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Machine Learning for 5G Signal Strength Forecasting Across Cities and Days from Field Trials

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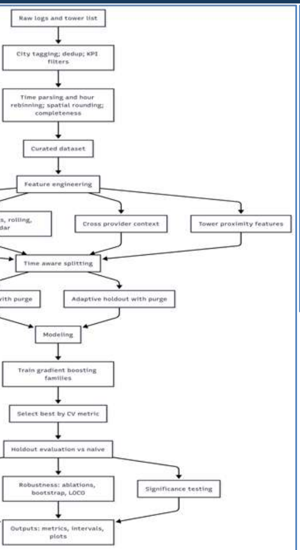
This paper presents a data-driven framework for forecasting 5G signal strength by integrating large-scale field measurements with time-aware machine learning models. A multi-operator drive-test campaign was conducted across three representative small cities in Greece, using handheld equipment to collect 5G key performance indicators under controlled spatial and temporal conditions. The curated datasets were processed through a standardized pipeline and modeled using XGBoost-based ensembles with temporal, spatial, and network-level descriptors. Comprehensive evaluations— including rolling-origin cross-validation, feature ablation, conformal uncertainty quantification, and leave-one-city-out testing—demonstrate that short-term temporal dynamics are the dominant predictors of 5G signal variation. The proposed framework achieves consistent accuracy gains over persistence baselines and generalizes effectively across cities and operators. These findings establish a reproducible methodology for spatio-temporal performance forecasting, contributing to data-driven characterization and optimization of next-generation cellular networks.

Key Contributions

- ✓ **Time-Aware XGBoost Framework: Developed an accurate temporal machine learning ensemble for next-day 5G signal forecasting.**
- ✓ **Proven Generalization & Performance: Validated stable cross-city performance using real-world, multi-operator drive tests.**
- ✓ **Uncertainty Quantification: Integrated conformal intervals to reliably measure and report prediction confidence across diverse environments.**
- ✓ **Feature Optimization: Proved that short-term temporal features are both necessary and sufficient; non-temporal descriptors offer only marginal gains.**

Methodology

End-to-end data pipeline:



Measurement Campaign

- Multi-operator drive tests across Korinthos/Nafplio/Loutraki
- Three daily slots: 09:00, 13:00, 18:00 over one week per city
- KPIs: RSRP, SINR, availability, operator

Data Pipeline

- City tagging, de-duplication, filtering
- Spatial grouping: coords rounded to (~110 m × 88 m)
- Complete coverage per cell required

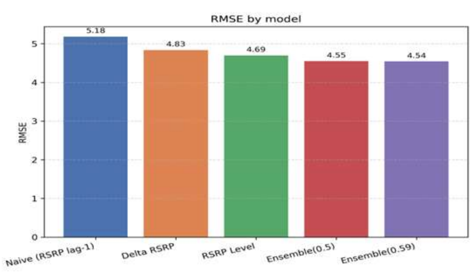
Feature Engineering

- Temporal: 1- and 2-day lags, rolling averages of mean and std
- Calendar: day of week, modal hour
- Spatial: rounded coords, tower proximity (haversine distance)
- Cross-provider: avg RSRP of others

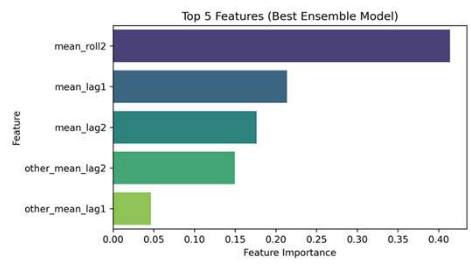
Models

- Naïve persistence baseline (lag-1)
- XGBoost: Level & Delta variants
- Equal-weight & optimized ensembles
- Rolling-origin CV with 1-day purge

Results



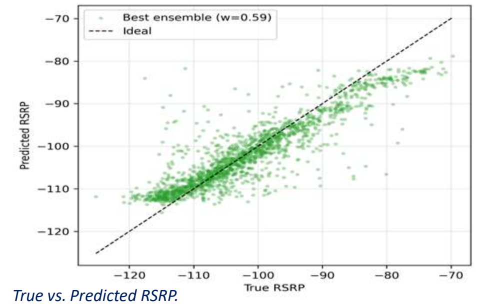
Out-of-fold RMSE by model variant.



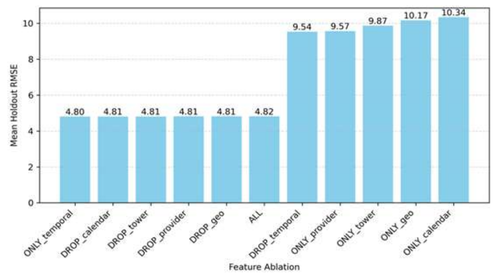
Top 5 features by importance (best ensemble).

- The ensembles rank best, and the Ensemble(0.59) is the best performing model
- Excluding temporal features roughly doubles the error (≈9.5). All top-5 features are exclusively temporal: mean_roll2 (≈40%), mean_lag1 (≈20%), mean_lag2 (≈17%)

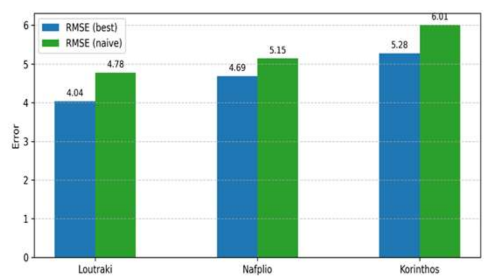
- **The ONLY temporal model attains the lowest mean holdout RMSE (≈4.80), statistically indistinguishable from the full-feature model (≈4.82).**
- **Averaged across the three cities, the proposed model attains 4.67 RMSE compared to 5.31 for the naïve baseline, a relative reduction of 12.1%.**



True vs. Predicted RSRP.



Holdout RMSE by ablation for the RSRP level model.



LOCO RMSE per city (best vs naïve).

Conclusions

- **XGBoost ensemble achieves strong accuracy and stable generalization across cities.**
- **Temporal features are both necessary and sufficient — non-temporal descriptors add marginal gains.**
- **LOCO validation: Loutraki 15.5%, Nafplio 8.9%, Korinthos 12.2% improvement over baseline.**
- **Short-term temporal dynamics capture most 5G signal variation → compact, effective forecasting.**

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