Future Telecommunications

A TECHNOLOGY ROADMAP AND ECOSYSTEM VIEW FOR THE UK

UKTIN R&D Future Capability Strategic Leadership Forum
Strategic Working Group Report

Executive Summary

In 2023, The Department for Science, Innovation and Technology (DSIT) tasked the UKTIN Future Capability Strategic Leadership Forum (FCSLF) to produce Capability Reports on the future of telecoms. Nine expert working groups (EWGs) were established to address key areas: Artificial Intelligence, Wireless Communications, Non-Terrestrial Networks, Security, Network Management, Core Networks, Optical/Photonics Technologies, Semiconductors, and Standards. In addition, the Academic Future Networks Strategy Group (ASG) was established to coordinate UK's academic community's views on future networks.

The UKTIN Future Capability Wave 1 papers, published in Summer 2024, focused on strategic, high-level challenges and capabilities. UKTIN Future Capability Wave 2, here, presents nine UK-centric R&D technology roadmaps between now and 2035+, assessed against criteria's such as: the UK's capabilities; market attractiveness; and the feasibility of success. The summaries for these papers are in the main body of this report, supported by synthesis and discussion of next steps.

Recommendation 1: Target Key Technology Areas.
Telecoms is too broad for any one country to address all of it, and it is essential to target support on areas that the UK can succeed. The FCSLF recommends these focus areas where the UK has special strengths in both academia and industry, with the best opportunity for success to lead to both economic growth and employment:

- Compound Semiconductors and Photonic ICs
- Specialist software and hardware components & subsystems for Future Wireless, NTN and Optical Networks
- AI in Telecoms
- Security & Resilience

Recommendation 2: Develop a Long-Term Vision.
Telecommunications is a long-horizon industry. The UKTIN roadmaps reflect this, looking beyond 2035. All future recommendations should be structured to support this timeframe.

Executive Summary

Recommendation 3: Act Now to Capture Opportunities.
Now is a crucial moment for action with a once-in-a-decade opportunity: the advent of 6G, direct-to-device in satellite communications, AI and quantum becoming commercial. Given the intersection of these with telecoms, there are many opportunities for UK to grow its own capabilities if rapid action is taken.

Recommendation 4: Take Advantage of Interdependencies and Synergies.
Significant synergies exist both within the EWG/ASG domains and more broadly: semiconductors underpinning all other technologies; AI is central to next-generation telecoms; security is a critical factor in every new system and quantum is underpinned by photonics. The focus technologies reflect these synergies.

Recommendation 5: Continue the UKTIN Future Capability consultative structure.
The knowledge and expertise built over the last two years within the EWGs/ASG is an asset for the UK that should be continued to be leveraged for long-term UK strategic roadmap management.

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Introduction

1.1/ Background & Context

On its formation, UKTIN was tasked with producing a series of UK telecommunications R&D&I Future Capability reports covering UK challenges, opportunities and capabilities into a structured UK telecoms technology review.

Nine expert working groups (EWG) were established in 2023 to address key areas:

- Artificial Intelligence
- Wireless Communications
- Non-Terrestrial Networks
- Security
- Network Management
- Core Networks
- Optical/Photonics Technologies
- Semiconductors
- Standards

In addition, an Academic Strategy Working Group (ASG), all within the UKTIN Future Capability activity. This has been supplemented by expertise from the UKTIN secretariat.

Each group consisted of senior figures from industry, academia and the third sector, all contributing on a voluntary basis over the past two years. Regular meetings were held within their respective groups and cross-collaboration between the groups to identify synergies and areas for co-operation.

The initial UKTIN Future Capability ("Wave 1")[1] papers that were published in Spring-Summer 2024, focused on strategic, high-level issues and included several recommendations. Additionally, the ASG's first paper provided an initial overview of the UK's academic-led research, innovation, and development (R&I&D) landscape in future networks and compared the UK's research ecosystem with the global landscape.

[1] REFERENCE TO UKTIN website with the Wave 1 reports

Following this, DSIT requested that the second set of papers ("Wave 2") adopt a more granular approach, to outline technology roadmaps for short-term (2025-30), medium-term (2030-35), and long-term (2035+) goals. Each technology was assessed and scored against a criteria set by DSIT such as the UK's capabilities, market attractiveness, and the feasibility of success.

These 9 Capability Papers with scoring and roadmaps have been submitted to DSIT. Each working group produced its own domain Executive Summary, which collectively form the core content of this report. Additionally, the ASG's second paper focused on identifying and prioritising academic research areas where the UK has strong capabilities in future network technologies.

The FCSLF was established to integrate diverse viewpoints from specific technology domains, as well as from industry and academia, into a comprehensive end-to-end perspective of the telecommunications sector. It plays a key role in guiding the analytical focus of the expert groups and in consolidating their findings. In the UKTIN Future Capability structure, the domain technical authority is in the individual expert working groups. The FCSLF is an enabling and integrative function and has refrained from imposing top-down expert views in the specific domains.

1.2/ Structure of this report

Section 2 presents the main contribution of this report in the form of technology roadmaps from a UK perspective, comprising of the Executive Summary from the 9 EWGs.

Each EWG addressed the question: "In which technology areas should the UK focus R&D&I resources in order to build critical UK capability and capture increasing UK market share of global future telecoms networks?". As part of this, they prepared technology roadmaps for three periods: 2025-2030, 2030-2035 and 2035+ for the key technologies within their scope. These were then scored against a variety of questions to assess the scale of the opportunity globally and the ability of the UK to succeed in that space.

Section 3 captures key recommendations and sets out next steps for the UKTIN FCSLF and EWGs. These "synthetic" recommendations include both strategic or structural themes that apply across all technologies, and four specific technology areas for focused investment.

Introduction

During the development of the technology domain roadmaps, the expert stakeholders were encouraged to consider cross-technology domain dependencies. These touchpoints stimulate thinking on where common themes and interdependencies between technology stacks may exist. These foundational elements created the first ecosystem management artifact of capability pillars where high interdependence in system architecture concepts is present and persistent.

Further work will be required to identify and address the interdependencies and synergies between the different areas, the capabilities in the UK and collaborating with international partners to shape and develop the UK capabilities in this area, in ways that contribute to economic growth and secure and resilient infrastructure.

Annex A provides a full list of the contributors to the UKTIN Future Capability structure.

UKTIN EWG Wave 2 Technology Roadmap Summaries

During Wave 2 of the UKTIN Future Capability activity, the EWG technology domains focused on the development of technology roadmaps and the distillation of insights from within their domains. During the distillation process, the UKTIN EWG Chairs were provided with several strategic questions from DSIT to assist with the relevance of their analysis to DSIT and to the wider ecosystem.

This section provides the short summary outputs of the 9-technology domain EWGs[2]. These summaries, alongside more detailed reports, have been the underpinning shared knowledge that has enabled the DSIT Policy making team to gain foresight on future telecoms technologies when looking ahead to 2035, and UKTIN Future Capability is now sharing them with the wider ecosystem.

2.1/ AI

This is a summary report produced by the UKTIN AI-EWG on the Research, Development and Innovation (R&D&I) Technology Roadmap to 2035 and beyond, to present a prioritised technology R&D roadmap for AI in Telecommunications in the UK. The group invited external expert speakers from the AI for Telecoms ecosystem to add further breadth and depth to their collective expertise. During the delivery process, the EWG proposed topics for consideration from global trends in which the UK could and/or should take part.

This process revealed five overriding themes: Physical Media Interface, Distributed AI, Sustainability, AI/Telecom intersection, and Ecosystem. These were ranked by the group in creating an AI-Technology in Telecom roadmap (see Figure 4), with the nine most promising technological and three ecosystem topics described in the main report.

[2] The FCSLF comprises of the 9 Technology Domain EWGs, the Academic Future Networks Strategy Working Group, and the Telecom Industry Coordination Group.

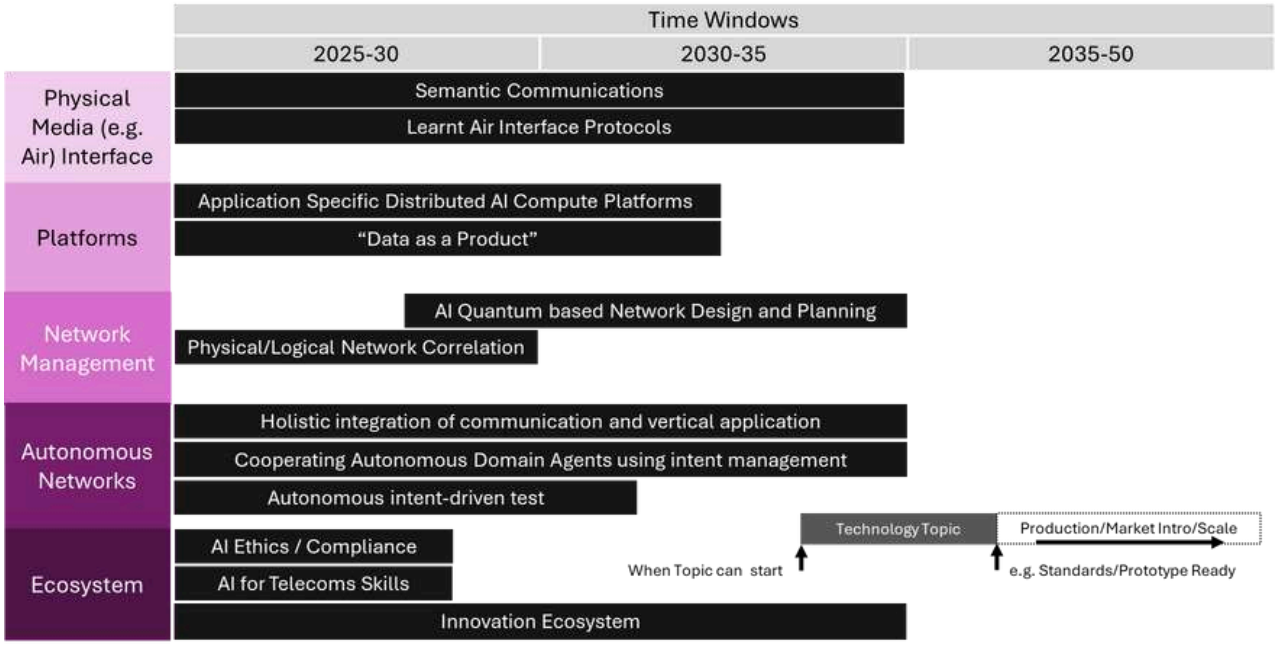


Figure 4: AI-EWG Roadmap for AI in Telecoms

These topics were then further ranked to reveal the top five topics for R&D&I based on a set of questions from UKTIN and DSIT on UK priorities. The ranking of the roadmap topics is presented in Table 1, based on the averages and medians of the scores for each topic's ranking, with 1 being of highest importance and 9 being the lowest ranking.

Technology Topic	Ranking	
	Average	Median
Cooperating Autonomous Domain Agents using intent management	**1**	**1**
Holistic integration of communication and vertical application	**2**	**4**
Efficient Application-Specific Distributed AI Compute Platform	**3**	**3**
Autonomous intent-driven test	**4**	**2**
Semantic Communications	**5**	**3**
Learnt Air Interface Protocols	**5**	**5**
Physical & Logical Network Correlation	**5**	**5**
Data as a Product	6	6
AI (Quantum) based Network Design and Planning	7	7

Table : 1 Ranking of the technology topics based on AI-EWG expert opinion (BOLD = selected for consideration)

As some topics had equal scores, the data presented equal importance on several topics. This means there are at least two or three topics at 5th rank for the top five topics, depending on if we consider median or average of the scores.
This report has also considered a number of topics related to the ecosystem that are regarded as foundations which are required to enable progress in other AI technology topics.

- Telecoms-specific AI Ethics & Regulatory Compliance resources and specialist support
- Assessment and planning of long-term telco-specific AI skills requirements for the UK
- Access to funding for telecom-specific AI innovation by entrepreneurs and startups

In short, the topics presented here are a selection from over 30+ topics that were narrowed down for relevance related to the challenge set for Wave 2 delivery of the technology roadmap. The group did not find any items to recommend whose innovation cycle would extend beyond the 2035 timeline. Research items for AI in Telecoms beyond 2035 are likely to be driven by fundamental advances in AI technology, which are hard to project for the AI-specialist community at this time and out of scope for this AI EWG.

For details on each selected topic, please refer to the 'AI-EWG Wave 1 UKTIN report' that provides a description of each topic, along with its expected outcome and reasons to be a UK's R&D&I's priority. The relevance of each topic was also captured in this activity, as shown in Table 2 for the synergies of each topic with other EWGs within UKTIN.

Technology Roadmap Focus Areas	Topic	EWG Synergy					
		WN	Semi	NM	Stand	Sec	Core
Physical Media (e.g. Air) Interface	Semantic Communications	✓	(✓)		✓	✓	
	Learnt Air Interface Protocols	✓	(✓)		✓	✓	
Platforms	Efficient Application-Specific Distributed AI Compute Platform	[✓]	✓		[✓]	✓	
	Data as a Product			✓		✓	
Network Management	AI (Quantum) based Network Design and Planning			✓		✓	
	Physical & Logical Network Correlation			✓	[✓]	✓	✓
Autonomous Networks	Holistic integration of communication and vertical application	✓		✓	[✓]	✓	
	Cooperating Autonomous Domain Agents using intent management			✓		✓	
	Autonomous intent-driven test	✓		✓	[✓]		
Ecosystem [these are "challenges"]	Telecoms-specific AI Ethics & Regulatory Compliance resources and specialist support				✓	✓	
	Assessment and planning of long-term telco-specific AI skills requirements for the UK						
	Access to funding for telecom-specific AI innovation by entrepreneurs and startups						

Table 2: Topic synergies with other EWGs

The main report also includes a section on the impact of selected topics on standards, indicating where the UK needs to intervene or simply remain aware of relevant standardisation activities around the noted topics.

2.2/ Wireless Networking Technologies

The Wireless Networking EWG framed its work in Wave 2 by considering the following overall question:

"In which technology areas should the UK focus R&D&I resources in order to build critical UK capability and capture increasing UK market share of global future telecoms networks?"

The EWG identified some 68 individual technology focus areas which represent opportunities for the UK to be aligned with these questions. After analysis and prioritisation (taking full account of DSIT's prioritisation criteria), five focus topics were identified as follows (in alphabetical, not priority order):

Topic (alphabetical not priority order)	Description
Network of networks (also known as 3D networks)	Networks comprising a blend of physical network topologies working together, such as terrestrial and non-terrestrial (satellite, HAPs, UAVs etc.), and potentially comprising multiple air interfaces.
Future wireless access architectures	Evolved logical architectures for wireless access, including cell-free networks, and heterogeneous combinations of Wi-Fi, IoT and cellular access.
AI for wireless networks	Applications of all forms of AI/ML to all layers of wireless networks. Applications include air interfaces, protocols, wireless network management, optimisation, analytics.
Intelligent radiating systems	Systems combining radiating and receiving elements (antennas and metamaterials) with associated hardware and adaptive baseband signal processing and control, including Reconfigurable Intelligent Surfaces and future extensions to massive MIMO.
Radiofrequency (RF) devices and circuits	High performance RF devices and circuits for wireless transmission and reception

To note, the focus was on wireless network technologies in which the UK can win market share, so while the consideration of specialised application areas (e.g. ISAC, railways, URLLC) is essential to set network requirements, these are not technologies in themselves and therefore are not considered as candidate technologies.

There are multiple cross-cutting requirements which need to be considered throughout these topics, and which may represent opportunities for UK market share in themselves, including wireless security, resilience and sustainability.

Representative examples of the technology areas under each of these topics are shown below, in approximate order of priority. The timescale for investment shown in each case spans between two points in time:

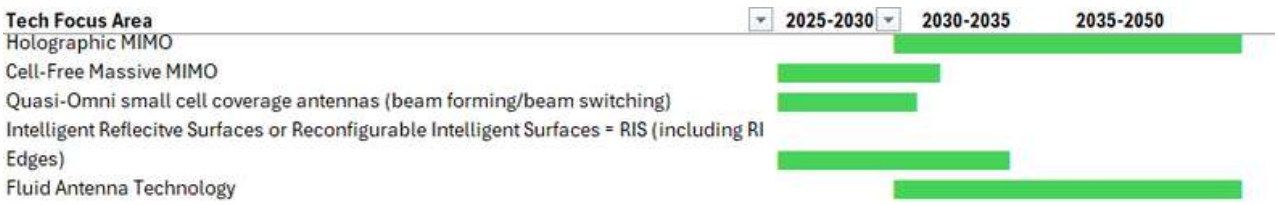
- The time from which R&D&I needs to ramp up
- The time by which R&D&I investment needs to yield market-ready prototypes and (where applicable) standards to be ready for the emerging market window.

Network of networks

Future wireless access architectures

AI for wireless networks

Intelligent radiating systems



Radiofrequency (RF) devices and circuits

2.3/ Non-Terrestrial Networks

Non-Terrestrial Networks is a growth area that has been recognised by the international telecommunications community as the key to future provision of ubiquitous and resilient services.

Recent advances in Low Earth Orbit (LEO) mega-satellite constellations and on-board processing, together with the enabling of spectrum use between NTN and TN and new NTN standards have heralded a new market in Direct-to-Devices (D2D), which is expected to play out as a major new market in the so called 5G advanced era up to 2030. Thereafter, 6G standards will emerge to enable a raft of new human centric services up to 2035 and beyond, which will rely on NTN converged with TN, to provide ubiquity of coverage. The convergence of NTN and TN is crucial to providing ubiquity of coverage as well as resilient services, and as already seen in the early stages of direct communication from satellite to a commercial mobile phone, is a disruptor not only for new technologies but also in heralding new business models and markets.

NTN can play a key role in addressing Government challenges. Kickstarting economic growth in rural and remote areas and breaking down barriers to opportunity to contribute to national GDP (12% of the UK population live and work in remote and rural communities, and contribute to 15.8% of GDP) will be greatly facilitated through the exploitation of NTN infrastructure and services once these become seamlessly integrated with terrestrial networks to minimise friction to service adoption.

The ability of NTN services to provide resilience and reach for mobile connectivity will enhance the effectiveness of our national police forces and will enable our NHS and health and social care communities operating in more remote and rural regions, both in terms of overall improvements in efficiency and reduction in response times to incidents and alerts with consequential reduction in long term illness and patient recovery times (thereby improving GDP in terms of workforce participation).

Technology Roadmap

This report focuses on a Roadmap of key NTN technologies over the 2025-35 decade from the R&D requirements to their eventual commercial implementations and proposed areas in which the UK should concentrate its R&D and commercial strategy. In producing the Roadmap, the NTN EWG produced a comprehensive telecommunications technology repository based around applications, services, connectivity and networking, enablers and devices.

In Section 2 of the report, a description of each of these areas, as they form the NTN context, is presented. This provides the backdrop as used by the NTN EWG together with the outputs of the technology repository to select, by discussion and consensus, key technologies and their R&D to commercial applications, as shown in the overall Roadmap in Section 3.

The technologies have been broken down into five categories: Satellite and HAPs Payloads, HAPs and UAV Systems, Connectivity & Networking, Devices and Terminals and 6G Technologies. In each category there are subdivisions relating to specific technologies with key milestones.

The report provides more detailed information in each category which are then evaluated in terms of growth potential, future market sizes, current UK status and international competition. A summary is as follows.

In the final section of the report, the areas in which the UK should target, R&D and commercial exploitation, are evaluated. In order to prioritise across our five technology categories, the EWG have used the seven questions posed by DSIT, which relate to i) Market saturation by international players, ii) Return on Investment and market size, iii) Potential for growth, iv) Criticality for the UK, v) Potential for competitive advantage, vi) Both profitability and relevance to national security, and vii) How foundational the technology and ability to converge with other critical technologies.

Based on this analysis the key points for the UK focus are as follows:

Satellites and HAPs Payloads

- The move from GEO to LEO constellations; the dominance of US Starlink and the UK exclusion from the EU RISS system are endangering UK future sovereignty in satellites. This threatens an essential element of the UK critical infrastructure and weakens its global military capabilities.
- Loss of sovereignty needs to be addressed by future collaborations e.g. AUKUS and defence and in-orbit demonstrators of new technology which can be rapidly transformed into operating systems. The UK has strength in small satellite manufacturing.
- The UK has strength in payload technologies-RF components, on board processing, networking and increasingly optical. There are opportunities to lead in these areas.
- There is a strong linkage across other technologies-AI, wireless, security and quantum, networking, semiconductors for which NTN opens opportunities.

HAPs and UAV Systems

- HAPs is a nascent technology with a strong UK industrial presence and academic R&D base. Applications are as fill-in between TN and satellite, with advantages for D2D services in high density areas.
- There is an opportunity for the UK to take a lead in this area with a potential large future global market, but this needs a HAPs operator to emerge.
- There is a need to support R&D as well as UK industrial development in platforms.
- There are synergies with technologies in defence, the aircraft sector, battery developments liquid hydrogen/hydrogen and advanced materials.
- The UAV market has potential for growth in comms, surveillance and air traffic taxis.

Connectivity and Networking

- 5G advanced and 6G markets are far from saturated and offer opportunity for the UK in high value niche areas and networks as a service (NaaS) but needs UK players to embrace special NTN requirements.
- Foreseeing high growth in converged networks with opportunities in open network architectures and software for management. Significant opportunities for converging NTN/TN network and service management.
- There is an opportunity for UK leadership in NTN/TN architecture and management with strong software contributions and for international partnerships (e.g. AUKUS for inward investment).
- UK strengths and players in networks & services, software, AI and NTN need to be brought together to focus on integration and in-orbit demonstrations.
- Need to harness considerable UK strengths built up via terrestrial networks and services to include the specific NTN environments.

Devices and Terminals

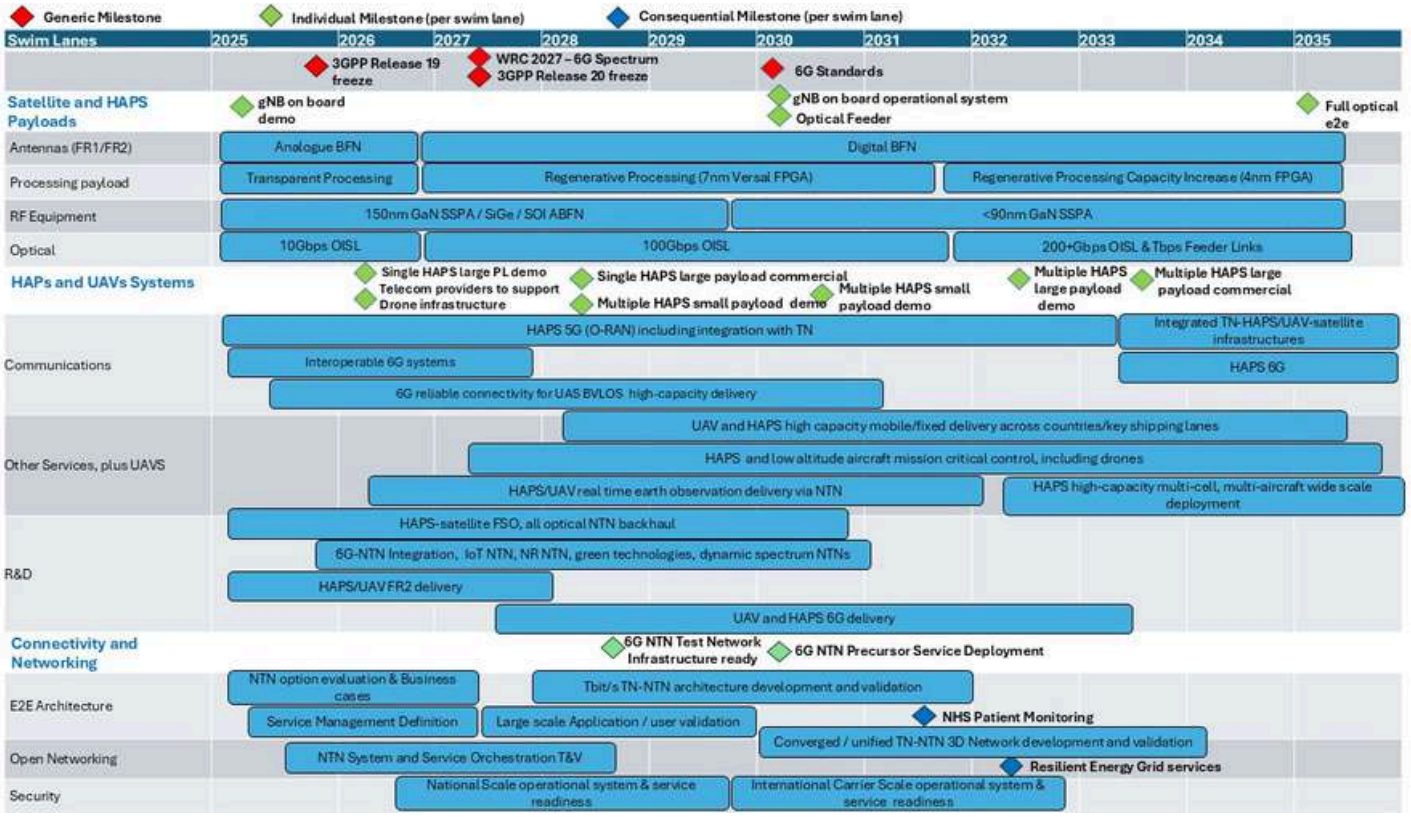
- The UK should continue to play a leading role in the supply chain for smartphone devices exploiting obvious competency in silicon design (ARM), RF and antenna technology.
- Exploitation of expertise in specialised terminals for mobile (airborne, vehicular, maritime, rail) offers the UK an opportunity in which to take leadership.
- Sovereign capability for government and military users where mobile (direct to vehicle) terminal needs may be prominent, make a UK supply chain important.
- Taking leadership in direct to vehicle technology presents a huge technology growth opportunity that furthermore enables many new use cases and industries.

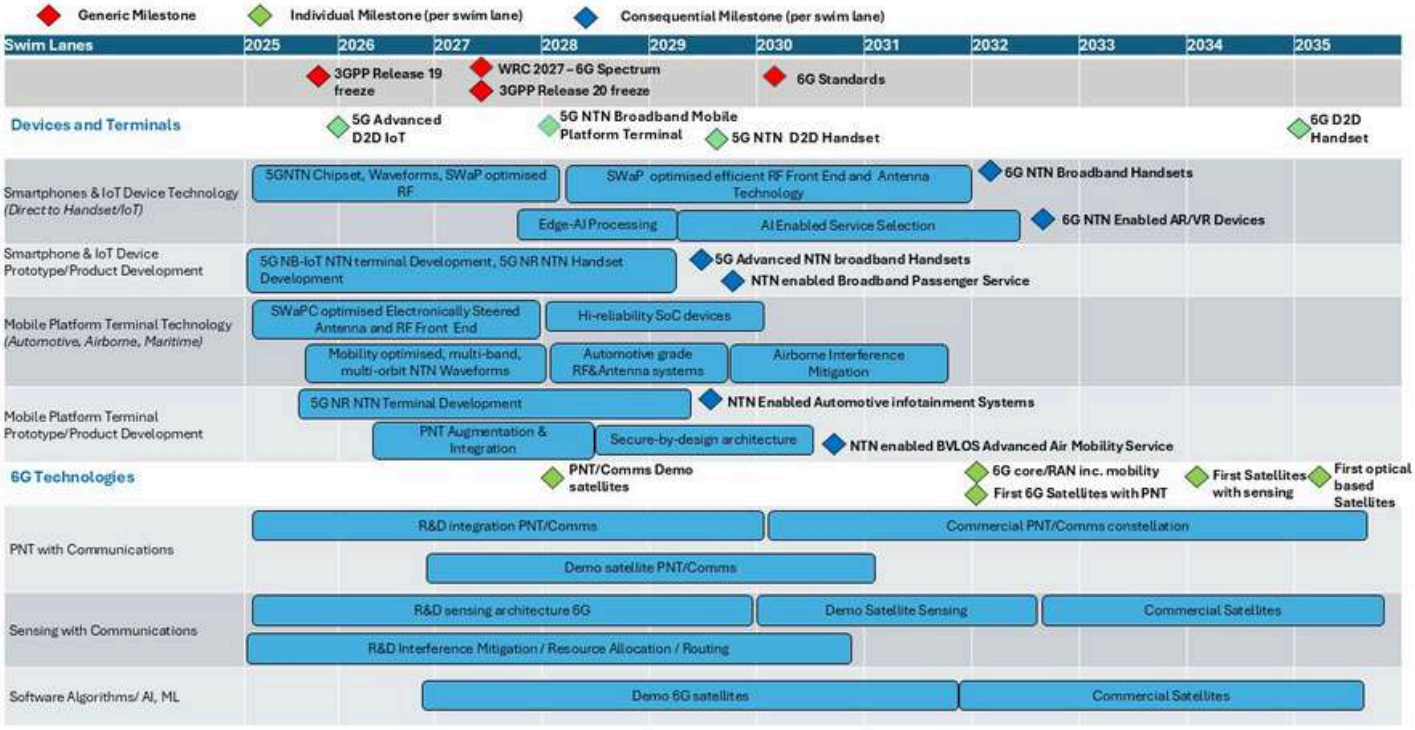
6G Technologies

- 6G converged NTN/TN represents a very large future market (TRL 3-5: 2025-30; TRL 5-8: 2030-33; TRL 9: 2035).
- There is an opportunity for UK leadership in 6G-NTN in-PNT, security, networking and AI.
- There are opportunities to integrate early stage 5G+/6G technologies into in-orbit demonstrators to accelerate TRL progression.
- Convergence of NTN/TN is key in 6G and is an area of strength in the UK which should be built on. This is foundational as it links across many other key technologies.

Finally, the EWG proposes a new strategic approach for accelerating delivery of NTN technologies in the rapidly moving convergent market between NTN and TN. This involves coherence and continuity through all stages, from R&D to commercial implementation.

Technology Roadmap





2.4/ Security

This paper sets out key R&D priorities of potential benefit to the UK. It also incorporates observations from the Security Group Paper launch event in Dorset earlier in 2024 and provides an indicative timeline for action.

The UK faces a major strategic security challenge because it has no long-term "informisation" strategy and faces a "code red" situation[3]. A longer-term vision covering security via a cross-party approach is urgently needed. The UK's security capability is being eroded already by those Nations that have such plans. Furthermore, even if such a strategy is adopted, unless security R&D capability can be deployed in a manner in line with relevant technical standards, it will still not be possible for the UK to benefit from its R&D.

Many of the industry have responded to the Government's Invest 2035 Industrial Strategy[4] Green Paper, which seeks to develop a credible 10-year plan. It states boldly "we will not repeat the mistakes of the past,"[5] and that "growth is the number one mission of this Government."[6] We are heartened to see the development of longer-term thinking. However, we are thinking more of a 20-year timeframe.

Security is unlike other fields in that it is a "gate" through which they must all pass to progress to successful monetizable outcomes that justify the significant expenditure of public funds involved. If the UK cannot secure its critical national infrastructure, then R&D that depends on it working cannot deliver the value required, and our economic and societal stability and National security will be at risk. The UK depends on digital services. The Green Paper makes two telling observations that underline security's pivotal role. The first is that the UK accounts for some 10% of the global fintech market, where if this share is maintained, revenues are like to more than triple by 2030[7]. The second refers to a source stating that "half of global trade is expected to be digital (bold type added) by 2050."[8] If the UK's security position is undermined the consequences are very serious.

[3] See: Future Capability Paper - Security | UKTIN
[4] Invest 2035: the UK's modern industrial strategy - GOV.UK
[5] Ibid, page 2
[6] Ibid, page 2
[7] Ibid, page 25
[8] Ibid, page 23 footnote 75 for the source, and in the text as well at paragraph 1

Finally, security is a field where implementation will have to be more "industry-led" and immediate if we are to deliver the required results. Again, as the Green Paper notes "The UK has considerable strengths in RDI; however, we can struggle to translate these into commercial goods and services domestically."[9] Should we fail, there will be no long-term to worry about anyway. We make no apology for how we selected the timeframes for action on the topics we identified. This is not an exercise in producing pretty Gantt charts. It is about understanding what really matters and how urgently. We would contend that nobody doubts that the UK must retain world-class security capability. In such a dynamic and rapidly evolving environment with new threat vectors constantly emerging, time is a luxury we simply do not have, and furthermore, any strategy that fails to accept the need for regular review over a sustained period is floored. Things may change in the future – but right now we face a "burning platform". If we do not address things immediately then there might be no platform left to save.

The group has agreed that the following five subjects are the priority security topics requiring attention. We explored more than just these topics in the report which follows, as per the original "ask" from UKTIN. Should therefore the reader want to form a broader picture they can. If not, then this Summary and the associated Roadmap can stand alone and still be comprehensible.

The top 5 Security R&D topics are:

- **SEPP & Inter Network/ signalling security**
- **Platform security implementations, RAN & Core**
- **Secure & Understandable remote access**
- **Securing legacy/ fallback and interop with pre-5G networks**
- **Decouple Telco implementations from Cloud / faster updates**

Additional information on all topics can be found in the main report should any topic be of particular interest to the reader.

We would also like to make a special mention of the need for longer term activity that needs to begin today (and in earnest) around ensuring standardisation of the Commercial Off-The-Shelf ('COTS') IT supply chains that enable telecoms and ensuring these are ready for use of post-quantum era cryptography for platform security applications. This is in line with our introductory comments regarding the need for a longer-term vision.

Non-practitioners might wonder why quantum does not figure more in our thinking. We would contend that it absolutely does, but we have ignored the hype around "quantum-everything" and tried to stay grounded. Telecoms is a sector that loves new and shiny buzz words, which sooner or later get replaced by even newer shinier ones. Quantum does appear in the main report, and as is clear, we are thinking of the post-quantum era as well in relation to the priorities we have agreed above.

[9] Ibid, page 31

2.4.1/ Roadmap for Security R&D

The roadmap generated by the group is shown in Figure 1, with key areas identified and with supporting information following thereafter. It is important to note that none of these identified areas sit beyond the medium-term horizon, since the priority matters impacting security today must be addressed today with an eye on the medium term to target the UK's limited resources to best effect.

Possible longer-term (10+ year) activities are noted elsewhere in this paper but deliberately not included here. In taking this line, we also reflect the government's own timescales set out in "Invest 2035 Industrial Strategy." This did not exist when the roadmap was originally discussed within UKTIN.

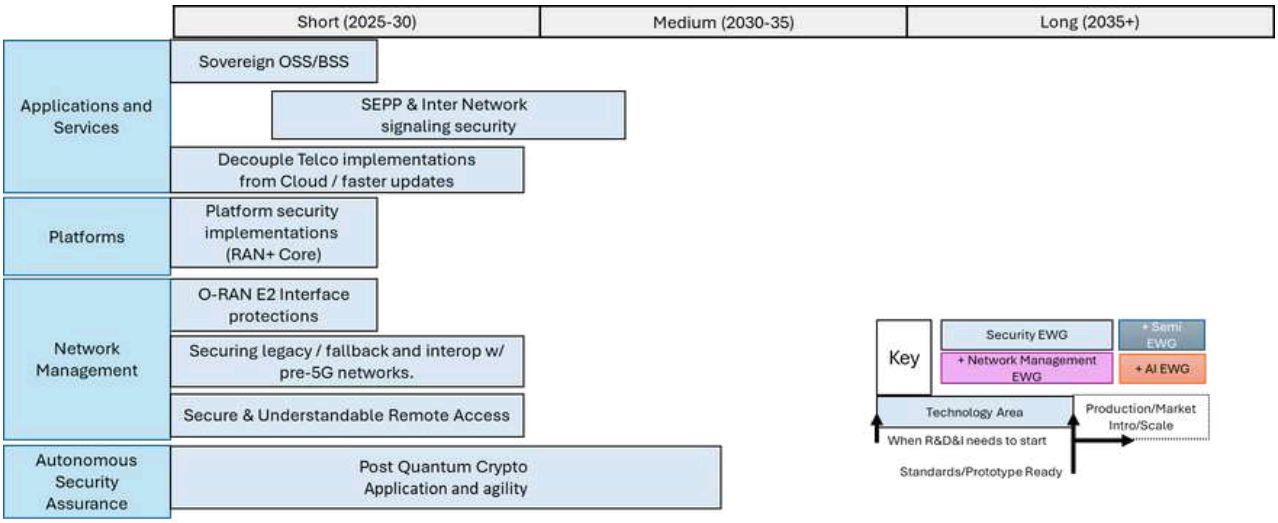


Figure 1: Security EWG Technology Roadmap

As identified in our earlier report,[10] "the fundamental problems affecting telecoms network security have not changed in the last 10 or more years, and these issues are now becoming more pressing and urgent." For example, whilst the emergence of a cryptographically relevant quantum computer may take place on a 10+ year horizon, the work to prepare for this must begin in the very short term. This is due to the alignment required across international standards groups to prepare for computer hardware platforms to use post-quantum cryptography in their platform security features, to allow sufficient time for products with these features to have reached meaningful market penetration by the time that a cryptographically relevant quantum computer may become available.

[10] Future Capability Paper - Security | UKTIN

Technology Roadmap Focus Areas	Topic	EWG Synergy				
		WN	Semi	NM	Stand	AI
Applications and Services	Sovereign OSS / BSS		(✓)	✓	✓	✓
	SEPP & Inter Network / signalling security	✓		✓	✓	✓
	Decouple Telco implementations from Cloud / faster updates	✓		✓	✓	✓
Platforms	Platform security implementations (RAN + Core)		✓	✓		✓
Network Management	O-RAN E2 Interface protections			✓		✓
	Securing legacy / fallback and interop w/ pre-5G networks			✓		
	Secure & Understandable Remote Access			✓	✓	✓
Autonomous Security Assurance	Post Quantum Crypto Application & Agility		✓	✓	✓	✓

Table 1 Topic TRL score and synergies with other EWGs

We believe that security underpins all other UKTIN's Future Capability Expert Working Groups largely work, and the above can only be a subjective guide. However, we have tried to consider the linkages, nonetheless. Technology Readiness Levels (TRLs) are less relevant and potentially misleading because our R&D actions need to happen fast. Arguing about levels rather misses the point. Industry is not "TRL focused," academia is. Since future R&D will have to be more "industry led" to achieve the stated policy goals their metrics matter more.

2.5/ Network Management

This document summarises the output of the UKTIN Network Management Expert Working Group (the NM EWG for short) activity towards a technological roadmap for telecommunications systems and services in Telecoms under its agreed Wave 2 scope:[11]

- A focus on R&D&I, its outcomes and timescales.
- A focus on technology rather than government, policy, investment.
- The selection of recommendations.
- Building roadmap based on those recommendations

In mid-2024, we released EWG Future Capability report (Section7.1.2)[12] which had 8 areas as opportunities for research, development, and innovation over the next 10-to-15-year period.

In this paper, we have further refined these areas into R&D technology specific topics. Other areas in the FC Report were related to process, organisation and skills development, these are not covered in this paper.

The primary focus is a prioritised roadmap for Network Management technologies in Telecommunications. Group members proposed topics for consideration from global trends where the UK could and/or should take part. Building on the themes explored in the NM EWG's Future Capability report released earlier in 2024, a roadmap was then generated from the most promising or critical ones. This process revealed the following five themes as a matter of priority:

1 > Open Networking

The open networking is about supporting multi-domain orchestration architectures and associated APIs as well as APIs for inter-operator network management interconnection. In today's complex and interconnected world, seamless interoperability and efficient management across diverse network domains are paramount. Open Networking, with its focus on standardised APIs and multi-domain orchestration, offers a compelling solution.

By investing in research and development of open, programmable network architectures and fostering a collaborative ecosystem across operators, vendors, and researchers, the UK can unlock significant benefits. This includes increased network agility, improved operational efficiency, and the ability to lead in future network technologies like 6G and beyond.

[11] EWGs 2nd Round of Future Capability papers: Proposed Scope of Work, Internal Document, UKTIN Future Capability Leadership Forum
[12] UKTIN Future Capability Paper: Network Management

However, the UK must act decisively to overcome challenges such as the existing prevalence of proprietary solutions and the need for robust security and trust mechanisms in API usage. Failure to embrace Open Networking could limit the UK's ability to innovate, monetise new services, and maintain control of its critical telecommunications infrastructure. This is a nascent market with high growth potential, ripe for UK leadership.

2 > Automation

The automation is about the development of technology to enable operators to move to TMF[13] Level 4-5 autonomy over the period based on Key Value Indicator (KVI) based Intent. As networks grow increasingly complex, the need for autonomous network management becomes ever more critical. The UK has a unique opportunity to lead in the development and deployment of intent-driven automation, enabling operators to achieve higher levels of autonomy and efficiency.

By investing in AI-powered service orchestration, intent translation capabilities, and "zero-touch" network management, the UK can reduce operational costs, improve service quality, and ensure the seamless delivery of critical services across key sectors like finance and healthcare. However, this requires overcoming challenges such as the transition from network-based to service-based management and ensuring the seamless integration of AI into network operations.

Failure to embrace automation could lead to increased operational complexity, hindered service management, and a potential decline in the UK's competitiveness within the rapidly evolving telecommunications landscape. This is a strategically vital area with high growth potential, demanding immediate scope.

3 > Customer Experience Management Tooling

This is about modelling & monitoring Customer Experience based on real-time network management telemetry combined with social and environmental data. In the digital age, customer experience is paramount. The UK must prioritise the development of advanced tools and techniques to model, monitor, and optimise customer experience in real-time.

By leveraging network telemetry data, social telemetry, and other behavioural data sources, the UK can build a deeper understanding of customer needs and preferences, leading to improved network design, enhanced service delivery, and increased customer satisfaction. This requires investment in digital twin technologies, AI-powered analytics platforms, and the development of Key Value Indicators (KVIs) that accurately reflect customer experience.

[13] www.tmforum.org

Failure to invest in these tools could hinder the UK's ability to meet evolving customer expectations, potentially impacting the competitiveness and profitability of its telecommunications sector. This is a high-growth area where the UK can leverage its existing strengths in AI and user experience research.

4 > Network Planning Tooling

This is about the tooling to support efficient planning of "complex" future networks leveraging new computing technologies such as Quantum computing. Efficient planning and optimisation of future networks will be crucial in a world of increasing complexity and demand. The UK must invest in advanced network planning tools that leverage AI, machine learning, and quantum computing to address challenges in network densification, coverage improvement, and cost optimisation.

By developing sophisticated planning and optimisation techniques, the UK can ensure the efficient allocation of resources, maximise network performance, and deliver a superior customer experience. However, this requires overcoming challenges such as the complex telecom's operator landscape and the need for continuous innovation to keep pace with evolving technologies.

Failure to invest in these tools could lead to reduced competitiveness, increased reliance on foreign technologies, and a potential decline in the UK's ability to effectively plan and manage its critical network infrastructure. This is a strategically vital area with high growth potential, demanding immediate action.

5 > Network Management Ecosystem

Cultivating a thriving network management ecosystem is vital for the UK to maintain its competitive edge in the global telecommunications landscape. This requires a multifaceted approach, encompassing research and development in various supporting areas, such as advanced analytics and monitoring, intent-based networking, change management control, open network management and trust, and AI-based automation.

By investing in these areas and fostering collaboration between academia, industry, and government, the UK can create a dynamic and innovative ecosystem that drives advancements in network management, supports the deployment of new technologies, and enhances the overall performance and resilience of the UK's telecommunications infrastructure.

Failure to nurture the ecosystem could hinder the UK's ability to adapt to evolving network demands and maintain its position as a global leader in telecommunications. This is strategically critical area with high growth potential, demanding a coordinated national effort to foster collaboration and innovation.

To define in more detail, the EWG have broken down each of the themes into specific technology R&D items where appropriate, adding in the timeline to maturity and the group's reasoning as to why the item is significant for the UK.

The roadmap generated by the group is shown in Figure 5. Some topics have clear alignment with other expert working groups such as the AI EWG.

- Start: The earliest time at which an activity could start, given all dependencies met
- Stop: The time by which a Proof of Concept might be delivered, or the technology is mature enough to be incorporated into a standard, etc. [NB Topics might deliver multiple such outcomes during activity]

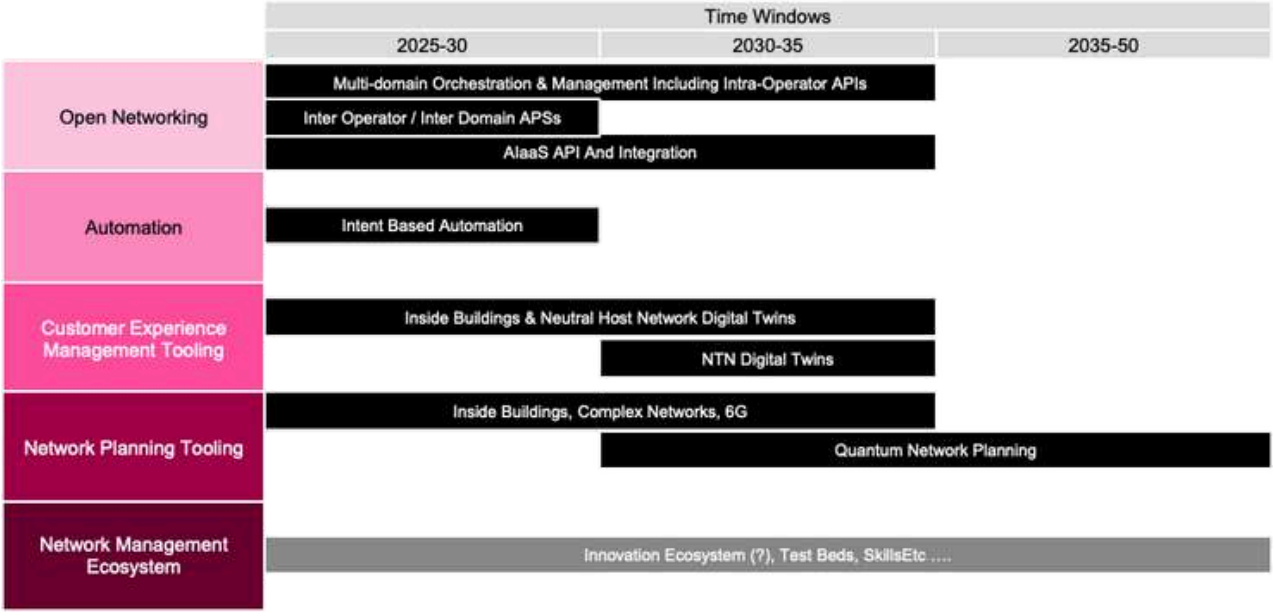


Figure 5: NM-EWG Roadmap for Network Management Technologies in Telecoms

2.6/ Core Networking Technologies

This document summarises the output of the UKTIN Core Technologies Expert Working Group (the Core EWG for short) activity towards a technological roadmap for telecommunications systems and services using wireless networking in Telecoms under its agreed Wave 2 scope:[14]

- A focus on R&D&I, its outcomes and timescales.
- A focus on technology rather than government, policy, investment.
- The selection of recommendations.
- Building roadmap based on those recommendations

[14] EWGs 2nd Round of Future Capability papers: Proposed Scope of Work, Internal Document, UKTIN Future Capability Leadership Forum

Technology Roadmap

In mid-2024 we released EWG Future Capability report (Section 3.1)[15] which had 14 main drivers as opportunities for research and innovation over the next 10 to 15 years. In this paper, we have further refined these areas into R&D&I technology specific topics. Other areas in the FC report were related to process, organisation and skills development which are not covered in this paper.

The primary focus is a prioritised roadmap for Core Network Technologies in Telecommunications. Group members proposed topics for consideration from global trends where the UK could and/or should take part. Building on the themes explored in the Core EWG's Future Capability report released earlier in 2024, a roadmap was then generated from the most promising or critical ones. This process revealed the following five themes as a matter of national priority:

Quantum Networking

In an era of escalating cyber threats and the looming dawn of quantum computing, safeguarding the nation's sensitive data and critical infrastructure is paramount. Quantum networking offers an unprecedented opportunity to achieve unbreakable encryption and secure communications. By strategically investing in Quantum Key Distribution (QKD), developing long-distance quantum communication protocols, and enhancing Quantum Position, Navigation, and Timing (PNT) systems, the UK can spearhead the development of ultra-secure communication technologies.

This will not only fortify national security but also unlock transformative applications in finance, healthcare, and defence, driving economic growth and establishing the UK as a global leader in quantum innovation. However, the path to quantum supremacy is not without its challenges. Scaling these nascent technologies, navigating high research, development, and innovation costs, and overcoming the hurdle of slow initial returns require a bold vision and unwavering commitment.

The UK must seize this opportune moment to invest in skills development, build robust quantum infrastructure, and foster international collaboration. Failure to act decisively risks leaving the nation vulnerable to cyber attacks, reliant on foreign technologies, and lagging behind in the global race for quantum dominance.

6G Core Technologies

To maintain its position at the forefront of mobile technology, the UK must boldly embrace the transformative potential of 6G. This next generation of wireless communication promises to revolutionise our digital landscape with ultra-fast speeds, ultra-low latency, and unprecedented network capacity. However, realising this vision requires a strategic focus on developing core 6G technologies, including AI-driven network orchestration, edge computing, Non-terrestrial Networks (NTN), and advanced management systems.

These advancements will not only enable seamless connectivity and unlock innovative applications in areas like autonomous vehicles and smart cities but also pave the way for sustainable network operations with a reduced carbon footprint. While the global race for 6G dominance is intensifying, the UK has a unique opportunity to leverage its strengths in AI and orchestration to lead the charge.

This demands strategic investment in research, development, and innovation, fostering collaboration between academia and industry, and actively participating in international standardisation efforts. Failure to act decisively risks the UK falling behind the competitors like China, hindering economic growth, and compromising national security.

Network Protocols for Security & Resilience

Protecting the UK's critical national infrastructure from the ever-growing threat of cyber attacks is no longer a choice, but a necessity. Strengthening network protocols is paramount to ensuring operational resilience and safeguarding essential services. This requires a multi-pronged approach, including enhancing Border Gateway Protocol (BGP) security, adopting robust addressing models like IPV6, and employing AI-driven traffic management.

By fortifying these digital defences, the UK can improve network reliability, mitigate the risk of large-scale disruptions, and safeguard the availability of critical services. However, navigating the complexities of implementing these security measures, addressing new vulnerabilities, and ensuring interoperability across diverse networks will require expertise and coordinated action.

The UK has a unique opportunity to differentiate itself in the emerging market for secure network protocols by leveraging its strengths in AI and advanced addressing models. Failing to prioritise this area could leave the UK vulnerable to devastating disruptions and technological stagnation.

Softwarisation & Programmability

Modernising the UK's telecommunications infrastructure demands a paradigm shift towards software-defined networks (SDN) and programmable technologies. By embracing these advancements, the UK can unlock unprecedented flexibility, scalability, and efficiency in network management.

Investing in SDNs, programmable data planes, and network function orchestration will not only enable rapid service deployment and improve cybersecurity resilience but also foster a thriving ecosystem of innovation in telecommunications services. This will position the UK as a global leader in programmable networks, driving economic growth and national competitiveness. However, this transformation is not without its challenges. Potential security vulnerabilities, a reliance in specialised skills, and the need to ensure compatibility across SDN controllers require careful consideration and mitigation strategies.

The market for these technologies is currently unsaturated, presenting a golden opportunity for the UK to lead in adoption and development. Failure to seize this moment risks limiting the UK's ability to monetise future networks, hindering innovation, and leaving critical infrastructure vulnerable to evolving cyber threats.

Future Telecommunications Architecture

To maintain its competitive edge in the global arena, the UK must reimagine its telecommunications architecture. Unlike Japan's ambitious Integrated Optical and Wireless Network (IOWN) initiative, the UK currently lacks a unified vision for next-generation networks. This presents both a challenge and an opportunity. By setting a bold national strategy and investing in key technologies like quantum, optical, and space communications, the UK can develop a future-proof architecture that fosters innovation, enhances economic competitiveness, and reduces reliance on foreign technologies.

A successful initiative would involve creating simplified, cost-efficient transport networks and deploying optical technologies for improved performance, ultimately securing the UK's position as a global leader in telecommunications.

To define in more detail, the EWG have broken down each of the themes into specific technology R&D items where appropriate, adding in the timeline to maturity and the group's reasoning as to why the item is significant for the UK
The roadmap generated by the group is shown in Figure 6. The key areas are:

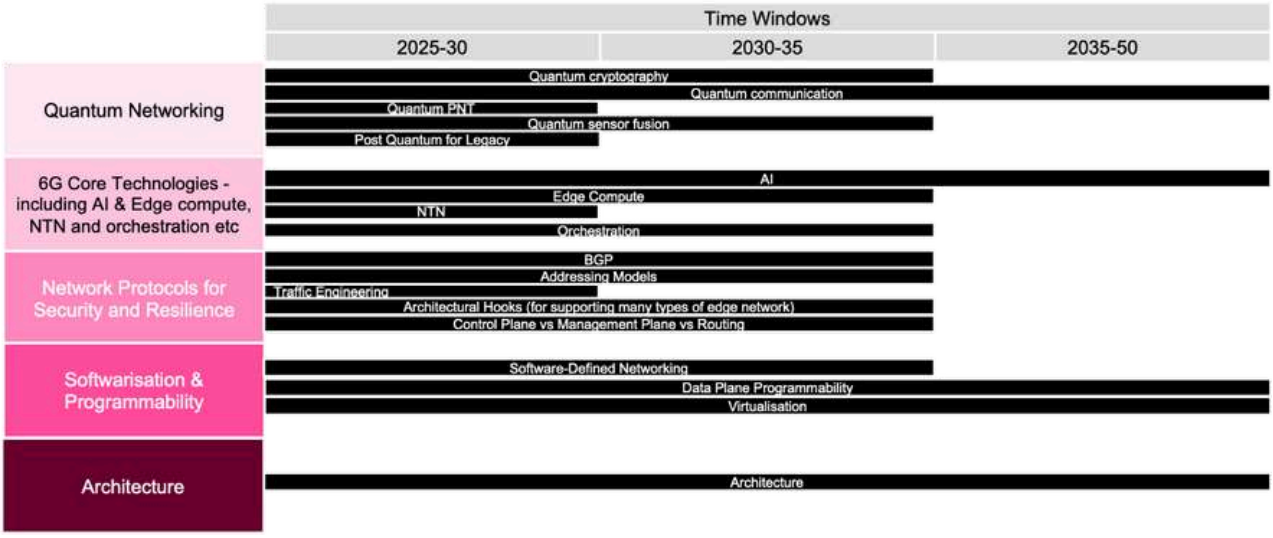


Figure 6: Core-EWG Roadmap for Core Networking Technologies in Telecoms

In addition, the team would like to draw the reader's attention to the need for joined-up people and skills to support these areas, reiterating the points made in the EWG's first report.

2.7/ Optical Communications

Developments in optical communications and photonics, along with parallel developments in compute semiconductors, are principal drivers in the ever-increasing capacity of global networking and compute. Moreover, compute semiconductors are now developing in a way that needs growing convergence and reliance on optical technologies into the future.

Optical communications and photonics is a broad area. This report has focused on a few specific areas of particular concern to the UK but is not intended to be exhaustive. There is some overlap with the work of other EWGs, most notably semiconductors, but also with core, security, network management, and AI.

Figure 7 below summarises some specific development timelines and, in the subsections below, each is described briefly along with recommendations.

To scope these timelines, overall developments leading to end customer services are assumed to fall into 4 broad phases: 1) research and initial proof of concept, 2) component development, 3) systems development and integration, and 4) service and operational development.

The five areas are not in an order of priority, but the order reflects a level of dependency, where later areas may have a dependency on development in early areas.

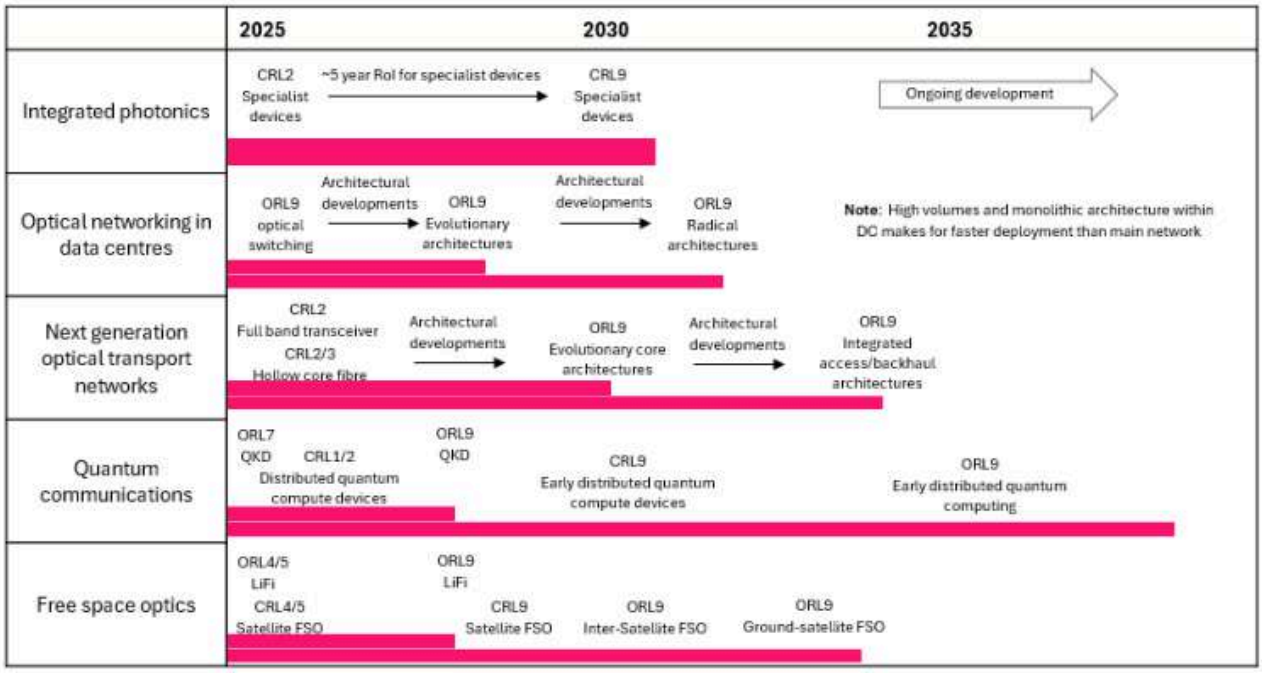


Figure 7: Development Timelines

2.7.1/ Integrated Photonics

Why: 1) Compute/AI semiconductor devices are becoming increasingly I/O bound, driving the need for very high-capacity communications between device packages. 2) high capacity optical pluggables require extensive signal processing logic.
What: 1) Development of optical functionality within standard silicon fabrication processes (silicon photonics). 2) Integration of communications and switching capabilities with other materials such as III-Vs and e.g. lithium niobate. 3) co-packaging of multiple 'chiplets' in a single package.
UK position in R&D: Strong in device technologies, weak in mass production technologies
Device production - seven question assessment: see table
Service and operations: not applicable

Recommended UK focus: Flexible, open source, UK based silicon photonics prototype foundry capabilities, embracing related technologies such as III-V, lithium niobate and heterogeneous integration, and synergistic with other strategic initiatives including semiconductors and quantum.

2.7.2/ Optical Networking in Data Centres

Why: 1) Compute/AI semiconductor devices are becoming increasingly I/O bound, driving the need for very high-capacity communications between device packages. 2) Increasing optical band rates and formats are not keeping pace with needed capacity leading to increase in the importance of SDM technologies.
What: 1) High capacity optical pluggables (see above). 2) Photonic inter-device interconnection (see above). 3) Evolving use of optical switching technologies integrated into spine/leaf packet switching architecture.
UK position in R&D: Strong in architectures. Weak in systems development and mass production engineering.
Component/system manufacture – seven question assessment: see table.
Service and operations: some strengths but main strength lies with US hyperscalers.

Recommended UK focus: Novel optical switching and transceiver devices and associated energy-efficient networking architectures.

2.7.3/ Next Generation Optical Transport Networks

Why: 1) Semiconductor technology is supporting increasing baud rate for pluggables. 2) Increasing baud rates are leading towards eliminating switching of the WDM layer and increasing the importance of SDM technologies. 3) Data centres are driving new low-cost optical technology which can be exploited by core, backhaul, and access networks. 4) Latency in optical transport is becoming a real value proposition leading to deployments of hollow core fibre.
What: 1) Pluggables supporting full bandwidth (amplifier or fibre). 2) core transport networking based on optical SDM (including new fibre types). 3) long draw length, massive production, and lower cost hollow core fibres. 4) next generation converged access PON technologies for home, business, and mobile x-haul. 5) long haul access systems assimilating aggregation done by current backhaul networks leading to access node bypass and closure.
UK position in R&D: Strong in architectures, standards and operations. Still leading in design, development and fabrication of hollow core fibre Weak in system development and production engineering.
Component/system manufacture - seven question assessment: see table
Service and operations: Strong.

Recommended UK focus: New networking architectures and cost-and energy-efficient optical transceiver and switching devices. Continue to support R&D in hollow core fibre.

2.7.4/ Quantum Communications

Why: 1) Systems based on 'quantum logic' are capable (in principle) of functionality and/or speed unachievable with 'classical logic', 2) It is possible to design cryptographic key distribution which cannot be eavesdropped (QKD), 3) quantum logic computers can (in theory) solve some problems beyond the limits of practical classical computers including cracking current encryption systems.
What: 1) Develop current QKD systems into commercial service, 2) develop qubit regeneration into viable commercial technology, 3) develop more general distributed quantum computing/networking architectures.
UK position in R&D: Strong in many areas but UK R&D funding levels are small in comparison to other R&D investment programmes, especially in China.
Component/system manufacture - seven question assessment: see table
Service and operations: does not yet really exist (BT leading with QKD early service offering).

Recommended UK focus: Specialist and leading-edge devices and distributed quantum computing/networking architectures.

2.7.5/ Free Space Optics (FSO)

Why: Bandwidth requirements for wireless/free space links are increasing but bandwidths available from traditional radio spectrum is limited by fundamental physics (Nyquist and Shannon).
What: 1) LiFi for in building requirements. 2) inter-satellite communication. 3) ground to satellite communications. 4) noting that terrestrial point to point has been available for some time but has not found significant commercial uptake.
UK position in R&D: Strong in LiFi and in some aspects of satellite systems.
Component/system manufacture - seven question assessment: see table.
Service and operations: does not yet really exist for either LiFi of satellite FSO.

Recommended UK focus: Industrialisation of satellite FSO and LiFi including route to low-cost manufacture.

2.8/ Semiconductors

The UKTIN Semiconductor Expert Working Group identified and assessed eight specific semiconductor technology areas against standard criteria specified by DSIT and UKTIN. Five of these areas were considered priorities for investment and support:

- Compound semiconductor (CS) photonic emitters (lasers): gallium arsenide (GaAs) Vertical Cavity Surface Emitting Lasers (VCSELs) and indium phosphide (InP) Edge Emitting Lasers (EELs)
- Compound semiconductor photonic detectors for current and future quantum devices: avalanche photodetectors (APDs) and single photon avalanche detectors (SPADs)
- Compound semiconductor RF devices and applications, particularly those using GaAs, gallium nitride (GaN), InP and silicon/germanium (SiGe) in telecom applications
- Silicon photonics and photonic integrated circuits (PICs) in the areas of transceivers, heterogeneous integration and advanced packaging of modules and devices
- System design: the design of semiconductor subsystems using IP blocks representing digital, analogue, mixed signal and RF functionality.

Three further areas were also assessed: Complementary Metal Oxide Semiconductors (CMOS), Micro Electromechanical Systems (MEMS) and memory. Figure 8 shows a high-level roadmap of four of the five priority areas; graphical presentation is not appropriate for 'system design'.

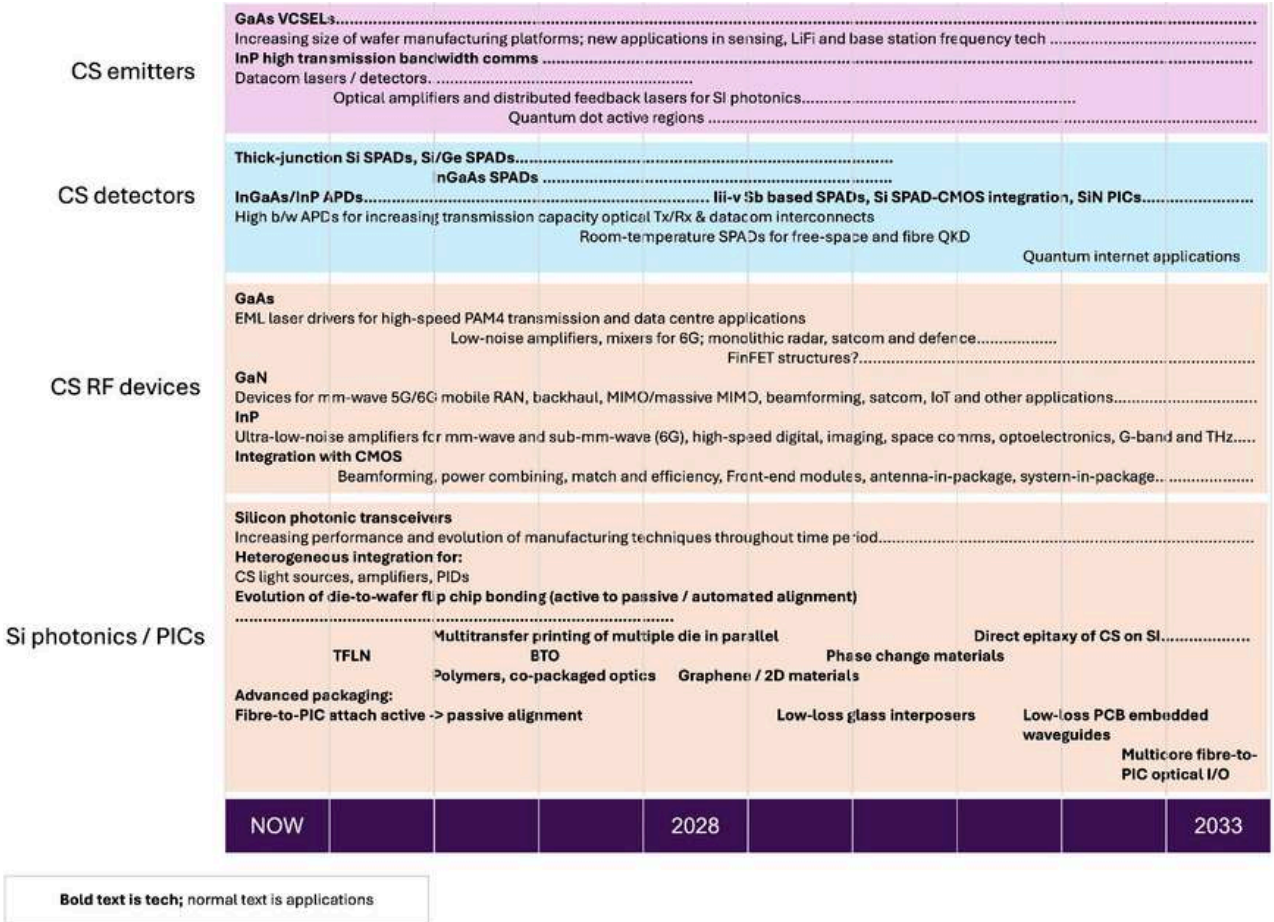


Figure 8: High-level roadmap for four prioritised semiconductor technology areas

System design as defined by the EWG does not lend itself to graphical treatment. Nonetheless, it is a critical constituent of the semiconductor ecosystem and a critical foundational technology underpinning all others, so the EWG evaluated the UK's strengths and potential in this area.

Recommendations

1. **Recognition:** The EWG recommends a national campaign to highlight the importance of semiconductors to multiple priorities and sectors of the government's Invest 2035 industrial strategy, including advanced manufacturing, clean energy industries and defence as well as digital & technologies
2. **Coordination:** The EWG supports the formation of a National Semiconductor Institute to act as a "super cluster", coordinating and supporting the activities of regional industrial clusters across the UK.
3. **Scale Up:** The EWG recommends an increased focus on later TRL stages, with targeted investment to grow start-ups and support established players' innovations. The UK needs a bold strategy that backs winners and doubles down on success especially backing technology areas that create synergies.
4. **Resilience and Security:** Invest in a 'UK Assured Supply Chain Initiative' to support critical national infrastructure with sovereign semiconductors where appropriate, working closely with like-minded international partners.
5. I**nternational Partnerships:** The EWG calls for support for UK participation in international R&D, innovation and supply chain development focussed on communication technologies.
6. **Infrastructure Investments:** The UK should invest in a silicon photonics pilot line for prototyping that aligns with its strengths in innovation and R&D, focusing on IP-friendly infrastructure.

2.9/ Impact of Standards on Roadmaps

Standards play a central role in a) enabling network operators to interconnect with each other in order to provide global services, b) enabling network operators and/or their systems integrators to integrate systems from major vendors, c) enabling major vendors to integrate the many components they need from component suppliers into the systems they supply to network operators and d) enabling a large user equipment ecosystem, where applicable.

While the importance and principle of standards is common across the telecoms industry, the way standards are developed, the nature of those standards, and how they are applied can vary widely. The way innovations affect future standards and the way existing standards may constrain innovation also varies across the industry. This section gives a short summary of the key features and impact of standards for each of the eight roadmap areas of this report. The full report includes an initial analysis of specific standards impacts and interactions for some of the prioritised R&D topics. In many cases, the potential standards dependencies cannot be fully identified at this stage, and ideally the R&D work should proceed with ongoing consideration of the resulting standards requirements and associated IP opportunities.

AI

AI is a new technology and many SDOs have recently created AI related initiatives. 3GPP already has work on standards to use of AI within the mobile system (notably the RAN) and by mobile edge applications (e.g. video feature recognition/extraction). O-RAN is giving more detailing and profiling to this work in 3GPP, while ETSI and IETF (amongst others) are developing AI standards more generally.

Meanwhile, many current deployments of AI have avoided interoperability issues requiring standards, however, as the technology matures and the range of applications grows, standards support will become increasingly beneficial.

Optical Communications and Photonics

Optical fibre-based communications are well established in all parts of the fixed network and many new developments are constrained to interwork with existing requirements. Notably, while there is great progress on new fibre types (e.g. hollow core fibre), these will take many years to be widely deployed, and in the meantime, next generation optical 'pluggables' need to be compatible with existing fibre types. These standards are mainly set by ITU-T SG15 and IEEE802.3.

Data centres have less complex architecture than main networks making innovation easier and now also drive the dominant volumes in the industry. This means that the major data centre players (e.g. Google, Amazon, Facebook, Apple, etc) are increasingly influential in setting standards in optical comms and photonics.

Security

Security and standards are strongly linked. For example, standards allow essential global interconnection between network operators, but that interconnection is also with nation states who do not share the UK's democratic values, and so protecting national security is a key aspect of standards.

Standards can also be essential to understanding the design of telecoms components and systems which is important to understand the 'attack surface' offered by these components and systems, and the resulting threats to national, cyber, and commercial security. It is also noted that, unlike many countries, the UK does not currently have a long-term strategy or body to coordinate security and standards.

3GPP, O-RAN, ETSI, IETF, NIST, NICC, amongst others, all have an important role in standards which affect security.

Core Networking Technologies

Because of the commercial and technical complexity of global networking, it is slow to evolve, meaning that existing standards can place significant constraints on innovation in core networking. Backwards compatibility is often essential. 'Layering' is a critical architectural concept in core networking standards which minimises the scope of backwards compatibility requirements.

Increasingly, core networking functionality is implemented by software and the hardware is often not impacted by changing standards. This 'softwarisation' is changing significantly the process of standardisation. While in the past, standards were agreed and written before systems were developed and deployed, now new systems are frequently developed and tested both functionally and commercially, then only after a clear 'winner' has emerged in the marketplace, does this get recognised as a standard.

IETF, 3GPP, and IEEE802.1 are all important bodies for core networking standards.

Wireless Networking Technologies

Many innovations in wireless networking require explicit support by standards to enable interworking across the air interface including the use of higher frequencies, new modulation and coding schemes, as well as new developments in MIMO technology. These standards will continue to be developed by 3GPP.

On the other hand, the emergence of 'multi-access' as a central feature of wireless networking in the next decade bringing all forms of NTN access, fixed/Wi-Fi access, and others into a seamless architecture needs to draw together many existing requiring all wireless standards bodies to work in new, more collaborative ways.

Other key innovations include the use of AI to optimise radio system usage, and advanced radio architectures such as 'cell-free', and 'intelligent reflective surfaces'. Many such innovations are embodied in adjunct functions or result from appropriate configuration and usage of the parameters and functionality of existing standards, and so – while standards dependent - have no direct standards implications.

Network Management

Network management interfaces are not normally required for interconnection between operators but enable the integration of systems from different vendors within a single network operator domain. In this context, network management standards have evolved as more 'indicative' rather than 'prescriptive'. They help to reduce the amount of specific integration work required but rarely eliminate it.
Two primary areas for network management standards are, first, the management interfaces on vendor equipment/systems which are normally standardised as part of the standardisation of these systems, for example, by 3GPP, IETF, IEEE802, and ITU-T. Second, overall management processes and associated information models are loosely standardised in generic and abstract form by TM Forum. This model is likely to continue in support of wider innovation.

A key innovation with network management itself is the use of AI in support of management processes. The impact of AI on network management standards is still at an early stage.

Non-Terrestrial Networking

While historically standards for satellites have been set independently from mainstream telecoms, for example by GSOA, recent moves to integrate satellite and other non-terrestrial systems into mobile architecture has meant that 3GPP is increasingly important as the focus for this 'multi-access' integration.

The main initial emphasis has been on treating NTN solutions as 'black box' access systems where 3GPP specify the external properties and interfaces but not the internal details of large parts of the NTN system. More integrated solutions are gradually being considered, for example hosting 3GPP access functions on NTN platforms.

Integration of NTNs into mobile architecture is at an early stage and 3GPP will play a key role in its development.

Semiconductors

There are standards associated with the physical properties of semiconductor devices and there is also a growing concern for 'open source' specification of semiconductor design to fabrication facilities. However, these specifications and standards are decoupled from the specification and standards of the networking functionality provided by the semiconductor devices.

Standards and specifications for the physical properties are outside the scope of normal telecommunications standards which are only concerned with the networking functionality. This separation is evident in the standards bodies involved. For optical devices, for example, the physical aspects are covered by BSI/CEN/ISO standards while the networking functionality is covered by ITU-T and IEEE802 standards.

This division of standards is likely to continue.

The UKTIN Future Capability Leadership Forum – Next Steps

"The Telecoms R&D Future Capability Strategic Leadership Forum is responsible for gathering insights and ultimately building new bridges between industry and academia. More than just an aggregator of inputs, the forum uses a "systems thinking" approach to telecoms research, development and innovation, aligning findings and perspectives." UKTIN website. [16]

In the previous section of this report, significant outcomes from interactions between the technology domain EWGs and DSIT have been presented. In this section, we present recommendations of the FCSLF. We then reiterate the UKTIN mandate towards the FCSLF, evidence progress, and look forward to the work items to be addressed in the next stage of UKTIN Future Capabilities forum.

3.1/ Recommendations

3.1.1/ Key Technology Groupings

The telecommunications sector is vast, and no single country can lead in every area. However, the UK has strong academic and industrial expertise in certain segments. With focused Government support and a coherent short-to-medium-term plan, these areas could become significant drivers of economic value and employment, as well as build sovereign capability where needed.

Components: Compound Semiconductors & Photonic ICs

The UK is widely recognised for its expertise in compound semiconductors and photonics, with a robust network of both industrial and academic centres of excellence. What sets the UK apart, however, is its presence across the entire value chain. In addition to world-class design and research capabilities, the UK has a significant manufacturing base in these technologies—an advantage that many nations lack. This creates a virtuous spiral as design and manufacture can feed on each other.

[16] UKTIN Future Capability Paper: Convening and Aligning the Ecosystem

This dual strength not only bolsters the telecoms sector, where compound semiconductors and photonics are essential components, but also positions the UK as a key player in quantum and AI that build on those components. This creates significant opportunities for cross-disciplinary synergies.

Regionally, the UK's leadership in these technologies is anchored by specific clusters of excellence. South Wales, for example, is a global hub for compound semiconductor development, with the Compound Semiconductor Cluster, while Scotland is strong in photonics. Other operations in the Northeast or Plymouth emphasise there is a national strength.

Finally, this intersection of design and manufacture can drive both economic growth and employment.

Specialist Hardware and Software Components and Subsystems for Future Wireless, NTN and Optical Networks

While the UK does not have the large system companies in wireless, it does have a collection of high value/high skill specialist suppliers of subsystems which could be leveraged to provide growth and employment. Indeed, it is possible in medium term some of those could develop to become larger system companies.

As the groundwork for 6G networks is laid, the UK's academic and industrial base offers critical contributions to the complex subsystems that underpin next-generation wireless telecom infrastructure. These include advanced antenna designs, RF filters, and baseband processing architectures in both hardware (including semiconductors, passive components and subsystems) software. Areas such as filters (established players like Filtronic or startups like Forefront RF) and signal converters further underscore the UK's leadership in areas like high-frequency RF systems.

Other areas identified in the UKTIN EWG work include advanced antennas (including satellite antenna, steerable/phased array and solid-state antennas), free space optics, etc.

NOTE: "wireless" as a technology space is not just cellular / 3GPP but includes other areas including NTN (both RF & FSO).

Similar logic applies to subsystems for photonics, for example petabit/s optical networks and future (hollow-core) fibre technologies and, indeed, potential wireless-optical convergence.

The top five Security R&D topics are:

- SEPP & Inter Network/ signalling security
- Platform security implementations, RAN & Core
- Secure & Understandable remote access
- Securing legacy/ fallback and interop with pre-5G networks
- Decouple Telco implementations from Cloud / faster updates

3.1.2/ Emergent Themes

During UKTIN Future Capability Wave 1 (capability and challenges discovery) and Wave 2 (technology road mapping), cross-EWG systemic themes or issues were identified.

Recommendation 1: Long-Term Vision.

Telecommunications is a long-horizon industry. The roadmaps reflect this, looking beyond 2035 and all recommendations should be viewed through a lens of 10+ years. While these timelines may not align neatly with typical government planning cycles, it is feasible to establish long-term strategies and institutions to maintain continuity through entities like institutes.

The possibility of a Future Telecoms Institute or similar entity has been raised in UK R&D&I ecosystem dialogues. Further in this section we identify a work item relevant to this consideration.

Recommendation 2: Act now to Capture Opportunities.

Now is a crucial moment for action with a once-in-a-decade opportunity for UK to rebuild capabilities in telecommunications. Decisions are being made on 6G now, which will present the biggest change to wireless architectures and technology in a generation, across terrestrial and non-terrestrial communications. While many of the technology choices will be made by the major system companies not necessarily based in the UK, there are many opportunities, identified in the UKTIN EWG roadmaps, for UK industry to make its mark.

Similarly, AI and quantum are transformative forces with projected major impacts on telecommunications. EWGs have identified intersections of these with telecommunications. Both quantum and AI draw on technologies from semiconductors, photonics. That means investments in those areas will create benefits & opportunities in quantum & AI. Application areas such as network management and security.

Finally, geopolitical tensions, threats to global trade, and supply chain disruptions present significant challenges to the UK's telecommunications sector, but they also offer a unique opportunity to strengthen domestic capabilities and forge international partnerships. Additionally, shifting geopolitical alignments and increased focus on regional supply chains open the door for the UK to position itself as a trusted partner in secure telecommunications infrastructure.

Recommendation 3: Exploit Interdependencies and Synergies.

Significant synergies exist between these areas, both within the 9 EWGs and more broadly across four of DSIT's five technology domains: semiconductors underpin all other technologies, AI is central to next-generation telecoms, wireless sub-systems create flexibility in supply chain, security is a critical factor in every new system, quantum is underpinned by photonics. The Key Technology Groupings were chosen for maximum impact across these synergies.

Many of the EWGs did expressly consider these synergies and dependencies and these are factored into their technology roadmap recommendations.

Recommendation 4: Continue with the ecosystem consultation established by UKTIN

This report and the nine detailed reports it is based upon are the result of direct input by about 140 experts across nine domains in telecommunication ecosystem in the UK, volunteering their time over almost two years. The networks and relationships built by this substantial effort have been very valuable to the ecosystem stakeholders, starting with the UK Government. The members of the UKTIN Future Capability (EWGs, Academic Working Group and FCSLF) have all expressed their willingness to continue. It is crucial that this valuable strategic ecosystem engagement, now it has been built, is not left to wither and the "institutional knowledge" be wasted.

3.2/ The FCSLF: distilling the UK telecoms R&D&I ecosystem

The telecoms sector is a significant growth driver in the UK's digital economy, contributing substantially to economic growth, innovation, and competitiveness. Economic contribution estimates indicate a telecoms sector contribution of £32.7 billion to the UK economy in 2022, making up 1.5% of total UK Gross Value Added (GVA)[17]. Telecoms accounted for 1.57% of total UK GVA in March 2023, showing slight in year growth; however, the sector's GVA grew faster than the overall UK economy between 2010 and 2022 (increasing by 306% in real terms, compared to 21.5% for the UK economy as a whole[18]). The UK tech sector, which includes telecoms, achieved $30 billion in venture capital investment in 2022, attracting investments from global tech giants like Amazon, Google, and Microsoft[19].

On the international stage, the UK is regarded as one of Europe's most advanced digital economies, with a strong presence of international technology enterprises and a thriving start-up ecosystem. The telecoms sector contributes to the UK's positive trade balance, exporting £8.8 billion while importing £5.2 billion[20]. This places telecoms as a foundational element of the UK's digital economy not just in providing essential critical infrastructure but also driving innovation, creating high-value jobs, and contributing significantly to economic growth and international competitiveness.

The Telecoms Diversification Taskforce, chaired by Lord Livingston, played a crucial role in shaping the establishment of UKTIN. The Taskforce provided expert advice on measures to accelerate diversification, including creating a "front door" for navigating fragmented R&D ecosystems. This recommendation directly led to the formation of UKTIN as a central hub for supporting new entrants and driving innovation aligned with Government objectives[21].

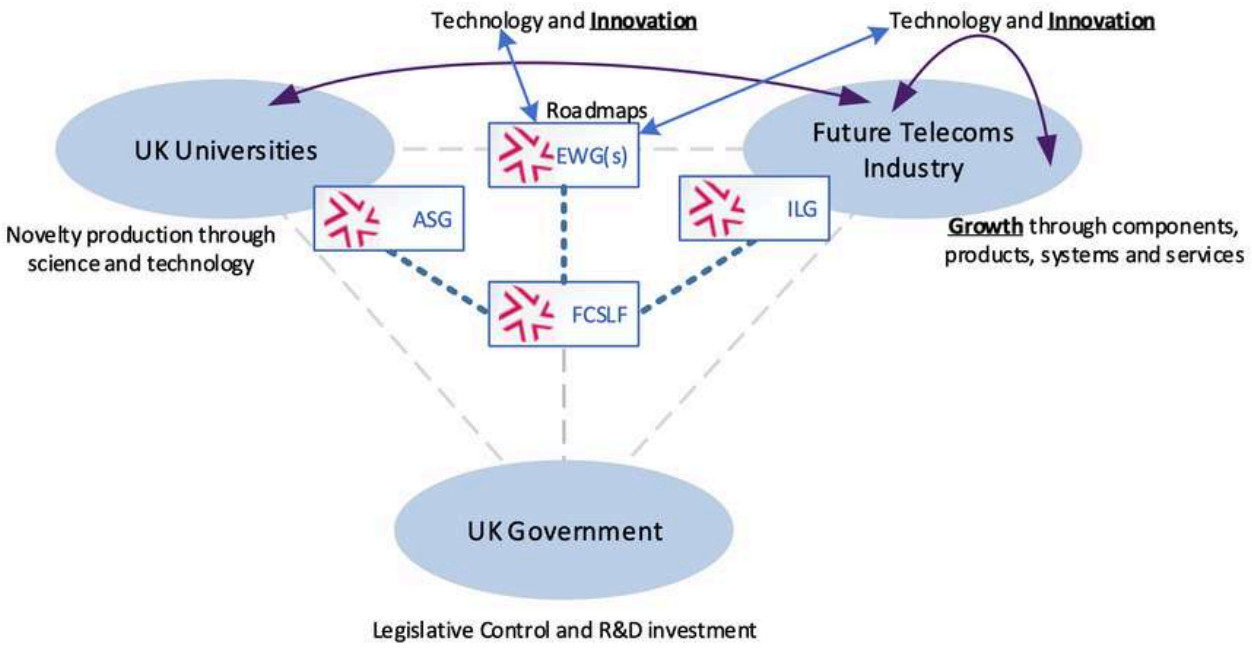
The formalising of the mandate for the creation of the UK Telecoms Innovation Network (UKTIN) stemmed from the UK's 5G Supply Chain Diversification Strategy, published in November 2020. The strategy aimed to diversify and strengthen the telecoms supply chain by fostering innovation, resilience, and competition. UKTIN was established as part of this broader initiative to support R&D in the telecoms sector and facilitate collaboration among industry, government, and academia[22].

[17] Gov.uk, Digital Sector Economic Estimates Gross Value Added 2022
[18] Imperial Centre for Sectoral Economics, The UK Telecommunications Sector 2024
[19] ChannelLife.co.uk article, "UK Hailed as Europe's most advanced digital economy", 16 Jan 2024
[20] Business.gov.uk, Future Telecoms
[21] Gov.uk, UK Telecoms Innovation Network Competition
[22] UKTIN, UK Government Telecoms Diversification Policy and Initiatives

3.2.1/ The FCSLF R&D&I Ecosystem Perspectives

The Future Capability Strategic Leadership Forum (FCSLF), embedded within the UKTIN programme, is mandated to define how UK R&D&I can accelerate the transformation of the national telecoms innovation ecosystem and enhance the UK's global position in future telecommunications. Its structure ensures balanced representation from academia (via the Academic Stakeholder Group – ASG), domain-specific technology experts (via Expert Working Groups – EWGs), and industry. EWGs, primarily composed of industry professionals, operate with neutrality regarding the origin of technological innovation—whether academic or industrial.

The FCSLF provides strategic oversight at the UK telecoms R&D&I ecosystem level. While established through the UKTIN project, the ecosystem management model remains under active refinement. It is grounded in principles of holistic design and inclusive stakeholder engagement, with a clear aim to be sustainable over a strategy perspective period.



The strategy extends well beyond the UKTIN programme, with a planning horizon through 2035. Recognising the rapid pace of ICT innovation, each EWG has assessed the tempo of change in its domain to support timely, evidence-based interventions aligned with long-term objectives.

The strategy perspective period for the ecosystem is not limited to the UKTIN programme duration but looking well beyond to 2035. The rapid innovation pace of ICT is well understood, and each EWG technology domain has considered the characteristic technology pace in their domain when developing their roadmaps. This understanding and characterisation helps to ensure an appropriate pace of monitoring and intervention can be observed whilst keeping one eye on the extended period.

Stakeholder inclusion for the ecosystem is evidenced by the representation of University, Industry and third sector perspectives, engagements with the UK Government (DSIT) and subsequent outputs as identified below.
The UK University sector is an essential part of the UK ecosystem. Through their excellence in research, they bring science and technology outcomes principally through TRL 1 to 3. The UKTIN Academic Strategy Group (ASG) has published two papers.

- UKTIN Academic Future Capability Paper 1: an overview and initial inventory of the UK's current academic-led Research, Innovation, and Development (R&I&D) landscape and ecosystem in future networks.
- UKTIN Academic Future Capability Paper 2: recently published[23], it serves as a strategic guide to identifying and prioritising promising research areas that will enable the UK academic research to maintain and expand its global influence in telecommunications.

During the last two years of the FCSLF, the ecosystem has seen the emergence of the Future Telecoms Hubs for the benefit of future telecoms. Notable areas where the missions of the Hubs[24] should, through industry collaboration, lead to joint capabilities with the industry sector are:

- Workforce development
- Commercialisation of research
- Infrastructure for experimentation (JOINER)
- International collaboration – through Horizon Europe in particular
- Research-driven Innovation

The technology domain EWGs are principally structured around forming an industry leadership outlook and have demonstrated their expertise through two processes: to horizon scan for technologies and the associated UK capabilities, and to generate UK-centric technology roadmaps that articulate an important perspective in strategy – when could technologies under development impact the business of telecoms.

[23] UKTIN, Academic Research Report
[24] UKRI Article, "Future communications research hubs for a connected UK" 10 Mar 2025

In industry, anticipating and planning for when technologies will be relevant informs patent generation, standardisation priorities, business and product line management, and prioritisation of R&D resource. The FCSLF with its constituent perspectives, can credibly provide a sustained engagement with the UK ecosystem and will implicitly be aware of priorities. Industry CxO or Senior R&D Management representative views are present as well as academic leaders. Thus, the FCSLF is presenting a knowledgeable and trusted technology-oriented sounding board capability for government policy makers and the ecosystem.

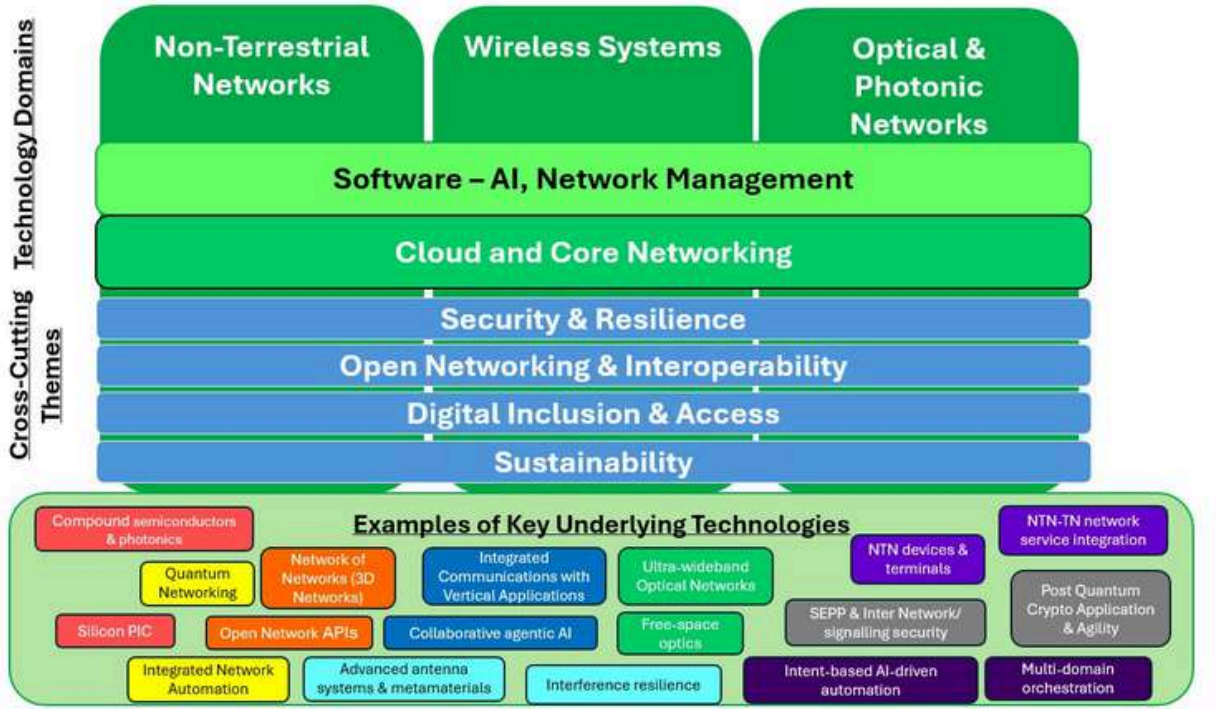
The UKTIN FCSLF ran a two Wave analysis approach for the EWGs based on DSIT's Future Telecoms directions and the UKTIN programme of work. Throughout, the FCSLF consulted continuously with UK Government (DSIT).

- UKTIN Future Capability Wave 1: Capabilities and Challenges (January 2023 - Summer 2024)
- The UKTIN structure of EWGs and SWGs are established.
- The views on capability and challenges for the UK telecoms sector for each of the EWG technology domains are identified.
- UKTIN Future Capability Wave 2: Technology Roadmaps development (June 2024 - March 2025)
- Technology domain roadmaps for UK capability development in the sector, specific to each EWG technology domain, are developed and extensively discussed with DSIT.
- An objective of delivering a strategically harmonised technology roadmap for capability development was deferred into Wave 3.

3.2.2/ Technologies, Harmonisation and Distillation

The road mapping exercise of the EWGs described technologies within their domain and potential linkages into other telecoms technology domains. Initial views on linkages between EWG technology domains can be found identified in the EWG summary reports in Section 2.

During the transition from UKTIN Future Capability Wave 1 to Wave 2, a representative view of the integrated technology space was shared between the FCSLF and DSIT. This diagram represents a useful harmonised view of the technology space and an initial identification of themes that could drive innovation. Here we see the constructs of Technology Domains and Cross-Cutting Themes. Within this representation, the EWG Chairs have provided example underlying technologies that may be explored through this framework.



Within the FCSLF, a harmonised roadmap review surfaced the unifying theme of architecture which perhaps wasn't so apparent through the EWGs work in their individual domains. We carry forward the term "architecture" in UKTIN Future Capability Wave 3 work items.

The process steps of 1) establishing an ecosystem view, 2) finding a harmonised representation, 3) distilling this representation in specific clear next steps, is an important function of the FCSLF. The EWGs have created an expansive information space, as have the ASG deliberations. The core capability for the FCSLF to master for productive information processing is precision in the criteria for distillation.

3.3/ FCSLF Next Steps– UKTIN Future Capability Wave 3

The UKTIN Future Capability Wave 3 of the Forum will run until the end of 2025, as the FCSLF continues to develop an authoritative view on the current and desirable R&D capabilities leading to competitive innovation from the UK.

The findings of the EWGs are an important step towards recommended intervention areas for the UK in telecoms. Without purposeful interventions, there can be no guarantees on mid to long term beneficial outcomes for growth. The UK market is not of the scale that it alone can be a global market maker in telecoms technologies. Technology, market, and political forces will serve to both accelerate, decelerate, and stop trends that have been anticipated by the FCSLF. Working with the ecosystem, coordinating its activities, and monitoring what the global ecosystem is engaged in is necessary to anticipate the right timings of public-private partnership driven interventions.

There are specific work items (WI) under consideration in the startup planning for Wave 3. In the following we set out the work items that at the time of writing are to proceed (Ongoing or Planned) and those under review (Candidate).

WI1 [Ongoing]: "Technology Family" distillation towards investment focus

Purpose: A consultation with DSIT on technologies identified in both Wave 1 and Wave 2 using the DSIT Technology Family and FCSLF Technology Groups as a starting baseline. To assist DSIT with determining funding focus and timelines.
Background: During Wave 2, the active development of the EWG technology domain roadmaps was accompanied by open dialogue with the UK Government (DSIT Advanced Connectivity Technology - team). By the end of Wave 2 this activity resulted in a view of the technology focus as Government starts to make choices, balancing ambition and budget.

The following are the technology groups that the FCSLF will consult on into Wave 3.

- Compound Semiconductors and Photonic ICs
- Specialised hardware and software components and subsystems for next generation wireless, NTN and optical networks
- AI for telecoms
- Security and Resilience

WI2 [Planned]: The feasibility of maintenance of the technology roadmap(s)

Purpose: Develop a recommendation for maintenance of roadmaps, which shall be based on the pace at which the EWG technology domains may be expected to advance, as well as other pertinent factors.

Background: Determining the readiness of technology for commercial application is a critical success factor in industry and thus for any Government that wants to support R&D&I in a sector. The interpretation of the roadmap with respect to sequencing of events in industry and the pace of innovation can vary significantly across the EWG technology domains. Pace of technology introduction is defined by many factors, investment level, complexity, the proportions of hardware vs software, manufacturing, inter-operability and deployment. Innovation in areas where architecture is predominantly software defined, through softwarisation and AI trends, is moving particularly fast at present creating challenges for maintenance of roadmaps.

WI3 [Planned]: Recommendation to establish adoption-focused Telecoms Institute

Purpose: Establish the scope and vision for an adoption-focused Telecoms Institute

Background: Future Telecoms R&D&I ecosystem was alerted to the possibility of an institute in the sector through extensive consultations carried out in 2023. The emerging consensus is that such an institute would be highly valuable but should complement the UK's world-leading early-stage university telecoms research, focusing instead on the ecosystem and technology capabilities to support UK industry from early stage to global market adoption and scale. EWG chairs, some of whom have extensive experience working across sectors, have seen the benefits that industry sectors, such as Aerospace, have garnered through creating grand challenges that are owned by sectors and their associated institutes. This work item will establish the scope, vision and enabling capabilities for such an institute, drawing on best practice from international institutes such as Fraunhofer, ETRI, ITRI and CSIRO.

WI4 [Planned]: Architecture as a value proposition

Purpose: Develop a view on how to crystalise the value creation and value capture of "architecture" in the UK Telecoms R&D&I ecosystem.

Background: The strategic thinking of the FCSLF in Wave 2 has implicitly encompassed architecture. EWG experts, senior in their industry, frequently use architecture and architects. The optimal integration of technologies comes through the engineering disciplines that define architectures. Solutions are formed through combining logical, functional, and deployment architecture perspectives, at a software, hardware and firmware component level. Aligning with the state-of-the-art in industrial architecture is essential to successful strategy development, and for gaining an understanding of the reasons for choices regarding emerging components, products and systems.

WI5 [Candidate]: Standards strategy to identify opportunity and drive adoption

Purpose: Develop a recommendation for the efficient maintenance of ecosystem knowledge regarding the normative standards state-of-the-art, perhaps selective of particular critical reference system standard(s), and raising awareness of opportunity.

Background: The FCSLF recognises the importance of standards as a normative statement of telecoms system requirements, and the role of standards in shaping the development of products and components. In some EWG technology domains competitive forces are known to result in solutions running ahead of standards, with de-facto vs de-jure outcomes. Standards strategy is a two-way process, establishing what is in the standards enables influencing of the standards to accommodate outputs from the UK.

WI6 [Candidate]: Demand driven vision for adoption acceleration

Purpose: Develop an approach to joining R&D capability, and demand prediction to adoption.

Background: The UKTIN continues with a mandate for adoption:
"Facilitating the adoption of advanced communication technologies into the wider economy in priority vertical sectors and throughout the nations and regions of the UK" UKTIN website[25]

[25] UKTIN article, "UK Telecoms Innovation Network – the future" 18 Mar 2025.

The UK can certainly influence successful (economically sustainable) adoption by operating at the earliest stages of adoption. R&D capability that works in early technology readiness levels can support and accelerate early-stage adoption. This is due to the deep knowledge of the workings of the component, product, system when moving from technology demonstration to industrial pilots to commercial system adoption. To date, the FCSLF approached planning through technology capability, challenge and roadmap perspectives. A strategic function can benefit from broader considerations and demand prediction can encompass economics and societal trends. Broader strategic thinking can benefit policy makers and industry by providing evidence for investment based on projected benefits to society and tax paying citizens.

WI7 [Candidate]: International strategy – thinking global and acting local

Purpose: Develop an approach to harmonisation with international R&D&I initiatives that can complement and shape successful outcomes for the UK sector and its sovereign capability.

Background: The UKTIN continues with a mandate for international outcomes. "To help promote UK capabilities and support Government policies in priority countries as well as helping to drive engagement in international programmes like Horizon Europe", UKTIN website[26]

Telecoms R&D is a global activity. International partnerships are critical for scale and impact. Identifying what the UK capability is for international partnerships and the competence of UK based entities in future telecoms R&D is crucial for the formation of joint ventures and collaborations on the international stage.

The UK has recently celebrated one year of association with Horizon Europe, a multi-billion Euro R&D&I programme, to which a significant proportion of which is allocated to telecoms and 6G. UK based R&D entities are encouraged to participate[27], in activities for shaping programmes beyond Horizon Europe are underway.

Strategic leadership from the UK can ensure the UK engages in current R&D&I calls and in the shaping of future opportunities. The TSCD Advisory Council explicitly identifies the Global Coalition on Telecommunications (GCOT) comprising UK, Australia, Canada, Japan, and US as an enabling initiative for international R&D collaboration, and so this initiative can also be in scope of this WI.

[26] UKTIN article, "UK Telecoms Innovation Network – the future" 18 Mar 2025.
[27] UKRI Event, Horizon Europe Showcase – Celebrating one year of association, 18 Mar 2025.

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