Report of the outcome of the SPF-DCMS supported UK Universities 6G research initiative - A compilation edited by the Chair of the SPF Cluster 2

CONTENT

(Note: This initiative has been a collaborative exploration. Therefore, neither the Expert Panel recommendations nor the published public comments will imply the endorsement of the UK Spectrum Policy Form (SPF) or its members or its partners in this initiative).

Preface

The critical success factor at the start of a next generation mobile technology cycle is the global alignment of "goals". It is the secret of how the mobile industry has successfully revolutionised its networks (roughly) every ten years. This alignment of human brain power and energy on a global scale behind a shared set of goals can move, if not mountains, our entire means of communicating on the move – as we saw with 2G/GSM and 4G and now unfolding with 5G.

This DCMS-UK Spectrum Policy Forum (SPF) supported 6G research initiative has explored our UK University research excellence in addressing a set of worthy goals for 6G. It has also created a UK universities community of interest in wireless research and built a bridge between the spectrum policy makers and the UK's University based long-term wireless research community. There are many people to thank for the way this initiative has exceeded everyone's expectations. Acknowledgements are set out in section 8 as they are too long to list in a short preface.

6G will be tackling a new age of immense technical and economic challenges. The most acute of the technical challenges will be the birth of a whole new "internet" of Artificial Intelligence on the 6G control planes of a complex mobile network of networks and connecting into the real time exploitation of a vast pool of radio spectrum.

The next generation of beamforming, Large Intelligent Surfaces and cell-less architectures will all break down some of the economic barriers to extending the reach of the Gb/s society. But the breakthrough for some of our most acute economic problems in extending high performance mobile broadband networks lies in the direction of a fusion of ideas on more advanced mobile technologies with a regulatory modernisation of the mobile industry that will be much needed post-2030.

As successful as initiative has been, it is only a tiny speck on a vast canvass of 6G activity now starting up around the world. But that tiny speck is a valuable seed that, if planted by the government in a national approach to 6G, can grow into an alignment of willing partners working towards better mobile broadband coverage, spectrum efficiency, energy efficiency, network economics, and solutions to a next generation mobile network of networks. The UK can expect a huge economic payback for an investment made now in our long-term 6G spectrum related research.

Prof Stephen Temple CBE, FREng CEng FIET
Chair of Cluster 2, UK Spectrum Policy Forum (SPF)
Visiting Professor 5GIC>>6GIC, University of Surrey

1. Background

The SPF, with the support of the Department for Digital, Culture, Media and Sport (DCMS), have made the space in one of its cluster groups, Cluster 2, for thinking really long-term about the exploitation of radio spectrum to support the next wave of digital services and infrastructure modernisation. This coincided with the world starting to think about possibilities of a 6G for beyond 2030. This made 6G a well time vehicle for thinking long-term about spectrum in a way that linked to the long-term future of our national mobile networks. It provided a common cause that would bring the UK research community closer to spectrum policy makers.

The initiative consisted of two main threads:

- An audit of the UK Universities research base to assess where its strengths were to meet the 6G challenges
- An examination of the radio spectrum implications for 6G

This is quite unique for the start of a new mobile generation and therefore the process itself has been a learning experience. This report records the process and the results and feeds into whatever national effort the government organises and funds for the UK to play an influential role in the unfolding global 6G initiative.

The Report also reproduces the recommendation of an Expert Panel convened as part of this initiative. One of those recommendations is that the government needs to mobilise the UK's long-term research resources and capability ***now*** if the UK is to make an effective international contribution to the next technology generation upgrade of national mobile and wireless infrastructures (6G). The reason is not to fall behind the leading countries that are already underway with their own 6G research programmes.

2. Scope of the initiative

The initiative was launched on a hypothesis that a component of 6G would address the key largely economic problems and challenges ahead that would hold back further improving mobile networks and services. It aligned this initiative with the University of Surrey 5GIC White Paper on 6G[i], the IET Guide "6G for Policy Makers"[2], and the Next Generation Mobile Networks (NGMN) White Paper "6G Drivers and Vision"[ii]. It also provided a solid foundation for the initiative since the critical economic problems holding back improving mobile broadband networks beyond 5G are well known. The problems around implementing the various imaginative 6G "visions" have yet to be discovered.

The consensus view of an Expert Panel is that a 6G spectrum initiative should address at least the five goals listed below (listed in no particular order, and not precluding other goals) and incorporate them into a 6G national strategy:

(i) **Widespread coverage** to prevent the manifestation of a "digital divide" and to contribute to improved health and social care outcomes and future transport ambitions.

(ii) **Innovation in spectrum management** (e.g. through the use of automation and AI), to improve spectrum efficiency and densify spectrum sharing, particularly in the low frequency, mid and mid high frequency bands suitable for mobile connectivity.

(iii) **Economic viability** of roll-out of next generation mobile infrastructure (through enabling new service possibilities or significant cost savings).

(iv) Alignment with the government's **net zero targets**.

Seamless connectivity – a "network of networks" (for example the integration of terrestrial and non-terrestrial networks) with high security and resilience.

Some have argued for other goals to be added and no doubt they should be. But these five goals are particularly useful to link together as they are interdependent i.e. they affect each

other. For example, it is possible to increase spectrum efficiency with more digital processing, but this increases energy consumption. Coverage can be expanded but this hits economic viability and so on. This makes a collaborative approach between government, regulator, mobile network operators, industry, and the research community so essential, as the success of 6G will be to find the optimal point of balance where the goals conflict.

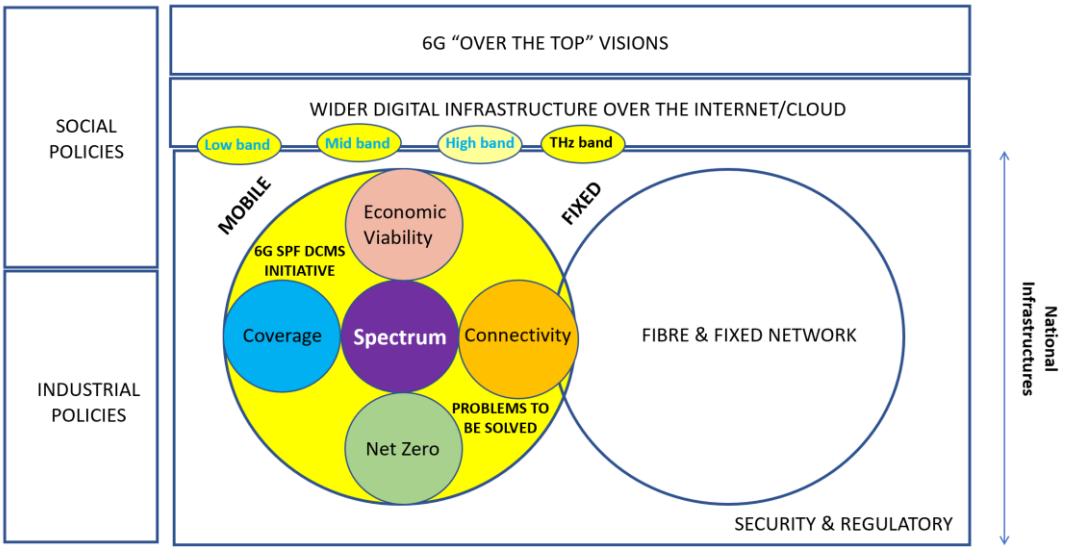


Figure 1 – The boundary of the 6G Research Initiative shown in the yellow circle

All past mobile generations have been multifaceted. Figure 1 sets the particular direction for 6G of this initiative in the wider canvass of possibilities. Thus, 6G is not to be seen as an exclusive label to be attached to any one idea. But when it comes to choices of where to invest limited research funding it is essential to ensure the UK is building on existing strengths and can sustain a critical mass of research if it is to be globally competitive – a point well made by an Expert Panel in its key recommendations set out in the next section.

3. Key Recommendations – An Expert Panel's View

The consensus view of an Expert Panel is that a 6G spectrum initiative should address at least the five goals listed in section 2.

Our Expert Panel's audit of current excellence of the UK University research base to address those five goals has shown that almost 60% of the research presented was rated as '*Significant and Extraordinary*' and, given the right support and focus, could propel the UK into international research leadership by solving critical next generation mobile and wireless technology problems around spectrum and coverage. An Expert Panel therefore propose the following eight key recommendations as part of a UK 6G strategy:

1. The government needs to mobilise the UK's long-term research resources and capability ***now*** if the UK is to make an effective international contribution to the next technology generation upgrade of national mobile and wireless infrastructures (6G).

2. The government should set a national 6G ambition of finding solutions to the enduring mobile and wireless infrastructure problems, as specified by the five goals.

3. The government should take action that would secure critical mass of research activity and be globally competitive, thus enabling the UK to be an attractive and leading partner in international collaborations. An additional government funding of £25 million per year for 6G spectrum related research would be an excellent investment as there are few better opportunities for matching known long-term national mobile and wireless infrastructure problems with UK research excellence to create and supply solutions.

4. The government should make participation in an approved "collaboration model" a condition of 6G research grants to Universities. This should enable government, Ofcom, the Mobile Network Operators, and relevant industries to systematically engage with the 6G research community, other service providers to advise in setting research strategic directions within the five goals, and mentor individual research projects of mutual interest. The model also needs international collaboration to be forged with countries sharing the same goals.
5. Later, an effective SME engagement programme with University-based 6G research has significant potential to further strengthen and diversify the UK's supply base and export of know-how and future products, in line with the government's Telecommunications Diversification Strategy. Research grants to SME's should include an element that pays for the cost of integrating their prototypes into new national 6G research and innovation multisite facilities.
6. The government should be organising a managed and coordinated national approach to efficiently and effectively take the results of relevant UK 6G research projects into global standards bodies, giving Universities, the research community, and UK SME's more impact acting collectively and taking due account of their needs.
7. 'Next generation' satellite and unmanned aerial vehicles technology needs to be on the 6G road map and associated spectrum needs considered.
8. The 6G radio frequency spectrum band choice, from low (frequency spectrum) band to terahertz, is an important consideration that will influence what 6G can deliver and where. The low and mid bands are where some of the biggest challenges will be around the five goals. Therefore, the government should have a research priority on low band and mid band frequencies research projects, and consider other frequencies that can address one or more of the above five goals in a significant way. The government should also encourage innovative ways of utilising a range of spectrum bands to achieve the above five goals.

4. Current UK University 6G research capability

One of the two threads of this initiative has been to assess the strength UK's University research base to be able to make a significant contribution to a 6G initiative addressing the five goals. The following process steps were used:

i) Showcasing the projects having the best potential to address the 5 goals

An analysis was conducted on the largest number of current EPSRC grants for projects falling within the scope of the five goals was carried out. Bristol, Strathclyde, and Surrey Universities were selected on the basis of this analysis and invited to each host a 6G research showcasing workshop. Annex 3 gives the guidelines drawn up by DCMS and the SPF and agreed with the hosting universities. It had two conditions for endorsing the workshops. They had to be open to all and at least 50% of the projects presented had to come from other Universities. Everything else was left to the discretion of the hosting Universities. This provided the added value of three independent views of what was important to a successful 6G initiative. The mix differed in each workshop with a slightly greater emphasis on Radio Frequency (RF) hardware, the Radio Access Network and Digital Signal Processing being differentiating features of Bristol, Surrey, and Strathclyde workshops respectively. The projects presented are given in Annex 1.

ii) Establishing an Expert Panel

A panel of experts was put together to meet the needs of DCMS for a wide spread of expert viewpoints. Professor Bob Stewart of the University of Strathclyde was asked to

Chair the Panel. The Expert Panel supporting the recommendations comprised of the following:

Name	**Designation**	**Organisation**
Mark Beach	Professor and Prosperity Partnership Lead	University of Bristol
Rahim Tafazolli	Professor and Director 5G/6GIC	University of Surrey
Bob Stewart (Chair)	Professor and Lead of Strath 5G Cluster	University of Strathclyde
James Dracott	Head of ICT	EPSRC
JF Fava-Verde	Innovation Lead (Digital)	InnovateUK - UKRI
Dave Townend	Wireless Research Manager	British Telecom
David Lister	Senior R&D Manager	Vodafone
Raj Sivalingam	Head of Spectrum	DCMS
Adam Beaumont	Chair aql group; Chair Northinvest	UK Entrepreneur
Abhaya Sumanasena	Managing Consultant	Real Wireless & Chair SPF Steering Board
Luigi Ardito	Senior Director, Government Affairs Europe	Qualcomm Europe & Vice-Chair SPF Steering Board
John Haine	Consultant	IoT Security Foundation
Ex Officio:		
Jo O'Riordan	Head of Spectrum Policy and Telecoms	UK SPF and techUK
Stephen Temple	Chair, Cluster 2: Long Term Spectrum Policy	UK SPF Cluster 2 Chair

The purpose of the Expert Panel was to arrive at a view on whether the UK had the strength in depth to make a success of a funded 6G initiative addressing the five goals. It was a piece of due diligence that needed to bring to light not only where particular UK research strengths existed but also the gaps.

iii) **Project Rating Methodology**

Rating the capability of the UK's University research base to tackle a 6G research programme addressing the five goals required a bit of innovation in its own right. The individual research projects were not being judged on their academic strength. Projects that would have failed this test were not even were not being given a slot on the respective workshops by the hosting Universities. The evaluated was to address their likely impact one or more of the five goals. A three-level impact rating score was devised with "impact descriptors":

- **Useful** – Would be a research project filling knowledge gaps or accumulating valuable data. If there was a meter that could measure "impact" it might move the needle by 1%. These projects were given a score of 1
- **Significant** - Would be a research project that had a noticeable impact in addressing one or more of the goals. With our instrument analogy is would move the needle by 10% and make it worth implementing. These projects were given a score of 2
- **Extraordinary** - Would be a research project that had a high-impact in addressing one or more of the goals. With our instrument analogy is would move the needle by 70-90%, where a 100% would be in breakthrough territory. These projects were given a score of 3

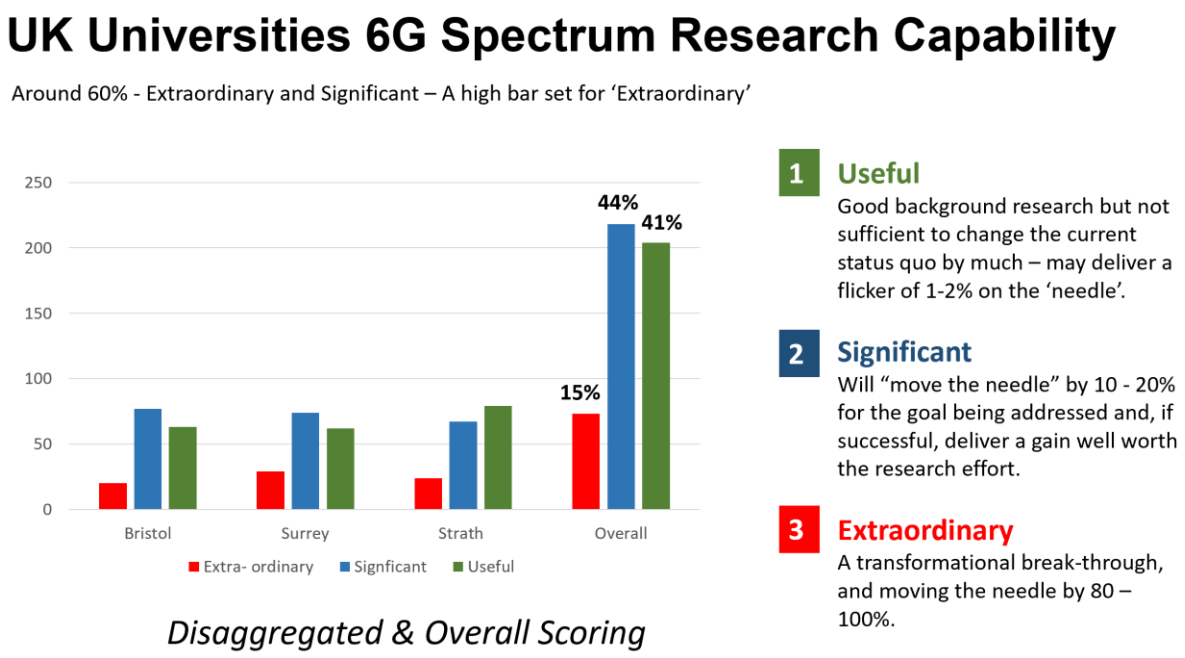
This approach stuck a good balance of having the granularity to differentiate between projects without being unduly complicated. In general, there was a uniform standard between all panel members in how the applied their scores between 1's and 2's. Some were more generous than others when it came to applying scores between 3's and 2's. This would suggest merging the 3's and 2's scores in the results for the sake of ensuring uniform interpretation between projects. It should be noted that not all projects were rated by all of the experts.

Results

No effort was made by experts to persuade each other to change their scores. The view was taken that the experts were looking at these projects through different prisms and they would naturally arrive at different scores and the number of expert panel members would iron out any individual biases.

The table below presents the summary scores from the Expert Panel.

	Extraordinary	Significant	Useful
Total marks	**73**	**218**	**204**
Percentage of Total	**15%**	**44%**	**41%**



Disaggregated & Overall Scoring

Figure 2 – A breakdown of the research capability assessment by workshop

A separate evaluation was done to see how many projects were addressing each of the five goals:

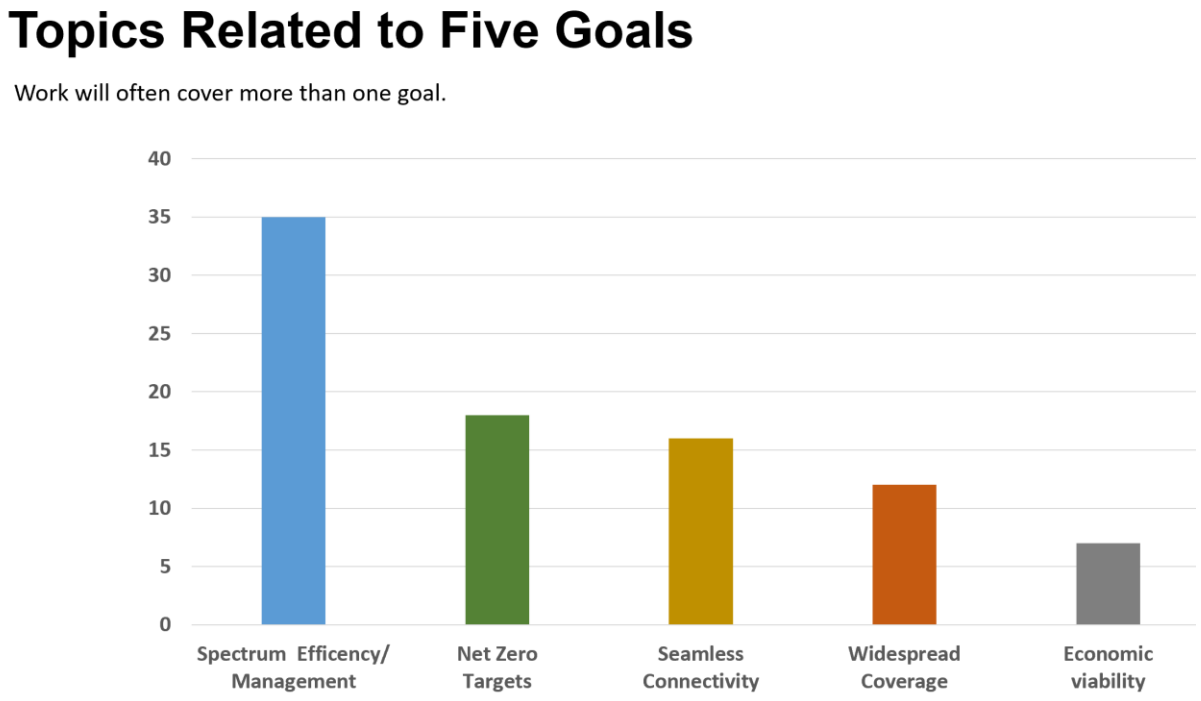


Figure 3 – The number of research projects addressing each of the five goals

Next an evaluation was done to see how the projects were grouping around spectrum bands.

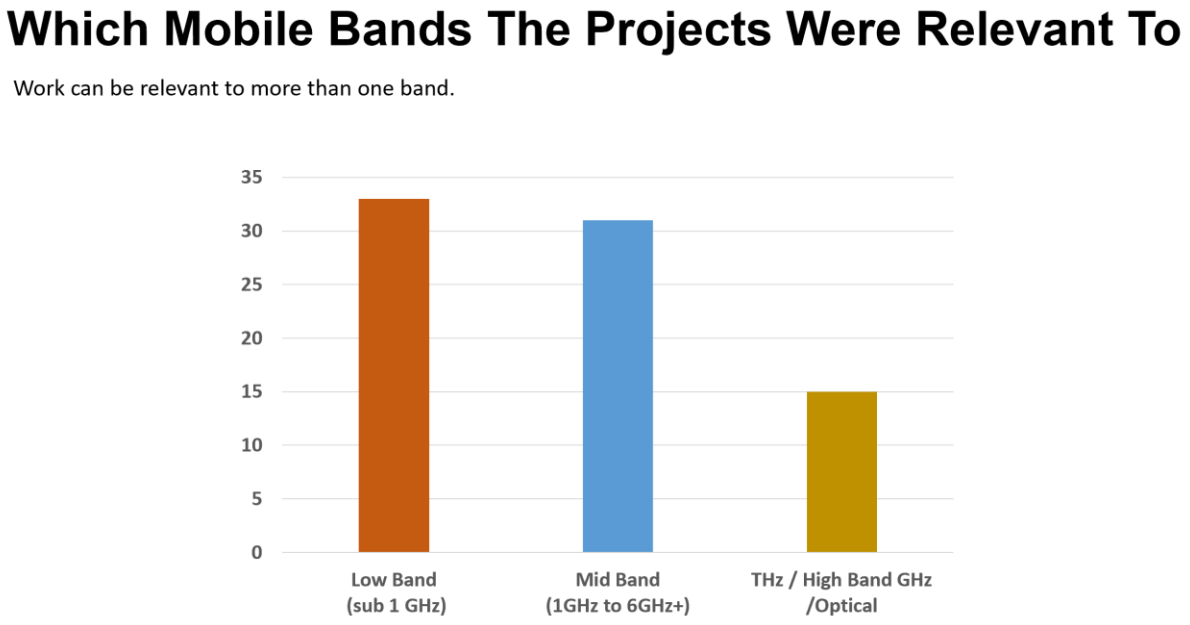


Figure 4 – Which spectrum band the research projects were relevant to

The results provide the evidence of where the UK has the research excellence in mobile technologies already in place upon to build a successful UK 6G research initiative addressing the five goals. The other research projects are still useful in filling knowledge gaps.

iv) **Conclusion of the evaluation**

Finally, the Expert Panel members were asked to review their scores and give the UK University research base that had been presented at all three workshops an overall rating in respect of its collective capability to have an impact on the five 6G goals from the choice of "useful", "significant" and "extraordinary". The Expert Panel's audit of current excellence of the UK University research base to address those five goals noted that almost 60% of the research presented was rated as '*Significant and Extraordinary'* and, given the right support and focus, *could propel the UK into international research leadership* by solving critical next generation mobile and wireless technology problems around spectrum and coverage.

5. 6G research collaboration model

One of the surprises for many people is to have found so much relevant research across such a large number of Universities. Having research spread across 25 Universities allows the best talent to contribute irrespective of where it is located. But it also suffers from a lack of critical mass and much of the research is out of sight of those that might want to exploit it. It is the most significant "gap" in the UK's current research activity in this wireless research area. That gap could readily be plugged with a high performing collaboration model. The Expert Panel has identified three component parts of such a model and implied the need for a fourth:

(i) Partnership with government, Ofcom, the Mobile Network Operators, and relevant industries

The Expert Panel recommends that the government makes participation in an approved "collaboration model" a condition of 6G research grants to Universities. This would enable government, Ofcom, the Mobile Network Operators and relevant industries to systematically engage with the 6G research community, other service providers to advise in setting research strategic directions within the five goals, and mentor individual research projects of mutual interest. The model also needed international collaboration to be forged with countries sharing the same goals.

(II) An effective SME engagement programme

The Expert Panel recommends an effective SME engagement programme with University-based 6G research has significant potential to further strengthen and diversify the UK's supply base and export of know-how and future products, in line with the government's Telecommunications Diversification Strategy. Research grants to SME's should include an element that pays for the cost of integrating their prototypes into a new national 6G research and innovation facility.

(iii) Routes into Global Standards Bodies

The Expert Panel recommends that the government should be organising a managed and coordinated national approach to efficiently and effectively take the results of relevant UK 6G research projects into global standards bodies, giving Universities, the research community and UK SME's more impact acting collectively and taking due account of their needs.

(iv) A bridge between the cellular and satellite mobile research and spectrum activities

The Expert Panel has recommended that 'next generation' satellite and unmanned aerial vehicles technology needs to be on the 6G road map and associated spectrum needs considered. This implies that a collaboration model will have to build a bridge with industries that have very different technology evolution traditions.

6. Potential implications for 6G spectrum policy

The 6G radio frequency spectrum band choice, from low (frequency spectrum) band to terahertz, is an important consideration that will influence what 6G can deliver and where. Figure 5 is taken from a presentation at the University of Strathclyde hosted workshop to communicate this very fundamental point to policy makers.

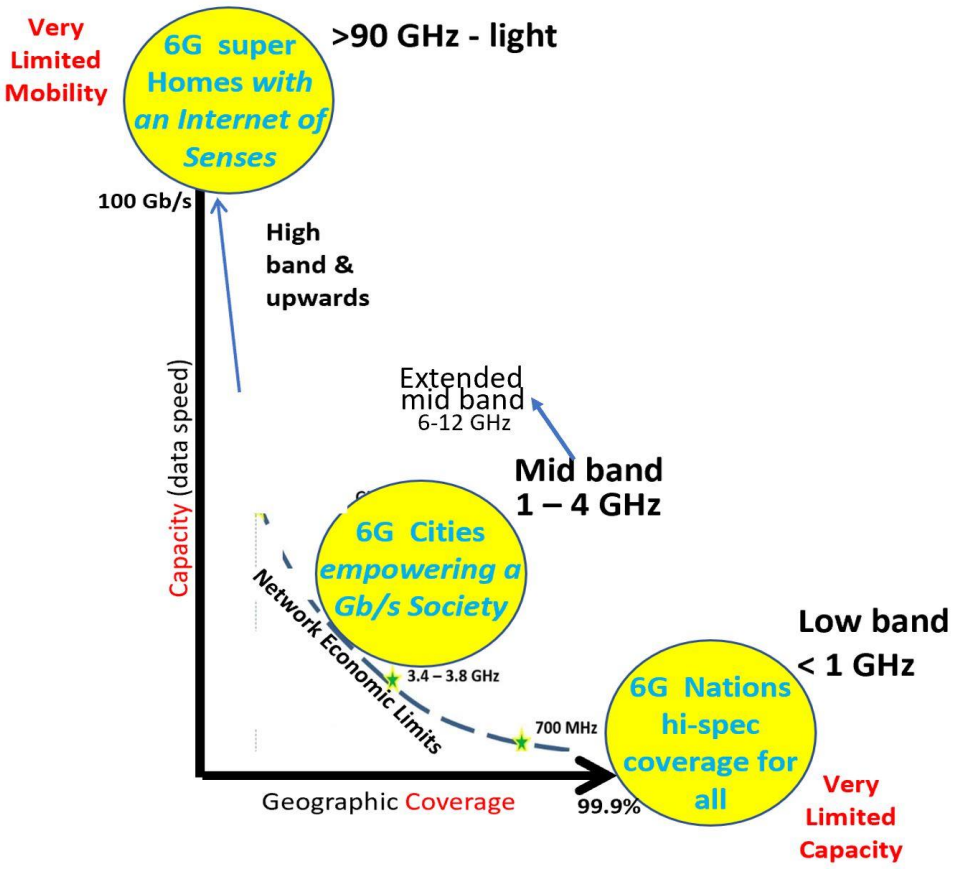


Figure 5 – How the choice of spectrum range shapes three distinct 6G opportunities

The three yellow circles in figure 5 give purely illustrative examples of how three very different range of frequency spectrum could support three very different 6G visions based upon three very different combinations of fundamental capacity and coverage attributes:

- **Super Homes** – A hugely rich virtual world can be created in the home (and other premises) in which people can visit the world and never leave their living room. But it is a virtual mobile world and not a physical one.
- **6G cities supporting a Gb/s society** – This is an exceptionally high-capacity broadband mobile world that delivers the capacity where and when people want it in all cities and towns. The Gb/s society was a part of the 5G vision that economic realities led to being shelved. There is some history where a later generation

complete the vision of an earlier one, for example, 2G completed the 1G journey and 4G completed the 3G journey. This opportunity may be seen as 6G completing the 5G vision journey

- **6G Nation delivering hi-spec coverage for all** – The economic challenge to lift data speeds in rural areas will be immense. Therefore, the focus must be on more than just raising data speeds if a 6G low band proposition is to be seen as a material advance. The term "hi-spec" coverage has been coined to capture all beneficial attributes important to users such lower latency, better Quality of Experience, resilience, security etc

Each of these opportunities need its own distinct technical, regulatory, and business strategy optimisation due to the huge disparity between them.

The low and mid bands are where some of the biggest challenges will be around the five goals. The Expert Panel recommends that the government should have a research priority on low band and mid band frequencies research projects that can address one or more of the above five goals in a significant way. The Government should also encourage innovative ways of utilising a range of spectrum bands to achieve the above five goals.

7. The Public Consultation

A huge effort has been made to ensure the whole process is open and transparent. All of the university hosted workshops have been open to all and free of charge. The Microsoft Team's chat was active which allowed questions to be put to presenters. All of the presentations have been available on-line on the UK SPF's section of the techUK website. The assessment of the Expert Panel and their recommendations together with this version of the Cluster 2 Chairman's report will be put up on the UK Spectrum Forum web site and open for public comment until 15 October.

The recommendations from the Expert Panel meeting on 23rd September will remain as their views and not be changed. Any alternative views from the public enquiry will be published in the final edition of this report. Bringing them together in the final edition of this report will allow the government and others using the report to see the range of views that have emerged.

For public comment responses to be published they will have address one or more of the questions, be within the maximum limit of a 250 words limit (total response per responder bar questions/name etc) and have a name (and affiliation where relevant) attached.

Below is an explanation for each of the questions and comments where additional information/views is seen to be particularly valuable for the initiative:

1. Do you believe that the five goals (which can be found in section 2 of the document) assumed as the basis for this initiative are the right goals that the government should set as national 6G research goals?

Figure 1 shows that beyond boundary of this 6G Research Initiative are a number of other areas likely to be embraced by a 6G global initiative. They will all be interesting to particular research groups. The likely UK funding will not allow every horse in the race to be backed. The Expert Panel suggest the government should have a research priority on low band and mid band frequencies research projects that can address one or more of the above five goals in a significant way. The purpose of this question is whether another area of research should be a more important 6G research investment priority and why? The "why" should include the benefits to the UK economy, the interest of mobile users post 2030 and mobile network vendor diversification objectives of the government.

2. Given that low and mid bands are where some of the biggest challenges will be around the five goals, do you think the government should place a particular research priority on low band frequencies and mid band frequencies projects that can more effectively address one or more of the above five goals in a significant way?

The question here is very narrow and is whether other bands are as important as mid and low band in addressing the five goals and why.

3. Can you identify any other significant research projects that have been missed that have the potential to also address the 6G research goals?

The three-workshop hosting universities made a huge effort to reach out to a large number of UK universities in order to showcase the projects with the most potential to address the five goals. But they may have missed some significant projects. The purpose of this question is to allow those research teams who believe they have been overlooked to draw attention to their projects, so the funding bodies have a complete a picture as possible where relevant research activity is taking place. The summary must include what the projects are expected to deliver against one or more of the five goals.

4. Can you identify any future regulatory innovations (post 2030) that should be on the SPF long-term thinking agenda?

The purpose of this question is to build up a "to-do" list of 6G related spectrum policy issues to be studied. We are not asking for solutions at this stage.

5. Do you have any other comments relevant to the UK's spectrum related research communities' approach to 6G, and/or our eight recommendations?

This is a catch-all question as we almost certainly have not thought of everything relevant to a national 6G research effort. But the comments need to fall within the scope of the initiative.

Public consultation process

Public comments received by the deadline, falling within the scope of this initiative and within the word limit will be cut and pasted under the appropriate sections in Annex 1 and attributed to the source.

Neither the Expert Panel recommendations nor the published public comments will imply the endorsement of the UK Spectrum Policy Form or its members or its partners in this initiative. The reconciliation of divergent views is what a successful next generation initiative sets out to achieve. For this reason, the recommendations of the Expert Panel meeting of 23rd September will remain the views that they have expressed. The final report will allow any alternative views to also be recorded. The UK views, however united or divergent, will be only one input to the global exchanges of view now underway. The UK will be more influential if it can establish a widely shared common view on the 6G goals.

The only substantive change envisaged being made to this Cluster 2 Chairman's compilation report will be:

- The addition of the public comments (to Annex 1), or in an exceptional case a public comment may be made into an additional section
- The addition to Section 5 of the conclusions of the Cluster 2 meeting on 5th October regarding the collaboration model.

The final version will then be published as the final compilation report of the results of the initiative.

8. Acknowledgements

This initiative has been a partnership between the UK Spectrum Policy Form with the support of DCMS and the three 6G research workshop hosting Universities:

- University of Bristol – Prof Mark Beach
- University of Strathclyde – Prof Bob Stewart
- University of Surrey 5G>>6GIC – Prof Rahim Tafazolli

They in turn drew on the support of 22 other UK Universities (making 25 in all) and Public Health England in the 54 presentations given at the three workshops.

Keynote addresses were given by (former) DCMS Minister for Digital Infrastructure Matt Warman MP, Dr Mike Short CBE, Chief Scientific Adviser at the Department for International Trade (DIT), and Richard Moore Principal, Spectrum Policy, at Ofcom.

Addresses to the first and third workshops were also given by Joe McGeehan, Emeritus Professor, The University of Bristol and Sir Jim McDonald, President of the Royal Academy of Engineering, University of Strathclyde.

The people giving up their time to provide their expertise at the meeting of the Expert Panel, Chaired by Professor Bob Stewart, and listed in Section 4ii above

Jo O'Riordan, Head of Spectrum Policy and Telecoms at techUK who has managed the process.

David Meyer SPF Chairman, Abhaya Sumanasena Chairman of the SPF Steering Board and Luigi Ardito Vice Chairman of the SPF Steering Board for their active support for the initiative**.**

The officials at the DCMS and Louise Lancaster in particular for her help in setting the guidelines for this initiative.

Annex 1 – Comments received in public comments phase

Public comments received by the deadline, falling within the scope of this initiative and within the word limit will be cut and pasted under the appropriate sections below and attributed to the source:

National 6G research goals

Research priorities in addressing the five goals

Relevant research projects not presented at the three showcasing workshops

Spectrum and regulatory policy issues to be considered on the path to 6G

Other relevant comments

Annex 2 – Research projects presented over the three workshops

BRISTOL
BR1.1 Spectral and Energy Efficient Radio Systems
BR1.2 Linear & Power Efficient RF sub-systems
BR1.3 Advances in RF Planar Filter Technologies
BR1.4 Multiband Direct RF Sampling for 5G and Beyond MIMO Receivers
BR2.1 Learning to Communicate
BR2.2 AI and Massive MIMO
BR2.3 C-RAN, vRAN, O-RAN and Cell-free Massive MIMO
BR2.4 Self-supervised learning: the next challenge for industrial AI
BR3.1 Next Generation Converged Digital Infrastructure
BR3.2 Seamless Connectivity for All
BR4.1 Frequency Reflective Surfaces
BR4.2 Looking at acoustic wave filters through an integrated photonic lens
BR4.3 New materials and geometries for next generation antennas
BR4.4 GaN Diamond for Efficient RF amplification
BR5.1 Spectrum Sharing - Database, Loans, Multiplexes & SDR for 6G Opportunities
BR5.2 Enhancing Spectrum Sharing with Fixed Links
BR5.3: Sub-THz Antennas and Devices for 6G Communications

SURREY
SU1.1 Spectrum allocation from a propagation perspective
SU1.2 Non-Stationary Channel Model and Capacity Behaviour of ELAA-mMIMO Systems

SU1.3 6G Technologies; Radio Waves and Health

SU2.1 Non-orthogonal signals for spectral and energy efficient transmission
SU2.2 Rate Splitting Multiple Access for 6G Communications and Sensing
SU2.3 Exploiting Electromagnetic Degrees of Freedom for Spectrum Efficiency Enhancements

SU3.1 The optical spectrum and Tb/s wireless systems in the 6G era
SU3.2 Power-efficient waveforms for visible light communication
SU3.3 RF Sampling and Software Defined Radio – Working with a 4 GHz Baseband using the Multichannel RFSoC

SU4.1 Self-Organised Radio and Core Networks: Achieving end-to-end optimal resource utilisation
SU4.2 On the energy efficiency, spectral efficiency and coverage of cell-free massive MIMO
SU4.3 Cell Sweeping - A New Paradigm for Cells Deployment and Cell-edge Enhancement

SU5.1 Spectrum co-existence for satellite and terrestrial systems
SU5.2 Blind Spectrum Sensing Using Stochastic Resonance
SU5.3 OpenRAN Lab at Surrey

SU6.1 A glimpse of next-generation wireless enabling techniques
SU6.2 Green and Secure Networks; Will 6G deliver the Duo?
SU6.3 Coverage enhancement with power efficient Reconfigurable Intelligent Surfaces

STRATHCLYDE
ST0.1 The importance of “mobile”, “generation” changes and the spectrum challenges of the 6G age.

ST1.1 Security, Resilience and Sustainability: The Benefits and Challenges Brought by SDR
ST1.2 RF finger printing to aid cyber security in low cost wireless IoT system
ST1.3 Digital Net Zero – Mapping the Challenge
ST2.1 5G/6G Private Networks for Vertical Markets: Just add some SDR and Spectrum
ST2.2 Software defined radio as a vehicle for commercialisation of university research: lessons learned in 5G and opportunities for 6G
ST2.3 Dynamic Spectrum Radio with Frequency Spread Filter Bank Multicarrier Transmitters
ST3.1 GHz Bandwidth Sensing by Sub-Nyquist Signal Processing
ST3.2 RF Sampling in Multiband Receivers for 5G: Analysis and Performance
ST3.3 Low Power Analog Processing with RF Correlation for Ultra-High-Speed Receivers
ST4.1 Spectrum Monitoring for Sharing- first principles SDR design and implementation
ST4.2 Autonomous Spectrum Awareness for Smart Spectrum Access and Sharing
ST5.1 Quirks and Opportunities of Training Deep Learning Systems for Future Wireless Networks
ST5.2 Spectrum-efficient Beamforming beyond 5G: Model-driven AI Algorithms and SDR Testbed
ST5.3 Machine Learning for 6G Physical Layer Design and Interference Control
ST6.1 Integration of Satellite Systems in 6G
ST6.2 The Role of LiFi in 6G
ST6.3 Exploiting rarely capitalised spectrum - Future technologies using THz and beyond THz bands
ST6.4 D band offering the next frontier and path forward for 6G communications for civil and defence

Annex 3 - Guidelines for the DCMS/SPF sponsored University run workshops on current research that could contribute to spectrum policy destinations for 6G.

1. Introduction

The SPF is making the space in one of its cluster groups to think really long-term about the exploitation of radio spectrum to support the next wave of digital services and infrastructure modernisation. The global efforts towards 6G provides a handy framework for this. The right place to start is the research we have currently underway in our Universities that could feed into an approach to 6G that seeks to solve critical policy problems ahead like improved spectrum efficiency, better coverage, and lower energy use. This guideline established the framework for this series of workshops.

2. Scope of the workshops

For the purpose of this initiative the 6G public policy goals shall be taken as:

- Economic viability of next generation wireless infrastructures (through enabling new service possibilities or significant cost savings)
- Widespread coverage, to prevent the manifestation of a “digital divide” and to contribute to improved health and social care outcomes and future transport ambitions.
- Innovation in spectrum management (eg through the use of automation and AI), spectrum efficiency and densification of spectrum sharing, particularly in the lower frequencies suitable for mobile.
- Alignment with the government’s net zero targets.
- Seamless connectivity between a “network of networks” (for example the integration of terrestrial and non-terrestrial networks) and their high security and resilience

These goals define the scope of the workshops. The presentations at the workshops need to explicit links to one or more of these five goals in order to mesh with the wider initiative.

3. Workshop objectives

The general aim of the workshops is to build a stronger link between research goals and spectrum policy goals through better mutual understanding. With an outcome led 6G initiative the technology can drive the policy and the policy can drive the technology. More specifically the goal is to identify the best ideas in the UK’s wireless research base in good time to understand their spectrum policy implications, provide advice to researchers to enable them to better steer towards the above goals, encourage collaborations and identify gaps.

4. Governance

Each hosting University has the freedom to decide on the agenda, speakers, length and format. The only two “rules of the game” are: a. 50% of presentations must be guest presentations from other Universities but selected by the host University according to the themes they want to project. The purpose is to ensure access to the initiative from other Universities having relevant research that will not have the opportunity in this series to host their own workshops. b. The workshops should be run on-line and open to all SPF members and other Universities. The workshops should be recorded so to facilitate non-real time participation.

5. Support from the Spectrum Policy Forum and DCMS

Help from the SPF is available to run the videoconferencing platform (Microsoft Teams), if required.

Annex 4 – Acronyms and specialist terms

3GPP – Global technical standards making body for 3G, 4G and 5G mobile technology generations.

5GPPP – The 5G Infrastructure Public Private Partnership. A joint initiative between the European Commission and European ICT industry

AI – Artificial Intelligence

C-RAN – Cloud or Centralised Radio Access Network

D-Band - 110–170 GHz

DCMS – Department for Culture, Media and Sport

Digital Divide – In this context means some parts of the country falling behind in the coverage of high-performance mobile connectivity.

ELAA-mMIMO - Extremely Large Aperture Array massive MIMO antenna. Instead of gathering all the antenna elements into a single box, which may be visible and heavy, the antennas are distributed over a substantially larger area and could be made invisible by integrating them into existing construction elements.

ETSI – European Telecommunications Standards Institute. Recognised regional standards body for telecommunications standards. ETSI provides a technical competence centre for 3GPP.

GaN - Gallium nitride. A binary III/V direct bandgap semiconductor.

Gb/s – Data speed expressed as 1000,000,000 bits per second

HAPS – High Altitude Platforms

IoT – Internet of Things. The Internet being accessed by devices rather than people.

LiFi – An implementation of WiFi that uses light wave frequencies rather than radio wave.

MaMIMO – A larger more complex version of a MIMO beam forming antenna.

MIMO – Multiple Input Multiple Output. A beam forming antenna comprising an array of elements.

Multiple Access – Means for the signals from different users to access a common radio transmitter/receiver without interfering with each other.

Net Zero refers to the balance between the amount of greenhouse gas produced and the amount removed from the atmosphere. Cellular radio depends upon the emission of energy at radio frequencies and so there has to be a judgement by policy makers on what effort the cellular mobile industry will have to make towards the Net Zero goal taking into account the importance to the economy, social wellbeing and safety that cellular mobile contributes as well as its vital role in “mitigation management” of severe disruptions from climate change.

Non-Orthogonal - Where one or more independent signals are correlated, then that model is “non-orthogonal”.

O-RAN – Radio Access Network with open standard interfaces allowing multiple vendors equipment to inter-work.

Planar Filter – A flat 2D resonators with patterns of strip elements on a dielectric substrate

Rate Splitting – In this context it means treating interference as noise if it is low and trying to cancel it if it is high.

RFSoC – Radio Frequency System-On-Chip.

RSPG – Radio Spectrum Policy Group. An advisory body to the EU Commission comprising independent regulators from the EU Member States.

SDR – Software Defined Radio

SME – Small to Medium sized Enterprise

SPF – Spectrum Policy Forum

Stochastic - Having a random probability distribution

Sub-Nyquist - Recovering signals by samples much fewer than suggested by the Nyquist theory suggested optimal rate.

V-RAN - Virtual Radio Access Network). Virtualising (and now also containerising) the baseband unit, so that it is run as software on generic hardware platforms

Annex 5 – Definition of a 6G "pioneer" band

- The three "5G pioneer bands" were adopted at such a speed across Europe that the definition of the term was left behind in a WG paper and long since forgotten. It is timely to re-introduce the definition for 6G
- A pioneer band is the result of a process designed to significantly boost the efficiency of research projects with long lead times where the commercial band of operation is not obvious to the research community
- A pioneer band comes in the form of "*advice*" from a cohort of spectrum regulators as the band that appears most likely to be available by a target date in enough countries to provide scale economies
- This allows spectrum dependent research, measurement programmes, test beds and prototypes to be done in a band with the greatest likelihood of a large part of the work not having to be repeated before turning the research into product
- *It doesn't guarantee the band will be available in all countries in the cohort of regulators or in any specific country.* But it is considerable better than arbitrary guesses by researchers with no knowledge of the complexities of legacy usages across many countries
- Whilst a pioneer band designation carries no guarantees of availability it has a self-fulfilling quality as, if the new technology has benefits and scale, it makes a more compelling case for it to be made available

Annex 6 – References

University of Surrey 5G/6GIC, 6G Wireless A Strategic Vision Paper, https://www.surrey.ac.uk/sites/default/files/2020-11/6g-wireless-a-new-strategic-vision-paper.pdf, 2021

[2] IET, 6G for Policy Makers, https://www.theiet.org/media/8766/6g-for-policy-makers.pdf, Feb 2021

[3] NGMN Alliance, 6G Drivers and Vision, https://www.ngmn.org/wp-content/uploads/NGMN-6G-Drivers-and-Vision-V1.0_final.pdf, April 2021

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