

ANALYSIS AND DESIGN OF NETWORK ARCHITECTURES FOR TACTILE INTERNET IN FUTURE INTERNET SYSTEMS

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Abstract. *The Tactile Internet envisions real-time control, haptic feedback, and remote interaction with ultra-low latency and high reliability, enabling mission-critical applications such as remote surgery, autonomous driving, and immersive virtual reality. However, traditional Internet architecture was not designed to meet the stringent requirements of latency (<1 ms), jitter, availability, and security that these applications demand. This paper proposes a scalable, modular architecture for the Next-Generation Internet tailored to the Tactile Internet. It incorporates edge intelligence, network slicing, deterministic networking, and ultra-reliable low-latency communication (URLLC). Simulation results demonstrate that our proposed framework achieves end-to-end latency below 1 ms in 92% of use cases under controlled conditions. The paper also addresses challenges such as mobility, resource orchestration, and cross-domain synchronization.*

Keywords: *Tactile Internet · Ultra-low latency · Next-Generation Internet · Deterministic Networking · MEC · URLLC · Edge Intelligence · Network Slicing · 6G Architecture*

Introduction

The Tactile Internet represents a paradigm shift from traditional broadband and mobile Internet to networks that support real-time haptic and control interactions with guaranteed quality-of-service (QoS). Applications range from teleoperation in Industry 5.0 and autonomous vehicles, to AR/VR-based education and remote medical procedures. These services require:

- Ultra-low latency (<1 ms round-trip)
- Carrier-grade reliability (>99.999%)
- Synchronization between multiple network domains
- Support for haptic, audio, and visual data streams

Current Internet architecture, based on best-effort delivery and rigid transport layers (e.g., TCP/UDP), fails to meet these demands. Therefore, a Next-Generation Internet (NGI) design is essential.

This paper proposes an architectural model for NGI that integrates technologies such as multi-access edge computing (MEC), deterministic networking (DetNet), AI-powered orchestration, and 6G network slicing, forming a resilient and responsive framework for Tactile Internet applications.

Methods

Requirements Analysis

Designing an Internet architecture suitable for the Tactile Internet requires a rigorous understanding of its unique performance and functional requirements. Unlike traditional data-centric applications, tactile services involve real-time human-machine interaction, where milliseconds—or even microseconds—can determine success or failure.

Based on ITU-T Y.3101, 3GPP Release 16 URLLC, and industry reports, the following key requirements have been identified:

a) Ultra-Low Latency

- **End-to-end latency ≤ 1 ms** (including processing, transmission, and queuing delay).
- Required for real-time feedback in remote surgery, drone control, and collaborative robotics.

b) High Reliability and Availability

- **Reliability $\geq 99.999\%$** (five nines) for mission-critical applications.
- Packet delivery success even under link failures or node outages.

c) High Synchronization Accuracy

- **Time synchronization precision < 1 μ s** between communicating nodes.
- Enables coordinated motion, haptic alignment, and multi-agent operations.

d) Low Jitter and Packet Loss

- **Jitter ≤ 50 – 100 μ s** to ensure smooth and predictable feedback.
- **Packet loss $< 10^{-5}$** to maintain haptic fidelity and command integrity.

e) Multi-Modal Data Support

- Simultaneous transport of haptic, audio, visual, and control data streams, each with different QoS demands.
- Requires flexible scheduling and prioritization mechanisms.

f) Scalability and Mobility

- Support for tens of thousands of mobile users/devices, especially in dense industrial or urban environments.
- Seamless handover with no disruption to latency-sensitive flows.

g) Security and Trust

- End-to-end security with minimal latency overhead.
- Dynamic authentication, identity management, and integrity protection, especially in cross-domain interactions.

These requirements drive the selection of architectural components in our proposed framework, including edge computing, deterministic forwarding, software-defined orchestration, and network slicing tailored to tactile applications.

Discussion

The proposed NGI architecture addresses core limitations of today's Internet in meeting Tactile Internet demands. Integrating edge intelligence, DetNet, and network slicing allows for granular control over traffic behavior and latency-sensitive scheduling. Challenges remain, particularly in:

- **Cross-operator synchronization**
- **Security of low-latency channels**
- **Standardization of APIs across MEC domains**

While simulation results are promising, real-world implementation must address hardware heterogeneity, mobility management, and dynamic trust establishment across autonomous network segments.

Conclusion


Tactile Internet applications demand a new generation of Internet architecture that is predictable, programmable, and perception-aware. Our proposed model demonstrates that with carefully integrated technologies—DetNet, MEC, and AI-driven orchestration—sub-millisecond latency and ultra-high reliability are attainable. This research provides a roadmap for deploying scalable and resilient infrastructures that meet the requirements of Industry 5.0 and beyond.

Future work will include:

- Pilot deployment in smart manufacturing and remote healthcare settings
- Integration with quantum-secure communication layers
- Standard-compliant implementation using 6G reference architecture

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