National University of Computer and Emerging Sciences
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Title: Report on Networking Systems of AI

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Introduction

In this research paper, the authors present a paradigm shift in the design and operation of modern communication networks and AI systems. They propose Networking Systems of AI (NSAI), a concept that deeply integrates distributed AI capabilities with next-generation communication networks such as 5G, B5G, and 6G. Rather than AI simply being used to enhance networks, or networks acting as passive carriers for AI workloads, NSAI envisions a system in which both AI and networking function as an intelligent, adaptive whole.

The motivation for NSAI arises from the increasing demand for intelligent, context-aware, and real-time services such as autonomous driving, smart manufacturing, immersive education, and healthcare applications. These require not only advanced computation but also a network infrastructure capable of supporting low-latency, high-bandwidth, and adaptive resource management. NSAI aims to fulfill these requirements by enabling AI to operate throughout the network—from cloud to edge to device—and by designing networks to behave like learning, optimizing systems.

NSAI Vision and Key Concepts

The authors articulate a forward-looking vision of NSAI that rests on two foundational ideas: “AI as a network” and “network as AI.” This means that AI capabilities are embedded into every layer of the network, and the network itself acts as a distributed AI agent capable of perception, decision-making, and adaptation.

To realize this, the paper introduces five strategic building blocks of NSAI:

- **Service-Customized Networks (SCNs):**

  These are dynamic, virtual networks tailored to specific service requirements, adjusting topology and resources in real-time.

- **Generalized Smart Services (GSS):**

  A middleware layer that handles service orchestration and hides underlying network complexity from applications.

- **Unified Air Interface (UAI):**

A proposed radio interface for B5G/6G that simultaneously supports eMBB, URLLC, and mMTC.

- **Micro/Nano Electronic Devices (MNEDs):**

  Smart, ultra-efficient terminal devices that integrate sensing, processing, and communication functions.

- **Ubiquitous Brain Network (UBN):**

  A long-term goal of integrating human cognition with AI systems through technologies such as brain–computer interfaces (BCIs).

Together, these concepts position NSAI not just as a technology upgrade, but as a new model for computing and communication in human society.

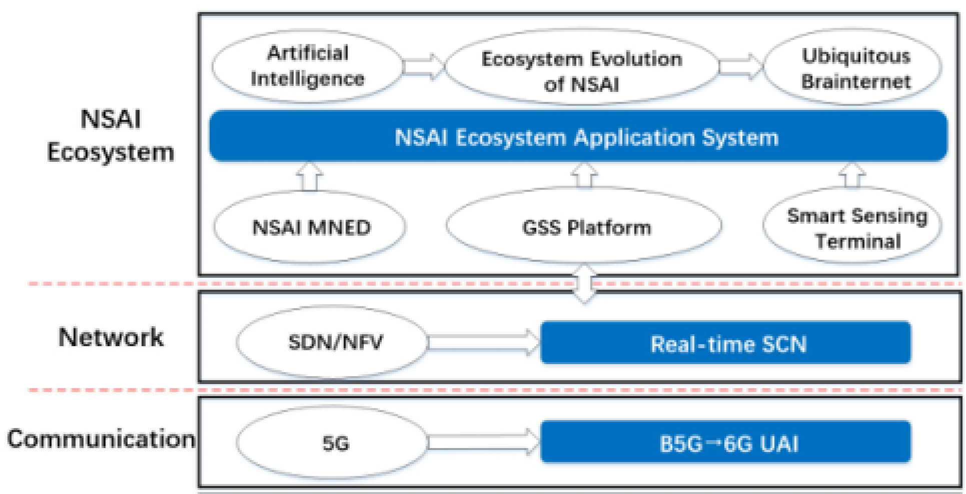


Fig. 4. Visions of NSAI, including SCN, GSS, UAI, MNED, and the evolution of the ecosystem.

Architecture of NSAI

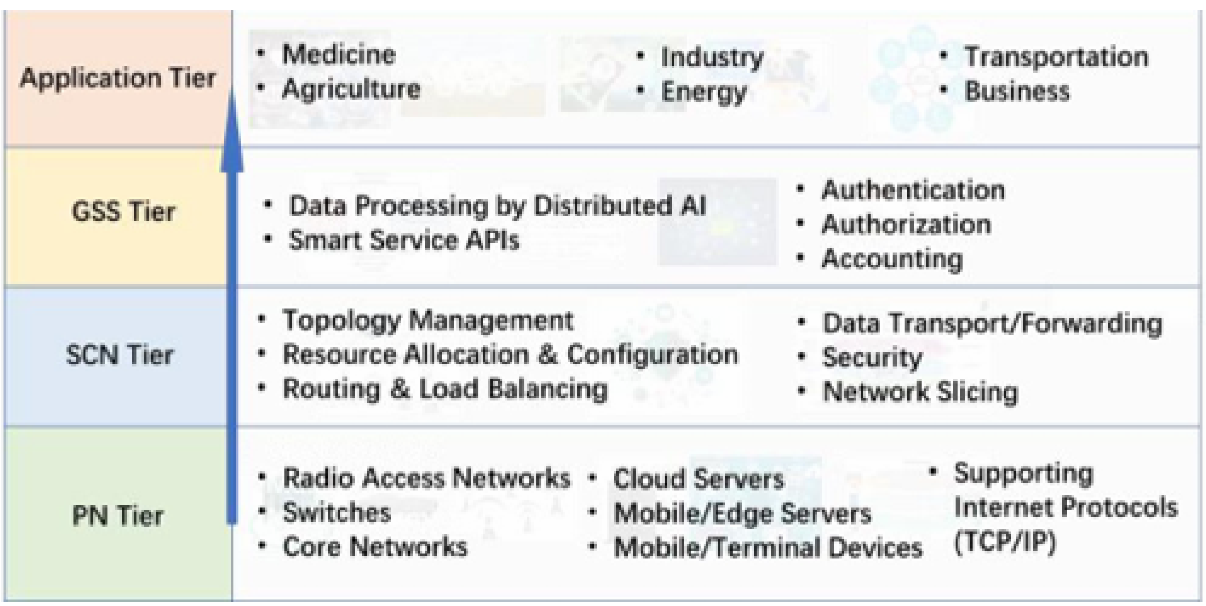
The NSAI architecture is structured across four logical tiers, each fulfilling distinct roles in enabling intelligent services:

The base is the **Physical Network (PN) tier**, which includes the actual communication infrastructure—wired and wireless networks, data centers, mobile edge computing platforms, and terminal devices. This layer is responsible for connectivity, throughput, and energy-efficient data transport.

Above this lies the **Service-Customized Network (SCN) tier**. This layer abstracts the physical infrastructure and creates virtual, programmable networks optimized for specific use cases. Using SDN and NFV principles, it dynamically reconfigures resources, manages topology, and ensures QoS through techniques like network slicing and multi-tenant control.

The next layer is the **Generalized Smart Service (GSS) tier**, which acts as the intelligence control hub of the architecture. It executes distributed AI workloads, manages AAA services, and provides an interface for applications to interact with the network without needing to know its inner workings. It supports federated learning, distributed optimization, and service-aware configuration.

Finally, **the Application (APP) tier** contains the end-user services that NSAI supports. These range from urban mobility platforms and healthcare monitoring systems to immersive learning applications using AR/VR, all of which rely on the responsiveness and intelligence of the underlying network.



Enabling Technologies

A wide range of technologies underpin the NSAI framework, and the paper provides an extensive review of these across tiers.

At the physical level, the authors highlight the growing importance of new waveforms and transmission technologies like OTFS and THz-band communication. Massive MIMO, optical backhaul using TDM-PON, and multihop communication protocols are also discussed as key enablers of the throughput and flexibility needed for NSAI.

Micro and nanoelectronics play a crucial role in making edge and terminal AI feasible. Special-purpose AI chips like TPUs and neuromorphic processors reduce energy consumption and latency, while advances in 3D chip integration and nanoscale architectures bring AI capability closer to users.

The SCN tier draws heavily on advancements in software-defined networking. SDN and NFV enable programmability, virtualization, and intelligent orchestration of services. Network slicing allows for application-specific logical networks with independently controlled QoS.

In the GSS layer, federated learning allows models to be trained on distributed devices without centralizing data—preserving privacy while enabling personalization. Multi-agent reinforcement learning (MARL) is explored for scenarios requiring collaborative AI, such as drone fleets or autonomous vehicle coordination.

The paper also discusses how blockchain technologies can reinforce AAA mechanisms by making them decentralized and tamper-proof. This is especially relevant in massive, open networks with billions of devices.

Application Scenarios

The versatility of NSAI allows it to support a broad range of future applications. One standout example is the use of digital twins—virtual replicas of real-world systems that update in real time. NSAI provides the computational intelligence and network responsiveness required to keep these digital replicas synchronized with their physical counterparts.

Immersive computing applications are another promising domain. Augmented reality (AR), virtual reality (VR), and mixed reality (MR) rely on low-latency, high-bandwidth connections with local AI processing, all of which are core strengths of the NSAI framework.

The use of knowledge graphs in conjunction with AI agents is also discussed. These graphs enable semantic understanding and logical inference, supporting intelligent search, autonomous planning, and decision-making in NSAI-powered services.

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Exemplary Applications of NSAI:

1. **Urban Microspace Service:**

- Integrates **IoT, Mobile Internet, and Digital Twins**, creating smart spaces like buildings and shopping malls.
- Enables real-time synchronization between online and offline environments, enhancing immersive experiences through **AR/VR**.
- Example: A virtual shopping experience replicating the physical ambiance and interactions.

2. **Transportation Service:**

- Facilitates fully autonomous driving, vehicle-road synergy, and smart traffic management.
- Uses real-time data to coordinate vehicle movements, enhance safety, and manage traffic dynamically.
- Example: Traffic lights become obsolete as vehicles communicate directly for seamless transit.

3. **Healthcare Service:**

- Combines **connected healthcare, smart patient monitoring, and telehealth**, allowing continuous care and remote diagnosis.
- Real-time data from wearable devices aids in emergency response and personalized healthcare management.
- Example: Remote monitoring and telesurgery enabled through integrated health networks.

4. **Educational Service:**

    - Supports **adaptive learning, smart classes, and virtual classrooms** using AI to personalize education.
    - Real-time data on student behavior helps customize teaching approaches.
    - Example: AI teachers and smart classrooms that track student engagement and learning progress.

5. **Industrial Service:**

- Implements **customer-driven manufacturing**, smart processes, and convergence of automation with IT.
- Real-time customization of production through **digital twins and automated logistics**.
- Example: Smart factories where AI-driven decisions optimize manufacturing efficiency.

Vision and Concept of UBN:

UBNs represent the next evolution of Networking Systems of AI (NSAI) by incorporating human intelligence through **AI-Empowered Brain-Computer Interfaces (ABCI)**. The primary goal is to converge human cognition with AI, merging **cyberspace, the physical world, and human society** into a unified system. This will create seamless interaction between humans and AI, enabling revolutionary applications like **telepathic communication** and real-time brain-to-AI interfacing.

AI-Empowered Brain-Computer Interface (ABCI):

ABCI extends traditional Brain-Computer Interface (BCI) technologies by integrating AI to enhance human sensory reconstruction and brain-machine interaction. Unlike conventional BCIs that primarily use **EEG signals**, ABCIs utilize more advanced techniques like:

- **Invasive Signal Acquisition:** High precision with **Electrocorticography (ECoG)** and implanted electrode chips for controlling devices.

- **Functional Brain Mapping:** Techniques like **fMRI** and **stereoscopic projection** for identifying brain areas related to specific functions (e.g., visual processing).

- **Emerging Applications:** ABCIs help in medical rehabilitation, such as enabling paralyzed patients to control **prosthetic limbs** and enhancing sensory experiences for those with **hearing or vision impairments**.

- **Research Directions:** Developing accurate, real-time, and noise-resistant brain signal acquisition methods remains a key challenge.

Ubiquitous Brain Networks (UBNs):

UBNs extend NSAI by incorporating **human intelligence as a core network component**. These networks facilitate **mind-to-mind communication** and task delegation to AI through thought processes, leading to a more connected human society.

- **Telepathic Communication:** Direct brain-to-brain networking to exchange complex thoughts and ideas without verbal communication.
- **Mind-Task Delegation:** Assigning AI tasks purely by thought, potentially controlling devices or even delegating complex computational tasks to AI systems.
- **Human-AI Integration:** Creates a **social network of minds** where human intelligence evolves alongside AI, revolutionizing education and human interaction.

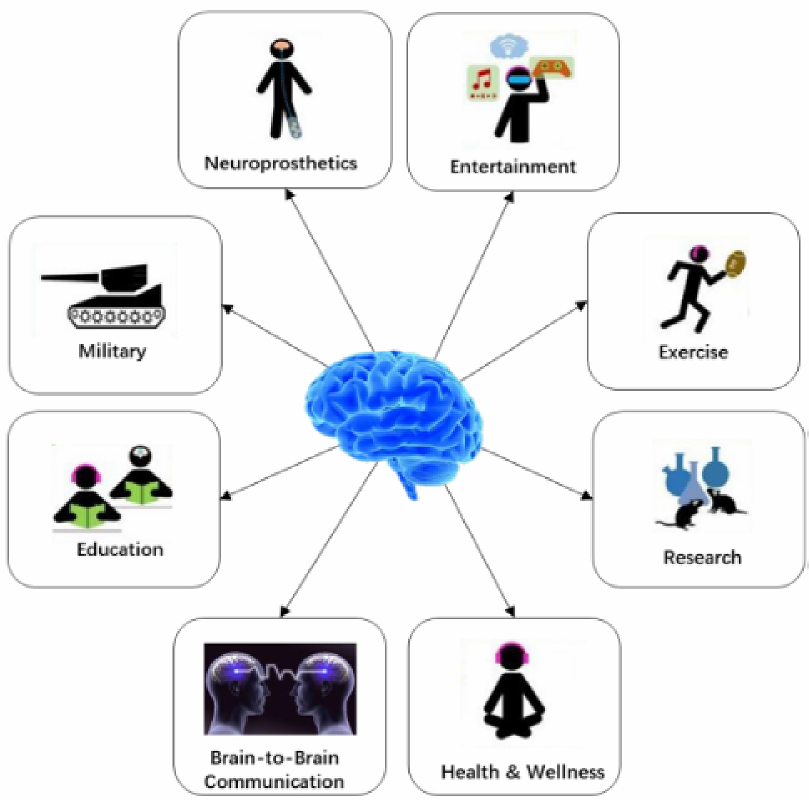

Fig. 24. UBNs.

Challenges and Research Opportunities

Technical **challenges** include:

- Achieving seamless interoperability across heterogeneous networks and devices.
- Ensuring privacy and data protection in distributed learning environments.
- Developing ultra-efficient, low-power AI hardware for terminals and edge nodes.

Research **opportunities** includes:

- Creating online-evolutive learning systems that adapt in real time without human intervention.
- Designing cross-layer optimization frameworks where applications influence network configuration and vice versa.
- Exploring human–AI coevolution through BCIs and the concept of the "Brainternet."

Security and Privacy Considerations:

One of the core challenges for NSAI is maintaining data security while enabling distributed AI. Using blockchain for decentralized identity management, coupled with federated learning for data privacy, are promising approaches. Additionally, secure edge devices with integrated AI capabilities are crucial for mitigating cybersecurity risks.

Future Directions:

NSAI's potential lies in advancing to Ubiquitous Brain Networks (UBNs) where human cognition seamlessly interacts with AI systems. Next-generation AI-driven communication will focus on context-aware and self-optimizing networks. Further, integrating cyber-physical-human systems will create a cohesive environment where technology enhances human capabilities.

Conclusion

This paper offers a compelling blueprint for the convergence of AI and communication systems into a unified, intelligent infrastructure. Through a thoughtful system architecture and an extensive survey of enabling technologies, the authors lay the groundwork for a future where AI is not only distributed and responsive but is structurally built into the fabric of our networks.

NSAI, as envisioned, has the potential to redefine the very nature of both computing and communications. It promises networks that are not just fast, but contextually aware and self-optimizing, powering a new generation of real-time intelligent services across every aspect of