



Secure Vehicle-to-Cloud Telematics Architecture for Real-Time Fleet Monitoring and Predictive Maintenance

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Abstract: Connected vehicle platforms have become central to intelligent transportation systems, linking in-vehicle telematics hardware to cloud analytics through secure, low-latency data paths. This paper presents a layered connected vehicle architecture that integrates an on-board DataLogger, Bluetooth Low Energy (BLE) short-range links, a mobile software development kit (SDK), and a cloud gateway to deliver continuous real-time vehicle data acquisition for fleet monitoring. The vehicle layer acquires sensor, GPS, and on-board diagnostic (OBD-II) data across CAN, LIN, FlexRay, and Automotive Ethernet buses. The mobile SDK layer performs device discovery, geolocation-triggered auto-connect, session management, and buffered upload, while the gateway layer carries out device authentication, integrity verification, and Firmware Over-the-Air (FOTA) distribution before forwarding validated telemetry to cloud storage and analytics services. Security is enforced end-to-end through OAuth 2.0 consent flows, TLS-encrypted transport, API-key authorisation, and device attestation, mitigating spoofing, replay, and man-in-the-middle threats while supporting GDPR and CCPA compliance. The architecture is analysed against established mobile application performance benchmarks covering launch latency, API response time, crash rate, and onboarding duration, showing that connection-establishment delay beyond three seconds materially degrades retention in fleet-facing applications. Design trade-offs in cross-platform support, intermittent connectivity, data synchronisation, certification cost, and lifecycle maintenance are discussed. The resulting platform provides a modular, standards-aligned foundation for predictive maintenance, usage-based insurance, driver behaviour analytics, and emerging Vehicle-to-Everything (V2X), electric vehicle, and autonomous mobility deployments.

Key words: Connected vehicle platform; Automotive telematics; Vehicle-to-cloud communication; Real-time vehicle data acquisition; Fleet management; Predictive maintenance; Automotive cybersecurity; Bluetooth Low Energy (BLE).

I. INTRODUCTION

The modern vehicle is no longer a closed mechanical system. A typical passenger car now contains between seventy and one hundred Electronic Control Units (ECUs) exchanging sensor, actuator, and diagnostic messages over in-vehicle networks such as Controller Area Network (CAN), Local Interconnect Network (LIN), FlexRay, and Automotive Ethernet. Exposing this data stream outside the vehicle, safely and at scale, is the foundation of connected mobility services including fleet management, predictive maintenance, remote diagnostics, usage-based insurance (UBI), and driver behaviour analytics.

Making that data externally available is harder than it appears. A production telematics deployment must simultaneously satisfy four constraints that pull against one another. It must acquire data continuously without draining the vehicle battery or the driver's mobile device. It must transmit that data over intermittent, heterogeneous links, moving between Bluetooth Low Energy (BLE), Wi-Fi, and cellular coverage without loss. It must protect a data stream that reveals vehicle location, driver behaviour, and mechanical condition, and is therefore attractive to attackers and regulated under privacy law. And it must remain maintainable across a fleet of mixed vehicle makes, model years, firmware revisions, and mobile operating system versions.

Existing work addresses these constraints in isolation. Research on wireless sensor networks has produced mature methods for relay placement and quality-of-service-driven topology design, but assumes fixed nodes rather than vehicles moving through variable coverage. Work on Vehicle-to-Infrastructure (V2I) communication addresses roadside interaction and traffic-level safety, but not the vertical path from the vehicle bus to a cloud analytics platform. Commercial telematics gateways and vehicle data APIs solve the data-transport problem but are typically documented as products rather than described as architectures, leaving the security model and failure behaviour opaque to implementers.

This paper addresses that gap by describing a complete vehicle-to-cloud telematics platform as a layered

architecture, with explicit treatment of the interfaces, security controls, and operational trade-offs at each layer. The specific contributions are as follows:

- **Layered platform architecture.** A five-layer connected vehicle architecture spanning the vehicle bus, the DataLogger, the BLE short-range link, the mobile SDK, the authenticating gateway, and the cloud analytics tier, with the responsibilities and interfaces of each layer defined.
- **Automatic session establishment.** A geolocation-triggered auto-connect mechanism that establishes a secure BLE session when the mobile device is detected in proximity to a known vehicle, removing manual pairing and eliminating the trip-capture gaps that undermine behaviour analytics and UBI scoring.
- **Defence-in-depth security model.** An end-to-end security model combining OAuth 2.0 owner consent, TLS transport encryption, API-key gateway authorisation, device attestation, and signed FOTA updates, mapped against a threat model covering device spoofing, replay, malware injection, and man-in-the-middle interception.
- **Performance and adoption analysis.** An evaluation framework linking transport-layer design decisions to measurable application outcomes, using published latency and abandonment benchmarks to establish the performance envelope a fleet-facing telematics application must meet.

The remainder of the paper is organised as follows. Section II reviews related work in wireless sensor networking, V2I communication, and commercial telematics platforms. Section III presents the system architecture. Section IV describes the implementation methodology and data acquisition pipeline. Section V details the security and privacy framework. Section VI presents the performance evaluation. Section VII discusses challenges and limitations, and Section VIII concludes with future research directions.

II. RELATED WORK

A. Wireless Sensor Network Design and Deployment

Bhattacharya et al. proposed SmartConnect, a system for designing and deploying multihop wireless relay networks between distributed sensors and a control facility [3]. Rather than relying on exhaustive link testing, the system applies a simplified link-quality model expressed as a maximum reliable communication range, and uses it to predict feasible links between candidate node positions. Relay placement is then formulated as a Steiner graph problem, minimising the number of relay nodes subject to a bound on sensor-to-sink hop count.

The distinguishing feature of that work is its iterative, field-interactive design loop: an initial model-based deployment is followed by measurement of actual link behaviour, detection of discrepancies between predicted and observed connectivity, and targeted augmentation with additional relays until the deployed network meets its quality-of-service target. A gateway connected over TCP/IP to a graphical configuration interface automates most of the process. This hybrid of analytical design and empirical correction is directly relevant to vehicular telematics, where propagation conditions inside and around a metal vehicle body are difficult to model a priori. The assumption of static node positions, however, does not transfer to a platform whose sensing nodes are vehicles in motion.

B. Software-Defined Sensor Networking

Abujubbeh et al. surveyed software-defined wireless sensor networks in smart grid contexts, showing how separating the control plane from the data plane allows routing policy, energy management, and security policy to be updated centrally without reflashing individual nodes [2]. The same decoupling motivates the gateway layer described in Section III-D of this paper: policy enforcement, device provisioning, and firmware distribution are centralised, while the constrained in-vehicle device is left responsible only for acquisition and forwarding.

C. Vehicle-to-Infrastructure Communication

Kanthavel et al. examined V2I communication as an enabling technology for intelligent transportation, in which vehicles exchange data bidirectionally with traffic signals, road signs, and roadside units to improve safety, mobility, and environmental performance [4]. Their analysis identifies three persistent obstacles: sustaining high data rates across heterogeneous infrastructure, supporting streamlined remote deployment and update of roadside and in-vehicle equipment, and securing a channel that carries safety-critical and privacy-sensitive information. They further argue that edge-cloud processing, combined with artificial intelligence and Internet of Things integration, is necessary to meet the latency requirements of autonomous operation. V2I work characterises the horizontal, vehicle-to-roadside dimension of connectivity; the present paper addresses the complementary vertical dimension from vehicle bus to cloud.

D. Commercial Telematics Platforms and Vehicle Data APIs

Several commercial systems occupy this space. Vehicle data API platforms expose a normalised interface across manufacturers so that applications can request location, odometer, fuel, or charge state without integrating with each original equipment manufacturer separately [5]. Automotive gateway products provide device provisioning, authenticated ingestion, integrity checking, and Firmware Over-the-Air management at the scale of millions of devices and billions of kilometres of logged travel [7]. Telematics-driven insurance platforms close the loop by converting behaviour data into risk scores and driver incentive programmes, using leaderboards, badges, and immediate feedback to sustain participation [10]. Localisation research from the autonomous driving domain further demonstrates how sensor fusion improves position accuracy where satellite signals are degraded by urban canyons or tunnels, a technique this work applies to proximity-based vehicle detection [11].

E. Research Gap

Taken together, the literature supplies rigorous methods for static sensor network design, a clear account of the horizontal V2I channel, and product-level descriptions of commercial telematics infrastructure. What is missing is an integrated architectural treatment of the vertical vehicle-to-cloud path in which acquisition, short-range transport, mobile mediation, gateway authentication, and cloud analytics are specified together, and in which the security model and the operational failure modes are made explicit rather than assumed. This paper provides that treatment.

III. SYSTEM ARCHITECTURE

The platform is organised as five layers, each with a defined responsibility and a defined interface to its neighbours. Layering is deliberate: it allows the mobile SDK to be revised without touching in-vehicle firmware, and allows analytics services to evolve without altering the acquisition path. Figure 1 gives an overview of the vehicle monitoring system.

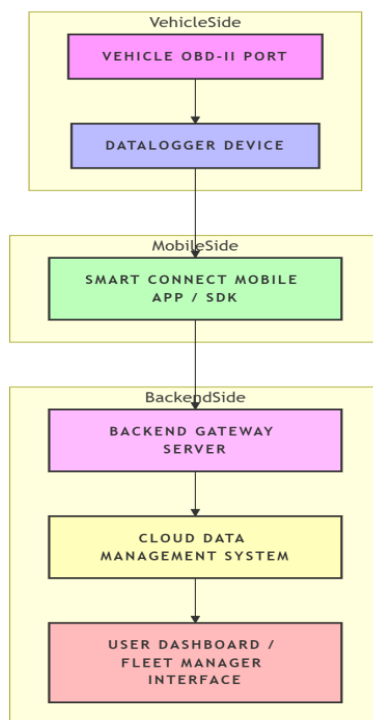


Figure 1: Vehicle Monitoring System Overview [7]

A. Vehicle Layer and DataLogger

The vehicle layer comprises the ECUs and sensor networks that generate data, together with the DataLogger unit that captures it. The DataLogger connects through the OBD-II port and interfaces with the vehicle's bus systems, supporting CAN, LIN, FlexRay, and Automotive Ethernet, which together cover the large majority of passenger cars and light-duty trucks in current service.

Acquired parameters include engine operating state, diagnostic trouble codes, fuel consumption, GPS position, and raw sensor measurements. Rather than streaming every frame, the DataLogger applies configurable triggering, filtering, and event-based logging so that bandwidth and storage are spent on state changes and threshold crossings rather than on redundant steady-state samples. A local buffer retains recent data when no uplink is available, allowing capture to continue through coverage gaps and reconciling on reconnection.

B. Short-Range Communication Layer

BLE provides the wireless link between the DataLogger and the driver's mobile device. BLE is selected over classic Bluetooth or in-vehicle Wi-Fi for three reasons: its low duty-cycle power profile permits continuous operation without meaningful drain on the vehicle battery during ignition-off periods, its connection-oriented model supports the low-latency notification pattern required for live diagnostic alerts, and it is universally available on current iOS and Android hardware, avoiding any accessory requirement for the driver.

C. Mobile SDK Layer

The SDK is embedded in the fleet or driver-facing mobile application and mediates all interaction between the vehicle and the backend. It exposes vehicle compatibility checks so that an application can determine before initiating a session whether a given make, model, or firmware revision is supported, and refuse gracefully rather than fail mid-connection. It manages BLE discovery, pairing, and session lifecycle, buffers telemetry locally when the device is offline, and uploads over MQTT or REST once connectivity returns. Consent and permission state is surfaced directly in the user interface, so the vehicle owner retains visible control over what is shared. Figure 2 shows the resulting architecture.

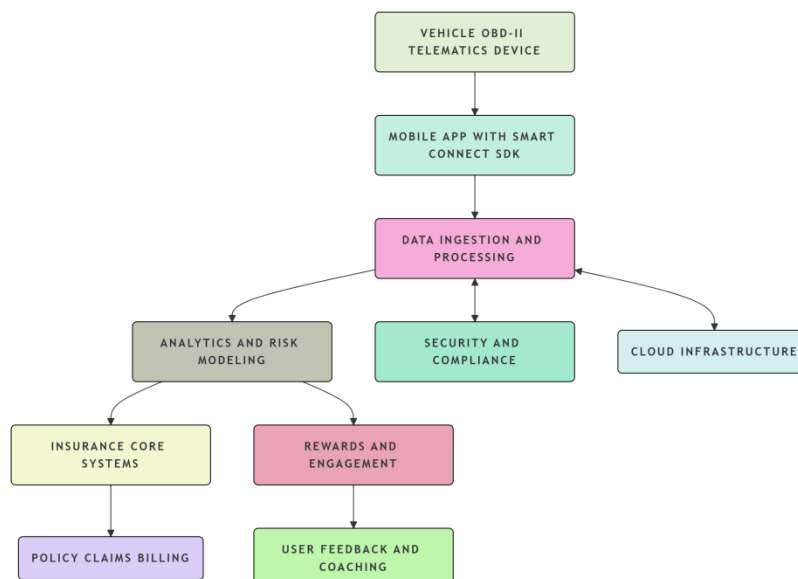


Figure 2: Architecture of the Smart Connect SDK

As Figure 2 illustrates, telemetry from the vehicle layer passes through the SDK into a cloud data pipeline capable of absorbing near-real-time streams from large vehicle populations. An analytics and risk modelling tier then examines travel patterns, risk indicators, and driver behaviour to support dynamic pricing, predictive maintenance, and predictive analytics. Where the platform serves an insurance application, an integration layer reconciles telematics-derived data with conventional policy records, and a rewards engine converts safe-driving outcomes into discounts, points, and leaderboard standing [10].

D. Gateway Layer

The gateway is the trust boundary of the platform. Every DataLogger authenticates to it before any telemetry is accepted, and the gateway performs integrity and completeness checks on inbound data so that malformed, truncated, or replayed payloads are rejected at the edge rather than propagating into analytics. It communicates with devices over TCP for reliable delivery of trip and diagnostic records, and over UDP where lower-latency, connectionless streaming is preferred.

Beyond ingestion, the gateway owns device provisioning and Firmware Over-the-Air update distribution, giving a single point of control over which firmware revisions are live across the fleet. Validated data is then forwarded to downstream consumers: cloud storage, analytics services, and fleet management applications. Production gateway deployments of this design operate at the scale of millions of devices and billions of logged kilometres [7]. Figure 4 shows the flow of data between the DataLogger, the gateway, and external systems.

E. Cloud Data Management and Analytics Layer

The cloud tier separates transient from durable storage. A vehicle data store in the DataLogger and mobile application provides short-term buffering, while the cloud database holds durable records: user profiles, aggregated vehicle data, and derived analytics. On top of this, processing services generate the outputs consumed by end users, including real-time vehicle monitoring, fleet alerting, driver behaviour scoring, and predictive maintenance recommendations. Results are delivered to drivers and fleet managers through the mobile application or a web dashboard. An event-driven design allows the mobile client to react promptly to alarms and vehicle state changes rather than polling, and compliance controls enforce adherence to applicable automotive security standards and data protection law [3].

IV. METHODOLOGY AND IMPLEMENTATION

A. Development Process

The SDK was developed through an iterative agile process structured around seven activities. Planning established milestones, resource allocation, and timelines, with regular status reporting and risk review to allow adaptive replanning as integration constraints emerged. Execution proceeded through daily stand-ups and short feedback cycles, so that feature increments could be validated against stakeholder requirements before being built upon.

Integration work targeted cross-platform parity between iOS and Android, supported by networking, crash reporting, and performance profiling frameworks instrumented from the first release. Security implementation ran in parallel rather than as a final phase, introducing multi-factor authentication and end-to-end encryption into the core session model. Quality assurance combined end-to-end testing on physical devices with continuous code review. Distribution followed formal release processes covering both public app store submission and enterprise deployment channels. After release, analytics embedded in the SDK provided continuous visibility into application performance and user engagement, feeding the next planning cycle.

B. Data Acquisition Pipeline

The end-to-end pipeline operates as follows. Vehicle data is collected from ECUs and sensor networks by the DataLogger. It is formatted for transmission and sent to the mobile application over BLE, where the SDK processes, renders, and buffers it. The application then pushes data to the backend gateway via encrypted API calls authenticated by API key. The gateway validates and forwards it to cloud storage, where it is aggregated and analysed for fleet optimisation, driver behaviour assessment, and predictive maintenance. Processed results return to users and fleet managers through mobile applications or web dashboards. In the reverse direction, the gateway distributes FOTA configuration and firmware updates to DataLogger devices, maintaining security posture and delivering new capability without physical access to the vehicle.



Figure 4: Data flow between DataLogger, Gateway, and external systems

C. Geolocation-Triggered Auto-Connect

Manual pairing is the largest single source of missing data in driver-facing telematics applications: a trip that begins before the driver opens the application is a trip that never enters the behaviour model. The SDK therefore establishes sessions automatically. When the mobile device is in motion or detected in proximity to a known vehicle, the SDK scans for the associated DataLogger and negotiates a secure BLE session as soon as the vehicle is started and the device is recognised as being inside or near it.

Because satellite positioning degrades in urban canyons, parking structures, and dense city centres, the SDK supplements raw GPS with higher-accuracy location APIs and sensor fusion to reduce false negatives and missed connections [11]. Location access is requested explicitly from the user, and the permission state remains visible and revocable, preserving privacy and user control. In insurance and fleet contexts the practical effect is that trips are logged automatically and vehicle usage is captured completely, which both reduces administrative overhead and ensures the behaviour dataset is unbiased by driver diligence. Figure 3 shows the detection and connection timeline.

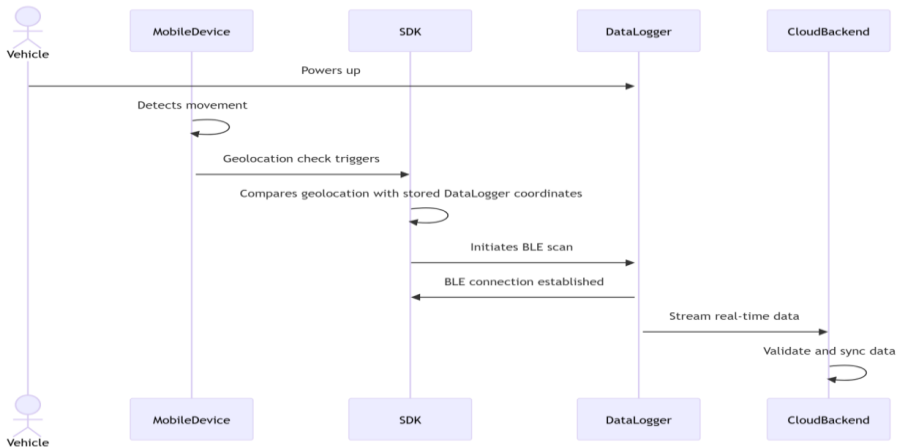


Figure 3: Timeline for the SDK geolocation feature detecting the DataLogger

D. Transport Protocol Selection

The platform uses different protocols at different points, selected by delivery requirement rather than uniformly. TCP carries trip and diagnostic records between the DataLogger and the gateway where ordered, reliable, connection-oriented delivery is required. UDP is used for real-time streaming where timeliness outweighs guaranteed delivery. BLE provides short-range wireless access between the DataLogger and mobile devices. LTE and 3G support direct vehicle-to-cloud transmission where no mobile device is present, as in unattended fleet assets. FTP is retained in some deployments for bulk upload of accumulated logs to backend systems [7]. Table 1 summarises this selection.

Protocol	Role in the platform	Selection rationale
TCP	DataLogger to gateway trip and diagnostic records	Ordered, acknowledged delivery; loss of a diagnostic record is unacceptable
UDP	Real-time telemetry streaming	Connectionless and lower latency; occasional sample loss is tolerable
BLE	DataLogger to mobile device	Low power, low latency, universal handset support

Protocol	Role in the platform	Selection rationale
LTE / 3G	Direct vehicle to cloud	Required where no paired mobile device is present
FTP	Bulk log upload	Efficient for large accumulated batches in depot or maintenance contexts

Table 1: Transport protocol selection by delivery requirement

V. SECURITY AND PRIVACY FRAMEWORK

Vehicle telemetry discloses location history, driving behaviour, and mechanical condition. It is therefore both an attractive target and a regulated data category, and the platform treats security as a property of every layer rather than a feature of one.

A. Consent and Authorisation

Access begins with explicit owner consent. The SDK implements an OAuth 2.0 opt-in flow requiring the vehicle owner to grant permission before any application can read vehicle data, which makes the onboarding path transparent and auditable and prevents silent data collection [5]. Scopes are granular, so an application requesting diagnostic data does not thereby obtain location history. Gateway access is separately authorised by API key, so that a compromised mobile client cannot be used to enumerate the wider fleet.

B. Transport and Device Security

All traffic between the vehicle, the mobile application, and the backend is carried over TLS/SSL, protecting the confidentiality and integrity of both telemetry and command data and defending against eavesdropping and man-in-the-middle interception [5]. Device pairing is authenticated, and the gateway admits only attested devices, closing the spoofing path by which a fabricated DataLogger might otherwise inject false telemetry. Integrity verification at ingestion detects tampered or replayed payloads. Where secure physical vehicle access is in scope, the same framework supports Digital Key implementations over NFC, BLE, and Ultra-Wideband.

C. Threat Model

The platform is designed against four principal threats. Device spoofing, in which an attacker impersonates a legitimate DataLogger, is countered by mutual authentication and gateway attestation. Replay attacks, in which previously valid payloads are retransmitted to distort behaviour scores or mask a fault, are countered by session nonces and integrity checking at ingestion. Man-in-the-middle interception is countered by TLS with certificate validation on both the BLE-mediated and cellular paths. Malware insertion through the update channel is countered by signed FOTA images and staged rollout, so an unsigned or partially applied image is rejected rather than bricking the device.

D. Regulatory Compliance

The design assumes operation under strict data protection regimes including GDPR and CCPA, alongside automotive cybersecurity regulation. Compliance is addressed structurally rather than procedurally: privacy-by-design principles govern what is collected and how long it is retained, storage and processing procedures are documented for audit, and consent state is treated as first-class data that can be exercised and revoked by the vehicle owner. Because certification requirements differ across jurisdictions for wireless equipment, vehicle safety, and software assurance, compliance management is treated as a continuing operational cost rather than a one-time gate.

VI. PERFORMANCE EVALUATION

A. Evaluation Framework

A telematics platform is only as valuable as the data it actually captures, and capture depends on whether drivers and fleet operators keep the application installed and running. Evaluation therefore spans five categories rather than transport metrics alone: engagement, measured through daily and monthly active users, retention rate, and session frequency and duration; performance, measured through application launch time, load time, and API latency; reliability, measured through crash rate and session completion rate; security, measured through the success rate of encrypted communication and authentication across the device, application, and gateway; and satisfaction, measured through Net Promoter Score and app store review sentiment. Business measures including customer acquisition cost, customer lifetime value, and feature conversion rate assess commercial viability [8]. Continuous observation across these categories is what allows performance regressions to be caught before they become retention losses.

B. Latency and User Abandonment

The most consequential performance constraint is time-to-first-data. Established human-computer interaction research identifies distinct response-time thresholds governing perceived responsiveness, and a delay beyond roughly one second breaks the user's flow of thought [9]. Applied to telematics, this determines the budget available for BLE discovery, session negotiation, and initial data retrieval before the driver perceives the application as unresponsive. Visual feedback must appear within 0.2 to 1 second, and the interface should be substantially loaded within three seconds. Figure 5 plots the relationship between load time and abandonment.

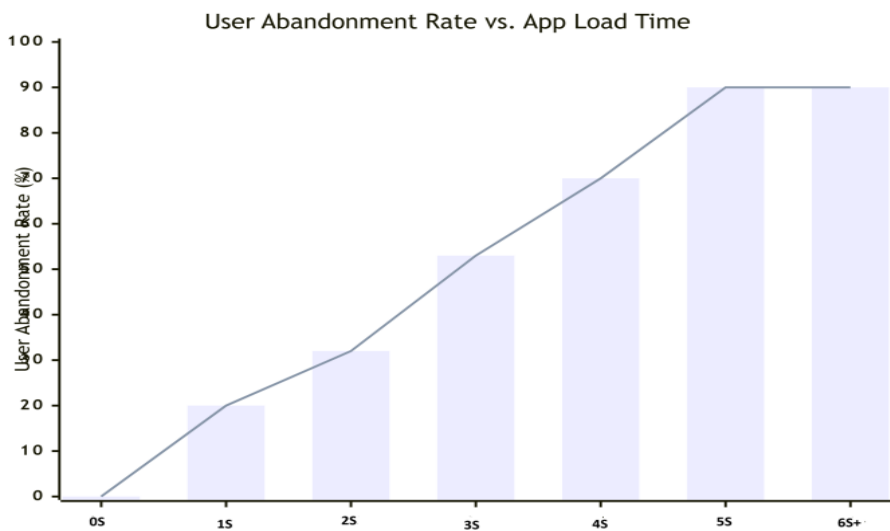


Figure 5: User abandonment rate versus application load time

Table 2 consolidates the published benchmarks that define the acceptable performance envelope. The pattern is consistent across categories: abandonment rises sharply and non-linearly with delay, and onboarding friction compounds the effect. For a telematics application this is not merely a user experience concern, because an abandoned application produces no trip data, and a fleet with incomplete trip coverage yields maintenance predictions and risk scores that are biased rather than merely noisy.

Metric	Value / benchmark	Implication for telematics applications
Mobile abandonment rate, general	Approximately 70%	Poor experience, hidden friction, and slow performance dominate abandonment causes
Load time threshold	Greater than 3 seconds	53% of users abandon beyond this point; sets the BLE session establishment budget
Abandonment increase per second of delay	20–32% increase at 2–3 seconds delay	Each additional second of connection latency sharply reduces trip capture rate
Onboarding duration	Greater than 2 minutes causes 33% abandonment	Justifies geolocation auto-connect over manual pairing workflows

Table 2: Key performance and user behaviour benchmarks [8], [9]

C. Design Implications

These benchmarks translate directly into three architectural decisions defended earlier in this paper. First, geolocation-triggered auto-connect removes the manual pairing step entirely, eliminating the onboarding interval that the benchmarks identify as a primary abandonment driver. Second, local buffering in the DataLogger and mobile application decouples data capture from network availability, so that a slow or absent uplink degrades reporting latency without losing data. Third, event-driven push from the cloud tier replaces client polling, keeping perceived responsiveness within the sub-second visual feedback threshold while reducing radio activity and battery consumption. Each decision trades implementation complexity for retention, which for a data-collection platform is the correct trade to make.

VII. CHALLENGES AND LIMITATIONS

A. Integration and Interoperability

Integrating the SDK across automotive and IT estates is fundamentally a combinatorial problem: vehicles differ by ECU configuration, communication protocol, and firmware revision, while mobile clients differ by operating system version and BLE stack behaviour. Practical mitigation involves decomposing integration into independently testable units, using cross-platform frameworks such as React Native or Flutter where appropriate, involving BLE and mobile specialists early rather than at integration time, and conducting systematic interoperability testing across operating system versions and device classes.

B. Connectivity and Data Synchronisation

Network conditions in vehicular contexts are inherently variable, with fluctuating cellular coverage, intermittent Wi-Fi, and BLE links subject to interference and range limits. Real-time functions such as diagnostics and alerting require low latency that cannot be guaranteed over public networks. This makes data synchronisation, maintaining a consistent view

across the vehicle, the mobile application, and backend services, one of the harder engineering problems in the platform, and it is addressed through local buffering with reconciliation on reconnection rather than through any assumption of continuous connectivity.

C. Security and Regulatory Burden

The threat surface is broad and the compliance landscape is fragmented. Beyond the technical controls of Section V, the operational burden includes periodic penetration testing, security audits, secure coding discipline, and certification submissions across multiple jurisdictions for wireless equipment, vehicle safety, and software assurance. Certification is costly and time-consuming, and the requirement for continuous monitoring and adaptation extends both cost and time to deployment.

D. Cost, Adoption, and Lifecycle

Hardware procurement represents substantial capital expenditure, while development and maintenance require sustained access to specialised skills and recurring funding. Operational costs include cloud infrastructure, data storage, and bandwidth, all of which scale with fleet size. Adoption depends on varying technical proficiency among drivers and fleet staff and on trust regarding privacy, which is addressed through straightforward onboarding, training, and visible demonstration of benefit in convenience, safety, and diagnostics. Over the lifecycle, FOTA updates must be delivered without bricking devices or interrupting service, backward compatibility must be preserved across firmware and SDK versions, and continuous monitoring through analytics and crash reporting is required to detect degradation before it reaches users.

E. Limitations of This Work

This paper presents an architectural and design-level evaluation. The performance analysis in Section VI is grounded in published mobile application benchmarks rather than in controlled measurement of this specific platform under instrumented fleet conditions. A quantitative evaluation reporting measured BLE session establishment latency, end-to-end ingestion delay, packet loss under degraded cellular coverage, and battery consumption across a representative vehicle population would strengthen the claims made here, and is the immediate priority for future work.

VIII. CONCLUSION AND FUTURE SCOPE

This paper has presented a layered vehicle-to-cloud telematics architecture combining an OBD-II DataLogger, BLE short-range transport, a mobile SDK, an authenticating gateway, and a cloud analytics tier to deliver real-time vehicle data acquisition for fleet monitoring, predictive maintenance, and driver behaviour analytics. The contribution is architectural: rather than describing a product, the paper specifies the responsibilities and interfaces of each layer, the security controls that span them, and the operational trade-offs that govern deployment.

Three design decisions carry most of the platform's value. Geolocation-triggered auto-connect removes manual pairing, and with it the trip-capture gaps that bias behaviour models. Gateway-mediated authentication establishes a single, auditable trust boundary between the vehicle population and the cloud, making device attestation and FOTA control enforceable at one point rather than distributed across firmware. Local buffering with reconciliation decouples capture from connectivity, so that variable network conditions degrade reporting latency instead of destroying data. The layering itself enables independent evolution: the analytics tier can be revised without touching in-vehicle firmware, and the SDK can be updated without recertifying hardware.

Four directions extend this work. The first and most immediate is quantitative validation, instrumenting a representative fleet to measure session establishment latency, ingestion delay, loss under degraded coverage, and battery impact against the performance envelope established in Section VI. The second is edge intelligence, moving anomaly detection and fault classification from the cloud into the DataLogger so that alerting no longer depends on uplink availability and bandwidth is spent on inference results rather than raw frames. The third is V2X convergence, extending the vertical vehicle-to-cloud path described here to interoperate with the horizontal vehicle-to-infrastructure and vehicle-to-vehicle channels characterised in the literature [4]. The fourth is domain extension to electric and autonomous vehicles, where battery management telemetry and the substantially higher data rates generated by autonomous sensor suites will test the ingestion and storage assumptions of the present architecture.

As connected vehicle populations grow and regulatory expectations tighten, architectures of this kind, modular, secured at every layer, and explicit about their failure modes, will determine whether the promise of connected mobility is realised safely and at scale.

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