

ORIGINAL RESEARCH



Comparative performance characterization of 4G (LTE) and 5G NR network bands in a hilly rural region: a case study in North Thingdawl, Kolasib District, Mizoram, India

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Mobile network performance in rural hilly regions is often affected by terrain and environmental conditions. The present field study examines the comparative performance of 4G LTE and 5G New Radio (NR) networks in North Thingdawl, Kolasib District, Mizoram. Field measurements were conducted using iPhone devices in Field Test Mode and the Ookla Speedtest application. Data were collected across three terrain conditions, namely hilltop, slope, and valley, under different weather conditions including clear sky, cloudy sky, and rainfall. Key performance indicators including Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Signal-to-Interference-plus-Noise Ratio (SINR), download speed, upload speed, and latency were analyzed. Measured data indicate 5G NR provides substantially higher download throughput and lower latency compared to 4G LTE, with an average download throughput of 747.53 Mbps compared to 95.89 Mbps for 4G LTE. Although 5G provides superior throughput, its performance is more sensitive to terrain variations, particularly in valley regions where signal degradation is observed due to higher frequency propagation characteristics. In contrast, 4G LTE demonstrates more stable coverage under challenging terrain conditions. The findings highlight the impact of terrain and environmental conditions on mobile network performance in rural hilly regions and provide useful insights for future network planning and deployment.

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Introduction

Mobile communication has become essential for daily life, education, business, and emergency services.^{1,2} However, mobile network performance in many rural and hilly regions is often influenced by terrain characteristics and environmental conditions.^{3,4,5,6} Mizoram, which is characterized by mountainous landscapes, slopes, and valleys, presents a challenging environment for wireless signal propagation. Therefore, North Thingdawl in Kolasib District, Mizoram, was selected as the study area to investigate the impact of geographical conditions on mobile network performance.

One of the major factors affecting wireless communication in hilly regions is terrain obstruction. Mountains, slopes, and valleys can obstruct and attenuate radio signals, resulting in variations in

signal quality and network performance.^{5,6} In addition, environmental factors such as rainfall, humidity, and cloud cover also influence signal propagation characteristics.⁶ As a result, mobile network performance may vary considerably under different terrain and weather conditions.

With the introduction of 5G technology, higher throughput and lower latency are expected compared to 4G LTE.^{7,8,9,10,11} Despite these advantages, 5G systems often operate at higher frequency bands that are more susceptible to blockage and propagation loss, particularly in hilly and obstructed environments.^{12,13,14,15} Therefore, it is important to evaluate the effectiveness of 5G deployment in such geographical regions.

Several studies have investigated the performance of 4G LTE and 5G networks under different environmental conditions.^{16,17,18} Existing research indicates that 5G can achieve substantially higher throughput and lower latency due to advanced radio technologies and wider bandwidth availability. However, studies also report that 5G performance is highly sensitive to terrain obstruction, weather conditions, and propagation loss.^{13,14,15} Most existing studies focus primarily on urban or semi-urban environments, while limited research has been conducted in rural hilly regions such as Mizoram.

The current work presents a comparative performance analysis of 4G LTE and 5G New Radio (NR) networks using real field measurements collected under different terrain and weather conditions. Measurements were conducted across hilltop, slope, and valley regions, and key performance parameters including RSRP, RSRQ,

SINR, download throughput, upload throughput, and latency were analyzed.

The main objective of this study is to evaluate and compare the performance of 4G LTE and 5G NR networks in a rural hilly environment and to provide useful insights for improving mobile network planning and deployment in similar geographical regions.

Materials and Methods

The study was conducted in North Thingdawl, a rural village, located in Mizoram. This area has three types of terrain, viz., hilltops, slopes, and valleys, which considerably affect radio signal propagation. Due to the uneven terrain and natural obstructions, mobile network performance varies across locations.

The network infrastructure in the study area is



Figure 1. Apple map showing the measurement locations in North Thingdawl, Mizoram. (Source: Map data ©2025 Apple.)



Figure 2. Reliance Jio 4G LTE and 5G NR base station used for field measurements. (Source: Author's original photograph, field survey 2025)

Table 1. Terrain and measurement details

Terrain	Coordinates	Elevation (m)	Distance from tower (m)
Hilltop	24°10'01"N, 92°41'41"E	750	78.15
Slope	24°10'04"N, 92°41'51"E	700	221.96
Valley	24°10'06"N, 92°41'59"E	650	456.24

limited and is primarily provided by Reliance Jio. The deployment consists of one 5G NR standalone (SA) base station and two 4G LTE base stations operating in the region. All measurements were taken with reference to the base station located at coordinates 24°10'02" N, 92°41'44" E. Figure 1 shows the geographical locations of the measurement points, including hilltop, slope, and valley regions in North Thingdawl, Mizoram.

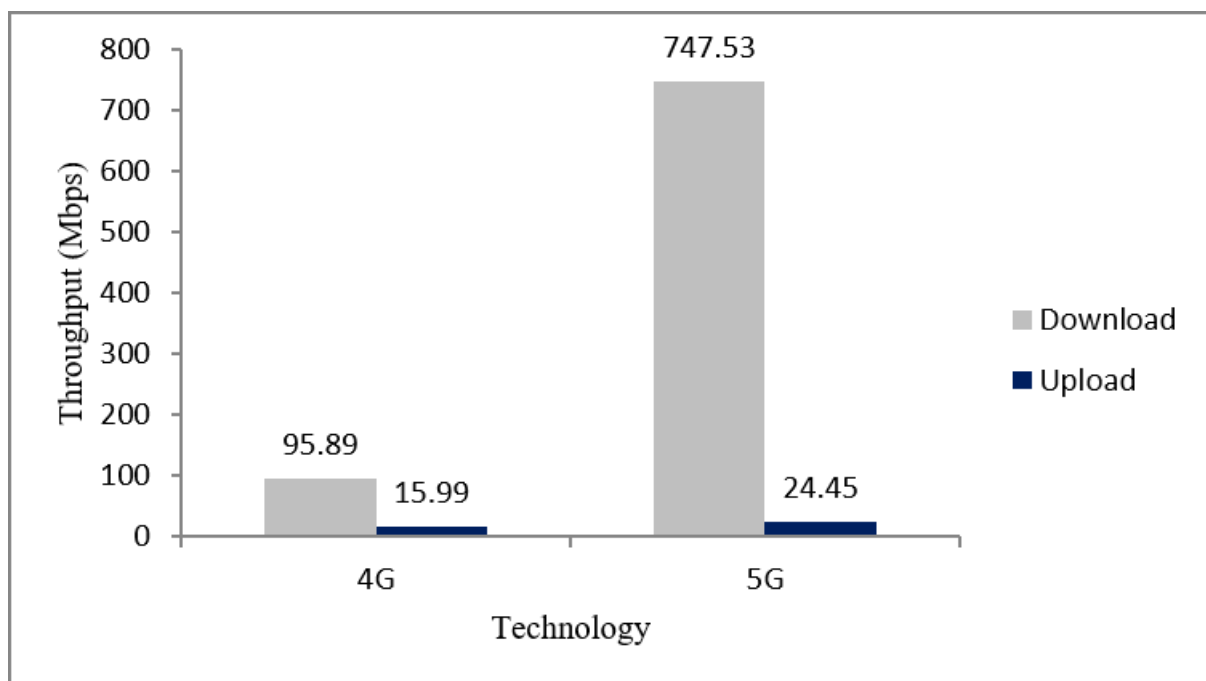
The mobile network infrastructure used during the field measurements is shown in Figure 2. Field measurements were carried out using iPhone 12 and iPhone 15 devices running iOS 26.1. Apple Field Test Mode (*3001#12345#*) was used to obtain radio parameters such as operating band, bandwidth, Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and Signal-to-Interference-plus-Noise Ratio (SINR). User-level performance metrics including download speed, upload speed, and latency were measured using the Ookla Speedtest application. The measurements were conducted on 4G LTE Band 40

and 5G NR Band n78.

To analyze the impact of terrain, measurements were collected at three different locations representing distinct geographical conditions. The details of these locations are presented in Table 1.

Signal quality was interpreted using standard threshold values where RSRP ≥ -80 dBm is considered good, -80 to -100 dBm is fair, and ≤ -100 dBm is poor. For RSRQ, threshold value ≥ -10 dB indicates good quality, -10 to -15 dB is fair, and ≤ -15 dB is poor. SINR values ≥ 20 dB are classified as good, 13 – 20 dB as fair, and ≤ 13 dB as poor. Latency ≤ 20 ms is considered excellent, 20 – 50 ms is acceptable, and ≥ 50 ms is poor.

Measurements were performed under different environmental conditions to evaluate the effect of weather on network performance. Data were collected during clear sky conditions with 61% humidity and 19 km visibility, cloudy conditions with 78% humidity and 11 km visibility, and heavy

**Figure 3.** Comparison of average downloads and upload throughput for 4G LTE and 5G NR.

rainfall conditions with 86% humidity, 44 mm precipitation over 24 hours, and 10 km visibility.

All measurements were conducted between 4:30 PM and 10:30 PM, with ambient temperatures ranging from 15°C to 30°C. For each terrain and weather condition, multiple readings (at least five) were recorded to ensure consistency and reliability. The final reported values represent the average of these readings, which helps to reduce the effect of random fluctuations in network performance.

The collected data were organized and processed using standard statistical methods. Average values were calculated for all measured parameters, and the results were presented using tables and figures.

Results

Overall Performance Comparison

The overall average performance shows a clear difference between 4G LTE and 5G NR. The average download throughput of 5G (747.53 Mbps) is substantially higher than that of 4G (95.89 Mbps), indicating substantial improvement in data performance. Similarly, 5G achieves lower average latency (20.33 ms) compared to 4G (45.18 ms), which improves real-time communication performance. As shown in Figure 3, 5G provides a clear advantage in both download and upload throughput.

Despite the throughput advantage, the average signal strength (RSRP) of 5G (−89.76 dBm) is weaker than that of 4G (−80.27 dBm). A similar trend is observed in SINR, where 5G (19.81 dB) is slightly lower than 4G (20.10 dB). This indicates that although 5G provides higher throughput, it is more sensitive to environmental and terrain conditions. This behavior is mainly caused by the higher frequency operation and propagation characteristics of 5G systems.^{13,14,15}

Terrain-wise Performance Analysis

The terrain-wise analysis reveals strong influence of geographical conditions on network performance. As shown in Figure 4, the hilltop location provides the best performance for both technologies due to clear line-of-sight conditions. At the hilltop, 5G achieves the highest average download throughput (811.67 Mbps) along with strong SINR performance (24.17 dB).

In contrast, the valley region shows reduced performance, especially for 5G NR. The average 5G SINR in the valley decreases to 17.05 dB, indicating that terrain obstruction and increased propagation loss considerably affect higher-frequency 5G signals. Although 5G still provides higher throughput than 4G LTE in the valley region, signal fluctuations are more noticeable due to the higher operating frequency band.

The slope region shows mixed behavior for both technologies. While 4G LTE demonstrates

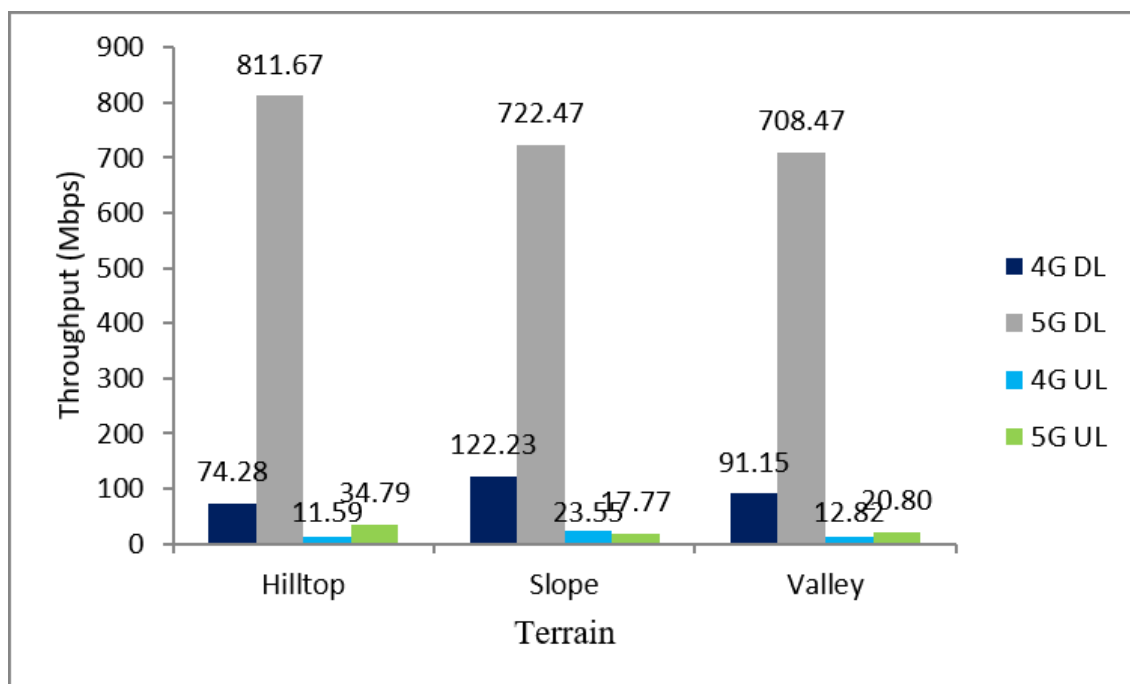


Figure 4. Terrain-wise comparison of download and upload throughput for 4G LTE and 5G NR

strong SINR performance (23.69 dB), 5G NR shows weaker signal strength with an average RSRP of -96.93 dBm. This behavior may be caused by partial terrain obstruction and signal reflection effects, which affect higher-frequency 5G signals more markedly.¹³

Overall, the results confirm that 5G performance is highly dependent on terrain conditions, whereas 4G LTE provides more stable coverage and signal quality in challenging hilly environments. The summary performance comparison across all terrains is presented in Table 2.

distribution of signal quality for 4G LTE and 5G NR under different terrain and weather conditions. The results show that 4G LTE exhibits a more compact distribution, indicating relatively stable signal quality across the measurement locations. In contrast, 5G NR demonstrates a wider distribution and greater variation in SINR values, reflecting higher sensitivity to terrain obstruction and environmental conditions.

Although 5G NR achieves higher throughput performance, its SINR values fluctuate more markedly compared to 4G LTE. The observed variations are mainly caused by increased

Table 2. Summary performance comparison of 4G LTE and 5G NR across terrains

Technology	Terrain	Avg RSRP (dBm)	Avg SINR (dB)	Avg DL (Mbps)	Avg UL (Mbps)	Avg Latency (ms)
4G LTE	Hilltop	-78.53	18.13	74.28	11.59	42.40
	Slope	-77.73	23.69	122.23	23.55	48.60
	Valley	-84.80	18.45	91.15	12.82	44.53
	Average	-80.27	20.10	95.89	15.99	45.18
5G NR	Hilltop	-83.53	24.17	811.67	34.79	19.20
	Slope	-96.93	18.22	722.47	17.77	19.73
	Valley	-88.80	17.05	708.47	20.80	22.07
	Average	-89.76	19.81	747.53	24.45	20.33

Latency Performance

Latency measurements indicate that 5G provides considerably lower delay compared to 4G across all terrains. The average latency of 5G ranges between 19–21 ms, whereas 4G latency varies from 41–49 ms. As shown in Table 2, 5G consistently achieves lower latency, making it more suitable for real-time applications such as video streaming and online communication.

SINR Distribution Analysis

The SINR boxplot (Figure 5) illustrates the

propagation loss, blockage, and signal reflection effects at higher frequency bands. This behavior explains why 5G NR provides superior peak throughput while showing reduced signal consistency in challenging hilly terrains such as slope and valley regions.

Performance Gain Analysis

The performance gain of 5G over 4G varies considerably across terrains. At the hilltop location, 5G delivers download speed improvements exceeding 1000% under clear and cloudy conditions, with latency reduction of approximately

Table 4. Terrain-wise performance gain of 5G over 4G (average)

Terrain	DL Speed Gain	UL Speed Gain	Latency Reduction	SINR Change
Hilltop	+993%	+200%	-54%	+33%
Slope	+491%	-25%	-59%	-23%
Valley	+677%	+62%	-50%	-8%

50%. However, in slope and valley regions, the gain is relatively lower, and SINR performance sometimes degrades due to terrain-induced signal attenuation. The overall 5G performance gain across terrains is summarized in Table 3.

Impact of Weather Conditions

Weather conditions can influence wireless signal propagation and network performance.^{6,13,18} In some cases, variations in throughput and SINR are observed between clear, cloudy, and rainy

compared to 4G LTE (45.18 ms), which enhances real-time communication performance. This latency reduction of approximately 55% is critical for emerging applications such as autonomous vehicles, remote surgery, and real-time gaming.

Third, 4G LTE exhibits more stable signal strength and SINR across different terrains, indicating better robustness in challenging environments. The narrower distribution of 4G SINR values confirms its resilience to terrain variations, which is consistent with its lower frequency operation and better propagation characteristics.

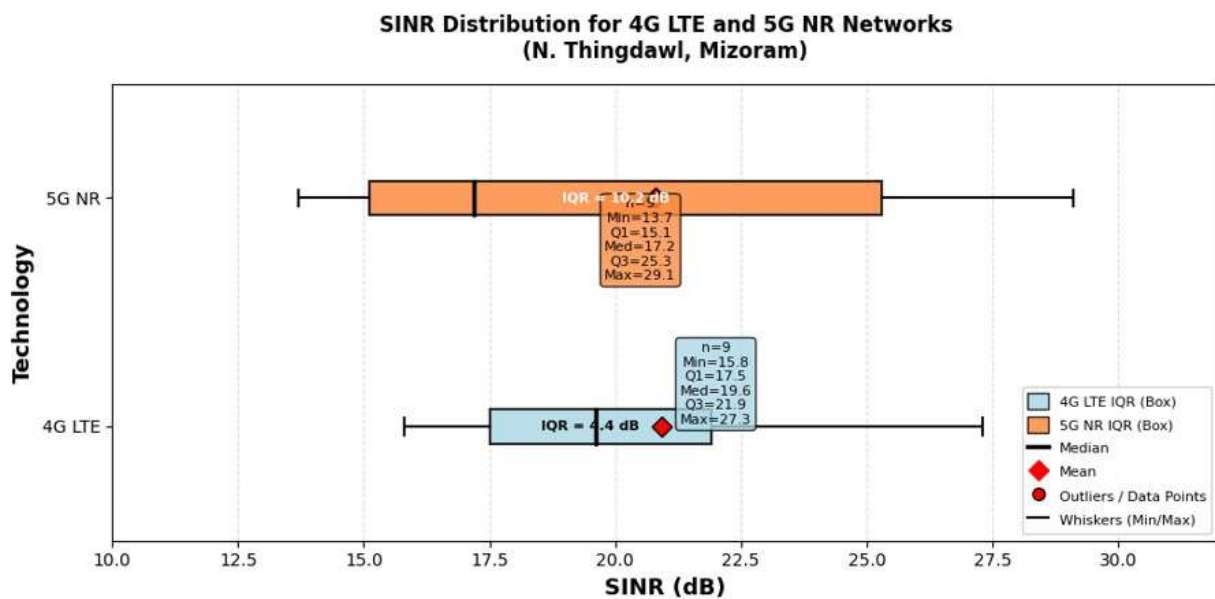


Figure 5. Boxplot of SINR distribution for 4G LTE and 5G NR

conditions. However, these variations are not always consistent, indicating that factors such as network load, interference, and scheduling also play a considerable role. Overall, the results indicate that terrain conditions have stronger influence on network performance than weather variations in the studied rural hilly environment.

Discussion

The results of this study highlight several important findings. First, 5G provides substantially higher download throughput compared to 4G LTE, demonstrating its capability to support high data rate applications. The average download throughput of 747.53 Mbps for 5G represents approximately an 8-fold improvement over 4G LTE. This substantial gain is attributed to the larger bandwidth (100 MHz versus 40 MHz) and advanced radio technologies employed in 5G networks.

Second, 5G achieves lower latency (20.33 ms)

Fourth, terrain has a strong impact on network performance, particularly for 5G, where valley regions experience notable signal degradation due to obstruction and increased path loss. At the hilltop location, 5G achieves its best performance with SINR of 24.17 dB and download throughput of 811.67 Mbps. However, in the valley region, SINR drops to 17.05 dB, representing a 29% degradation. This confirms the higher sensitivity of 5G to terrain conditions due to its higher frequency operation.

Fifth, 5G performance demonstrates higher variability under changing environmental conditions, whereas 4G remains relatively consistent. The broader interquartile range of 5G SINR (10.20 dB) compared to 4G (4.38 dB) confirms this observation.

The practical implications of this study are significant for network operators and policymakers. In rural hilly regions, the deployment of 5G infrastructure requires careful consideration of terrain characteristics. The results suggest that while 5G can provide substantial performance

benefits, its effectiveness depends on proper base station placement and density. Increasing the number of base stations and optimizing their placement can improve coverage and reduce signal degradation in valley and slope regions. A hybrid approach combining 4G LTE coverage and 5G capacity may be optimal for ensuring reliable connectivity across different terrains.

Conclusion

This study presents a comparative performance analysis of 4G LTE and 5G NR networks in a rural hilly environment based on field measurements conducted in Mizoram. The results demonstrate that 5G NR substantially outperforms 4G LTE in terms of download throughput and latency. The average 5G download throughput reaches 747.53 Mbps, compared to 95.89 Mbps for 4G LTE, while also maintaining lower latency of 20.33 ms versus 45.18 ms.

Despite these advantages, the findings show that 5G performance is more sensitive to terrain conditions, particularly in valley regions where signal degradation occurs due to obstruction and higher propagation loss. In comparison, 4G LTE provides a more stable signal quality and consistent performance across different terrains, indicating better robustness in challenging geographical environments.

The study also shows that environmental factors such as weather conditions and network load can influence network performance, although their impact is less considerable compared to terrain effects. Overall, while 5G offers major improvements in speed and latency, its effectiveness in rural hilly regions depends on proper network planning and infrastructure deployment.

Future work may include additional measurement locations, different frequency bands, and longer observation periods to further validate the findings. Future studies may also investigate mobility-based measurements under different traffic conditions. In addition, advanced propagation models and machine learning techniques can be explored for network optimization in rural hilly environments.

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Conflict of Interest

The author declares no conflict of interest. The focus and outcome of this paper are not restricted or regulated by any funding agency or institute.

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