A Cross-Country Measurement Study of Inter-cell Interference in Cellular Networks

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As cellular networks densify, inter-cell interference becomes an increasingly important factor for understanding real-world channel quality, especially during the transition from LTE to 5G. Yet how interference differs across operators, bands, and deployment strategies in operational networks remains largely unexplored. In this paper, we present the first large-scale cross-country measurement study of inter-cell interference, spanning all three major US operators, all 5G frequency bands, and two measurement campaigns two years apart, covering more than 5,700 km across diverse geographic environments. Our analysis reveals four main findings. First, co-channel neighbor count and interference level are decoupled in 5G and the former is a poor proxy for the latter. Second, operators achieve competitive SINR through fundamentally different strategies: either via strong received signal or via effective interference suppression. Third, unlike LTE, where denser channels consistently degrade SINR, 5G densification preserves or improves SINR. Finally, interference improvement alone does not guarantee throughput gains; resource block allocation is an equally important constraint.

CCS Concepts: • **Networks** → **Mobile networks**; **Network measurement**; **Network performance analysis**.

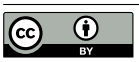
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1 Introduction

Cellular networks are becoming increasingly dense as operators expand 5G coverage and capacity. This densification is necessary for delivering the high bandwidth and low latency promised by 5G, especially as networks move toward higher-frequency spectrum such as mid-band and mmWave. However, denser deployments also make inter-cell interference harder to ignore. A UE served by

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one cell may receive signals from neighboring cells operating on the same frequency, and these co-channel signals can reduce the effective channel quality even when the serving-cell signal is strong. Therefore, understanding inter-cell interference is important for explaining real-world performance, especially as 5G networks continue to evolve from broad coverage layers toward denser capacity-oriented deployments.

Although inter-cell interference is a fundamental issue in cellular networks, its real-world impact is not uniform. Different operators may deploy different spectrum bands, cell densities, carrier configurations, and interference-management strategies, which can lead to very different interference outcomes. The effect also depends on radio technology and band: LTE, 5G-low, 5G-mid, and mmWave differ in coverage range, deployment density, and propagation characteristics. In addition, as 5G networks are evolving, the interference environment observed today may differ substantially from earlier deployments. These factors make inter-cell interference difficult to understand from a single viewpoint, motivating a large-scale measurement study that captures operator diversity, band heterogeneity, and deployment evolution simultaneously.

To study these effects in operational networks, we conducted two cross-country driving measurement campaigns across the continental United States, one in 2022 and one in 2024. Both campaigns follow the same route from Los Angeles to Boston, covering 5,700+ km across highways, suburban areas, and major cities. During each campaign, we measured the three major U.S. operators, AT&T, T-Mobile, and Verizon. The collected dataset spans all the cellular technologies available along the route, including LTE, 5G low-band, 5G mid-band, and mmWave. This dataset allows us to compare inter-cell interference across operators and technologies, and also to examine how the interference landscape changes as 5G deployment evolves over time. To our knowledge, this is the *first* large-scale study of inter-cell interference in operational networks across a diverse mix of geographic environments, operators, and frequency bands. Prior work has been limited to a narrow deployment setting in a campus environment [13]. The key findings of our work are as follows:

•**Co-channel neighbor count and interference level are decoupled in 5G.** Verizon has the most co-channel neighbors yet the lowest interference, while AT&T has fewer neighbors per channel than Verizon yet the worst interference and SINR. This decoupling holds across operators, bands, area types, and over time, and reveals that cell count and deployment density are poor proxies for interference quality in 5G networks.

•**Operators achieve competitive SINR through fundamentally different strategies.** T-Mobile operates in a signal-rich, interference-rich regime on n41, achieving good SINR through strong received signal. Verizon achieves nearly identical median SINR on n77 through a different path – weaker signal but substantially lower interference, consistent with more effective interference management techniques such as beamforming and downlink power control. AT&T, despite having comparable RSRP to T-Mobile and operating in the same band as Verizon, achieves the worst SINR of the three operators, illustrating that neither strong signal nor band choice alone guarantees good interference outcomes.

•**5G densification does not degrade SINR.** Despite nearly doubling its 5G interfering-cell density between 2022 and 2024, Verizon's median SINR slightly improves, driven by a mature n77 deployment where interference suppression techniques become more effective as cell density increases. This stands in sharp contrast to LTE, where denser channels consistently degrade SINR, and suggests that LTE-era interference intuitions do not transfer to 5G network planning.

•**Interference improvement does not guarantee throughput improvement.** High SINR is necessary but not sufficient for high throughput. In dense mid-band deployments, RB allocation is the binding constraint at high SINR, and many high-SINR samples still achieve low throughput due to limited scheduler resource allocation. Reducing interference improves the RF foundation for performance but delivers limited user-visible gains if scheduling decisions do not follow.

In summary, this paper makes the following main contributions. (1) We collect a multi-operator, multi-band, cross-country cellular measurement dataset covering LTE and 5G networks across the three major US carriers in two different years. (2) We provide the first large-scale cross-country measurement study of inter-cell interference in operational LTE and 5G networks, connecting RF-layer interference behavior to deployment strategies, longitudinal evolution, and user performance. (3) Our dataset and analysis scripts are publicly available [1].

2 Related Work

Inter-Cell Interference Measurement and Studies. Inter-cell interference has been extensively studied from different perspectives, including interference control for LTE heterogeneous networks [3, 11, 40], interference measurement method, interference-aware resource-allocation design and dynamic-TDD/cross-link-interference management in 5G NR [12, 15, 27, 34, 47], and RAN slicing or coordination systems that account for radio conditions [10, 52]. Some studies further evaluate interference-management algorithms through simulations or realistic RF plans [11, 40, 47]. Early LTE measurement studies also examined interference-related radio-layer behavior [37, 38]. However, real-world measurement studies that directly characterize inter-cell interference across operators, bands, and channels remain limited.

The closest work to ours is [13], which presents the first real-world measurement study of 4G/5G inter-cell interference in a campus environment, using a well-established UE-side methodology to identify co-channel interfering cells and estimate interference from RSRP and SINR. Their main finding — 4G densification degrades SINR while 5G stabilizes it as signal and interference grow at comparable rates — provides a valuable baseline. However, their campus setting structurally limits what can be observed: the narrow deployment context covers only a small number of channels per band, and results are aggregated across operators rather than compared, making operator strategy differences invisible. Our work applies the same measurement approach at a cross-country scale across all three major US operators, all 5G bands, and two measurement campaigns two years apart. Our findings are qualitatively different from [13] and hard to discover in a geographically limited setting, yet all have direct implications for network planning and regulation.

4G/5G Measurements. A large body of measurement work has characterized commercial cellular networks across coverage, throughput, latency, energy, mobility, carrier aggregation, MIMO, and application QoE [4, 7, 7–9, 14, 16–26, 28, 30, 32, 35, 36, 39, 42–45, 45, 46, 49–51, 53, 55–57], including large-scale cross-country driving studies [4, 9, 17, 22, 24, 25, 28, 56] or crowdsourced studies that track 5G deployment evolution over time [5, 31, 33, 54]. While these works provide important context, they use RF metrics such as RSRP, SINR, MCS, and resource allocation primarily to explain coverage, capacity, or user-perceived performance rather than to isolate how co-channel neighboring cells shape RF quality. Our work places inter-cell interference itself at the center of the analysis, examining for the first time how RSRP, interference, SINR, and co-channel cell density vary across operators, bands, area types, and deployment evolution.

3 Methodology

Measurement setup. We conducted two cross-country driving measurement campaigns across the continental US, from Aug. 8 to Aug. 15, 2022 and from Nov. 1 to Nov. 8, 2024, including both weekday and weekend driving. Daily driving generally began around 9–10 AM and continued into the evening, sometimes as late as 8–9 PM, with short breaks for meals, refueling, and occasional equipment troubleshooting. Measurements therefore covered morning through evening conditions, including afternoon and evening commuting hours in several metropolitan areas, but did not include overnight or early-morning conditions. Both campaigns followed the same route from Los Angeles to Boston, covering more than 5,700 km across interstate highways, suburban areas, and

major cities, and measured all three major US mobile network operators (AT&T, T-Mobile, and Verizon) *concurrently*, using separate smartphones, one per operator. The driving route is shown in Fig. 14 in §C. Additional measurements were conducted within several major cities encountered along the routes. The vehicle speed ranged from 5 mph in cities to 90 mph on interstate highways.

As with prior cross-country drive-test studies of cellular networks [4, 9, 17, 22, 24, 25, 28, 56], our methodology captures each location at a single point in time rather than through repeated measurements across times of day or days of the week. This means that time-of-day effects, diurnal load variation, and day-of-week traffic patterns are not separable from the spatial and longitudinal comparisons we report. We partially mitigate this by covering both weekday and weekend driving within each 8-day campaign and by driving during comparable hours. We cannot, however, rule out that some portion of the operator differences or year-over-year changes we observe reflects load conditions specific to the time each measurement was taken. Repeated same-location, same-time-of-day measurements are logistically difficult to obtain at cross-country scale and are left to future work.

We used Samsung Galaxy S21 Ultra devices in the 2022 campaign and a newer model, Samsung Galaxy S24 Ultra, in the 2024 campaign. Although the use of two different models could, in principle, confound the longitudinal comparisons in §7, our LTE and 5G measurements provide a useful internal comparison because they underwent the same device transition. As shown in §7.2, the median LTE co-channel neighboring cell count remains one for all three operators, while the mean increases only slightly. In contrast, the substantially larger increases in 5G neighboring cell counts, alongside the expansion in observed mid-band coverage and cell count, suggest real deployment changes rather than a uniform increase in neighbor detection caused by the newer device. For measured RSRP, our longitudinal results (§7) also show diverse operator- and band-specific patterns, including Verizon showing lower RSRP in 2024 despite the newer phone. This comparison however, does not entirely eliminate device-related confounding and a simultaneous comparison of both device models under matched network conditions is left to future work. For the RF and interference analysis in §5-§6, §8, which compares operators within the same year using the same device, the phone is not a confounding factor.

All phones operated in the default automatic network-selection mode, with no manual band or radio access technology (RAT) configuration. Each phone was connected to an Accuver XCAL Solo device [2], which records lower-layer cellular KPIs by tapping into the phone's Qualcomm diagnostic interface. We conducted backlogged uplink and downlink throughput tests throughout both drives to capture MAC-layer performance alongside the RF measurements. From the XCAL logs, we extract timestamped cellular measurements including the serving primary cell and secondary cells, RAT, frequency band, physical layer signal measurements (RSRP, SINR), neighboring cell information, and MAC throughput per cell. All metrics are at 100 ms granularity. For LTE neighboring cells, which are logged by Qualcomm diagnostic at uneven intervals, we apply per-channel 100-ms max-N bucketing to match the granularity of the other KPIs. Area type (rural, suburban, urban) was logged in real time by an observer in the vehicle during the 2024 campaign based on visual judgment of the surrounding environment. Since both campaigns followed the same route, we applied the same area-type labels to the 2022 dataset by matching GPS coordinates to the 2024 classification.

Unless otherwise noted, our analysis focuses on the serving primary cell; secondary-cell are not included.

3.1 Definitions

Interference. Following prior work [13], we estimate received interference power from the serving cell's RSRP and UE-reported SINR as:

$$\text{Interference (dBm)} = \text{RSRP (dBm)} - \text{SINR (dB)}. \tag{1}$$

This formula captures the aggregate power of all signals other than the serving cell received in the reference signal bandwidth, which includes both inter-cell interference and thermal noise. We assess the contribution of thermal noise using the standard receiver noise-floor calculation:

$$N_{\mathrm{dBm}} = 10\log_{10}\left(\frac{k_{\mathrm{B}}T_0B}{10^{-3}\,\mathrm{W}}\right) + NF_{\mathrm{dB}} \approx -174 + 10\log_{10}\left(\frac{B}{1\,\mathrm{Hz}}\right) + NF_{\mathrm{dB}}, \tag{2}$$

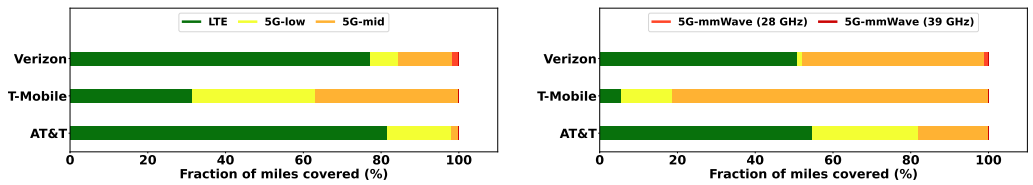
Here k_{B} is Boltzmann's constant, $T_0 = 290\,\mathrm{K}$, B is the reference-signal noise bandwidth and NF accounts for receiver-added noise. We consider receiver NF assumptions of 7dB for LTE and low/mid band 5G, and 10dB for 5G mmWave, following the ITU guidelines for evaluation of radio interface technologies [29, Table 5(b)]. The modeled noise floors are approximately -125.2, -122.2, and -113.2 dBm for LTE, low/mid band 5G, and mmWave 5G, respectively. In the 2024 campaign, 96.53% of LTE samples and 96.38% of NR samples have estimated interference-plus-noise power at least 3 dB above the receiver noise floor, while 80.19% of LTE samples and 78.73% of NR samples exceed the noise floor by more than 10 dB, corresponding to a noise contribution of less than 10% of the estimated interference-plus-noise power. In samples closer to the noise floor, the estimate overstates inter-cell interference; we interpret results in these regimes with appropriate caution.

Channels. Within each frequency band, operators deploy cells on specific frequency channels identified by their NR-ARFCN or LTE EARFCN.

Interfering cells. We define an interfering cell as a detectable neighboring cell operating on the same channel as the serving cell. The interfering-cell count at each measurement sample is the number of such co-channel neighbors logged by XCAL at that time. Since only cells strong enough to be detected by the UE can meaningfully contribute to co-channel interference, this count is the operationally relevant quantity.

4 Deployment and Coverage

Coverage. Fig. 1 shows the fraction of driving miles covered by each technology for each operator in 2022 and 2024. In 2024, T-Mobile leads with 94% of miles on 5G, 81% of which is high-speed 5G (mid-band or mmWave). Verizon's 5G coverage is 49% and almost exclusively high-speed, while AT&T matches Verizon's total 5G coverage at 45% but with only 18% on high-speed bands. In 2022, T-Mobile already had significant 5G coverage while Verizon and AT&T were still heavily LTE-dependent.



(a) 2022 (b) 2024

Fig. 1. Cellular technology breakdown per operator.

Cell Counts and Band Usage. Table 1 summarizes unique primary cells per operator, RAT, and band in 2022 and 2024. The dominant trend is a dramatic mid-band 5G expansion: T-Mobile's n41 grew from 542 to 2,235 cells, Verizon's n77 from 302 to 1,681, and AT&T's n77 from 80 to 785. Notably, T-Mobile also deployed 367 n25 cells, absent in 2022, suggesting it is adding mid-band capacity on new spectrum rather than simply densifying — a different strategy from Verizon and AT&T, which concentrate growth on a single band. Low-band 5G remained flat or declined across all operators, confirming the mid-band-centered nature of 2024 deployments. LTE continues to

Table 1. PCell counts by RAT and band, 2022 and 2024.

(a) AT&T

RAT	Band	Band type	#Cells (2022)	#Cells (2024)
4G	Band 5	low	1	2
	Band 12	low	258	553
	Band 14	low	16	94
	Band 2	mid	831	1291
	Band 4	mid	1	0
	Band 30	mid	70	219
	Band 66	mid	424	917
	Total		**1601**	**3076**
5G	n5	low	627	599
	n2	mid	0	30
	n41	mid	2	0
	n66	mid	3	30
	n77	mid	80	785
	n260	mmWave	46	15
	Total		**758**	**1459**

(b) T-Mobile

RAT	Band	Band type	#Cells (2022)	#Cells (2024)
4G	Band 12	low	66	57
	Band 13	low	1	0
	Band 14	low	0	4
	Band 26	low	3	0
	Band 71	low	67	46
	Band 2	mid	672	501
	Band 4	mid	3	11
	Band 25	mid	16	0
	Band 41	mid	35	0
	Band 66	mid	338	629
	Total		**1201**	**1248**
5G	n71	low	354	347
	n25	mid	0	367
	n41	mid	542	2235
	n90	mid	8	0
	Total		**904**	**2949**

(c) Verizon

RAT	Band	Band type	#Cells (2022)	#Cells (2024)
4G	Band 5	low	125	263
	Band 12	low	0	1
	Band 13	low	295	374
	Band 2	mid	197	582
	Band 4	mid	2	6
	Band 66	mid	896	1741
	Total		**1515**	**2967**
5G	n5	low	160	36
	n2	mid	0	3
	n77	mid	302	1681
	n260	mmWave	1	2
	n261	mmWave	44	179
	Total		**507**	**1901**

grow for AT&T and Verizon, consistent with its role as an NSA anchor layer in NSA deployments, while T-Mobile's stable LTE count reflects its 5G SA deployment (60% coverage in 2024). Verizon remains the only operator with significant mmWave presence.

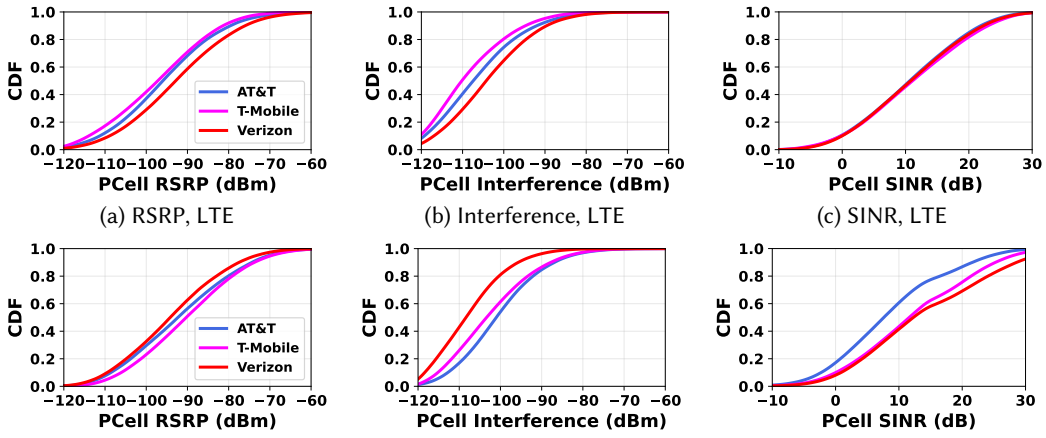
5 Interference Landscape in LTE and 5G

In this section, we present a cross-country overview of inter-cell interference in LTE and 5G networks using the 2024 dataset. We analyze RSRP, interference, and SINR distributions across operators, then examine interfering-cell counts, and finally study how these metrics vary across area types.

5.1 Signal Quality: RSRP, Interference, and SINR

LTE. Figs. 2a-2c plot the CDFs of RSRP, interference, and SINR for LTE. The three operators exhibit clear RSRP differences following the ordering Verizon > AT&T > T-Mobile (Fig. 2a). However, these gaps do not translate into similarly large SINR differences. The SINR distributions remain largely comparable across operators (Fig. 2c). The reason is a signal-interference coupling characteristic of LTE deployments: as the network is densified to improve received signal in a given area, it typically also increases co-channel interference from neighboring cells on the same shared spectrum, since both effects stem from placing more cells closer together. Verizon's LTE measurement samples are heavily concentrated on Band 66 (61.91%), whereas AT&T's are distributed primarily across B2 (44.44%) and B66 (32.21%), with additional contributions from B12 and B30. T-Mobile's samples are nearly evenly split between B66 (47.97%) and B2 (46.49%). This greater single-band concentration for Verizon is also evident in the unique-cell counts in Table 1.

5G. The 5G picture differs substantially, as shown in Figs. 2d-2f. The RSRP ordering reverses to T-Mobile > AT&T > Verizon, in contrast to LTE. More strikingly, the signal-interference coupling that characterizes LTE breaks down in 5G: AT&T has the second-strongest RSRP (Fig. 2d) but the highest interference (Fig. 2e) and the worst SINR among the three operators (Fig. 2f), while Verizon has the weakest RSRP, yet it achieves the lowest interference and the best SINR. This decoupling between signal strength and interference suggests that 5G operators are realizing fundamentally different interference environments despite deploying the same technology. We examine this finding in depth in §6.



(a) RSRP, LTE (b) Interference, LTE (c) SINR, LTE

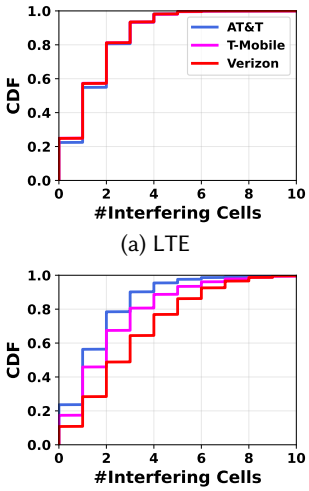
(d) RSRP, 5G (e) Interference, 5G (f) SINR, 5G

Fig. 2. RSRP, Interference, and SINR in LTE and 5G.

5.2 Interfering cells: LTE vs. 5G

Fig. 3 plots the CDF of interfering-cell count for LTE and 5G. For LTE (Fig. 3a), all three operators show broadly similar distributions with a median of 1 interfering cell and mean values close to 1.5, consistent with the comparable SINR distributions observed in Fig. 2c. The 5G results (Fig. 3b) are strikingly different and initially counterintuitive. Verizon observes substantially more interfering cells than the other two operators (a median of 3, compared to 2 for T-Mobile and 1 for AT&T), yet Figs. 2e, 2f show Verizon has the lowest overall interference and the best SINR. This apparent contradiction is the central puzzle of the paper.

The number of interfering cells reflects deployment density, but the resulting interference level also depends on how much power each neighboring cell contributes to the UE, shaped by cell spacing, beamforming behavior, channel reuse strategy, and transmit power control. Disentangling these factors requires a deeper analysis at the band and channel level, which we present in §6.



(a) LTE

(b) 5G

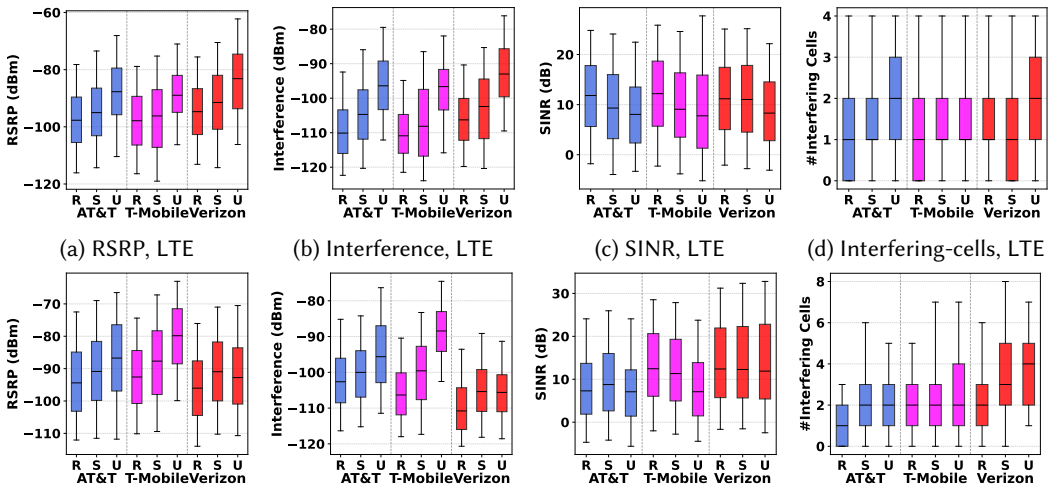
Fig. 3. # of interfering cells.

5.3 Area-type Breakdown

Figs. 4a-4d and 4e-4h decompose RSRP, interference, SINR, and interfering-cell count by area type for LTE and 5G, respectively.

LTE. All three operators show consistent trends across area types. RSRP and interference (Figs. 4a, 4b) both increase from rural to suburban to urban, reflecting denser deployments in more populated areas. Despite the stronger received signal in urban areas, SINR does not improve correspondingly (Fig. 4c); AT&T and T-Mobile both exhibit gradually decreasing SINR as the environment becomes denser, confirming that the interference increase outpaces the signal gain in LTE. Verizon shows a slightly different pattern, with SINR stable from rural to suburban before declining in urban areas. The interfering-cell count (Fig. 4d) follows the expected trend for AT&T and Verizon, increasing from rural to urban, while T-Mobile remains at a median of 1 across all area types, consistent with its lower overall LTE deployment density along the route.

5G. The 5G area-type results reinforce the operator contrast from §5.1 and provide additional evidence for the factors responsible for Verizon's low interference. Across all operators, RSRP and



(a) RSRP, LTE (b) Interference, LTE (c) SINR, LTE (d) Interfering-cells, LTE

(e) RSRP, 5G (f) Interference, 5G (g) SINR, 5G (h) Interfering-cells, 5G

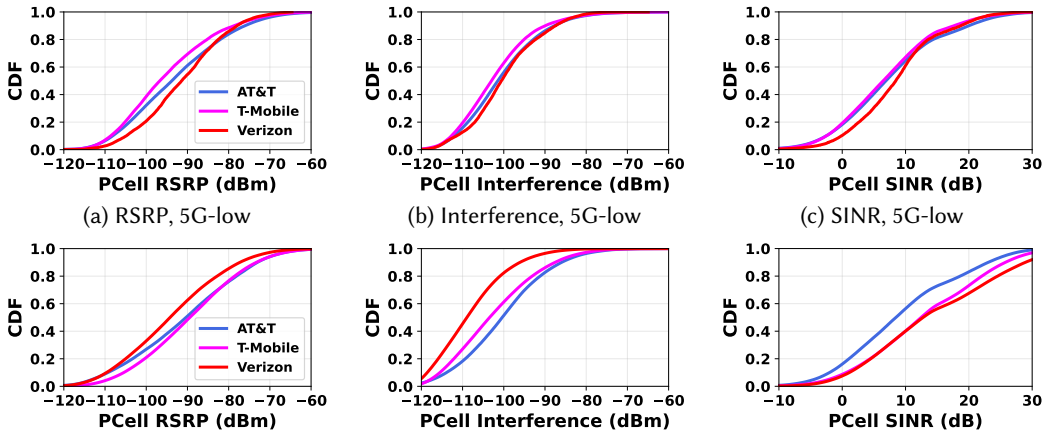
Fig. 4. LTE and 5G measurements by area type. (R – rural, S – surburban, U – urban).

interference increase from rural to suburban (Figs. 4e, 4f), consistent with denser deployments in more populated areas. However, Verizon is the only operator whose urban RSRP falls below its suburban RSRP — a pattern not seen in LTE or in the other two 5G operators. This anomaly may itself reflect Verizon's interference management strategy: if the network applies more aggressive downlink power reduction in dense urban environments to limit inter-cell interference, the UE would observe lower RSRP despite being closer to cells, consistent with Verizon maintaining the lowest interference across all area types despite its high interfering-cell density.

Beyond this anomaly, the area-type breakdown reveals how Verizon's interference advantage evolves across environments and provides a clue about its origin. The interference gap between Verizon and AT&T follows a non-monotonic pattern across area types: it narrows from rural to suburban (8.15 to 5.36 dB) but widens substantially in urban areas (9.99 dB), where Verizon achieves its largest interference advantage. Strikingly, this widening occurs precisely in the environment where AT&T has its strongest RSRP advantage over Verizon (6.02 dB in urban vs. 1.63 dB in rural), yet despite AT&T's stronger signal in urban areas, Verizon suppresses interference more effectively than anywhere else along the route.

One possible explanation of Verizon's largest urban interference advantage despite lower RSRP is beamforming. In dense urban environments, spatially directed beams can more effectively suppress interference from neighboring cells, while in rural and suburban areas the geometry is less favorable for spatial isolation. The SINR gap follows a similar non-monotonic pattern (5.1, 3.51, and 4.81 dB for rural, suburban, and urban respectively), with the slightly smaller urban SINR gap relative to rural explained by AT&T's stronger urban RSRP partially offsetting Verizon's interference advantage. By contrast, AT&T and T-Mobile show decreasing SINR as the environment becomes denser, indicating that their interference grows faster than their signal in urban deployments. Verizon's interfering-cell count grows steadily from rural to urban (medians of 2, 3, and 4), yet it achieves its largest interference advantage in urban areas, indicating that interfering-cell count and interference level are decoupled for Verizon, and pointing to a density-dependent interference suppression mechanism. We examine this and alternative explanations such as downlink transmit power control, site geometry, and antenna tilt in more detail in §6.

Summary. The 2024 interference landscape reveals a clear split between LTE and 5G behavior and a striking operator divergence in 5G. In LTE, signal strength and interference are tightly coupled,



(a) RSRP, 5G-low (b) Interference, 5G-low (c) SINR, 5G-low

(d) RSRP, 5G-mid (e) Interference, 5G-mid (f) SINR, 5G-mid

Fig. 5. CDFs of signal quality KPIs for 5G-low and 5G-mid.

leaving SINR broadly comparable across operators despite RSRP differences. In 5G, this coupling breaks down: Verizon achieves the lowest interference and best SINR despite having the highest number of co-channel neighboring cells, while AT&T has the worst SINR despite competitive RSRP. The area-type breakdown provides an initial clue about the root cause: despite AT&T having its strongest RSRP advantage over Verizon in urban areas, Verizon's interference advantage is also at its largest there, suggesting that a density-dependent interference suppression mechanism such as beamforming is more effective in dense urban environments. Fully explaining Verizon's counterintuitive behavior and the broader operator divergence in 5G requires a deeper analysis at the band and channel level, which we present in §6.

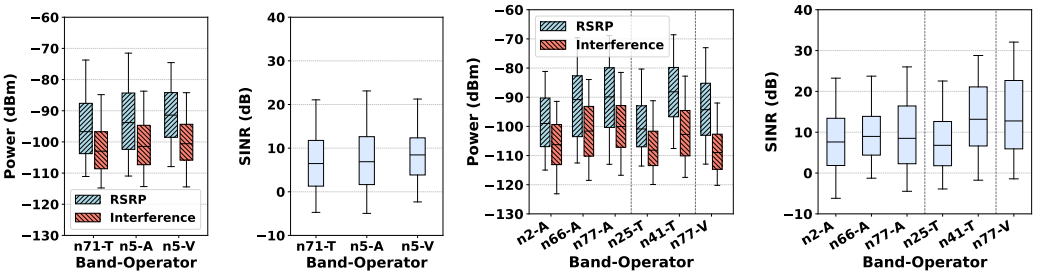
6 Why Does 5G Interference Differ Across Operators?

The cross-country results in §5 reveal substantial operator differences in 5G interference and SINR that do not follow the same signal-interference coupling observed in LTE. In this section, we investigate the sources of these differences, progressing from a band-level overview to an operator-specific analysis of mid-band interference strategies. We show that the differences arise from two distinct levels: band choice, which gives T-Mobile a propagation advantage on n41 relative to Verizon and AT&T on n77, and within-band deployment strategy, where Verizon and AT&T achieve very different interference outcomes on the same n77 band. We also show that the counterintuitive finding from §5 — that more interfering cells do not imply stronger interference — holds consistently across operators and bands, and identify the likely mechanisms behind it.

6.1 Band-level Overview

Before comparing operators, it is important to establish what "overall 5G" means for each operator in terms of band composition, since the aggregate results in §5 reflect very different band mixes. For T-Mobile and Verizon, mid-band dominates — around 88% of observed 5G cells for both operators (Table 1). For AT&T, the picture is different: low-band and mid-band contribute roughly equally to its 5G footprint, with low-band slightly larger, meaning AT&T's aggregate 5G interference results are shaped by both bands rather than mid-band alone. This compositional difference is important context for interpreting the operator comparisons that follow.

Low-band. Fig. 5b shows that interference distributions are close across operators in 5G low-band, with T-Mobile having marginally lower interference. The SINR gap (Fig. 5c) is mainly driven by



(a) RSRP/interference, 5G-low (b) SINR, 5G-low (c) RSRP/interference, 5G-mid (d) SINR, 5G-mid

Fig. 6. Major 5G-low and 5G-mid bands. T: T-Mobile, A: AT&T, V: Verizon

RSRP differences (Fig. 5a); Verizon appears strongest in RSRP and median SINR, but this result should be interpreted cautiously: Verizon deploys low-band 5G very sparingly (only 1.9% of observed 5G cells), so its low-band samples reflect a small number of specific deployment contexts rather than a representative picture of its overall 5G performance. AT&T, for which low-band represents a major component of its 5G footprint, shows the widest RSRP and SINR distributions in its main low band (n5) compared to Verizon's n5 and T-Mobile's n71 (Figs. 6a, 6b), consistent with serving users across a broad range of coverage conditions. Overall, 5G low-band does not create meaningful interference differentiation across operators — the distributions are too close to explain the operator gaps observed in §5.

Mid-band. Mid-band is where the main operator differences emerge and is the focus of the remainder of this section. Fig. 5d shows that T-Mobile and AT&T have stronger median RSRP than Verizon (-89.4, -90.4, and -94.2 dBm respectively), yet Verizon achieves the highest median SINR (12.78 dB vs. 12.47 dB for T-Mobile and 8.48 dB for AT&T, Fig. 5f) with a better upper tail, by maintaining substantially lower interference (-109.0 dBm median vs. -103.4 and -100.4 dBm, Fig. 5e). The mechanisms behind these differences, which involve both band choice and within-band deployment strategy, are examined in §§6.2 and 6.3.

mmWave. mmWave is a special case rather than a main driver of overall 5G results, given its limited geographic coverage and small sample share. Fig. 15 in §D shows that AT&T and Verizon show nearly identical median RSRP on mmWave (-94.6 dBm), with AT&T achieving slightly higher median SINR (9.28 vs. 7.18 dB) due to lower interference, while Verizon shows a wider distribution with a stronger upper tail (95th percentile SINR of 20.5 vs. 17.8 dB). These differences reflect local deployment density and blockage dynamics rather than systematic operator strategy, and we do not analyze mmWave further in this section.

6.2 The n41 vs. n77 Contrast: Band Choice and Its Tradeoffs

T-Mobile's mid-band advantage over Verizon and AT&T in terms of RSRP originates partly from its choice of n41 (2.5 GHz) over than n77 (3.7 GHz). At 2.5 GHz, path loss is approximately 3.4 dB lower than at 3.7 GHz for the same distance and transmit power, giving T-Mobile a physics-driven propagation advantage that translates directly into stronger received signal. On top of this, T-Mobile's n41 deployment is substantially denser than Verizon's or AT&T's n77 deployment — T-Mobile observed 2,235 n41 cells along the route in 2024 compared to 1,681 n77 cells for Verizon and 785 for AT&T. Both the propagation advantage and the deployment density contribute to T-Mobile's stronger RSRP, and these two factors cannot be fully disentangled with our dataset.

However, T-Mobile's stronger signal comes at a cost: n41 also generates higher interference than Verizon's n77. T-Mobile operates in a signal-rich but also interference-rich regime; stronger

AT&T n77

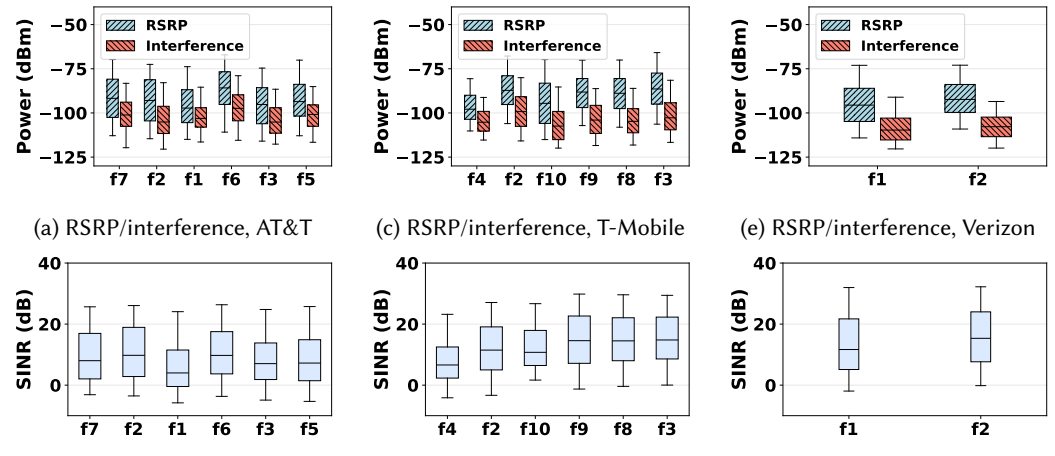
Freq.	f7	f2	f1	f6	f3	f5
Cells	25	63	78	376	44	186
Interf.	1.13	1.21	1.62	2.20	2.24	2.32

T-Mobile n41

Freq.	f4	f2	f10	f9	f8	f3
Cells	45	818	39	368	567	378
Interf.	1.16	1.91	2.18	2.30	2.51	3.53

Verizon n77

Freq.	f1	f2
Cells	1021	659
Interf.	2.84	3.38



(a) RSRP/interference, AT&T (c) RSRP/interference, T-Mobile (e) RSRP/interference, Verizon

(b) SINR, AT&T (d) SINR, T-Mobile (f) SINR, Verizon

Fig. 7. Channel-level analysis for the primary 5G mid-bands (AT&T n77, T-Mobile n41, Verizon n77). Different channels of a band are labeled as f_1, f_2, ... Only channels with at least 20 cells are included for a meaningful comparison. Channels are sorted in increasing order of average interfering-cell count ("Interf." in the tables).

received signal is accompanied by stronger co-channel interference, while Verizon operates in a lower-signal but also lower-interference regime. The net effect on SINR is that T-Mobile and Verizon end up with nearly identical median SINR (12.47 vs. 12.78 dB) through opposite paths.

The channel-level analysis for n41 in Figs. 7c and 7d reveals how T-Mobile's n41 deployment handles increasing density. Excluding the outlier channel f10 (only 39 observed cells, compared to hundreds for most other channels), Fig. 7d shows a clear and consistent finding: SINR does not degrade as channel density increases. It actually improves from sparse to moderate density channels (f4→f9, SINR improving from 6.61 to 14.57 dB) and then stabilizes among the three densest channels (f9, f8, f3) at approximately 14.5–14.8 dB. Fig. 7c shows why: among the dense channels, both RSRP and interference increase at roughly the same rate as density grows (RSRP changing by 2 dB and interference by 1.3 dB from f9 to f3), leaving SINR essentially unchanged. This suggests that beyond a certain deployment density threshold, further n41 densification reaches a stable operating point where signal and interference scale together, neither improving nor degrading channel quality.

AT&T presents a puzzling contrast to both operators. Despite achieving median RSRP comparable to T-Mobile's n41 (-90.4 vs. -89.4 dBm, Fig. 5d), AT&T suffers the worst interference (-100.4 dBm) and worst SINR (8.48 dB) among the three operators, on the same n77 band as Verizon but without Verizon's interference suppression effectiveness. We examine the Verizon vs. AT&T contrast in detail in the next section.

6.3 Within n77: Verizon vs. AT&T

As established in §5.1, Verizon has more interfering cells than AT&T overall, which already rules out deployment sparsity as an explanation of their drastically different interference outcomes. The channel-level analysis rules out channel reuse as well: AT&T spreads its n77 cells mainly across six channels with a maximum average interferer count of 2.32 per channel (Fig. 7a), while Verizon

concentrates on just two channels with average interferer counts of 2.84 and 3.38 (Fig. 7e). Therefore, AT&T has both fewer interfering cells overall and fewer co-channel neighbors per channel on its primary mid band than Verizon, yet still experiences worse interference. The explanation must lie in how much power each interfering cell contributes to the UE rather than in the number or distribution of co-channel neighbors.

Two possible mechanisms are consistent with this finding. First, beamforming: spatially directed beams can reduce the interference contribution of each neighboring cell by steering energy toward intended users and away from others. The area-type evidence from §5.3 supports this hypothesis. Verizon's interference advantage over AT&T widens specifically in urban environments (9.99 dB gap) compared to rural areas (8.15 dB gap), consistent with beamforming being more effective in dense urban environments where the UE is surrounded by more co-channel neighbors from diverse directions, giving the neighboring gNB more spatial degrees of freedom to suppress interference. Second, downlink transmit power control: if Verizon's network applies more aggressive power reduction on the downlink in dense environments, each neighboring cell would contribute less interference to the UE. We cannot confirm these hypothesis from UE-side measurements alone since we do not have access to gNB transmit power data, but they are consistent with Verizon maintaining its interference advantage across all area types and density levels and it is further supported by the area-type RSRP anomaly noted in §5.3, where Verizon's urban RSRP falls below its suburban RSRP, unlike any other operator.

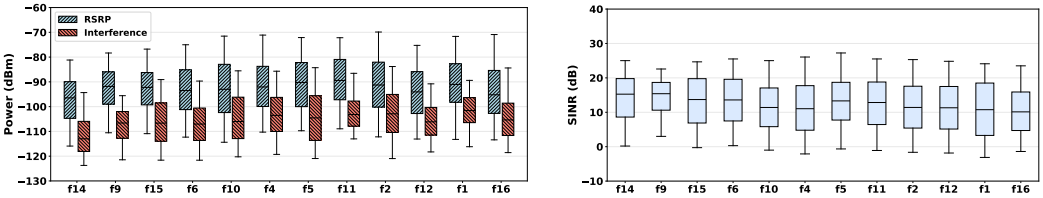
Several other factors such as deployment geometry and antenna tilt could contribute to this difference of the serving signal and the aggregate interference received by the UE. One factor which we can rule out is the TDD configuration differences, since we confirmed via our traces that both operators use the same TDD pattern nationwide on the relevant band.

The three-operator comparison reinforces the argument that interfering-cell count is a poor proxy for interference level. At the aggregate level, T-Mobile has a lower median interfering-cell count than Verizon (2 vs. 3, Fig. 3b), yet has higher interference (Fig. 5e), illustrating that fewer co-channel neighbors do not guarantee lower interference when each neighbor contributes more power. The channel-level data adds further nuance: T-Mobile's densest n41 channel f3 (3.53 average neighbors, 378 instances, Fig. 7c) is actually denser than either of Verizon's two n77 channels (2.84 and 3.38, Fig. 7e), but f3 represents a minority of T-Mobile's samples — channels f2 (818 instances) and f8 (567 instances) are more representative and have substantially lower neighbor counts, which explains T-Mobile's lower aggregate median interfering-cell count. AT&T, despite having fewer interfering cells than Verizon overall and fewer co-channel neighbors per channel, achieves the worst interference and lowest SINR of the three operators indicating again that neighbor count and channel reuse strategy are insufficient to explain interference outcomes, and that per-cell power contributions, shaped by beamforming, power control, or site geometry, are the fundamental differentiating factors in 5G.

6.4 LTE vs. 5G: A Fundamental Difference in Interference Scaling

Figs. 8a, 8b show the channel-level results for Verizon's most popular LTE band (Band 66). The results for AT&T's and T-Mobile's most popular LTE bands (Band 2 and Band 66, respectively) are qualitatively similar and are included in §E (Figs. 17a, 17b, 17c, 17d) due to space limit. The channel-level analysis for LTE reveals a fundamentally different scaling behavior from 5G. Across AT&T Band 2, T-Mobile Band 66, and Verizon Band 66, SINR tends to decrease as the average number of interfering cells increases; channels with more co-channel neighbors consistently show worse channel quality. This monotonic degradation contrasts sharply with the 5G results in Fig. 7, where denser channels either preserve or improve SINR. The difference reflects a fundamental distinction between LTE and 5G interference management: LTE deployments rely primarily on frequency reuse

Frequency	f14	f9	f15	f6	f10	f4	f5	f11	f2	f12	f1	f16
Cells	20	24	51	53	172	471	79	57	470	94	25	199
Interfering cells	0.73	0.81	0.96	1.04	1.09	1.12	1.13	1.14	1.22	1.22	1.49	1.50



(a) Verizon RSRP & interf. (b) Verizon SINR

Fig. 8. Channel-level analysis for Verizon's primary LTE Band (Band 66).

and cell planning to manage interference, whereas 5G deployments benefit from beamforming and more sophisticated interference suppression techniques that can maintain channel quality even as co-channel neighbor density grows. This LTE-5G contrast is consistent with the aggregate results in §5 and provides channel-level confirmation that 5G interference management is qualitatively different from its LTE counterpart.

The LTE finding is consistent with [13], which observes the same monotonic SINR degradation with densification in a campus setting. For 5G, however, [13] finds SINR remains stable across channels. Our results go further, showing that this stability can arise from fundamentally different operator strategies rather than a uniform signal-interference co-scaling.

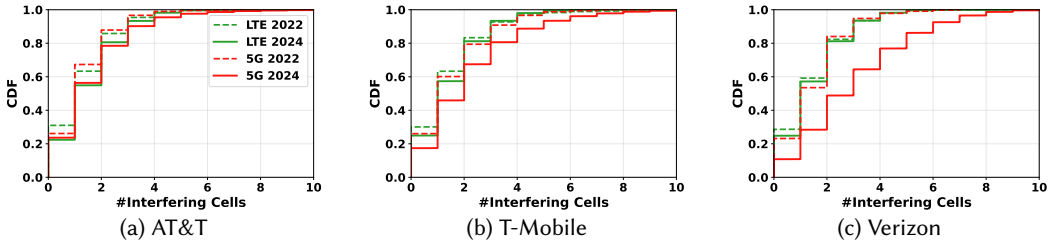
Summary. The operator differences in 5G interference observed in §5 arise from two distinct levels. At the band level, T-Mobile's n41 at 2.5 GHz provides a propagation advantage over n77 at 3.7 GHz, resulting in stronger RSRP but also higher interference; T-Mobile and Verizon nonetheless reach nearly identical median SINR through opposite paths: T-Mobile via strong signal, Verizon via interference suppression. Within n77, Verizon achieves much lower interference than AT&T despite more interfering cells and higher per-channel interferer density, ruling out deployment sparsity and channel reuse as explanations. AT&T is the most puzzling case: comparable RSRP to T-Mobile and fewer co-channel neighbors per channel than Verizon, yet the worst interference and SINR of the three operators. Together, these findings are consistent with per-cell power contributions shaped by mechanisms such as beamforming, power control, or site geometry. Finally, unlike LTE where denser channels consistently degrade SINR, 5G densification preserves or improves it — a finding with direct implications for network planning.

7 Does Densification Hurt Interference? A Longitudinal View

In §5, §6, we characterized the 2024 interference landscape and the strategies that shape it. In this section, we examine how that landscape evolved from 2022 to 2024, asking whether the rapid 5G densification observed over this period degraded interference and SINR. The answer has direct implications for network planning: if densification preserves SINR when interference is managed effectively, operators can continue expanding 5G coverage without sacrificing channel quality.

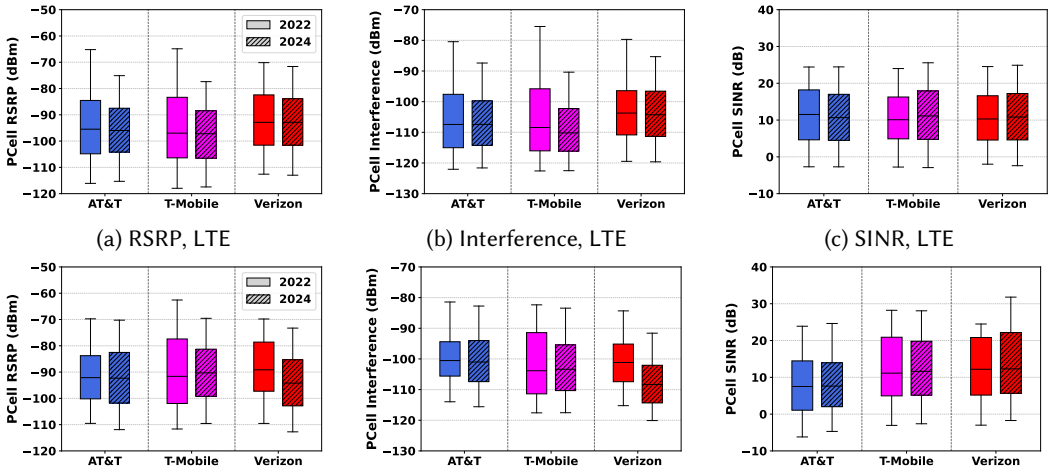
7.1 Deployment Evolution

The dominant trend from 2022 to 2024 is a dramatic expansion of mid-band 5G, already summarized in §4. The key numbers for the interference analysis that follows are the scale of this expansion: T-Mobile n41 grew from 542 to 2,235 cells, Verizon n77 from 302 to 1,681 cells, and AT&T n77 from 80 to 785 cells — roughly 4x, 5.5x, and 10x growth, respectively. This mid-band expansion is the primary driver of the interference environment changes we examine below. LTE cell counts also



(a) AT&T (b) T-Mobile (c) Verizon

Fig. 9. Interfering cell evolution.



(a) RSRP, LTE (b) Interference, LTE (c) SINR, LTE

(d) RSRP, 5G (e) Interference, 5G (f) SINR, 5G

Fig. 10. RF quality evolution.

grew for AT&T and Verizon but remained stable for T-Mobile, consistent with LTE continuing to serve as an NSA anchor layer for the two operators still expanding their 5G footprint.

7.2 Interfering-Cell Density Evolution

Fig. 9 plots the interfering-cell count CDFs for LTE and 5G in both years. For LTE, the interfering-cell distribution remains roughly stable across all three operators. The median stays at one interfering cell and the mean increases only slightly (from 1.26 to 1.51 for AT&T, 1.39 to 1.46 for T-Mobile, and 1.39 to 1.46 for Verizon). Despite AT&T and Verizon roughly doubling their LTE cell counts (Tables 1a, 1c), UEs do not observe meaningfully more co-channel LTE neighbors. This stability reflects the mature and planned nature of LTE frequency reuse, where new cells are added on existing channels in ways that do not substantially increase co-channel neighbor density.

The 5G picture is very different. The average number of 5G interfering cells increases substantially for all three operators: from 1.24 to 1.62 for AT&T, from 1.49 to 2.15 for T-Mobile, and from 1.48 to 2.97 for Verizon. The latter represents a near-doubling of co-channel neighbor density. This is a direct consequence of the mid-band expansion: as operators densify n41 and n77, UEs encounter more co-channel cells. The key question is whether this increased interfering-cell density translates into worse interference and degraded SINR, which we examine next.

7.3 RF Quality Evolution

Figs. 10a-10c show that LTE RF quality changes only modestly between 2022 and 2024, consistent with the stable interfering-cell environment in §7.2. The median RSRP remains nearly unchanged

for all three operators. SINR is also broadly stable; AT&T decreases slightly from 11.52 to 10.66 dB, while T-Mobile and Verizon marginally improve from 10.09 to 11.12 dB and 10.30 to 10.82 dB, respectively. The small interfering-cell count changes are reflected in broadly stable aggregate SINR across all three LTE operators, consistent with the channel-level finding in §6.4 that LTE SINR degrades with interfering-cell density, since the density itself changed little from 2022 to 2024.

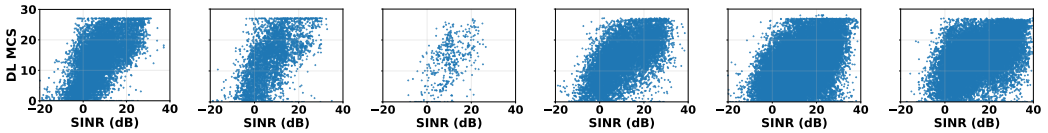
For 5G, the picture is strikingly different despite substantially higher interfering-cell density in 2024. As shown in Figs. 10d-10f, the median SINR does not degrade for any of the three operators. For T-Mobile and AT&T, the median RSRP, interference, and SINR remain essentially unchanged, but the distribution shapes evolve differently. T-Mobile's distributions narrow in 2024. All three metrics become more tightly concentrated around the same medians, reflecting a mature, stable network that has converged to a consistent operating point. AT&T's RSRP and interference boxplots become taller (wider spread) in 2024, likely reflecting the heterogeneous conditions introduced by rapid mid-band expansion, yet the SINR distribution narrows slightly, suggesting some improvement in interference management at the tails even as median SINR stays flat. The most notable longitudinal change is Verizon's, examined in detail in the following section.

7.4 The Verizon Case: Doubling Interfering-Cell Density While Improving Interference

Verizon's longitudinal trajectory is the most striking in the dataset and serves as the strongest test of whether 5G densification can preserve — or even improve — interference management. From 2022 to 2024, Verizon's average 5G interfering-cell count nearly doubles (1.48→2.97), driven by its rapid n77 expansion from 302 to 1,681 cells. Despite this, Verizon's median RSRP drops from -89.13 to -94.19 dBm — a weakening of the serving signal — while median interference drops even more substantially, from -101.16 to -108.36 dBm. The net result is counterintuitive: that Verizon's median SINR slightly improves despite a denser co-channel environment and weaker received signal.

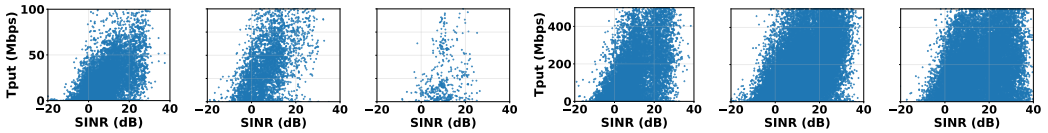
The drop in both RSRP and interference, on the other hand, is the expected consequence of Verizon's dramatic n77 mid-band expansion, from a nascent deployment covering roughly 14% of the route in 2022 to a dense, mature deployment covering nearly 47% in 2024, with low-band 5G essentially eliminated. As Verizon's n77 deployment matures and densifies, the shorter range of mid-band cells means UEs connect at closer distances, naturally reducing the observed RSRP relative to 2022's mix of low and mid-band cells, while interference is suppressed more effectively than the low-band cells they replaced, possibly by using the mechanisms we discussed in §6.3. This stands in contrast to [13], which finds 5G SINR stable but unchanged with densification. The longitudinal results further suggest that this interference suppression capability strengthens as the deployment matures and densifies, suggesting that beamforming effectiveness improves as cell density increases and the UE is surrounded by more co-channel neighbors in diverse spatial directions.

Summary. From 2022 to 2024, all three operators substantially densified their 5G mid-band deployments, with Verizon's 5G interfering-cell density nearly doubling. Yet, the median 5G SINR did not degrade for any operator; it remained stable for T-Mobile and AT&T and slightly improved for Verizon. This stands in contrast to LTE, where the channel-level analysis in §6.4 shows that denser channels consistently degrade SINR, a pattern that kept aggregate LTE SINR stable in 2022→2024 only because LTE interfering-cell density itself barely changed. The Verizon case is the most compelling illustration: a near-doubling of co-channel neighbor density accompanied by improved interference and slightly improved SINR, driven by a deployment shift from low-band to n77 mid-band that amplifies the interference suppression. Together, these results reinforce that 5G densification does not hurt interference when operators deploy bands and techniques that effectively suppress per-cell power contributions.



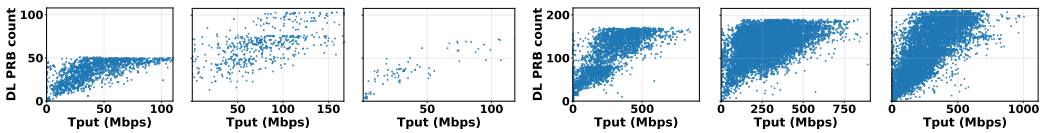
(a) AT&T Low (b) T-Mobile Low (c) Verizon Low (d) AT&T Mid (e) T-Mobile Mid (f) Verizon Mid

Fig. 11. 5G MCS vs. SINR across operators and band types.



(a) AT&T Low (b) T-Mobile Low (c) Verizon Low (d) AT&T Mid (e) T-Mobile Mid (f) Verizon Mid

Fig. 12. 5G Throughput vs. SINR across operators and band types.



(a) AT&T Low (b) T-Mobile Low (c) Verizon Low (d) AT&T Mid (e) T-Mobile Mid (f) Verizon Mid

Fig. 13. 5G PRB count vs. throughput across operators and band types under high SINR, high MCS.

8 Impact on User Performance

In this section, we examine when lower interference (higher SINR) translates to better throughput and when it does not, analyzing the relationships among SINR, MCS, and throughput across operators and bands. We analyze only PCell throughput, excluding throughput contributed by secondary cells through carrier aggregation.

SINR and MCS. Fig. 11 plots MCS against SINR for all operators and the two main 5G bands (the mmWave results are included in §D, Fig. 16, due to space limit). Higher SINR enables higher MCS across all operators and bands, consistent with expected link adaptation behavior, and the relationship is clearest in low-band and mmWave. Mid-band tells a more complex story: the scatter is substantially wider, with several samples showing low MCS despite high SINR. This pattern differs in intensity across operators; T-Mobile and Verizon show the widest scatter, and AT&T the narrowest, consistent with their interference environments. T-Mobile's dense n41 deployment creates a more variable interference environment, making accurate CQI estimation harder and causing the scheduler to select conservative MCS values. AT&T's less dense mid-band deployment results in more stable CQI estimates and closer MCS-SINR tracking. Conservative link adaptation strategies such as OLLA [6, 41, 48] and HARQ retransmission history may play a significant role beyond instantaneous SINR, and vendor-specific scheduling implementations may further contribute to operator differences.

SINR and throughput. Fig. 12 plots throughput against SINR. We observe a positive correlation across all operators and bands: very low SINR reliably predicts low throughput and the trend is visible throughout the SINR range. However, the strength of this correlation varies substantially by band. In mid-band, the scatter is much wider, with high- and low-throughput samples appearing at almost every SINR value, especially for T-Mobile and Verizon, reflecting the same variable interference environment that drives MCS scatter in Fig. 11. The key asymmetry is that low SINR reliably predicts low throughput, but high SINR does not reliably predict high throughput, particularly in mid-band. This reveals that, while interference limits throughput at the low end, at high SINR other factors become the binding constraint.

The role of RB allocation. To isolate the impact of resource allocation, we filter samples to those with SINR > 15 dB and MCS > 10 – conditions under which the channel quality is favorable and link adaptation has selected a reasonable modulation order – and plot throughput against the number of allocated RBs in Fig. 13. Pearson's correlation coefficients between throughput and RB count are 0.668, 0.603, and 0.844 in low-band and 0.753, 0.465, and 0.741 in mid-band for AT&T, T-Mobile, and Verizon, respectively. These positive associations show that limited RB allocation contributes to low throughput even under favorable radio conditions. The weaker mid-band correlation of T-Mobile reflects more high-RB / low-throughput observations. Nevertheless, high throughput is rarely observed with low RB allocation, consistent with allocated resources being an important prerequisite to realize throughput gains. We conclude that scheduler's resource allocation decision, driven by network load, competing users, and scheduling policy, is the primary throughput determinant once SINR crosses a usable threshold.

9 Implications

Our study has several implications for operators, vendors, and the research community on how to interpret, plan, and optimize inter-cell interference in operational LTE and 5G networks.

Cell count is a poor proxy for interference quality. A central finding of our study is that the number of detectable co-channel neighboring cells is a poor predictor of the resulting interference level. This result suggests that operators and regulators relying on cell count or deployment density as proxies for interference risk drawing incorrect conclusions about network quality. A more informative evaluation framework tracks interference power, SINR, and co-channel neighbor density jointly, at the band and channel level, rather than relying on aggregate cell counts or coverage fractions alone.

Band choice and interference management are equally important for SINR outcomes. Our results show that AT&T, despite having comparable RSRP to T-Mobile and deploying the same n77 band as Verizon, achieves the worst SINR of the three operators, illustrating that neither strong signal nor the right band choice guarantees good interference outcomes. This has a practical implication for operators: expanding coverage and improving signal strength are necessary but not sufficient goals; the ability to suppress interference from co-channel neighbors is an equally important determinant of user-perceived channel quality. Vendors developing interference management features should benchmark their effectiveness against real-world operator deployments rather than idealized simulation environments, where the gap between operators like Verizon and AT&T on the same band would not be visible.

Interference-suppression effectiveness compounds with deployment maturity. Our results show that Verizon's interference advantage over AT&T widens in urban environments where cell density is highest, and Verizon's interference actually improves between 2022 and 2024 despite nearly doubling its interfering-cell count. This motivates evaluating interference and SINR alongside deployment growth, rather than assuming that more neighbors necessarily imply worse channel quality. Further evaluation of interference-management approaches, including beamforming, downlink power control, and antenna-tilt optimization, could help identify effective strategies for maintaining channel quality as deployments densify.

LTE-era interference intuitions do not apply to 5G. In LTE, denser channels consistently degrade SINR while in 5G, densification preserves or improves it when operators deploy effective interference management. Operators and vendors who apply LTE-era assumptions will systematically underestimate 5G's ability to scale through densification. 5G network planning tools and simulation frameworks should be updated to reflect this fundamentally different interference scaling behavior rather than extrapolating from LTE models.

Interference improvement alone does not guarantee throughput gains. Our analysis in §8 shows that at high SINR, RB allocation becomes the binding constraint, and many high-SINR samples still achieve low throughput due to limited scheduler resource allocation. This has a direct implication for operators optimizing network performance: reducing interference improves the RF foundation for throughput, but user-visible gains will only materialize if the scheduler allocates sufficient resources to exploit the improved channel conditions. In dense mid-band deployments operators should jointly evaluate interference conditions and scheduling efficiency rather than treating them as independent optimization targets.

10 Conclusion

This paper presented the first large-scale, cross-country measurement study of inter-cell interference in operational LTE and 5G networks, spanning all three major US operators, all 5G frequency bands, and two measurement campaigns two years apart. Moving beyond aggregate coverage and throughput metrics, we characterized the interference environment at the operator, band, channel, and area-type level, and tracked its evolution as 5G deployments expanded substantially between 2022 and 2024.

The central lesson of this work is that 5G interference management is not uniform: operators deploying the same band and technology can achieve radically different interference outcomes, and densification can improve rather than degrade SINR when interference suppression mechanisms are sufficiently mature. The operator differences we observe – most strikingly between Verizon and AT&T on the same n77 band – show that the gap between operators who manage interference effectively and those who do not is large and consequential for users. This stands in sharp contrast to LTE, where interference scales predictably with deployment density and leaves little room for operator differentiation. At the same time, even well-managed interference is not sufficient for high throughput. Our analysis shows that scheduler resource allocation decisions are an equally important factor that determines whether improved channel conditions translate into user-visible performance gains. Together, these findings challenge several assumptions inherited from LTE-era network planning and have direct implications for how operators plan 5G densification, how vendors develop and benchmark interference management features, and how the research community models 5G interference at scale.

Acknowledgments

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Appendix

A Ethics

This work does not raise any ethical concerns. The study was carried out by PhD students and faculty. We purchased multiple unlimited cellular data plans from one of the three major US carriers and our experiments comply with their customer agreements.

B Reproducibility Statement

The dataset and related processing scripts will be open-sourced upon acceptance of the paper.



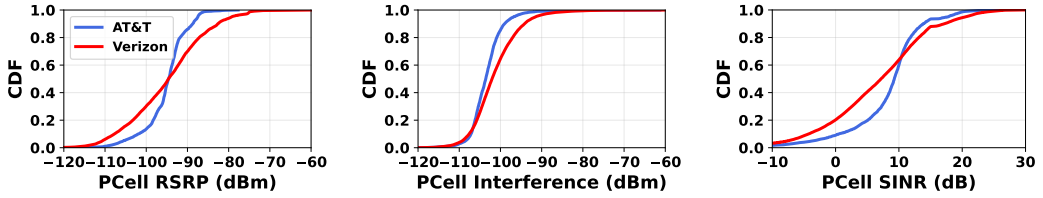
Fig. 14. Driving route.

C Driving Route

Fig. 14 shows the driving route from Los Angeles, CA to Boston, MA, passing through Las Vegas, NE, Salt Lake City, UT, Denver, CO, Omaha, NE, Chicago, IL, Indianapolis, IN, Columbus, OH, Cleveland, OH, Buffalo, NY.

D 5G mmWave User Performance

Fig. 15 plots the CDFs of mmWave RSRP, interference, and SINR. Figs. 16a-16c, 16d-16f plot MCS vs. SINR, throughput vs. SINR, and RB count vs. throughput (for SINR > 15 dB and MCS > 10) in the case of mmWave for AT&T and Verizon, respectively.



(a) RSRP (b) Interference (c) SINR

Fig. 15. CDFs of signal quality KPIs for 5G mmWave.

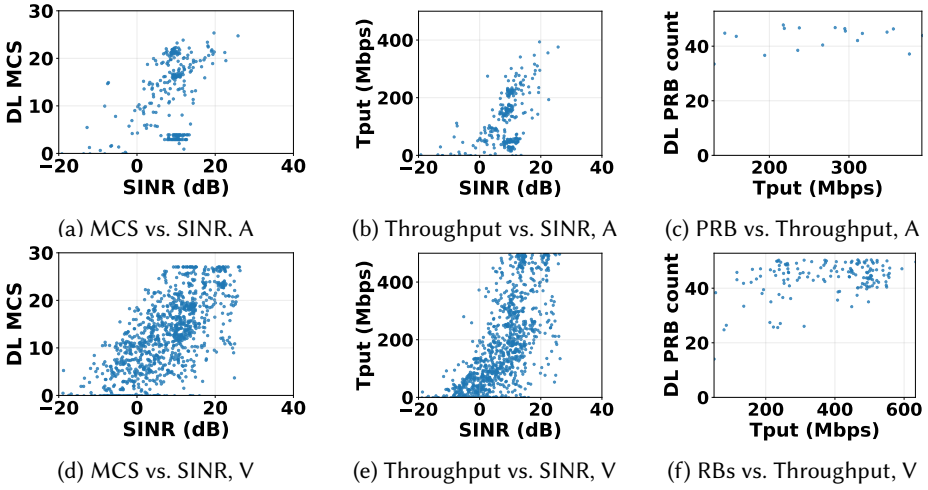


Fig. 16. MCS, throughput, ans RBs vs. SINR for mmWave: AT&T (top, A) and Verizon (bottom, V).

E Additional LTE Channel-Level Analysis Results

Figs. 17a, 17b, 17c, 17d plot the channel-level analysis results for AT&T's Band 2 and T-Mobile's Band 66.

AT&T Band 2

Freq.	f11	f3	f17	f4	f15	f9	f7
Cells	123	215	124	382	98	264	20
Interf.	1.17	1.20	1.26	1.27	1.29	1.43	1.70

T-Mobile Band 66

Freq.	f13	f3	f9	f17	f16	f12	f11
Cells	106	25	46	21	21	168	158
Interf.	0.82	0.88	1.11	1.35	1.57	1.65	1.72

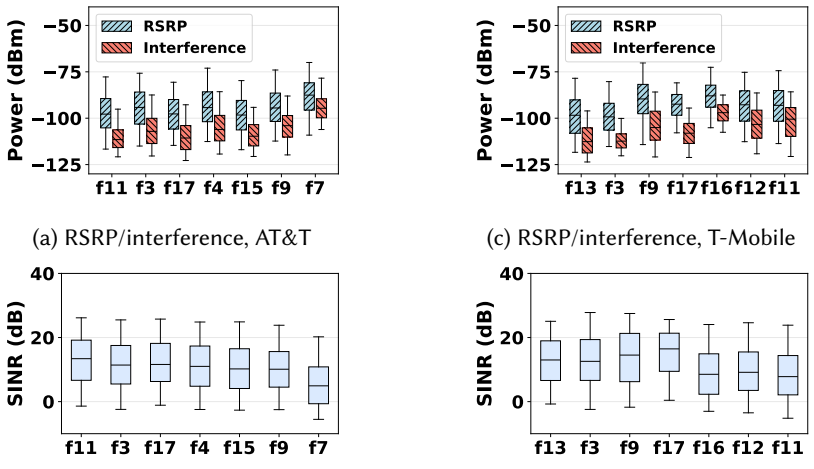


Fig. 17. LTE channel scaling across operators (AT&T Band 2, T-Mobile Band 66).

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