Untangling the future of quantum communications

The next generation of the Internet will be powered by sub-atomic particles—and it's much closer than you think.

In early 2023, a rocket will thunder into the skies over southern England with a satellite that will use the mysterious power of quantum mechanics to secure some of the world's most sensitive communications.

Built by a $1.4 billion startup called Arqit and backed by some of the world's biggest countries and companies, the satellite joins a cascade of developments that are bringing the world closer to a quantum era that could be both practical and profitable well before the end of the decade.

After spending years imagining the possibilities, researchers are now building and testing the equipment that will form the backbone of a powerful quantum Internet—where quantum communications will start integrating with the world's increasingly hyper-connected economy.

And it's happening a lot quicker than most people realize. The first commercial quantum links are nearly here, with a quantum Internet connecting distant networks ready in 3 to 5 years.

Every new industry is created by first movers. Their products set the standard, they capture the first customers, and their brand becomes forever associated with a new innovation. Now it's happening with quantum communications. The first companies are already moving into position and harnessing the knowledge, resources and talent that will ensure they enter the quantum era ahead of everyone else.

What are quantum communications?

Quantum communications are not the same thing as the powerful quantum computers that will process information exponentially faster than conventional computers.

Instead, quantum communications involve the sending of information. And to understand why they will revolutionize cybersecurity and transform the Internet, we need to take a quick look at the science behind them—at the quantum particles that are so counter-intuitive even Albert Einstein scratched his head and called them 'spooky.'

The No-Cloning Principle

Of all the quantum properties this is the one that excites people in your cybersecurity department. It refers to the idea that the act of observing quantum information will cause it to change. To see why this is bad news for hackers, consider a letter sealed with wax. With a conventional letter, a broken seal reveals that the letter was opened. But if you open a 'quantum' letter, breaking the seal not only reveals that it was opened, it changes what the letter says.

> In short, trying to read quantum information changes the information, which means it can't be intercepted, stored or read.

Entanglement

When Einstein called quantum particles 'spooky,' he was talking about entanglement. Scientists have discovered that some quantum particles are linked in a way that a change in one will trigger a change in the other—even when they are physically separated. It doesn't matter if one of the linked particles is in the next room or on the moon—it will react to a change in its twin.

To understand how this link—or entanglement—applies to communications, imagine we have two entangled typewriters: one in New York and its twin in San Francisco. Now, at first glance it seems we have a new way to communicate. A change in a key on the typewriter in New York will trigger a change in a key on its entangled twin in San Francisco.

But there's a problem because we need more than entanglement to communicate. Remember the no-cloning principle? We can't know the status of either typewriter key without looking at it—and by looking at it we change it. So even though we have a strangely powerful link across the United States, our entangled typewriters alone can't communicate any useful information.

Teleportation

Fortunately, there's a solution. Researchers found a way to capture the status of one of the entangled particles and then send it as a quantum unit of information (called a qubit) to its entangled twin. This successful transfer of quantum information is called teleportation.

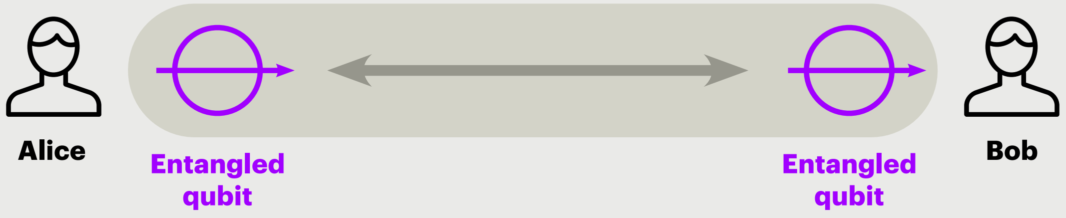
There is another problem, however. The qubits of information sent between our entangled twins must travel via conventional communications such as fiber optic cables and satellites—and it's not that easy. These qubits are in the form of photons, and photons have a habit of bumping into molecules in the air and inside the cables—which causes them to be absorbed along the way.

But then researchers had a Eureka moment.

TELEPORTATION: The ability to share quantum information without physically sending it.

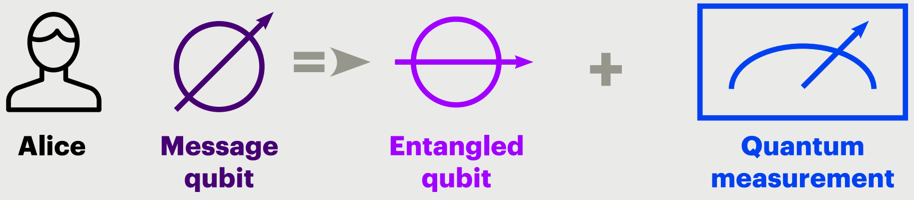
STEP 1

To enable communication from Alice to Bob, they each must first receive one of two entangled qubits via a quantum channel.



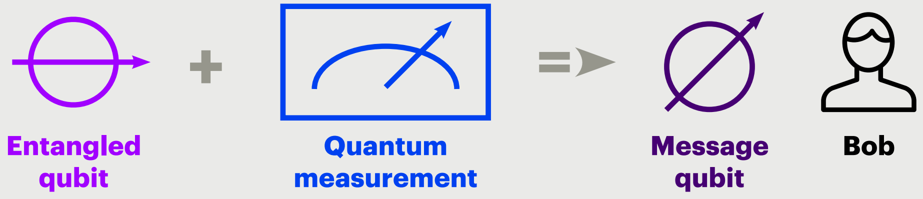
STEP 2

Next, Alice prepares a qubit state to reflect the message for Bob. Afterward, Alice combines the message qubit with the entangled qubit in her possession. Finally, Alice measures the resulting quantum state and sends the hint to Bob over a classical channel.

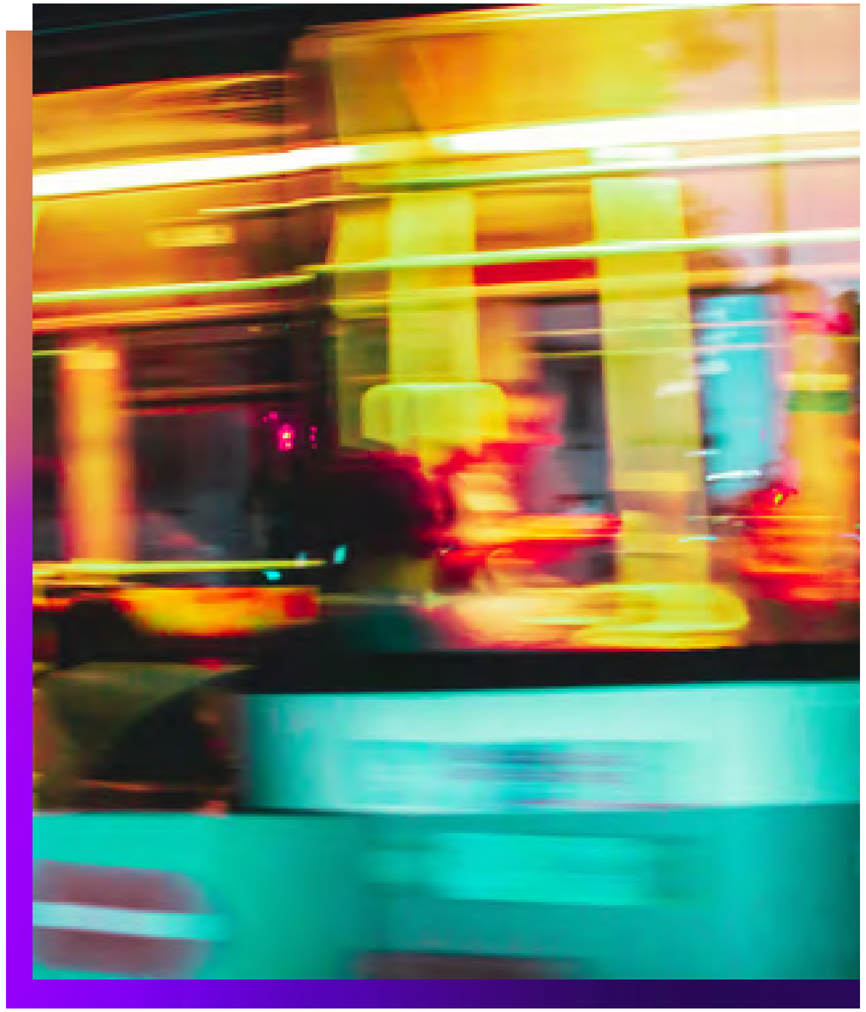


STEP 3

Bob combines the hint from Alice with his entangled qubit, resulting in a qubit with the same state as Alice's message qubit.



Source: Accenture



Entanglement Swapping

While trying to keep the photons, or qubits of information, intact as they speed through the air and under the oceans, scientists discovered entanglement swapping. Let's return for a moment to our typewriters in New York and San Francisco.

It turns out that they can be entangled with a third typewriter, which we will put somewhere in the middle—like Omaha. Now the photons can travel a shorter distance to our entangled typewriter in Omaha where—with the addition of a little technical wizardry called a 'repeater'—we can effectively create a secure bridge between New York and San Francisco.

We are now beginning to see what a quantum Internet might look like—with entangled repeaters connecting a powerful and secure constellation of quantum computers, phones, sensors and other devices all over the world.

> Clearly, the science behind quantum particles isn't always easy to understand. But their impact on the world is becoming clearer every day.

The race is on

If you were driving in the suburbs outside Chicago or New York in the last year, there's a chance you were driving above quantum particles that were zipping through networks that run for dozens of kilometers under the city streets.

Meanwhile in England, a research lab has been sending quantum information through a fiber optic network near Bristol, while in Japan the multinational conglomerate Toshiba is working on quantum communications that it expects to generate $3 billion in revenue for the company by 2030.[1, 2]

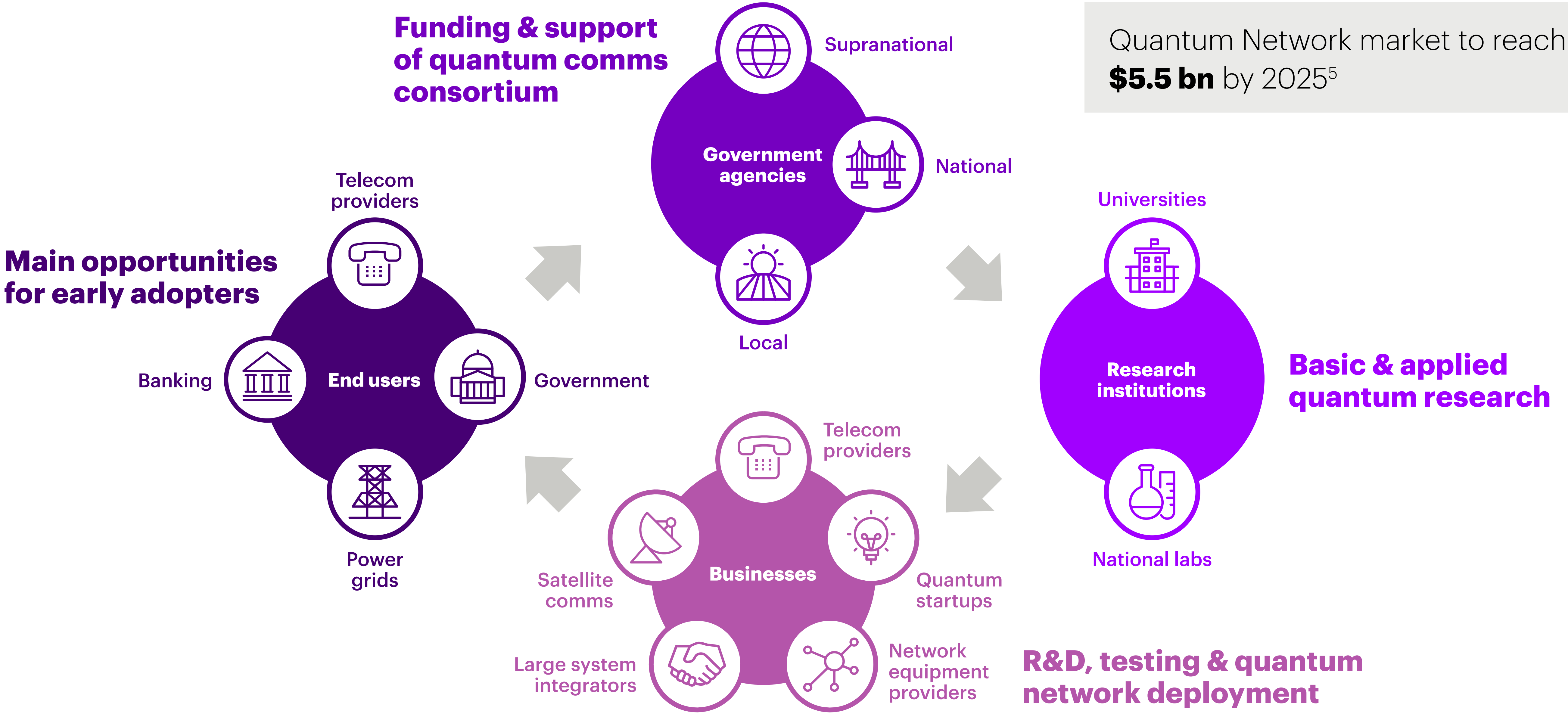
And then there's China. Not only do they already have a quantum satellite in orbit—this satellite is linked to stations on the ground that are part of a sprawling 4,600-kilometer quantum network connecting Beijing and Shanghai.[3]

Every new test on these networks and others scattered around the world brings us another step closer to practical quantum communications. Unsurprisingly, it's also fueling a race to be first.

Government spending on quantum programs has increased to $23 billion—and it's just getting started.[4]

QUANTUM COMMUNICATIONS NETWORKS ECOSYSTEM: Multistakeholder partnerships play a critical role.

Quantum Network market to reach **$5.5 bn** by 2025[5]



Source: Accenture Research

The world awakes

In the US, the Department of Energy (DOE) allocated $625 million in 2020 to set up several research labs that will harness the collective firepower of academia, government and private companies. They also developed a blueprint that points the way forward to the future quantum Internet.[6]

The effort by the DOE builds on existing programs such as the Quantum Economic Development Consortium and the Chicago Quantum Exchange that bring together a who's-who of academics and companies including ATT, Cisco, Verizon, Google, Microsoft, Boeing, IBM, Corning and JPMorgan Chase.[7, 8]

Another program funded with a $51 million grant from the National Science Foundation has helped the University of Arizona establish a Center for Quantum Networks involving participants from both academia and industry.[9]

China is busy as well. They created a National Laboratory for Quantum Information Sciences backed with $10 billion in funding over five years, while the European Union is working with companies including Airbus, Leonardo and Orange on a project called EuroQCI.[10]

The Netherlands said in April it will spend over $700 million to build quantum labs and the UK assigned another $200 million to quantum research in March.[11] Also in Europe, the Dutch telecommunications company KPN said in July 2020 that it will build a quantum network for clients in the Netherlands, Belgium, France and Germany. This follows an announcement that BT Group, Toshiba and Arqit are developing their own quantum network.

In India, the National Mission on Quantum Technologies & Applications was established last year with a $1 billion budget, while Canada launched its National Quantum Strategy in July 2020 backed with almost $300 million.[12, 13]

The world's leading financial institutions are keen to be first as well—with JPMorgan Chase, Goldman Sachs and Nomura Securities already testing the impact of quantum technology on their financial models and communications.

This is a brief snapshot of some of the quantum programs kicking into gear around the world. Together with other projects in Japan, Australia, Israel, Singapore, South Korea and elsewhere, the race to a quantum future is on—and it's picking up speed.

This race to be first goes beyond national prestige. The first governments and companies to create a viable quantum network will be the first to enjoy completely secure communications. They will be the first to sell these secure communications to others, and they will set the rules and standards upon which quantum networks will be built.

While these technologies are continuing to evolve, there is a fairly clear picture of how quantum communications will need to be integrated into existing telecom networks (see Diagram on page 11).

Opportunities

The **quantum Internet** will open up opportunities in 3 key areas

1 Secure communications

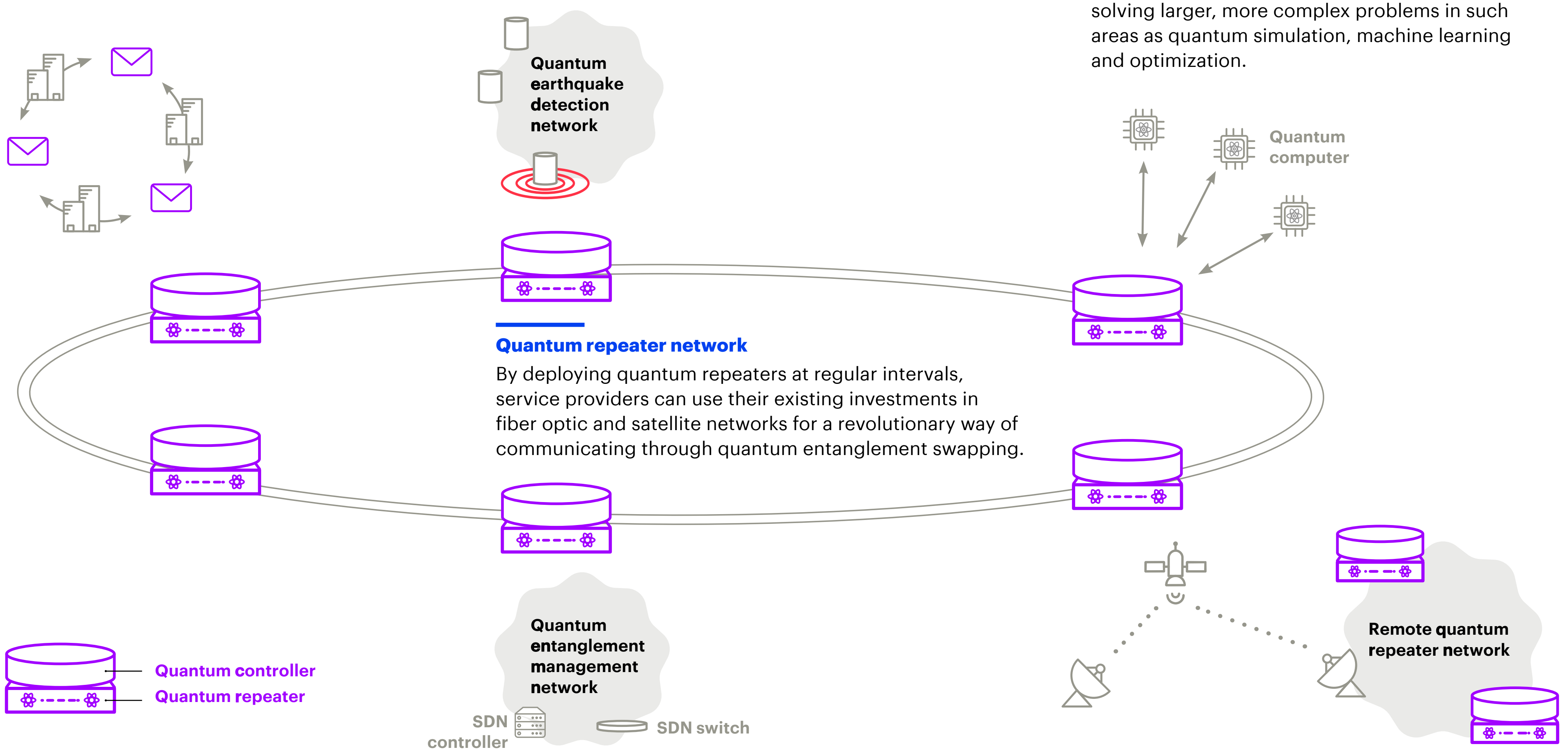
Teleportation over swapped entanglement provides for a robust communication framework. With it companies can soon transmit messages more securely than before.

2 Quantum sensing

Quantum sensors provide new ways of remotely observing the physical world and transmitting the results back for analysis. For example, scientists are working on ways quantum gravimeters can improve earthquake detection.

3 Distributed quantum computing

Networking quantum computers will enable solving larger, more complex problems in such areas as quantum simulation, machine learning and optimization.



Quantum repeater network

By deploying quantum repeaters at regular intervals, service providers can use their existing investments in fiber optic and satellite networks for a revolutionary way of communicating through quantum entanglement swapping.

Foundations

These opportunities will require network carrier capabilities deployed on top of the existing internet

Quantum repeater

An integrated network element that generates and swaps quantum entanglements combined with a controller to manage processes.

Quantum control plane

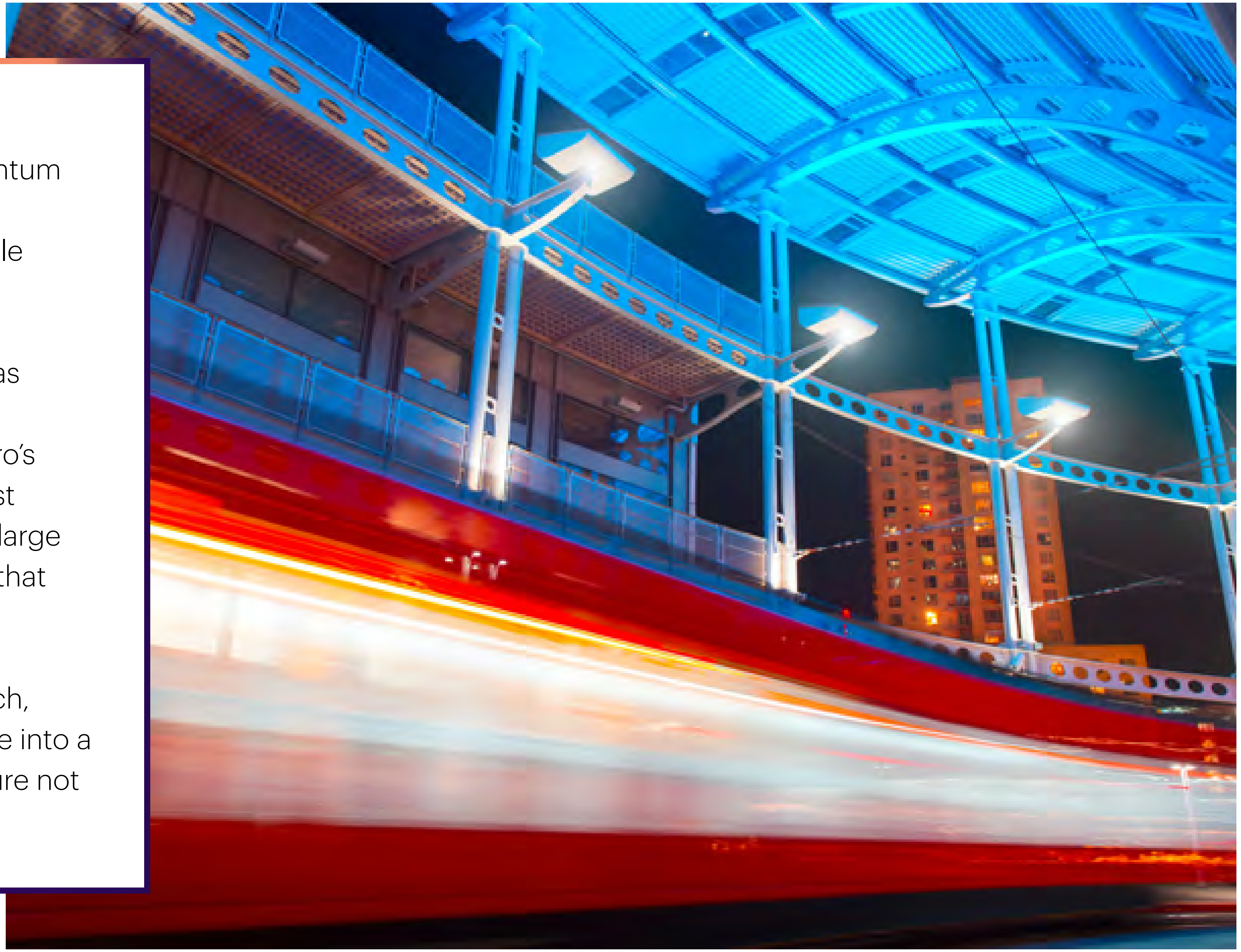
The deployment of quantum repeaters will require a new management plane to control them. Existing Software Defined Network capabilities can do so by having a central SDN Switch interact with local agents on the repeaters.

Source: Aliro Quantum

In July, the US Air Force handed several contracts to a startup called Aliro that is one of many helping to build the future quantum Internet.[14] Spun out of NarangLab at Harvard University, Aliro is developing software that would facilitate the flow of unhackable qubits among quantum computers and devices.

Aliro says the software, which it calls Quantum Entanglement as a Service, would allow telecommunications carriers to provide their customers with quantum entanglement on-demand.[15] Aliro's work on software solutions for quantum communications is just one component of an expanding ecosystem of governments, large companies and nimble quantum startups (see list on page 17) that are starting to build a quantum Internet.

Together with the accelerating pace of investment and research, they are rapidly turning the predictions about a quantum future into a tangible and transformative technology that will make this future not just possible, but inevitable.



To QKD or not to QKD?

This is an important moment at the dawn of the quantum era. But not everyone agrees where it unfolds from here, and much of the disagreement centers around something called QKD.

QKD is short for Quantum Key Distribution, a type of quantum encryption that promises to protect our most sensitive communications like they have never been protected before.

QKD is closer to mainstream commercial encryption than other quantum solutions. It's the technology behind Arqit's satellite launch in 2023 and has the support of companies including BT Group, Northrop Grumman and Sumitomo. Another company working on QKD technology—Toshiba—estimates the market will be worth $20 billion by 2035.[16]

When it comes to quantum cryptography, Asia leads the pack. Academy and industry are working at full steam to develop a comprehensive and strategic patent portfolio to protect innovations in the field of quantum key distributions, including space-based QKD. A steep increase in global patents applications since 2013 have made China the most prolific patenting country in QKD, with more than two thirds of the total count.[17]

Called the "low-hanging fruit" of quantum communications, QKD is popular and seemingly imminent as a commercially viable solution. But it has run into some serious opposition among stakeholders that range from small startups to the US NSA.[18]

The problem with QKD encryption, they say, is that it incurs high costs for limited returns and would still be vulnerable to some of the cyber threats we are experiencing now.

Other critics say QKD simply doesn't go far enough. This is because QKD is designed to work with the conventional, non-quantum communications that are in use today. While QKD encrypts them with a quantum key, it doesn't transform communications into actual quantum information.

In other words, it promises a quantum short-cut to better cybersecurity, but without providing the world with a much more secure and powerful quantum Internet. These skeptics of QKD have been busy working on solutions of their own.

Looking ahead

There is always a cloud of uncertainty around new technology. When the Internet began to take shape in the late 1990s, some could see the sweeping social and economic transformation that was on the horizon, while others said it would have the same impact as the fax machine.

This is where we are with the quantum Internet today—with the way forward still being defined as academics, businesses and governments jostle for position. But whoever prevails, they have all learned one very important lesson from the birth of the original Internet—a failure to become part of the process early means abandoning the field to those who do.

And, of course, the choice couldn't be any clearer for telecommunication businesses—because a hyper-connected economy with secure quantum communications will draw a very sharp line between the companies that innovated early, and those that did not.

Getting started

The best way to understand the potential of a new technology is to get involved—and thanks to the rapidly expanding ecosystem of government programs, private labs and new startups seeking partners, there has never been a better time to begin.

> Leveraging their expertise in global internetworking, telecommunications companies can start now with some important first steps to ensure they are in position for the opportunities that lie ahead.

Connect

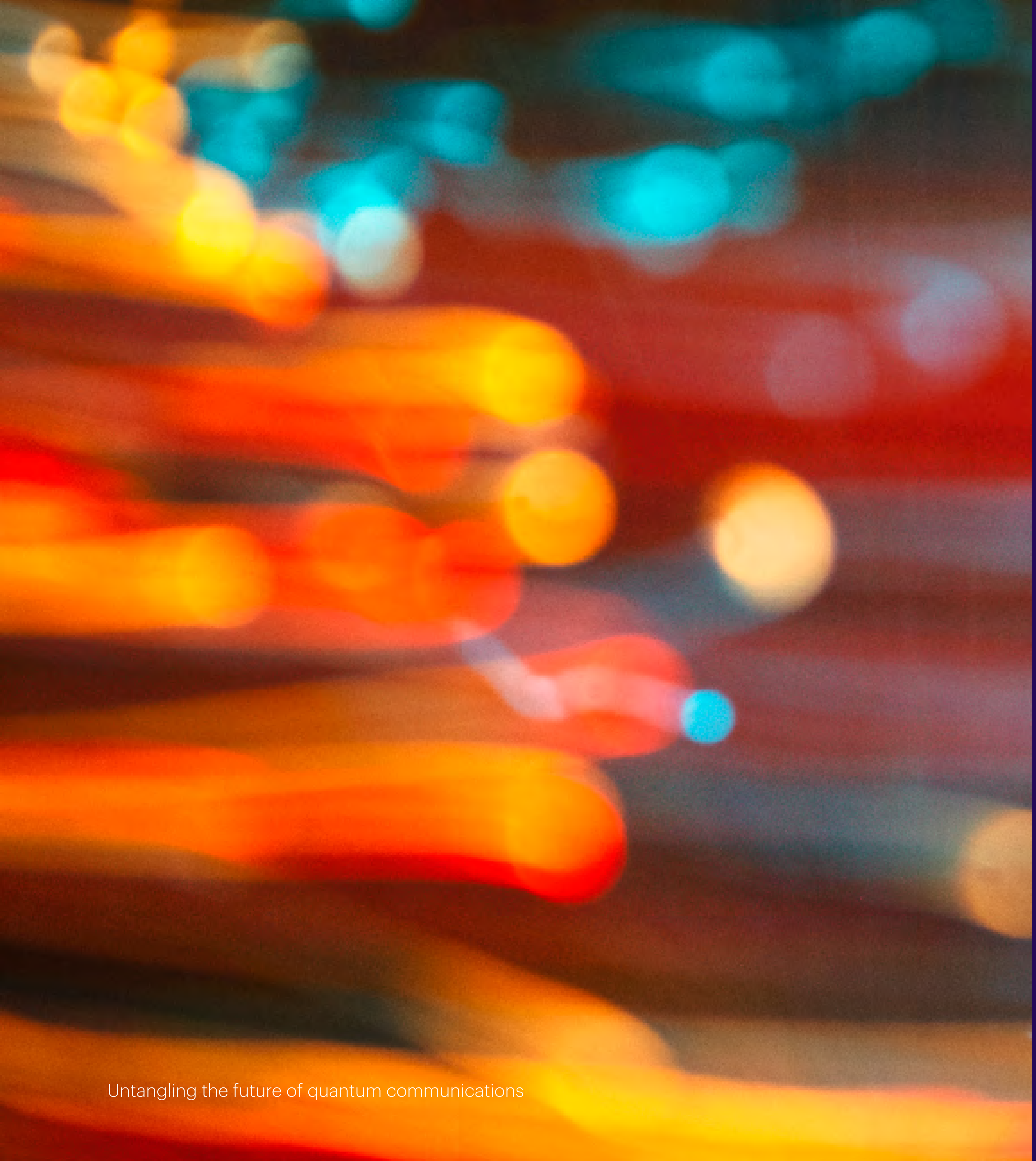
with one of the growing number of national and international groups that are bringing together experts from academia, governments, startups and telecom providers. Quantum communications is a team effort.

Partner

with quantum network advisors to test your capabilities in quantum network simulators and network testbeds. This can begin today, with the help of startups that allow you to design and run virtual quantum networks.

Start

building an in-house Quantum Center of Excellence where your own experts can begin creating a roadmap to success.



There are many ways to get started with quantum communications. The key is to start soon—while the technology is new and so many opportunities have yet to be tapped.

An emerging ecosystem

The following is a partial list of the hundreds of quantum startups that are now emerging to develop a quantum Internet.

Aliro Quantum: developing software to manage quantum networks, as well as a quantum network simulator.[19]

Ki3 Photonics Technologies: develops photonic systems for generating entangled photons.

Miraex: offers photonics components for sensing, networking and computing. Their Quantum Transducer converts microwave wavelength photons to the optical domain at the single-photon level.

NuCrypt: provides an entangled photon source as well as technology spanning fiber optics, nonlinear optics, electronic control systems, communication systems, optical measurement technology and quantum optics.

Nu Quantum: specializes in single-photon devices and has provided components for BT's work on QKD in the UK.

Oxford Instruments: provides imaging cameras to detect single photons.

QphoX: develops quantum transduction devices that convert photons between the microwave domain and optical telecom frequencies.

Quantum Opus: develops superconducting nanowire single-photon detectors.[20]

Qubitekk: provides lasers that create entangled photon pairs, single-photon detectors, as well as QKD systems for both demonstrations and industrial control systems.

Qunnect: spun off from Stony Brook University, Qunnect develops entangled photon sources and quantum memories, a key component for entangled quantum networks.

S Fifteen Instruments: provides single-photon detectors that operate at both visible and infrared wavelengths.

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