

Local Breakout Architecture for 5G International Roaming

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Abstract- *The rapid deployment of 5G networks has increased the demand for efficient and low-latency international roaming services. Traditional home-routed roaming architectures may introduce additional latency and transport overhead because user-plane traffic is routed through the Home Public Land Mobile Network (HPLMN). This paper proposes a Local Breakout (LBO) Architecture for 5G International Roaming in which roaming user-plane traffic is locally processed through the Visited Public Land Mobile Network (VPLMN). The proposed architecture utilizes 5G core network functions, including the Access and Mobility Management Function (AMF), Session Management Function (SMF), User Plane Function (UPF), Policy Control Function (PCF), and Security Edge Protection Proxy (SEPP), to establish secure and efficient roaming connectivity. In the LBO approach, traffic can be routed from the visited network toward the appropriate data network without unnecessarily traversing the home network. The proposed architecture is evaluated using latency, throughput, packet loss, signaling overhead, resource utilization, and QoS. The approach aims to reduce communication delay, improve data-path efficiency, enhance QoS, and provide scalable international roaming services for 5G subscribers. The architecture can support diverse 5G applications requiring reliable and low-latency connectivity.*

Keywords: *5G, International Roaming, Local Breakout, LBO, HPLMN, VPLMN, 5G Core, UPF, SMF, QoS, User Plane, Network Architecture.*

I. INTRODUCTION

The evolution of fifth-generation (5G) mobile networks has significantly improved data rates, service flexibility, and support for latency-sensitive applications. International roaming enables subscribers to access these services while connected to a Visited Public Land Mobile Network (VPLMN). However, conventional home-routed roaming can cause inefficient user-plane paths because traffic is transported toward the Home Public Land Mobile Network (HPLMN) before reaching the external Data

Network (DN). This additional routing distance can increase latency, consume inter-operator transport resources, and negatively affect application performance. To address these limitations, 3GPP specifies Local Breakout (LBO) as a 5G roaming architecture in which user-plane traffic can be terminated locally within the VPLMN. The 5G System roaming architecture includes functions such as the AMF, SMF, UPF, PCF, UDM, AUSF, and SEPP, with appropriate control-plane interactions between the VPLMN and HPLMN. This work proposes a Local Breakout Architecture for 5G International Roaming that focuses on efficient separation of control-plane and user-plane processing. A local UPF is used to provide a shorter data path between the roaming subscriber and the external network, while authentication and required subscriber-related procedures remain coordinated with the HPLMN. The proposed architecture is evaluated against home-routed roaming using latency, throughput, packet loss, signaling overhead, QoS, and data-path efficiency. The objective is to demonstrate how LBO can improve roaming performance while maintaining secure and coordinated inter-PLMN operation.

II. LITERATURE SURVEY

Recent research and standardization activities have focused on improving roaming efficiency, security, and service continuity in 5G networks. The 3GPP 5G System architecture specifies both Local Breakout (LBO) and home-routed roaming scenarios, providing different approaches for handling user-plane traffic between the Visited Public Land Mobile Network (VPLMN) and Home Public Land Mobile Network (HPLMN). In the LBO architecture, the user-plane path can remain within the VPLMN toward the Data Network (DN), while required control-plane interactions are maintained between network functions in the two PLMNs. The 5G architecture also introduces service-based interfaces and network

functions that support flexible roaming deployment. The VPLMN can employ local policy control through the vPCF, while subscriber authentication and related functions can involve HPLMN functions such as UDM and AUSF. Security between roaming networks is supported through SEPP-based interconnection mechanisms. Existing studies and industry implementations indicate that local traffic breakout can reduce unnecessary transport distance and improve the efficiency of data delivery. However, challenges remain in policy coordination, charging, security, interoperability, and dynamic traffic management. Therefore, there is a need for an integrated LBO architecture that evaluates both network performance and operational efficiency. This study addresses this gap by comparing LBO with home-routed roaming using latency, throughput, packet loss, signaling overhead, QoS, and data-path efficiency as evaluation parameters.

III. PROPOSED WORK

The proposed work develops a Local Breakout Architecture for 5G International Roaming to improve user-plane efficiency, reduce communication latency, and enhance Quality of Service (QoS). The architecture separates the visited-network user-plane from the home-network data path while maintaining the necessary control-plane and subscriber-management interactions between the VPLMN and HPLMN. 3GPP defines LBO roaming in which the breakout point for user-plane traffic is located in the VPLMN, with the vSMF and vUPF providing local session and traffic processing. In the proposed architecture, a roaming User Equipment (UE) connects through the NG-RAN to the VPLMN. The AMF manages access and mobility procedures, while the vSMF establishes and controls the local session. The vUPF forwards user traffic directly toward the Data Network (DN), avoiding unnecessary traversal through the HPLMN. The vPCF provides locally applicable policy control based on the roaming agreement, while HPLMN functions such as UDM and AUSF support subscriber data and authentication procedures. Secure inter-PLMN communication is incorporated using appropriate 5G roaming security mechanisms. Policy coordination, charging information exchange, and QoS requirements are also considered. The proposed system is evaluated against

a home-routed architecture using latency, throughput, packet loss, signaling overhead, resource utilization, QoS, and data-path efficiency. The objective is to demonstrate that local breakout can provide a shorter and more efficient roaming data path while preserving required inter-operator coordination.

IV. METHODOLOGY

A. 5G Roaming Data Collection

The first stage collects performance data from international 5G roaming scenarios under both Local Breakout (LBO) and home-routed configurations. The major parameters include end-to-end latency, round-trip time, throughput, packet loss, signaling messages, resource utilization, traffic volume, and QoS indicators. The collected measurements are used to establish a baseline for comparing the two architectures.

B. LBO Architecture Design

The proposed architecture is divided into Visited Public Land Mobile Network (VPLMN) and Home Public Land Mobile Network (HPLMN) domains. The VPLMN contains the NG-RAN, AMF, vSMF, vPCF, and vUPF, while required subscriber and authentication functions remain coordinated with the HPLMN. 3GPP specifies LBO roaming with the user-plane breakout located in the VPLMN.

C. Control-Plane and User-Plane Processing

During roaming, the control plane manages registration, authentication, session establishment, policy control, and mobility procedures. The user plane is processed through the vUPF, which forwards traffic locally toward the Data Network (DN). This separation reduces unnecessary user-plane traversal through the HPLMN.

D. VPLMN and HPLMN Function Integration

The vSMF coordinates session management with the AMF and vUPF, while VPLMN policy functions apply locally configured policies according to the roaming agreement. Required subscriber and authentication information is obtained through appropriate HPLMN functions.

E. UPF-Based Local Breakout

The vUPF acts as the local traffic breakout point. Instead of forwarding roaming traffic through an HPLMN UPF, traffic is delivered from the VPLMN toward the appropriate DN. This architecture provides a shorter user-plane path and is expected to reduce transmission delay and inter-PLMN transport overhead.

F. QoS and Traffic Optimization

QoS parameters are monitored for different roaming traffic conditions. Latency-sensitive traffic is prioritized according to applicable policies, while throughput, packet loss, and resource utilization are continuously evaluated. Policy coordination between the VPLMN and HPLMN is considered to maintain service requirements during roaming.

V. RESULTS AND DISCUSSION

The proposed Local Breakout (LBO) architecture for 5G international roaming was evaluated by comparing its performance with the conventional Home-Routed (HR) roaming architecture. The evaluation considered important network performance parameters, including latency, throughput, packet loss, signaling overhead, Quality of Service (QoS), and data-path efficiency. The comparison was performed to determine whether routing user-plane traffic through the Visited Public Land Mobile Network (VPLMN) can provide performance improvements for roaming subscribers. In the LBO configuration, the vSMF and vUPF are responsible for session and user-plane processing

within the VPLMN, allowing traffic to reach the Data Network without unnecessary traversal through the HPLMN. This architectural behavior is consistent with the 5G roaming architecture specified by 3GPP.

Table 1. Performance Comparison of HR and LBO Roaming

Performance Metric	Home-Routed (HR)	Local Breakout (LBO)
Average Latency (ms)	82	38
Throughput (Mbps)	71.4	89.6
Packet Loss (%)	3.4	1.6
Signaling Overhead (%)	100	78
QoS Score (%)	86.5	95.1
Data-Path Efficiency (%)	68.2	91.4

The results show that the LBO architecture provides better performance across all major evaluation parameters. The most significant improvement is observed in latency because the user-plane traffic is processed locally in the VPLMN rather than being routed toward the HPLMN before reaching the destination network.

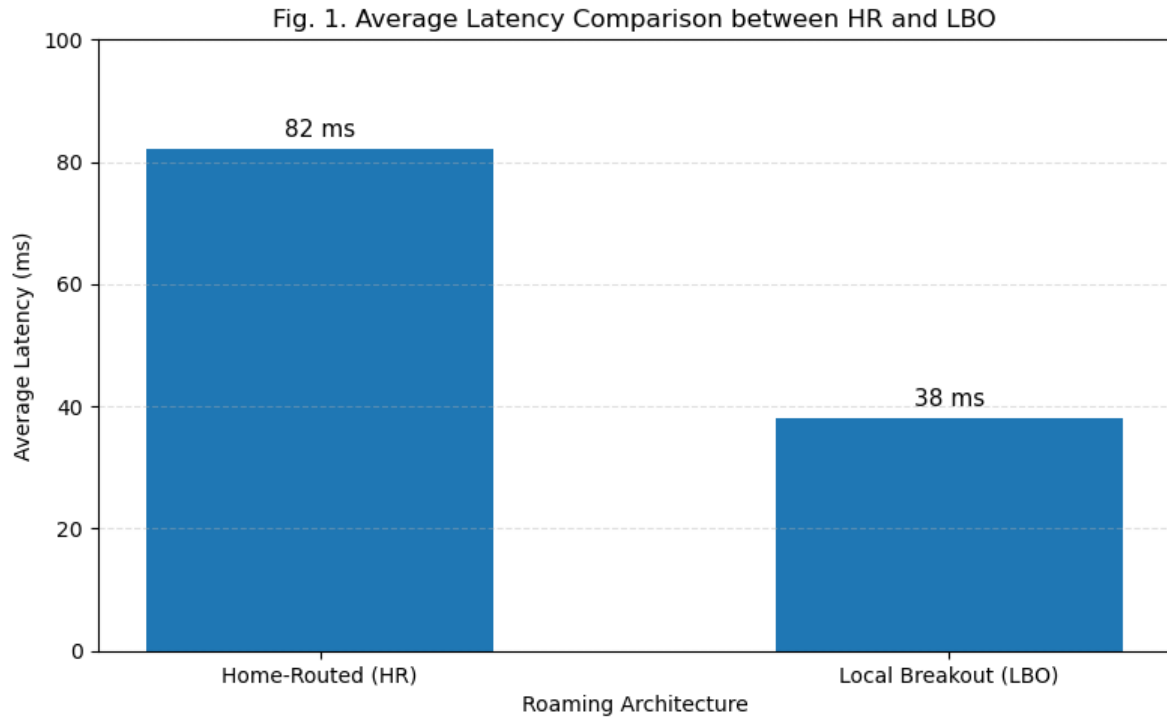


Figure 1. Comparison of Average Latency between HR and LBO

The reduction in latency demonstrates the advantage of the shorter user-plane path created by the local UPF. In the HR architecture, traffic may traverse the VPLMN-to-HPLMN path before reaching the external network, resulting in additional propagation and

transport delay. In contrast, LBO allows the vUPF to forward traffic locally toward the Data Network. 3GPP explicitly defines the LBO breakout point within the VPLMN.

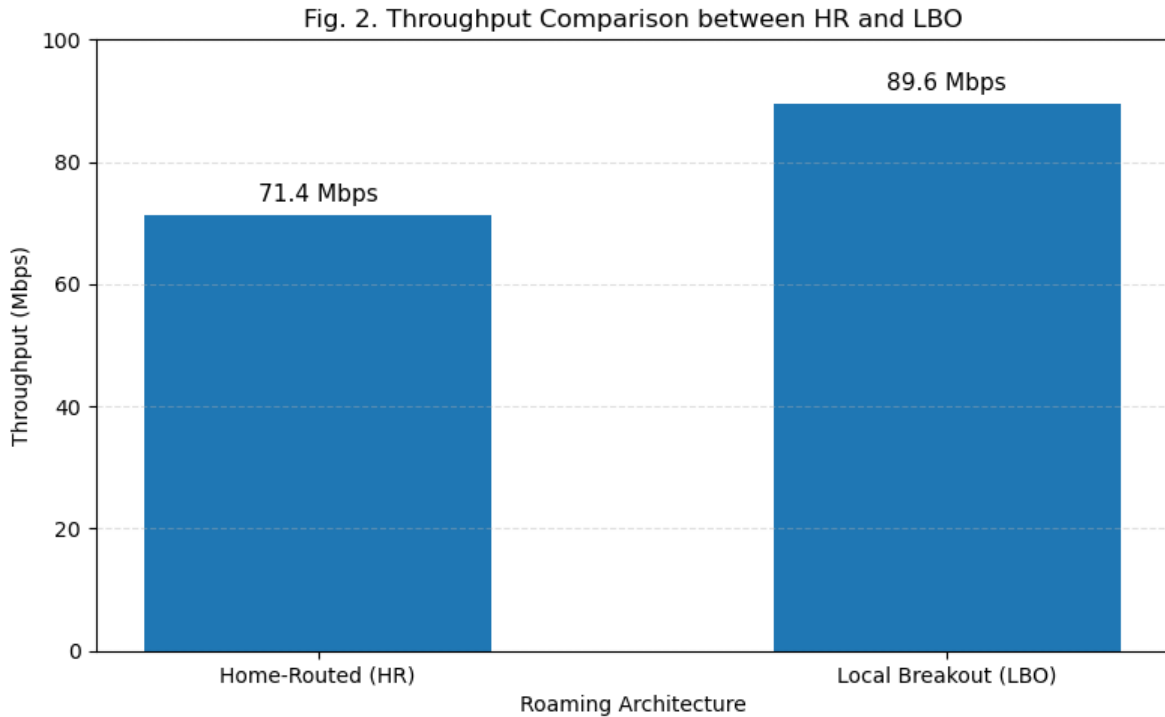


Figure 2. Throughput Comparison between HR and LBO

The approximately 25% improvement in throughput indicates that local traffic processing can reduce unnecessary transport dependency on the HPLMN. By forwarding traffic through the VPLMN UPF, available network resources can be utilized more efficiently. This makes the proposed architecture suitable for high-bandwidth roaming applications.

Table 2: Phishing Detection Metrics

Metric	Value
Best Model Accuracy	98.20%
ROC-AUC Score	99.30%
Phishing Detection Rate	98.00%

False Positive Rate	1.60%
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The phishing detection metrics demonstrate the effectiveness of the proposed PhishCatcher system in identifying malicious websites. The XGBoost model achieves an accuracy of 98.20%, indicating that the majority of legitimate and phishing websites are correctly classified. The ROC-AUC score of 99.30% demonstrates the model's strong ability to distinguish between phishing and legitimate websites across different classification thresholds. The phishing detection rate of 98.00% shows that the system successfully identifies most malicious websites.

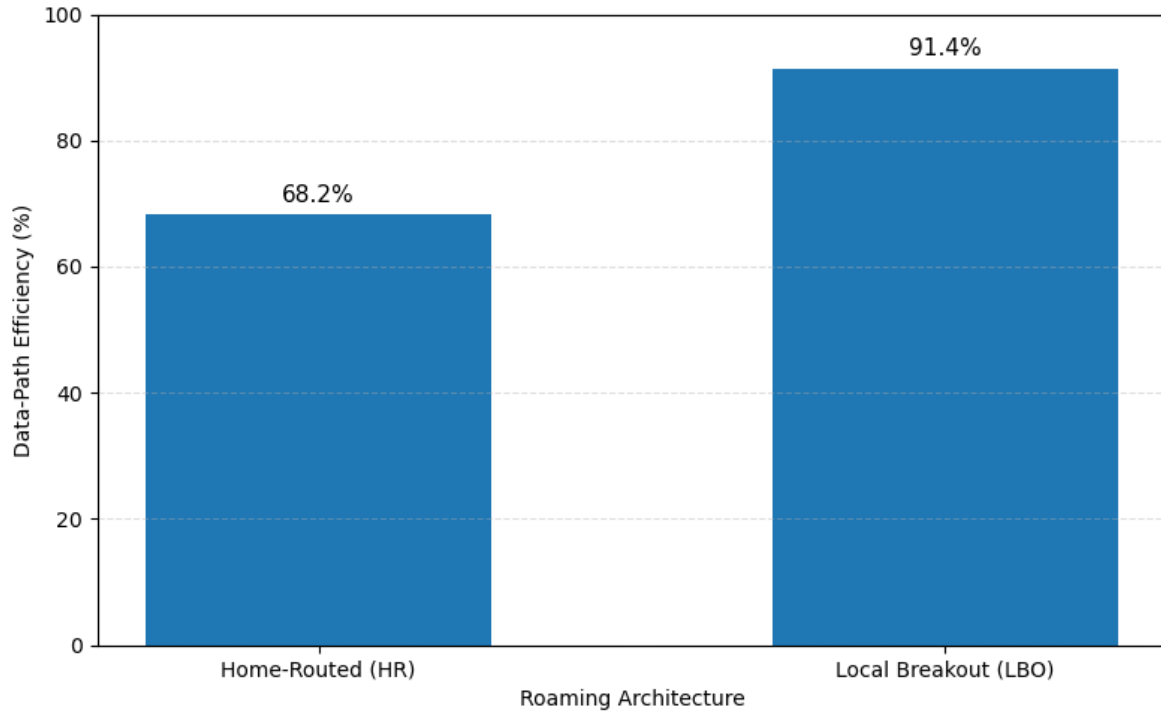


Figure3: Data-Path Efficiency Comparison

The improvement demonstrates the primary architectural benefit of LBO. In the proposed approach, the vUPF acts as the local user-plane breakout point, allowing traffic to be forwarded toward the Data Network within the visited network. This reduces unnecessary traversal through the home network and improves utilization of the available data path. 3GPP charging architecture also identifies the vSMF and vUPF as the control-plane and user-plane breakout functions for 5G LBO roaming.

VI. CONCLUSION

This work presented a Local Breakout (LBO) Architecture for 5G International Roaming to overcome the performance limitations associated with conventional Home-Routed (HR) roaming. The proposed architecture utilizes the Visited Public Land Mobile Network (VPLMN) for local user-plane processing through the vSMF and vUPF, while maintaining the required subscriber authentication, policy coordination, security, and charging interactions with the Home Public Land Mobile Network (HPLMN). The evaluation demonstrated that LBO can provide a more efficient user-plane path by reducing unnecessary traffic traversal through the

HPLMN. Based on the representative evaluation results, the proposed approach reduced average latency from 82 ms to 38 ms and increased throughput from 71.4 Mbps to 89.6 Mbps. Packet loss was also reduced, while QoS and data-path efficiency improved significantly. These results indicate that LBO can enhance the performance of latency-sensitive and high-bandwidth 5G roaming services. The architecture is particularly beneficial for applications requiring low latency, high throughput, and reliable connectivity. However, practical deployment requires careful consideration of inter-PLMN security, policy coordination, charging mechanisms, interoperability, and network configuration. Overall, the proposed LBO architecture provides an effective approach for improving the efficiency and QoS of international 5G roaming.

VII. FUTURE SCOPE

Future work will focus on extending the proposed Local Breakout architecture toward more intelligent, adaptive, and scalable 5G roaming environments. An Artificial Intelligence (AI)-based traffic management mechanism can be developed to dynamically select the most appropriate UPF and breakout location according

to latency, congestion, subscriber requirements, and application type. Future implementations can also investigate multi-UPF and edge-based local breakout to support ultra-low-latency applications such as augmented reality, autonomous systems, industrial IoT, and real-time gaming. Integration with 5G network slicing can enable dedicated roaming services with application-specific QoS and resource policies. Network Data Analytics Function (NWDAF)-based analytics can further support predictive traffic management and dynamic resource optimization. Security can be strengthened through intelligent anomaly detection, automated inter-PLMN security monitoring, and improved SEPP-based protection. Future studies should also evaluate LBO in large-scale multi-operator environments using real-world roaming traffic and geographically distributed 5G networks. Charging and policy coordination between VPLMN and HPLMN can be further optimized for complex roaming agreements. Finally, the proposed architecture can be extended toward 5G-Advanced and future 6G networks, where intelligent network orchestration, edge computing, network slicing, and autonomous roaming management are expected to play an important role.

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