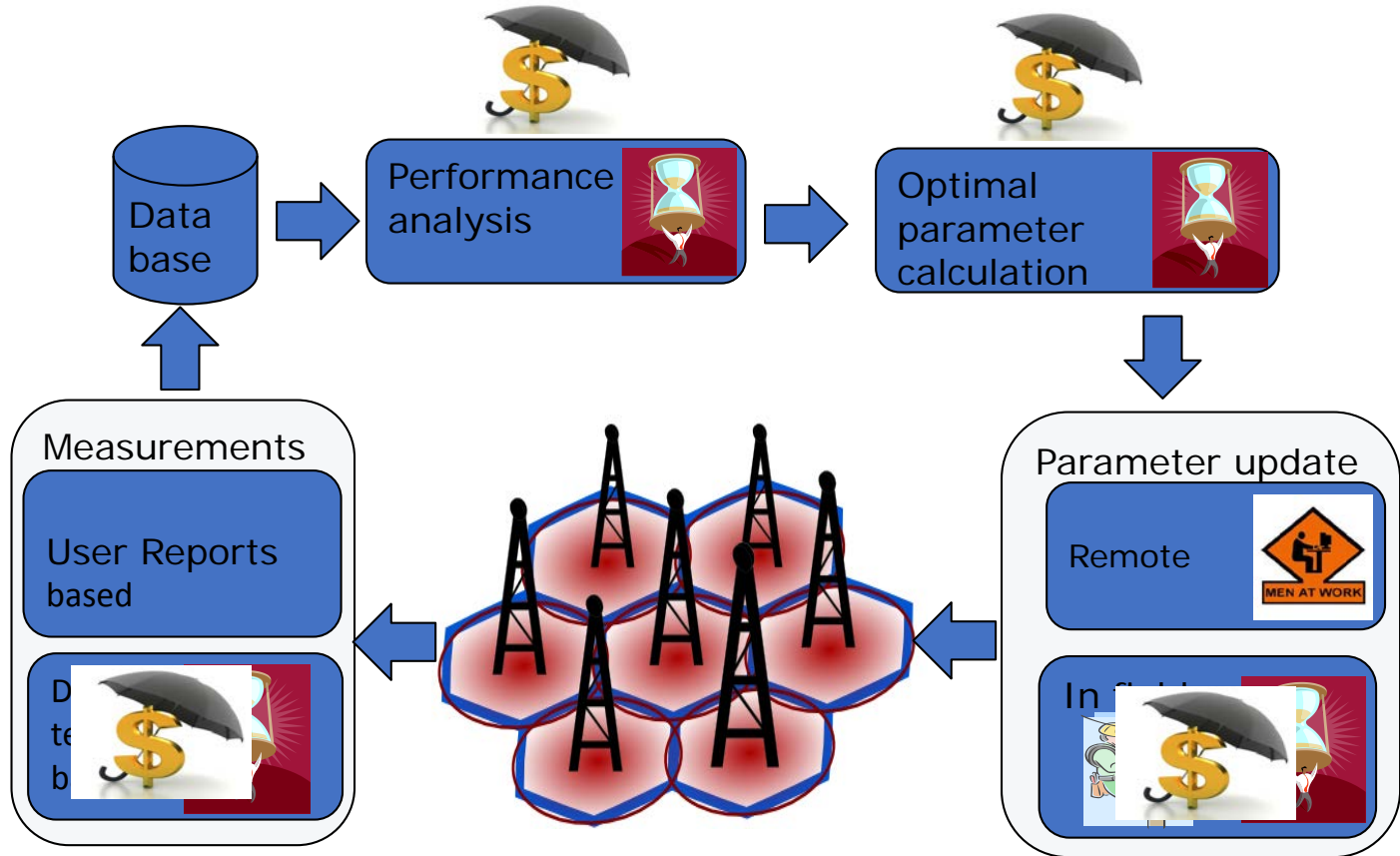
Need a "Leap"



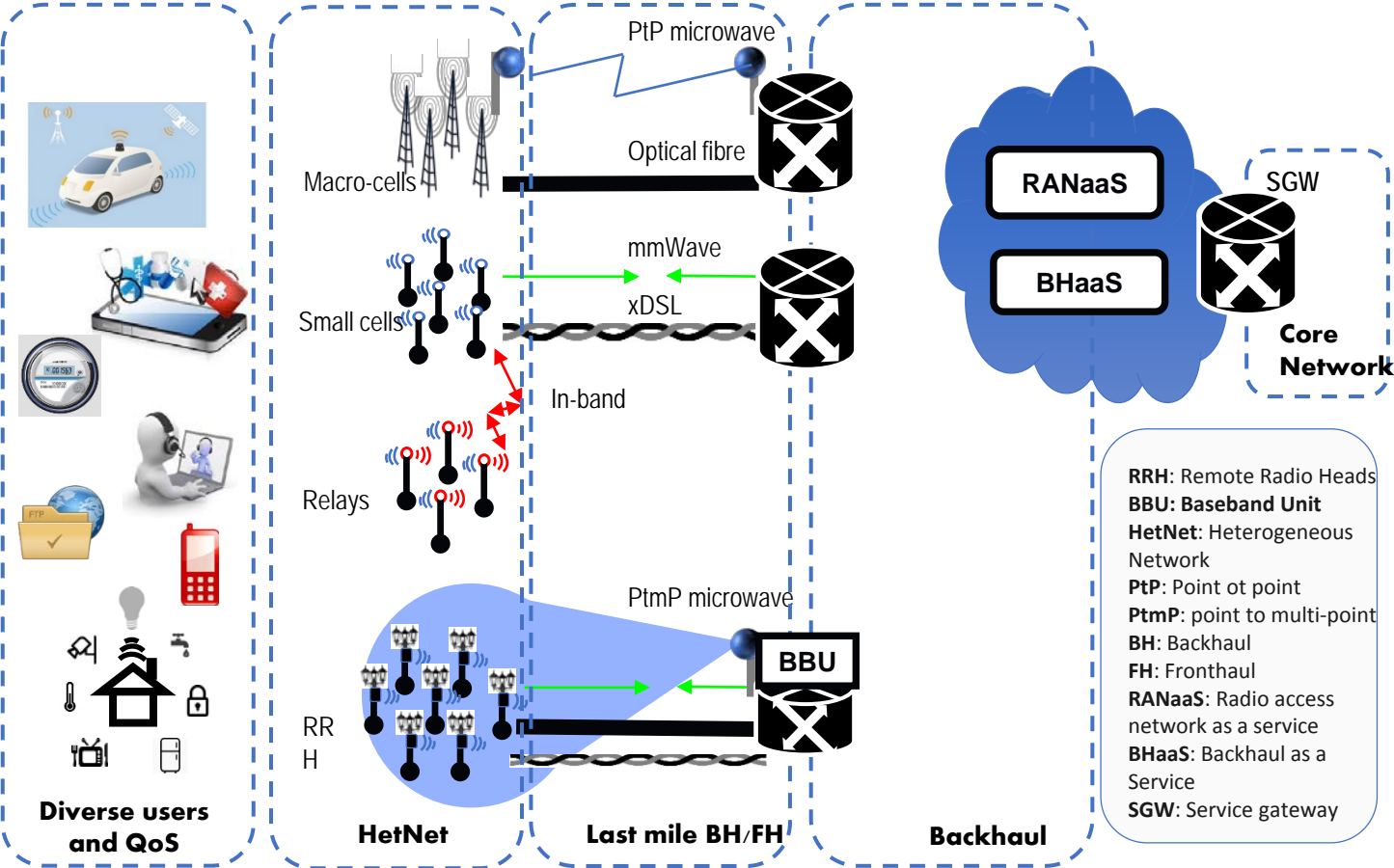
Typical Cellular Deployment



How SON will transform things!

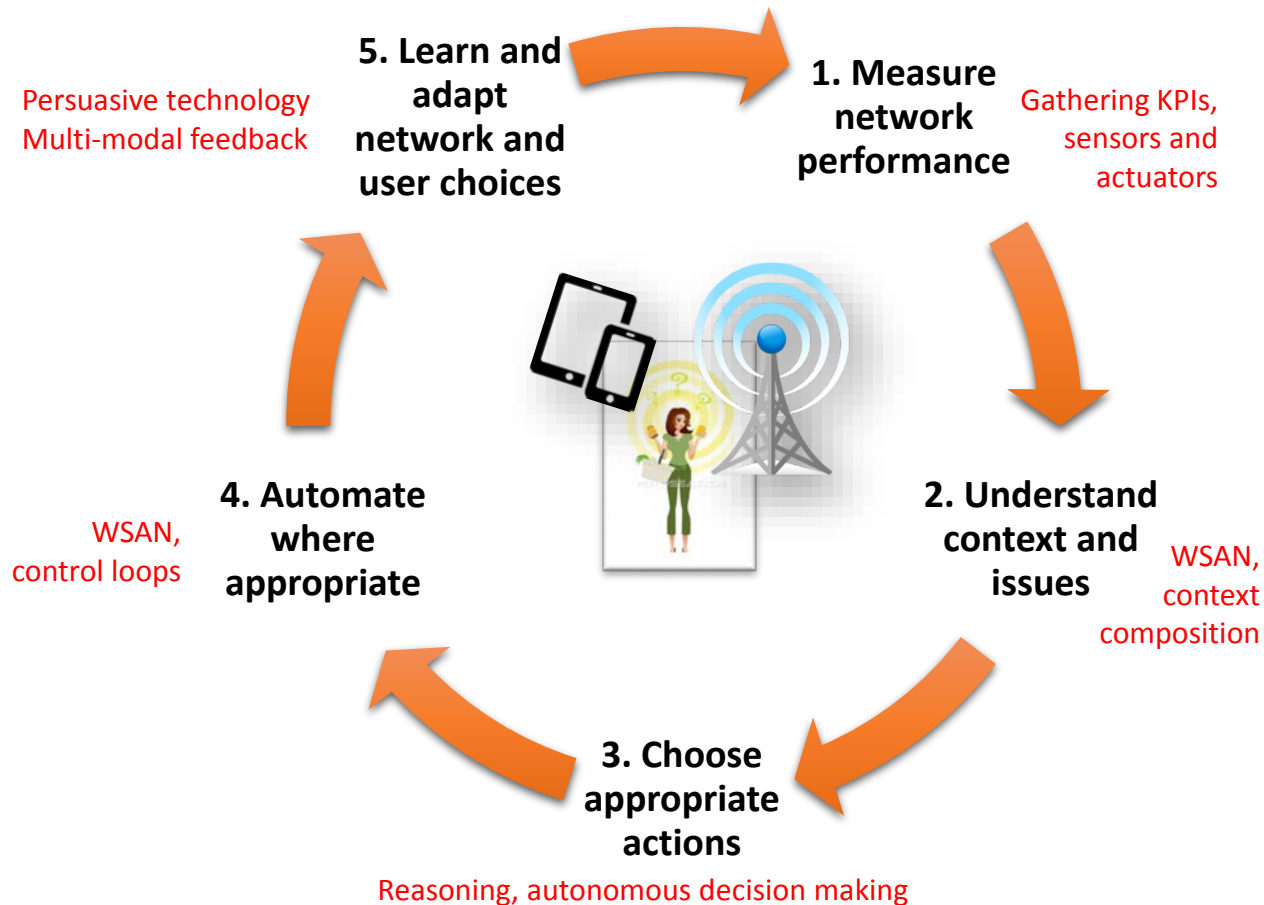


End-to-end view

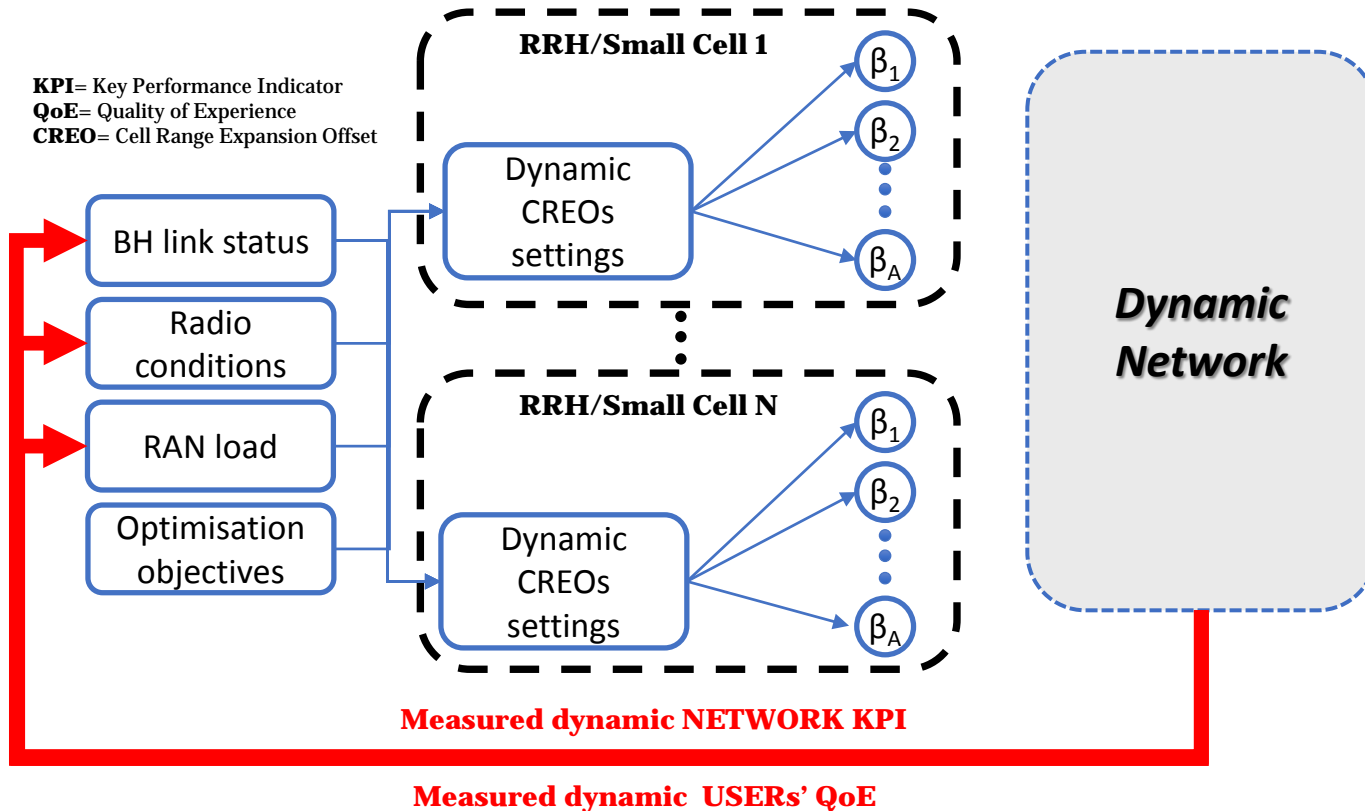


Diverse user demands need to be matched to diverse backhaul available

Machine Learning for SON



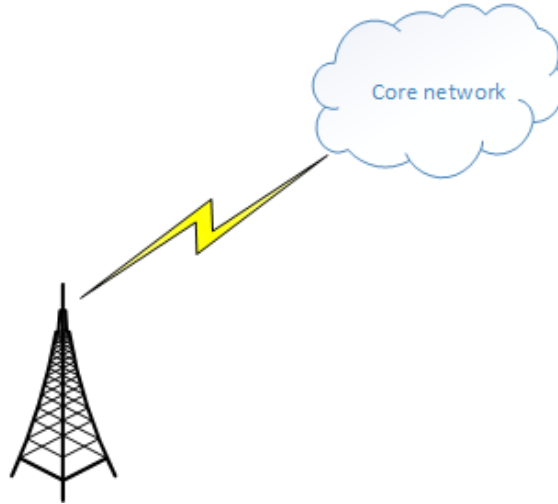
Machine Learning for SON



Challenged for popup networks



Quick deployment



Fronthaul/backhaul



Power requirement

Outline of solutions

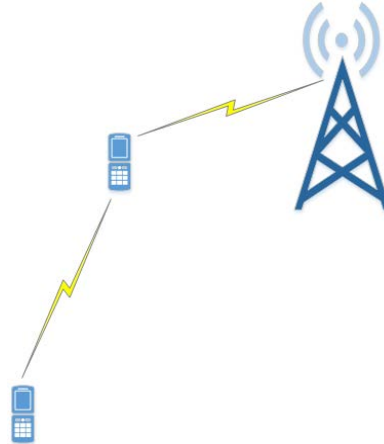


Drone BSs



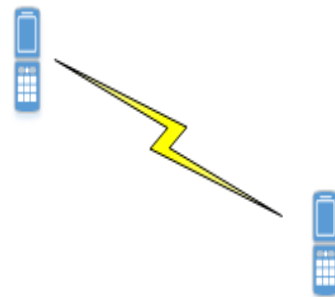
Truck-mounted BSs

Intelligent clustering of users
and BS positioning based on
reinforcement learning



Multihop communication

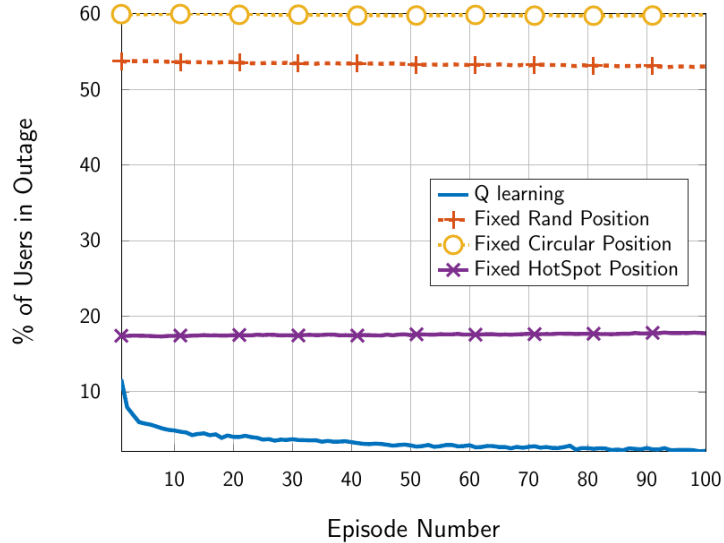
Novel routing, channel
selection and resource
allocation schemes



D2D communication

Intelligent pairing of
users for D2D
communication

Selected results

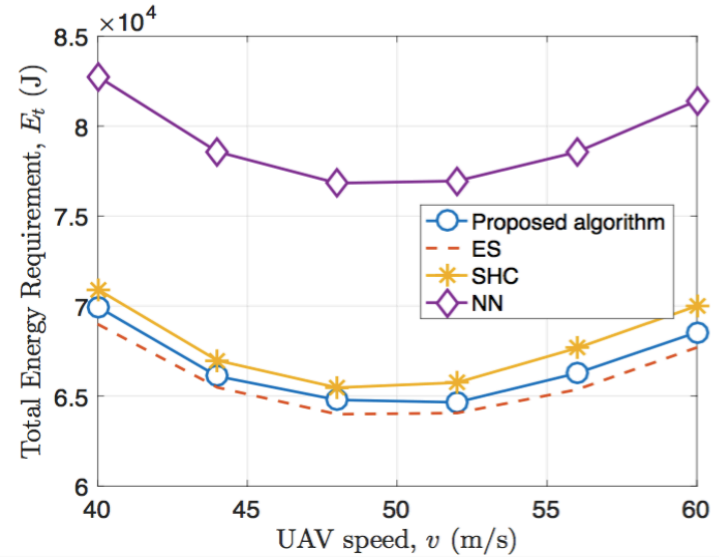


Self-configured drone formation

ES: Exhaustive Search

SHC: Shortest Hamiltonian Cycle

NN: Nearest Neighbor

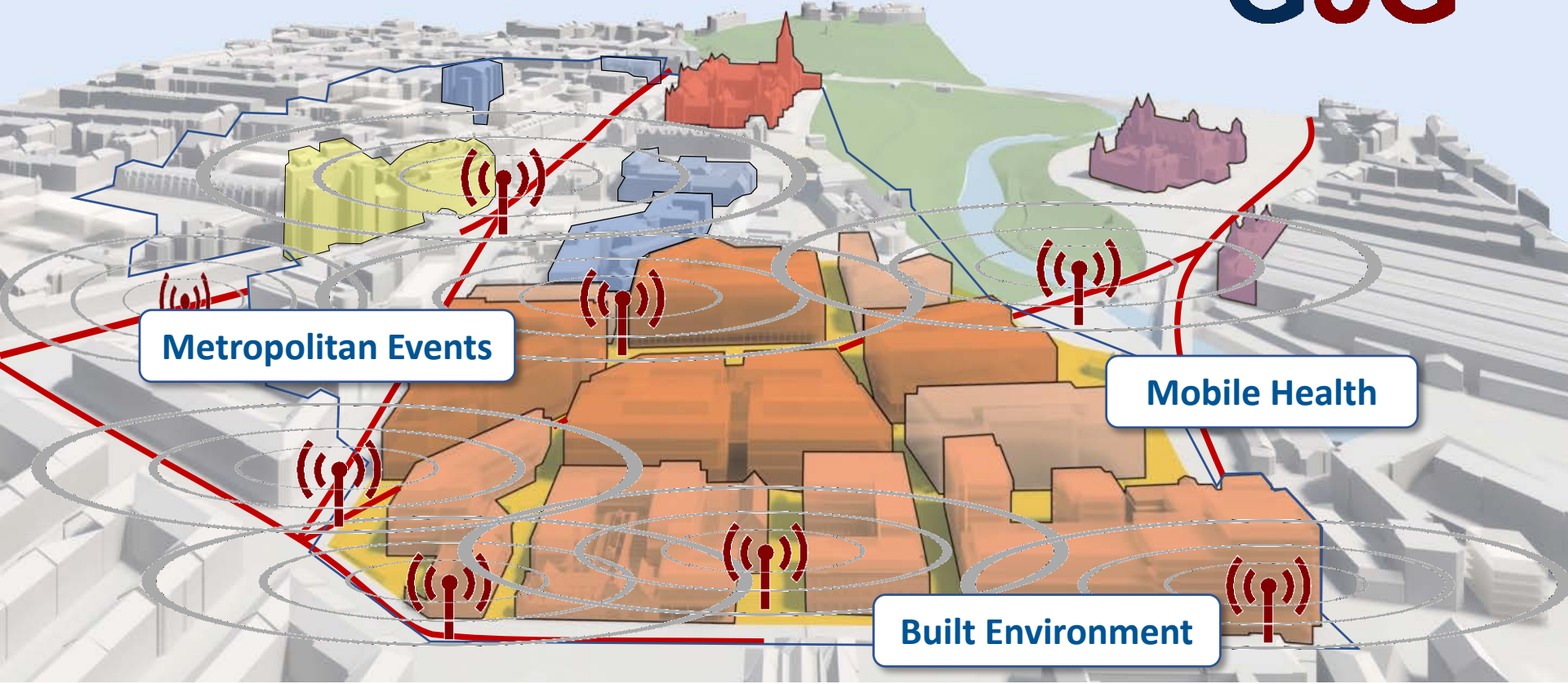


Holistic energy minimisation

5G Testbed and Trials

Smart Urban Campus / Smart City District
Demonstrator for future 5G services

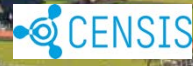
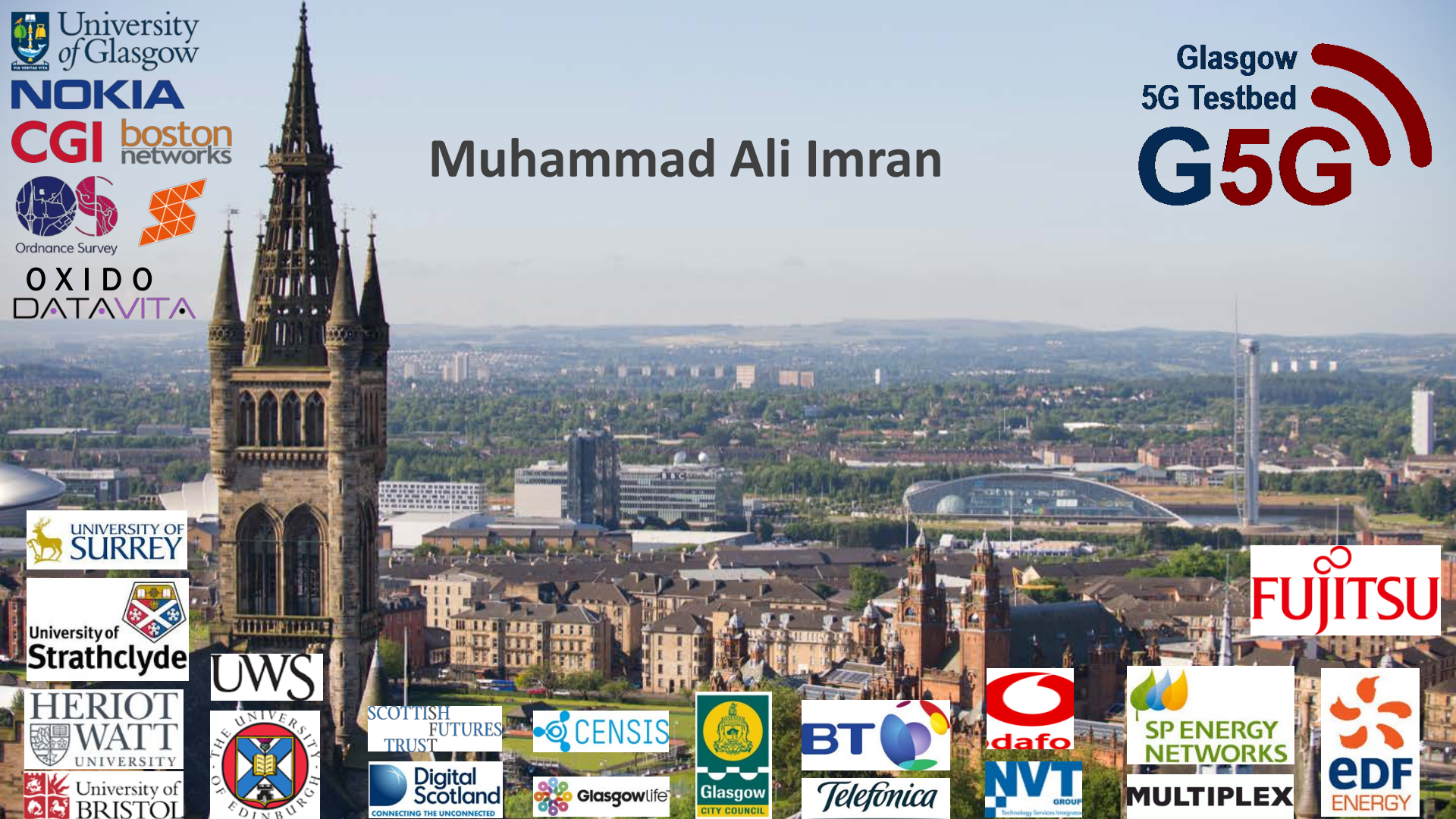
Glasgow
5G Testbed
G5G





Muhammad Ali Imran

Glasgow
5G Testbed
G5G





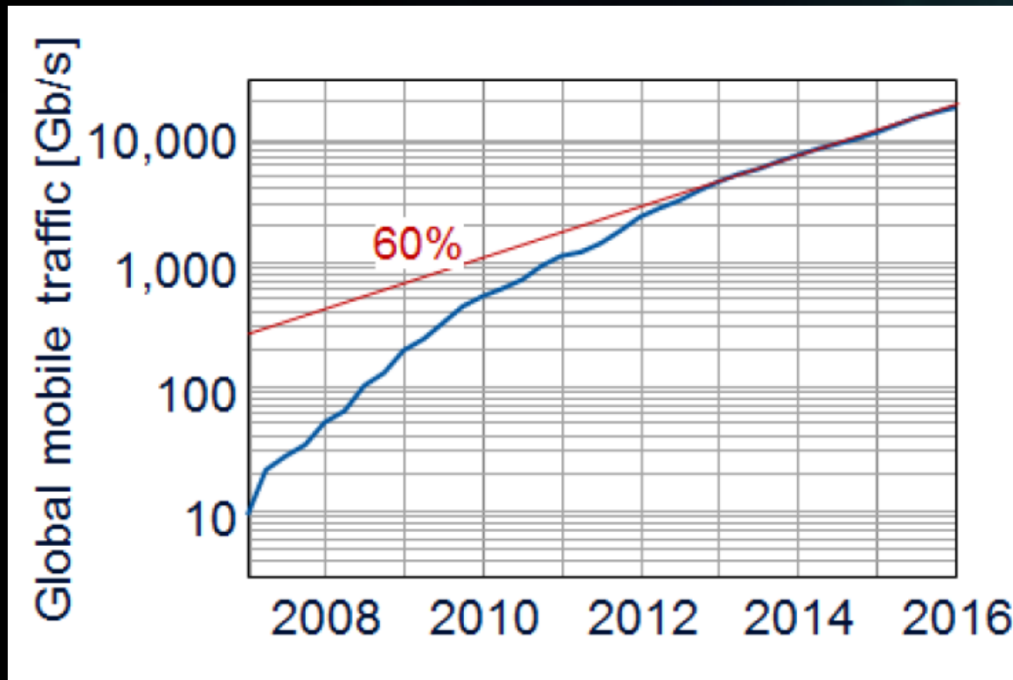
LiFi for 5G and Beyond

Professor Harald Haas

company confidential



Spectrum Crunch



Winzer, Neilson, "From Scaling Disparities to Integrated Parallelism: A Decathlon for a Decade, *IEEE/OSA JLT*, 2017

In 20 years (6G?), this means $\times 12,000$ bandwidth

500 MHz used for WiFi in 5 GHz band will need to become **6 THz**

20 times shortfall!

The small cell concept

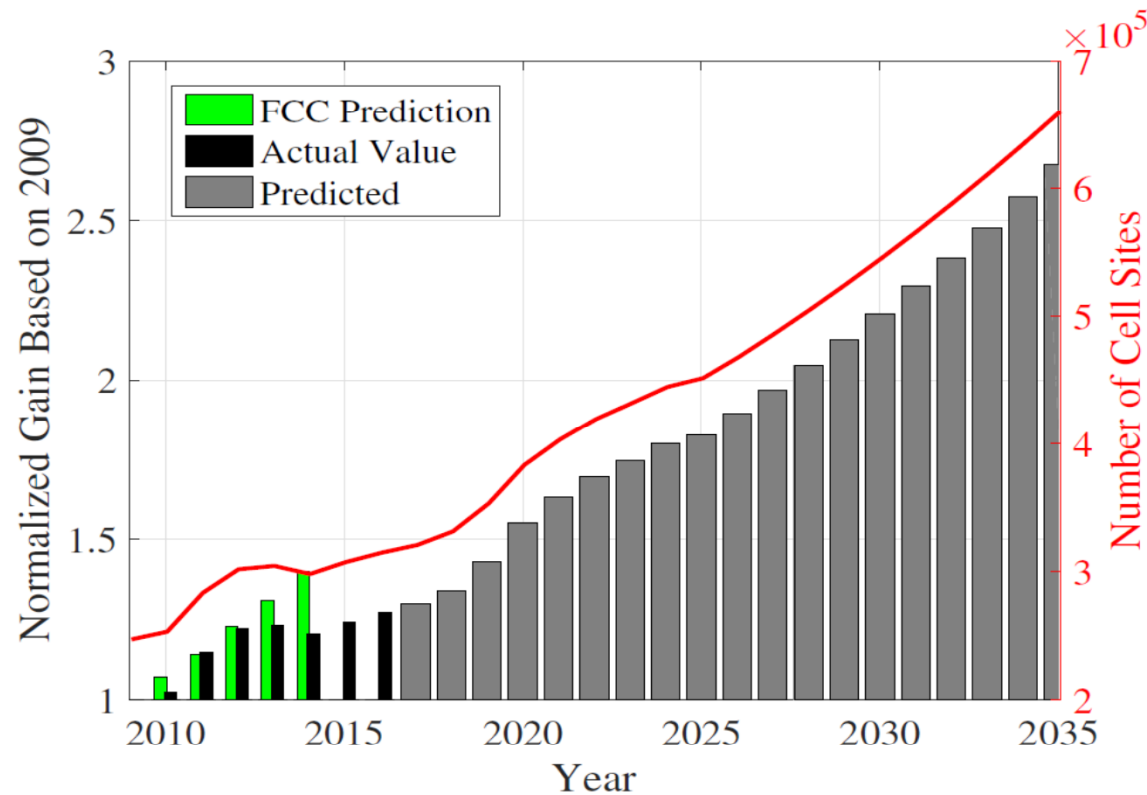


Fig. 4. Reported and predicted number of cells sites in US.

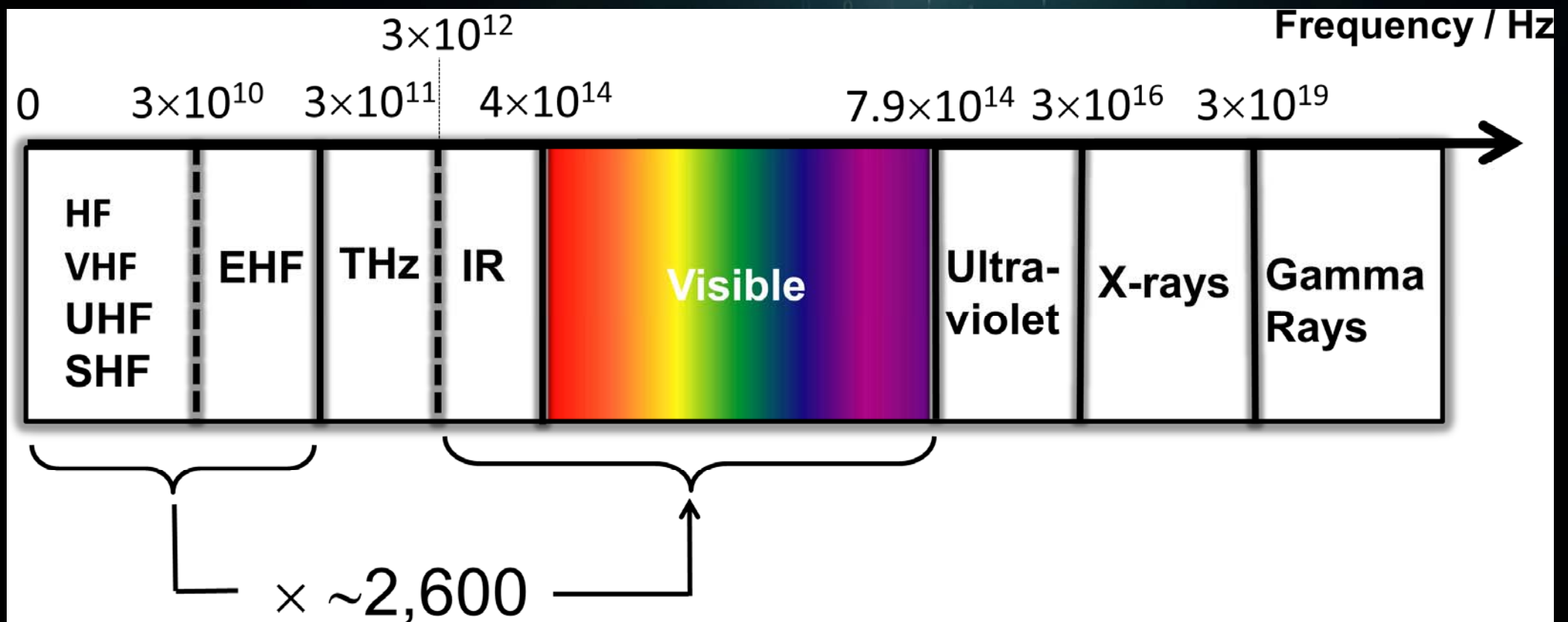
T. Cogalan and H. Haas, "Why Would 5G Need Optical Wireless Communications?," *PIMRC*, October 2017.

Hitting physical limits in cellular RF communications



Source: [illegible]

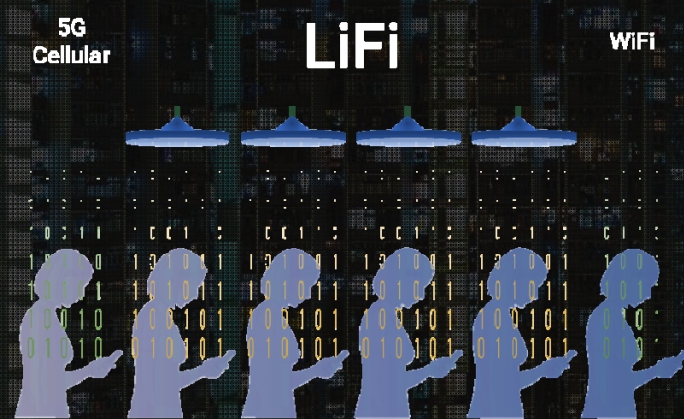
The electromagnetic spectrum



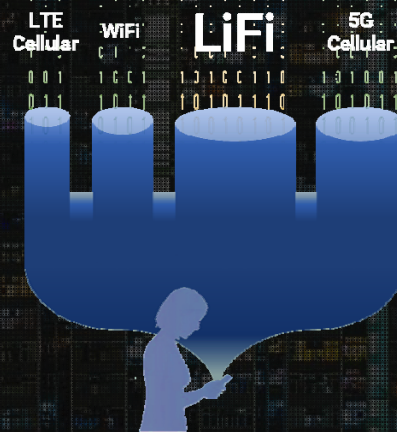
LiFi will be the largest data pipe

How is LiFi better than WiFi? In a word, bandwidth.

Radio is incredibly crowded already, and it's certain to fall short of our growing data demands. So we need something else for wireless transmission. Enter Li-Fi. We could meet our 20-year data demands using just 0.8% of the light spectrum.



Intercarrier Handover



Carrier Aggregation

It also benefits many other areas!



Gigabit Home & Office



Smart Transport



AR VR



Artificial Intelligence



Industry 4.0

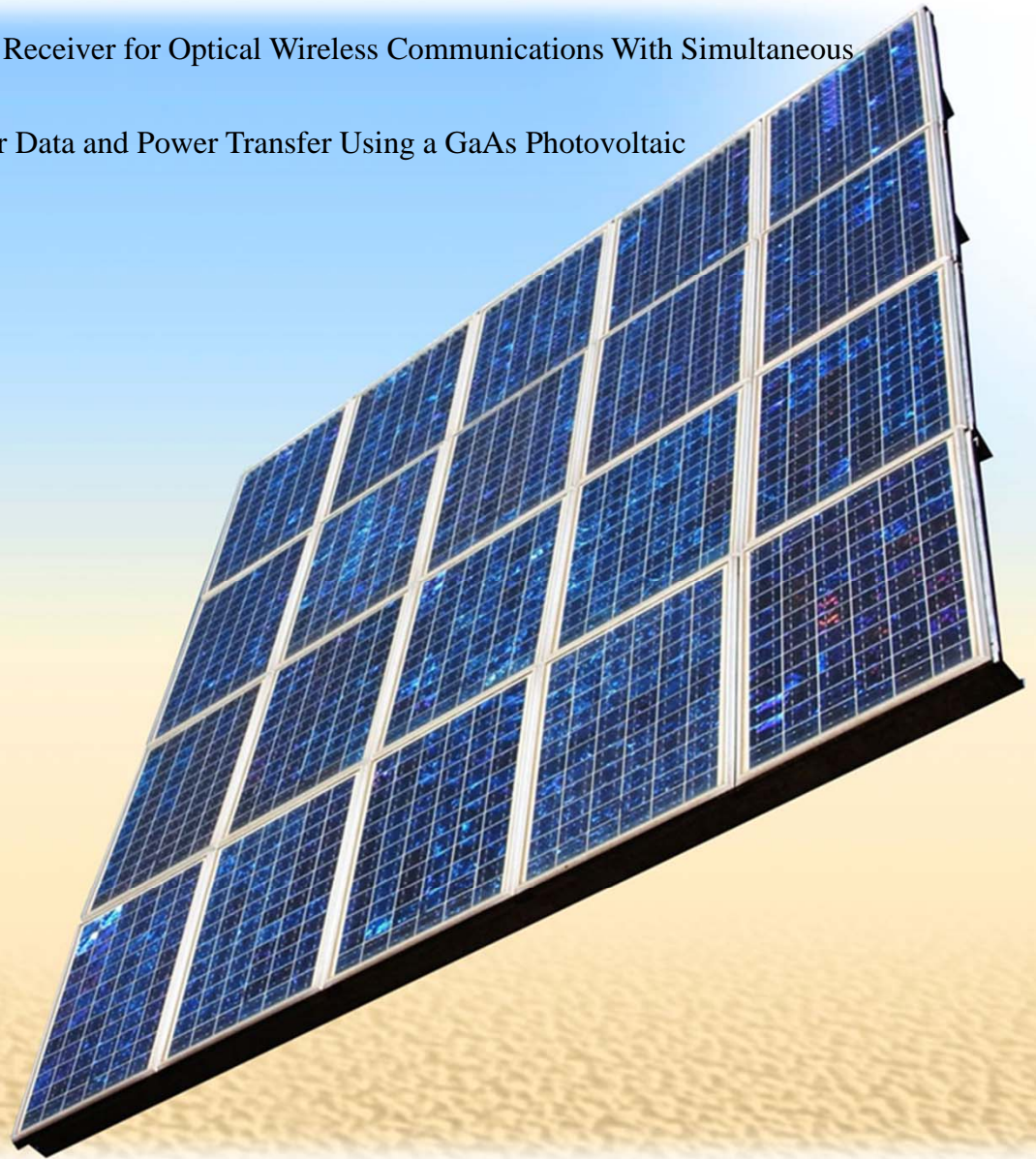


Healthcare & Medical

pureLiFi

Z. Wang, D. Tsonev, S. Videv and H. Haas, "On the Design of a Solar-Panel Receiver for Optical Wireless Communications With Simultaneous Energy Harvesting," *IEEE JSAC*,. 2015


J. Fakidis, S. Videv, H. Helmers and H. Haas, "0.5-Gb/s OFDM-Based Laser Data and Power Transfer Using a GaAs Photovoltaic Cell," in *IEEE Photonics Technology Letters*, 2018





Misconception: Interference from sunlight

		Dark Room	Sunlight Irradiance	Sunlight + Blue Filter	
M 450 nm blue L 100 μm diame Thorlabs AC DC bias	S8664-50K [19.6 mm²]	Average SNR [dB]	17.57	12.42	16.64
		SNR degradation compared to Dark Room	0%	29.33%	5.32%
		Data rate @ BER< 3.8e-3 [Mbps]	416.44	313.35	396.71
		Degradation of data rates compared to Dark Room.	0%	24.8%	4.7%
	S8664-05K [0.19 mm²]	Average SNR [dB]	18.58	16.42	17.36
SNR degradation compared to Dark Room		0%	11.6%	1.7%	
Data rate @ BER< 3.8e-3 [Mbps]		1139.26	1015	1122.34	
Degradation of data rates compared to Dark Room.		0%	10.9%	1.5%	

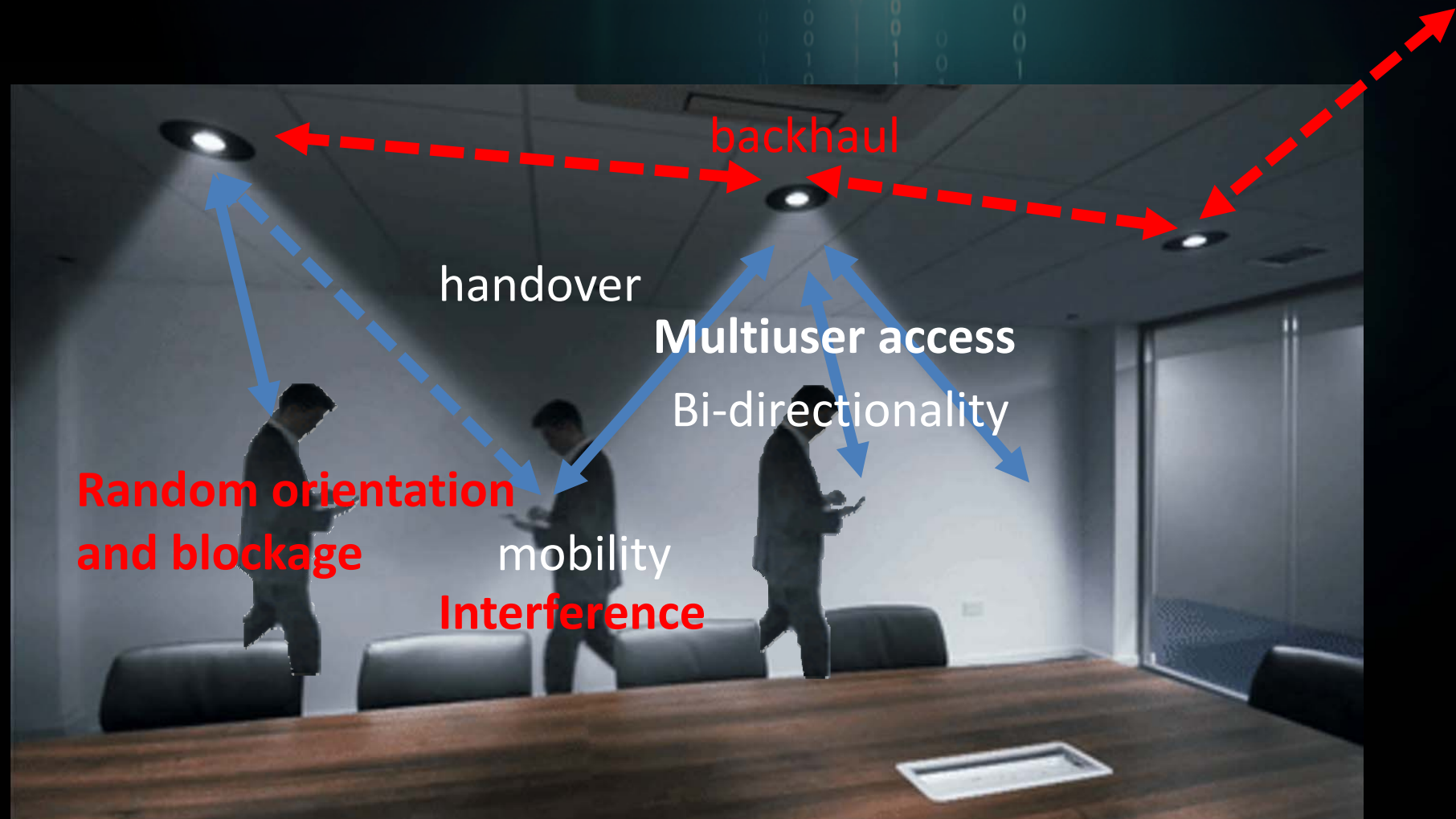


ology,

Handover



LiFi wireless access technology

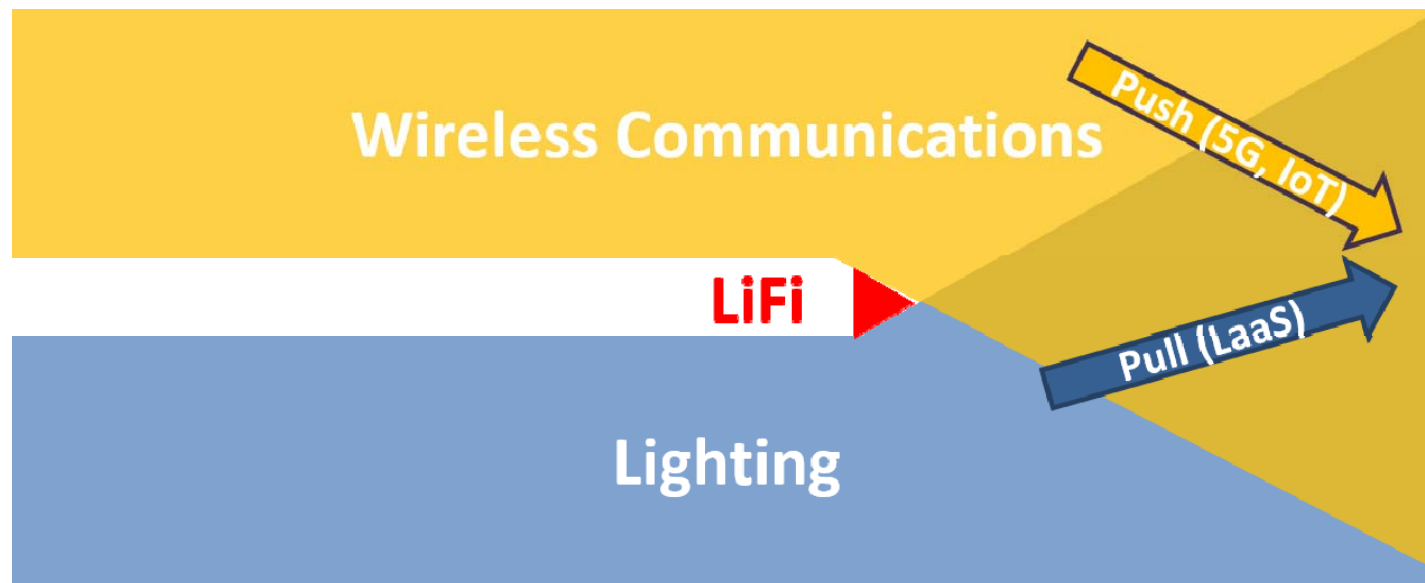


VLC + Solar cell receiver as 5G backhaul solution



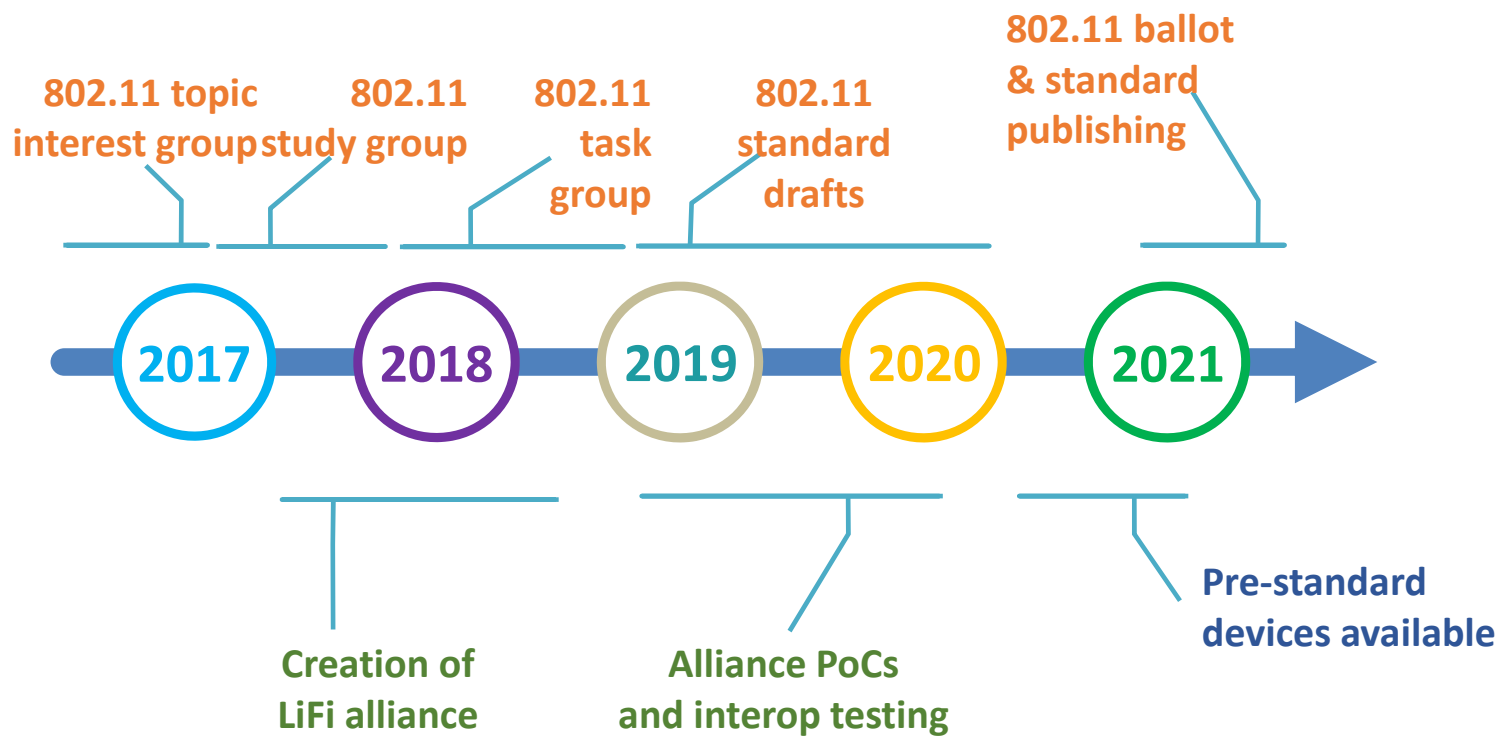
The 'LiFi' disruption

The **advent of LED lighting** has shifted the business metric of the lighting world from \$/bulb to **\$/lux**. The additional energy management allows for building optimisation.



Added communications and the increasing desire for infrastructure data means a convergence to **\$/bit**.

IEEE 802.11 bb LC Study Group



Driving LiFi 802.11bb standardisation as part of 5G



5G



802.11bb

With cross-industry support,
pureLiFi leads the
Light Communications Task Group standardising
LiFi 802.11bb as a
5G bearer, complementary to
& interoperable with WiFi



LiFi is real...

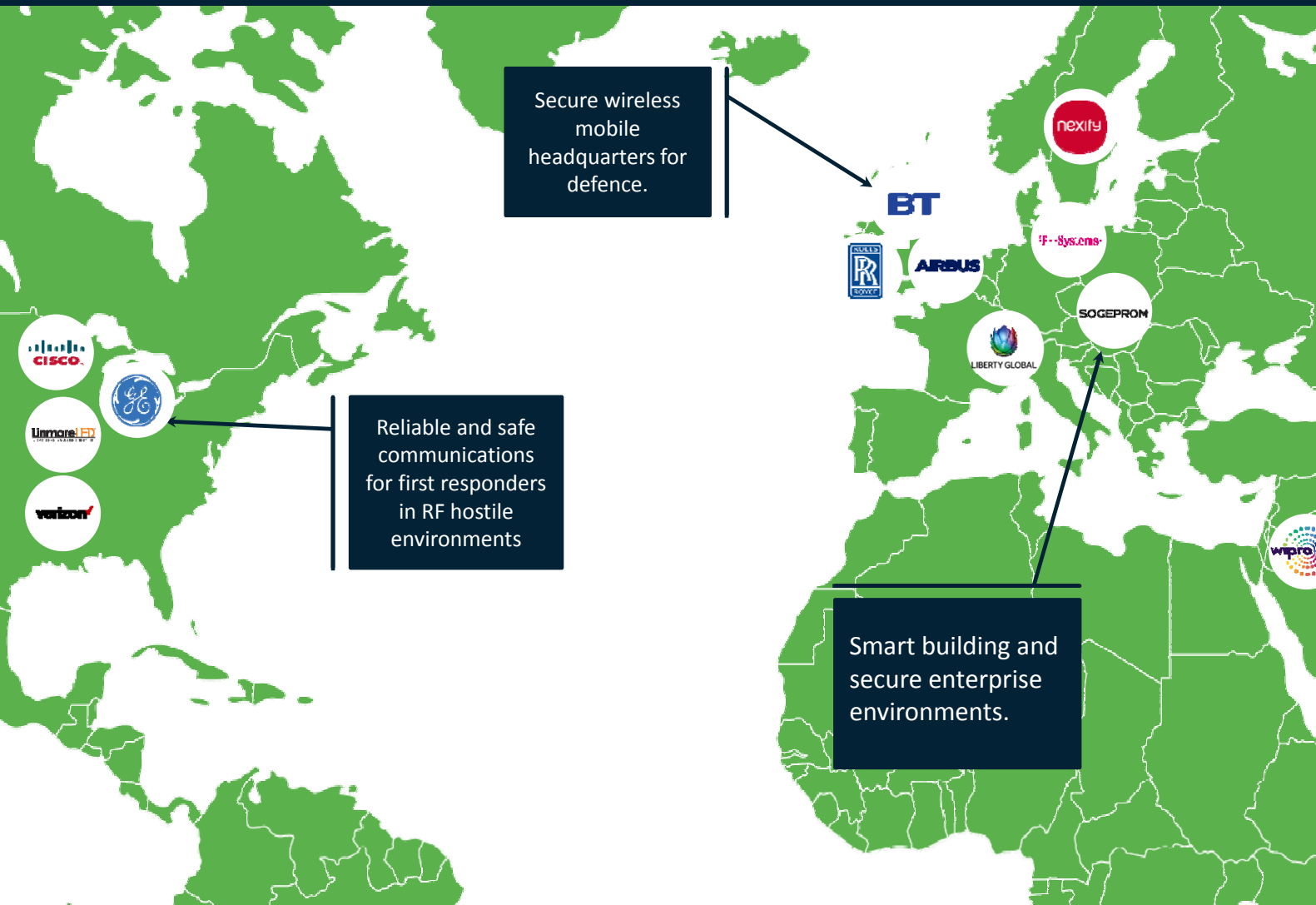


“PureLiFi Demos Skype Call Over LiFi

Samsung Galaxy case and Dell laptop proof-of-concepts demonstrate that when the components are small enough to be built into phones getting this up and running on the Samsung Galaxy S14 (or whatever they call it) won't be a problem.”



pureLiFi Customer & Partner Deployments



All Time

65
Deployments

20
Countries

16
Use Cases

Since 2016

52
Deployments

16
Countries

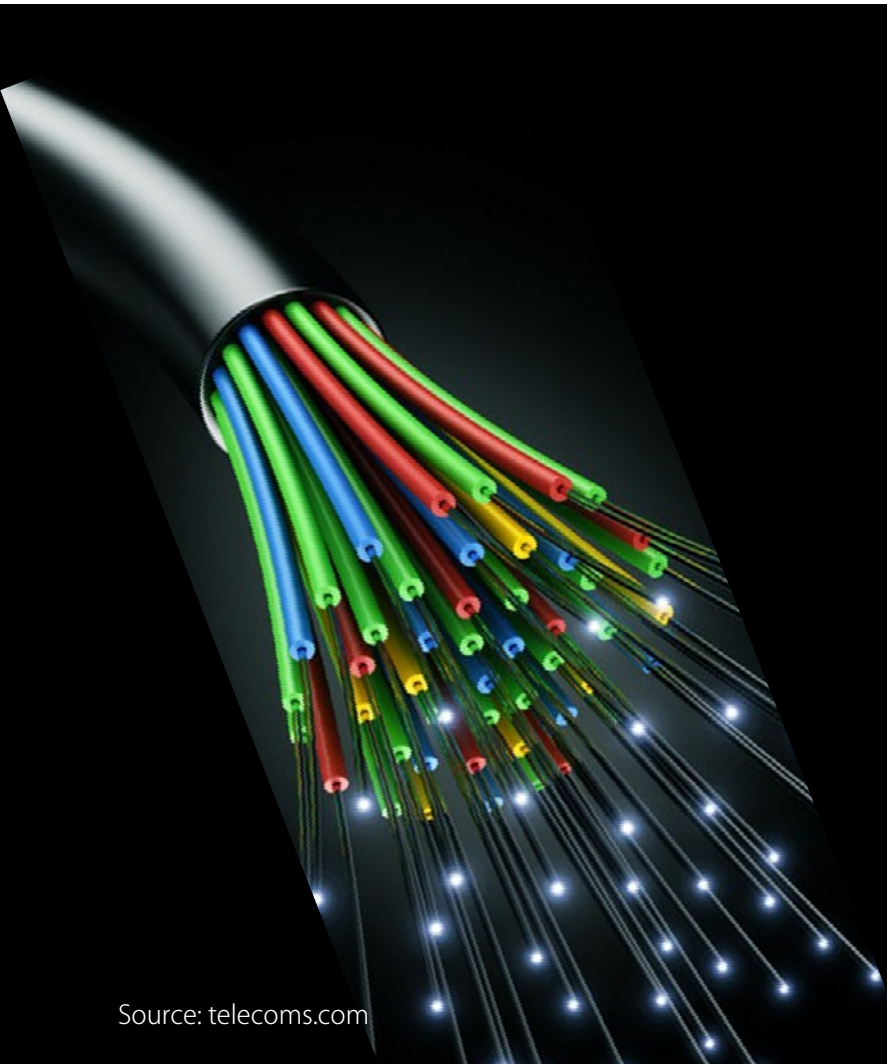
12
Use Cases

Past 6 Months

32
Deployments

14
Countries

10
Use Cases



Source: telecoms.com



Source: 123rf.com

Electromagnetic spectrum is continuum → Move from cm-Wave to mm-Wave to nm-Wave !!



5GRIT - 5G Rural Integrated Testbed

Monday 14th May 2018, University of Strathclyde

BROADWAY
PARTNERS
BROADBAND FOR ALL

Our Vision: 100% Connectivity, Now!

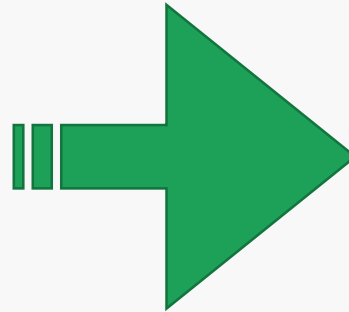
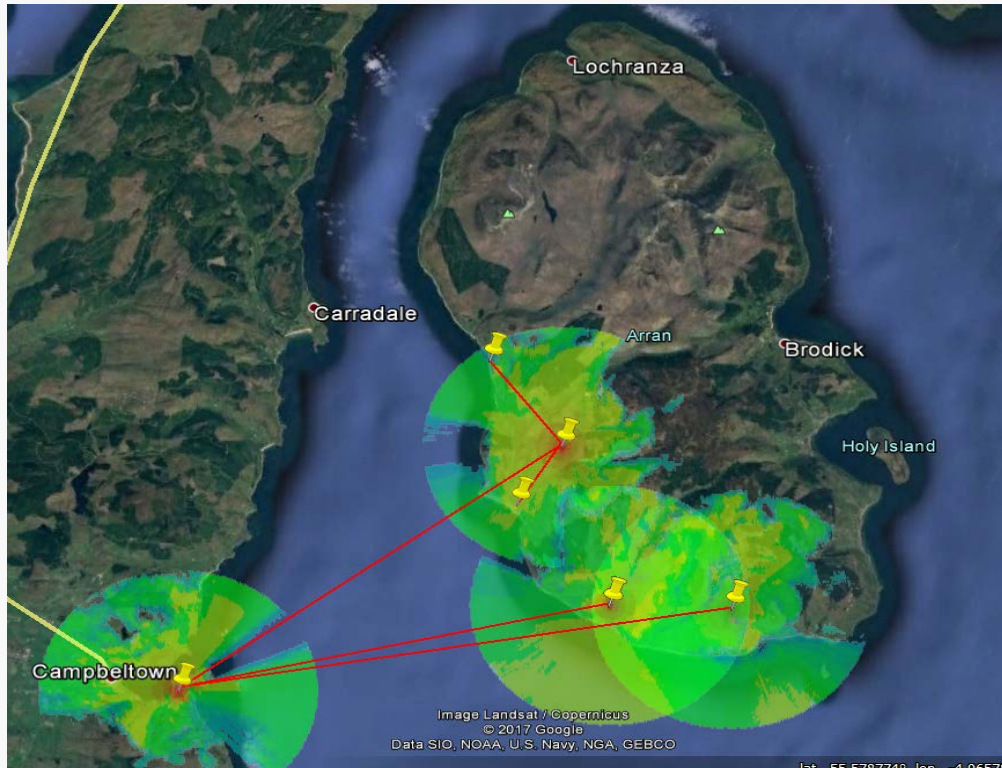
- Broadway has a simple mission – to help make Scotland a digital leader, starting with a target of 100% great broadband
- Why? Because **we can**:
 - Scotland has the technology and the skills
- And because **we're worth it**:
 - People, communities, businesses, farmers, government, the economy and the country all benefit
- Broadway is a leader in the commercialisation of TVWS:
 - ✓ A silver bullet for filling broadband 'not spots'
 - ✓ Proven deployment in Scotland and Wales, working with the leaders in the space – Nominet, Universities of Strathclyde & KCL
- Arran is our proving ground...



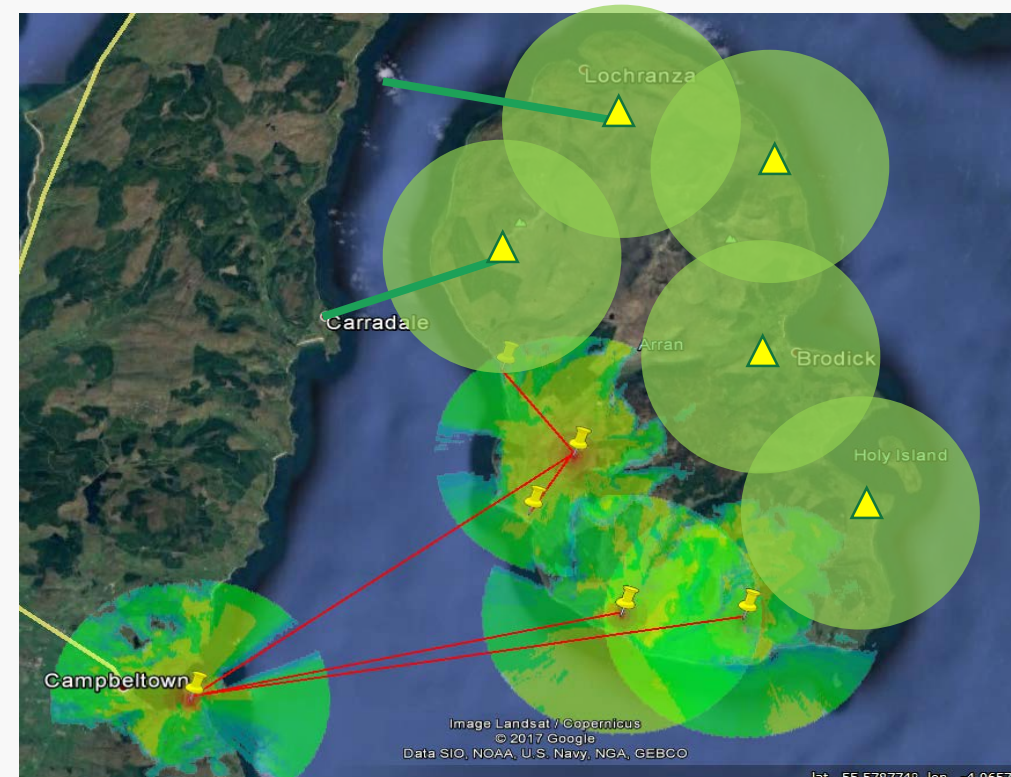
Arran Coverage, Existing and Planned

- 'Scotland in Miniature' is our test-bed for developing the technical and commercial model for universal, affordable broadband, using hybrid 5GHz/TVWS networks

Arran – now



Arran – end 2018

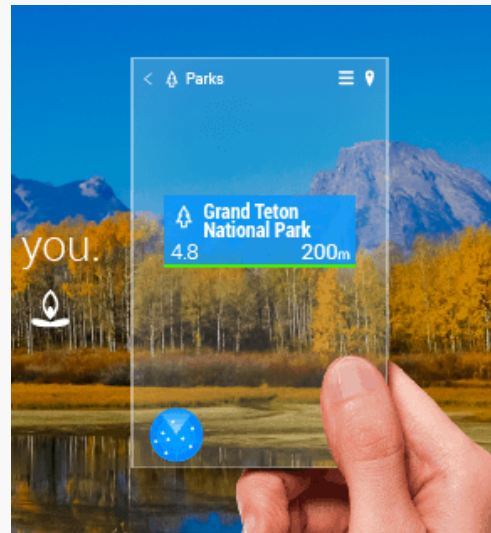


5G Pilot Testbeds

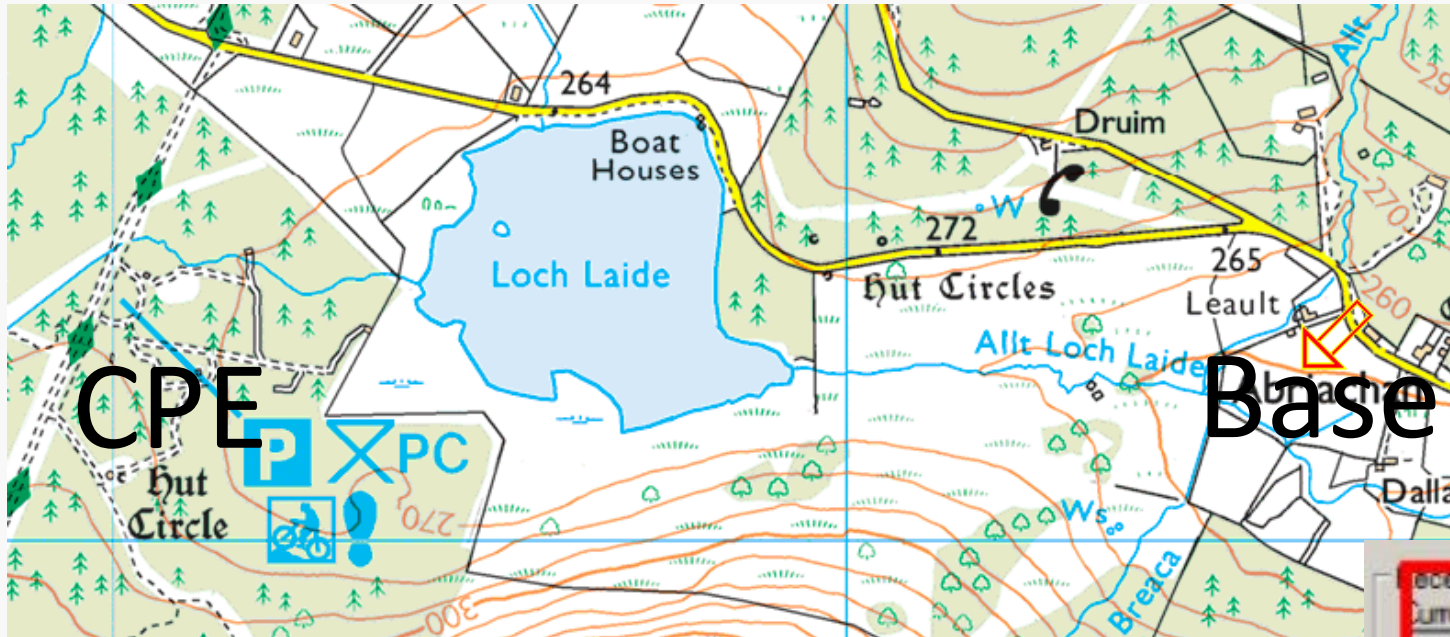
- Broadway is a proud member of both 5G Pilot Award consortia focused on the rural opportunity: Cisco/Strathclyde-led **RuralFirst**, and the Quickline-led **5GRIT**
- Both focused on delivering 5G benefits for the (neglected) rural markets
- Huge benefits of collaboration
- Broadway offers consortia members:
 - Networks in Scotland and Wales to host technologies and applications
 - Practical experience of small cell/low cost network deployment
 - Specific experience in TVWS spectrum sharing
 - Access to customers, 'user personas', stakeholders

5G Rural Integrated Testbed.5GRIT

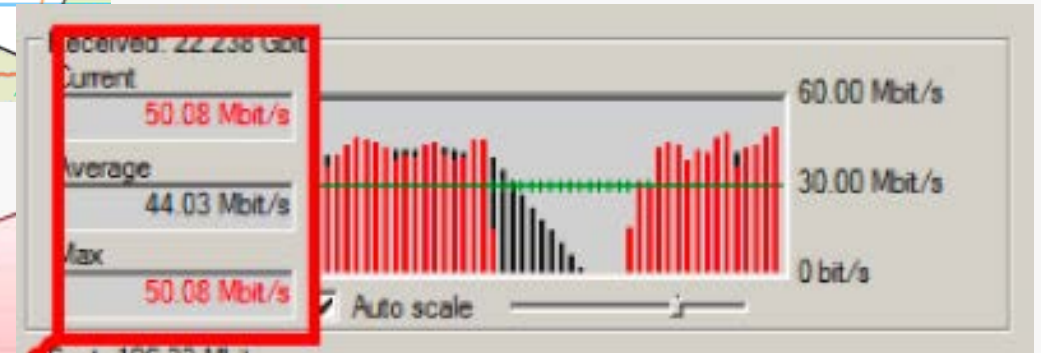
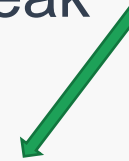
- Three main aims of 5GRIT:
 - Stress-test TVWS
 - Develop high bandwidth Precision Agriculture and AR applications
 - Develop new commercial models



First UK Use of Three Channel TVWS



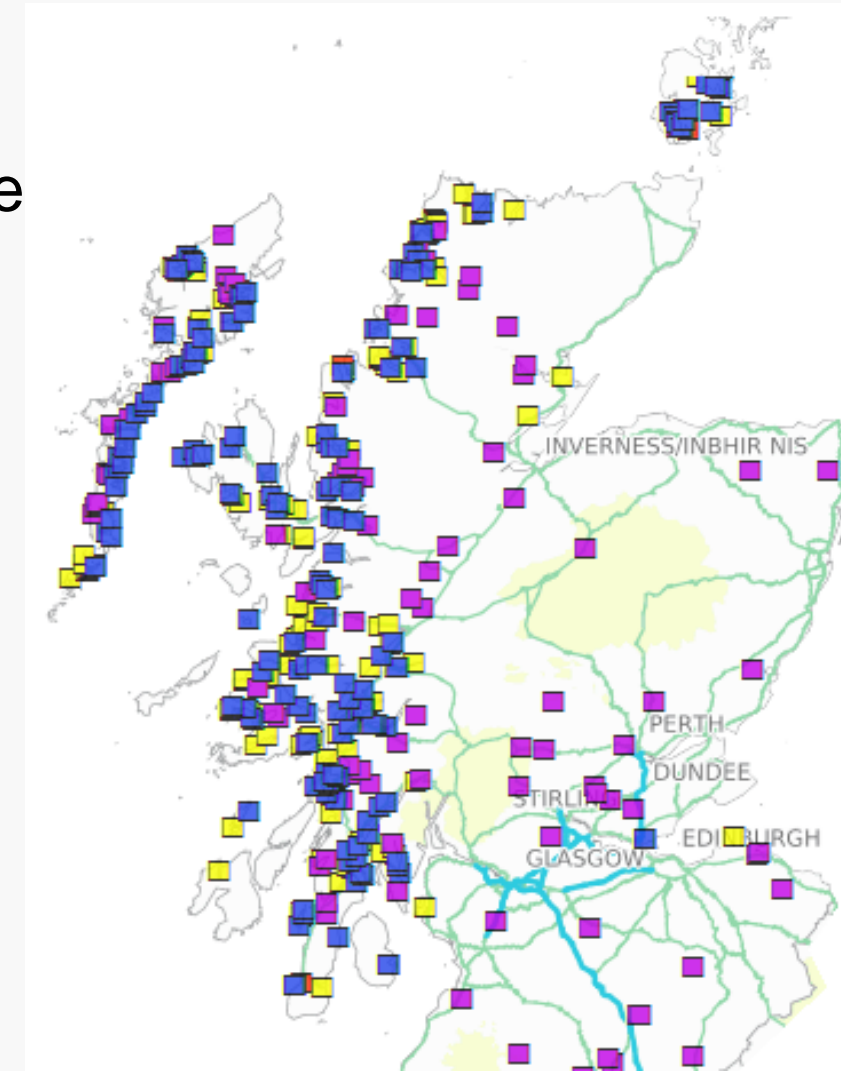
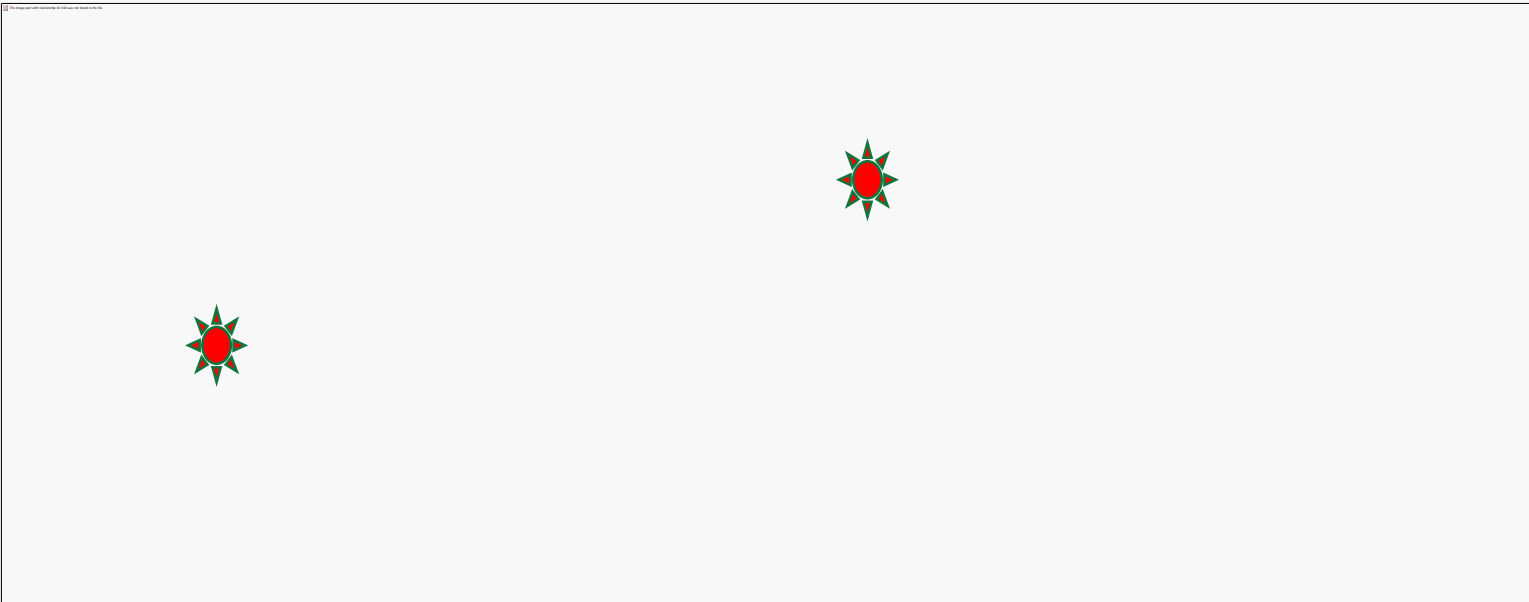
44Mbps average, 50Mbps peak



Next stop - 100MBps

Fish Farming – the Challenge and Opportunity

1. Scottish fish-farming plans to double output by 2030.... and need better connectivity
2. Rural communities also need better connectivity
3. The 5G Pilots offer a fantastic opportunity to prove the technical and commercial case, bringing together Strathclyde, Cisco, Agri-Epi, CENSIS and 5GRIT



IEEE 5G Summit

University of Strathclyde,
Glasgow, Scotland, UK.

Monday 14th May, 2018.

Gold sponsors:

