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Emerging Networks Technologies in the Digital Transformation Age (Based on SDN, IBN, IoT, 5G/6G, Blockchain)

Mykhailo Klymash | Mykola Beshley | Andriy Luntovskyy | Ilona Scherm

This paper provides a comprehensive overview of the main communication and networking technologies emerging in digital transformation. The focus is on emerging technologies such as software-defined networking (SDN) based on network functions virtualization (NFV), cloud and edge computing, 5G/6G, AI solutions for deploying cognitive communication networks. Practical and innovative applications of such networks are also discussed, including network security, smart cities, e-health and smart systems. A number of key issues in the areas of Internet of Things (IoT) and intent-based networking (IBN) smart systems are examined. Fundamental concepts and architectures for new developments in communications are proposed.

Keywords: IoT, SDN, NFV, Cloud Computing, 5G/6G, Artificial intelligence, IBN.

Dieser Beitrag liefert einen umfassenden Überblick über die wichtigsten Kommunikations- und Netzwerktechnologien, die bei der digitalen Transformation zum Einsatz kommen. Der Schwerpunkt liegt dabei auf neuen Technologien wie softwaredefinierten Netzen (SDN) auf der Grundlage der Netzfunktionsvirtualisierung (NFV), Cloud- und Edge-Computing, 5G/6G und KI-Lösungen für den Einsatz kognitiver Kommunikationsnetze. Darüber hinaus werden praktische und innovative Anwendungen solcher Netze erörtert, darunter Netzsicherheit, intelligente Städte, E-Health und intelligente Systeme. Eine Reihe von Schlüsselfragen in den Bereichen Internet der Dinge (IoT) und absichtsbasierte Vernetzung (IBN) intelligenter Systeme werden untersucht. Es werden grundlegende Konzepte und Architekturen für neue Entwicklungen in der Kommunikation aufgezeigt.

1. Introduction

Digital transformation is the integration of digital technologies to transform a service or business by replacing digital or manual processes with digital ones. A digitization process transforms manual activities into digital forms that are processed, stored and transmitted through digital devices and networks [1].

Networking technology has developed significantly in recent years as user requirements for information services have increased remarkably. Today's information and communication networks must manage traffic generated from many other sources, such as streaming video, Network Attached Storage (NAS), Voice over IP (VoIP), virtualization, cloud and IoT devices, and services that generate demand for high-bandwidth systems.

This paper examines the major trends in networking technology that rank in the top 10 in 2022-2023. The need for high-speed Internet, automated and intelligent resource management, cloud and edge computing models, and server-to-server data migration have led to a shift in the need for high-bandwidth, low-latency networking technologies. Emerging network technologies in the digital transformation age are shown in Fig.1.

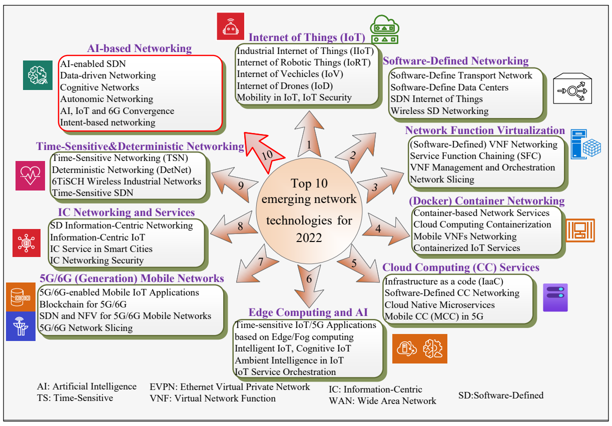

Fig.1 Emerging network technologies in the digital transformation age [2]

New emerging technologies are changing the architectures of networks and services. Key benefits of future networks include intelligent network management, a faster process of innovation, which contributes primarily to the fast pace of technological progress and competition, increased network reliability and security, quality of experience, and harmonized access control policies.

2. EMERGING NETWORK TECHNOLOGIES: DEFINITION, CONCEPTS AND APPLICATION

2.1. Internet of things

The evolution of technology is moving at a rapid pace, and with it, so is technological innovation. "M2M" and "IoT" are two innovative terms that are often discussed in the tech innovation community.

Many scenarios for the use of IoT technologies, which are now commonly referred to as the Internet of Things paradigm, are actually ordinary M2M connections (Machine-to-Machine): they implement the collection, management and visualization of data for the needs of an enterprise without human intervention. The definition of machine-to-machine communication M2M (Machine to Machine) is quite simple [3]. It originates from telemetry technology and means the transfer of data between two devices, usually directly, without processing elsewhere. This concept was already known before the advent of the Internet. The idea of IoT arose on the basis of M2M, enriching this technology with new features and capabilities. The Internet is used not only as a vehicle but also as a system for the interaction of many similar devices combined into a single system, often operating in several different environments.

IoT allows the development of applications in many different domains, such as home automation, industrial automation, medical aid, traffic management, and many others. Accordingly, IoT can be classified as follows: Industrial Internet of Things (IIoT), Internet of Robotic Things (IoRT), Internet of Vehicles (IoV), Internet of Drones (IoD). The different IoT applications have a range of QoS requirements, which can be typically categorized as best effort (no QoS), differentiated services (soft QoS) and guaranteed services (hard QoS), especially for mission-critical IoT applications [4].

2.2. Software-Defined Networking

Recent advances in networking technology are aimed at simplifying the construction and management of networks. Software Defined Networking (SDN) is a paradigm shift that fundamentally changes the architecture of network devices and, as a consequence, the entire communication network. Specifically, SDN promotes the distribution of the control plane and data in network devices. This approach allows to centralize the control logic in a structure called SDN Controller. Thus, network devices become simple forwarding elements, processing data packets in accordance with the instructions of the logic that is in the controller. SDN technology based on OpenFlow allows system administrators to solve problems of high throughput, the dynamic nature of modern services, network adaptation to constantly changing business needs, and complexity of operation and management.

Currently, SDN technology is used for the development of various infrastructures and is classified into the following areas: Software-Define Transport Network, Software-Define Data Centers, SDN Internet of Things [5], Wireless SD Networking.

2.3. Network Function Virtualization

NFV is a network architecture concept that separates network functions from related specialized hardware, making them a more modular unit that can be deployed or linked to create a network service. The need to separate network functions from network devices arises when the use of new services in the network becomes more complex than the demand for the network grows. In a legacy network, there are many middle blocks that are closely related to one or more related network services. In particular, middle blocks are network objects or devices that are capable of transmitting, transforming, filtering, inspecting, or controlling network traffic to better manage the network.

Technically, all network functions offered by legacy network devices can be virtualized and called a virtualized network function (VNF). VNFs can be created and deployed in any NFV infrastructure facility (NFVI). VNFs can be linked together to create specialized network services to provide the necessary and varied user requirements. The benefits of NFV are summarized below [6]:

- Flexibility in the deployment of new network services.
- Independent reconfiguration.
- High scalability.
- Reduced time to deploy new services on the network.
- Reduced capital and operating costs.
- High performance and network management by allocating resources on demand.

The combined use of SDN and NFV enables the important concept of network slicing. Network slicing can be defined as a group of network functions that work together with a specific radio access technology (RAT) to achieve optimum network utilization. In other words, network slicing is a way to support communication services through a dedicated connection. Network slicing allows a network operator to build multiple logical networks (each for a specific use case) on the same physical infrastructure.

2.4. (Docker) Container Networking

Container networking is a virtualization method that divides applications into independent blocks. Containers are similar to virtual machines but have several key differences [7].

Containers can run large distributed applications with low overhead. This is achieved by sharing a stripped-down operating system kernel (usually Linux-based), which makes them more efficient than virtual machines (VMs). Containers are also simpler than virtual machines.

The container is created from a prepared image assembled from a special registry, such as the Docker Hub or another private registry. To perform its functions, the platform uses a Docker daemon, which is a server or a long-running process that runs on the operating system and accepts requests from the Docker engine API.

As the daemon "instances" a container, it assigns it a unique network address connecting it to a virtual Ethernet bridge to communicate between containers. In the case of Docker, the bridge is called docker0. All containers in the system communicate with each other by

directing packets to docker0, which then automatically forwards those packets across the subnet.
When creating new types of applications, developers have the option of using a containerized software system built from microservices linked together using APIs.
Containerized systems require less storage space and run faster. With microservices, each container behaves as if it were its own Web site with its own Web server. Containers can access each other's workloads through API calls. The APIs are parsed by the DNS server assigned by the container daemon.
Container orchestration systems, such as Kubernetes and Apache Mesos, are network operations centers used to manage container subnets.
As a virtual subnet, a Docker or Rocket container network is a kind of SDN.
Separating the Docker subnet from the underlying network hardware is extremely important. This allows entire container networks to migrate between platforms, including from private clouds to public clouds, without change. Container networks can span multiple platforms - for example, core services can run on private premises, while overflow containers can be installed in a public cloud such as Amazon Web Services (AWS). This improves efficiency and ensures consistent bandwidth and application performance even during times of peak network load. Containers offer many advantages in managing IoT data, deploying and supporting applications and operating systems.

2.5. Cloud computing

Cloud computing refers to the use of various services such as software development platforms, storage systems, servers and other software over an Internet connection.
Cloud computing can be deployed in the form of business models, which may vary depending on specific requirements. Some of the standard service models used are described below [8]:

- Software as a Service or SaaS. In SaaS, consumers can buy the ability to access or use software or services hosted in the cloud.
- Platform as a Service or PaaS. PaaS allows consumers to buy access to platforms, allowing them to deploy their software and programs in the cloud. The consumer does not control the operating systems or network access, which can create some constraints on the nature of the applications that can be deployed.
- Infrastructure-as-a-Service or IaaS. Consumers can control and manage operating systems, applications, network connectivity and storage without managing the cloud itself.

Cloud computing in mobile applications (MCC) is a method of using cloud technology to create mobile applications. Today's sophisticated mobile applications perform tasks such as authentication, user location accounting, and providing targeted content and communication to end users. Therefore, they require extensive computing resources such as storage capacity, memory and processing power. With cloud computing, it is possible to reduce the load from mobile devices due to the power of cloud infrastructure. Developers create and update feature-rich mobile apps using cloud services and then deploy them to be accessed remotely from any device. Mobile apps use cloud technology to store and process data in a way that can be used on all types of old and new mobile devices.
The benefits of using cloud computing

- Scalability/Flexibility

Cloud computing allows companies to start with a small amount of cloud computing and expand fairly quickly and efficiently. Downsizing can be done quickly if the situation requires it. It also allows companies to add additional resources as needed, allowing them to meet growing customer needs.

- Reliability

Services that use multiple redundant sites support business continuity and resumption after a failure.

- Maintenance

Cloud service providers perform system maintenance themselves.

- Mobile Availability

Cloud computing also supports mobile accessibility to a greater extent.

- Cost savings.

2.6. Edge Computing and AI

The concept of " edge computing" refers to storing data and processing power closer to the device or data source where it is most needed.
The definition of edge computing is a generic term for devices taking some of their key processes and moving them to the edge of the network (close to the device). These processes include computation, storage, and networking.
Edge Computing enables the distribution of computing resources and application services over the link through a decentralized computing infrastructure. Computational needs are met more efficiently when Edge Computing is used. Wherever there is a need to collect data or when a user performs a certain action, it can be performed in real time. Generally, the two main benefits associated with edge computing are improved performance and reduced operating costs, which are briefly described below.
Benefits of using Edge Computing:

- Improved performance.

In addition to collecting data for transfer to the cloud, edge computing also processes, analyzes, and performs necessary actions on the collected data locally. Since these processes are completed in milliseconds, it becomes essential to optimize technical data, no matter what the operations may be.
Transferring large amounts of data in real time in a cost-effective way can be a problem, primarily when it is done from remote industrial sites. This problem is eliminated by adding smart data to devices at the edge of the network. Marginal computing brings analytical capabilities closer to the intermediary eliminator machine. This system provides less costly asset performance optimization options.

- Reduced operational costs

The cloud computing model has connectivity, data migration, bandwidth and latency options that are rather expensive. Using edge computing requires significantly less bandwidth and lower latency. Using edge computing creates a valuable continuum from device to cloud that can handle huge amounts of data. More expensive bandwidth additions are no longer required because there is no need to transfer gigabytes of data to the cloud. It also analyzes sensitive data on the local network, thereby protecting sensitive data. Enterprises are now opting for modern computing. This is due to their optimized performance, compliance and security protocols, and lower costs.

Edge computing helps reduce reliance on the cloud and, as a result, improve data processing speeds. In addition, there are already many advanced devices with processing power and available memory. Moving to advanced computing power allows these devices to be used to their full potential. A multi-level system of edge and cloud computing for future network is depicted in Fig.2.

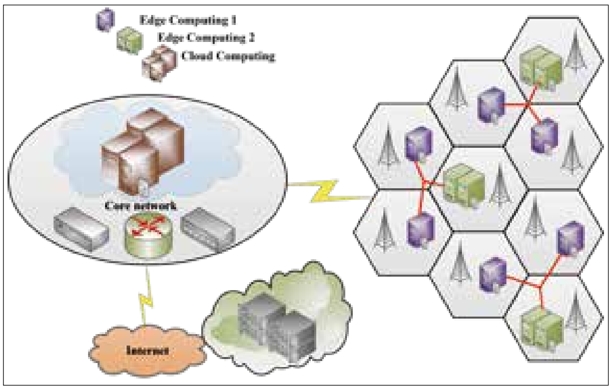

Fig.2 A multi-level system of edge and cloud computing for future network

Edge computing is establishing a new computing paradigm that brings AI and machine learning to where data generation and computation take place: at the edge of the network. Combining edge computing and AI has led to a new direction: Edge AI.

Edge AI provides faster computation and insight, better data security, and effective control of continuous operation. As a result, it can improve the performance of AI-enabled applications and reduce operational costs. Edge AI can also help AI overcome related technology challenges.

Edge AI simplifies machine learning, autonomous application of deep learning models and advanced algorithms on Internet of Things (IoT) devices themselves, away from cloud services.

2.7. 5G/6G (Generation) Mobile Networks

At present, it is too early to speculate about what key technologies will characterize the nascent 6G, because it is not known what the drivers for 6G might even be. However, the next-generation system does not usually emerge in a vacuum. By examining the industrial and technological trends of previous generations, the directions and trajectories associated with each new generation can be identified. We present observations about these trends and their potential for subsequent 5G and 6G releases.

Fig. 3 shows a depiction of the technological evolution from past generations of mobile communications to 6G. In previous generations, each generation had one representative technology. However, starting with 4G, radio access technology (RAT) includes a combination of several new technologies based on orthogonal frequency division multiplexing (OFDM); and in 6G the technical areas are expected to become more diversified. This is because communication quality close to the Shannon limit has already been achieved by OFDM-based technology, and, at the same time, the requirements and use cases will expand as described in the previous chapter. Therefore, in 6G, the high-level requirements will be met by a combination of various technologies. In addition, the definition of RAT 6G also needs to be clarified. The technical areas considered as candidates for 5G and 6G evolution are described below.

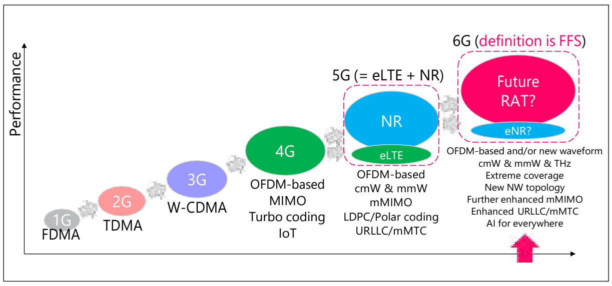

Fig. 3 Technological evolution up to 6G in mobile communications [9]

5G and 6G use higher band wireless spectrum to transmit data faster than 4G, 3G and 2G networks. If we compare 5G and 6G, however, the former is allocated low and high band frequencies - below 6 GHz (gigahertz) and above 24.25 GHz, respectively. The 6G will operate in the 95 GHz to 3 THz (terahertz) frequency range. Since different spectrum is used, 5G and 6G technology could provide various uses for different industrial sectors to improve their efficiency.

Considering the performance factor, 6G will facilitate higher performance, which is much better than the recently deployed 5G wireless networks. Working in the terahertz frequency band, 6G will deliver peak data rates of 1,000 gigabits per second with less than 100 microseconds of over-the-air latency. Both 5G and 6G networks are expected to be 100 times faster than 5G in terms of speeds, with improved reliability and network coverage.

The Internet of Things (IoT) is becoming reality today with the deployment of 5G-based solutions after extensive testing of the 5G network, which was not possible with previous networks, such as 4G LTE, due to poor planning of the frequencies used. The frequencies in use were too narrow and congested to carry the data needed by smart devices to achieve the desired results. This is where 5G has filled the gap, and moving forward with 6G, we expect to connect ten times as many devices per square kilometer with more connected devices in the coming years.

The time necessary for a packet of information to travel over a frequency is called latency. On 4G networks, the delay was about 50 milliseconds (ms), while on 5G networks, the delay is ten times less than on 4G, i.e., 5 ms. On the 6G Internet, latency will drop to 1 millisecond, which is five times less than on fifth-generation networks and will allow massive data transfers in less than a second [10].

Blockchain technology (BCT) has attracted significant attention due to decentralization, transparency, limited spectrum resources, inherent privacy and security, weak interoperability, privacy, and the emergence of new smart applications, including industrial IoT and Industry 5.0. The mismatch between data-intensive requirements and the capabilities of the 5G network determines the need for a decentralized 6G architecture based on blockchain [11]. The convergence of AI, blockchain, IoT, SDN, NFV for 6G is depicted in Fig.4.

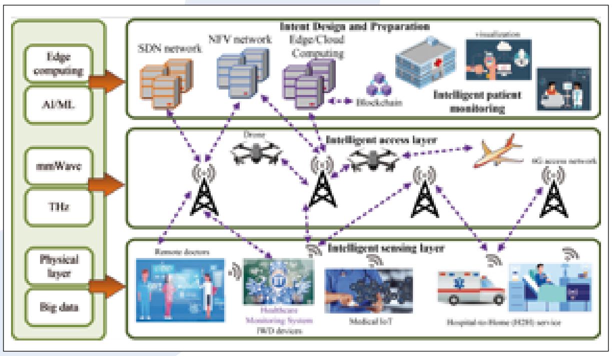

Fig. 4. The convergence of AI, blockchain, IoT, SDN, NFV for 6G

Undoubtedly, we may see ultra-high speeds and power that will attract customers to 6G services. However, what will be the architecture and components of 6G that will pave the way for a reliable and resilient 6G network? Connectivity and automation using advanced versions can help in the development of such networks predicted in previous discussions. It is also proposed to overcome the shortcomings of existing networks, improve network design and optimize the network. Advanced artificial intelligence systems, SDN/NFV/BCT technologies and powerful edge computing will provide the higher speed of 6G to coordinate complex systems and create a seamless Internet connection.

2.8. Information-centric Networking and Services

Information-Centric Networks (ICN) is an approach to developing Internet infrastructure to support such use directly by introducing unique named data as a core principle of the Internet. Data is becoming independent of location, application, storage and means of transport, enabling intranet caching and replication. The expected benefits include increased efficiency, scalability based on information/bandwidth demand, and increased resiliency in complex communication scenarios. These concepts are known by various terms, including but not limited to: Information Network (NetInf), Named Data Network (NDN), and Publication/Subscription Network.

New security models are needed for ICN. Today's host-centric trust model - obtaining data from a trusted server through a secure connection - is no longer applicable. Instead, security/trust/identity functions are tied to the information objects themselves, using signed objects and ensuring the integrity of names and data. Moreover, not all objects will be universally accessible, requiring authorization and boundary-defining mechanisms.

The ICN paradigm is also expected to require new interfaces for applications to interact with the network. For example, the new API will allow application developers to take advantage of the location-independent naming, caching and multiple-access functionality of ICN.

An ICN approach would potentially have better energy efficiency than existing approaches because data is transported over shorter distances on average. Even though the network needs to power more cache memory, this can be energy efficient because the cooling load can be better distributed over a larger but smaller number of installations. The ICN has the capability to improve relevant metrics, such as invested energy per user perceived latency.

2.9. Time-Sensitive and Deterministic Networking

Time-sensitive and deterministic networks have become a future-proof technology for achieving stringent QoS guarantees, such as limited end-to-end latency and jitter, as well as higher reliability. As the mass deployment of time-sensitive and deterministic networks has progressed, however, they have also presented many challenges, such as synchronous and asynchronous scheduling and shaping mechanisms, and so forth. One of the most important applications for fifth-generation networks and systems is the tactile Internet. Tactile Internet requires a 1ms end-to-end delay from future networks, which is the most challenging task in terms of creating a fifth-generation communication network. Therefore, fifth-generation communication networks are also called ultra-low latency networks.

2.10. AI-based Networking

According to scientists and IT experts, artificial intelligence (AI) is set to revolutionize all aspects of network connectivity. The emerging future of zero-touch, software-defined, self-healing networks that detect anomalies and block network threats will be different from proprietary, hardware-based, manually controlled networks.

Artificial intelligence offers a more dynamic network infrastructure. This approach provides intelligent traffic management and network resource allocation that is more secure and better adapts to user requirements as they evolve.

Making a cognitive network means that the network can monitor and allocate resources on its own. By monitoring, the network can find patterns of resource use on its own and act to optimize resource efficiency. A cognitive network reaches its highest level of automation when the human operator of the network is freed from the tasks of managing and configuring the network.

At first, the user will guide the network through the learning and decision-making process, but eventually we can reach an autonomous network where the human only observes and controls the automated operation but is no longer actively involved in the configuration tasks.

The network, if supposed to be autonomous, must be given a certain level of freedom to choose its actions. One way to do this is to manage it with intent. An intent is the formal specification of all expectations, including requirements, goals, and constraints, placed on a technical system. Intents define what goal to achieve, unlike many modern management interfaces where the system is rather told what to do. Artificial intelligence intent-based networking is depicted in Fig.5.

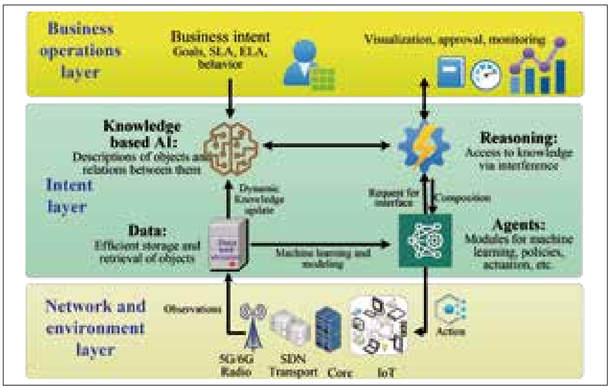

Fig. 5 Artificial intelligence intent-based networking [12]

The intent is processed by an intent manager [13]. Several intention managers may be distributed in a network and in a hierarchy (a so-called federated cognitive network). Each intent manager is accountable for a specific part of the network. Top-level intents can be sent by users.

According to the basic ideology, such a next-generation network concept is called intent-based network (IBN) [14] and is capable of calculating application and user behavior, learning and reconfiguring on the fly to minimize operational costs, improve reliability and security of network processes. SDN is expected to play a role in implementing IBNs that promise to give network administrators more control over networks through a combination of automation and machine learning. Although SDN and intent-based networks are often seen as identical, they represent different concepts with similar goals. IBN is still under development and closed to open testing, which in turn is drawing special attention in the academic community for the development of future intelligent IBN networks.

Conclusion

With the advent of the era of digital intellectual transformation, the world is undergoing profound changes. Digitalization is linked to the organization of intelligent transportation, entertainment, healthcare, and the smart city, and will enhance the quality of service. Emerging 6G networks will become a game changer for the next generation of wireless and wired communications systems that will address the limited data rates that are increasing with the billions of data programs that traditional networks are facing. Some key radical 6G technologies, combined with existing 5G technologies, will guarantee high quality of service to achieve ubiquitous wireless communications, from the telecommunications industry to the digital smart industries. The paper explains that Internet of Things (IoT) technology is reforming the current industry into a smart infrastructure along with the 6G architecture. The use of blockchain technology is relevant for future networks due to decentralization, transparency, lack of spectrum resources, privacy and security.

It is established that networks will gradually become cognitive systems, leveraging artificial intelligence. Such networks will be able to sense, think, acquire new knowledge and act autonomously. They will be fully controlled by intent-driven technologies, simplifying the human task of defining services and operational goals, while becoming the supporting infrastructure for a truly digital society.

Data-driven operations, distributed intelligence, continuous learning, and intent-based automation will be key factors in this evolution. Moreover, all networking technologies discussed in this paper will need to be combined in different aspects of functional architecture, deployment scenarios, and areas of responsibility for different vendors. Only then will we be able to achieve the necessary capabilities to optimize performance and operational efficiency in the new era of digital transformation.

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