Quantum Networking: Deployments, Components and Opportunities—2017-2026

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Report Description

For the past 15 years, major service providers and research institutions worldwide have run quantum network trials. We are now entering a period in which permanent quantum networks are being built. These are designed initially to support quantum encryption services, but will soon also provide the infrastructure for quantum computing.

CIR believes that as quantum networks are deployed, they will eventually create opportunities at the service level, but more immediately at the components and modules level. This is because quantum networks will require a slew of new optical networking technologies to make them function effectively. In this report, CIR identifies the leading opportunities that will emerge from the building of quantum networks throughout the world. This report includes:

- Profiles of all the leading quantum networks and related R&D around the globe. We discuss which technologies and components these networks are using and developing and how quantum networks will impact the telecommunications and data communications more generally. For each of these networks, current and planned applications are discussed and we also analyze where the potential for commercialization will be found.
- Ten-year forecasts of the deployment of quantum network nodes around the globe with breakouts by technologies used, applications served and the kinds of components being used. These forecasts are developed in the context of a roadmap for future needs for encryption, high-performance computing (HPC), and big data infrastructure support.
- A thorough analysis of the commercialization potential for the technologies associated with quantum networking. This analysis will discuss how leading commercial organizations active in building today's quantum networks expect to build businesses around their experience.

This report will be essential reading for marketing, business development and product managers throughout the data communications and telecommunications industry, especially those at firms in the fiber optic and

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small satellite sectors. The report will also be valuable for those planning business development and investment in the quantum computing and quantum encryption businesses.

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Chapter One: Introduction

1.1 Background to this Report

Quantum networks—networks which transmit qubits rather than bits—are currently being built all over the world based on both fiber optic and satellite transmission. The immediate purpose of these networks is either (1) as research tools to explore some of the more fascinating aspects of quantum mechanics—teleportation and entanglement in particular—or (2) to provide ultra-secure quantum key distribution (QKD) for encrypted communications that are in imminent danger as quantum computers.

As the use of quantum technology becomes more common to make data streams more secure and new applications emerge for quantum networks, the market for specialized interfaces and nodes to support these networks will become sizable—big enough to attract large equipment vendors, and leading edge enough to encourage start-ups.

1.1.1 Quantum Interfaces and Quantum Repeaters

Much of the quantum network infrastructure will utilize existing digital transmission technology. The two main differences will be (A) instead of digital network interfaces, there will be network interfaces that code information in qubits and (B) amplifiers—a key enabling technology for long-distance digital optical networks—are inconsistent with the laws of quantum mechanics. As a substitute new kinds of quantum repeaters are being invented and will take a key role in the evolution of node technology in long-haul quantum networks going forward. We profile the way CIR sees quantum repeater technology evolving in Exhibit 1-1.

Exhibit 1-1: Evolution of the Repeater Technology for Quantum Networks

Type of repeater	Evolution
Trusted node	The state of the art in terms of practical repeaters in quantum networks. Information about the quantum state is measured and retransmitted. At least one trusted node is used in any satellite network
Quantum repeaters without qubit/bit conversion vulnerability using quantum memories	Currently under development, but easily could be five years before they are deployed. Subject to considerable amounts of R&D activity
Quantum repeaters not using quantum memories	Although a quantum amplifier is technically impossible, this would be the nearest possible thing. NTT (and possibly others) are researching this possibility, although we do know yet whether it is a practical possibility
Transport platform	ZTE has begun with a project launch of this kind for OTN networks. However, we also envision similar products for metro and data center deployment. New entrants too—possibly Nokia

Source: CIR

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1.1.2 The Components of Quantum-Secure Networks

Initially QKD customers are those for whom data hacks are an existential danger. Such customers include governments, financial institutions, aerospace and the military. These organizations are ready to pay the high prices currently associated with QKD. CIR thinks this kind of QKD customer will generate just $45 million in revenues in 2017. What we believe is going to happen is that there will be a two-stage expansion of the quantum-secure networks.

QKD equipment costs to decline: As quantum computers proliferate the security threat they represent will spread to less vulnerable organizations and increased hacking incidents will bring "tier two" customers into the QKD market.

As a result, CIR projects that revenues from this kind of QKD will grow to $885 million by 2022. These revenues, we believe, will mostly flow to the handful of companies who have been developing QKD gear for as long as two decades. Our research suggests that these vendors are already adapting their technology so that it could be affordable to medium-sized data centers.

Quantum-secured mobile communications to emerge in less than five years: In the long-run, quantum-secured *mobile* communications are likely to be a bigger business than the kind of corporate QKD we have described above. It will also create important new opportunities for firms that have never seen themselves as part of the quantum networking or QKD communities.

To enable quantum-secured mobile communications networks entirely new classes of quantum devices will have to be designed and fabricated. There will have to be a new class of chips/chipsets that embody QKD technology (or a security arrangement based on quantum number generators) and which are small enough and low cost enough to fit into a cell phone. SK Telecom's recently announced quantum-secure chip will cost less than $10 when mass produced and will have a size of 5mm x 5mm and shows that such devices can be built.

In addition, a miniaturized mobile quantum interface represents a special challenge, since the qubit stream can easily be disrupted. CIR sees this leading to the need for new kinds of free space optical (FSO) networking combined with miniaturized beam tracking systems and light filters to keep the encryption working under changing light conditions. As we see it, this opportunity does not fit well with the firms that are already well-established in the quantum networking space and instead will create opportunities for manufacturers of mobile phone and smartcard chips, MEMS companies, photonics start-ups, etc.

Thus, quantum-secured mobile communications is an application of quantum networks that remains within the encryption sphere, it presents different opportunities for different firms than the QKD systems that have been the focus of quantum networks up to now.

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Given the current state of the technology we don't see any revenues from quantum secure mobile communications happening until at least 2021, but if the necessary technology is commercialized, very small penetrations by quantum encryption of the smartphone and smart card markets could easily generate well over one billion dollars annually.

1.1.3 Interfaces for Quantum Computer Timesharing

Revenues from cloud-based quantum computing are negligible and will probably stay that way for at least another three years. After that, we anticipate large corporations and the military will want to timeshare quantum computers to solve difficult supply chain and modeling problems. Meanwhile, big pharmaceutical and specialty chemical firms will begin to use quantum computers to develop and design complex materials and drugs.

IBM has already offered cloud-based access to its quantum computer through its Quantum Experience (QX) offering. We anticipate that IBM will soon be joined by other important IT firms, most likely including HP Enterprise and Google, both of which have already established beachheads in the quantum computing world. One primary reason why end users will have a need to timeshare over a cloud or network is quantum computers are expensive resources—sharing them makes economic sense. Also the kind of end users that quantum computer firms currently attract are often highly distributed organizations, so again, networks or clouds seem to be called for.

Quantum computers will start to use quantum networks: As far as we can tell, "timesharing" of quantum computers is currently being carried out over conventional digital networks. Nonetheless, it seems to us that a natural future development of quantum computer timesharing would be to shift to a quantum network platform—that is a network that actually carries qubits.

The argument for such a trend emerging is partly from historical analogy and partly from the practical advantages that would appear from such a trend. The history lesson is that digital computers were initially networked over analog lines, right up until digital networks became widely available—will a similar pattern be repeated with quantum computers? In aggregate, CIR expects service revenues from timeshared quantum computing resources to reach tens of millions of dollars within five years.

If quantum computer timesharing starts to occur over quantum networks, it will be possible to keep information in the form of qubits, which eliminates the need (and related costs) for conversion from qubits to bits. In the past, Electrical-to-optical and analog-to-digital conversions have added costs and errors to previous networking generations and similar issues may be expected to arise with bit-to-qubit conversions.

A second advantage of using quantum networks as platforms for quantum computing timesharing is that QKD will, in a sense, be especially easy to deploy. However, for now the quantum networking opportunity that seems most likely to emerge from quantum

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computer timesharing are interfaces or boards that can convert between qubit and bits in some way.

1.1.4 A Quantum IoT Emerging?

CIR believes it is possible that a *quantum* IoT (QIoT) will emerge as a part of the shift towards IoT. A quantum sensor uses quantum phenomena (e.g., entanglement) to achieve levels of sensitivity or resolution that cannot be achieved with conventional sensors and we think that such sensors—although they may be quite expensive—will have strong use cases attached to them.

Quantum sensor networking will find a first use in military applications where their exceptional sensitivity could detect very small quantities of toxins and report the presence of these toxins back to a command and control facility. The main civil application where we see significant potential for QIoTs over the next five to ten years is in (physical) security applications. This could *begin* with installations in large government buildings, but there is also a huge addressable market for QIoTs is offices and industrial buildings and even in large residences. In additions QIoTs emerging to support geosurvey work in the oil and gas industry.

In most cases, quantum sensors would have to work in combination with other sensors in an IoT. It doesn't seem likely to us that quantum sensors represent a strong economic alternative to conventional digital sensors, but it is possible that quantum sensor subnetworks might exist inside an otherwise conventional IoT. This suggests a future need perhaps for some kind of quantum ZigBee connection, although quantum sensors would not necessarily have qubit outputs and therefore wouldn't need quantum interfaces as such.

In any case, Quantum ZigBee products will not appear any time soon, nor are they likely to be needed in the next five years. It is also possible that the FSO technologies developed for mobile communications might serve for QIoTs just as well.

1.1.5 The Quantum Internet: Hardware and Risks

The developments outlined above, considered together, have led some observers to discuss the possibility of a "Quantum Internet" emerging, although the term is used very loosely so far. However, in terms of what the components of that "Quantum Internet" would be, the narrative above—and indeed the rest of this report—is intended to provide important clues. In Exhibit 1-2 we summarize where we see the primary opportunities for networking equipment manufacturers looking at these opportunities from a 2017 perspective.

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Exhibit 1-2: Hardware and Components for the Quantum Internet

	National and regional networks	Corporate QKD networks	Quantum-secured mobile communications	Quantum computer timesharing	QIoTs
Quantum repeaters	Yes	Sometimes	Not as currently conceived		Possibly for quantum subnets of conventional IoTs
Bit-to-qubit conversion	Yes	Yes	Integrated into communications chip	At least initially	Unclear
FSO	No	No	Yes	No	Possibly
Positioning systems					
Specialty fiber	Possibly		No	Possibly in the future	No

Source: CIR

Risks of the Quantum Internet: While CIR is bullish on the Quantum Internet, none of the above should be taken to mean that investments in this new kind of networking are without risk. Perhaps the biggest of these is the tacit assumption that the quantum Internet will grow out of today's QKD networks

But this is not necessarily the case. Quantum technology may ultimately not be the way that encryption systems counter the quantum computer threat—there are *software-based* protections being developed for this threat under the name post-quantum encryption. For now, quantum technology is more mature, but this may not be the case forever. So, it is at least possible that, in a few years, the QKD systems on which the Quantum Internet is supposedly going to be built, may simply not emerge.

The other risk that needs to be considered is that quantum computers themselves never become a force to be reckoned with. Quantum computers exist today, but they are at a relatively primitive stage of development and, in particular, cannot solve most of the difficult problems that the textbooks say they will solve in the future. There is, in fact, no guarantee that quantum computers will evolve quickly or at all and if they don't, many of the opportunities that are discussed in this report will never emerge.

1.2 Objective and Scope of Report

The primary objective of this report is to identify the opportunities that CIR expects to arise in the quantum networking space in the next decade. Most of these opportunities are mentioned in Section 1.1 of this Chapter, but are discussed in more detail in the main body of this report, along with appropriate revenue generating strategies for each of them.

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The opportunities in quantum networking are also quantified in ten-year forecasts, and profiles are presented of the leading players active in this space. These include service providers and hardware/component firms as well as R&D facilities. This is a worldwide study and provides breakouts for quantum networking markets in all major developed countries.

1.3 Methodology of this Report

The information for this report has been obtained from both primary and secondary (interview) sources. However, the analysis of this data is based on CIR's 35-year experience in understanding the patterns of technology deployment and of communications networks in particular.

The forecasting methodology is discussed in more depth in the main body of the report. It begins with the current state of quantum network deployment in each of the countries considered and then extrapolates from there based on the status of applications and end user sectors for quantum networking in each country.

1.4 Plan of Report

In addition to this Chapter One and the Executive Summary, this report consists of three other Chapters. In Chapter Two, we discuss the evolution of the primary technologies with which this report is concerned.

In Chapter Three, we provide profiles of the leading quantum networks in operation today, while in the concluding Chapter—Chapter Four—we provide detailed forecasts of the markets analyzed in this report.

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