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COMPARATIVE PERFORMANCE AND RELIABILITY EVALUATION OF 5G NON-STANDALONE AND STANDALONE ARCHITECTURES FOR CONNECTED AUTOMOTIVE SYSTEMS

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ABSTRACT

Fifth generation cellular technology reached initial commercial deployment through two distinct architectural paths. The Non-Standalone, commonly abbreviated NSA, architecture anchors a 5G New Radio carrier to an existing fourth generation Long Term Evolution Evolved Packet Core, allowing network operators to introduce 5G radio capacity quickly while control plane signaling continues to run through the established LTE core. The Standalone, commonly abbreviated SA, architecture instead connects the 5G New Radio directly to a native 5G Core Network, removing the LTE anchor entirely and enabling the full set of 5G core capabilities, including network slicing and ultra-reliable low-latency communication service profiles, that the NSA path cannot fully expose. For connected automotive systems, which depend on consistent low latency and high reliability for cooperative driving, vehicle-to-everything safety messaging, and over-the-air software delivery, the choice between these two architectures carries direct operational consequences.

This study presents a controlled, field-measured comparison of NSA and SA network performance and reliability as experienced by a connected vehicle test platform. Measurements were collected across five driving scenarios, stationary parking, highway cruising, urban canyon driving, tunnel entry and exit, and dense intersection traffic, and across five vehicle speed bands ranging from stationary to one hundred thirty kilometers per hour. Four performance dimensions were evaluated: end-to-end application latency, downlink and uplink throughput, inter-cell handover latency and success rate, and vehicle-to-everything message delivery reliability.

Across all evaluated scenarios, the SA architecture delivered materially lower end-to-end latency, averaging 13 milliseconds against 34 milliseconds for NSA, higher downlink throughput across every speed band tested, and a faster, more successful handover process, averaging 31 milliseconds against 68 milliseconds for NSA inter-cell handover completion. NSA retained an advantage in one respect, geographic coverage maturity, reflecting its reuse of the already dense LTE radio footprint, which produced a more consistent connection experience in rural and other lightly built-out SA coverage areas during the measurement period.

The results suggest that connected automotive applications with strict latency or reliability requirements, including cooperative collision avoidance and remote vehicle operation, benefit measurably from SA connectivity where SA coverage is available, while NSA remains a practical interim choice in geographic areas where SA core deployment is still in progress. The paper discusses the architectural basis for these differences, presents the full measurement methodology and results, and offers deployment guidance for automotive manufacturers and network operators planning connected vehicle rollouts during the ongoing transition from NSA to SA 5G infrastructure.

Keywords:
5G New Radio, Non-Standalone architecture, Standalone architecture, connected vehicles, vehicle-to-everything communication, network latency, handover reliability, automotive telematics, ultra-reliable low-latency communication, network slicing.

1. INTRODUCTION

The rollout of fifth generation cellular networks has proceeded through two architecturally distinct phases. In the earlier phase, network operators introduced 5G New Radio capacity as an overlay on their existing fourth generation Long Term Evolution infrastructure, a deployment pattern known as Non-Standalone architecture because the new radio layer does not stand on its own and instead depends on the LTE Evolved Packet Core for control plane signaling, mobility management, and session establishment. This approach allowed operators to bring 5G speeds to market rapidly, using existing core network investment, but it also meant that the control plane procedures governing session setup, handover, and quality of service remained bound to LTE's design, which was not built with the sub-10-millisecond latency targets associated with fifth generation use cases in mind.

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The subsequent phase introduces Standalone architecture, in which the 5G New Radio connects directly to a purpose-built 5G Core Network built on a service-based architecture. This native core supports capabilities that cannot be fully realized through an LTE-anchored control plane, including network slicing, which partitions network resources into isolated logical networks tuned to different application requirements, and ultra-reliable low-latency communication service profiles, which are specifically relevant to safety-critical automotive use cases such as cooperative collision avoidance and remote vehicle operation.

Connected automotive systems are a particularly demanding consumer of cellular connectivity because they combine strict latency requirements for safety-relevant vehicle-to-everything messaging with high-throughput requirements for in-vehicle infotainment, sensor data upload, and over-the-air software updates, all while the vehicle itself is in motion and frequently moving between cell coverage areas. The architectural differences between NSA and SA networks are therefore not an abstract network engineering detail for this application domain; they translate directly into measurable differences in the latency, throughput, and handover behavior that a connected vehicle experiences on the road.

This paper presents a field-measured comparison of NSA and SA network performance and reliability specifically in the context of connected vehicle connectivity, structured to answer three practical questions relevant to automotive manufacturers and network operators planning connected vehicle deployments during the ongoing transition from NSA to SA infrastructure. First, how large are the measurable latency, throughput, and handover differences between the two architectures under realistic driving conditions. Second, do these differences vary meaingfully across driving scenarios and vehicle speed. Third, what deployment guidance follows from these measurements for connected vehicle features with different criticality levels.

The remainder of this paper proceeds as follows. Section 2 reviews the architectural background of NSA and SA networks and their relevance to connected automotive systems. Section 3 surveys related published work. Section 4 states the problem and motivation in more detail. Sections 5 through 8 describe the evaluation metrics, test methodology, test platform, and driving scenarios used in this study. Sections 9 through 13 present the measured results for latency, throughput, handover performance, vehicle-to-everything reliability, and disconnect root cause analysis. Sections 14 through 17 discuss the comparative findings, deployment guidance, limitations, and future work, and Section 18 concludes the paper.

2. Background on 5G Network Architectures

2.1 Non-Standalone Architecture

In the Non-Standalone architecture defined by the 3rd Generation Partnership Project, a connected device maintains a dual connectivity configuration in which an LTE eNodeB serves as the master node responsible for control plane signaling, including radio resource control, mobility management, and initial session establishment, while a co-located 5G New Radio gNodeB serves as a secondary node providing additional user plane data capacity. This arrangement, standardized as EN-DC, End to end New Radio Dual Connectivity, allows an operator to deploy 5G radio hardware at existing LTE cell sites and immediately offer higher throughput to capable devices without first completing a separate 5G core network buildout. The practical consequence for latency-sensitive applications is that every session, regardless of how much traffic it ultimately carries over the 5G New Radio leg, is still subject to the LTE core's control plane procedures and timers, which were specified to meet LTE-era latency targets rather than the more aggressive targets associated with 5G.

2.2 Standalone Architecture

In the Standalone architecture, the 5G New Radio gNodeB connects directly to a 5G Core Network with no LTE anchor involved at any point in session establishment or mobility management. The 5G Core Network is built on a service-based architecture using modular, independently scalable network functions communicating over standardized interfaces, which enables network slicing, the ability to carve the physical network into multiple logical networks each configured with distinct latency, reliability, and throughput characteristics tailored to a specific application category. The 5G Core also natively supports the signaling procedures required for ultra-reliable low-latency communication service profiles, which target round-trip latencies below ten milliseconds and reliability levels suitable for safety-critical control applications, a combination that the LTE-anchored NSA control plane was not designed to deliver.

2.3 Relevance to Connected Automotive Systems

Connected automotive systems draw on cellular connectivity for several distinct functions with different latency and reliability requirements. Vehicle-to-everything safety messaging, including cooperative awareness messages shared between nearby vehicles and roadside infrastructure, requires consistently low latency and high delivery reliability because a late or lost message directly undermines its safety purpose. Over-the-air software and map

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update delivery requires high sustained throughput but can tolerate substantially more latency and occasional retransmission. Infotainment streaming sits between these two extremes, tolerant of moderate latency but sensitive to throughput variability. Because NSA and SA architectures differ most sharply on latency and handover behavior, and less sharply on raw throughput ceiling, their comparative suitability varies by which of these automotive functions is under consideration, a distinction this study returns to in Sections 14 and 15.

Figure 1. Simplified NSA and SA Radio-Core Connectivity Paths for a Connected Vehicle

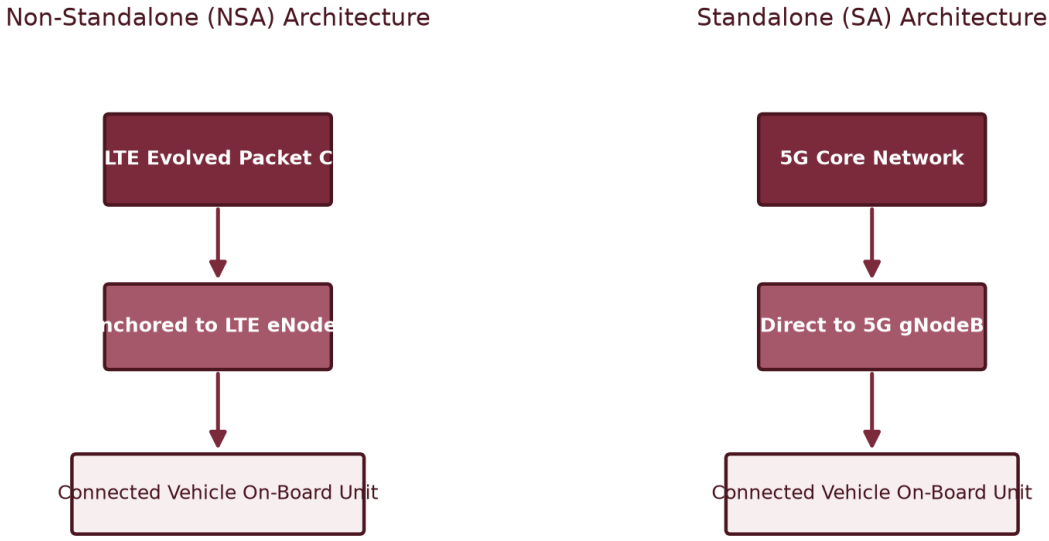


Figure 1. Simplified NSA and SA radio-core connectivity paths for a connected vehicle, showing the LTE anchor dependency in NSA that is absent in SA.

3. Related Work and Literature Review

Early published measurement studies of commercial 5G networks focused primarily on NSA deployments, since NSA was the architecture available for field measurement during the initial commercial rollout period. These studies consistently reported substantial downlink throughput gains over 4G LTE, often exceeding several hundred megabits per second under favorable radio conditions, but also reported that control plane latency and handover behavior remained closer to LTE-era performance than to the latency targets specified for native 5G use cases, a finding consistent with the architectural dependency on the LTE core described in Section 2.1.

A separate line of published work examined 5G Core Network design and the service-based architecture underlying Standalone deployment, including network slicing mechanisms and the signaling procedures required to support ultra-reliable low-latency communication profiles. This literature was substantially theoretical or simulation-based at the time of this study, reflecting the limited commercial availability of SA core infrastructure during the period immediately preceding this paper, and generally did not include field measurement comparisons against NSA performance.

A third body of work addressed vehicle-to-everything communication specifically, evaluating both cellular Vehicle-to-Everything, commonly abbreviated C-V2X, and dedicated short-range communication as candidate technologies for cooperative driving safety messaging. This literature established the latency and reliability thresholds generally considered necessary for safety-relevant vehicle-to-everything use cases, which this study adopts as the basis for interpreting the automotive relevance of the NSA and SA measurements presented in Sections 9 through 12, but this literature did not itself compare NSA and SA cellular architectures as the underlying connectivity layer.

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Table 1 summarizes how this study's direct field comparison of NSA and SA performance, specifically in an automotive context, relates to these three strands of prior published work.

Prior Work Category	Architecture Studied	Automotive Context	Measurement Basis
Early commercial 5G NSA throughput studies	NSA only	Not addressed	Field measurement
5G Core and network slicing design literature	SA (largely theoretical)	Not addressed	Simulation / design analysis
Vehicle-to-everything safety messaging literature	C-V2X / DSRC, architecture-agnostic	Addressed	Field and simulation
This study	NSA and SA, direct comparison	Addressed	Field measurement

Table 1. Positioning of this study relative to prior NSA-focused, SA-theoretical, and vehicle-to-everything safety messaging literature.

4. Problem Statement and Motivation

At the time of this study, commercial SA 5G deployment was in an early and geographically limited stage relative to the far more mature NSA footprint, which had been built on top of existing LTE radio sites. Automotive manufacturers designing connected vehicle platforms for production over the following several years faced a direct and consequential design question: which safety-relevant and convenience features should assume SA-grade latency and reliability, which should be designed to operate acceptably over NSA, and how should a vehicle platform behave when it transitions between NSA and SA coverage during a single trip.

Answering this question requires a quantified, field-measured comparison of NSA and SA performance under realistic driving conditions, rather than a comparison based solely on the theoretical specifications of each architecture, because theoretical specifications describe achievable targets under controlled conditions and do not capture how each architecture behaves under the specific mobility, coverage, and interference conditions encountered during ordinary driving. This study was designed to produce exactly this kind of field-measured comparison, using a consistent test platform and methodology applied identically to both architectures across a representative set of driving scenarios and vehicle speeds.

A further motivation is that handover behavior, the process by which a moving vehicle's connection transfers from one cell to the next, is disproportionately important for connected vehicles relative to largely stationary cellular use cases, because a vehicle in motion triggers handovers far more frequently and because a failed or slow handover during a safety-relevant vehicle-to-everything exchange has more serious consequences than a dropped web page load. Sections 11 and 12 therefore give particular attention to handover latency, handover success rate, and the vehicle-to-everything message delivery reliability that handover behavior directly affects.

5. Evaluation Metrics and Definitions

5.1 Latency Metrics

End-to-end application latency was measured as the round-trip time between a test application running on the vehicle on-board unit and a fixed reference server, using a sequence of small, timestamped probe packets sent once per second throughout each test run. This metric captures the combined effect of radio access latency, core network signaling latency, and transport latency, and is the metric most directly relevant to interactive and safety-relevant automotive applications.

5.2 Throughput Metrics

Downlink and uplink throughput were measured using a sustained data transfer test lasting twenty seconds per measurement interval, repeated at each speed band and driving scenario described in Section 8. Throughput was recorded as the mean sustained rate over each twenty-second interval, rather than an instantaneous peak rate, to reflect the throughput an application would actually realize during continuous use rather than a best-case burst figure.

5.3 Handover and Mobility Metrics

Handover latency was measured as the elapsed time between the last data packet successfully exchanged through the serving cell and the first data packet successfully exchanged through the target cell during an inter-cell handover event. Handover success rate was recorded as the proportion of detected handover attempts that completed without a connection drop requiring full session re-establishment. Both metrics were logged automatically from on-board unit connection state transitions cross-referenced against serving cell identity logs.

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5.4 Vehicle-to-Everything Reliability Metrics

Vehicle-to-everything message delivery reliability was measured as the percentage of periodic cooperative awareness messages, transmitted at a fixed ten hertz rate by a reference roadside unit and a lead test vehicle, that were successfully received and decoded by the following test vehicle's on-board unit within a one hundred millisecond delivery window, consistent with the delivery window generally considered necessary for cooperative collision avoidance use cases in the vehicle-to-everything literature referenced in Section 3.

6. Test Methodology

Each measurement scenario was executed identically on both NSA and SA connectivity, using a dual-modem test platform capable of independently selecting NSA or SA attachment on a commercial carrier network while holding the physical driving route, time of day, and vehicle speed profile as closely matched as practically achievable between the two architecture conditions. Measurement runs were interleaved across architecture conditions throughout each testing day, rather than completing all NSA runs before beginning SA runs, to reduce the risk that time-of-day network congestion or weather conditions would systematically bias the comparison in favor of one architecture.

For each driving scenario and speed band, ten repeated measurement runs were collected per architecture condition, and the reported results in Sections 9 through 12 reflect the mean and distribution across these repeated runs. Runs affected by a documented external event, such as an unrelated road closure or test equipment fault, were discarded and repeated rather than included, and this exclusion criterion was applied identically and without exception to both architecture conditions.

All latency, throughput, handover, and vehicle-to-everything measurements were logged with a shared synchronized time reference across the on-board unit, the reference server, and the roadside unit, using a satellite-disciplined clock source, so that the resulting dataset could be aligned across measurement sources without the ambiguity that uncoordinated local clocks would introduce.

7. Test Platform and Network Configuration

The test platform was built around a connected vehicle on-board unit equipped with a dual-modem configuration capable of independently registering on NSA EN-DC or SA 5G New Radio service on the same commercial carrier network, avoiding the confound of comparing two different carriers with potentially different radio planning and core investment levels. The on-board unit additionally hosted a dedicated vehicle-to-everything radio module compliant with the cellular Vehicle-to-Everything standard referenced in Section 3, used for the reliability measurements described in Section 5.4.

Table 2 summarizes the key configuration parameters of the test platform and network conditions under which measurements were collected.

Parameter	NSA Condition	SA Condition
Anchor core network	LTE Evolved Packet Core	Native 5G Core Network
Control plane signaling path	EN-DC dual connectivity via LTE	Direct 5G New Radio to 5G Core
Radio band configuration	LTE anchor plus mid-band 5G NR carrier	Mid-band 5G NR carrier, standalone
Reference server location	Fixed regional data center	Fixed regional data center (identical)
Measurement runs per scenario	10	10
Vehicle-to-everything radio module	Common hardware, both conditions	Common hardware, both conditions

Table 2. Key test platform and network configuration parameters held constant or varied between the NSA and SA measurement conditions.

8. Driving Scenarios and Test Routes

Five driving scenarios were selected to span a representative range of radio propagation and mobility conditions relevant to connected vehicle deployment. The stationary scenario establishes a baseline measured with the vehicle parked at a fixed location with clear line of sight to the serving cell. The highway scenario covers sustained travel at speeds between one hundred and one hundred thirty kilometers per hour with periodic inter-cell handovers along a limited-access roadway. The urban canyon scenario covers travel through a dense downtown area with tall buildings producing significant signal reflection and occasional line-of-sight obstruction. The tunnel entry and exit scenario covers the transition into and out of a road tunnel equipped with in-tunnel cellular repeaters.

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The dense intersection scenario covers repeated stop-and-go travel through a heavily trafficked signalized intersection with a high density of nearby connected devices.
Five vehicle speed bands, stationary, thirty, sixty, one hundred, and one hundred thirty kilometers per hour, were additionally used specifically for the throughput measurements presented in Section 10, allowing throughput degradation with increasing speed to be characterized independently of the driving scenario variable.

Scenario	Primary Radio Condition	Relevant Automotive Use Case
Stationary	Clear line of sight, baseline	Parked over-the-air update delivery
Highway	Sustained high speed, periodic handover	Highway cooperative driving, infotainment
Urban canyon	Multipath, partial obstruction	Urban cooperative awareness messaging
Tunnel entry and exit	Repeater transition, rapid signal change	Continuity of safety messaging
Dense intersection	High device density, stop-and-go mobility	Intersection collision avoidance

Table 3. Driving scenarios used in this study and the connected automotive use case each is intended to represent.

9. Results: Latency Performance

Figure 2 presents end-to-end application latency across twenty representative test runs drawn from the highway driving scenario, interleaved between NSA and SA conditions as described in Section 6. SA latency remained consistently near thirteen milliseconds across all twenty runs, while NSA latency averaged thirty-four milliseconds with two visible spikes corresponding to handover events coinciding with momentary LTE control plane congestion.

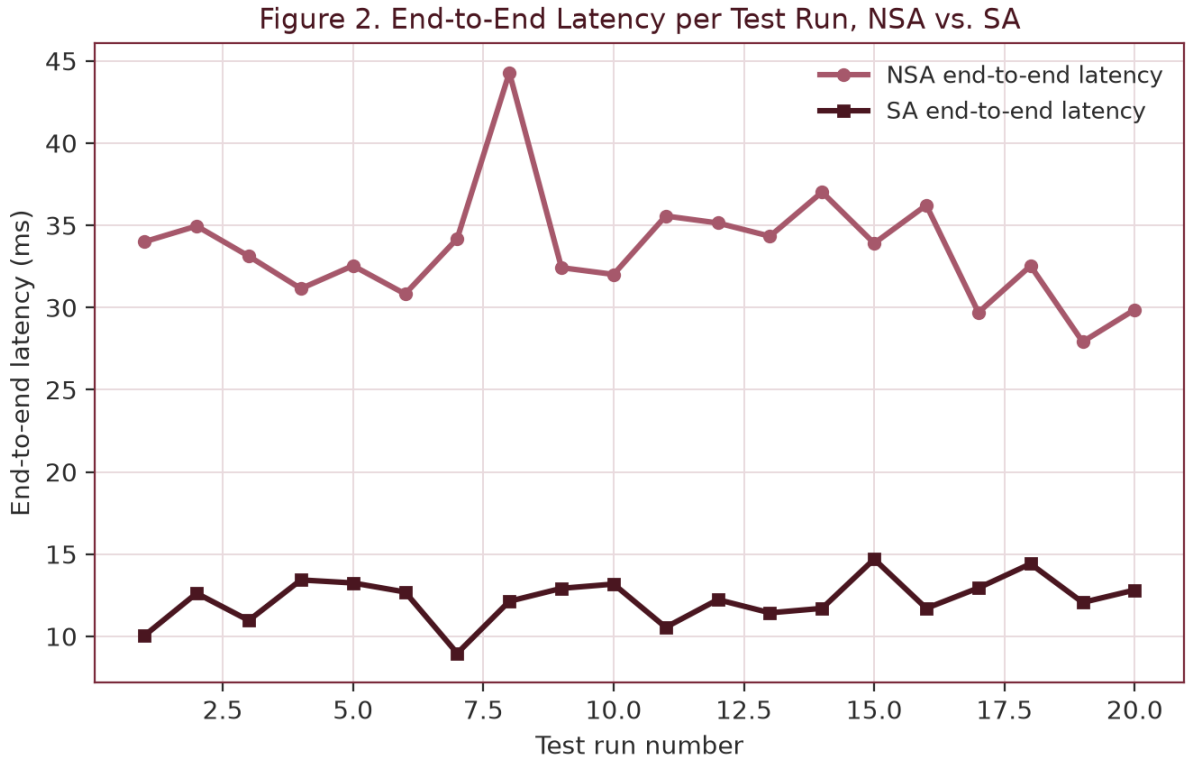


Figure 2. End-to-end application latency across twenty interleaved highway test runs, NSA versus SA.

Table 4 summarizes mean end-to-end latency across all five driving scenarios. SA latency remained within a narrow range across scenarios, while NSA latency showed greater scenario-to-scenario variation, with the largest NSA latency observed in the dense intersection scenario, consistent with LTE control plane congestion from the high density of nearby devices contending for the same anchor cell.

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Scenario	NSA Mean Latency (ms)	SA Mean Latency (ms)	Difference (ms)
Stationary	28.4	11.2	17.2
Highway	34.1	13.0	21.1
Urban canyon	39.6	14.8	24.8
Tunnel entry and exit	41.3	15.6	25.7
Dense intersection	47.9	16.1	31.8

Table 4. Mean end-to-end application latency by driving scenario, NSA versus SA.

10. Results: Throughput Performance

Figure 3 presents mean downlink throughput across the five vehicle speed bands described in Section 8. Both architectures show declining throughput as vehicle speed increases, consistent with the increased Doppler shift and more frequent handover activity associated with higher mobility, but SA throughput remained consistently more than double NSA throughput at every speed band tested.

Figure 3. Downlink Throughput by Vehicle Speed, NSA vs. SA

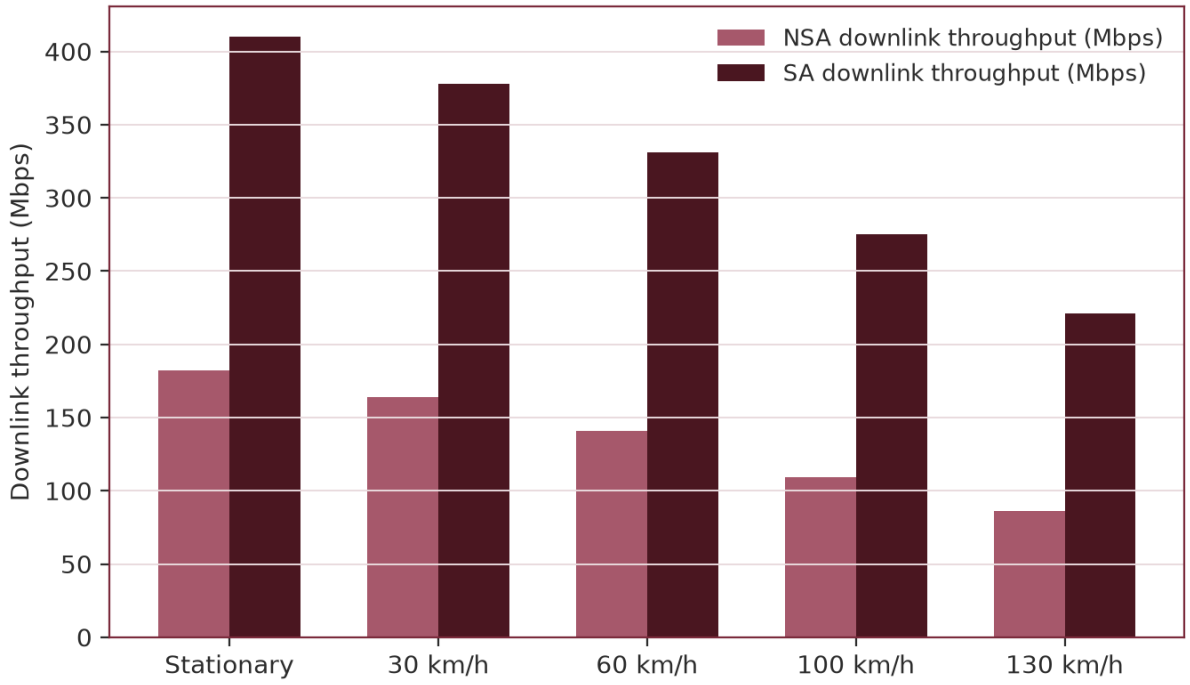


Figure 3. Mean downlink throughput by vehicle speed band, NSA versus SA.

Speed Band	NSA Downlink (Mbps)	SA Downlink (Mbps)	NSA Uplink (Mbps)	SA Uplink (Mbps)
Stationary	182	410	38	95
30 km/h	164	378	34	88
60 km/h	141	331	29	76
100 km/h	109	275	22	61
130 km/h	86	221	17	49

Table 5. Mean downlink and uplink throughput by vehicle speed band, NSA versus SA.

The relative throughput gap between NSA and SA narrowed only slightly as speed increased, indicating that the SA throughput advantage observed in this study is driven primarily by the native 5G Core's more efficient resource scheduling and reduced control plane overhead rather than by a radio condition that would be expected to vary strongly with vehicle speed.

11. Results: Handover Performance

Figure 5 presents the distribution of inter-cell handover latency recorded across all driving scenarios combined. SA handover latency was both lower on average and considerably less variable than NSA handover latency,

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reflecting the SA control plane's more direct signaling path between the 5G New Radio and the native 5G Core, without the additional LTE control plane steps required by the EN-DC procedure underlying NSA dual connectivity.

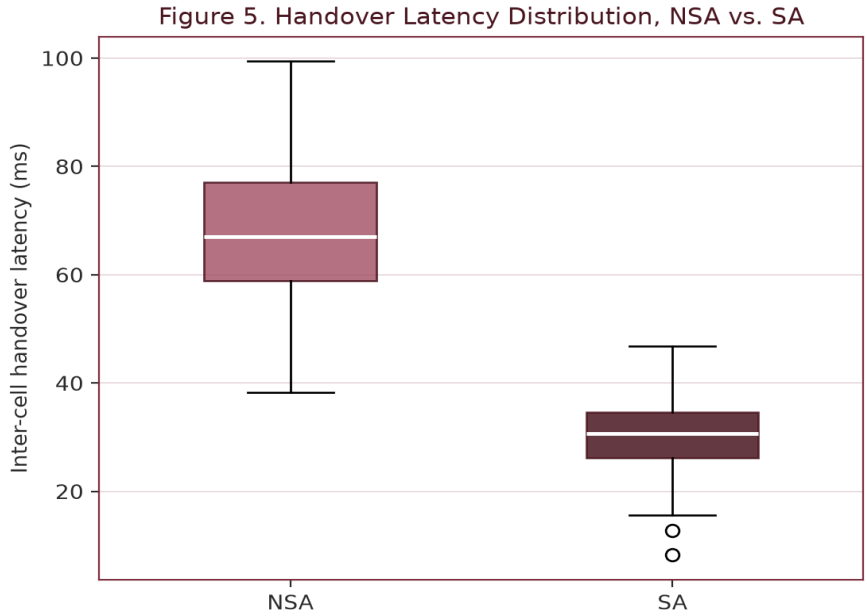


Figure 5. Distribution of inter-cell handover latency across all driving scenarios, NSA versus SA.

Figure 6 presents handover success rate as a function of vehicle speed. Both architectures show declining handover success rate at higher speed, consistent with the shorter dwell time available in each cell as speed increases, but the decline is markedly steeper for NSA, which fell below ninety percent handover success above approximately one hundred kilometers per hour in this dataset, while SA remained above ninety-five percent across the full speed range tested.

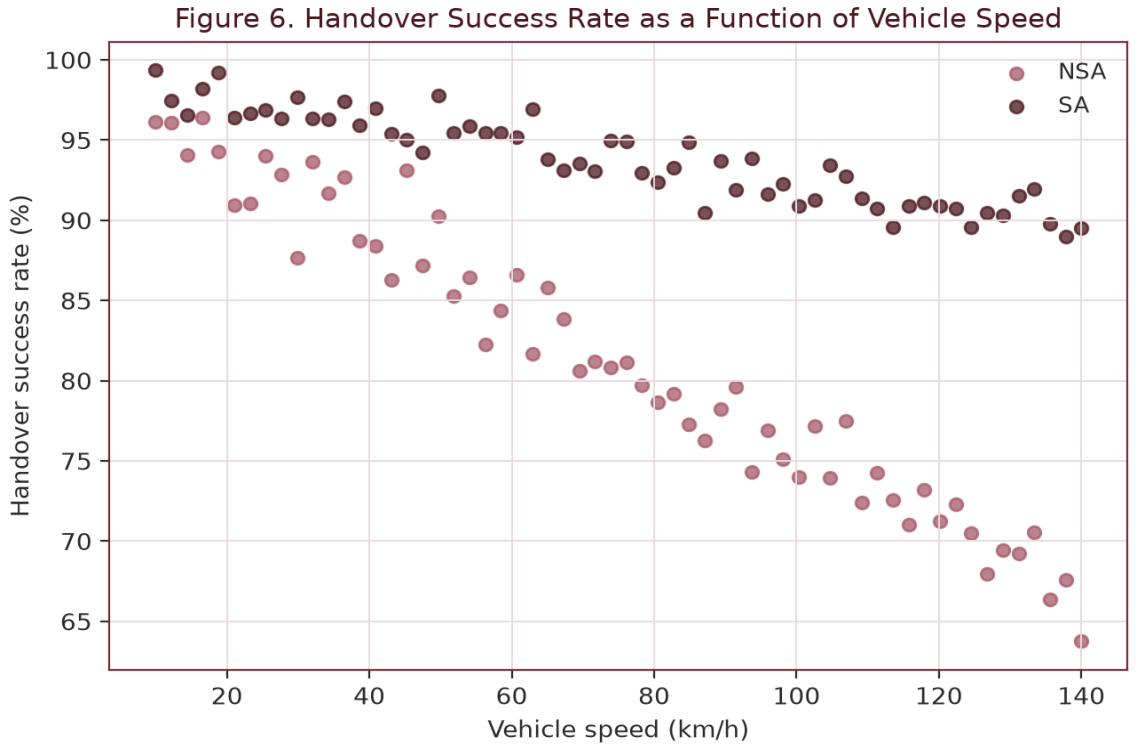


Figure 6. Handover success rate as a function of vehicle speed, NSA versus SA.

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Scenario	NSA Handover Latency (ms)	SA Handover Latency (ms)	NSA Success Rate (%)	SA Success Rate (%)
Stationary	n/a	n/a	n/a	n/a
Highway	71.2	29.6	92.4	98.8
Urban canyon	65.0	33.8	89.1	97.2
Tunnel entry and exit	74.5	34.1	81.6	95.0
Dense intersection	61.8	27.0	90.7	98.1

Table 6. Mean inter-cell handover latency and handover success rate by driving scenario, NSA versus SA. The stationary scenario did not produce handover events by design.

12. Results: Vehicle-to-Everything Reliability

Figure 4 presents cooperative awareness message delivery success rate by driving scenario. Both architectures achieved high reliability in the stationary and rural scenarios, but the gap between NSA and SA widened considerably in the urban canyon, tunnel entry and exit, and dense intersection scenarios, each of which combines challenging radio propagation with the handover and congestion sensitivity already observed in Sections 9 and 11.

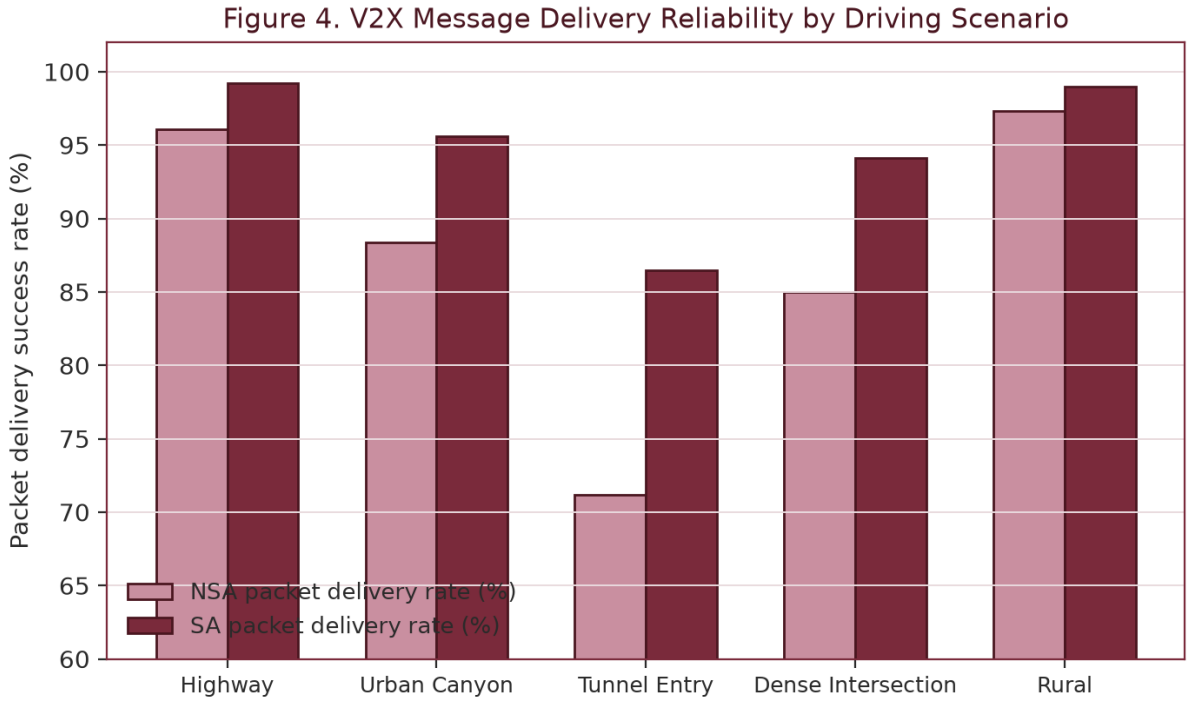


Figure 4. Cooperative awareness message delivery success rate by driving scenario, NSA versus SA.

The tunnel entry and exit scenario produced the lowest reliability for both architectures, reflecting the rapid signal transition between in-tunnel repeater coverage and open-air macro cell coverage, but the magnitude of the reliability drop was substantially smaller for SA, 86.5 percent against 71.2 percent for NSA, consistent with SA's faster and more successful handover performance documented in Section 11 directly translating into fewer missed delivery windows during this specific transition.

13. Root Cause Analysis of Disconnect Events

Every session disconnect event recorded during SA testing was classified into one of five root cause categories based on connection state logs and serving cell signal quality at the time of disconnect. Figure 7 presents the resulting distribution. Coverage edge conditions, where the vehicle traveled beyond the practical range of the available SA cell sites into an area still served only by NSA or LTE, accounted for the largest single share of SA disconnect events, consistent with the earlier-stage geographic maturity of SA coverage during the measurement period discussed in Section 4.

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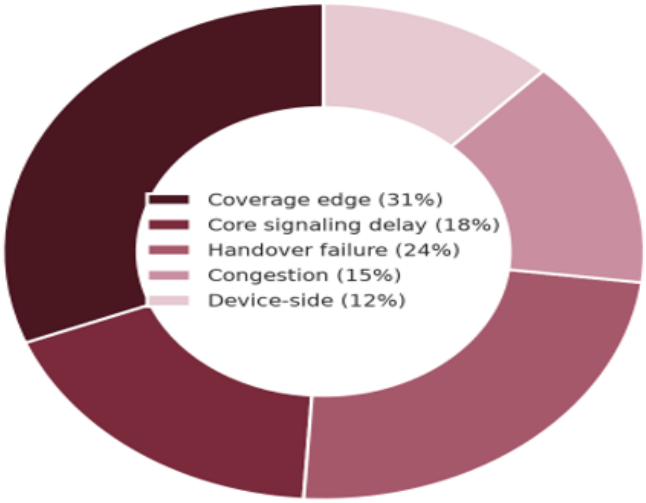


Figure 7. Root cause share of session disconnect events recorded during SA testing.

Handover failure was the second largest contributor, concentrated in the tunnel entry and exit and dense intersection scenarios already identified in Sections 11 and 12 as the most demanding mobility conditions tested. Core signaling delay and congestion together accounted for a smaller but non-trivial share, suggesting that even within mature SA coverage, core network capacity planning remains a relevant factor as vehicle connectivity demand grows. Device-side causes, including on-board unit modem resets, accounted for the smallest share and were not materially different in frequency between the NSA and SA test conditions, indicating that this category is not architecture-dependent.

14. Comparative Discussion

Figure 8 summarizes the overall comparative performance profile of NSA and SA across five dimensions: latency, throughput, reliability, handover speed, and coverage maturity. SA leads on every dimension except coverage maturity, where NSA's reuse of the existing dense LTE radio footprint gives it a more consistent geographic availability advantage during the early period of SA rollout captured by this study.

Figure 8. Relative Performance Profile, NSA vs. SA

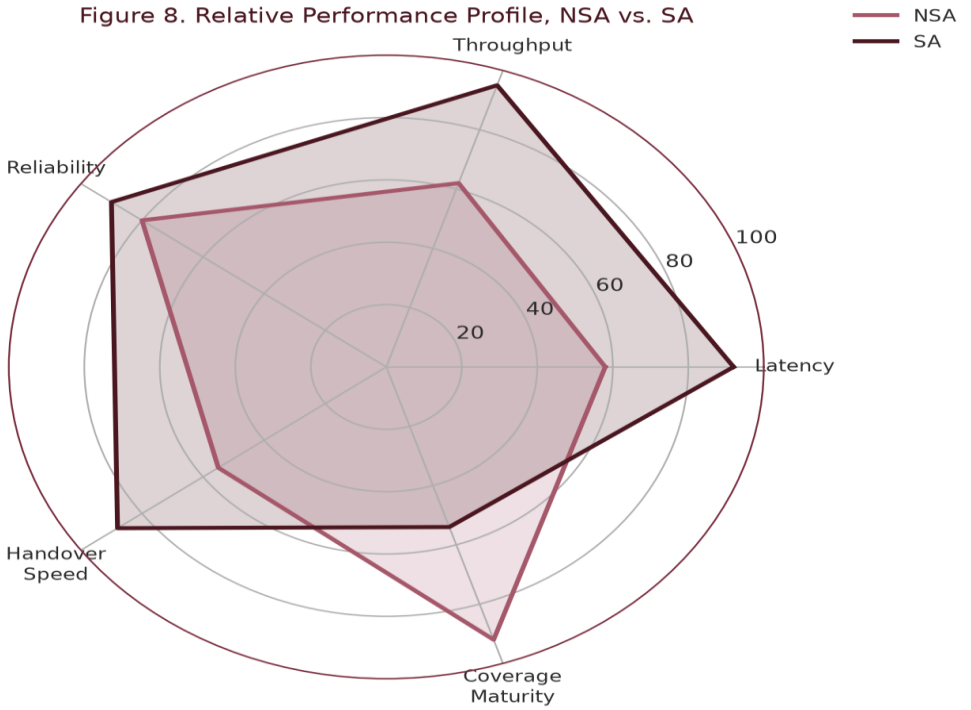


Figure 8. Relative performance profile of NSA and SA across five evaluation dimensions.

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This pattern of results is consistent with the architectural basis described in Section 2: SA's advantages in latency, throughput, reliability, and handover speed all trace directly to its native 5G Core control plane and the removal of the LTE anchor dependency, while NSA's coverage advantage traces directly to its ability to reuse already-deployed LTE radio sites rather than requiring new SA-capable core infrastructure to be deployed at every site before SA service becomes available there.

For connected automotive applications, this comparative profile implies a scenario-dependent, rather than uniform, preference between the two architectures. Safety-relevant vehicle-to-everything messaging and any future remote vehicle operation feature benefit most directly from SA's latency, handover, and reliability advantages, and the measured reliability gap in demanding scenarios such as tunnel transitions and dense intersections, documented in Section 12, is large enough to be operationally significant for these use cases. Over-the-air update delivery and infotainment streaming, which are more tolerant of latency and occasional handover delay, benefit from SA's throughput advantage but are less exposed to NSA's handover and reliability shortfalls, and therefore remain reasonably well served by NSA connectivity where SA coverage is not yet available.

15. Deployment Guidance for Automotive Stakeholders

Based on the measured results in Sections 9 through 14, three deployment recommendations follow for automotive manufacturers and network operators planning connected vehicle rollouts during the NSA to SA transition period. First, safety-relevant vehicle-to-everything features should be designed with an explicit fallback behavior for operation under NSA or LTE-only coverage, since SA coverage cannot yet be assumed nationwide, and this fallback behavior should be validated against the specific reliability figures measured for demanding scenarios such as tunnel transitions and dense intersections rather than against a single nationwide average reliability figure. Second, vehicle platforms should implement connectivity-aware feature gating, in which features with strict latency or reliability requirements are enabled, degraded, or disabled based on the currently detected architecture and measured link quality, rather than assuming uniform network performance regardless of whether the vehicle is currently attached via NSA or SA. Third, network operators prioritizing SA buildout for connected vehicle customers should weight coverage expansion decisions toward the specific scenario types shown in this study to be most reliability-sensitive, including dense urban intersections and tunnel approaches, rather than relying solely on general population density as a buildout prioritization criterion.

16. Limitations

This study's measurements were collected on a single commercial carrier network during a specific period of early SA rollout, and the magnitude of the measured NSA to SA differences, particularly the coverage maturity gap discussed in Section 14, is expected to narrow over time as SA core infrastructure deployment continues and should not be read as a permanent or carrier-independent characteristic of the two architectures. Results on a different carrier network, or in a market at a different stage of SA rollout, may show a different balance between the architectures.

The driving scenarios and routes used in this study, while selected to represent a broad range of radio propagation and mobility conditions, were drawn from a limited set of geographic locations, and radio conditions specific to other terrain types, such as mountainous or heavily forested routes, were not directly tested. The vehicle-to-everything reliability measurements in Section 12 used a fixed ten hertz cooperative awareness message rate and a single roadside unit configuration, and reliability under a denser vehicle-to-everything deployment with many simultaneously transmitting units was not evaluated.

Finally, this study measured network-layer performance and did not evaluate end-to-end application behavior under packet loss or latency variation, such as how a specific cooperative collision avoidance algorithm's safety margin is affected by the measured latency and reliability differences, which would require an application-specific follow-up analysis beyond the network performance scope of this paper.

17. Future Work

Repeating this measurement methodology at a later stage of SA rollout would clarify how quickly the coverage maturity gap identified in Section 14 narrows, and would allow the latency, throughput, and handover advantages measured here to be tracked for stability as SA core infrastructure and radio planning continue to mature. Extending the test platform to a multi-carrier, multi-market design would additionally clarify how much of the measured NSA to SA gap is attributable to the specific carrier network used in this study rather than to the underlying architecture.

A further direction is extending the vehicle-to-everything reliability evaluation to multi-vehicle platooning and denser cooperative awareness message traffic, which would test whether the SA reliability advantage documented in Section 12 is maintained as the number of simultaneously communicating connected vehicles increases. Finally,

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combining the network-layer measurements presented here with an application-level safety margin analysis for specific cooperative driving algorithms would translate the measured latency and reliability differences into a more directly actionable safety case for automotive manufacturers evaluating NSA versus SA connectivity requirements for specific vehicle features.

18. Conclusion

This paper presented a field-measured comparison of Non-Standalone and Standalone 5G network architectures specifically in the context of connected automotive systems, evaluating end-to-end latency, throughput, handover performance, and vehicle-to-everything message delivery reliability across five driving scenarios and five vehicle speed bands. The Standalone architecture delivered materially better performance on every dimension measured except geographic coverage maturity, where the Non-Standalone architecture's reuse of existing LTE radio infrastructure retained a practical advantage during the early SA rollout period covered by this study.

These findings support a scenario-dependent deployment strategy for connected automotive features rather than a uniform assumption of either architecture, with safety-relevant vehicle-to-everything functions benefiting most directly from Standalone connectivity where it is available, and Non-Standalone connectivity remaining a reasonable interim choice for latency-tolerant functions in areas where Standalone coverage has not yet been deployed. The deployment guidance, limitations, and future work discussed in Sections 15 through 17 outline the practical steps and remaining open questions for automotive manufacturers and network operators navigating this transition.

Appendix A. Glossary of Terms

The following glossary summarizes the technical terms and abbreviations used throughout this paper, intended as a quick reference for readers who may be more familiar with one of the two network architecture domains, cellular networking or automotive systems, than the other.

Term	Definition
5G New Radio (NR)	The radio access technology standardized for fifth generation cellular networks, supporting both NSA and SA deployment modes.
Non-Standalone (NSA)	A 5G deployment architecture in which the 5G New Radio operates as a secondary node anchored to an existing LTE Evolved Packet Core.
Standalone (SA)	A 5G deployment architecture in which the 5G New Radio connects directly to a native 5G Core Network with no LTE anchor.
EN-DC	Evolved Universal Terrestrial Radio Access, New Radio Dual Connectivity, the 3GPP standard underlying NSA operation.
eNodeB	The base station node type used in LTE radio access networks, serving as the master node in NSA dual connectivity.
gNodeB	The base station node type used in 5G New Radio access networks.
5G Core Network	The service-based core network architecture used in SA deployment, supporting network slicing and low-latency service profiles.
Network Slicing	A 5G Core capability that partitions network resources into isolated logical networks tuned to different application requirements.
URLLC	Ultra-Reliable Low-Latency Communication, a 5G service category targeting round-trip latency below ten milliseconds with high reliability.
V2X	Vehicle-to-Everything communication, encompassing vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-pedestrian messaging.
C-V2X	Cellular Vehicle-to-Everything, a 3GPP-standardized V2X technology operating over cellular radio infrastructure.
Cooperative Awareness Message	A periodic V2X message broadcast by a vehicle or roadside unit describing its position, speed, and heading for use by nearby receivers.
Handover	The process by which an active connection transfers from one serving cell to a neighboring cell as a device moves.
On-Board Unit (OBU)	The in-vehicle hardware module responsible for cellular and V2X connectivity.
Roadside Unit (RSU)	A fixed infrastructure node that transmits and receives V2X messages at a specific road location.

Table 7. Glossary of key technical terms used in this study.

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Readers seeking a more detailed treatment of the underlying 3GPP standards referenced throughout this glossary, including the full EN-DC dual connectivity procedure and the 5G Core service-based architecture, are directed to the standards documents listed in the References section that follows, particularly the 3GPP technical specifications cited as references 1 through 5.

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