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Original Article

Shannon Capacity Analysis for 4G LTE Networks in Makassar Industrial Estate Based on Optimized Measurements and SINR Evaluation

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ABSTRACT

This work investigates the difference between theoretical LTE channel capacity and throughput measured in the Makassar Industrial Estate. Drive tests were conducted during four time periods, including morning, afternoon, evening, and night, along routes that pass warehouses, manufacturing facilities, and other large structures. At each measurement point, RSRP, RSRQ, RSSI, SINR, modulation scheme, and downlink throughput were recorded. SINR values were converted from decibels to linear scale and inserted into the Shannon formula using a channel bandwidth of 20 MHz. Morning measurements produced Shannon capacity estimates between 10.51 Mbps and 75.20 Mbps. Locations with nearly identical RSRP frequently yielded very different capacity values because of differences in SINR. Across all four periods the calculated Shannon capacity was higher than the measured throughput at most observation points, one afternoon sample (SINR = 7 dB) recorded a throughput of 89.47 Mbps that exceeded the corresponding Shannon estimate of 51.80 Mbps, an anomaly that may reflect carrier aggregation, measurement-window mismatch, or scheduling effects. The results indicate that interference and resource-allocation behavior, rather than received power alone, largely determine the practical data rate observed in this industrial setting.

KEYWORDS

Shannon Capacity, 4G LTE, SINR, Drive Test Measurement, Network Performance Evaluation.

1. INTRODUCTION

Digital services, industrial automation, and Internet-connected devices are expanding rapidly. This growth creates steady demand for wireless networks that are both reliable and capable of carrying large volumes of data. Cities and industrial zones in particular need networks that can support many active connections at once while also handling monitoring tasks and data-intensive applications. Makassar serves as a key economic hub in eastern Indonesia. Commercial activities, services, and industrial development continue to expand across the region. Reliable mobile broadband infrastructure becomes increasingly necessary to sustain that growth. The availability of reliable mobile networks has therefore become an important factor in supporting digital transformation and operational efficiency across various sectors (Razak et al., 2020).

Although fourth-generation (4G) LTE networks have been widely deployed, achieving consistent capacity remains challenging, particularly in environments with complex propagation characteristics. Industrial and semi-urban environments may introduce additional propagation impairments due to building structures, metallic surfaces, obstruction, and interference sources. These factors influence key radio parameters such as received signal strength, signal quality, and signal-to-interference-plus-noise ratio (SINR), which directly affect achievable data rates. In this study, the measurement area is located in the Makassar Industrial Estate, South Sulawesi, Indonesia. This area represents an industrial environment characterized by industrial facilities, built structures, and potential radio propagation challenges that may affect LTE network performance. Therefore, evaluating network performance based only on coverage indicators is insufficient to understand the actual capacity limitation of cellular systems (Palinggi & Aan Saputra, 2020).

Shannon defined a clear baseline for channel limits. Engineers use this concept to calculate the absolute maximum data speed possible under specific bandwidth and signal constraints. Within cellular systems, this theoretical ceiling serves as a theoretical benchmark to see how closely real-world performance matches ideal capability (Kang et al., 2021; Putra et al., 2018; Saragih et al., 2022; Zhang et al., 2013). Past wireless research frequently references this approach. Yet, most of those works depend heavily on simulated computer models rather than real field measurements. Looking at comparison between theoretical capacity and measured throughput gives a clearer picture of what operational cellular networks can achieve and the factors limiting practical performance.

Existing LTE performance studies commonly evaluate network quality using parameters such as RSRP, RSRQ, SINR, and throughput (Belo, 2021). Still, the link between measured radio conditions and theoretical capacity in real settings particularly where reliable industrial connectivity is critical remains understudied. A quantitative analysis of the capacity gap between Shannon theoretical limits and actual throughput can provide a deeper understanding of whether performance degradation is primarily caused by insufficient signal quality, interference, or other network constraints (Andrews et al., 2014).

This work investigates the Shannon capacity behavior of an active 4G network through real drive test data and signal quality assessments. Standard coverage checks usually focus only on signal strength. Instead, this research links actual radio measurements directly to theoretical capacity limits. The study achieves three main objectives (Karo Karo et al., 2020; Sun et al., 2024). It assesses LTE Shannon capacity using genuine field metrics. It analyzes how signal variations alter both theoretical limits and real throughput. It also quantifies the performance gap between mathematical models and practical network behavior under harsh propagation conditions.

The remainder of this paper is organized as follows. Section II presents related works on LTE performance evaluation, SINR-based capacity analysis, and Shannon capacity estimation. Section III describes the measurement methodology, data acquisition process, and capacity calculation approach. Section IV discusses the obtained measurement results and analyzes the relationship between radio parameters, Shannon capacity, and throughput performance. Finally, Section V concludes the findings and discusses possible directions for future research.

2. *METHODS OF RESEARCH*

2.1. Research Method and Measurement Procedure

This research relies on real field data to test how far 4G LTE networks can push their theoretical limits when signals face tough obstacles (Andrews et al., 2014; Ghosh et al., 2010; Khan et al., 2022). The workflow merges drive test logs with radio metric studies and Shannon capacity math. Standard evaluations usually stop at basic coverage maps. Instead, this paper digs deeper into how measured signal quality links directly to the highest data speeds a channel can actually handle (Farida & Yunianto, 2020; Mogensen et al., 2007; Ramadhan et al., 2025).

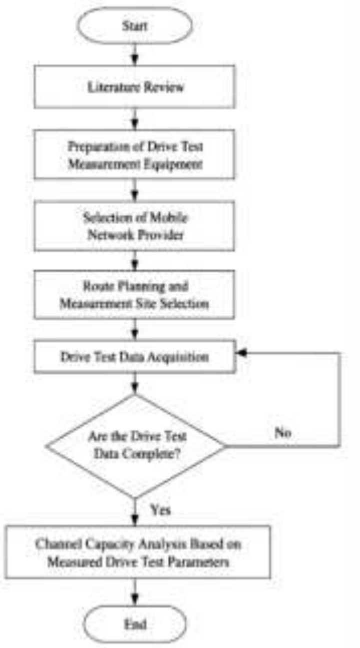

Fig. 1 - Flowchart of Research Methodology for LTE Shannon Capacity Analysis Based on Drive Test Measurements

The overall research procedure is illustrated in Fig. 1. The research begins with a literature review to establish the theoretical foundation related to LTE performance evaluation, SINR analysis, and Shannon channel capacity. Subsequently, measurement preparation is conducted by configuring the required drive test equipment and selecting the mobile network provider used during the measurement process.

After the preparation stage, measurement routes and survey locations are determined to ensure representative data collection. The drive test process is then performed to obtain real network performance parameters. The collected data are evaluated through a completeness verification stage. If the measurement data are insufficient or contain missing information, the data acquisition process is repeated. Once the dataset is considered complete, the measured parameters are processed for capacity analysis (Kang et al., 2021; Palinggi & Aan Saputra, 2020; Putra et al., 2018; Saragih et al., 2022).

The final stage involves analyzing the channel capacity based on the parameters obtained from field measurements. The calculated Shannon capacity is then compared with measured network performance indicators to evaluate the relationship between theoretical capacity limits and practical LTE performance.

2.2. Drive Test Data Acquisition

The measurement dataset used in this study was obtained through a drive test approach to capture actual LTE network conditions experienced by mobile users. The drive test measurement was conducted in the Makassar Industrial Estate area, South Sulawesi, Indonesia. The selected area represents an industrial propagation environment where buildings, infrastructure, and surrounding communication activities may influence LTE signal quality and interference characteristics. Drive testing is widely used in cellular network evaluation because it provides direct measurements of radio performance parameters along predefined routes.

Four measurement sessions were conducted: morning (approximately 10:00–11:00), afternoon (14:00–16:00), evening (17:00–19:00) and night (20:00–22:00). The temporal spread allows comparison of capacity behavior under different network-load conditions.

During the measurement process, several LTE radio parameters were collected, including Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Signal-to-Interference-plus-Noise Ratio (SINR), and throughput. These parameters represent different aspects of network performance, where RSRP indicates received signal strength, RSRQ represents signal quality, SINR reflects interference conditions, and throughput describes the practical data transmission performance.

The measurement data were obtained from a mobile LTE network operating in the investigated area. Although the analysis is motivated by the requirements of industrial and high-demand communication environments, the dataset represents actual field propagation conditions and is analyzed to evaluate the capacity behavior of LTE networks under realistic radio conditions.

2.3. Analysis of Shannon Capacity

The measured radio parameters are analyzed to determine their influence on the theoretical capacity of the LTE channel. Among the measured parameters, SINR is considered the primary parameter because it directly represents the relationship between useful received power and interference-plus-noise components.

The theoretical maximum channel capacity is calculated using Shannon's capacity equation (Nur Halisa H et al., 2022):

$$C = B \ \log_2(1 + SINR) \qquad (1)$$

where C represents the theoretical channel capacity in bits per second, B denotes the available bandwidth, and SINR represents the signal-to-interference-plus-noise ratio in linear scale. The bandwidth parameter used in Shannon capacity calculation was set according to the LTE channel bandwidth configuration during measurement.

Before applying the Shannon equation, SINR values measured in decibel units are converted into linear scale using (Nur Halisa H et al., 2022):

$$SINR_{linear} = 10^{\frac{SINR\,(dB)}{10}} \qquad (2)$$

The calculated Shannon capacity represents the ideal upper bound of data transmission under the measured radio conditions. To evaluate practical network performance, the theoretical capacity is compared with measured throughput obtained during the drive test. The difference between Shannon capacity and actual throughput is analyzed as the capacity gap, which indicates the impact of practical network limitations such as scheduling, protocol overhead, and radio resource management.

2.4. Capacity Gap Analysis

To quantify the difference between theoretical and practical network performance, the capacity gap is evaluated using:

$$G = \left[\frac{(C_{Shannon} - T_{Measured})}{C_{Shannon}}\right] x100\% \qquad (3)$$

where G represents the percentage gap between theoretical capacity and measured throughput.

A larger capacity gap indicates that the practical LTE network operates further from its theoretical limit, which may be influenced by interference, scheduling efficiency, channel variability, or implementation constraints.

Ultimately, connecting raw field metrics to theoretical limits relies entirely on proper scale conversion. Translating decibel figures into linear values enables the Shannon equation to process live signal conditions accurately. This established baseline creates the required foundation for tracking system constraints and evaluating real-world efficiency

3. RESULT AND DISCUSSION

3.1. LTE Radio Measurement Results

The drive test measurement results provide an overview of the LTE network performance under real propagation conditions. Four measurement periods were analyzed to observe the variation of radio parameters and their influence on theoretical channel capacity. The evaluated parameters include RSRP, RSSI, RSRQ, SINR, modulation scheme, measured throughput, and calculated Shannon capacity.

The analysis focuses not only on signal availability but also on the relationship between signal quality and achievable capacity. Although high received signal strength generally indicates better coverage conditions, the achievable throughput is strongly influenced by interference conditions represented by SINR.

3.2. Shannon Capacity and Throughput Performance Analysis

Comparing Shannon capacity against measured throughput shows a persistent gap across all observation periods. In general, the theoretical Shannon capacity is higher than the measured throughput because Shannon theory assumes an ideal communication channel without considering practical network limitations.

SINR emerges as the strongest predictor of theoretical capacity. Higher SINR values increase the achievable capacity because the channel can support higher spectral efficiency. Conversely, low SINR conditions caused by interference and propagation impairments reduce the theoretical capacity limit.

This finding suggests that network optimization must go beyond boosting signal strength. Reducing interference and improving signal quality are equally critical.

3.3. Capacity Gap Analysis

To further evaluate LTE efficiency, the difference between theoretical Shannon capacity and measured throughput is analyzed. The capacity gap represents the unused theoretical capacity caused by practical system limitations.

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$$Capasity\ Gap\ (\%) = \left[\frac{(C_{Shannon} - T_{Actual})}{C_{Shannon}}\right] x100\% \quad (4)$$

Real world measurements tell a clear story. Cellular networks routinely fall short of their mathematical ideals when handling actual traffic in the field. When this disparity widens, it proves that variables like background interference, dynamic block scheduling, and sudden channel changes dictate real data speeds far more than raw signal presence alone.

Table 1: LTE Radio Performance and Shannon Capacity Estimation During Morning Measurement

Time	RSRP (dBm)	RSSI (dBm)	RSRQ (dB)	SINR (dB)	Interference and Noise Calculation (dBm)	Modulation Scheme	Throughput (Mbps)	Shannon Capacity (Mbps)
10:14:44	-89 Normal	-61 Excellent	-8 Excellent	4 Normal	-93	QPSK	5.85 Normal	36.20
10:17:40	-81 Normal	-52 Excellent	-10 Good	2 Normal	-83	QPSK	0.127 Poor	27.64
10:18:43	-86 Normal	-58 Excellent	-9 Excellent	1 Normal	-87	QPSK	0.265 Poor	23.16
10:20:45	-79 Good	-47 Excellent	-10 Good	3 Normal	-82	16 QAM	1.071 Bad	32.08
10:22:47	-86 Normal	-55 Excellent	-10 Good	4 Normal	-90	QPSK	0.174 Poor	36.20
10:24:49	-85 Normal	-53 Excellent	-11 Good	11 Good	-96	QPSK	0.262 Poor	75.20
10:26:51	-87 Normal	-57 Excellent	-10 Good	4 Normal	-91	QPSK	0.108 Poor	36.20
10:29:53	-84 Normal	-48 Excellent	-19 Normal	-8 Poor	-76	64 QAM	0.158 Poor	10.51
10:31:55	-90 Normal	-54 Excellent	-16 Normal	-8 Poor	-82	QPSK	0.365 Bad	10.51
10:34:57	-95 Bad	-55 Excellent	-17 Normal	-4 Poor	-91	QPSK	3.785 Normal	13.43

Table 2: LTE Radio Performance and Shannon Capacity Estimation During Afternoon Measurement

Time	RSRP (dBm)	RSSI (dBm)	RSRQ (dB)	SINR (dB)	Interference and Noise Calculation (dBm)	Modulation Scheme	Throughput (Mbps)	Shannon Capacity (Mbps)
14:41:42	-93 Bad	-55 Excellent	-18 Normal	11 Good	-104	QPSK	0.198 Poor	75.20
14:48:41	-86 Normal	-55 Excellent	-11 Good	15 Good	-101	QPSK	4.536 Normal	100.60
14:53:30	-98 Bad	-69 Excellent	-8 Excellent	7 Normal	-105	QPSK	89.474 Excellent	51.80
14:59:31	-91 Bad	-59 Excellent	-12 Good	4 Normal	-95	16 QAM	2.212 Normal	36.20
15:03:02	-90 Normal	-57 Excellent	-12 Good	13 Good	-103	QPSK	0.138 Poor	87.80
15:12:49	-88 Normal	-53 Excellent	-12 Good	19 Good	-107	QPSK	5.083 Normal	126.60
15:31:52	-88 Normal	-55 Excellent	-12 Good	16 Good	-104	QPSK	0.123 Poor	107.00
15:41:52	-82 Normal	-51 Excellent	-9 Excellent	5 Normal	-87	64 QAM	0.611 Bad	41.20
15:50:27	-89 Normal	-57 Excellent	-11 Good	8 Normal	-97	QPSK	24.122 Excellent	57.40
15:53:02	-80 Good	-51 Excellent	-9 Excellent	14 Good	-94	QPSK	0.919 Bad	94.20

Table 3: LTE Radio Performance and Shannon Capacity Estimation During Evening Measurement

Time	RSRP (dBm)	RSSI (dBm)	RSRQ (dB)	SINR (dB)	Interference and Noise Calculation (dBm)	Modulation Scheme	Throughput (Mbps)	Shannon Capacity (Mbps)
17:43:06	-89 Normal	-53 Excellent	-15 Normal	11 Good	-100	QPSK	0.049 Poor	75.20

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17:48:00	-87 Normal	-53 Excellent	-13 Good	12 Good	-99	QPSK	0.035 Poor	82.35
17:51:11	-94 Bad	-63 Excellent	-9 Excellent	5 Normal	-99	QPSK	0.042 Poor	41.20
17:56:02	-85 Normal	-53 Excellent	-12 Good	-2 Poor	-83	16 QAM	0.027 Poor	14.08
18:03:00	-87 Normal	-53 Excellent	-14 Good	9 Normal	-96	QPSK	6.309 Normal	63.43
18:08:39	-80 Good	-51 Excellent	-7 Excellent	20 Excellent	-100	QPSK	5.087 Normal	133.00
18:14:01	-86 Normal	-57 Excellent	-7 Excellent	12 Good	-98	QPSK	1.07 Bad	82.35
18:17:39	-85 Normal	-55 Excellent	-8 Excellent	13 Good	-98	64 QAM	0.021 Poor	87.80
18:26:53	-86 Normal	-55 Excellent	-9 Excellent	6 Normal	-92	QPSK	0.412 Poor	46.33
18:30:40	-79 Good	-51 Excellent	-6 Excellent	17 Good	-96	QPSK	0.211 Poor	114.73

Table 4: LTE Radio Performance and Shannon Capacity Estimation During Night Measurement

Time	RSRP (dBm)	RSSI (dBm)	RSRQ (dB)	SINR (dB)	Interference and Noise Calculation (dBm)	Modulation Scheme	Throughput (Mbps)	Shannon Capacity (Mbps)
20:44:46	-92 Bad	-55 Excellent	-15 Normal	8 Normal	-100	QPSK	0.146 Poor	57.40
20:54:25	-88 Normal	-57 Excellent	-9 Excellent	12 Good	-100	QPSK	0.146 Poor	82.35
21:02:17	-94 Bad	-55 Excellent	-16 Normal	10 Good	-104	QPSK	0.236 Poor	66.44
21:06:19	-80 Good	-51 Excellent	-14 Good	-3 Poor	-77	16 QAM	0.133 Poor	10.00

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21:16:22	-83 Normal	-55 Excellent	-7 Excellent	6 Normal	-89	QPSK	0.135 Poor	46.33
21:22:04	-84 Normal	-55 Excellent	-7 Excellent	24 Excellent	-108	QPSK	0.118 Poor	156.40
21:31:09	-88 Normal	-59 Excellent	-7 Excellent	17 Good	-105	QPSK	0.160 Poor	114.73
21:36:23	-86 Normal	-55 Excellent	-8 Excellent	7 Normal	-93	64 QAM	0.140 Poor	57.40
21:40:14	-89 Normal	-57 Excellent	-10 Good	8 Normal	-97	QPSK	0.363 Bad	57.40
21:50:55	-71 Good	-51 Excellent	-8 Excellent	19 Good	-90	QPSK	0.122 Poor	126.60

Table 1, morning test results display shifting LTE performance while signal strength remains steady. RSRP metrics show that coverage stays solid across the route. Yet, changing SINR levels lead to distinct variations in capacity.

The calculated Shannon capacity ranges from approximately 10.51 Mbps to 75.20 Mbps, while the measured throughput remains significantly lower than the theoretical capacity limit. This difference indicates that the channel capacity predicted by Shannon theory represents an ideal upper bound, whereas practical LTE performance is affected by interference, scheduling mechanisms, and network implementation factors.

The results also demonstrate that SINR provides a stronger indication of achievable capacity compared with received signal strength alone. Locations with comparable RSRP values may experience different throughput performance due to different interference conditions.

Table 2 shows wider performance shifts during the afternoon test runs. These afternoon numbers vary much more than the earlier morning data. Shifting signal quality points to unstable interference patterns. These variations may be associated with changes in network load, interference conditions, and environmental factors.

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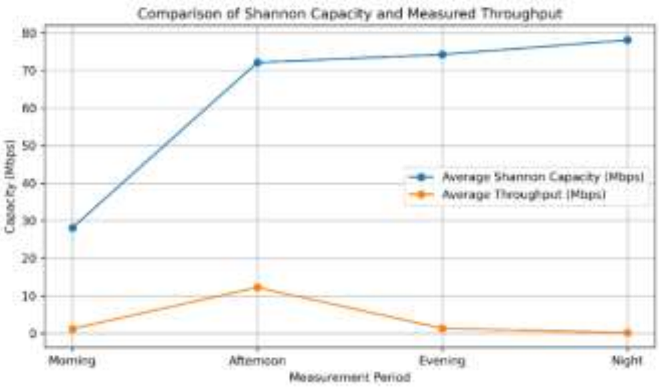

Fig. 2 - Comparison of Shannon Capacity and Measured Throughput During Different Measurement Periods

Several measurement points demonstrate relatively high Shannon capacity values; however, the corresponding throughput remains below the theoretical limit. This finding confirms that improving signal quality alone does not guarantee proportional throughput improvement because practical LTE systems are constrained by radio resource allocation, modulation efficiency, and interference management. The afternoon results emphasize the importance of considering both signal strength and signal quality when evaluating network capacity.

The recorded throughput of 89.47 Mbps exceeds the theoretical Shannon limit of 51.80 Mbps at one observation point. This anomaly indicates the activation of multiplexing technology or spectrum aggregation that the basic single Shannon equation fails to accommodate. The capacity formula applied in this analysis assumes a simple transmission model with one spatial stream operating over a fixed 20 MHz frequency band. Real cellular network conditions allow test hardware and base stations to run multiple antenna features. This configuration multiplies the data transmission streams spatially. Carrier aggregation mechanisms can also activate instantly to combine several frequency bands when the system detects high traffic demand. This spatial expansion and additional spectrum allocation mathematically raise the upper bound of the channel capacity beyond conventional calculation limits. The data deviation provides empirical evidence that advanced network features in modern LTE architectures can boost actual bit rates even when the device experiences a relatively low signal-to-interference ratio.

Table 3 captures the evening test runs. The gap between mathematical limits and real speed stretches out much further during this time. Certain spots still maintain healthy signal strength and quality readings. Even so, dropping signal-to-interference-plus-noise levels pull down the total channel capacity.

This condition highlights the impact of interference on LTE performance. In practical cellular networks, a strong received signal does not necessarily represent an efficient communication channel because interference can significantly reduce spectral efficiency. The Shannon capacity analysis provides additional insight by showing the maximum theoretical performance that could be achieved if channel conditions were ideal.

Table 4 outlines the night measurement logs. The gap between theoretical limits and actual speed grows even larger at this hour. While a few spots keep solid signal strength and quality numbers, weaker signal conditions pull down the final channel capacity.

This condition highlights the impact of interference on LTE performance. In practical cellular networks, a strong received signal does not necessarily represent an efficient communication channel because interference can significantly reduce spectral efficiency.

The Shannon capacity analysis provides additional insight by showing the maximum theoretical performance that could be achieved if channel conditions were ideal.

Figure 2 illustrates the comparison between average Shannon capacity and measured throughput during four different measurement periods. The results show that the theoretical Shannon capacity consistently exceeds the measured throughput in all periods. This difference indicates the presence of a capacity gap between the ideal channel limit and the practical LTE performance. Although the channel theoretically supports higher data rates, the achievable throughput is constrained by practical network factors, including interference, resource allocation mechanisms, channel variability, and protocol overhead.

The largest difference between Shannon capacity and measured throughput is observed during the evening and night periods, where relatively high theoretical capacity values are not directly translated into higher user throughput. This condition indicates that sufficient signal availability does not always guarantee efficient data transmission, because interference conditions and network resource utilization significantly affect practical performance.

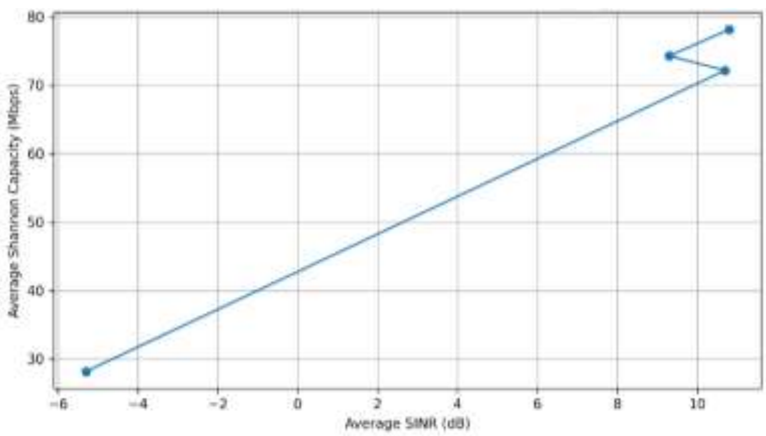

Fig 3 - Relationship Between SINR and Shannon Capacity

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Figure 3 illustrates the relationship between average SINR and Shannon capacity. The results show that higher SINR values generally produce higher Shannon capacity because improved signal quality increases the theoretical spectral efficiency of the LTE channel. This relationship confirms that SINR is one of the dominant parameters affecting theoretical capacity estimation.

4. CONCLUSION

This study evaluates the Shannon capacity characteristics of a 4G LTE network based on drive test measurements and SINR analysis under realistic propagation conditions. The theoretical Shannon capacity exceeded the measured throughput at most measurement points, indicating a substantial gap between ideal channel capacity and practical LTE performance. One anomalous afternoon measurement produced throughput above the single-channel Shannon estimate and requires further investigation.

The analysis confirms that SINR is a critical parameter influencing theoretical capacity estimation because variations in signal quality directly affect the achievable spectral efficiency. Although several measurement points show relatively high Shannon capacity values, the measured throughput remains limited due to practical network constraints, including interference conditions, resource allocation mechanisms, and channel variability.

The findings indicate that LTE network performance evaluation should consider not only signal strength indicators but also the relationship between signal quality and theoretical capacity limitations. The proposed analysis approach provides additional insight into understanding the factors affecting the difference between theoretical channel capability and real network performance.

Future studies may extend this work by incorporating additional measurement locations, wider bandwidth configurations, and more detailed analysis of network-level parameters to further investigate capacity optimization strategies for high-demand communication environments.

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