GRAND CHALLENGES 2025

Internet of Everything: resilient and efficient

GESELLSCHAFT FÜR INFORMATIK

The evolution and future of the Internet into the Internet of Everything bring new requirements and significant challenges for communication networks. How to meet these demands is discussed in this Grand Challenge.

The Internet has long been part of our everyday lives and enables innovation in a wide range of areas of society. Through the networking of people, machines, things, data, processes and services, as well as the merging of the physical and virtual worlds, the importance of the Internet will continue to increase in the future, both socially and economically. The basis for all this are global communication networks. On the one hand, they provide connectivity and transfer the gigantic data volumes quickly, almost in real time. On the other hand, they are still efficient, reliable, and secure, which means that the applications and services can be used in high quality.

The evolution and future of the Internet into the Internet of Everything bring new requirements and significant challenges for communication networks. The Internet of Everything encompasses the idea that not only physical objects (Internet of Things) and people, but also sensory experiences (Internet of Senses), virtual realities – and practically everything – can be connected and integrated into a larger digital ecosystem. People can move, communicate and interact immersively in both physical and virtual spaces as avatars in augmented reality environments and in virtual worlds. Real and virtual worlds are merging, especially through digital twins. The fusion of communication and compute infrastructures poses challenging tasks for computer science: for example, for the native integration of artificial intelligence into networks or the integration of technologies for capturing sensor data and technologies into communication networks. A high-performance communications infrastructure is essential for the successful implementation of applications in areas such as Industry 4.0, smart cities, smart grids, virtual reality, networked driving and telemedicine, as well as for the effective collection, transmission, and processing of large amounts of data. The further development of communication networks and of the networking of the worlds are drivers of innovation for the future.

What exactly is behind this challenge?

The fusion of physical and virtual worlds is a visionary concept in which technologies enhance and expand human sensory experiences by integrating digital information and sensations into our daily lives. Human individuals and machines, in particular computers, artificial intelligence and digital twins, will work together in the future in everyday life or in a professional environment to achieve common goals or accomplish tasks.

This requires high-performance, high-speed networks for data transport, with data processing taking place closer to the source or within the networks to act quickly enough and in near real time. The simultaneous use of communication, computing, and sensor functions in an integrated communication-sensor-compute system enables optimized and efficient use of resources and data. Then, sensors capture the required information and at the same time enable communication to transfer this information to the relevant places. This is particularly important in applications where real-time data and actions are required. In connected

vehicles, sensors are used to collect environmental data such as traffic conditions and distance monitoring. At the same time, these vehicles communicate with each other via wireless networks to exchange data and increase road safety.

Global network coverage requires the integration of new technologies into today's Internet, for example through non-terrestrial networks, but also through specialized networks, such as industrial networks or smart city networks. In particular, the development and implementation of the sixth generation of mobile communications systems (6G) seeks to embrace the convergence of networks and technologies.

The complexity of communication networks is increasing, which is due to billions of networked people and devices, high demands, but also the heterogeneity of the involved components. Therefore, interoperability is essential for global networks. To control and optimize the systems, network monitoring and management approaches are needed that draw on explainable models and methods of artificial intelligence. Virtualized networks and slices for specific applications also support manageability. The resilience and reliability of the network infrastructure and the entire communication-sensor-compute infrastructure are key. Such critical infrastructure is essential to the smooth functioning of society and the economy.

The communication networks of the future should be human-centered, putting people and their needs first. To achieve this, the development and implementation of the networks must aim to natively consider and improve human experiences. This may include improving connectivity, speed, capacity, security, and usability to enhance people's quality of life and enable new fields of application.

Promoting sustainability in communication networks not only helps to reduce environmental impacts but can also provide long-term economic benefits and strengthen society as a whole. This is particularly important at a time when digitalization is playing an even greater role in our lives. In addition to energy efficiency and reducing energy consumption to shrink our ecological footprint, the integration of renewable energy sources and zero-energy devices plays a significant role. However, novel approaches to the production and operation of networks that consider the scarcity of resources must also be researched and implemented. These challenges require a concerted effort to advance communication networks and meet the evolving needs of our interconnected world.

Why is it important to tackle the problem?

Many of the requirements are in direct conflict with each other, meaning that in practice, suitable trade-offs have to be found. The desired convergence of networks and technologies, as well as scalable and flexible solutions, increases the complexity. Networked worlds can generate and process enormous amounts of data. This complexity requires automation in the monitoring and management of networks, which, however, must make comprehensible and explainable decisions.

- The quality of services and applications as perceived by users, which is the so called quality of experience, as well as the reliability and availability of the systems, must be guaranteed. However, the optimization of networks, the protection of privacy and of personal information can come into conflict with each other.

- The massive energy consumption and resource usage of networked systems can pose ecological challenges. The development of environmentally friendly technologies and practices is therefore of great importance. Sustainability and energy efficiency require a paradigm shift in networks but can directly conflict with quality and availability.
- The integration of different technologies and platforms is complicated. It requires the development of interoperable standards, protocols, and infrastructures to enable seamless communication and collaboration between different systems, especially for integrated communication-sensing-computation systems.
- The networked worlds can also raise new ethical, legal and social questions. The responsible development and use of these technologies are crucial to maximize the benefits and minimize the possible risks.
- Communication networks are a critical infrastructure of the modern digital society, whose high availability, traceable behavior and compliance with quality standards are essential. However, this requires a trade-off between regulation and standardization on the one hand and free technological development on the other.

In what time frame a solution can be expected?

Over a period of five to 15 years, partial solutions will emerge, and a gradual transformation of the existing Internet will take place.

What efforts have already been invested in the solution?

There are numerous approaches to solving selected problems, but to date, there has been a lack of coordinated action and a joint Grand Challenge within the entire field of computer science.

Which disciplines have to work together on this challenge?

An interplay of different disciplines of computer science is necessary to realize the networked worlds of the future: communication networks and distributed systems; database management for storing and managing large databases; security and data protection; artificial intelligence, for example for automation; software development of software-based, programmable and virtualized networks; IoT technologies, sensor technology, embedded systems and the integration of physical devices into digital worlds; human-computer interaction for user-friendliness and human interaction in networked systems and augmented realities.

What target scenarios and criteria can be established?

The smooth interaction of different devices, platforms, technologies, and systems in networked worlds is crucial. If different components are compatible with each other and can interact seamlessly, this indicates that the goal of networking has been achieved. Key value indicators can be defined and recorded to assess the quality of networked worlds, for example with regard to the ecological and economic sustainability of communication networks or the quality of life of people.

What social, societal or economic problems can be addressed with the Grand Challenge?

Networked worlds have the potential to address a wide range of social and economic issues through solutions at the application level. These include telemedicine, online education, environmental protection technologies, efficient mobility, social interaction, flexible working, security systems and disaster protection. This contributes to improving the quality of life and overcoming global challenges.

Digitization and networking enable flexible working and access to job opportunities anywhere in the world. Automation and robotics in industry improve safety, efficiency, and productivity. Sensor networks and IoT technologies enable the monitoring of environmental parameters and contribute 4ot he early detection of environmental problems. Networked monitoring systems and sensor networks can improve public safety and the response to natural disasters. Early warning systems enable a timely response to potential hazards. Remote monitoring and telemedicine enable better patient care. Real-time health data can be analyzed to track disease outbreaks and improve prevention. Virtual classrooms and distance learning can provide educational opportunities for disadvantaged populations.

About the authors

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Further reading

VDE Association for Electrical, Electronis & information Technology: Information Technology Vision 2035, VDE Impulse Paper, Offenbach am Main, November 2024.
https://www.vde.com/de/itg/publikationen/studien/vde-impulse-paper-information-technology-vision-2035