

How OCUDU Enabled Trajectory-Aware Handover Optimization for Tele-Operated Driving

NSF DRIVE-SAFE Project on POWDER Wireless | OCUDU Ecosystem Foundation | 2026

Executive Summary

The NSF-funded DRIVE-SAFE project, using the OCUDU Ecosystem Foundation’s OCUDU Technical Project on the NSF-funded POWDER Wireless testbed at the University of Utah, demonstrates how an open, modifiable 5G RAN enables intrinsically low-latency network services. By feeding real-time vehicle trajectory into a network mapping service that dynamically updates 5G handover policy, DRIVE-SAFE eliminates unnecessary handovers on a tele-operated driving route, reducing end-to-end latency and jitter to enable this delay-sensitive service. The full architecture was demonstrated over the air on the POWDER testbed in July 2026, with OCUDU used to implement the 5G RAN — including the handover policy mechanism itself. The most important outcome isn’t the specific latency numbers — it is that this category of cooperative, application-aware network service can now be built and tested in a real world environment, because OCUDU exists.

At a Glance

Context	Detail
Sponsor	NSF Technology, Innovation and Partnerships (TIP) Breaking Low Program
Partners	University of Minnesota · University of Utah · UC Riverside · GM · Nokia
Platform	OCUDU Technical Project · O-RAN xApp · POWDER Testbed
Use Case	Trajectory-aware handover optimization for tele-operated driving
Published	2026
Demonstration	Over-the-air, POWDER testbed, University of Utah, July 2026
Demo Event Video	Drive-SAFE Project remote driving on the POWDER testbed

The Challenge: Threshold-Based Handovers Weren't Built for Driving Remotely

Tele-operated driving requires low latency and bounded jitter between a remotely operated vehicle and a teleoperation center, along with significant uplink bandwidth and high downlink reliability. Sensor data — including high-quality video — needs to reach the remote driver in time, while control actions need to reach the vehicle just as reliably, with as little variation as possible.

Normal 5G handover mechanisms trigger a hand-off based on preset thresholds and the signal strength of neighboring base stations. That's typically adequate for everyday human mobility, but it can introduce unnecessary handovers — including “ping-pong” handovers, where a session repeatedly bounces between the same base stations before settling down. For tele-operated driving, the extra delay and jitter such unnecessary handovers cause is directly at odds with the application's requirements.

What Was Holding the Industry Back

Before this work, several structural barriers prevented this category of work from existing at all:

- Existing 5G/NextG network-wide handover logic is threshold-based and application-agnostic, and cannot optimize handovers for specific services or devices.
- Sophisticated use case exploration requires the ability to make fundamental changes to low-level RAN mechanisms, and few open-source 5G stacks are stable enough to support that.
- Realistic, real-world test environments combining a connected vehicle platform with a real 5G network were not readily available.

"We know operators are interested in application-aware network services, but it is very difficult to explore such capabilities without mature open source 5G stacks and real-world testing facilities."

DRIVE-SAFE Project Team

The Solution: A Trajectory-Aware Network Mapping Service

DRIVE-SAFE implemented an O-RAN-enabled, trajectory-aware, policy-driven handover optimization architecture for a teleoperated vehicle operating over a cellular network. A Network-to-Application Mapping Service (NMS) maintains vehicle-route-to-network mappings and manages route-specific mobility policies. To realize these policies inside the RAN, the team built a pass-through xApp that interfaces with the NMS and installs or removes handover policies in the RAN according to the service needs. Inside the OCUDU open source RAN stack, an E2SM policy manager handles RIC Subscription and RIC Control messages to install per-route, per-UE handover policies.

Component	Description
Teleoperation Application	Drive-by-wire vehicle and teleoperation station; source of real-time position and pre-defined trajectory.
Network Mapping Service (NMS)	Maintains vehicle-route-to-network mappings and derives route-specific mobility policy (custom A3 offsets).
O-RAN xApp	Pass-through policy component: obtains the target UE ID and installs or removes NMS-defined policy in the RAN.
OCUDU E2SM Policy Manager	Handles RIC Subscription and RIC Control messages inside the OCUDU open source RAN stack to enforce per-route, per-UE handover policy.

See a demo video of the Solution, here: [DRIVE-SAFE remote driving on the POWDER testbed](#)

OCUDU's Critical Contribution

OCUDU's open source, modifiable 5G RAN stack made it possible to add RIC Subscription/RIC Control handling and per-route, per-UE policy logic that existing 5G stacks don't expose. For the full over-the-air demonstration, OCUDU was used to implement the 5G RAN, including the handover policy mechanisms. Without an open stack, mature enough for real-world testing, this architecture would have remained a proposal rather than a working system.

Results and Proof: Two Threads of Evidence

Two threads of evidence, each answering a different question about whether trajectory-aware handover optimization works and why it matters.

Thread 01 — Drive-Test Comparison: With vs. Without Trajectory Awareness

Drive tests in the POWDER testbed at the University of Utah compared two mobility scenarios on the same route. Without trajectory-aware optimization, the vehicle performed two unnecessary handovers (cell 1 > cell 2 > cell 1); the second was the more disruptive, with uplink BLER reaching 45.2% and latency reaching 368.4 ms. With trajectory-aware optimization active, the vehicle remained connected to cell 1 throughout, eliminating both unnecessary handovers.

Metric	Without Trajectory Awareness	With Trajectory Awareness
Unnecessary handovers	2 (cell 1 > cell 2 > cell 1)	0 — vehicle stays on cell 1
Peak UL BLER at handover	45.2% (2nd handover)	Avoided
Peak latency at handover	368.4 ms	Avoided
Whole-route P95 latency	586.8 ms	353.4 ms (–233.4 ms, –39.8%)

Thread 02 — Broader Impact: What Handovers Cost Teleoperation

These drive tests are motivated by a broader analysis of teleoperated-vehicle handovers, which shows that during the 3-second post-handover period, P99 video frame latency increases by 52.14% and P99 uplink BLER by 18.51%, compared to the 2-second pre-handover period. These degradations stem from vehicle-side video frame buffering and the reset of the OLLA offset coefficient after handover — precisely the disruption trajectory-aware policy is designed to prevent.

"The interesting result isn't that trajectory-aware handover works in theory — it's that we could deploy and measure it over-the-air, with a real base-station and a real drive-by-wire vehicle, because the RAN stack was mature enough and open to modification."

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What Makes This Approach Different

Traditional mobility management relies on threshold-based, application-agnostic handover logic. This work breaks that model:

- **Application-aware policy:** handover decisions account for what the network service actually needs — a specific, known route — rather than generic signal-strength thresholds.
- **Surgical intervention:** policy changes target only the base stations along the vehicle's route, not a network-wide reconfiguration.
- **Standards-compliant integration:** the architecture runs on top of standard O-RAN interfaces (E2SM-RC, RIC Subscription/Control) rather than vendor-specific extensions.
- **Open source, modifiable RAN:** the same networked-API pattern this use case demonstrates, an application telling the RAN what's coming next, is also explored by the Linux Foundation's CAMARA Project.

Reusable Technology: What the Broader OCUDU Ecosystem Inherits

Building trajectory-aware handover policy into the RAN surfaced protocol-stack scaffolding useful well beyond this one use case:

Contribution	Detail
O-RAN xApp for policy control	Pass-through xApp pattern for installing NMS-defined mobility policy via E2SM-RC — reusable for any application-informed handover use case.
E2SM Policy Manager	RIC Subscription/RIC Control handling inside the OCUDU RAN stack for per-route, per-UE policy enforcement.
Network Mapping Service reference	Vehicle-route-to-network mapping and custom A3-offset policy derivation, usable as a template for other trajectory-aware services.

Next Steps: From Proof of Concept to Platform

OCUDU is not carrier-grade today, and neither is anything built on it, including this use case. That's not the point. The point is that low-latency, application-aware network services have gone from a theoretical proposal to something buildable and testable in the open.

- **Today:** a complete over-the-air demonstration on the POWDER testbed, with measured latency and handover improvements on a real drive-test route.
- **Near-term:** expanding real-world testing to more routes in the POWDER testbed and refining the trajectory-to-policy mapping.
- **6G horizon:** cooperative, closed-loop network APIs (of which this use case is one example) becoming a standard pattern as 5G/NextG and 6G standardization continues.

"This isn't a story about a faster network. It's about proving that low-latency, uplink-heavy services can be built on an open 5G stack, and tested over the air, not just simulated."

DRIVE-SAFE Project Team

GET INVOLVED

Read more about the DRIVE-SAFE project at nsf-breaking-low-drive-safe.net. Explore the POWDER testbed and how to request access for related research at powderwireless.net. Follow the broader networked-API pattern this use case builds on through the Linux Foundation's Camara Project at camaraproject.org.

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