EPSRC
Engineering and Physical Sciences Research Council

UK Research and Innovation

Quantum Technology Communications Workshop

7 March 2018

Malmasion Hotel, Leeds

Report on Outputs

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March 2018

1. Motivation

Today the UK is leading a global race to industrialise this new technology, thanks to the National Quantum Technology Programme, an alliance of academia, industry and government brought together to exploit our research strengths. But international competitors are catching up fast. To stay in front and reap the rewards, we need to maintain the momentum that has been established in phase one of the programme.

Over the next 5 to 10 years, commercial quantum technology devices are likely to become as prolific and profitable as today's electronics. They will have a huge impact on our lives, benefitting healthcare, defence, security, aerospace, transport, civil engineering, telecoms and finance. Many advances that we expect to shape our future industrial strategy depend on technology that is not available today, but can be delivered by second generation quantum technologies.

EPSRC is planning for future investment in the area of quantum technologies and this involves identifying quantum technology research challenges and priorities for the UK. This workshop was focussed on the research challenges and priorities in the area of quantum communications.

2. Objectives

The objectives of the workshop were;

- Discuss the main research challenges in the area of Quantum Communications;
- Identify the research challenges on the proformas and prioritise the challenges;
- Discuss the innovation challenges in the area of Quantum Communications;
- Generate output that will inform our future strategy concerning Quantum Communications;
- Determine what disciplines and skills need to be involved in the innovation priorities;
- Identify who we need to collaborate with internationally.

The objectives of the workshop should be considered with regard to the background information in Section 3.

3. Background

The existing EPSRC Quantum Technology Hubs end in November 2019. There is agreement amongst the delivery partners and strategic advisors of the UK National Quantum Technologies Programme that a second phase of the National Programme should include a substantial technological research programme delivered through Hubs. This approach is supported by the Quantum Technologies: Blackett Review "The Quantum age: technological opportunities".

It is envisaged that the Quantum Technologies research programme will be a smaller proportion of a second phase of the National Programme than is the case in the first phase

of the National Programme, and will be joined by new instruments such as Innovation Centres and Challenge Programmes.

Research conducted in the second phase should be integrated with the wider research and innovation landscape and investments. There is ongoing uncertainty over the financial envelope in a second phase period. The existing Quantum Technology Hubs have established capabilities and expertise which should be built upon.

3.1 Future research priorities and Hub portfolio

There are three stages to identifying future research priorities and refreshing the Quantum Technologies Hubs portfolio

(A) Research priorities in quantum technologies and for research Hubs (January to March 2018).

Engagement with Quantum Technology Hubs, quantum technology researchers, non-quantum technology researchers, industry and users, to obtain perspectives on the research challenges and opportunities in quantum technology, and development of these into research priorities for a second period of the National Programme.This workshop forms part of the activities under this early stage of the process:

a. Identifying technological research priorities
b. Providing information that can be used in scoping the research programme in a second phase of the National Quantum Technologies Programme, in terms of priorities, disciplines and perspectives that should be involved
c. Quantum Technology research hubs are envisaged as being part of an overall landscape of research and innovation in a second phase, and will need to work with other activities
d. It is only part of the process, and attending this workshop does not guarantee participation in Hub consortia, and non-attendance doesn't exclude it
e. EPSRC are working closely with our National Programme delivery partners, in particular Innovate UK in this process

(B) Identifying Hub partners (April to October 2018)

Identification of the research priorities that should be addressed by Quantum Technology Research Hubs in a second phase, development of a vision for a Hub portfolio, and the formation of consortia to deliver this Hub portfolio.

(C) Developing Hub proposals (November 2018 to March 2019)

Development of proposals Quantum Technology Research Hubs which will address the most important research priorities in quantum technologies for the UK in a second phase period of the National Programme. Including their assessment and preparation for making awards

4. Delegate Selection

Delegates were selected based on their expertise in quantum communications and associated areas of research. This included representatives from major investments made through the National Programme, including the Quantum Technology Hubs, Quantum Technology Fellows, Quantum Technology Capital grant holders, as well as holders of other EPSRC grants.

Participants were selected based on advice from the National Programme Strategic Advisory Board (SAB), members of EPSRC's Strategic Advisory Network and Strategic Advisory Teams, and the Quantum Technology Hubs. This was to ensure a balanced group, with a diverse representation of technical expertise and a diverse representation of institutions and industry from across the quantum communications and and classical communications domains. Attendees are shown in Annex 1.

5. Agenda for the Quantum Technologies Communications Workshop

10.00	Registration and Coffee
10.30	Welcome, aims of the workshop and the need for UK research priorities in QT Presenter- Liam Blackwell
10.50	Innovate UK activities Presenter- Simon Plant
11.00	Quantum Communications Presenter- Tim Spiller
11.30	Q & A following presentations
11.45	Breakout session 1 Research challenges in Quantum Communications in the UK
12.45	Breakout session 2 Identification of research priorities
13.15	Lunch
13.50	Breakout session 3 Introduction to the session What are the key innovation challenges the UK should tackle and what expertise needs to be involved. Session feedback

15.00	Final comments from attendees/what happens next?
15.30	Workshop closes- networking time with coffee

6. Workshop Outputs

a) Summary of the workshop

As the agenda in section 4 indicates a series of presentations took place to inform the delegates of the aims for the workshop and give and overview of the current landscape in quantum communications in both the research and the innovation areas. Following presentations by Liam Blackwell, Simon Plant and Tim Spiller the delegates were asked to take part in a series of facilitated sessions or breakout sessions throughout the day, which are summarised below;

Breakout session 1 – A discussion of the research challenges in Quantum Communications in the UK.

Breakout session 2 - Identification and prioritisation of research priorities in Quantum Communications in the UK.

Breakout session 3 - What are the key innovation challenges in Quantum communications the UK should explore and what expertise needs to be involved.

Delegates were asked to work in teams on tables to describe the research challenges in the UK. Outputs were captured on proformas. After the research challenges were captured the delegates were asked read all proformas and to vote for their top three priorities. (breakout session 2). Prioritisation was carried out by placing green dots next to research challenges on the proforma. The proformas in the annex show how the delegates voted.

The final breakout session (session 3) asked the delegates to think about the innovation challenges in the UK for quantum communications. In addition, the delegates were asked to discuss which expertise or skills we would need to achieve the innovation challenges.

b) Group Outputs

The outputs for each breakout session are summarised in the Annex. In addition the table below shows the research challenges which were considered important to prioritise by the delegates. Research area prioritisation was carried out by workshop delegate voting.

Research Priorities Medium Term (2019-2024)	**Number of votes**
Bring free space and satellite capability into UK and Comms Programme	12
Entanglement based tech	7
Development of detectors (single photon low noise, high rate, low jitter – perfect! All wavelengths!) Preferably not actively cooled, with low power.	5
CV as well as DV QKD for coherent systems	4
Sources of entanglement (High Fid. Coherent, Bright, Narrow Band + wavelength multiplex) On demand if possible Constellation to network topology	3

PAN personal area networks Close link between quantum comms and quantum imaging – links to Quantic in fibre coherent imaging, structured light free -space comms and hacking -detectors and sources -integrated components (Quantum Memories and Quantum Repeaters (compact if possible) Wide bandwidth (GHz) (with all the desirable properties) Optical ground stations – locations, weather, optical characteristics (ƛ, multi ƛ) manufacture Self-testing systems such as MDI QKD Comp. security using quantum computing PKE, Quantum FHE MP compt QC vs PQC scaling up (secure blockchain link) Key QKD component technologies ⇒ tailored to future system requirements “Real Data” transactions (use cases) Demonstrators e.g. banking, healthcare Digital signature/ Full stack demo Free space optical comms > 10,000ft Quantum RF <10,000ft	2
Short range free space Long distance Free space (e.g. satellite) Hacking security Quantum Identity Proof Authentication Detectors Long 10.10um.to.1.5um Detectors wavelength conversion Optics Fibres Adaptive optics Low loss	1

Bring entanglement into the UKQN (multi-dimensional) -reach extension, point to point ⟹ networks plus increasing key rates Hybrid systems side channel security Quantum sat + QKD (Q) Authentication – not just distribution System to system integration standards Application/communication/ data rate/ latency / duration/ time of security of information to analysis Sources Quantum repeaters/ memory- assisted protocols quantum memory Formal CS methods for verification of systems (also long term) Memories cold atom Solid state Tracking Entangled sources Pair entanglers/ waveguide and detectors Electronics Network engineering who are quantum savvy Amplifiers (optical and electronic) supply chain	

Research Priorities Long term (beyond 2024)	**Number of Votes**
New protocols and use coms beyond QKD	6
Long wavelength free space QKD (e.g. TH_3 ?) for mobile phones etc Repeaters	2
Pan EU/Global Quantum network E2E plug 'n' play telecom solution data + quantum sec Entanglement distillation, Networked based QIP Distributed Quantum Comp Joint communication protocols Entanglement across long distances – fibre subsea Superconducting detectors	1

Room temp 100% low jitter	

7. Summary

The research challenge areas identified on the day are shown in the table above. The research priority areas which received the highest number of votes for the medium term (2019-2014) were:

- Bring free space and satellite capability into UK and Comms Programme
- Entanglement based tech
- Development of detectors (single photon low noise, high rate, low jitter – perfect! All wavelengths!) Preferably not actively cooled, with low power.
- CV as well as DV QKD for coherent systems

The research priority areas which received the highest number of votes for the longer term (beyond 2024) were:

- New protocols and use coms beyond QKD
- Long wavelength free space QKD (e.g. TH_3 ?) for mobile phones etc
- Repeaters

It should be noted that there are a number of other research priorities which were mentioned by the delegates which did not get any votes. These research priorities have been recorded in the proformas in Annex 2.

In addition to the information on the research priorities, Annex 2 shows additional information on the key innovation challenges the UK should tackle and what expertise needs to be involved. Delegates were not asked to vote on these areas and therefore the full lists are shown.

8. Next Steps

This report will be emailed to attendees and added to the EPSRC website. The report will be considered as a key input in discussions with our delivery partners on the National Quantum Technologies Programme and its Strategic Advisory Board on priorities for Quantum Technologies Research Hubs in a second phase.

EPSRC have run workshops in other quantum technology areas and there will be workshop reports produced for each of the workshops. In addition to the workshops, EPSRC are gathering input from a range of sources which will also feed into discussions on research and innovation priorities. The scope for Quantum Technologies Research Hubs in a second phase of the National Programme will be published in June, with details of how to register an interest in being part of a Hub's consortia.

The input received from the workshops and other engagement will also be used by the EPSRC Quantum Technologies Theme when planning future activities and funding.

Annex 1: Workshop Attendees

Liam	Blackwell	EPSRC
Wendy	Carr	EPSRC
Amanda	Howes	EPSRC
Helen	Hunt	EPSRC
Gerald	Buller	Heriot-Watt University
Iris	Choi	University of Oxford
Martin	Dawson	University of Strathclyde
Julio	Hernandez-Castro	University of Kent
John	Jeffers	University of Strathclyde
Peter	Knight	NPL
Cong	Ling	Imperial College London
Simon	Plant	Innovate UK
Loyd	McKnight	Fraunhofer
Daniel	Oi	University of Strathclyde
Ciara	Rafferty	Queen's University Belfast
Mohsen	Razavi	University of Leeds
Maurice	Skolnick	University of Sheffield
Tim	Spiller	University of York
Rob	Young	Lancaster University

Note- workshop delegates in the table above consented to be included in this report as attendees of the workshop.

Annex 2: Workshop Proformas

A full version of the Communications workshop proforma results can be found on the following pages.

For reference – the delegates voted using green dots which have been replicated on the proformas below.

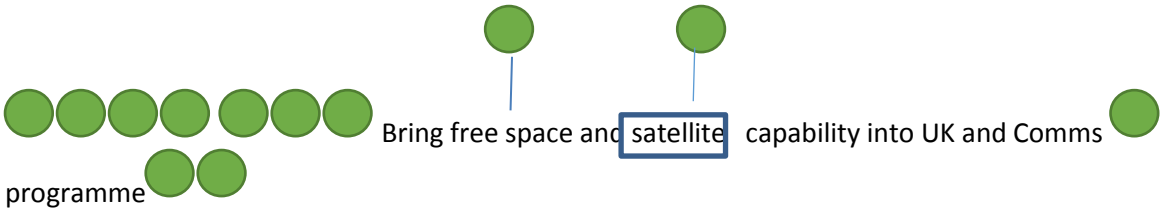
Quantum Communications Workshop Proforma 1

Quantum Communication in the UK proforma

TABLE 5

What are the Quantum Communications research priorities for the UK?

In the medium term (2019- 2024)



Base activity on non ITAR technology (e.g. Europe wide)


Close link between quantum comms and quantum imaging
– links to Quantic in fibre coherent imaging, structured light free
-space comms and hacking
-detectors and sources
-integrated components


Bring entanglement into the UKQN (multi-dimensional)

-reach extension, point to point → networks plus increasing key rates

Small → medium → long distance networks (horses for courses fibre v's sat)


Hybrid systems side channel security

Quantum sat + QKD

CV as well as DV QKD for coherent systems

Co-existence of QKD and classical comms (optical/ethernet/IP)

Optimised protocols for QKD?

Improve security e.g. quantum memories, repeaters

Enabling tech to remove trusted nodes

Focus on plug and play (more of an innovation challenge)

(Q) Authentication – not just distribution

Long Term (beyond 2024)

Pan EU/Global Quantum network

Inc. entanglement to extend QC

= secure

Satellite swarms

Full plug and play Quantum repeater

Long ƛ Free space QKD (e.g. TH_3 ?) for mobile phones etc

Integrated with classical radio and quantum core (QKD)

Computing (e.g. secure "WiFi")

E2E plug 'n' play telecom solution data + quantum sec

Extend quantum memory technology ⟹ full quantum networks with quantum storage

END OF THIS PROFORMA

Quantum Communications Workshop Proformas

Quantum Communication in the UK proforma

TABLE 6

What are the Quantum Communications research priorities for the UK?

In the medium term (2019- 2024)

Development of detectors (single photon low noise, high rate, low jitter – perfect! All wavelengths!) Preferably not actively cooled, with low power.

Sources of entanglement (High Fid. Coherent, Bright, Narrow Band + wavelength multiplex) On demand if possible

(Quantum Memories and Quantum Repeaters (compact if possible)
Wide bandwidth (GHz) (with all the desirable properties)

Optical ground stations – locations, weather, optical characteristics (ƛ, multi ƛ) manufacture

Free space to fibre coupling

System to system integration → standards

Constellation to network topology

Active optical systems (mainly coupling efficiency)

Self-testing systems such as MDI QKD 

Space- distributed entanglement – possible systems and technical development

Long Term (beyond 2024)

New protocols and primitives for communication

 Entanglement distillation, Networked based QIP Distributed Quantum Comp

Joint communication protocols

Multiparty protocols

Cloud computing

END OF THIS PROFORMA

Quantum Communications Workshop Proformas

Quantum Communication in the UK proforma

TABLE 4

What are the Quantum Communications research priorities for the UK?

In the medium term (2019- 2024)

Comp. security using quantum computing PKE, Quantum FHE 

MP compt

QC vs PQC scaling up 

Black box problem

Balance b/t R and D and innovation

Secure blockchain

Entanglement based tech 

Long Term (beyond 2024)

Miniaturisation / low/ cost/ high temp leading to practical implementation

Quantum comm. Faster than classic comm. (not just secure)

END OF THIS PROFORMA

Quantum Communications Workshop Proformas

Quantum Communication in the UK proforma

TABLE 1

What are the Quantum Communications research priorities for the UK?

In the medium term (2019- 2024)

Understanding trade off

Hacking

Application/communication/ data rate/ latency / duration/ time of security of information to analysis

Underlying technical hardware/crypotosoftware

Key QKD component technologies ➡ tailored to future system requirements

Sources

Quantum repeaters/ memory- assisted protocols quantum memory

Formal CS methods for verification of systems (also long term)

Single photon detectors

- Superconducting
- SPAQs

Error free quantum gates

- Efficient cryogenics

Cheap electronics

Long Term (beyond 2024)

New protocols and use coms beyond QKD 

IoT, the cloud, quantum networked quantum computing testbeds for quantum repeaters

Materials for Quantum 

e.g. LNAs

Diamond NV centres – Maser at 10GHz

Pentacene (Rabi oscillations) (2 GHz)

Manufacturability 

Cost 

END OF THIS PROFORMA

Quantum Communications Workshop Proformas

Quantum Communication in the UK proforma

TABLE 3

What are the Quantum Communications research priorities for the UK?

In the medium term (2019- 2024)

Applications

Short range free space

PAN = Personal Area Networks

Long distance Free Space (e.g. satellite), HAPS
Timing

Fibre Network

Random Numbers

Hacking security
Penetration Testing

Operation on bright fibre

Entanglement distribution/ for Quantum Computation

Signatures

Quantum Identity Proof

Authentication

End application e.g. banking

Technologies

Detector

Array/imaging 1.5um

Long 10.10um> to > 1.5um

Wavelength conversion (up Conv.)

Superconductor detectors

Optics

Fibres

Adaptive optics

Low loss comments

Fibre Network Capacity

Low loss switch

Low loss Modulation

Single photon sources

Waveguide circuits for low LoIi

Memories cold atom

Solid state

Repeaters


Tracking

Entangled sources

Pair entanglers/ waveguide and detectors

Electronics

Software Interface (Key management)

Ground Stations or Airbourne Station (pointing and tracking etc)

Challenges

Skills

Encoding/ interface to 46/56 network

Network engineering who are quantum savvy 

Demonstrators

"Real Data" transactions 

(use cases)

e.g. banking, healthcare

Digital signature/ Full stack demo

Free space optical comms > 10,000ft

Quantum RF <10,000ft

Supply Chain

Sovereign capability

Amplifiers (optical and electronic) 

Sources and detectors

5 x 9's availability of keys

Long Term (beyond 2024)

Applications

Entanglement across long distances

Fibre terrestrial

Fibre subsea 

Satellite to ground

Satellite to satellite

Repeaters 

Superconducting detectors 

Room temp 100% low jitter 

Wavelength conversion to quantum

Gbit rate for second key rate

Technologies

Key exchange at data rate

Quantum safe and security understanding

New attack algorithm

END OF THIS PROFORMA

Quantum Communications Workshop Proformas

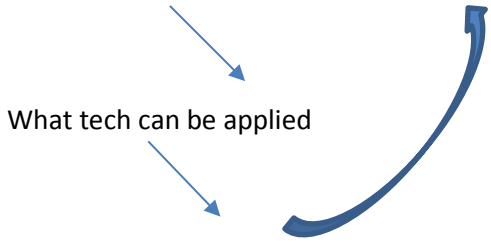
Quantum Communication in the UK proforma

TABLE

Innovation priorities in Quantum Communications

In medium term (2019-2024)

What's the market opportunity/failure



Cost of devices and producing them → (inc free space optics)

Improvement of rate/range performance

Development of QKD space payloads

Photonic Integration

Building Local Supply chain/ crafting ITAR – insensitive products

Hybrid QKD + Classical Comms

Low latency- high security comm

Standards + certification

The Long Term (beyond 2024)

Integration in autonomous vehicles

+ Internet of Things

Entanglement-based comms/protocols/apps

END OF THIS PROFORMA

Quantum Communications Workshop Proformas

Quantum Communication in the UK proforma

TABLE 5

What are the UK's innovation priorities in Quantum Communications

In the medium term (2019- 2024)

Testing, validation, certification
- Component perf
- System perf
- System security
- Software

standards

EZE comms including

QSafe

QComms-QKD, QAuth……..

Plug 'n play – whole system

Compatible with existing infrastructure

Killer APPS e.g. beyond pt-pt QKD with AES/OTP

e.g.Authentication / signatures (Transferable message authentication)

Working with end customers

Performance increased (Advantage of existing) driven by innovation, govt to promote environment to encourage innovation

Affordability
- Subcomponents ~£ (cost)
- Systems

Use Cases

QComms built-in option to comms protocols

Interoperability – standard protocols, key management, format (hardware)

More vendors

Long Term (beyond 2024)

More of  !

Energy efficiency

Seamless integration/ Plug n' Play

Global Security

"Data comms" + "Data at Rest" security. Security by design (less/no human element- No passwords)

International Framework

END OF THIS PROFORMA

Quantum Communications Workshop Proformas

Quantum Communication in the UK proforma

TABLE

Innovation priorities in Quantum Communications

Which disciplines and skills need to be involved?

Interdisciplinary team

Security (hacking)

Networks

Quantum

Classical Comms

Optics

Computing

Electronics

Signal processing

Protocols

CDT? Optical comms / Quantum CDT interaction

UK

Who do we need to collaborate with internationally?

International academic partners where the collaboration will enable the UK to maintain its sovereign capability.

Collaborate with international standardisation bodies.

END OF THIS PROFORMA

Quantum Communications Workshop Proformas

Quantum Communication in the UK proforma

TABLE

Innovation priorities in Quantum Communications

Which disciplines and skills need to be involved?

Semi-conductor development

Fibre optics

High speed Electronics

Integrated Photonics

New materials

Telecom Engineering

Cryptography

Security Engineering

Network Engineering

Who do we need to collaborate with internationally and why?

International academic partners where the collaboration will enable the UK to maintain its sovereign capability.

Collaborate with international standardisation bodies.

END OF THIS PROFORMA