A unified networking experience in decentralized environments

Unified networking experience technology (UNEXT) white paper series

Realizing services end-to-end in unified networking experience technology (UNEXT), an intelligent networking platform being created by Nokia Bell Labs, can mean interacting with other networking domains, systems and resources under the control of their respective stakeholders, even if there is no single centralized authority coordinating the interactions. Thus, it is essential that UNEXT has the capability for autonomous end-to-end service coordination among heterogeneous stakeholders, including capabilities for negotiation, data sharing, orchestration and assurance, all based on dynamic notions of trust or its absence. This paper outlines how this can be achieved in UNEXT.

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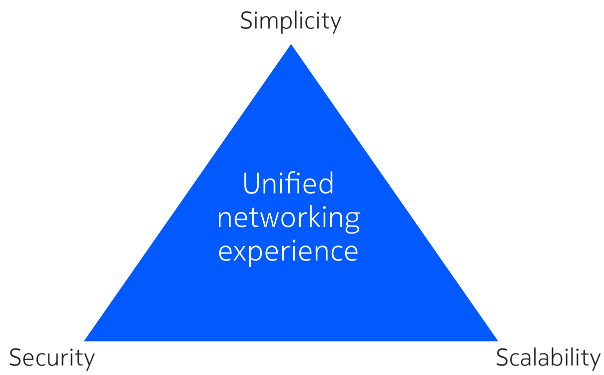
The UNEXT vision

As envisioned, unified networking experience technology, or UNEXT [1], is an intelligent networking system providing telecommunications in a simple, secure and scalable manner (Figure 1). It will enable networking to be a self-managing, interactive system that provides users and applications with resources and services that will be able to scale across heterogeneous users, operators and execution environments.

Figure 1. UNEXT vision



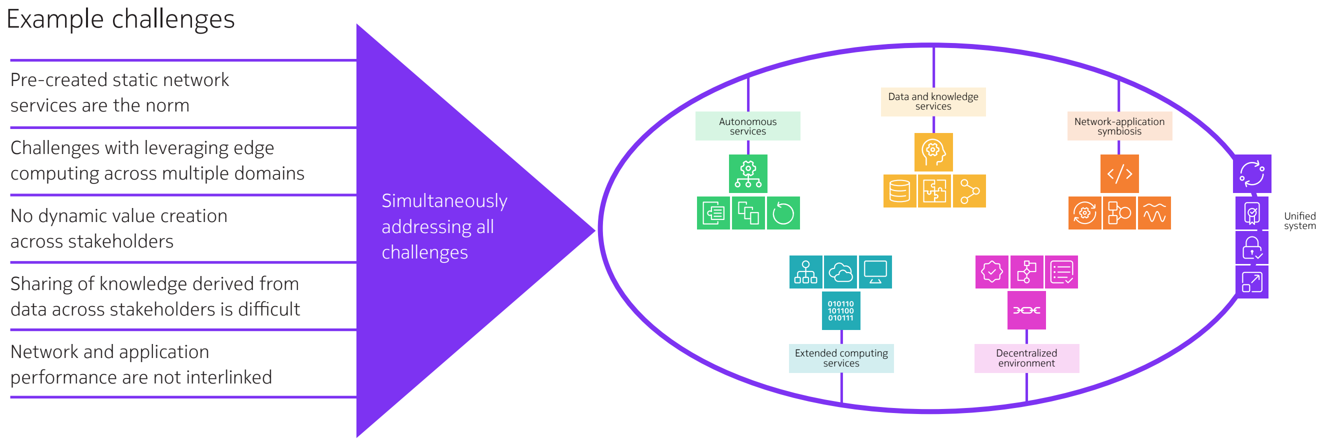
Achieving these aspirations requires tackling why networking today is neither simple, secure, nor scalable. We identified five sets of technology capabilities that could address and produce solutions for undesirable networking characteristics and behaviors. Once created, these technologies will simultaneously mitigate the causes of complexity, insecurity and scalability impediments in networking. The sets of capabilities defined for investigation are the following (Figure 2):

Autonomous services: As networking systems become increasingly complex, the degree of human-guided automation becomes increasingly mismatched with the complexity of network operations and procedures needed to deliver services. Further, we expect service-related activities such as service design, provisioning, new service creation, service complexity and request-to-delivery response times to surpass the capabilities of human-involved network operations. As a result, autonomous decision-making and service realization, including the discovery, design, composition and exposure of new services, as well as automatic integration with business processes, will be an essential capability in UNEXT.

Network-application symbiosis: An important part of the networking experience is the combination of network services and endpoint applications that rely on them. Enabling applications and the network to interwork and co-optimize carrier-grade application reliability, network usage and quality of experience will enhance the user experience.

Decentralized environments: To provide end-to-end services, UNEXT needs to interact with itself and other networking domains, systems and resources under the control of their stakeholders. Services will still require completion even if there is no single centralized authority coordinating them, such as in the network cloudification trend with network functions and microservices running in serverless environments. Thus, an essential capability will be enabling, among heterogeneous stakeholders, end-to-end autonomous service coordination, including negotiation, data sharing, orchestration and assurance, all based on dynamic notions of trust or its absence.

Figure 2. UNEXT capabilities



Extended computing services: Compute resources abound in networks that can be utilized for end-to-end service delivery and achieving the sought-after quality of experience. To address the challenges and leverage these resources across multiple domains, it will require defining the abstraction, orchestration and support for compute capabilities across the device-edge-cloud continuum.

Knowledge and data services: At the core of UNEXT is the ability to accommodate the flood of data from all areas—users, operators, systems, and environments—and retain and update it as evolving knowledge, all to enable sound decision-making. This provides the basis for future data- and AI-driven networking solutions.

Importantly, the aforementioned capability sets will overlap in terms of the technologies required to provide or address their associated use case categories. Further, a collection of technologies alone is not sufficient for UNEXT. To develop this system design and technology integration, we need a unified system that at least includes the identified capability-enabling technologies. The result will be the UNEXT system, an autonomous networking system that enables cross-stakeholder service provisioning and execution in a simple, secure and scalable manner by design.

Decentralized environments

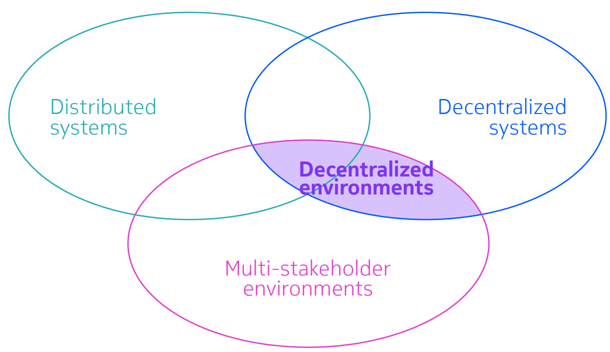
Before developing technologies and approaches for operating in decentralized environments, one must first understand what they are in terms of UNEXT and their characteristics.

Context

The UNEXT project's decentralized environments research focuses on the distinction between decentralized and distributed systems, taking stakeholder considerations into account. A distributed system is a collection of independent or physically separated components that operate together to produce an outcome. A decentralized system lacks a central authority or decision-making component, instead distributing control among its components.

These definitions of systems are slightly more general than those for computing, where decentralized computing is considered a proper subset of distributed computing. However, the intention here is to allow technologies developed for decentralized environments to be as widely applicable as possible.

Figure 3. Decentralized environments in relation to system architectures and their stakeholders



Distributed systems aren't necessarily decentralized, and vice versa (Figure 3). For example, a blockchain, which is a type of distributed ledger technology (DLT) [2], is a distributed system. Typically, public permissionless blockchains such as BitCoin [3] are also decentralized, i.e., there is no central authority for identity verification or approving transactions; essentially, anyone can view transactions or even perform them. In contrast, private permissioned blockchains have an aspect of centralization because of the presence of a central authority controlling permissioned-based access to the blockchain using identity verification, even though a consensus and, thus, decentralized mechanism is employed among the admitted blockchain users for transactions.

An alternative example of a centralized distributed system would be a network function (NF) composed of multiple microservices executing in multiple cloud environments. The central authority would provide the decision logic of the NF, controlling the services provided by it. Finally, examples of a decentralized non-distributed system would be a locally hosted (i.e., single server) leader election system where the outcome is determined by the consensus of tabulated votes cast by system users or, in a reliability context, a k-out-of-n system of n localized components where only k need to function to achieve the system reliability goal.

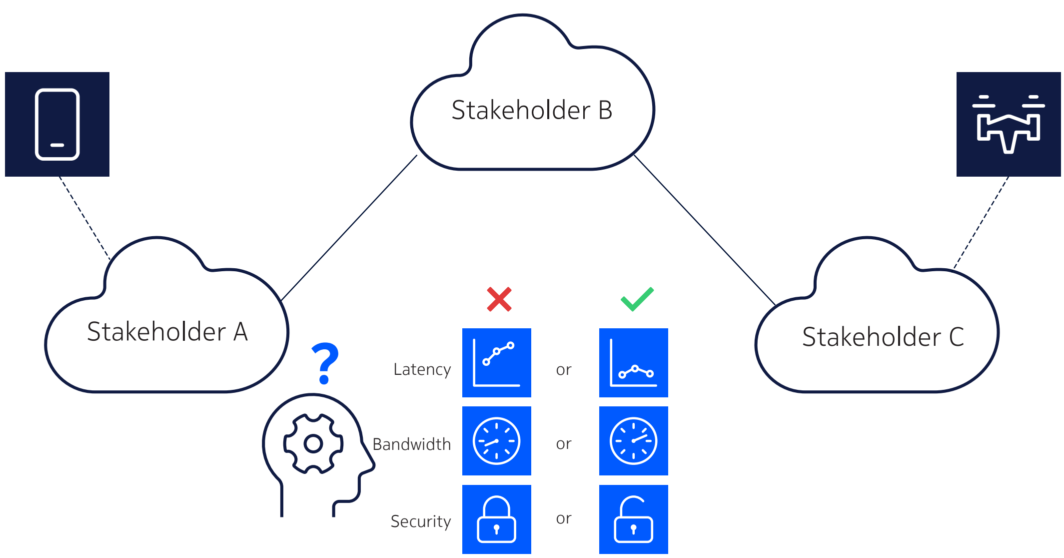
Note that a disaggregated system is commonly understood as a system decomposed or disaggregated into components that can be obtained from multiple vendors and/or open sources instead of the entire system being sourced from a single vendor. The interoperation of the components is enabled by using industry-defined interfaces and protocols and, additionally, by providing commonly defined features and services instead of proprietary ones. Disaggregated systems can be distributed and/or decentralized.

These definitions of various systems architectures include the notion of stakeholders, such as system owners, operators or users. More generally, in telecommunications, a stakeholder is an organization, entity or person with an interest or concern in the success of a system, component, or service. Here, we interpret success broadly and to encompass, for instance, meeting performance objectives or expectations. Examples of stakeholders include network operators, service providers, cloud hosts, enterprises, webscalers, federation members, tenants, system administrators, decision-making entities, and control entities, among others. In certain situations, users are also considered to be stakeholders. We refer to mixes of stakeholder types occurring in certain scenarios as heterogeneous stakeholders.

Definition and fundamentals

One of the most important aspects of UNEXT is providing quality networking experiences that are simple and secure. This in part entails completing services end-to-end, which, at times, will require an instance of UNEXT, i.e., a deployed complete UNEXT system, to interact with other network systems, infrastructures, resources, and applications. These typically will each have their own stakeholders and associated decision-making entities representing them that are distinct from those of the UNEXT instance. Therefore, service completion can require interactions among UNEXT components and multi-stakeholder decentralized systems, which are possibly distributed as well (Figure 3). We refer to these interacting multi-stakeholder service-providing systems as decentralized environments.

Figure 4. Multi-stakeholder negotiation and orchestration for end-to-end service realization



The interactions a UNEXT instance can have with the networking or computing components of other stakeholders are multifaceted (Figure 4). For example, the interactions can take the form of negotiations for compute or transport resources, networking services, security requirements, and service SLAs. Interactions can also occur as part of orchestrating resources and applications for service fulfillment or SLA assurance. Other types of interactions can be information exchanges among stakeholders or components within a stakeholder's system. Note that a component of a UNEXT instance can be an initiator of interactions and/or a responder (often referred to as a counterparty).

Meeting the negotiated expectations of all parties involved in interactions is fundamental for successful interactions among multi-stakeholder systems. This requires trust. While the term trust can mean many things, in the UNEXT project, trust is defined as the confidence one element has that the second element will behave as expected. This is a broad, quantifiable definition that can include a system's expected security behavior or its ability to meet SLAs, e.g., its reliability or availability. It is context-dependent and multi-dimensional.

Trust is an important attribute of UNEXT, and establishing and maintaining it is a key to its operation. Having trust, or at least understanding it, will enable dynamic trust-based negotiation and orchestration even among heterogeneous stakeholders. Thus, one essential part of decentralized environment research within UNEXT is developing the technologies to enable trust-based interactions among multiple stakeholders and integrating those technologies into the UNEXT system.

Trust is necessary for two main reasons. One reason is the absence of information among the parties involved in the interactions, such as details about the counterparty's infrastructure, security capabilities or resilience. This information opacity exists because of stakeholder boundaries. A stakeholder may be unwilling or unable to share details about their system and its capabilities with other parties. A second reason is that stakeholders may not want other stakeholders to fully control their systems. Therefore, interactions for the service completion of different stakeholder systems are predicated on mutual behavioral expectations. Hence, the opacity of information and control is an attribute common to all decentralized environments. The technologies designed for decentralized environments for the interactions of multi-stakeholder systems will need to address this issue in some way.

Information about and control of a system might be incomplete for another reason, namely, abstraction. Networking layers within a single system, for example, often use abstraction to hide complexity and provide scalability, potentially viewing themselves as system stakeholders. An important difference in single-system stakeholder environments is that the underlying granular information and control are available, at least in principle, although perhaps not always in practice. So, the technology developed for decentralized environments, including technologies related to the presence or absence of trust, is also applicable to the single stakeholder case, i.e., internally to a UNEXT instance. This is also a significant dimension of the research.

Example environments

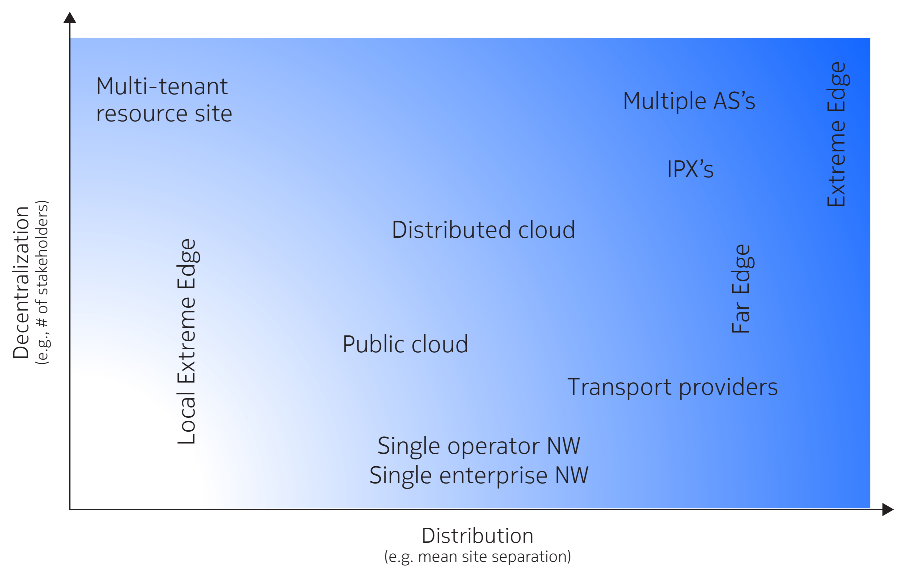
Today's networks contain decentralized environments, and as communications ecosystems evolve, we expect new forms to emerge. Here, we provide some examples of these environments. The examples highlight potential applications of the developed technologies.

Edge resource sharing environments: The concept of leveraging increasingly abundant and capable compute resources at the edges of networks closest to applications (e.g., far edge and extreme edge) continues to evolve to minimize latency and cost and maximize performance and sustainability [4].

Enterprise on-demand services: Enterprises frequently require services on demand, such as alternative interconnections among multiple campus locations, system backup for disaster recovery, and new connections to non-campus locations. Whatever the service, the enterprise will need to negotiate with one or more service providers to deliver the service end to end in accordance with its performance and security requirements.

Public clouds: Commercial cloud providers offer compute resources (xPU, memory, and storage) as a service. Specifics of the compute resources can differ among public cloud providers, necessitating that network functions and applications running in them be compatible or adaptable to the compute environments.

Figure 5. Potential decentralized environments categorized by notional degrees of decentralization and distribution



End-to-end transport across multi-stakeholder domains: Digital and optical transport services may be required from the stakeholder's networks, so an operator would need to negotiate for them, including the SLAs and security expectations. This need is particularly relevant for new services or services requiring transport during times of high resource utilization.

Roaming ecosystem: International roaming is enabled by internet packet exchange (IPX) providers interconnecting mobile network operators (MNOs) across the globe [5]. This private ecosystem consists of multiple interconnected IP backbone operators who offer services and security to MNOs, as well as monetizing the data flowing through their networks.

Open disaggregated network domains: To avoid vendor lock-in, a relatively recent trend is to disaggregate network components and rely on open-source software, standard APIs and interfaces, and non-proprietary interoperability features. This has occurred in the open RAN (O-RAN [6, 7]) and in open and disaggregated transport networks (ODTN) [8], resulting in multi-vendor, multi-stakeholder environments where, in some cases, access to resources can be negotiated and shared.

IP network peering: As the internet is a network of networks, peering among autonomous systems (AS) via border gateway protocol (BGP) provides end-to-end connectivity. Even today, the structure of the internet is not well understood since the AS-AS peering arrangements are based on the economics and connectivity of numerous independent ASs and their neighbors [9].

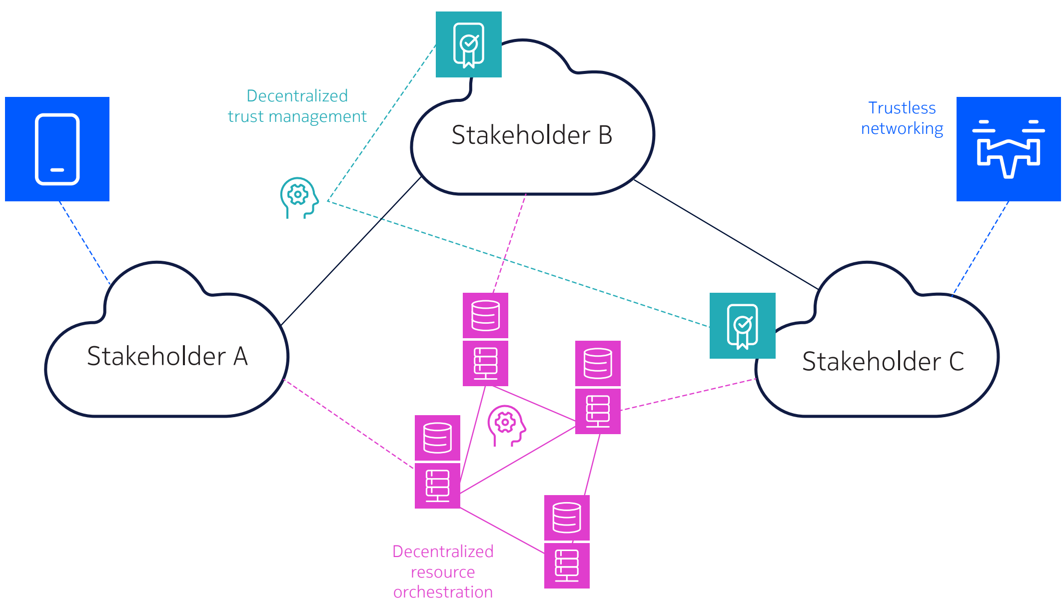
These examples illustrate the variability and complexity that decentralized environments can have and also suggest some of their security challenges. Figure 5 is a depiction of the span of possible decentralized environments in terms of a notional two-dimensional space of distributed and decentralized systems. We could add at least one additional consideration: timeframe. Interactions among systems that involve actions like trust establishment and maintenance, negotiation, orchestration, and conflict resolution can take time, the amount of which might make those types of actions unsuitable in low latency, rapid provisioning, or other time-critical situations. Such situations may arise, for instance, during the orchestration of compute resources at a local extreme edge, where compute resources are positioned as close to the user as possible to minimize latency and improve performance. Figure 5 illustrates this potential limitation of decentralized environment technology by not fully extending the shading to the systems in the lower left of the diagram (few or single stakeholders, limited distribution), which may be low-latency systems.

Challenges and approaches

A central challenge that UNEXT addresses is how to provide quality and secure networking experiences when multi-stakeholder environments are involved.[1] This necessitates operating end-to-end with security and performance when both information and control are incomplete in some domains, i.e., in the presence of opacity (Figure 6). Key UNEXT functionalities needed for achieving this in decentralized environments are trust determination, negotiation, orchestration, and trustless networking.

As defined in UNEXT, trust is the confidence one element has in another that the second element will behave as expected. A UNEXT instance needs to determine it to form a basis for interactions with systems of heterogeneous stakeholders or even itself. Trust between two entities is not necessarily static, however, it can change with context and is applicable to each particular set of interactions. Therefore, a challenge in decentralized environments is to identify the most effective technologies for defining and managing trust relationships among different entities and actors and to effectively utilize these technologies for negotiations and resource orchestration. Furthermore, since trust is dynamic, the UNEXT system must have trust resiliency, meaning the capability to adapt its interactions with other systems across a range of trust levels and assumptions.

Figure 6. Meeting the challenges of decentralized environments



One of UNEXT's primary goals is to streamline networking, particularly in situations where a stakeholder's UNEXT instance needs to negotiate for services or resources with other stakeholders' systems. Automated negotiation capabilities and the system's autonomy in making commitments with other parties can help achieve simplicity.

1 This is in addition to other technical challenges addressed by UNEXT in single-stakeholder environments.

Once negotiations result in the reservation of resources and/or services from stakeholder systems, orchestration among those systems is necessary to commit to and utilize them. Typically, decentralized environments function as distributed systems, where the system maintains or replicates its state in a distributed manner across the system. This raises the specter of database inconsistency because of delays inherent in distributed database updates, and this could result in colliding attempts to provision the same resources, thus requiring tradeoffs such as between setup latency and (strong) consistency.

Finally, even when a UNEXT instance cannot establish, assume, or require trust with one or more stakeholders' systems or itself, interactions among the systems' components are still necessary to provide quality services simply and securely. In these cases, we require approaches for enabling services with minimal trust assumptions (e.g., [10]) while still providing security, confidentiality or privacy. Therefore, technologies and methods with strong or inherent security properties, behaviors, or guarantees can enable service delivery in these trustless networking circumstances. Trustless networking approaches encompass more than a limiting case of the trust-level-based approaches discussed previously. In particular, in trustless networking, one can dispense completely with trust determination and, instead, make ***a priori*** minimal or no assumptions about the trust granted to users, components, resources and assets, and, accordingly, develop a system or subsystem approach that still provides the requisite security protections.

Conclusion

The technologies developed for decentralized environments are essential for a UNEXT system's ability to interact with itself and networking systems, resources, infrastructures, and applications of multiple stakeholders for networking experience fulfillment. They will enable dynamic trust-based negotiation and orchestration among heterogeneous stakeholders, even in the absence of a central controlling authority. They will also enable networking experiences among multiple stakeholders when trust cannot be assumed or expected. When control and information about trust, security and infrastructure are insufficient across domains, UNEXT empowers a stakeholder to tackle the challenge of operating end-to-end securely and efficiently for quality service realization.

Abbreviations

AS	Autonomous system
BGP	Border gateway protocol
DLT	Distributed ledger technology
IPX	Internet packet exchange
MNO	Mobile network operator
NF	Network function
ODTN	Open and disaggregated transport network
O-RAN	Open radio access network
SLA	Service level agreement
UNEXT	Unified networking experience technology

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