ROADMAP FOR THE DEVELOPMENT OF "THROUGH" DIGITAL TECHNOLOGY **"QUANTUM TECHNOLOGIES"**

Moscow
2019

1. Preamble, introduction, general description of the direction of development of the SDT

Roadmap (RD) for the development of end-to-end digital technology (DST) in the Russian Federation "quantum technologies" (CT) is developed with the aim of obtaining in the medium term and long-term perspective of practically significant scientific, technical and practical world-class results in the following subtechnologies: quantum computing, quantum communications and quantum sensors. In parallel with the work on the road The map is working on researching the patent landscape of quantum technologies.

A necessary condition for a breakthrough in the field of CT is not only the support research and launch infrastructure projects on a national scale, but and implementation of organizational measures to overcome barriers. General budget of the program proposed by this DC is 51.1 billion rubles, including extrabudgetary financing in the amount of 8.7 billion rubles. Investments for the development of quantum technologies in Russia are needed today.

More than 120 experts from leading scientific organizations of the Russian Federation and representatives of the industry. The key proposals of this roadmap are:

1. Comprehensive support for breakthrough scientific and technological projects, aimed at the development of CT.
2. Consolidation of the scientific and technological community as part of the creation projects on a national and global scale.
3. Creation of an innovation ecosystem in Russia and creation of conditions for transition of quantum developments from laboratories to industry, as well as the formation of business communities.
4. Organization cooperation between research departments and potential consumers of quantum technologies from key areas industry.
5. Development of human resources in the field of quantum technologies through introduction of new types of educational programs at all levels.
6. Carrying out a set of organizational measures aimed at to reduce bureaucratic friction.

The development of CT is fully consistent with the Strategy for Scientific and Technological Development Russian Federation (SNTR), Strategies for the Development of the Information Society Russian Federation (SRIO) and 204 Decree of the President of the Russian Federation "On national goals and strategic objectives of the development of the Russian Federation for the period up to 2024".

- Description of end-to-end digital technology

"The first quantum revolution", which marked the development of physics in the first half of XX century, led to the emergence of lasers, transistors, nuclear weapons, and subsequently - mobile telephony and the Internet. Technologies of the “first quantum revolution” today are used almost everywhere: in computers, mobile phones, tablets, digital cameras, communication systems, LED lamps, MRI scanners, scanning tunneling microscopes and many other devices. According to various expert estimates estimate the industry of the "first quantum revolution" in monetary terms in terms of $3 trillion a year. At the same time, Moore's law, which describes the growth performance of modern computers no longer works.

Since the end of the 20th century, the world has been on the threshold of the “second quantum revolution”, which can have an even greater impact on the world. Its key difference from the "first quantum revolution”, in which technologies and devices were built on the management of collective quantum phenomena lies in the ability to control complex quantum systems at the level of individual particles, such as atoms and photons. Technologies, based precisely on such a high level of control over individual quantum objects, it is customary to combine the term "quantum technologies".

Today, CTs are beginning to play an increasingly important role in matters of national security, as well as in such strategically important industries as information technology and medicine. Quantum technologies are in demand for further progress in all strategic areas of the digital economy, for example, for the development artificial intelligence in the long term. Even though the quantum technologies have a large scientific component, this fact is not an obstacle for their rapid development and implementation in the industry. CTs are divided into three main subtechnologies.

Quantum computing is a new class of computing devices that uses for problem solving principles of quantum mechanics. It is predicted that in a number of tasks a quantum computer will be able to give a multiple acceleration compared to with existing supercomputer technologies. Examples are spheres cybersecurity, artificial intelligence and the creation of new materials.

Quantum communications is a technology of cryptographic information protection, using individual quantum particles to transmit keys. Main the advantage of quantum communications is the security of information, guaranteed the laws of physics.

Quantum sensors and metrology - a set of high-precision measuring devices based on quantum effects. High degree of state control individual microscopic systems allows you to create ultra-precise quantum sensors with a spatial resolution comparable to the size of single atoms, as well as high-precision atomic clocks.

The technology closest to commercial applications is quantum communications that is already understood by the market.

In technologically advanced countries, research and development in the field of CT are under the watchful eye of the state. Large public investment in this scientific and technological area are explained by the strategic importance of quantum technologies to ensure the protection of the interests of the state, in particular, in the information field. Geopolitical leaders create targeted development programs CT. In the US Congress approved a $20 billion CT development project, in Europe operates the Quantum Flagship program with a budget of more than 3 billion euros (after completion previous program 2013-2016), China is establishing the National Quantum laboratory with a budget of up to $12 billion.

In addition to government programs, a significant acceleration in the development of CT was given investments from the world's largest corporations such as Google, Microsoft, Intel and IBM. Other companies such as Airbus and Volkswagen are already solving with CT specific technological challenges. Total investments of private companies in CT approaching a billion dollars a year. Private investment in quantum projects growing rapidly, especially in China, Japan and Singapore.

CT is largely based on the achievements of fundamental science in those areas in which Russian scientists are traditionally strong. Soviet-Russian The school of quantum physics is one of the strongest in the world. All Nobel Prizes for physics of Soviet and Russian scientists are associated with achievements in the field of quantum physics. The scientific school has suffered significantly due to the mass exodus of scientists abroad in the 90s and 2000s, which, however, formed the strongest Russian-speaking international scientific diaspora. At the same time, dozens remained in Russia scientific groups conducting world-class research. appeared in the last a decade of a trend towards the return of Russian scientists who have taken place abroad and to attract foreign scientists without Russian experience will provide for Russia's potential for a breakthrough and capture of leading positions in certain areas CT.

Strengthens this position by the fact that the industry of quantum technologies in the world is only at the stage of formation. Therefore, it is currently possible with a sharp start, join the quantum technological race, despite on the current backlog. Targeted support for the development of CT will reduce gap in areas such as quantum computing, and in a number of areas, for example, in the field of quantum communications, create competitive products with export potential and enter international markets.

The role of CT is already recognized at the highest level. This is largely why quantum technologies belong to the priority areas of scientific and technological development and have been mentioned by the President of the Russian Federation V.V. Putin in the Annual Address to the Federal Assembly in 2016.

Annual message of the President of the Russian Federation V.V. Putin to the Federal Assembly: “We need our own advanced developments and scientific solutions. Digital technologies, other so-called end-to-end technologies, which today determine the face of all spheres of life. Countries that can generate them will have a long-term advantage. Others will find themselves in a dependent, vulnerable position. These are digital, **quantum technologies,** robotics, neurotechnology, etc. Digital technologies also carry risks. Cyber defense needs to be strengthened. The development of the digital economy, in its implementation we will rely on Russian companies”

- List of subtechnologies according to the NS protocol:
  - Quantum Computing.
  - Quantum communications.
  - Quantum sensors and metrology.
- Qualitative criteria to identify a sub-technology from a sample a large number of technological solutions (signs for each sub-technology):
  - Quantum computing: using quantum effects to solve computing tasks.
  - Quantum communications: technologies aimed at eliminating the threat information security, including by quantum computers, include using the properties of quantum systems for the transmission of keys. Core technology - quantum key distribution (QKD). The main advantage of CRC is security information guaranteed by the laws of physics.
  - Quantum sensors: using the properties of quantum systems to high-precision measurement of physical quantities, miniaturization or energy efficiency.

- Brief description of subtechnologies.

Quantum Computing.

Definition. Quantum computers and simulators are computing systems that using quantum phenomena to solve problems. Devices based on quantum computing, can be many times superior to classical computers with solving problems of cryptanalysis, modeling of complex systems, as well as computer learning and artificial intelligence. As existing quantum computers, the appearance of the first applied results can be expected in the direction accelerating machine learning tasks and modeling new promising materials.

priority sectors. The most promising and leading platforms three are considered in the world: superconducting chains, neutral atoms and ions in traps.

readiness levels. According to the QTRL classification of development companies in the world currently corresponds to QTRL levels 4–5, i.e. in computing systems these companies have not yet solved the problem of implementing quantum error correction codes and, accordingly, they cannot be fully implemented in practice. meaningful algorithms (for example, Shor's algorithm). In the Russian Federation, to date, implemented prototypes of quantum computers with 2 qubits (according to DC FPI 2–10 qubits) and quantum simulators with 10–20 qubits. This corresponds to QTRL level 3–4.

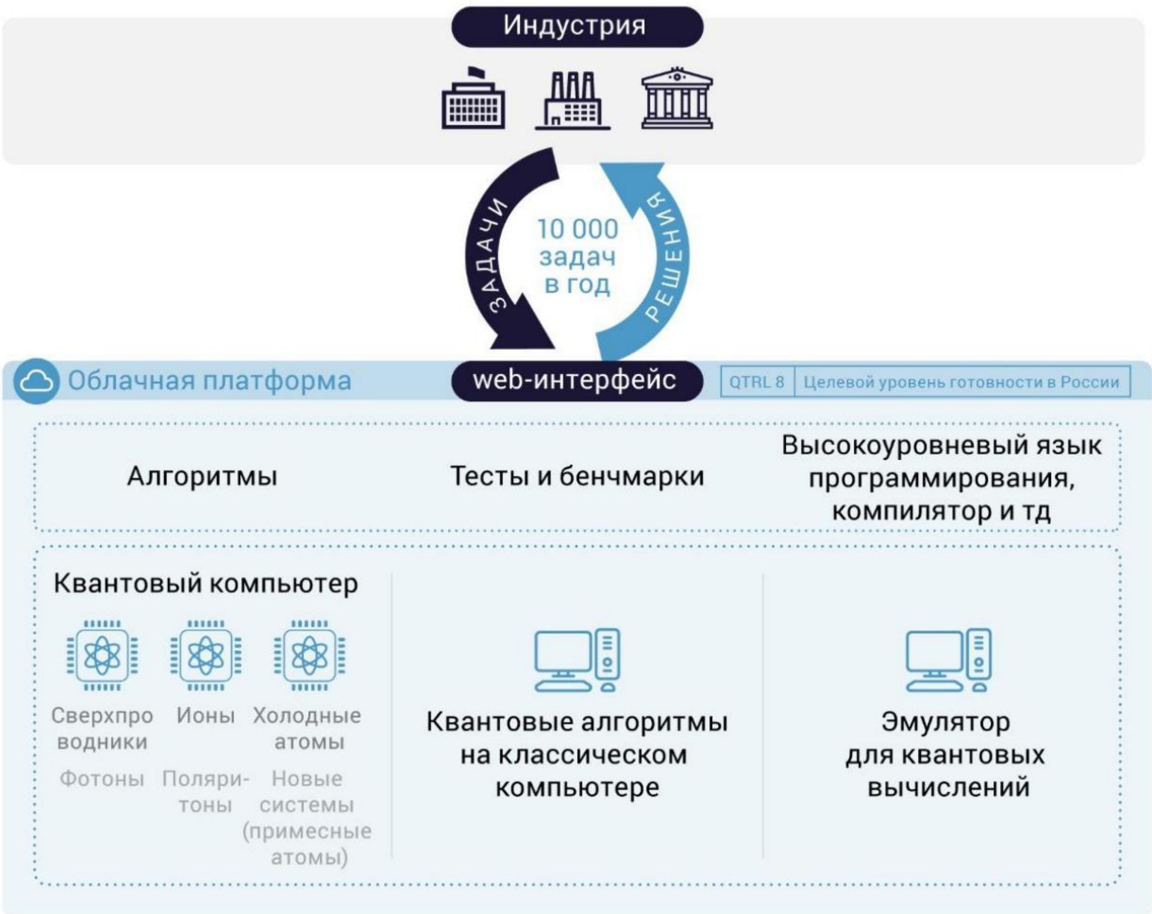
Key Specifications: Number of qubits implemented in a quantum computer, the size of a quantum register; degree of connectivity of qubits in the register; accuracy of quantum register initialization; condition measurement accuracy qubits; qubit lifetime; a set of valid logical operations; authenticity (precision) implementation of a set of logical operations that can be performed on quantum register.

The computational capabilities **of a quantum simulator** are determined by the class systems and phenomena that can be modeled with it, as well as the accuracy simulation results. Therefore, when evaluating their implementation, it is advisable to compare not the number of quantum particles in them, but the spectrum and demand for tasks to be solved this type of simulator.

Comparison Russia-World. Significant scientific groundwork has been created in Russia in the field of quantum computing, various element bases are also being developed for construction of quantum computers and quantum simulators. most promising and There are three leading platforms in the world: superconducting chains, neutral atoms and ions in traps (development level QTRL-4-QTRL-5). These destinations rather strongly developed in Russia (QTRL-2-QTRL-4). There is a backlog on quantum calculations using photons and integrated optics, quasiparticles (polaritons), as well as exploratory research on impurity atoms in silicon.

Extensive theoretical research is underway in the following areas: tomography quantum states and processes, error suppression in quantum computers, variational quantum algorithms, quantum machine learning algorithms, emulation quantum computing, optimization of quantum operations, resource research existing quantum computers.

Leading organizations: VNIIA im. N.L. Dukhov; IAE SB RAS; Institute applied physics of the Russian Academy of Sciences (Nizhny Novgorod); Institute of Spectroscopy RAS (ISAN); ITF them. L.D. Landau RAS; IFP A.V. Rzhanov SB RAS; IFP them. P.L. Kapitsa RAS; ISSP RAS; KNITU-KAI; KIPT; KFU; Moscow State Pedagogical University (MSGU); MSTU named after N.E. Bauman; MIPT; NUST MISiS; Novosibirsk State Technical University (NSTU, Novosibirsk); Russian Quantum Center (RCC, LLC "MCCT"); Skolkovo Institute of Science and Technology (Skoltech); Saint Petersburg State University of Information Technologies, Mechanics and Optics (ITMO); FIAN them. P.N. Lebedev; FTI them. A.F. Ioffe; FTIAN them. K.A. Valiev RAS; Center for Quantum Technologies, Lomonosov Moscow State University M.V. Lomonosov (TsKT Moscow State University named after M.V. Lomonosov).



Rice. 1. Quantum Computing to Solve Industry Challenges by 2024

Quantum communications.

Definition. Technologies aimed at eliminating the threat to information security, including by quantum computers, include the use properties of quantum systems for key transmission. The main technology is KKK. Main The advantage of QKD is the security of information guaranteed by the laws of physics.

Priority industries. Protection national information-telecommunications networks, ensuring information security for the financial sector, government agencies, large technology companies and critical information infrastructure.

readiness levels. The readiness level in the world is TRL-9 as in solutions point-to-point, and in networks with a trusted node. KRK equipment for networks with untrusted hosts is at the lab testing level. Today level the readiness of domestic point-to-point solutions can be estimated as TRL-8. While in terms of quantum networks based on trusted nodes, domestic developments of quantum networks are far behind the level of China and the EU: TRL-6 versus TRL-9.

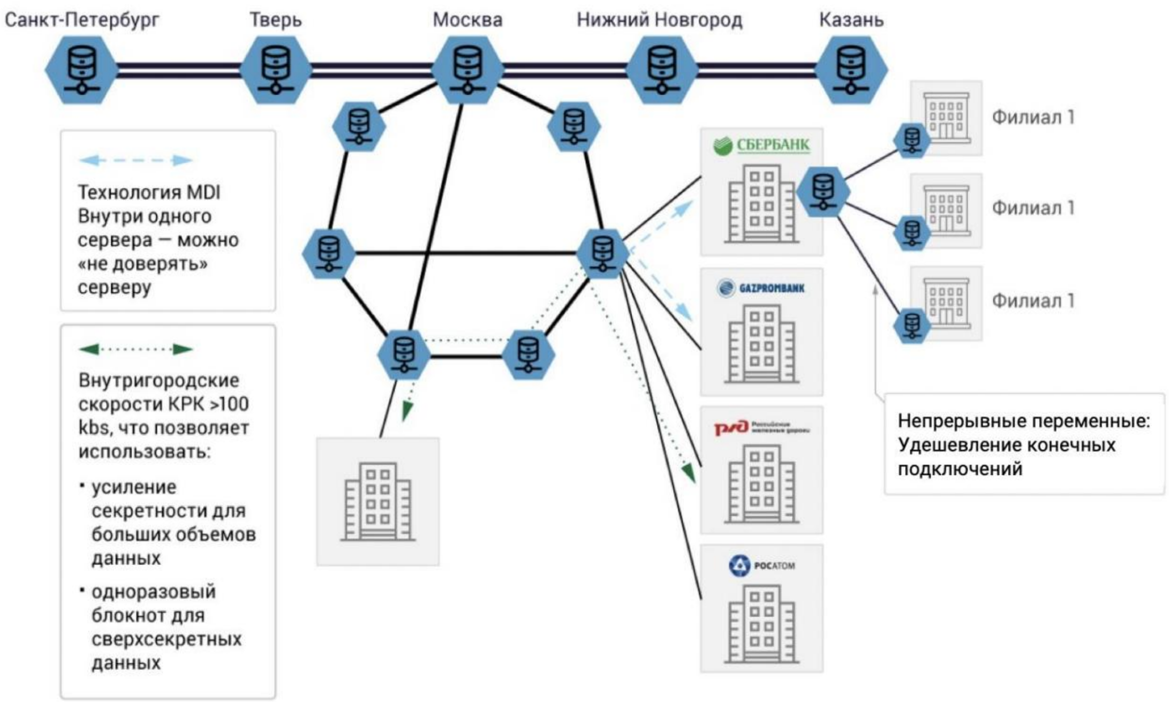
Key characteristics: the maximum range of distribution of secret keys, rate of distribution of secret keys, degree of secrecy of keys, price, infrastructure requirement. Parameters can be further supplemented based on the results discussions with the Regulator.

Comparison Russia-World. Historically, the dynamics of the movement of Russian teams very positive. As a result of a late start, only in 2016 were presented field testing of prototypes, which corresponds to a lag of 12–14 years. For 3 years the backlog on point-to-point decisions has been reduced to 3 years. Over the next 3-4 years it is necessary to eliminate the backlog completely during the duration of the program. In this regions in Russia there are significant scientific, technical and technological backlogs. There are several teams that demonstrate prototypes of new solutions (including prototypes of QKD networks) and conduct tests in real conditions. During the period functioning of the program proposed in this DC, it is supposed to create a number of market solutions for QKD systems certified by the regulator.

Actualization of the threat of a quantum computer will increase the speed of market development quantum communications both in Russia and abroad. Construction support quantum networks will form strong market players who will create both backbone networks, and branched city.

New solutions should allow the transition from point-to-point solutions to architecture "star" with reduced connection costs and solutions without the requirement for trust intermediate node. Accelerated development of domestic players will allow capturing 8% world market, which, in turn, should ensure the development of the industry beyond the horizon CE programs.

Leading organizations: CJSC Superconducting Nanotechnologies (Skontel); IFP A.V. Rzhanov SB RAS; Moscow State Pedagogical University; PJSC Rostelecom; RCC (together with companies KuRate, S-Terra, CryptoPro, Amicon, Security Code, MIAN im. V.A. Steklov); ITMO University (together with Quantum Communications, Smarts, Quanttelecom and KNITU-KAI Quantum Center); TsKT Moscow State University M.V. Lomonosov (together with InfoTeKS and Cryptosoft companies).



Rice. 2. An example of quantum network infrastructure in the Russian Federation by 2024

<u>Quantum sensors and metrology.</u>

Definition. Quantum sensors are high-precision measuring instruments, based on quantum effects. Quantum sensors are expected to have high spatial and temporal resolution, which will improve accuracy measurements in comparison with existing classical sensors, and the use properties of superposition, entanglement, compression of quantum states, in turn, will provide in the future the highest possible measurement sensitivity due to overcoming the standard quantum limit.

priority sectors. A high degree of control over the state of individual microscopic systems, provided by quantum technologies, allows you to create quantum sensors with high sensitivity. The development of technologies of various new generation sensors can give a powerful impetus in several areas at once: defense and security, navigation (space, unmanned vehicles); construction, oil production and exploration; medical diagnostics/therapy; industry 4.0.

readiness levels. General assessment of the level of readiness of quantum technologies sensors in the world TRL 3–9 and in the Russian Federation TRL 1–5.

Key features: Quantum sensors allow you to measure various physical quantities. In general, the key characteristics of sensors are: precision, sensitivity to changes in the magnitude of the detected signal; specificity to the analyzed signal; spatial and temporal resolution; dynamic range; operating range (frequency, temperature, etc.); time response or analysis; relative frequency reproducibility (time standards / frequencies); the possibility of multiple use due to the regeneration of the detecting surfaces (for example, in biosensors); Energy consumption; dimensions / mobility; complexity of maintenance and operation; life time; cost (capital and operating costs).

Comparison Russia-World. There is a steady development trend in the world quantum technologies and, in particular, quantum sensors. Level of general readiness (depending on the type of sensor) in the world is estimated TRL 3-9. On the market solutions in the field quantum sensors are represented mainly by foreign companies. In Russia (Technology Development Level TRL 1-5) Universities are the main developers and research institutes.

At the moment in the Russian Federation there are a number of promising solutions in the field of quantum sensory, based on the technological backlog of research organizations and manufacturing companies. Among these solutions, which have practical applications and commercial prospects include: optical atomic clocks; gravimeters/accelerometers based on rubidium atoms; gyroscopes based on ensembles of spins in solid body; local magnetic field and temperature sensors based on nitrogen-substituted vacancies in diamond and electric field – on color centers; electromagnetic sensors fields based on coherent states of spins in magnetically ordered media; spintronic sensors; magnetoplasma sensors; solid-state photomultipliers; spectrograph (electronic nose) using microresonators; sources and receivers of single photons. An important supporting technology is the development cheap laser modules.

Rice. 3. Areas of use of quantum sensors in the Russian Federation by 2024

Leading organizations: JSC ISS named after Reshetnev; JSC RIRV; VNIIFTRI; Time-H; ILP SB RAS; IAP RAS; ISAN; ISSP RAS; Moscow State University M.V. Lomonosov; MIPT; NUST MISiS; MEPhI; Joint Institute for Nuclear Research, FTI im. Ioffe; OOO "Analogue Photon Detector" (LLC "DEFAN"); RCC; Saint Petersburg State University of Information Technologies, Mechanics and Optics; FIAN them. P.N. Lebedev; TsKT Moscow State University M.V. Lomonosov; Center for Advanced Technologies and hardware.

- Prioritization of subtechnologies.

Support for all three major DH sub-technologies is critical to development of the Russian Federation.

From the point of view of the country's strategic interests, one of the key quantum computing technology. Both for future markets and for the state security, the effects of the use of this subtechnology will be very large. Also in this area there is a risk of restricting access to products of foreign manufacturers.

In terms of technological maturity closest to market entry is a quantum communications technology that provides, among other things, the national safety. In this area, the country is required to have its own products with the maximum degree of localization of production (both end devices and and component) to eliminate the risk of bookmarks in the equipment and, as a result, access to protected information.

Products based on quantum sensing and metrology will be able to transform many industries, but to unleash their market potential, interaction is required with the industry. Consideration of issues of prioritization of products of this subtechnology must be carried out separately for each individual product.

- Effects from the development of SDT (technological leadership, economic development, social progress).

National security. Quantum technologies can play a key role to create a competitive economy of knowledge and high technologies. Implementation national technology projects in the field of CT will help ensure national security and technological independence.

Technological leadership, socio-economic development. quantum technologies are based on the achievements of fundamental science in traditionally strong Russian scientific fields. Their development contributes to the technological leadership of the Russian Federation, and economic development and social progress. If the target is reached level of effects, this DC will ensure the introduction and development in the Russian Federation by 2024 the main technological innovation areas that will strengthen position of the country in the international arena and will provide long-term leadership in the field digital technologies and innovative development. Target indicator by place in the ranking GCI index (Global Competitiveness Report) - top 20 (now 43rd).

The comprehensive development of quantum technologies will not only have a significant effect on the pace of economic development, but will also improve its structure qualitatively, significantly will increase the share of GDP attributable to science-intensive and innovative products, expand the speed of adaptation of innovative solutions by individual market participants, will lay the basis for creating a long-term backlog of technological development. In other words, will increase not only the international index of digitalization, but also other recognized indicators the level of development of the country and its involvement in the world economy.

- **Key market trends and drivers for the development of DH.**

Quantum Computing.

ÿ The main consumer of quantum technologies is the state. This due to the strategic importance of quantum technologies to ensure national security.

ÿ According to Markets and Markets, the main growth drivers for the market quantum computing will be the fight against cybercrime, the use of quantum computing in the automotive and defense industries, as well as increasing the volume public investment. Europe, USA, China, UK, Japan, Canada and Australia have created programs for the development of quantum technologies.

ÿ Another driver for the development of quantum computing is the development machine learning and artificial intelligence. According to Accenture half of growth the economy of developed countries by 2035 will be due to AI - this is $ 2.5 trillion per year. If assume that the share of applications of quantum computing in AI will be 20%, then the corresponding monetary equivalent could be up to $500 billion a year.

ÿ Along with government support programs, interest in quantum technologies are shown by such companies as Google, IBM, Microsoft, Intel Alibaba, Hewlett Packard Enterprise, Nokia Bell Labs, and Raytheon. The first consumers have already appeared in the world quantum technologies. These include Lockheed Martin, Airbus, Volkswagen, etc.

ÿ Quantum computers can be applied to simulate new materials. The question of the possible application of quantum computers is widely discussed. for the synthesis of materials with superconductivity properties at room temperature, which will allow leveling losses in the transmission of electricity.

ÿ By consuming less energy in the future, quantum computers will be cheaper to use than classic supercomputers. The power consumption of quantum computers will be more than 100 times less, which will allow save tens of billions of dollars a year in the future.

Quantum communications:

ÿ The growth of the total number of data. By 2020, IDC forecasts the digital universe reaches 40 zettabytes. In total, since the beginning of 2010, the volume of data has grown 50 times.

ÿ Growth in the proportion of data in need of protection. According to IDC forecasts, the share information in need of protection is steadily growing: from 30% to 40% by 2020. At the same experts (Positive Technologies) note that the level of data protection not high enough.

ÿ Growth of investments in IT infrastructure (storage and management of information, equipment, telecommunications and personnel) from 2012 to 2020 by 40%. Investments in information storage and protection, Big Data and Cloud Computing will grow significantly faster.

ÿ Increasing number of information security incidents. Growing concern industry regarding data security. Total losses from cybercrime now over $1 trillion. per year, including 600 billion rubles. in Russia. Forecast for 2020 - up to $ 2.1 trillion

ÿ "Digitalization" of the economy: the rapid adoption of cloud technologies and blockchains. According to IDC forecasts by 2020 using cloud services will be almost 40% of the data is processed.

ÿ Accelerating the growth rate of quantum computing technology by increasing investments from the state (USA - $20 billion, China - $10 billion, European Union - 3 billion euros, etc.), from private companies (Google, Intel, IBM, Microsoft, Alibaba, Huawei, etc.), as well as from venture funds. According to The Economist, venture investors have invested more in projects in the field of quantum technologies $250 million in recent years. This applies to both startups developing hardware for quantum computers, as well as software and other technologies.

ÿ Large international companies in the field of consulting and audit (PwC, Accenture, Deloitte, etc.) Recommend Reviewing Long-Term Provisioning Plan information security due to quantum computers.

Quantum sensors:

ÿ One of the main market trends will be the use of quantum sensors in medecine. In particular, their use will be in demand in cytology. and creation of new medical devices, for example, for diagnostics and treatment cancer and other diseases.

ÿ Another major trend is the growing demand for the Internet of Things, which greatly stimulates the growth of the market for quantum sensors.

ÿ Also, the growth of the relevant market stimulates the development of global navigation systems, which are widely used in aerospace and automotive industries to navigate.

- High-level assessment of the presence of synergistic effects.

At the meeting of the National Assembly of the ANO "Digital Economy" it was decided to develop CT within a separate STC.

Quantum technologies are in demand for further progress in all strategic directions of the digital economy:

ÿ ~~Big Data: Using Quantum~~ Algorithms to Accelerate big data processing.

ÿ ~~Neurotechnologies and artificial intelligence: the use of quantum~~ algorithms to speed up the solution of machine learning and artificial intelligence problems; quantum sensors for neural interfaces.

ÿ ~~Distributed ledger systems ("blockchain"): protecting distributed~~ registries and blockchains using quantum cryptography and post-quantum algorithms.

ÿ New production technologies: quantum optimization production processes using quantum computing; protection is critical important industrial segments with the help of quantum cryptography and post-quantum algorithms; interactivity of production using quantum sensors.

ÿ Industrial Internet: integration of quantum sensors into the industrial internet of things.

ÿ Robotics and Sensory Components: Quantum and Quantum–inspired algorithms for robotics, in particular when integrating machine training in robotic systems; development of sensory systems based on quantum sensors, for example, for energy harvesting.

ÿ Wireless Technologies: Securing Data Networks and computing systems of cloud infrastructure using quantum key distribution and post-quantum algorithms.

ÿ Technologies of virtual and augmented reality: the use of quantum computing to speed up the processes implemented by virtual technologies and augmented reality.

- The list of risks and possible restrictions on the development of backlogs for DH, creating promising Russian solutions based on them.

The main mechanism for eliminating risks is the launch in the Russian Federation of large-scale scientific and technological programs to support quantum technologies and supporting technologies.

Table 1 - Directions, stages and activities for solving technological **problems**

Risks and restrictions	**Action to solve or overcome**	**Expected result**	**performance**
Scientific–technological (for details see Table 3)	Implementation of complex scientific and technological projects on this subject International cooperation Organizational forms for updating and prioritizing the roadmap Development of own technological solutions in the most important areas Support in Russia for the production of high-tech equipment - development of supporting technologies	Developed a mechanism for managing DC Prioritization of development directions is built Implemented projects to develop their own technological solutions for the most important directions	2019–2024
Organizational (see Table 5 for details)	Creation of an organizational form of DC management Creation of communication platforms for the exchange of best practices, regular scientific	Created organizational form of DC management	2019–2024

	seminars and specialized conferences Reduction of bureaucratic friction and creation of a comfortable infrastructure for work Implementation of new		
Personnel (for details see Table 5)	educational programs, primarily in specialized universities, work with talented schoolchildren and circle movement Programs to bring talent back from abroad (example: China's 1000 Talent Program)	Educational programs, including the international cooperation Implemented a program to work with the diaspora	2019–2024
Market (for details see Tables 3 and 5)	Participation of industry representatives in the formation of plans for integrated scientific and technological projects, and government support for demand Co-financing the construction of quantum communications infrastructure Introduction of relevant KPIs for state-owned companies	Increased demand for based on quantum technologies products Co-financing of infrastructure construction quantum communications Conducted activities for stimulate demand for services in the field of quantum communications	2019–2024

2. Current status and development targets up to 2021 and 2024 (technological and separate economic)

Table 2 - SDT targets

Index	**2019**	**2021**	**2024**
Number of publications on quantum technologies, per year	560	800	1200
including. the number of publications in journals with IF more than 3	190	290	480
Number of RIA, per year	thirty	50	60
Quantum Computing Number			
of qubits in a superconducting quantum computer	2	5–10	30–50
Number of qubits in a quantum computer on neutral atoms Number of	10	50	100
qubits in a quantum computer on ions	1	5	55

Index	2019	2021	2024
Number of channels in a quantum computer on photons	10	50	100
The number of particles in the quantum computer/simulator on polaritons Number of	50	100	1000
experiments on the quantum cloud platform	0	20	10000
Quantum communications (including pilot implementations)			
Total length of networks, km Supported	100	1000	10000
number of ports in point-to-multipoint networks	24	64	128
Maximum range outside the laboratory, km	100	200	250
Secret key generation rate, kbps per 25 km	10	100	5000
Equipment certification	-	+	+
Quantum sensors A			
number of types of industrial samples of quantum sensors have been developed.	2	4	6
	10–16	10–17	10–18
micron	10	2	0.5

Due to the fact that the technical characteristics of quantum sensors cannot be are universally defined for all types of quantum sensors, the definition targets, taking into account their relationship with each other, requires discussion with potential consumers. In addition, the directions of development within the framework of subtechnology quantum sensors will be prioritized.

3. Action plan for the development of "end-to-end" digital technology "Quantum technologies"

Table 3 - Directions, stages and activities for solving technological problems (separately for each subtechnology)

No. p / p	Necessary measures (actions) to solve the technological problem Subtechnology:	Expected result with specification	Implementation period	Suggested Support Tool*	Responsible operators of support measures
1	**Quantum communications Technological task:**				
1.1	**implementation of projects aimed at the development of quantum communications** 2019–2020 Support for leading companies, Pilot				
1.1.1	regional projects on the implementation of quantum-based QKD are used how companies	to distribute keys in element of the protection system information	projects for 5 large companies certified products for Support of		RVC JSC, Russian Foundation for the Development of Information Technologies
1.1.2	Multiplexing quantum and classical communication	Collaboration quantum channel with classic	2019–2021	Support for programs of activities of PERSONS, Grant support for small businesses	RVC JSC, Innovation Promotion Fund, National Project "Science" of the Russian Ministry of Education and Science Russian Foundation for the Development of Information
1.1.3	Implementation of satellite quantum cryptography	Successful implementation of QKD in the "Earth-Satellite" mode	2019–2023	Grant support for small businesses, Support for the development and implementation of industrial solutions	Technologies Innovation Promotion Fund, Ministry of Industry and Trade of Russia, National Project "Science" of the Ministry of Education and Science of R
1.1.4	Realization of the export potential of solutions for KKK	The emergence in the Russian Federation of products for CRC with competitive for the global market characteristics	2020–2024	Support by subsidizing the interest rate on the loan, Support for leading companies	Ministry of Telecom and Mass Communications of Russia, RVC JSC Russian Fund for the Development of Information Technologies
2	**Sub-technology: Quantum computing Technological**				
2.1	**task: implementation of projects aimed at the development of quantum computing** Creation of the first prototypes 2019–2021				
2.1.1	Implementation of quantum technologies Grant support for small businesses Support for programs of activities of individuals	quantum computers processors with 50-100 qubits; The task of achieving quantum superiority (solutions quantum computer tasks, which is unresolved classical technologies			Innovation Promotion Fund, RVC JSC, National project "Science" of the Ministry of Education and Science of Russia
2.1.2	Launch of a cloud platform for More than 10 companies use		2019–2024	Grant support for small	Innovation Promotion Fund,

No. p / p	Necessary measures (actions) to solve the technological **problem** of quantum computing	Expected result with specification	Implementation period	Suggested Support Tool*	Responsible operators of support measures
	(providing an API and having high-level programming languages) and a quantum processor emulator; tested on real physical systems error suppression and correction methods	cloud platform for quantum computing. The developed cloud platform uses at least 3 various types of quantum processors and has at least 10,000 launches per year to solve problems. It is integrated error suppression and correction methods 3		enterprises, Support for programs of activities of PERSONS	RVC JSC, National project "Science" of the Russian Ministry of Education and Science Russian Foundation for the Development of Information Technologies
2.1.3	Scaling quantum computers	prototypes of quantum processors with 30–50 qubits were created; solved the problem of achieving quantum superiority; implemented and tested 5 quantum algorithms for solving industrially demanded tasks **Subtechnology:**	2021–2024	Support for the development and implementation of industrial solutions, Support for the programs of activities of the LIC	Ministry of Industry and Trade of Russia, RVC JSC, National project "Science" of the Ministry of Education and Science of Russia Russian Foundation for the Development of Information Technologies
	Quantum sensors and metrology Technological task:				
	implementation of projects aimed at the development of quantum sensors and metrology Demonstration of prototypes of sensors for the				
3.3.1 3.1.1	industry	Demonstration of 2 types of quantum sensors	2019–2020	Grant support for small businesses, Support for programs of activities of PERSONS	Innovation Promotion Fund, RVC JSC, National project "Science" of the Ministry of Education and Science of Russia
3.1.2	Real world sensor testing	3 types of quantum sensors are being tested	2019–2021	Industry Solution Support, Small Business Grant Support	Skolkovo Foundation, Innovation Promotion Foundation
3.1.3	Implementation of sensors in IoT and medicine	5 projects launched introduction of quantum sensors	2019–2023	Support for the development and implementation of industrial solutions, Support for programs of activities of PERSONS, Grant support for small businesses	Ministry of Industry and Trade of Russia, RVC JSC, Innovation Promotion Fund, National Project "Science" of the Ministry of Education and Science of Russia

No. p / p	Necessary measures (actions) to solve the technological problem	Expected result with specification	Implementation period	Suggested Support Tool*	Responsible operators of support measures
3.1.4	Small-scale production	Created 6 types of quantum sensors Russia has a new generation sensor-based products	2019–2024	Support for leading companies, Grant support for small businesses	RVC JSC, Innovation Promotion Fund Russian Foundation for Information Technology Development

*– Some areas may be partially funded by the National Project "Science"

4. Estimation of required resources in relation to support instruments (until 2024)

Table 4 - Assessment of the need for financing by areas of development, billion rubles

	Full DC budget										Prioritization based on the approved CE budget		
Quantum Computing -	**4.9**	**2.1**	**3.2**	**2.8**	0	**2.2**	0	**12.8**	**2.4**	0	**81%**	**9.93**	**2.4**
within budgetary funds - within	3.7	2.1	3	2.3	0	1.7	0	12.8	0	0	78%	9.93	0
extrabudgetary funding Quantum	1.2	0	0.2	0.5	0	0.5	0	0	2.4	0	100%	0	2.4
communications - *within*	**0.15**	**0.81**	**3.120**	**1,840**	**1.17**	**2.94**	0	**6.59**	**3.44**	**1.25**	**100% 6.59**		**3.44**
budgetary funds - under	0.15	0.81	2.180	0.875	0.385 2.19		0	6.59	0	1.25	100%	6.59	0
extrabudgetary funding Quantum sensors	0	0	0.94	0.965	0.785 0.75		0	0	3.44	0	100%	0	3.44
- within budgetary	2	1	**1.5**	2	**0**	1	0	7	**0.5**	0	**76% 5,189**		**0.541**
funds - under extrabudgetary funding	2	1	1.5	1.5	0	1	0	7	0	0	74% 5,189		
Total budgetary funds Total extrabudgetary	0	0	0	0.5	0	0	0	0	0.5	0	100%		0.541
funds Total	**5.85**	**3.91**	**6,680**	**4.675**	**0.385 4.89**		**0**	**26.39**	**0**	**1.25**		**21.709**	
	1.2	0	**1.14**	**1.965**	**0.785**	**1.25**	**0**	0	**6.34**	0			**6.381**
	7.05	**3.91**	**7,820**	**6.640**	**1.17**	**6.14**	0	**26.39**	**6.34**	**1.25**		**21.709**	**6.381**

In the case of additional funding for certain items, the exempt the funds will be used to finance the rest of the items.

Table 5 - Assessment of the need for financing of supporting, organizational and sectoral activities, billion rubles.

Project Description	Full DC budget		Prioritization based on the approved CE budget Percentage		
	Budget financing	extrabudgetary noe financed ing	of funding	Total for subSTP (CE budget)	Total for sub-DH (extrabudgetary CE)
Organization of profile special courses in within the framework of the school departments of quantum technologies on the basis of universities, as well as centers of additional education	1	0	50%	0.5	0
Formation of standards and verified methods for educational courses in schools, colleges, universities	0.5	0	70%	0.35	0
Organization of a long-term information and educational campaign to attract domestic specialists in Russian research and commercial organizations	0.2	0	100%	0.2	0
Promotion of professional education: further development of competencies in the field of quantum technologies on the WorldSkills platform	0.05	0	100%	0.05	0
Formation of infrastructure and package of support measures for the development profile start-ups in the territories of Russian science cities and technology parks (Skolkovo, Innopolis, Sirius Park, etc.)	5	0	50%	2.5	0
Organization of a series of hackathons (development competitions) with subsequent financing of the best projects	0.3	0	100%	0.3	0
Organization of the work of an intersectoral center for the implementation of CT in the activities of domestic corporations	0.7	0	50%	0.35	0
Organization of the work of an intersectoral knowledge management center in the web format -resource	0.4	0	50%	0.2	0
Organization of a long-term information and educational campaign to attract foreign personnel to Russian research and commercial organizations	0.3	0	100%	0.3	0
Advisory support for the entry of Russian specialized enterprises into the international market	0.5	0	100%	0.5	0
Development and implementation of a comprehensive program to promote products and services created by Russian start-ups in the foreign market	1	0	100%	1	0
Creation of a separate organizational structure for the management of DC	1.2	0	100%	1.2	0

Project description	Full DC budget		Prioritization based on the approved budget of the DO		
	Budget financing	extrabudgetary noe financed ing	Percentage of financing by ing	Total by sub-TP (Budget DO)	Total Sub-MTF (Extra-budget of the DO) and
Formation of industry projects	3.6	2.4	70%	2.52	1.68
TOTAL	**14.75**	**2.4**		**9.97**	**1.68**

In the case of additional funding for certain items, the exempt the funds will be used to finance the rest of the items.

Thus, all DC activities involve the allocation of 51.15 billion rubles. (including 8.74 billion rubles of extra-budgetary funds) for the implementation of the proposed initiatives, including 34.00 billion rubles. for the main development projects and 17.15 billion rubles. for organizational, personnel and industry events.

- Prioritization of allocation of funds by support instruments in the context of subtechnologies.

Due to the fact that the markets for quantum technologies are currently only are formed, and also have a large scientific and technical component, primarily turn it is necessary to support R&D (R&D stage) aimed at the development of SDT and the creation of specific market products in the future. Also important is support for industry and infrastructure projects for implementation, especially for quantum communications as the closest technology to the market.

Within the framework of the approved budget financing of the National DE Program prioritization of funding was carried out in the context of individual projects (more see Appendix 1). As a result, taking into account the prioritization of projects, the activities of the DC assume the allocation of 40.99 billion rubles. (including 8.061 billion rubles of extra-budgetary funds), including 29.34 billion rubles. for the main development projects and 11.65 billion rubles. for organizational, personnel and industry events.

- **CONCLUSIONS**

Comprehensive CT support is needed for a breakthrough. At the same time, I would like to note the role of organizational measures:

ÿ One of the critical barriers to the implementation of the program and plan actions of the DC is the lack of consolidation of the scientific and technological community and its relationship with the industry. For the purpose of managing this DC, it is proposed **to create a separate organizational structure** (following the example of ANO "Digital Economy").

ÿ **International cooperation and work with the diaspora.** important Russia's competitive advantage is its extensive, highly skilled and passionate Russian-speaking scientific diaspora abroad. attraction intellectual resources of thousands of scientists who found themselves abroad after the collapse of of the Soviet Union, will ensure a sharp increase in the country's creative potential in a key scientific area. A similar program (“1000 talents”) has been successfully implemented in China.

As a result, the integrated implementation of the DC will allow:

1. Close the gap on such critical technology directions like quantum computing.

2. To create competitive products in the direction of quantum communications with export potential and enter international markets.

3. Implement national technology projects in the field of CT, contributing to national security and technological independence.

Based on the recommendations of the CE Supervisory Board, currently with experts an ambitious plan is being worked out to implement the quantum computing program.

Annex 1 - Prioritization of financing in the context of individual areas, billion rubles

	Full DC budget Budget					**Prioritization based on the approved budget of the CO** Budget			
Subtechnology	Off-budget	Budget zhet	Total financed	Percentage (outside CE)	ovations	Off-budget	Budget (outside the CO)		Total
Quantum Computing	**12.800**	**2.400**		**15,200**		**9,930**	**2,400**		**12.330**
Superconducting quantum computers and simulators Quantum	3.000	1.200		4,200	100%	3,000	1,200		4.200
computers and simulators based on neutral atoms Quantum computers	2.250	0.600		2,850	100%	2,250	0.600		2,850
and simulators based on ions in traps Quantum computers and simulators	1.500	0.600		2,100	100%	1,500	0.600		2,100
based on photons and integrated optics Simulators based on polariton condensates Quantum	1,000			1,000	30%	0.300			0.300
computing on impurity atoms and quantum dots in silicon	1,100			1,100	30%	0.330			0.330
Quantum error suppression methods Quantum Error Correction Codes Quantum Algorithms	2.000			2.000	30% 0.350	0.600			0.600
Quantum Computing Emulator Cloud Quantum	0.350			100%	0.400 100%	0.350			0.350
Computing Platform	0.400					0.400			0.400
	0.300			0.300	100%	0.300			0.300
	0.450			0.450	100%	0.450			0.450
	0.450			0.450	100%	0.450			0.450
quantum communications	**6.590**	**3.440**	**1.250**	**11.280**		**6,590**	**3.440**	**1,250**	**11,280**
Quantum point-to-point key distribution Quantum	**0.662**	1.228	0.950	1,890	100%	0.662	1.228	0.950	1,890
networks based on trusted nodes Quantum networks	3.238	1.477	0.200	4.715	100%	3.238	1.477	0.200	4.715
based on untrusted nodes QKD in open space for	1.400	0.250	0.050	1,650	100%	1,400	0.250	0.050	1,650
satellite solutions and unmanned vehicles Post-quantum cryptography Quantum sensors **and**	1.040	0.335	0.050	1.375	100%	1.040	0.335	0.050	1.375
metrology	0.250	0.150		0.400	100%	0.250	0.150		0.400
	6.959	**0.541**		**7,500**		**5.189**	**0.541**		**5.730**
Organizational events	**14.750**	**2.400**		**17,150**		**9.970**	**1.680**		**11.650**
Organization of specialized special courses within the framework of the school education program, departments of quantum technologies on the basis of universities, as well as centers of additional	1,000			1,000	50%	0.500			0.500
education Formation of standards and verified methods for educational courses in schools, colleges, universities	0.500			0.500	70%	0.350			0.350

Subtechnology	Full DC budget Budget					Prioritization based on the approved budget of the CO Budget			
	Off-budget	Budget zhet	Total financed	Percentage (outside CE)	ovations	Off-budget	Budget (outside the CO)		Total
Organization of a long-term information and educational campaign to attract domestic specialists to Russian research and commercial organizations Promotion of professional education: further development of	0.200			0.200	100%	0.200			0.200
competencies in the field of quantum technologies on the platform WorldSkills	0.050			0.050	100%	0.050			0.050
Formation of infrastructure and a set of support measures for the development of specialized start-ups in the territories of Russian science cities and technology parks (Skolkovo, Innopolis, Sirius Park, etc.) Organization of a series of	5,000			5,000	50%	2,500			2,500
hackathons (development competitions) with subsequent financing of the best projects Organization of the work of an	0.300			0.300	100%	0.300			0.300
intersectoral center for the implementation of CT in the activities of domestic corporations	0.700			0.700	50%	0.350			0.350
Organization of the work of the intersectoral knowledge management center in the format of a web resource	0.400			0.400	50%	0.200			0.200
Organization of a long-term information and educational campaign to attract foreign personnel to Russian research and commercial organizations	0.300			0.300	100%	0.300			0.300
Advisory support for the entry of Russian specialized enterprises into the international market	0.500			0.500	100%	0.500			0.500
Development and implementation of a comprehensive program to promote products and services created by Russian startups in the external market	1,000			1,000	100%	1,000			1,000
Creation of a separate organizational structure for the management of DC	1,200			1,200	100%	1,200			1,200
Formation of sectoral projects	3,600	2,400		6,000	70%	2.520	1.680		4,200
TOTAL	**41.099**	**8,781**	**1.250**	**51.130**		**31.679**	**8.061**	**1,250**	**40,990**