The Future of Industrial Connectivity: The 5G LAN-Type Service

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Private 5G is emerging as a key communication technology for industry, offering greater bandwidth, reliability, security, and lower latency than existing wireless technologies. However, integrating 5G with legacy systems that rely on local area networks (LANs) poses significant challenges, due to differences in communication models. To address this, the Third-Generation Partnership Project (3GPP) introduced the 5G LAN-type service, designed to enable LAN functionality within 5G and Beyond-5G networks. Beyond leveraging the advanced capabilities of 5G, this service enhances industrial networks with seamless legacy integration, simplified configuration, ultralow latency, and high dependability. Despite its potential, the 5G LAN-type service remains underexplored, with limited research and practical deployments available. This article presents an overview of the 5G LAN-type service, outlining key use cases, technical design, benefits, and open issues. We aim to promote a deeper understanding of this emerging technology and encourage further contributions from both academia and industry.

The Fourth Industrial Revolution is transforming industrial operations through the integration of advanced technologies, such as the Internet of Things, big data analytics, artificial intelligence, and autonomous robotics. However, the success of this transformation heavily depends on the capabilities of the underlying network infrastructure, as emerging applications require high-performing, scalable, and reliable networks. In this context, 5G or Beyond-5G (B5G) networks are considered key enablers[1] because they support diverse communication services suitable for a wide variety of industrial applications, including enhanced mobile broadband, massive machine-type communication, and ultrareliable low-latency communications. Compared to Wi-Fi, 5G offers broader geographical coverage, mobility, higher reliability, and stronger security.

While public 5G networks are now deployed in many countries, private 5G (i.e., nonpublic 5G networks) remains in the early stages of deployment. A private 5G network is a dedicated wireless system restricted to a closed group of users, typically within an enterprise. In industrial or enterprise networks, Wi-Fi and Ethernet are widely used to form local area networks (LANs), enabling seamless device-to-device communication that are critical for the efficient operation of various industrial applications.

Private 5G could replace traditional wireless LAN technology, as it can significantly enhance performance compared to existing LAN-based systems. However, fundamental differences exist between conventional LANs and mobile networks like 5G. Devices in a mobile network, often referred to as user equipment (UE), are designed to connect only to external data networks (e.g., the Internet). This means that two devices in a 5G network are logically isolated from each other, even if they are physically close and connected to the same mobile network. Data communication between two UEs must traverse through external systems, resulting in applications operating in legacy LAN-based systems that cannot function normally when switched to 5G. This architectural difference presents a significant integration hurdle when transitioning industrial systems to 5G.

To overcome this challenge, the Third-Generation Partnership Project (3GPP) introduced the 5G LAN-type service in Release-16.[2,3] The goal is to support LAN functionalities on top of the 5G network while

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inheriting all of its benefits. Essentially, the 5G LAN-type service first allows the control plane to create and manage 5G LAN virtual networks (VNs), which comprise a group of devices connecting to 5G networks. The data plane is then configured with forwarding rules to enable communication among devices in the same VN so they can interact as if on a traditional LAN. Other LAN features, including device discovery, multicast, and broadcast, are also supported by the 5G LAN-type service.[2]

The 5G LAN-type service can facilitate the transition to 5G/B5G networks in industrial settings with existing Ethernet/Wi-Fi systems. By extending 5G capabilities, the 5G LAN-type service can accelerate the adoption of 5G in Industry 4.0. Although technically based on the same 5G technology, private deployments often have different requirements and use cases. It is important to note that the use of 5G LAN-type service is not limited to industrial scenarios as residential and enterprise networks can also benefit. To the best of our knowledge, only a few mobile network operators (MNOs) have trialed the 5G LAN feature, and it remains a niche service with limited commercial adoption.

Despite LAN being a mature technology, replicating its functionalities within 5G systems introduces numerous technical challenges. Given the early stage of 5G LAN-type service development, only a few works have explored this topic. Kyung et al. review standardization aspects of the 5 G LAN-type service[4] and further propose a location-aware extension to optimize user-plane paths and reduce communication delay.[5] Duan et al. demonstrate that industrial Ethernet PROFINET can operate over 5G LAN using network slicing and quality-of-service (QoS) mechanisms.[6]

While related to the 5G LAN-type service, these studies do not provide a comprehensive architectural explanation or practical deployment guidance for enterprises and IT professionals. This article therefore has two objectives: 1) to present the 5G LAN-type service in an accessible manner by outlining its use cases, technical design, and advantages compared to traditional LAN/wireless LAN (WLAN), and 2) to highlight the open challenges that must be addressed for real-world deployment, thereby motivating further research and industrial adoption.

WHY IS THE 5G LAN-TYPE SERVICE REQUIRED?

Industrial Networks

Many industrial applications demand strict network performance, including ultralow latency, high reliability, and dense device connectivity.[8] For instance, factory automation systems rely on real-time data exchange among sensors, actuators, and machines (e.g., robotic arms and automated guided vehicles). Intelligent transport systems require uninterrupted, low-latency communication, while sectors like ports, mining, and energy prioritize wide-area coverage and consistent performance.[9]

Industrial networks use various communication technologies to meet these requirements. Wired technologies, like Ethernet/IP, PROFINET, and EtherCat offer real-time communication and high reliability. However, their inflexibility and time-consuming installation make wireless solutions, notably Wi-Fi, preferable for rapid deployment and reconfiguration of LANs.[10] Despite this, Wi-Fi has limitations, including nondeterministic latency, low reliability, and small coverage areas. Scaling Ethernet or Wi-Fi networks to thousands of devices increases deployment complexity and degrades performance. Moreover, interconnecting LANs over dispersed locations requires additional technology, such as a virtual private network (VPN) or leased lines.

Private 5G can address these limitations and is emerging as a key communication technology in various sectors, such as manufacturing, mining, ports, energy, health care, transport, airports, utilities, and media. However, for a smooth transition, communication should remain transparent to end devices, enabling them to function without modification. Ideally, private 5G should function similarly to Ethernet LANs or WLANs from the device perspective. The 5G LAN-type service delivers this capability, allowing private 5G networks to support direct communication among industrial devices.[6] Essentially, devices within a 5G LAN-VN can operate as if on the same "local" network, as illustrated in Figure 1(a). However, a key advantage is that this next-generation LAN can span large geographical areas while delivering 5G-grade network performance.

Enterprise Networks

Most enterprises use Ethernet LANs or WLANs to connect printers, scanners, computers, and servers. This internal network can be accessed either within office premises or remotely via a dedicated VPN over the Internet. Both methods have their limitations: The former is restricted to specific locations, while the latter requires complex technical configurations. The 5G LAN-type service overcomes these limitations. With increasing adoption of cellular-enabled devices and the "bring your own device" policy, integrating 5G into enterprise environments is increasingly attractive.[7] If devices can communicate over a 5G network, enterprises can consider replacing traditional LANs with private 5G. The 5G LAN-type service enables intra-network communication among devices in the same 5G LAN-VN from any location with 5G coverage, as illustrated in Figure 1(b). Beyond performance, 5G's enhanced security features make it a preferred choice over other wireless technologies in sensitive enterprise environments.

5G LAN-TYPE SERVICE ARCHITECTURE

The implementation of 5G LAN-type service consists of three main components: 1) VN management, 2) packet data unit (PDU) session management, and 3) data plane forwarding,[11] as illustrated in Figure 2.

- *5G VN management:* A 5G VN is a group of UE devices that communicate privately using a 5G LAN-type service. Each VN includes a group identifier, member list, and associated data, such as QoS settings. VN management can be implemented as an application function in the control plane of the 5G core (5GC), with data stored in the unified data repository. When a UE joins a VN, its subscription data and related VN settings can be retrieved by other network functions, such as the access and mobility management function and session management function (SMF), to control access and connectivity.
- *PDU session management:* A PDU session establishes a logical connection between a UE, user plane function (UPF), and a data network (DN), enabling data transmission. To enable 5G LAN communication, a dedicated PDU session is created for each VN, allowing all member devices to communicate over the same virtual LAN, as shown in Figure 2. This requires extending the functionality of a UPF to handle data packets associated with the 5G LAN-type service.
- *Data plane forwarding:* The UPF in the 5GC is responsible for forwarding data between UEs and DNs. UPF implements packet processing rules (i.e., packet detection, forwarding, QoS, buffering, and monitoring rules) provided by the SMF to regulate all traffic from and to UEs.[12] Packet flow is controlled by matching incoming data against packet detection rules and applying forwarding action rules. For VN traffic, the UPF uses a special internal interface to route data between devices in the same VN.

Three traffic forwarding modes are supported in 5G LAN-type service: *local switch, N19-based*, and *N6-based* forwarding, as shown in Figure 2. In *local switch* mode, traffic between devices served by the same UPF is routed locally, enabling fast device-to-device communication without involving the DN. When devices connect to different UPFs, N19-based forwarding is utilized as N19 interfaces connect two UPFs in a 5G system. N6-based forwarding, the conventional method, sends traffic to a DN. Advanced data plane features (e.g., QoS, multicast/broadcast communication) can also be integrated into the UPF to enhance 5G LAN-type service capabilities.

WHAT BENEFITS CAN A 5G LAN PROVIDE?

Seamless Integration

5G is an alternative communication technology to Wi-Fi and Ethernet in the deployment of next-generation

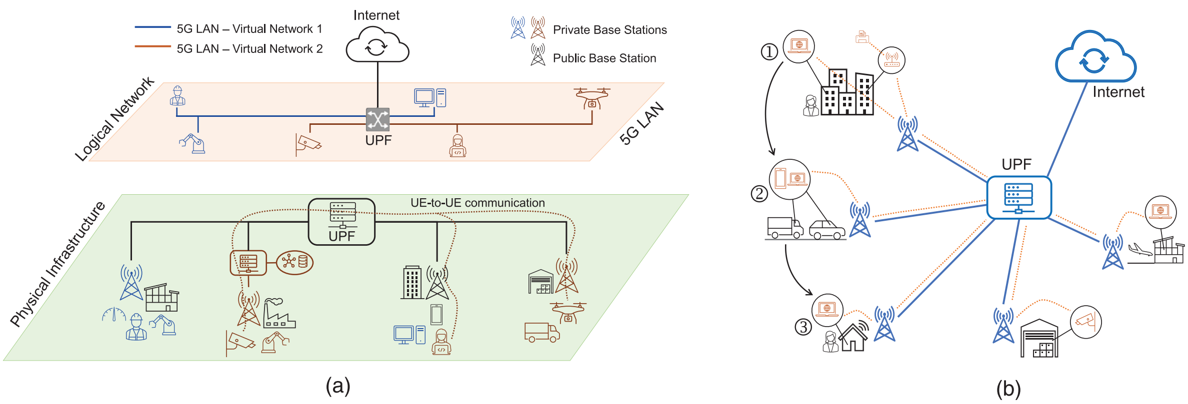

FIGURE 1. (a) Industrial use case of 5G LAN, showing a variety of devices connected on two virtual LANs over 5G, with packets forwarding via the user plane function. (b) Enterprise use case of 5G LAN-type service: employees can access the enterprise network from anywhere, such as at the office (1), on the road (2), or at home (3).

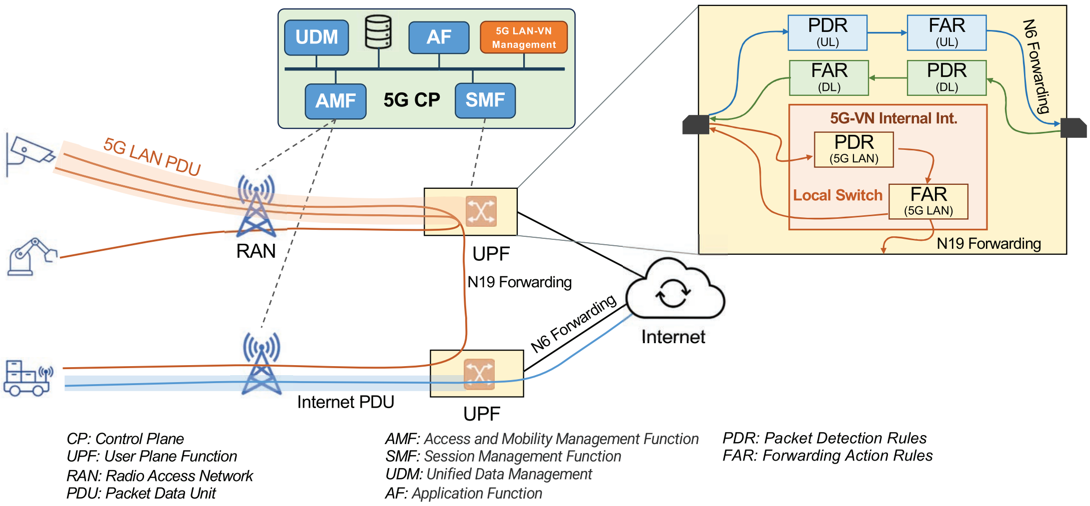

FIGURE 2. Architecture of 5G LAN-type service, showing the key components and packet flows. Two more forwarding approaches are added in UPF for 5G LAN communication as local switch and N19 forwarding.

LANs. Rather than replacing Wi-Fi entirely, 5G is designed to coexist with various technologies as it supports non-3GPP devices (e.g., Wi-Fi and LoRa devices) to connect to and transmit data via the 5GC.[13] The 5G LAN-type service allows devices in 5G networks to communicate with each other regardless of the communication technologies they employ, enabling the seamless integration of private 5G into existing LAN infrastructure.

Zero Configuration

A major advantage of 5G LAN is simplified deployment. Traditional LANs require physical setup and manual configuration of switches, routers, and endpoints, a process that becomes increasingly complex in large networks. In contrast, 5G devices can join the network using physical or eSIMs, with configurations handled remotely by the operator. Once connected, devices can instantly communicate with others in the same 5G LAN-VN, regardless of location. This reduces technical overhead and enables faster, more scalable deployments.

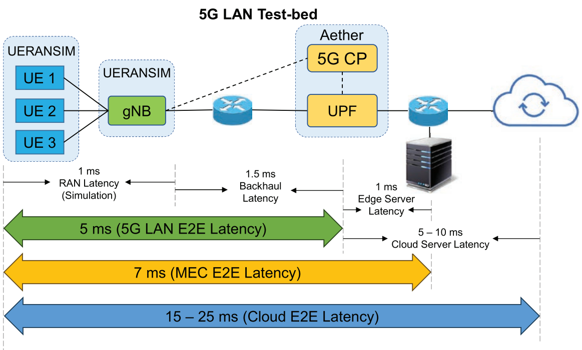

FIGURE 3. End-to-end latency comparison between 5G LAN, multiaccess edge computing (MEC), and cloud forwarding. The testbed configuration is described in Phan et al.[15]

Ultralow Latency

The 5G LAN-type service enables direct UE-to-UE communication through the UPF, bypassing edge or cloud data paths. This minimizes end-to-end latency because packets remain within the local 5G data plane rather than traversing external networks. In our testbed (described in Phan et al.[15]), we evaluated three forwarding paths—5G LAN, multiaccess edge computing, and cloud offloading—and observed that 5G LAN achieved the lowest latency, as shown in Figure 3. Since the dominant contributors to delay are radio and backhaul networks, a simplified architecture that combines 5G LAN with an edge UPF can satisfy the latency requirements of industrial applications,[14] particularly those involving time-sensitive operations.

Enhanced Dependability

In private 5G setups without LAN-type service, device communication often depends on external networks (e.g., cloud). Outages in those networks can disrupt local operations. By contrast, 5G LAN allows devices to communicate directly within the same VN, even if access to external systems is lost. This local continuity mirrors the reliability of traditional LANs, ensuring that mission-critical systems remain functional.

Business Opportunity

Beyond its technical advantages, 5G LAN presents new business opportunities for MNOs. As a software-based feature, it supports incremental deployment and easy integration with existing infrastructure, allowing targeted rollouts by region or sector. MNOs can also delegate management of virtual LAN groups to customers or third-party providers, similar to traditional LANs, enabling flexible and efficient service delivery.

OPEN ISSUES

Technical Challenges

Service Discovery and Selection

There is currently no standardized method for UE to discover available 5G LAN services or VNs. It remains unclear what information should be broadcast by the network or what discovery mechanisms should be implemented. 5G LAN requires a simple and effective discovery process to help UEs locate and join available VNs with minimal configuration.

VN Authentication

While mobile networks have well-established authentication procedures, no standard yet exists for verifying whether a UE is authorized to access a specific 5G LAN-VN. Without this, secure access control within private 5G LANs remains a challenge.

Access Restriction

Some organizations may need to restrict access to 5G LAN services based on location or time, for example, limiting connectivity to devices within company premises. Although 5G supports enhanced positioning capabilities, standardized methods to enforce such restrictions are still lacking.

Multicast and Broadcast Communication

Traditional LANs rely on multicast and broadcast for group communication and device discovery. To replicate LAN functionalities, 5G LAN must support similar mechanisms tailored to mobile environments.

Network Isolation

Ensuring that communication is restricted within each VN is critical. In traditional networks, technologies like VLAN and VXLAN provide isolation. Adapting these technologies for 5G without adding complexity is still an open issue.

Network Optimization

Enabling device-to-device communication within a 5G LAN-VN requires adding multiple packet detection and forwarding rules into the UPF. With thousands of devices per VN, this can lead to excessive rule management and performance issues. Optimizing rule placement based on device locations can help reduce latency and improve scalability.

Network Reliability

Industrial and time-sensitive applications require consistent QoS and low latency. Delivering consistent QoS to all members of the same 5G LAN-VN and maintaining service continuity for 5G LAN communication under high mobility is nontrivial.

Practical Applicability

Spectrum and Deployment Autonomy

5G LAN can operate over a licensed or unlicensed spectrum because its technical design is defined at the 5GC level and is therefore independent of radio spectrum selection. However, spectrum policy determines deployment ownership models. Enterprises may deploy a private 5G network and 5G LAN-type service using a shared or unlicensed spectrum without relying on a mobile network operator. When operating in unlicensed bands, 3GPP defines listen-before-talk mechanisms to enable fair coexistence with Wi-Fi. However, interference management in dense wireless environments remains an open challenge.

Automated Deployment

Transitioning 5G LAN from concept to deployment requires solving the automated deployment challenge. Developing fast, simple, and scalable methods for VN deployment is essential for broad adoption. MNOs should enable trusted organizations to dynamically create and manage 5G LAN-VNs through application programming interfaces or network applications, similar to how cloud networks are managed today.

Identifying High-Impact Applications

Identifying compelling use cases is key to unlocking the value of 5G LAN. Applications that demand ultralow latency and reliable UE-to-UE communication, such as factory automation, autonomous vehicles, and time-sensitive networking, are ideal candidates.[17] Other promising applications include data distribution service protocol, video streaming, and distributed federated learning, all of which benefit from efficient multicast support.[18]

CONCLUSION

The 5G LAN-type service has strong potential to enhance private 5G networks, particularly for industrial applications. By replicating LAN functionalities in a 5G network, it enables LAN-type UE-to-UE communication, facilitates the integration of legacy systems and the emergence of ultralow latency applications. However, as a relatively new feature with limited commercial deployment, the 5G LAN-type service requires further research and development to mature. Advancing its capabilities and exploring new use cases are essential next steps. This technology presents valuable opportunities for both academia and industry, and we look forward to future studies that will drive its adoption and impact.

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