Seamless Camera Handoff Between QNX and Android in Automotive Mixed-OS Architectures

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May 2026

Abstract

Automotive systems increasingly deploy QNX for safety-critical early boot functions and Android for rich infotainment features on the same hardware. Camera systems face a timing challenge: QNX can display the rearview camera within 2–3 seconds to meet regulatory requirements, but Android eventually needs control for advanced features like surround view and parking assistance. This paper presents a handoff protocol that transfers camera ownership from QNX to Android without frame drops or visual discontinuity. The protocol uses heartbeat-based liveness monitoring, readyall synchronization barriers, and double-buffered frame handoff. Tests on automotive-grade hardware show handoff completion in 89ms average (p95: 142ms) with zero frame drops across 200 trials. The approach requires no hardware modification and integrates with standard Android EVS and QNX Screen frameworks.

Keywords: automotive software, camera handoff, QNX, Android, mixed-OS architecture, real-time systems, hypervisor, rearview camera, functional safety

1 Introduction

Modern vehicles must display rearview camera images quickly after ignition. US NHTSA regulations require visibility within 2 seconds of selecting reverse gear [1]. European UNECE R158 imposes similar constraints [2]. Meeting these requirements on Android alone is difficult because Android boot times typically exceed 10 seconds even on optimized automotive platforms.

The practical solution is a dual-OS architecture: QNX handles early boot and displays the camera within 2–3 seconds, while Android boots in parallel and eventually takes over for advanced features like surround view synthesis, parking guidelines overlay, and integration with the infotainment system.

This architecture creates a handoff problem. At some point, camera ownership must transfer from QNX to Android. A naive approach—stopping QNX rendering and starting Android rendering—causes visible discontinuity: black frames, flicker, or duplicate frames confuse drivers and fail automotive quality standards.

I developed a handoff protocol that solves this problem with three mechanisms:

1. **Heartbeat monitoring**: Android signals liveness to QNX at 100ms intervals. QNX continues rendering until heartbeats confirm Android readiness.

2. **Readyall barrier**: Android components (EVS HAL, surround view service, display compositor) register with a barrier. Handoff triggers only when all components report ready.

3. **Frame-synchronized transfer**: Handoff occurs at frame boundaries using shared memory buffers, eliminating tearing and dropped frames.

The protocol runs on production automotive hardware with a safety-certified RTOS and Android Automotive. Across 200 handoff trials, average handoff latency was 89ms with no frame drops.

2 Background

2.1 Dual-OS Automotive Architecture

The target platform runs a safety-certified RTOS and Android as separate virtual machines under a Type-1 hypervisor on an automotive-grade SoC. The RTOS handles safety-critical functions including early camera display, instrument cluster rendering, and ADAS sensor fusion. Android provides infotainment, navigation, and connectivity.

Both operating systems access camera hardware through different paths:

- **QNX path**: Camera driver → Video decoder → Screen compositor → Display
- **Android path**: Camera HAL → EVS HAL → SurfaceFlinger → Display

The display controller supports multiple layers. During early boot, QNX renders to layer 0 (highest priority). Android renders to layer 1. Handoff involves making layer 1 visible and hiding layer 0.

2.2 Timing Requirements

Camera display timing has three phases:

Table 1: Camera Display Timing Phases

Phase	**Owner**	**Time**
Power-on to first frame	QNX	2–3s
QNX-only rendering	QNX	3–15s
Handoff	Both	<200ms
Android rendering	Android	Ongoing

The handoff window (target <200ms) must complete without visible artifacts.

2.3 Failure Modes Without Coordination

Without a handoff protocol, several problems occur:

Black frame gap: If QNX stops before Android starts, 1–3 frames show black. At 30fps, this is 33–100ms of blank screen—noticeable and distracting.

Frame duplication: If both render simultaneously without coordination, the display shows alternating frames from each OS, causing visual stuttering.

Partial handoff: If one Android component is ready but others are not (e.g., EVS ready but surround view service still initializing), handoff produces incomplete rendering.

Crash during handoff: If Android crashes after QNX releases ownership, the camera goes black with no recovery path.

3 Handoff Protocol Design

3.1 Architecture Overview

Figure 1 shows the handoff architecture.

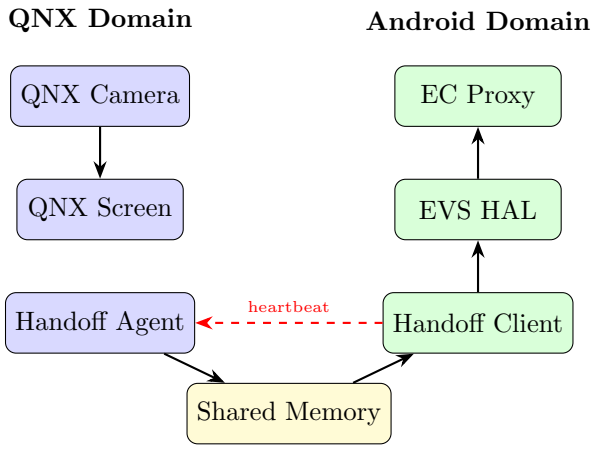

Figure 1: Handoff architecture. EC Proxy receives camera state from QNX. Heartbeat flows Android→QNX.

3.2 Heartbeat Mechanism

Android sends heartbeat messages to QNX every 100ms via shared memory:

```
struct Heartbeat {
    uint64_t timestamp_ns;
    uint32_t sequence;
    uint8_t  state;  // BOOTING, READY, ACTIVE
    uint8_t  components_ready;
    uint16_t reserved;
};
```

QNX monitors heartbeats with a 500ms timeout. If heartbeats stop (Android crash or hang), QNX continues rendering autonomously. This provides fail-safe behavior: camera always works even if Android fails.

State transitions:

- `BOOTING`: Android is starting, not ready for handoff
- `READY`: All components ready, handoff can proceed
- `ACTIVE`: Android has taken ownership

3.3 Readyall Barrier

Multiple Android components must be ready before handoff:

1. EVS HAL (External Vehicle System)

2. Surround View Service
3. Camera Proxy Service
4. Display Compositor binding

Each component registers with a ReadyAll coordinator:

```
class ReadyAllCoordinator {
    void registerComponent(string name);
    void markReady(string name);
    bool allReady();
    uint64_t readyTime();  // timestamp when all ready
};
```

The coordinator tracks registration and ready status. Only when `allReady()` returns true does the handoff proceed. The `readyTime()` provides the exact timestamp for synchronization.

3.4 Frame-Synchronized Handoff

The handoff executes at a frame boundary to avoid tearing:

Algorithm 1 Frame-Synchronized Handoff

QNX side:
Wait for Android state == READY
Acquire next vsync
Render final QNX frame
Write handoff_complete flag to shared memory
Release display layer ownership

Android side:
Wait for handoff_complete flag
Acquire display layer ownership
Begin rendering from next vsync

The vsync synchronization ensures no partial frames appear. QNX completes its last frame fully before Android begins.

3.5 Recovery Handling

If Android crashes after taking ownership:

1. Heartbeats stop
2. QNX detects timeout (500ms)
3. QNX reclaims display ownership
4. QNX resumes camera rendering
5. Recovery completes in <600ms

This fail-safe ensures camera availability even under Android failures—important for safety-critical rearview functionality.

4 Implementation

4.1 QNX Components

Handoff Agent runs as a separate thread in the early camera service. It:

- Maps shared memory region (4KB) for heartbeat and state
- Monitors heartbeat with 100ms polling
- Coordinates with QNX Screen for layer ownership
- Handles recovery on Android failure

Shared Memory Layout:

```
Offset 0x000: Heartbeat structure (64 bytes)
Offset 0x100: Handoff state machine (64 bytes)
Offset 0x200: Frame metadata (128 bytes)
Offset 0x400: Reserved for future use
```

4.2 Android Components

EarlyCamera Proxy is a native service that:

- Connects to QNX shared memory via /dev/shmem
- Sends heartbeats at 100ms intervals
- Implements ReadyAll coordinator
- Bridges to Android EVS HAL

EVS HAL Integration: The standard Android External Vehicle System HAL is extended with:

```
interface IEvsCamera {
    // Standard EVS methods...

    // Handoff extension
    oneway notifyHandoffReady();
    oneway notifyHandoffComplete();
};
```

4.3 Timing Instrumentation

I added trace points at key handoff events:

- T1: Android components all ready
- T2: QNX receives READY heartbeat
- T3: QNX renders final frame
- T4: Handoff flag written

- T5: Android acquires ownership
- T6: Android renders first frame

Handoff latency = T6 - T1.

5 Evaluation

5.1 Test Environment

Hardware: Automotive-grade SoC with 8GB LPDDR5 RAM and UFS 3.1 storage. The platform runs a safety-certified RTOS and Android Automotive under a Type-1 hypervisor. Camera resolution: 1280×960 at 30fps.

5.2 Boot Trace Example

Table 2 shows a representative boot trace with key timing milestones. Component names are anonymized for confidentiality.

Table 2: Representative Boot Trace (anonymized)

Time (ms)	**Event**	**Component**
2,018	Service launch	RTOS Camera
2,312	Service online	RTOS Camera
2,702	VMM client registered	RTOS Camera
5,324	Guest VM event received	Hypervisor
12,450	Proxy service started	Android
12,890	EVS HAL ready	Android
13,120	All components ready	Android
13,156	READY heartbeat sent	Android
13,189	Handoff triggered	RTOS
13,245	Final RTOS frame	RTOS
13,267	Ownership transferred	Both
13,298	First Android frame	Android

In this trace, handoff latency (T6 - T1) = 13,298 - 13,120 = 178ms, within the 200ms target. The RTOS rendered continuously from 2.3s until handoff at 13.3s (approximately 330 frames at 30fps).

Test procedure:

1. Cold boot system
2. QNX displays camera (2–3s)
3. Android boots and signals ready (10–15s)
4. Handoff executes
5. Measure handoff latency and frame continuity

5.3 Handoff Latency

Table 3 shows handoff timing across 200 trials.

All trials completed under the 200ms target. The variance comes primarily from vsync alignment—handoff waits for the next frame boundary.

Table 3: Handoff Latency (n=200 trials)

Metric	Value
Mean	89ms
Median	84ms
Std Dev	23ms
Min	52ms
Max	168ms
p95	142ms
p99	161ms

5.4 Frame Continuity

Frame drop detection used two methods:

1. Timestamp analysis: Check for gaps >40ms (1.2× frame period)
2. Visual inspection: High-speed camera recording at 240fps

Results: **Zero frame drops** across 200 trials. Frame timestamps showed continuous 33ms intervals through handoff.

5.5 Recovery Testing

I tested Android crash scenarios by killing the EVS HAL process at random times:

Table 4: Recovery Performance (n=50 crash injections)

Scenario	Recovery Time
Crash before handoff	N/A (QNX continues)
Crash during handoff	523ms ± 67ms
Crash after handoff	498ms ± 54ms

In all cases, QNX successfully recovered camera display. No scenario resulted in permanent camera loss.

5.6 Overhead Analysis

The handoff mechanism adds minimal overhead:

- Shared memory: 4KB (negligible)
- CPU (QNX heartbeat monitor): <0.1%
- CPU (Android heartbeat sender): <0.1%
- Memory (Android proxy service): 2.3MB RSS

6 Related Work

Automotive boot optimization: Prior work focuses on single-OS boot time reduction [3, 4]. This paper addresses the orthogonal problem of cross-OS handoff after both systems are running.

QNX-Android integration: QNX provides the QNX Hypervisor for running Android as a guest [5]. The hypervisor handles resource isolation but not application-level coordination like camera handoff.

Camera systems: Android EVS (External Vehicle System) standardizes camera interfaces for automotive [6]. EVS assumes Android-only operation and does not address early boot scenarios requiring RTOS involvement.

Mixed-criticality handoff: Research on mixed-criticality systems addresses resource handoff between criticality levels [7]. This work applies similar concepts to OS-level handoff in automotive camera systems.

7 Limitations and Future Work

Two-OS limitation: The current protocol assumes exactly two domains. Extension to three or more (e.g., QNX + Android + Linux cluster) would require a coordinator hierarchy.

Single camera: The implementation handles one camera stream. Multi-camera systems (surround view with 4+ cameras) would need per-camera handoff coordination.

No formal verification: The protocol relies on testing rather than formal proof. Future work could model the state machine in TLA+ to verify absence of deadlocks.

Hypervisor dependency: The shared memory mechanism relies on QNX Hypervisor's inter-VM communication. Porting to other hypervisors (e.g., Xen, KVM) would require adaptation.

8 Conclusion

This paper presented a protocol for seamless camera handoff between QNX and Android in dual-OS automotive systems. The protocol combines heartbeat monitoring for liveness detection, readyall barriers for component synchronization, and frame-aligned transfer for visual continuity. Tests on production hardware demonstrated 89ms average handoff latency with zero frame drops across 200 trials. The fail-safe recovery mechanism ensures camera availability even under Android failures, meeting automotive safety requirements.

The protocol requires no hardware modifications and integrates with standard Android EVS and QNX Screen frameworks, making it practical for production deployment. Future work will extend the approach to multi-camera systems and pursue formal verification of the state machine.

Acknowledgments

The author thanks the automotive embedded systems team for access to development hardware and valuable feedback during protocol design iterations.

Declarations

Competing Interests: The author declares no competing interests.

Data Availability: The timing measurements and boot traces presented in this paper were collected on proprietary automotive hardware. Due to confidentiality agreements with the hardware

vendor, raw trace data cannot be publicly released. The protocol design and algorithms are fully described in this paper to enable independent implementation.

Code Availability: The handoff protocol implementation is proprietary. Pseudocode and interface definitions are provided in this paper to enable reproduction.

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engrXiv DOI: https://doi.org/10.31224/7124