SPF 6G wireless R&D initiative: A report for DCMS

A compilation edited by the Chair of the SPF Cluster 2

Contents

(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 Forum (SPF) or its members or its partners in this initiative. The report brings together a wide body of views and records the results and fresh insights as an input to any policy development within DCMS for a national/international 6G strategy.).

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.

The SPF were commissioned by DCMS to organise this 6G research initiative to explore our UK University research excellence in addressing a set of worthy goals for 6G. In the process 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 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 (Long-Term Spectrum Strategy), UK Spectrum Policy Forum (SPF)
Visiting Professor 5GIC>>6GIC, University of Surrey

1. Background

The SPF were commissioned by the Department for Digital, Culture, Media and Sport (DCMS), to make 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.

This Report also reproduces the recommendations of an Expert Panel convened as part of this initiative and intended explicitly for DCMS. 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 6Gi, 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.**

v. **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.

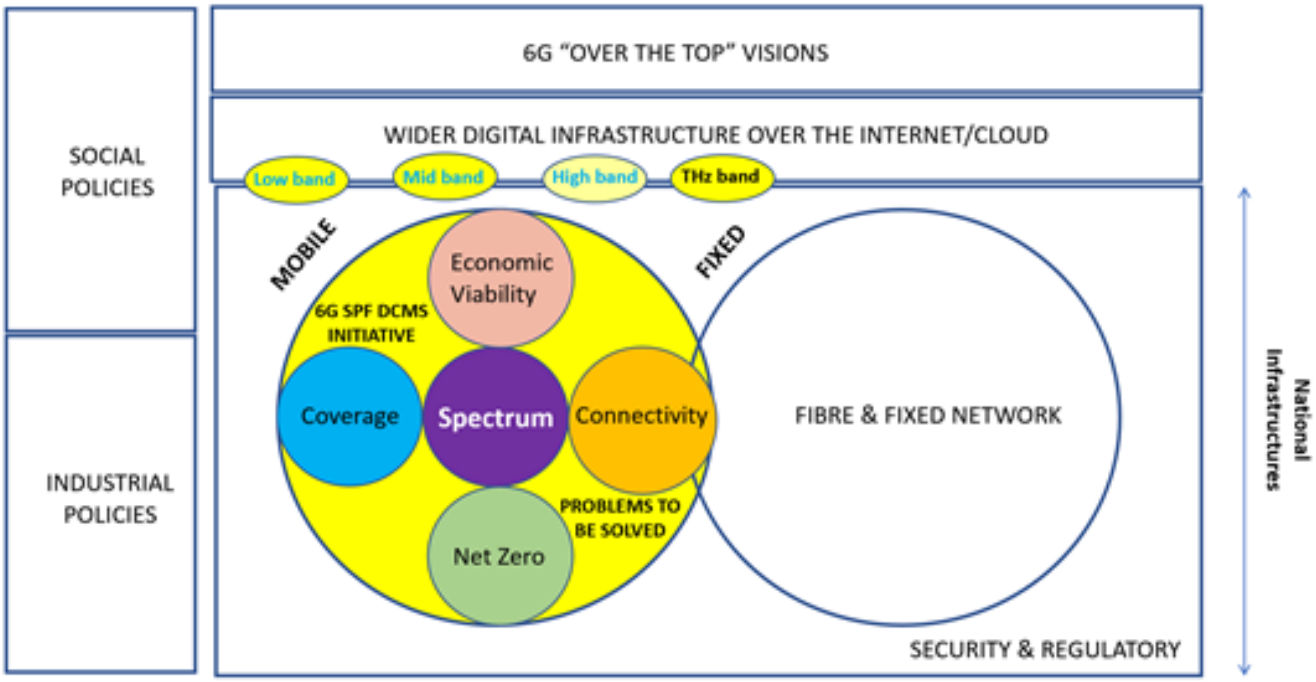


Figure 1 – The boundary of the 6G Research Initiative shown in the yellow circle

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 key recommendations are explicitly intended for DCMS. 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, other service providers and relevant industries to systematically engage with the 6G research community, 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 taking 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. 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 2.

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 Entrepeneur
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

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 being given a slot on the respective workshops by the hosting Universities. The evaluated was to address their likely impact on 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%

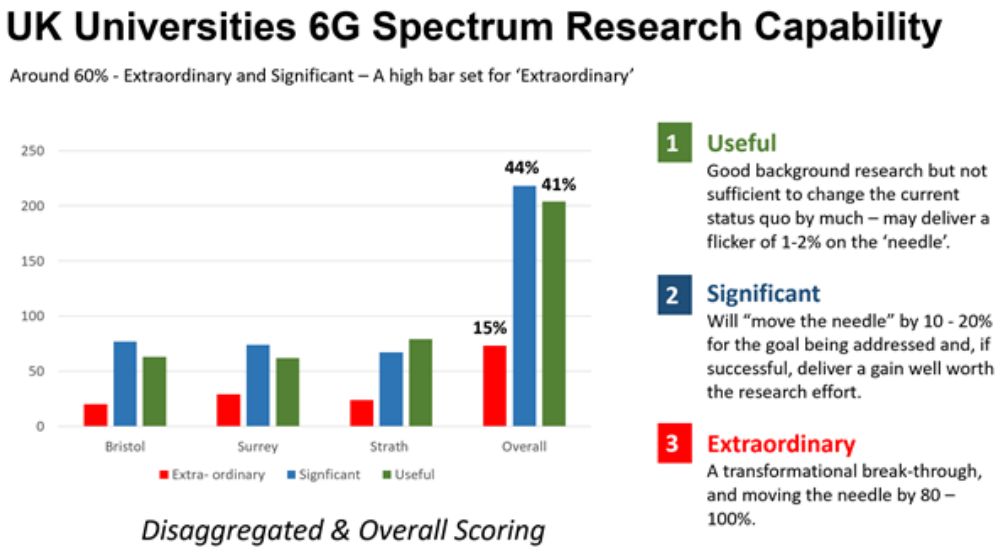


Figure 2 – A breakdown of the research capability assessment by workshop

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

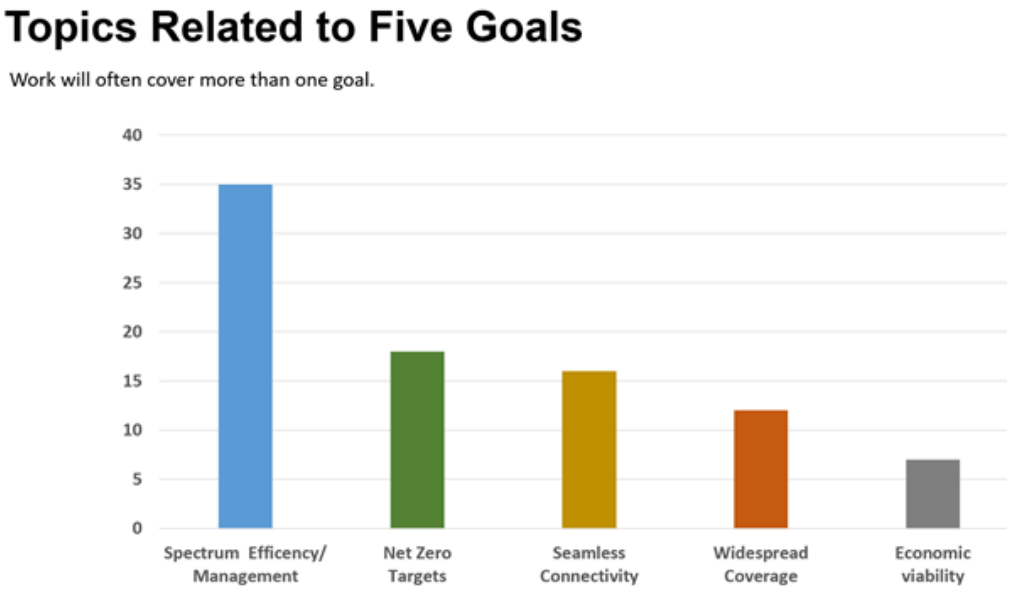


Figure 3 – The number of research projects addressing each of the five goals

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

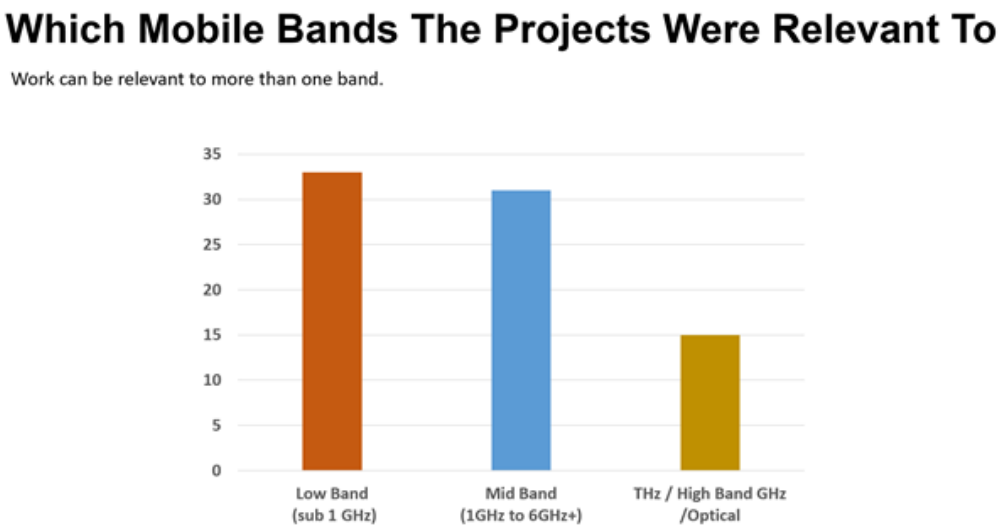


Figure 4 – Which spectrum band the research projects were relevant to

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.

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

6G Research Collaboration Model

One of the surprises for many people is to have found so much relevant research and momentum 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. The UK can do better than this. It is the most significant "gap" in the UK's current research activity in this mobile and wireless research area. But what is the right collaboration model to redress the issue?

Option 1:

One University becomes the UK 6G Centre of Excellence and research teams relocate to that one centre.

Option 2:

Three or so Universities with complementary expertise form a partnership and become a hub of a UK 6G Centre of Excellence that manage research clusters of a wider number of research associates (other universities) and partners focussing on the same topic.

Option 3:

Research distributed across unlimited number of Universities i.e. the status quo

The Chairman of the Expert Panel, Prof Bob Stewart was invited to lead a "brainstorming" session in the Cluster 2 meeting to kick-start getting ideas onto the table that DCMS and EPSRC could draw upon.

A strawman "example" was seen as a good place to begin. This is set out in 5.1 below.

Ofcom also offered to introduce their ideas on 6G spectrum as a basis for cooperation with the 6G research community. These are set out in 5.2 below.

5.1 Collaboration Model - Strawman Ideas 1.0

This fleshes out Option 2 that would be a model sitting somewhere between a fully centralised and a fully decentralised model.

5.1.1 Principles

- £25m per year in first three years (this is 10+ year endeavour)
- Three focussed/themed hubs at £8.3m per year
- UK Wide Participation – integrating the excellent momentum in UK Universities
- Mobile Industry tier 1s, SME, Ofcom, Govt Partnership for the UK
- Advisory Board – Engaged and dynamic
- Funding Board – Empowered and rapid response mode
- Internationalisation Strategies
- Complementary and additional to EPSRC/ UKRI / InnovateUK
- Supporting the UK Telecommunications Diversification Strategy

5.1.2 Six Component Parts

a. Hub Core Staff

b. Hub National Technology Infrastructure

c. Technology Partner Programmes

d. Infrastructure / Lab / Showcase Facilities

e. Mobile Industry / SMEs Matched Funding Pot

f. National Events / Workshops

5.1.2(a)

Hubs Core Staff

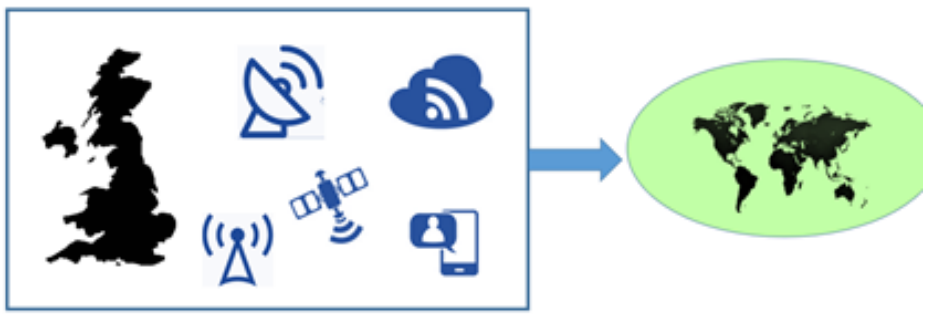
Category	Staffing Levels	Roles	Per Annum
Leadership		6G Spectrum Initiative Director Lead Academic *Industry* Professor R&D Industry Liaison Manager	**£288,200**
Engineering		Core R&D Engineering Champions	**£235,800**
Management		Hub Programme Manager Administration & Secretarial Contracts and Process	**£248,900**
Overheads		Estates, facilities, technicians, finance, services): Residual cost @ *80% FEC* (full economic costing) on technical positions	**£248,900**

£1,021,520 per annum

5.1.2(b)

6G Hub National Technology / Infrastructure Facilities

Showcase and Collaborative Facilities/Testbeds/Demonstrators and more
(International visibility & partnership, physical existence, integrated with UK universities)



£1,000,000 per annum

5.1.2(c)

UK Universities Technology Partner Programme

20 UK University Technology Partner Projects & Programmes @ £150,000 annum.
(Support existing work already identified via the initiative?)

£3,000,000 per annum

5.1.2(d)

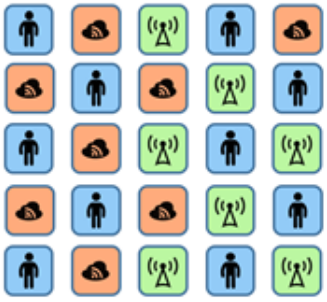
Key UK Infrastructure Facilities

6 Key Infrastructure / Lab / Showcase Facilities at £300,000 per annum
(*Create UK showcase projects and facilities across UK Universities)*

£1,800,000 per annum

5.1.2(e)

Short Projects / EngD/PhD Costs / Secondments
(PhDs/EngDs/Short KTPs – Research talent training & growth essential for 10 year journey)

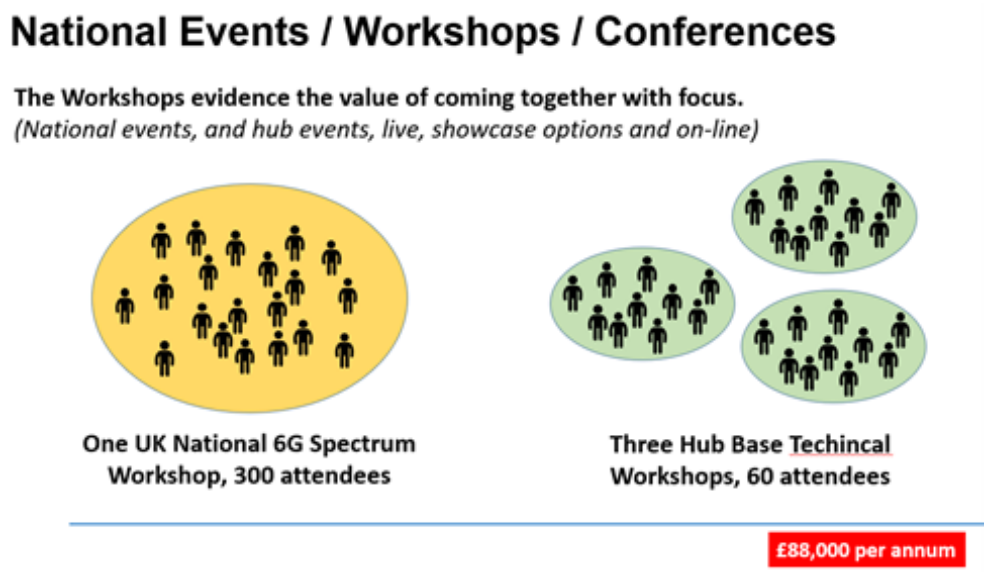


25 Industry EngDs / PhDs, £27k per annum = £675,000

10 Industry SME, MNO, Ofcom Partnership Projects at £75,000 per annum = £750,000

£1,425,000 per annum

5.1.2(f)



5.1.3 Some More Detailed Points in the Design of a 6G Research Collaboration Model

- **Collaboration**, common purpose and engagement across academia, industry, and government.
- Building **advisory and partnerships** with UK regulator Ofcom and MNOs and other 'public' network stakeholders.
- Integrating the existing **6G relevant national activities** and capabilities.
- Running UK national **6G workshops and events** open to all partners and stakeholders.
- Supporting mutually agreed contributions to **international standard bodies.**
- Strategic and supportive strategy for UK participation in **Horizon Europe.**
- Driving **international collaboration** and building UK influence in 6G spectrum and technology.
- Creating **complementarity to EPSRC/UKRI and Innovate UK** funding portfolios on advanced communications.
- Creating 6G **SME engagement** programmes with accessible (low cost), workable and 'easy' points of entry.
- Support **momentum of existing UK University 6G R&D** activities unearthed in the initiative workshops and more.
- Budget considerations – What could be achievable momentum and activity with proposed £25m per year?
- Supporting and dovetailing with the **UK DCMS Telecommunications Diversity Strategy.**
- Management of **IPR and licensing strategies** to support UK industry and particularly SMEs.
- Mechanisms to support both **low TRL** (Technology Readiness Level) and **high TRL**, and research of both theoretical and experimental nature.
- UK 6G Testbeds and Trials – **considering 6G 'pioneer' frequency bands** for the future.
- Frequency bands for 6G Spectrum Research: from **low band to terahertz to visible light.**

5.1.4 Alternative Ideas

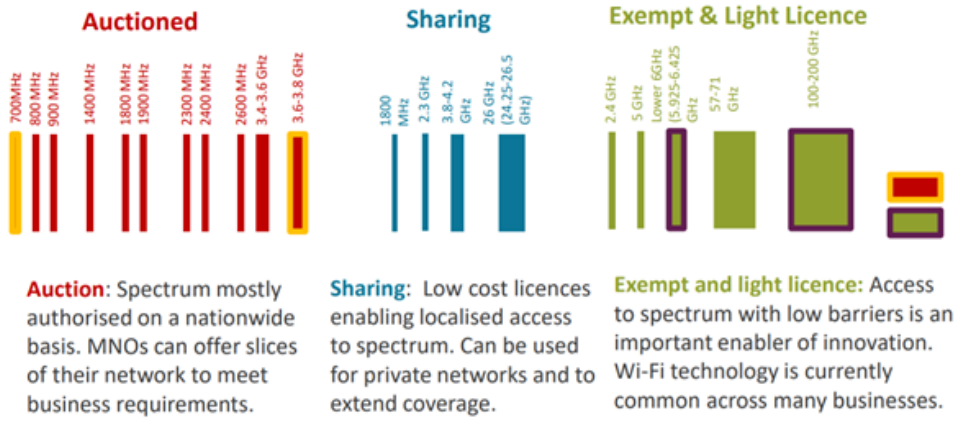
In the discussion at the Cluster 2 meeting mention was made of the Mobile Virtual Centre of Excellence and other past collaboration models. Another proposal put forward was for an organization that would be separate from the universities that are participating. It could be a distinct body or joint venture (public/private), or it could be 'hosted' by an existing public body – for example, the Digital Catapult.

5.2 Ofcom perspective on Spectrum and 6G Research

The presentation by Ofcom to the Cluster 2 meeting was in two parts: their general approach to identifying new spectrum needs and their views on 6G research as a basis for collaboration.

5.2.2 Views on 6G Research as a basis for collaboration

- The key need from a spectrum point of view is efficient and effective radio networks, there is a need for research into enhancing spectral efficiency across all frequency bands
- 6G will be deployed in existing frequency bands currently used for mobile, we need ways of effectively migrating these bands from previous generations to 6G (such and improved Dynamic Spectrum Sharing)
- We should not assume 6G will be deployed first in 'new' bands. 'New' bands should only be identified if there is a clear demand that cannot be satisfied in exiting spectrum



5.2.1 New Spectrum Needs

Spectrum is critical for wireless. Ofcom have sought to make sure that spectrum bands, with different characteristics, can be accessed by a wide range of players, including MNOs, system integrators and directly by businesses, to deploy the connectivity solutions that meet their requirement. Their consultation process will seek to identify how demand may change in future, and the spectrum implications.

- There is already a significant amount of spectrum allocated for mobile in Low, Mid, and High (i.e. mmWave) bands. Low and Mid bands are extensively used and additional Low and Mid band spectrum is coming on stream following the recent 700 MHz, 3.6-3.8 GHz auction. 1175 MHz (almost 30 %) of spectrum under 4 GHz is already allocated to mobile – including the 400 MHz of shared access spectrum at 3.8-4.2 GHz brings this to just under 40%.

- It is very unlikely that further Low frequency spectrum can be made available for the foreseeable future given the Governments decision on renewal of the DTT licences to 2034 (notwithstanding the new revocation clause). As well as DTT there is important use by other services (e.g. PMSE, Railways, Utilities, SRDs, etc) in Low frequency spectrum that also needs to be accommodated. Coverage issues cannot be solved by throwing more Low frequency spectrum at the problem, we need innovative ways of using a range of different spectrum bands and technologies to provide the services people need, where they need them.
- A significant quantity of mmWave spectrum was identified at WRC-19. We need to look at how networks can make effective use of this as it is made available (e.g. at 26 and 40 GHz)
- THz spectrum (e.g. > 100 GHz) is interesting for applications requiring extremely wide bandwidths but has development challenges and is most likely some way off. We have already facilitated innovation in this spectrum by releasing over 18 GHz of EHF spectrum above 100 GHz
- Shared access spectrum needs to play a key role in 6G (in bands such as 3.8 – 4.2 GHz, 26 GHz, etc). Mobile networks will increasingly need to share spectrum resources with other users and technologies – finding ways to allow better more effective sharing is vitally important.
- And the evolution and integration of a range of different access technologies (e.g. Wi-Fi, Satellite, etc) is vital for the development of 6G
- There are challenges that results from the increase in energy efficient building stock, as a consequence of climate change policy, that needs to be looked at. Energy efficient buildings tend to be very difficult for radio waves to propagate into – this could result in the need for a shift from a predominantly ‘outdoor in’ to an ‘indoor in’ model for the provision of indoor coverage

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.

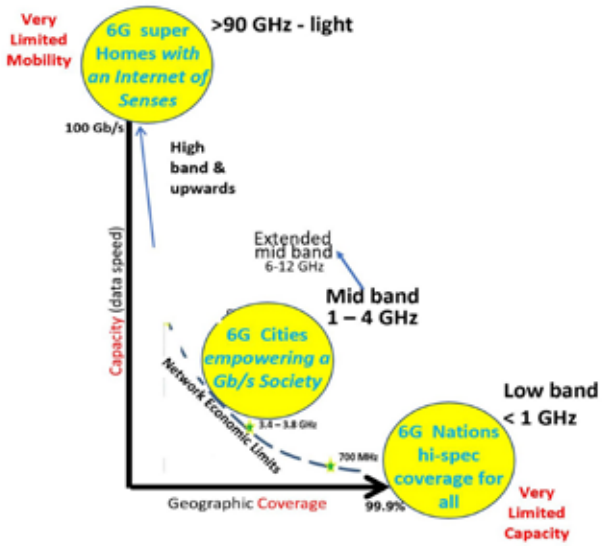


Figure 5 – How the choice of spectrum range shapes three distinct 6G opportunities

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 was made to ensure the entire process was open and transparent. All of the university hosted workshops were 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 were available on-line on the UK SPF's section of the techUK website.

A consultation document, by Chairman of Cluster 2, which contained the assessment of the Expert Panel, their recommendations, and the consultation questions, was put onto the UK SPF section of the techUK website. The consultation ran between 4 and 15 October 2021.

The recommendations from the Expert Panel meeting on 23 September have remained as their views and not changed. Any alternative views from the public enquiry have been published in this final edition of this report in Annex 1. Bringing them together in the final edition of this report allows the government and others using the report to see the range of views that have emerged.

Respondents were given a 250-word limit for three reasons:

1. Officials interested in those responses are concerned with direction of 6G rather than detail
2. If the report become too encyclopaedic it would become difficult to read
3. To make the editing task manageable within the tight timescale the SPF had in mind.

Below was the explanation given for each of the questions:

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 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 were cut and pasted in Annex 1 in alphabetical order of the organisation they were from. Comments from individuals were shown under "independents"

The only substantive change of this report between the edition for public consultation and the final edition has been:

- The addition of the public comments (to Annex 1)
- Adding the University and presenter names (to Annex 2)
- A replacement section 5 to record the valuable material from the Cluster 2 meeting and "brain storming" on a research collaboration model that took place on 5 October.

8. Acknowledgements

This initiative has been under a mandate agreed with DCMS and has been a partnership between the UK Spectrum Policy Forum Cluster 2 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 their 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.

Annex 1 - Comments received in public comments phase

The UK Spectrum Policy Forum thanks the following for their comments:

1. **Analysys Mason** - Chris Nickerson and Janette Stewart
2. **BT** - Chris Cheeseman
3. **Copsey Comms** - Brian Copsey
4. **EMEA Satellite Operators Association (ESOA)** - Aarti Holla
5. **Global mobile Suppliers Association (GSA)** - Reza Karimi
6. **Harlette Capital Ltd** - Naomi McGill
7. **Independent** - Simon Pike
8. **Independent** - Simon Saunders
9. **InterDigital** - Alain Mourad
10. **Kings College London** - Toktam Mahmoodi
11. **Nokia** - Mirela Andouard and Matthew Baker
12. **Pilkington Technology Management Ltd** - Stephen Day
13. **Plum Consulting** - Ian Corden
14. **Real Wireless** - Simon Fletcher
15. **Shure Incorporated** - Prakash Moorut
16. **University of Bristol** - Dimitra Simeonidou
17. **University of Bristol** - Mark Beach
18. **University of Sheffield** - Timothy O'Farrell
19. **Virtual Centre of Excellence in Mobile and Personal Communications Ltd. (mVCE)** - Executive Committee
20. **Webb Search** - William Webb

These contributions add to as the information to be found in the main report and have the same status.

Record of individual public comments:

1. Organisation: Analysys Mason

Name: Chris Nickerson and Janette Stewart

Question 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?

Analysys Mason was asked by a leading wireless technology vendor to investigate frequency ranges relevant to 6G as part of a study that commenced earlier this year. Our research brief considered whether forming part of 6G solutions might include bands below 1GHz, mid and high bands (building upon the foundations of 5G deployment), and much higher bands, in the sub-THz/THz ranges.

We found that whilst various research projects are investigating future use of sub-THz and THz frequencies, there needs to be a clearer understanding of the use cases, system designs and architectures for these frequencies before commercial interests will be raised.

There is commercial interest in enabling existing frequency bands used for 5G and other current generations of mobile technology to be available for 6G, including existing low-bands, mid-bands and the mmWave bands identified at WRC-19. Ensuring that 6G technology will natively support these existing bands was identified as being important to enable existing mobile networks to evolve. There is also commercial interest in making additional spectrum available for mobile use both in low, and mid-band ranges.

Improved co-existence and sharing could open up opportunities for flexible use of new bands. Further research into the feasibility of wider frequency ranges that devices can tune across (specifically from 7GHz up to 10GHz or 12GHz) might give greater flexibility at a regional level. For example, flexible use of 7125–8500MHz is under review in the USA, as is mobile use of 10GHz, and/or 12GHz, in some markets.

2. Organisation: BT

Name: Chris Cheeseman

BT has participated in the expert group established to advise DCMS on 6G research priorities and welcomes this opportunity to provide our additional views on the Recommendations that have emerged from the expert group.

Given the limitation of 250 words that has been allowed for consultation responses we have necessarily restricted our comments to high level views only, as set out in the below. Should any point require clarification we would be happy to discuss this with the SPF.

Question 1: Do you believe that the five goals (which can be found below and 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?

Yes, these goals are important areas for 6G research projects.

The challenge of delivering the required future growth in mobile network capacity and the technical capabilities to support new services is also an important goal.

The benefits of widespread coverage go beyond the examples mentioned and include other industrial sectors.

Convergence and integration of fixed and mobile networks, and possibly satellite and other platforms will be of increasing importance in the long-term.

Question 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?

Availability and exploitation of additional spectrum sub-1GHz, at mid band and in mmWave and higher bands will be important to deliver future mobile service requirements, including backhaul options

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

No.

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

It will be important to align 6G research with Ofcom's forthcoming mobile spectrum roadmap as well as exploitation of opportunities arising from ITU / CEPT harmonisation initiatives, including the outcome of the ITU WRC-23 conference where sub-1GHz mobile and broadcasting requirements will be reviewed.

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

No

3. Organisation: Copsey Comms

Name: Brian Copsey

Question 1: Do you believe that the five goals (which can be found below and 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?

No, the point missing is increased spectrum for non-network use. Considering 6G (and 5G) as a platform enables many verticals to enhance their communications, such use is either too expensive via a network or is not enabled by the network

Question 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?

Yes, Innovation in spectrum management & seamless connectivity are especially important plus exploring vertical markets which could have their communication improved especially in the industrial and entrainment sectors.

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

No

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

Yes, making legacy networks more spectrum efficient and how to increase the amount of non-network spectrum available and investigating time limited use of geographical located spectrum

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

Yes.

Recommendation 6 does not place enough emphasis on engaging with global and European standardisation, greater engagement with the extensive UK network engaged in such work is needed

There is no mention of research into any other verticals than mobile

4. Organisation: EMEA Satellite Operators Association (ESOA)

Name: Aarti Holla-Maini

This response is submitted by ESOA, the EMEA Satellite Operators Association. Given the 250 word limit our responses are high level views only. If you would like further information, we would be happy to discuss this with the relevant person.

Question 1: Do you believe that the five goals (which can be found below and 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?

Satellite will bring augmented coverage, reinforced availability, and reliability to 6G. As for 5G, the sector will support 6G standards development in 3GPP/other fora. 6G research should consider (i) Technology Neutrality: spectrum & funding for all technologies (ii) Certainty for incumbent users of spectrum as significant spectrum is already identified for mobile technologies (iii) Economic viability of 6G/minimal risk of increasing the digital divide.

Question 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?

Even with 6G, a significant portion of mobile traffic will likely be offloaded to unlicensed bands.[1] More spectrum for mobile will also not address the economics of network densification required to deliver 6G services.

1. Cisco VNI Global IP Traffic Forecast 2017-2022

Question 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 EU HEXA-X flagship project which considers global service coverage and networks of networks in its vision for 6G, opens the door to a satellite component.

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

Additional effort should be spent on:

1. Design Satellite network components that enable broader accessibility of communications in different 6G use cases/application scenarios.

2. Develop Artificial Intelligence/Machine learning techniques for network management/orchestration & satellite RAN access optimization and for a combination of network technologies (including satellite).

3. Develop highly flexible radio protocols able to support a wide range of services and optimized for both satellite & mobile environments.

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

5G/6G blur boundaries between technologies & licensed/unlicensed bands. Coexistence must be measured through simulations based on the best available information. E.g. Fixed Mobile Convergence aims to remove distinctions between fixed/mobile/wireless to create seamless services. Cognitive radio, geolocation databases, higher frequencies bring new opportunities and new technical/regulatory challenges to be considered.

5. Organisation: GSA

Name: Reza Karimi

Question 1: Do you believe that the five goals (which can be found below and 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?

With regards to Goal (ii), broadly speaking, spectrum sharing should only be considered where there is a clear demand for additional spectrum which otherwise cannot be made available, and where the benefits outweigh the costs. In other words, spectrum sharing should not be considered as a goal in itself but must bring tangible net benefits to users of spectrum. Furthermore, the meaning of "spectrum efficiency" is not fully clear, and this can be conflated with "spectral efficiency". For this reason we suggest that the term "spectrum efficiency" be replaced with "efficient use of spectrum", and that this should be emphasised for all frequency ranges. In short, GSA proposes that Goal (ii) be re-phrased as:

> ii) **Innovation in spectrum management** (e.g. through the use of automation and AI), to ensure the efficient use of spectrum, particularly in the low, mid and high (including sub-THz) frequency bands suitable for mobile connectivity.

Question 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?

GSA recommends that research into the high bands, in addition to the low and mid bands, should also be encouraged and all three should be equally prioritised. It is also noted that political support will be needed to champion rural coverage research in low bands.

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

GSA considers that the Government should support participation in international standards activities, e.g., by encouraging UK organisations to join bodies such as 3GPP and to submit their proposals. Government coordination of inputs to standardisation should not be encouraged as it can distort global cooperation.

6. Organisation: Harlette Capital Ltd

Name: Naomi McGill

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

6G will be much enriched if space satellites are a part of the network of networks envisages for 6G. If the UK embraces this proposition, then policy makers need to have a deep understanding of the near space environment and its regulatory challenges. In particular, there is no reliable architectural model of where everything is and their attributes. This leads onto not having any sort of effective process to request objects to move out of harm's way at very short notice.

Reference:

Military developing Free Space Optical(FSO) or Laser communications for ultrafast secure communications that are harder to detect and disrupt | International Defense Security & Technology Inc. (idstch.com)

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

Satellites can do more than just enhance telecommunications coverage of high-capacity connectivity. They can also beam solar energy to the earth as a contribution to Carbon Net Zero objectives. 6G could be a window of opportunity to accelerate the development of such dual-use platforms using the latest advanced free space optics (FSO) technology.

As time is running out on solving the Net Zero issue, it is worth posing the question on whether deployment of such dual use space technology for 6G has to wait until 2030 or later when its already being deployed in space today.

References:
https://committees.parliament.uk/writtenevidence/37423/pdf/

Applications of wireless power transmission (itu.int)

7. Organisation: Independent

Name: Simon Pike

Question 1: Do you believe that the five goals assumed as the basis for this initiative are the right goals that the government should set as national 6G research goals?

The UK should develop a national view on its expectations and objectives for 6G, and not unquestioningly accept the performance objectives handed down by ITU. This should involve all stakeholders, so it needs to sit above these five goals and inform how they are applied.

Question 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?

I am sceptical about the potential of 'Terahertz bands' (above 100GHz) for mobility applications. However, increasing spectrum efficiency is likely to need more advanced fronthaul, requiring higher bandwidths that may only be available at these higher frequencies. A key enabler will be improving the efficiency of devices for RF power generation, with R&D possibly jointly with or through the Compound Semiconductor Catapult.

Some commentators on 6G have suggested that its applications could include teleportation, holographic images, and communication of the senses of smell, taste and touch. If feasible, these would employ coding to reduce the bitrate required, as video is today. It is important to develop a peer-reviewed evidence base of their feasibility, their likely coding compression ratio, and their requirements for network performance - for both home and portable devices. This would inform UK objectives for 6G and contributions to international bodies.

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

Synergies with the Catapults - including Digital, Satellite Applications and Compound Semiconductor - should be explored.

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

The spectrum above 100GHz is fragmented by numerous allocations and designations to passive services. Achieving wide bandwidths may require co-band sharing of active and passive services. The propagation and atmospheric absorption characteristics may make this feasible. The UK should contribute to current ITU studies on this topic.

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

Yes.

6. Organisation: Independent

Name: Simon Saunders

Question 1: Do you believe that the five goals (which can be found below and 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?

The five goals are generally laudable.

The wording of the net-zero goal seems weak: “alignment with the government’s net zero targets” comes across as a tick-box exercise. UK wireless networks should be a strong and active tool for achieving net zero goals in the wider economy, being efficient in their own energy use, making use of carbon neutral sources of energy universally (diesel generators are still in common use), and delivering benefits to other sectors. As a result the overall aspiration for wireless networks across all emission scopes should - and realistically can - be carbon negative, allowing the economy overall to achieve its net zero targets faster.

Question 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?

A balanced spectrum portfolio across low, mid and high bands is certainly essential for 6G, but the ends rather than the means should be the focus. While the diagram in figure 5 is accurate as regards conventional macrocell topologies, there are significant opportunities for other topologies to contribute to delivering 6G coverage with very different spectrum requirements. For example, small cell topologies provide a “bottom up” approach to filling coverage gaps (both indoors and in local remote communities) and are less needy of low and mid band spectrum. Similarly satellite and other airborne platforms provide a ‘top down’ approach to extensive coverage, again with very different spectrum needs.

So research should focus on how to alleviate the demand for additional low band spectrum through hybrid topologies and through more spectrum access and sharing approaches, rather than on simply seeking new dedicated spectrum bands for traditional wireless architectures.

Question 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 research projects have a good spread and include some exciting opportunities but are very concentrated on physical layer techniques. While these are essential and welcome, there needs to be much stronger focus on the needs for new distributed and neural computing architectures, software techniques, cloudification and orchestration.

9. Organisation: InterDigital

Name: Alain Mourad

Question 1: Do you believe that the five goals (which can be found below and 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?

I believe the above 5 goals are rightfully placed on the priority list for the development of 6G. These however are not exclusive to 6G but have been targeted in 5G and continue today to be targeted in 5G-Advanced as evidenced in current 3GPP Release 18. These goals do not seem to include key service scenarios that are underpinning the enhancements in 5G-Advanced that 6G will inevitably carry forward. These include noticeably use cases around XR (AR/VR) connectivity, smart industries, and joint communication, sensing and positioning.

Question 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?

Whilst I agree that the mid-band should be a priority in view of its potential in support of most of the 5G impending use cases, the high band should not be deprioritized on the 6G research agenda. The specifications in the high band (above 24 GHz) started in 5G continue in 5G-Advanced and are expanding to above 71 GHz. These are envisioned to further continue in 6G (above 95 GHz). These are rich of research challenges and therefore have high potential for innovations and global standardization impact.

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

Whilst this is great to see the UK 6G research communities' approach focused on and led by the UK universities, this is critical to complement this by adding key private R&D communities too so some form of a public-private partnership may be established to maximize impact especially in global 6G standards (ETSI, 3GPP, IEEE, IETF).

10. Organisation: Kings College London

Name: Toktam Mahmoodi

Question 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?

Four of these are general and important goals, while the second item i.e. "innovation in spectrum management" is by no means on top of the technology innovations required at this stage of wireless research. There has been extensive works in this area since 3G and there is no clear further innovation in this consultation document. On the other hand, aspects related to network intelligence, and resilience, the reliable use of AI in network management, and machine and human interactions, are all major challenges in 6G that will allow e.g. smart manufacturing and autonomous driving to success.

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

There are various aspects of the network as a whole that needs further research that includes but not limited to convergence, satellite and its use for remote coverage, network autonomy and openness at all levels but in particular at the access, etc. In a nutshell, while spectrum challenges might also be of importance, they are a small fraction of the big picture of 6G research and a contribution to the successful delivery of 6G.

11. Organisation: Nokia

Name: Mirela Andouard and Matthew Baker

Question 1: Do you believe that the five goals (which can be found below and 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?

1. We believe the goals are perhaps too focused on capacity and coverage, which are the traditional focus of eMBB, but miss the new "beyond-data" applications and use cases of 6G that require, for example, low latency and sensing capabilities.

2. We believe that goal (ii) should focus on improving the efficient use of spectrum. Spectrum sharing should not be a goal in itself but occur only where the benefits outweigh the costs of clearing spectrum.

Question 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 report does not clearly substantiate the view that low and mid bands present the biggest challenges, e.g., is the challenge the potential limited availability? Also, from the presentation, it seems that high/mmWave bands were dismissed on the grounds that their key challenge (of economic viability) is too large. mmWave bands have specific value for local deployments and the challenges they present should be addressed.

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

Integration of "beyond-data" applications and use cases of 6G requiring sensing, timing, and positioning features, all provided by the same network technology.

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

Flexible spectrum usage and its regulation should be studied taking into account e.g., variable duplexing schemes, devices with different classes of power levels, and deployments in spectrum under different authorisation schemes (licenced, licence-exempt).

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

Recommendation 6: The government should support open participation in international standards activities, e.g., by encouraging UK organisations to join bodies such as 3GPP and to submit their proposals. However, government coordination of inputs to standardisation should not be encouraged as it can distort global cooperation.

12. Organisation: Pilkington Technology Management Ltd

Name: Stephen Day

Question 5. Can you identify any other significant research projects that have been missed that have the potential to also address the 6G research goals?

Radio Transparent Building Materials.

Thermal insulation of walls and windows is using progressively more foil and conductive coatings to achieve low thermal emissivity materials. Very little thought and product development has been in this area yet the potentials are;

1. Improved penetration into homes and offices that don't have any additional hardware to provide indoor networks.
2. Delivery of broadband into homes/offices from street furniture locations to electronics routers the user can place on window ledges for easy installation.
3. Use of office windows for small cell base stations to cover the public street or outdoor areas around a private 5G/6G network owners premises.
4. Availability of radio communication to emergency services such as fire.

Academic studies of propagation through the building facades have always focused on what has already been constructed. Little or no guidance is given to architects to make buildings 5G/6G compatible or upgrade them to be more compatible.

There are aspects to this not just for the manufacture of more radio transparent building materials but also electronics and antenna that would be used mounted in/on these building materials. Collaboration is essential. As an example, transparent window glass can't be sold if the architect sees no electronics that will make use of this building feature, the electronics manufacturers will not make products to mount on windows until they know transparent window glass is available.

13. Organisation: Plum Consulting

Name: Professor Ian Corden PhD CEng FIET

Question 1: Do you believe that the five goals (which can be found below and 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?

We agree that the five goals are all important objectives for 6G; we were involved in defining them.

Question 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?

Government should put in place a programme to establish a 6G R&D Strategy for UK, working with other nations' 6G hubs. We agree that some focus must be placed on the low and mid bands; the THz bands must be just one part of the 6G whole.

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

Key technology areas have been recognised in the Government's work on Diversification. Key areas have been noted as software-defined networks, 6G sensing, quantum communications, open standards, and cluster computing. With good funding in place for quantum and fibre programmes, Government must ensure focus on wireless R&D. Key areas will include reconfigurable materials, advanced antennas, signal processing, and cell-less and new architectures, high precision network timing, AI, and ultra-high-resolution communications. Critically, Government should encourage R&D collaboration and cross-sector research.

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

Dynamic spectrum access and advanced spectrum management must be supported. We would also encourage the Spectrum Policy Forum to consider new commercial models, enabling increased levels of competition and innovation. In the FTTP side of the industry, altnet competition has been hugely successful in driving better services for consumers. Innovation and competition in the mobile side of the industry is, in our view, weak, and in need of improvement.

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

Government should take note not only of key emerging technology areas, but also the mechanism for efficient R&D and the route to market; UK R&D collaboration is critical

14. Organisation: Real Wireless

Name: Simon Fletcher

Real Wireless, world's leading independent wireless advisory firm, welcomes the opportunity to respond to the Public Consultation: On recommendations to government on how to harness the potential of 6G.

Question 1: Do you believe that the five goals (which can be found below and 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?

Real Wireless agrees with the 5 goals identified based on the evidenced input from the UK University sector. We do however encourage flexibility based on potential for international 6G collaborations. Techno-economic driven strategies for wireless systems have moved from site to multi-site across terrestrial, HAPs and satellite. A significant limiting factor continues to be spectrum resource availability. The power performance of systems is significantly impacted by the spectrum utilised. Breaking down industry and use case silos of wireless systems will bring large benefits not only to the wireless industry in terms of their Net Zero targets but also Net Zero benefits for many industry sectors that use wireless systems.

We support the importance of the spectrum efficiency in low and mid bands as bringing wireless services to all through good coverage is essential. The development of future innovative connectivity solutions should not be limited to low or mid spectrum bands. By breaking down spectrum silos of industries the UK can lead standardised and coherent approaches to sharing of spectrum from 400MHz to mmWave as needed. Innovations in the market should set the direction for a multitude of solutions. Spectrum policy must not constrain the search for solutions in high bands which are suited to meet wireless communications requirements for the next decade.

We encourage the SPF to think internationally. We co-chair the UK5G International Working Group alongside DIT and would welcome engagement with the SPF on strategic planning regarding international engagement strategies for UK thought leadership on spectrum policy innovation.

15. Organisation: Shure Incorporated

Name: Prakash Moorut

Question 1: Do you believe that the five goals (which can be found below and 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?

The overarching goal should be to facilitate access to spectrum by a broad range of users and not just public mobile networks run by Communications Service Providers. E.g., explore local licensing, shared access and unlicensed regime more to allow verticals to access spectrum, including on a short-term basis and shortly before the use.

Question 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?

In addition to public mobile, we should ensure that other services/systems like Programme Making and Spectrum Events (PMSE) or DECT continue to get access to highly sought-after low and mid-bands.

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

No.

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

Yes. How to enable access to users which need spectrum shortly before the use and in a sporadic manner, e.g., via automation and AI?

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

Yes. Consider more than just public mobile and regional/international harmonization of spectrum access approach and regulations.

16. Organisation: University of Bristol

Name: Professor Dimitra Simeonidou, Director of the Smart Internet Lab

Question 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?

These goals alone set a very low level of ambition for the UK 6G research and do not align with international initiatives (academic and industrial) which set targets for both technology and system level R&D. 6G should be about novel open network architectures addressing convergence, disaggregation, softwarisation leveraging on advances of AI/ML, and cloud hosting to deliver future end-to-end mobile network solutions. The five-point goals above could be listed for any network of any generation. I remember these points from the 4G era. Do we need an "expert panel" to tell us these?

Question 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 UK government should not base a national 6G vision on spectrum efficiency/policy considerations alone. It is the wrong starting point for driving 6G research and the UK will fall behind the international R&I agenda.

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

This work has missed the opportunity to address network architecture challenges, convergence and overall end-to-end network considerations. The process of running these workshops was not inclusive or transparent. Not all relevant and world leading research from UK Universities was presented. Speakers were not informed that they would be evaluated by the "expert panel". I question the entire process and purpose of this work.

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

N/A

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

It will be helpful to become more familiar with the international research landscape and drive UK research leadership in the sector rather than acting for a small group of stakeholders with a large personal agenda. Similar past approaches did not help the UK.

17. Organisation: University of Bristol

Name: Professor Mark Beach

Question 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?

Interventions in addition to spectrum policy / funding are necessary to achieve widespread coverage and seamless connectivity. This includes better use of fibre to the home and 'piggy-backing' on this bit-pipe with MNO access points, as well as expanding fibre connectivity in rural areas. In addition, Massive MIMO base station technology (FR1 band) could be applied to dynamically enhance coverage as well as network capacity. Signal and device classification techniques using machine learning, for example RF Finger Printing, not only aids RF cyber intrusion detection, but can be applied for active spatial-temporal link detection in spectrum sharing scenarios. Practical viability of reconfigurable intelligent surfaces in terms of scalability (multi-users, multi-channel, city-wide landscape) must be assessed in terms of economic viability.

Question 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?

Enhancing receiver specifications would aid spectrum sharing as well as possible use of waveform cancellation technologies.

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

RF device characterisation for efficient RF power amplifiers by Paul Tasker et al (Cardiff University). Research through EPSRC TOUCAN (PI Simeonidou, Bristol) addressed seamless connectivity through SDN and technology agnostic agents for optical (fibre), optical (LiFi) and wireless devices and networks. Programme grant completed Dec 2020, hence was not included in the academic review. The outcomes and knowledge gained is relevant to 6G network architectures. Innovation by UK SMEs such as Blu Wireless, Zeetta Networks, and more recently ForeFrontRF, also need to be captured and integrated within UK capability map.

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

Any funded academic programme associated must have technology transfer embedded ensuring UK plc can benefit.

18. Organisation: University of Sheffield

Name: Professor Timothy O'Farrell

The SPF initiative to promote and foster research activities in UK universities related to 6G is both welcome and needed. Bringing the initiative to the broader research community is also important and appreciated. Engaging academic research from all areas of the UK will realise the full potential of this initiative and contribute to the broader Government mission of levelling up. Following are my personal responses to the questions raised in the consultation.

The effort put into this initiative by the organising committee is highly appreciated.

Question 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?

The goals identified are significant, especially net zero targets. However, they should not be set as exclusive national 6G research goals. Considerable debate remains on what constitutes 6G technology and research. Therefore, the process for setting goals should be reviewed regularly and refreshed accordingly. A noticeable missing goal is semiconductor chip development. Chip supply underpins many aspects of wireless technology development. A UK based chip design and fabrication capability for 6G technologies would be a game changer for the UK.

Question 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?

Prioritising low and mid band frequencies is pragmatic and likely to yield viable solutions for reasonable research costs. However, prioritising this over high band carries a risk of considerable missed impact. A successful technology breakthrough at high frequency bands could solve many of the challenges identified by the five goals (less coverage). The international community is addressing high band research in terms of devices and techniques. Therefore, calibrating this priority against the international landscape is critical to ensure a successful outcome for a national 6G research programme.

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

If not already identified, the regulations that will emerge around achieving net zero are likely to impact mobile radio networks in the post 2030-time frame. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009924/rhc-future-technological-innovations-role-regulation.pdf.

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

Making participation in an approved "collaboration model" a condition of 6G research grants requires further details to endorse fully. An essential aspect of such a collaboration model is that it is open and transparent to all universities enabling the most promising research ideas to emerge and be supported. Also, the definition of what constitutes 6G research is ambiguous.

19. Organisation: Virtual Centre of Excellence in Mobile and Personal Communications Ltd. (mVCE)

Name: Submitted on behalf of the Executive Committee of mVCE

mVCE welcomes the initiative of the Spectrum Policy Forum to engage research activities in the UK Universities. We thank Stephen Temple for his efforts in keeping us and the wider research community informed of the initiative, he clearly strived for an inclusive approach. Our response to questions of particular interest is below.

Question 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?

From the five research goals, mVCE places net zero targets as the topic of the highest priority. We promote this area, utilising our well researched Green Radio knowledge (acquired through a strategic partnership with EPSRC), and encourage more research in this domain.

We recognise the limits of the remit of the spectrum policy forum, and fully acknowledge that access to spectrum remains and is always an important element of wireless systems. We do however recognise significant trends in networking and IT systems that have and will continue to disrupt traditional approaches. We regard software-isation, and the societal changes that it implies, as a significant underpinning and disrupting force in beyond-5G systems.

Question 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 broad scope and capability of the University sector has been recognised through the series of events, and this Consultation document – an excellent start. The strength in scope and depth in the UK University sector is oftentimes overlooked, we promote it and believe it has been well represented in this activity. Some further extraction of outcomes from the legacy of the TI3 programme[2], to which mVCE gave recommendations prior to formation, could be beneficial.

2. https://epsrc.ukri.org/research/ourportfolio/themes/ict/introduction/priorities20122016/ti3/

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

Our focus is recommendation 4. mVCE has deep experience of operational models that provide triple-helix services to University, Industry and Government agencies. The strengths and weaknesses of which cannot be conveyed in this short response. We would be delighted to engage in further discussions on approaches around visions and research oversight supporting various closed, semi-closed, and open collaboration models delivering various desired outcomes.

20. Organisation: Webb Search

Name: William Webb

Question 1: Do you believe that the five goals (which can be found below and 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?

What should 6G be?

The process of specifying, standardising and designing 5G has not been optimal – targets have not been met and business cases have not emerged - a different approach should be used for 6G.

We need to decide what 6G should be. But who is "we"? At the moment it is the same organisations that designed 5G – hence the calls for "bigger and better". A better team might include sociologists, VCs, application designers, economists, regulators and politicians. And even end users. Recommendation, do not leave 6G design to the engineering research institutions.

Rural coverage remains an issue and 5G does not address it. 6G could help "defragment" the very messy spectrum below 1GHz. 6G could embrace shared spectrum allowing self-deployment, in-building solutions, systems for verticals and dynamic new entry of different kinds of operators. Recommendation, look to the economics of network provision and design a system that realistically will deliver ubiquitous good-quality mobile broadband.

It has long been clear that pervasive IoT connectivity is needed. IoT has not taken off because complete solutions are not readily available for industries wishing to deploy it. 5G changes nothing – it just rebrands 4G's NB-IoT as the 5G machine connectivity solution. 6G could help fix this – not with 1ms latency, but with practical, economic end-to-end solutions that entities like smart cities can deploy. Recommendation, focus on getting existing connectivity such as NB-IoT, packaged in a manner that allows us to realise the 50 billion vision.

Annex 2 - Research projects presented over the three workshops

	Presentation title	University	Presenter
University of Bristol hosted workshop on 26 May			
Session 1 | RF Transceivers & System Performance Enhancement			
BR1.1	Spectral and Energy Efficient Radio Systems	Edinburgh	John Thompson
BR1.2	Linear & Power Efficient RF sub-systems	Bristol	Tommaso Cappello
BR1.3	Advances in RF Planar Filter Technologies	Heriot Watt	Jiasheng Hong
BR1.4	Multiband Direct RF Sampling for 5G and Beyond MIMO Receivers	Sheffield	Tim O'Farrell
Session 2 | Next Generation Massive MIMO & AI Driven Systems			
BR2.1	Learning to Communicate	UCL	Christos Masouros
BR2.2	AI and Massive MIMO	Bristol	Wael Boukley Hassan
BR2.3	C-RAN, vRAN, O-RAN and Cell-free Massive MIMO	York	Alister Burr
BR2.4	Self-supervised learning: the next challenge for industrial AI	Bristol	Robert Piechocki

Session 3 | Future Network Architectures			
BR3.1	Next Generation Converged Digital Infrastructure	Lancaster	Nick Race
BR3.2	Seamless Connectivity for All	Bristol	Dimitra Simeonidou
Session 4 | New Materials for RF Engineering			
BR4.1	Frequency Reflective Surfaces	Queen Mary	Yang Hao
BR4.2	Looking at acoustic wave filters through an integrated photonic lens	Bristol	Krishna Coimbatore Balram
BR4.3	New materials and geometries for next generation antennas	Exeter	Alastair Hibbins
BR4.4	GaN Diamond for Efficient RF amplification	Bristol	Kevin Morris
Session 5 | Spectrum Sharing & Higher Frequency Bands			
BR5.1	Spectrum Sharing - Database, Loans, Multiplexes & SDR for 6G Opportunities	Strathclyde	David Crawford
BR5.2	Enhancing Spectrum Sharing with Fixed Links	Bristol	Simon Wilson
BR5.3	Sub-THz Antennas and Devices for 6G Communications	Birmingham	Alexandros Feresidis/ Costas Constantinou

University of Surrey hosted workshop on 1 July

Session 1 | Radio Waves modelling			
SU1.1	Spectrum allocation from a propagation perspective	Durham	Sana Salous
SU1.2	Non-Stationary Channel Model and Capacity Behaviour of ELAA-mMIMO Systems	Surrey	Yi Ma
SU1.3	6G Technologies; Radio Waves and Health	Public Health England	Dr. Azadeh Peyman
Session 2 | New Physical layer Techniques			
SU2.1	Non-orthogonal signals for spectral and energy efficient transmission	UCL	Izzat Darwazeh
SU2.2	Rate Splitting Multiple Access for 6G Communications and Sensing	Imperial	Bruno Clerckx
SU2.3	Exploiting Electromagnetic Degrees of Freedom for Spectrum Efficiency Enhancements	Surrey	Pei Xiao
Session 3 | New Frequency Bands and towards Tbps			
SU3.1	The optical spectrum and Tb/s wireless systems in the 6G era	Leeds	Jaafar M.H. Elmirghani
SU3.2	Power-efficient waveforms for visible light communication	Surrey	Fabien Heliot

SU3.3	RF Sampling and Software Defined Radio – Working with a 4 GHz Baseband using the Multichannel RFSoC	Strathclyde	Louise Crockett, David Northcote
Session 4 | Radio Access Network			
SU4.1	Self-Organised Radio and Core Networks: Achieving end-to-end optimal resource utilisation	Glasgow	Muhammad Imran
SU4.2	On the energy efficiency, spectral efficiency and coverage of cell-free massive MIMO	QUB	Hien Quoc Ngo
SU4.3	Cell Sweeping - A New Paradigm for Cells Deployment and Cell-edge Enhancement	Surrey	Atta Quddus
Session 5 | Co-existence			
SU5.1	Spectrum co-existence for satellite and terrestrial systems	Surrey	Barry Evans
SU5.2	Blind Spectrum Sensing Using Stochastic Resonance	Surrey	Seiamak Vahid
SU5.3	OpenRAN Lab at Surrey	Surrey	Konstantinos Nikitopoulos and Rahulan Yogaratnam
Session 6 | Enabling Techniques			
SU6.1	A glimpse of next-generation wireless enabling techniques	Southampton	Lajos Hanzo

SU6.2	Green and Secure Networks; Will 6G deliver the Duo?	Kings College	Mohammad Shikh-Bahaei
SU6.3	Coverage enhancement with power efficient Reconfigurable Intelligent Surfaces	Surrey	Mohsen Khalily

University of Strathclyde hosted workshop on 16 September

Session | Introduction			
ST0.1	The importance of "mobile", "generation" changes and the spectrum challenges of the 6G age.	SPF/University of Surrey	Stephen Temple
Session 1 | Security and Sustainability			
ST1.1	Security, Resilience and Sustainability: The Benefits and Challenges Brought by SDR	University of Strathclyde	James Irvine
ST1.2	RF finger printing to aid cyber security in low cost wireless IoT system	University of Bristol	Mark Beach
ST1.3	Digital Net Zero – Mapping the Challenge	University of Bristol	Chris Preist
Session 2 | Software Defined Radio			
ST2.1	5G/6G Private Networks for Vertical Markets: Just add some SDR and Spectrum	University of Strathclyde	Malcolm Brew / David Crawford

ST2.2	Software defined radio as a vehicle for commercialisation of university research: lessons learned in 5G and opportunities for 6G	University of Southampton	Rob Maunder
ST2.3	Dynamic Spectrum Radio with Frequency Spread Filter Bank Multicarrier Transmitters	University of Strathclyde	Kenneth Barlee
Session 3 | RF Sampling			
ST3.1	GHz Bandwidth Sensing by Sub-Nyquist Signal Processing	University of Surrey	Yue Gao
ST3.2	RF Sampling in Multiband Receivers for 5G: Analysis and Performance	University of Sheffield	Tim O'Farrell
ST3.3	Low Power Analog Processing with RF Correlation for Ultra-High-Speed Receivers	University of East London	Jaswinder Lota
Session 4 | Spectrum Sharing			
ST4.1	Spectrum Monitoring for Sharing- first principles SDR design and implementation	University of Strathclyde	David Northcote
ST4.2	Autonomous Spectrum Awareness for Smart Spectrum Access and Sharing	Liverpool	Miguel López-Benítez

Session 5 | Artificial Intelligence (AI) Enabled SDR			
ST5.1	Quirks and Opportunities of Training Deep Learning Systems for Future Wireless Networks	University of Strathclyde	Sarunas Kalade
ST5.2	Spectrum-efficient Beamforming beyond 5G: Model-driven AI Algorithms and SDR Testbed	Loughborough University	Gan Zheng
ST5.3	Machine Learning for 6G Physical Layer Design and Interference Control	University of Sussex	Maziar Nekovee
Session 6 | Candidate Bands for 6G Comms			
ST6.1	Integration of Satellite Systems in 6G	Heriot-Watt University	George Goussetis
ST6.2	The Role of LiFi in 6G	University of Strathclyde	Harald Haas
ST6.3	Exploiting rarely capitalised spectrum - Future technologies using THz and beyond THz bands	University of Glasgow	Muhammad Imran
ST6.4	D band offering the next frontier and path forward for 6G communications for civil and defence	Swansea University	Amit Mehta

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 (SPF) 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

DECT - Digital European Cordless Telephone

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.

EPSRC - Engineering and Physical Sciences Research Council

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

FR1 band Sub-6 GHz freqencies

FSO - Free Space Optics

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

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

GSA - Global mobile Suppliers Assocation

HAPS – High Altitude Platforms

IEEE - Institute of Electrical and Electronics Engineers (standards body for WiFi standards)

IETF – Internet Engineering Task Force

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

IPR – Intellectual Property Rights

ITU – International Telecommunications Union

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.

ML- Machine Learning

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

NB-IoT – Narrow Band Internet of Things

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

PMSE - Programme-making and special events

RAN – Radio Access Network

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.

SDN – Software Defined Network

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.

THz – Terahertz (Referring to a range of frequencies between 100 GHz and 10 THz but sometimes as low as 90 GHZ is also referred to as terahertz)

TRL – Technology Readiness Level

VC – Venture Capital

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