# Shannon Capacity Analysis of a 4G Network at Site UPD104 Racing Center

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***Abstract— This study analyzes the Shannon channel capacity of a 4G network at Site UPD104 Racing Center, Makassar, and compares it against the network's actual delivered throughput. Channel capacity was evaluated using the Drive Test method in dedicated mode, measuring radio and data-transfer parameters in real time during simultaneous download and upload sessions with a Samsung Galaxy Note 5 running TEMS Pocket, analyzed in TEMS Investigation 23.1. The parameters examined were RSSI, RSRP, RSRQ, SINR, the modulation scheme selected by the network, actual throughput, and the theoretical Shannon capacity computed from the measured SINR and a 20 MHz channel bandwidth on the 1800 MHz band. Results show RSSI, RSRP, and RSRQ were consistently Excellent to Good, with RSSI 100% Excellent (-80 to -40 dBm), RSRP 52.7% Excellent, and RSRQ 63.0% Excellent, while SINR was more variable, split mainly between Good (57.5%) and Normal (34.3%), indicating residual interference. These SINR levels, combined with adaptive modulation reaching 64-QAM, correspond to theoretical Shannon capacities of roughly 70 to 107 Mbps at individual measurement points. However, the measured throughput for both download and upload sessions was entirely in the Poor category (100% below 324 kbps), revealing a very large gap between theoretical channel capacity and actual delivered performance. This gap indicates that the radio link itself is not the limiting factor, and that the effective capacity utilization of the network is constrained by factors beyond the radio interface, such as backhaul capacity or network congestion, warranting further investigation of the transport network.***

***Keywords— 4G LTE; Shannon Capacity; Drive Test; SINR; Modulation Scheme; Throughput***

## I. Introduction

The rapid advancement of telecommunication technology has driven growing demand for reliable, high-capacity internet service. Fourth-generation (4G) mobile networks address this need by offering high data rates, low latency, and large capacity for a wide range of modern internet-based services. Built on an all-IP architecture, 4G provides faster and more stable connectivity than previous generations, supporting both personal and business digital activities.

A central theoretical question in evaluating any wireless link is how much data it can actually carry. Claude Shannon's channel capacity theorem [1] provides the fundamental upper bound on the error-free data rate that a communication channel can support, given its bandwidth and signal-to-interference-plus-noise ratio (SINR). In an operational 4G network, however, the network additionally applies adaptive modulation and coding to trade data rate against robustness, so the modulation scheme actually selected, and the throughput actually delivered to the user, may fall well short of the theoretical Shannon capacity implied by the radio conditions; Mogensen et al. [2] showed that LTE's achievable spectral efficiency consistently trails the Shannon bound once realistic link-level impairments are accounted for. Quantifying this gap is essential for operators seeking to understand whether a poorly performing site is limited by its radio link or by other segments of the network, such as the backhaul.

Bakri et al. [3] analyzed Shannon capacity on LTE networks in Makassar and showed that channel capacity increases with both bandwidth and SINR, and that the theoretical capacity computed from Shannon's theorem can differ substantially from the throughput actually observed in the field, consistent with broader Quality of Service assessments of LTE networks in the same city [8]. Building on this line of work, the present study evaluates the Shannon channel capacity of an operational 4G site and compares it against the site's real, drive-test-measured throughput, in order to characterize how efficiently the radio link's theoretical potential is realized in practice.

This study focuses on Site UPD104 Racing Center, an active Telkomsel 4G site in Makassar, as a case study for this capacity analysis. Field measurements were carried out through a drive test covering the streets surrounding the site, from which the RSRP, RSSI, RSRQ, SINR, modulation scheme, and throughput were recorded and used to compute the Shannon capacity at each measurement point. Comparing this theoretical capacity with the corresponding actual throughput allows the study to assess how much of the radio link's potential capacity is realized as usable data rate, and to identify where the resulting gap most likely originates.

Based on this background, the research addresses the following problems: (1) what is the Shannon channel capacity of the 4G network at Site UPD104 Racing Center based on drive test measurements, and (2) how does this theoretical capacity compare with the network's actual throughput and modulation scheme. The scope of the study is limited to Site UPD104 Racing Center and to the parameters RSRP, RSSI, RSRQ, SINR, modulation scheme, throughput, and Shannon capacity. The objectives are to determine the Shannon capacity of the 4G network at the site from field-measured SINR and bandwidth, and to analyze the relationship between that theoretical capacity and the network's actual measured throughput, providing a reference for operators seeking to improve 4G network efficiency and contributing to the literature on Shannon capacity analysis of operational LTE networks.

## II. Literature Review

### *A. 4G Long Term Evolution (LTE)*

LTE is the standard defined by 3GPP for high-level wireless data access, evolved from GSM/EDGE and UMTS/HSPA networks, designed to deliver higher data rates, lower latency, greater capacity, and more efficient radio-resource use theoretically up to 100 Mbps downlink and 50 Mbps uplink. The LTE architecture comprises the User Equipment (UE), the Evolved-UTRAN (eNodeB), and the Evolved Packet Core (EPC), which includes the Mobility Management Entity (MME), Home Subscriber Server (HSS), Serving Gateway (SGW), Packet Data Network Gateway (PDN-GW), and Policy and Charging Rules Function (PCRF).

### *B. Radio Performance Parameters*

QoS is a method for measuring how well a network performs and for characterizing service-provider behavior [9]. Four key radio-level indicators, formally defined by 3GPP for E-UTRA physical-layer measurements [11], are used: RSRP, the power of the LTE reference signal received in a given band, RSRP(dBm) = RSSI(dBm) − 10log(12×N); RSSI, the total received power including interference and noise, RSSI(dBm) = 10log(12×N) + RSRP(dBm); RSRQ, the ratio of N×RSRP to RSSI, RSRQ(dB) = 10log(N) + RSRP(dBm) − RSSI(dBm), used for cell ranking in handover; and SINR, the ratio of wanted signal to interference-plus-noise, SINR(dB) = RSRP(dBm) − (I+N)(dBm) [5].

The 3GPP specifications standardize these definitions and the integer reporting ranges used for radio resource management [12], but do not themselves define qualitative categories such as “Excellent” or “Poor”; the Excellent-to-Poor classification bands applied in this study (Table 1 and Table 2) instead follow the threshold convention consistently used in the applied LTE drive-test literature [5], [7]. Field measurements on live LTE networks confirm that these indicators are interrelated in practice: RSRP tracks the overall SNR, RSRQ improves as the gap between RSSI and RSRP narrows, and higher SINR reliably yields higher achieved throughput [4]. Consistent with this, optimization studies show that raising the average SINR of a site through radio-parameter tuning directly improves the proportion of throughput samples reaching the Excellent category [6].

Table 1. Standard classification of RSRP, RSSI, RSRQ, and SINR [5]

| Category | RSRP (dBm) | RSSI (dBm) | RSRQ (dB) | SINR (dB) |
|---|---|---|---|---|
| Excellent | -70 until 25 | -80 until -40 | -9 until 20 dB | 20 until 30 |
| Good | -80 until -71 | - | -14 until -9 | 10 until 20 |
| Normal | -91 until -81 | -100 until -80 | -19 until -14 | 0 until 10 |
| Bad | -100 until -91 | - | -24 until -19 | - |
| Poor | -140 until -101 | -140 until -100 | -40 until -24 | -30 until 0 |

Throughput is the effective data-transfer rate delivered to the user (bps), reflecting the fraction of available bandwidth actually used; it is influenced by network equipment, data type, number of concurrent users, topology, client/server specifications, electrical interference, and weather [7].

Table 2. Standard classification of throughput [7]

| Category | Throughput (kbps) |
|---|---|
| Excellent | ≥ 12,000 |
| Good | 7,200 – 12,000 |
| Normal | 1,500 – 7,200 |
| Bad | 324 – 1,500 |
| Poor | < 324 |

*C. Modulation Scheme*

LTE employs adaptive modulation and coding to trade data rate against robustness according to the instantaneous radio condition. QPSK encodes 2 bits/symbol and is used under poor conditions; 16-QAM encodes 4 bits/symbol; and 64-QAM encodes 6 bits/symbol, used when SINR is high, delivering a higher bit rate. The network continuously adapts the modulation order to the measured SINR, so the modulation scheme observed during a drive test is itself an indicator of the instantaneous radio-link quality.

*D. Shannon Channel Capacity*

Channel capacity is the maximum error-free data rate that a communication channel can support. In 1948, Claude Shannon formulated the fundamental theorem giving the capacity of a band-limited channel corrupted by additive white Gaussian noise as

$$C = B \log_2(1+SINR) = 3.32\, B \log_{10}(1+SINR) \qquad (1)$$

where C is the channel capacity (bit/s), B is the channel bandwidth (Hz), and SINR is the signal-to-interference-plus-noise ratio. Capacity increases with both bandwidth and SINR, and represents the theoretical ceiling on error-free throughput for the measured radio condition, independent of the modulation and coding actually in use. Comparing this theoretical capacity against the throughput that is actually delivered therefore indicates how efficiently a network realizes the potential of its radio link.

*E. Bit Error Rate (BER)*

BER is the fraction of transmitted bits received in error; for example, a BER of $10^{-6}$ implies one erroneous bit per one million bits transmitted. BER is closely related to SINR: for a given modulation order, higher SINR yields lower BER, and the relationship becomes less favorable as the modulation order increases from QPSK to 64-QAM.

*F. Drive Test*

Drive testing is a field-measurement technique in radio-network optimization used to collect real RF conditions around an eNodeB [5]. Modes include Idle Mode (signal quality without an active session), Dedicated Mode (signal quality during an active voice/data session, used here to assess data quality), and QoS Mode (scripted call set-up/end sequences). Data-collection approaches include Single Site Verification, cluster measurement, benchmarking, and optimization drive tests.

## III. Results and Discussion

*A. Location, Time, and Materials*

The research was conducted at Site UPD104 Racing Center which had implemented dual homing topology as shown in Figure 1. This research operates Telkomsel 4G site in Makassar, from February to June 2025. Data collection used the drive test method with a PC for visual monitoring, TEMS Pocket as the field drive-test tool, a Samsung Galaxy Note 5 handset with a Telkomsel SIM as the measurement terminal, a data cable for log-file transfer, Google Earth for route planning, and TEMS Investigation 23.1 for analysis.

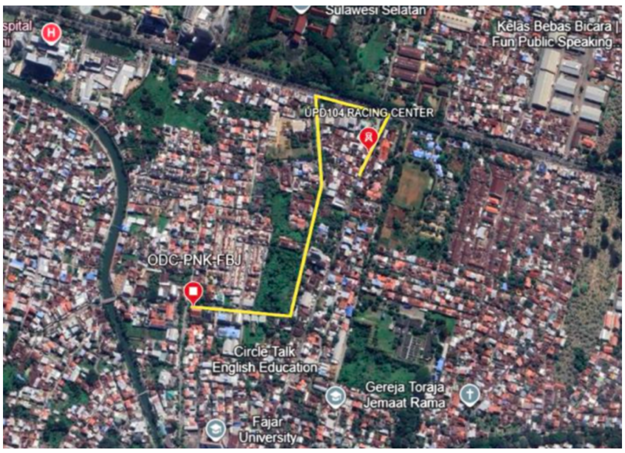


Figure 1. Location of Site UPD104 Racing Center

*B. Procedure and Data Collection*

The procedure followed: literature study; preparation of drive-test equipment; route determination and site survey; field data collection via drive test, plotted automatically from a moving vehicle; and log-file analysis. Measurements were taken in Dedicated Mode with simultaneous download/upload sessions, recording RSRP, RSRQ, RSSI, SINR, and throughput together with Shannon capacity and modulation scheme. Data were collected on 13 May 2025 between 16:26–16:46 WITA under clear weather, on the 1800 MHz band with 20 MHz bandwidth. The route began at Jalan Penjernihan Raya, continued through Jalan Urip Sumoharjo and Jalan Racing Centre, and ended at Jalan Mesjid Baiturrahman. The download session was recorded 16:34 until 16:40 WITA and the upload session 16:43–16:46 WITA.

*C. Data Analysis*

Drive-test log files were analyzed in TEMS Investigation 23.1 and summarized as tables, graphs, and route maps showing the percentage of measurement points in each QoS category for RSRP, RSSI, RSRQ, SINR, and throughput, together with Shannon capacity and modulation scheme, following the classifications in Table 1 and Table 2.

## IV. Result and Discussions

Drive testing was performed on 13 May 2025 using a Samsung Galaxy Note 5 with TEMS Pocket, analyzed in TEMS Investigation 23.1. Route of drive test is showed in Figure 2 and Table 3 and Table 4 summarize the measured radio-parameter distributions for the download and upload sessions, which form the basis for the Shannon capacity calculation presented afterward.

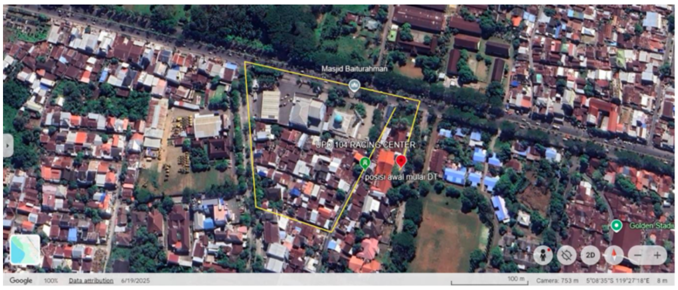


Figure 2. Drive test route at Racing Center

*A. Download Session (Dedicated Mode)*

Table 3. Parameter distribution for download session

| Parameter | Category | Number of points | % |
|---|---|---|---|
| RSSI | Excellent | 25,522 | 100.0 |
| RSRP | Excellent | 26,878 | 52.7 |
| RSRP | Good | 22,659 | 44.4 |
| RSRP | Normal | 1,468 | 2.9 |
| RSRQ | Excellent | 34,151 | 63.0 |
| RSRQ | Good | 17,940 | 33.1 |
| RSRQ | Normal | 2,037 | 3.7 |
| RSRQ | Bad | 94 | 0.2 |
| SINR | Good | 31,161 | 57.5 |
| SINR | Normal | 18,592 | 34.3 |
| SINR | Poor | 4,469 | 8.2 |
| Throughput | Poor | 54,222 | 100.0 |

RSSI was Excellent (100%) throughout, and RSRP was predominantly Excellent-to-Good (97.1% combined). RSRQ was likewise mostly Excellent-to-Good (96.1%), with only 0.2% Bad, attributable to environmental obstructions (buildings, trees, passing vehicles) causing reflection, attenuation, scattering, and diffraction, as well as receiver sensitivity. SINR was more variable 57.5% Good, 34.3% Normal, 8.2% Poor indicating residual interference. Despite favorable radio conditions, throughput was Poor across 100% of points (0–324 kbps), well below the 12,000 kbps Excellent threshold.

*B. Upload Session (Dedicated Mode)*

Table 4. Parameter distribution for upload session

| Parameter | Category | Number of points | % |
|---|---|---|---|
| RSSI | Excellent | 24,589 | 100.0 |
| RSRP | Excellent | 24,907 | 52.8 |
| RSRP | Good | 21,569 | 45.8 |
| RSRP | Normal | 671 | 1.4 |
| RSRQ | Excellent | 29,218 | 57.8 |
| RSRQ | Good | 19,574 | 38.7 |
| RSRQ | Normal | 1,021 | 2.0 |
| RSRQ | Bad | 742 | 1.5 |
| SINR | Good | 26,898 | 53.2 |
| SINR | Normal | 19,378 | 38.3 |
| SINR | Poor | 4,279 | 8.5 |
| Throughput | Poor | 50,555 | 100.0 |

The upload session shows a similar pattern: RSSI remained 100% Excellent, RSRP 98.6% Excellent-to-Good, and RSRQ 96.5% Excellent-to-Good with a slightly larger bad share (1.5% vs 0.2%).

SINR distribution was close to the download session (53.2% Good, 38.3% Normal, 8.5% Poor). Throughput was poor across all 50,555 points, confirming the bottleneck is not specific to one traffic direction.

*C. Shannon Capacity vs. Actual Throughput*

Representative sample points illustrate the relationship among SINR, adaptive modulation, theoretical Shannon capacity, and measured throughput, using 20 MHz bandwidth on the 1800 MHz band. At SINR = 10 dB: $C = 3.32\times20\times10^6\times\log10(1+10) = 69.12$ Mbps; at SINR = 3 dB: $C = 3.32\times20\times10^6\times\log10(1+1.995) = 31.61$ Mbps.

Across both sessions the pattern is consistent: even when RSRP, RSSI, and RSRQ indicate Excellent-to-Good conditions and the network selects 64-QAM implying a theoretical Shannon capacity above 70 until 100 Mbps, the measured throughput is close to zero. This gap is far larger than residual bit errors (estimated BER of $10^{-1}$ to $10^{-2}$ at several points) can explain, pointing to a bottleneck beyond the radio link most plausibly the backhaul, core network, or test server/application.

Table 5. Sample points for download session

| Time | SINR | Modulation | Throughput | C (Mbps) |
|---|---|---|---|---|
| 16:34:50 | 12.5 | 64QAM | 0.00 | 73.23 |
| 16:35:00 | 10.0 | 64→16Q | 0.00 | 69.12 |
| 16:35:42 | 0.5 | QPSK | 0.00 | 11.69 |
| 16:36:55 | 12.0 | 16QAM | 0.00 | 81.41 |
| 16:37:04 | -3.0 | QPSK | 0.00 | 11.69 |

Table 6. Sample points for upload session

| Time | SINR | Modulation | Throughput | C (Mbps) |
|---|---|---|---|---|
| 16:43:12 | 1.9 | QPSK | 0.01 | 31.61 |
| 16:43:45 | 19.9 | 64QAM | 0.00 | 87.71 |
| 16:44:06 | 0.1 | QPSK | 0.02 | 5.18 |
| 16:45:21 | 19.9 | 64→16Q | 0.00 | 87.71 |
| 16:46:10 | 39.8 | 64QAM | 0.00 | 106.90 |

*D. Download vs. Upload Comparison*

RSSI was identical (100% Excellent) in both directions. RSRP was marginally better for upload in the Excellent (52.8% vs 52.7%) and Good (45.8% vs 44.4%) categories, while download had more Normal-category points (2.9% vs 1.4%). RSRQ favored download in Excellent (63.0% vs 57.8%) but upload had more Good (38.7% vs 33.1%) and Bad (1.5% vs 0.2%) points. SINR was slightly better for download (57.5% vs 53.2% Good). Throughput was identically Poor (100%) in both directions, indicating the limiting factor affects both traffic directions equally.

# V. Conclusion

Drive-test measurements of the 4G network at Site UPD104 Racing Center show that RSSI, RSRP, and RSRQ were consistently Excellent-to-Good for both download and upload, confirming a strong and stable radio link, while SINR exhibited more variability, indicating residual interference. Combined with the bandwidth and the adaptive modulation reaching 64-QAM, these SINR levels correspond to theoretical Shannon capacities of roughly 70 to 107 Mbps at individual measurement points. However, the measured throughput was Poor (below 324 kbps) at 100% of points in both directions, indicating a severe shortfall between the network's theoretical channel capacity and its actual delivered performance. This pattern suggests the bottleneck lies outside the radio access segment most likely the backhaul, core network, or measurement configuration rather than from weak radio signal conditions. While Site UPD104 Racing Center exhibits favorable radio-link conditions and a high theoretical Shannon capacity, the persistently low actual throughput means that capacity is not yet being efficiently realized as usable data rate for end users.

1. Throughput measurement with different terminal devices and test servers to identify the root cause of the near-zero throughput.
2. Measure network performance during peak busy hours (10:00 until 12:00 WITA) with dedicated-mode download and upload throughput testing under varying traffic loads.

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