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# Impact of Frequency Bands on 4G LTE Coverage Planning: A Comparative Study in Padang City

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***Abstract***— The rapid growth of mobile data services has intensified demand for reliable 4G Long Term Evolution (LTE) coverage in urban areas with heterogeneous terrain. This study investigates the coverage performance of 4G LTE networks across four frequency bands—900 MHz, 1800 MHz, 2100 MHz, and 2300 MHz deployed in four sub-districts of Padang City, West Sumatra, Indonesia: Padang Utara, Padang Timur, Padang Barat, and Padang Selatan, totaling 33.26 km². Coverage characteristics are evaluated through link budget analysis, Maximum Allowable Path Loss (MAPL) computation, and Atoll-based radio propagation simulation. The Okumura-Hata model is applied for 900 MHz, while the COST-231 Hata model is used for 1800 MHz, 2100 MHz, and 2300 MHz. Key performance indicators include Reference Signal Received Power (RSRP) as the primary coverage metric, Signal-to-Interference-plus-Noise Ratio (SINR) as a quality indicator, and throughput as a supporting metric. Results show that 900 MHz achieves the widest coverage with a mean RSRP of −59.96 dBm (95.9% Excellent) using only 4 sites, while 2100 MHz yields the weakest mean RSRP of −87.51 dBm despite 21 sites. The 2300 MHz band—though highest in frequency—outperforms 2100 MHz in both RSRP and SINR due to its denser 33-site deployment. These findings confirm the fundamental trade-off between operating frequency, path loss, cell radius, and required site density in urban LTE deployment, and provide practical guidance for multi-band network planning in complex urban environments.
***Keywords***—4G LTE; Coverage Planning; Frequency Bands; RSRP; SINR.

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## I. Introduction

The proliferation of smartphones and bandwidth-intensive applications has accelerated mobile broadband traffic growth globally. In Indonesia, penetration of 4G LTE as the dominant access technology continues to rise, as documented by Badan Pusat Statistik [1] and national internet surveys [2] . Against this backdrop, the quality of LTE radio coverage particularly in dense urban areas becomes a critical factor for network operators and planners.

LTE, standardized by the 3rd Generation Partnership Project (3GPP) from Release 8 onward, supports multiple frequency bands through Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes [3]. The radio coverage performance of an LTE network is fundamentally determined by the operating frequency band. Lower frequency bands such as 900 MHz experience lower free-space path loss and reduced penetration attenuation, enabling wider cell radii per site. Conversely, higher frequency bands such as 2100 MHz and 2300 MHz suffer greater propagation loss, requiring denser site grids to achieve equivalent coverage [4][5].

In Indonesia, the Ministry of Communications and Information Technology (Kominfo) allocates LTE spectrum across 900 MHz (Band 8, FDD), 1800 MHz (Band 3, FDD), 2100 MHz (Band 1, FDD), and 2300 MHz (Band 40, TDD). Operators such as Telkomsel deploy these bands simultaneously to balance coverage breadth and signal quality across diverse urban morphologies. Understanding the distinct propagation behavior of each band is therefore fundamental to rational multi-band network planning.

Several studies have examined LTE coverage and propagation characteristics. Ibrahim et al. [6] investigated indoor penetration losses in 4G/LTE networks, demonstrating that higher frequencies incur substantially greater building penetration attenuation. Agustin and Arohman [7] analyzed LTE coverage planning based on link budget parameters, providing insight into the relationship between MAPL and cell radius. Alfaresi et al. [8] compared the Okumura-Hata and COST-231 Hata propagation models for LTE deployment in urban environments, validating their applicability for multi-band coverage analysis. Silalahi et al. [5] analyzed the implementation of LTE 900 MHz specifically for coverage extension, confirming that low-band deployment significantly reduces required site counts. Dharmi and Putra [9] conducted coverage optimization at 1800 MHz, revealing the sensitivity of cell radius estimates to shadowing margin and penetration loss assumptions. Caya and Usman [10] evaluated LTE network design for an Indonesian city, providing a reference methodology directly applicable to this work.

Padang City, the capital of West Sumatra Province, presents a distinctive propagation environment. Its urban core—comprising Padang Utara, Padang Timur, Padang Barat, and Padang Selatan sub-districts, totaling 33.26 km²—is characterized by dense mixed-use buildings, government facilities, and a coastal geography that produces complex multipath and shadowing conditions [1]. Despite the practical importance of this region, no prior published study has systematically compared the LTE coverage performance of all four primary frequency bands within this specific urban area using a unified simulation methodology. This represents the core research gap addressed by this paper.

This study contributes a systematic, simulation-based comparative coverage analysis of 900 MHz, 1800 MHz, 2100 MHz, and 2300 MHz LTE bands in Padang City, employing Atoll radio planning software with calibrated propagation models and operator-sourced hardware parameters. The specific objectives are: (1) to compute link budget parameters and MAPL for each frequency band; (2) to estimate cell radius and site count requirements for the study area; (3) to simulate RSRP and SINR spatial distributions via Atoll; and (4) to compare and interpret the coverage trade-offs across all four bands, with throughput included as a supporting metric.

## II. The Materials and Method

### *A. Study Area*

The study area covers four sub-districts of Padang City: Padang Utara (8.08 km²), Padang Timur (8.15 km²), Padang Barat (7.00 km²), and Padang Selatan (10.03 km²), totaling 33.26 km² [1]. This region constitutes the administrative, commercial, and educational core of Padang City, characterized by dense mixed-use development, multi-story buildings, and coastal terrain along the Indian Ocean. The combination of urban morphology and coastal geography produces a propagation environment where diffraction, multipath, and shadowing effects are pronounced, making it well-suited for studying frequency-dependent path loss behavior. All simulation inputs—including digital terrain elevation model (DEM) data, clutter classification, and site coordinates—are derived from data specific to this geographical area.

### *B. LTE Network Technical Parameters*

Network configuration follows 3GPP Release 8 specifications [3] and Kominfo frequency allocation regulations. Four bands are modeled: 900 MHz (Band 8, FDD, 10 MHz), 1800 MHz (Band 3, FDD, 20 MHz), 2100 MHz (Band 1, FDD, 20 MHz), and 2300 MHz (Band 40, TDD, 20 MHz). eNodeB hardware parameters are derived from Telkomsel field deployment data: RRU 4499 44B8 for 900 MHz, RRU 4480 44B1 for 1800 MHz and 2100 MHz, and RRU 8863 for 2300 MHz. Antenna models are MOBI MB4B/QMF-65-16/16DE-IN-TSL for 900 MHz and 2300 MHz, and Commscope TBXLHA-6565C-VTM for 1800 MHz and 2100 MHz. Transmit power is 47.78 dBm for 900–2100 MHz bands and 47.00 dBm for 2300 MHz.

User Equipment (UE) parameters follow standardized LTE planning assumptions [7][10]. Receiver sensitivity is derived from the thermal noise floor, a UE noise figure of 6 dB, and a minimum required SINR of −7 dB (QPSK at cell edge) [3]. Shadowing margin is set at 10 dB for dense urban environments, consistent with log-normal shadowing assumptions in published LTE planning studies [8][9]. Penetration loss values increase with frequency: 12 dB at 900 MHz, 15 dB at 1800 and 2100 MHz, and 17 dB at 2300 MHz, reflecting stronger indoor attenuation at higher frequencies [6].

### *C. Propagation Models*

The Okumura-Hata model is applied for the 900 MHz band, empirically validated for frequencies between 150 MHz and 1500 MHz in macro-cellular urban environments [8]. Path loss for large urban areas ($f^c \geq 400$ MHz) is expressed as:

$$L_u\,(dB) = 69.55 + 26.16\cdot\log_{10}(f^c) - 13.82\cdot\log_{10}(h_{te}) - a(h_{re}) + (44.9 - 6.55\cdot\log_{10}(h_{te}))\cdot\log_{10}(d) \quad (1)$$

where $a(h_{re}) = 3.2[\log_{10}(11.75\, h_{re})]^2 - 4.97$ for large cities ($f^c \geq 400$ MHz), $h_{te}$ is the eNodeB antenna height (m), $h_{re}$ is the UE antenna height (1.5 m), and d is distance (km).

For 1800 MHz, 2100 MHz, and 2300 MHz, the COST-231 Hata model is applied [8][11]. This model extends the Okumura-Hata formulation to 2000 MHz and introduces a dense-urban correction factor:

$$L_p\,(dB) = 46.33 + 33.9\cdot\log_{10}(f^c) - 13.82\cdot\log_{10}(h_{te}) - a(h_{re}) + (44.9 - 6.55\cdot\log_{10}(h_{te}))\cdot\log_{10}(d) + C \quad (2)$$

where $C_m$ = 3 dB for dense urban areas and 0 dB otherwise. The COST-231 Hata model is applied to the 2300 MHz TDD band as a conservative approximation, consistent with practice in simulation-based LTE planning studies for sub-3 GHz frequencies [11][4].

### *D. Link Budget and MAPL*

The link budget is computed for the downlink direction, which is the coverage-limiting path in LTE systems. The Maximum Allowable Path Loss (MAPL) quantifies the maximum tolerable end-to-end signal attenuation while maintaining minimum service quality [3]:

$$MAPL = EIRP - S^R{}_x - M_i{}^n{}_t - M_s{}^\varphi - L_{pe}{}^n - L^b{}_o \quad (3)$$

where $EIRP = P_{tx} + G_{tx} - L_{tx}$ (effective isotropic radiated power), $S^R{}_x = N_t{}^h + NF + SINR_{mi}{}^n$ (receiver sensitivity), $M_i{}^n{}_t$ is the interference margin, $M_s{}^\varphi$ is the shadowing margin, $L_{pe}{}^n$ is indoor penetration loss, and $L^b{}_o$ is UE body loss. Table I summarizes the key link budget parameters for all four frequency bands.

TABLE I
LINK BUDGET PARAMETERS FOR EACH FREQUENCY BAND

| **Parameter** | **900 MHz** | **1800 MHz** | **2100 MHz** | **2300 MHz** |
|---|---|---|---|---|
| Tx Power P_Tx (dBm) | 47.78 | 47.78 | 47.78 | 47.00 |
| Antenna Gain G_Tx (dBi) | 16.0 | 16.8 | 17.0 | 17.0 |
| Cable Loss L_Tx (dB) | 0.71 | 0.80 | 0.83 | 0.90 |
| EIRP (dBm) | 63.07 | 63.78 | 63.95 | 63.10 |
| Thermal Noise N_th (dBm) | −104 | −101 | −101 | −101 |
| Noise Figure NF (dB) | 6 | 6 | 6 | 6 |
| Min. SINR (dB) | −7 | −7 | −7 | −7 |
| Rx Sensitivity S_Rx (dBm) | −105 | −102 | −102 | −102 |
| Penetration Loss L_pen (dB) | 12 | 15 | 15 | 17 |
| Shadowing Margin M_sf (dB) | 10 | 10 | 10 | 10 |
| Interference Margin M_int (dB) | 7 | 7 | 7 | 7 |
| MAPL (dB) | 138.67 | 133.38 | 133.55 | 130.70 |

### *E. Cell Radius and Site Count Estimation*

Given the MAPL for each band, the maximum cell radius d (km) is derived by inverting the respective propagation model equation. For a hexagonal cell geometry, the area covered per site is $A_{cell} = 2.6 \times d^2$ [7][10]. The required number of sites for the study area is then obtained by dividing the total area (33.26 km²) by $A_{cell}$. Table II presents the computed cell radii, per-site coverage areas, and resulting site count estimates for each frequency band.

TABLE II
CELL RADIUS, COVERAGE AREA, AND SITE COUNT ESTIMATES

| **Frequency** | **MAPL (dB)** | **Cell Radius (km)** | **Cell Area (km²)** | **Total Sites** |
|---|---|---|---|---|
| 900 MHz | 138.67 | 2.548 | 16.88 | 4 |
| 1800 MHz | 133.38 | 0.933 | 2.26 | 17 |
| 2100 MHz | 133.55 | 0.820 | 1.75 | 21 |
| 2300 MHz | 130.70 | 0.633 | 1.04 | 33 |

### *F. Atoll Simulation Setup*

The Forsk Atoll radio planning tool is used to simulate spatial distributions of RSRP, SINR, and throughput across the study area [12]. All link budget parameters from Table I and site counts from Table II are imported into Atoll, together with DEM data and urban clutter classification for Padang City. Coverage predictions are generated at a spatial resolution of 50 m × 50 m, which provides sufficient granularity for sub-district level analysis while remaining computationally tractable.

### *G. RSRP and SINR Classification Thresholds*

Simulation outputs are classified using threshold categories defined in Tables III and IV, following 3GPP TS 36.213 measurement standards [3] and classification schemes adopted in LTE planning literature [9][10][13].

TABLE III
RSRP SIGNAL QUALITY CLASSIFICATION

| **RSRP Range (dBm)** | **Category** |
|---|---|
| RSRP ≥ −75 | Excellent |
| −85 ≤ RSRP < −75 | Very Good |
| −100 ≤ RSRP < −85 | Good |
| −110 ≤ RSRP < −100 | Bad |
| RSRP < −110 | Poor |

TABLE IV
SINR QUALITY CLASSIFICATION

| **SINR Range (dB)** | **Category** |
|---|---|
| SINR ≥ 20 | Excellent |
| 13 ≤ SINR < 20 | Very Good |

| | |
|---|---|
| $0 \le \text{SINR} < 13$ | Bad |
| $-15 \le \text{SINR} < 0$ | Poor |

## III. Results and Discussion

### *A. Link Budget and Coverage Planning Results*

The link budget results in Table I reveal a consistent pattern: as operating frequency increases, both penetration loss and path loss increase, which cumulatively reduces MAPL. The 900 MHz band achieves the highest MAPL of 138.67 dB, corresponding to a cell radius of 2.548 km and a per-site coverage area of 16.88 km². Only 4 sites are required to cover the entire 33.26 km² study area. At the opposite extreme, the 2300 MHz band attains an MAPL of only 130.70 dB, resulting in a cell radius of 0.633 km and a coverage area of 1.04 km² per site, requiring 33 sites more than eight times the number needed at 900 MHz.

This inverse relationship between frequency and cell radius is consistent with the propagation physics underlying both the Okumura-Hata and COST-231 Hata models: the path loss exponent and the frequency-dependent term both increase with carrier frequency [8]. The 1800 MHz and 2100 MHz bands occupy intermediate positions (17 and 21 sites, respectively). Although the MAPL difference between 1800 MHz and 2100 MHz is marginal (0.17 dB), the slightly lower penetration loss at 1800 MHz (15 dB vs. 15 dB) produces a modestly larger cell radius (0.933 km vs. 0.820 km), attributed to differences in the COST-231 Hata frequency term. These site-count estimates form the basis for all Atoll simulations.

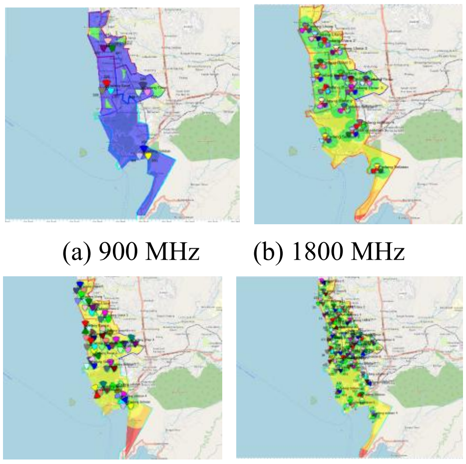



Fig. 1. Simulated RSRP spatial distribution for (a) 900 MHz, (b) 1800 MHz, (c) 2100 MHz, and (d) 2300 MHz LTE bands across the Padang City study area. Color scale: red (≥ −75 dBm, Excellent) to blue (< −110 dBm, Poor).

### *B. RSRP Coverage Analysis*

Table V presents the RSRP simulation results for all four frequency bands. The 900 MHz band delivers the strongest coverage, with a mean RSRP of −59.96 dBm and 95.9% of the study area classified as Excellent. With only 4 eNodeB sites deployed, the Okumura-Hata model predicts sufficiently low path loss at this frequency to maintain strong signal levels across nearly the entire 33.26 km² area. The standard deviation of 9.26 dBm indicates a spatially uniform distribution, and no Bad, Poor, or no-coverage pixels are present.

TABLE V
COMPARATIVE RSRP SIMULATION RESULTS ACROSS FREQUENCY BANDS

| **Indicator** | **900 MHz** | **1800 MHz** | **2100 MHz** | **2300 MHz** |
|---|---|---|---|---|
| Mean RSRP (dBm) | −59.96 | −83.19 | −87.51 | −84.86 |
| Std. Deviation (dBm) | 9.26 | 8.57 | 10.87 | 7.55 |
| Excellent (≥ −75 dBm) % | 95.9 | 16.57 | 10.22 | 2.82 |
| Very Good % | 4.1 | 45.19 | 35.44 | 53.67 |
| Good % | 0 | 34.37 | 41.55 | 39.46 |
| Bad/Poor % | 0 | 3.88 | 12.80 | 4.05 |
| No Coverage | None | None | None | None |

At 1800 MHz, the mean RSRP decreases to −83.19 dBm (Very Good category), with 79.1% of the area achieving at least the Good threshold and only 3.88% in the Bad/Poor range. The reduction in RSRP relative to 900 MHz is a direct consequence of the higher path loss exponent in the COST-231 Hata model, combined with a 3 dB increase in penetration loss (15 dB vs. 12 dB). The 17-site deployment is sufficient to maintain baseline coverage with no gaps.

The 2100 MHz band exhibits the weakest mean RSRP among all bands at −87.51 dBm, with 12.80% of the area in the Bad/Poor categories the highest proportion in this study. The elevated standard deviation of 10.87 dBm signals pronounced spatial variability, attributable to the interplay between greater shadowing at this frequency and the irregular geometry of 21 sites across the study area. These results indicate that the 2100 MHz deployment is operating near a transitional threshold: not dense enough to suppress RSRP variability, yet dense enough that inter-site distances generate non-trivial coverage heterogeneity.

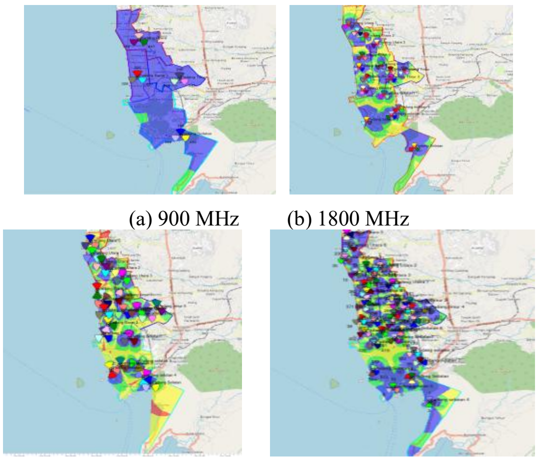
A notable finding is that the 2300 MHz band outperforms 2100 MHz in mean RSRP (−84.86 dBm vs. −87.51 dBm), despite operating at the highest frequency. This result is directly attributable to the substantially higher site density at 2300 MHz (33 sites), which reduces the average UE-to-eNodeB distance and more than compensates for the additional free-space path loss at higher frequency. The smallest standard deviation (7.55 dBm) among all bands further confirms that the 33-site deployment produces the most spatially homogeneous RSRP distribution. This finding is consistent with the ultra-dense networking principle—that sufficiently high site density can offset frequency-induced propagation disadvantages [5].

## C. SINR Analysis

SINR captures signal quality from the perspective of both noise and inter-cell interference, and thus provides a complementary perspective to RSRP. As shown in Table VI, the SINR rankings across bands do not perfectly mirror the RSRP rankings, which warrants separate analysis.

TABLE VI
COMPARATIVE SINR SIMULATION RESULTS ACROSS FREQUENCY BANDS

| Indicator | 900 MHz | 1800 MHz | 2100 MHz | 2300 MHz |
|---|---|---|---|---|
| Mean SINR (dB) | 36.57 | 20.07 | 17.61 | 23.70 |
| Std. Deviation (dB) | 10.24 | 10.14 | 11.55 | 9.57 |
| Excellent (≥ 20 dB) % | 94.3 | 45.09 | 39.9 | 62.86 |
| Very Good (13–20 dB) % | 4.5 | 27.58 | 22.0 | 22.91 |
| Bad (0–13 dB) % | 0.7 | 27.26 | 34.3 | 14.17 |
| Poor (< 0 dB) % | 0 | 0.07 | 3.8 | 0.05 |



(a) 900 MHz (b) 1800 MHz

(c) 2100 MHz (d) 2300 MHz

Fig. 2. Simulated SINR spatial distribution for (a) 900 MHz, (b) 1800 MHz, (c) 2100 MHz, and (d) 2300 MHz LTE bands. Color scale: green (≥ 20 dB, Excellent) to red (< −15 dB, Poor).

The 900 MHz band achieves the highest mean SINR of 36.57 dB, with 94.3% of the area in the Excellent category. With only 4 active sites, co-channel interference sources are scarce; the dominant signal from the serving eNodeB far exceeds interference contributions, yielding SINR values well above the 64-QAM modulation threshold. This configuration is characteristic of sparse macro-cell deployments where interference is not yet the limiting factor.

At 1800 MHz, the mean SINR drops to 20.07 dB marginally above the Excellent threshold with 27.26% of the area in the Bad category. The 17-site deployment increases the number of co-channel interference sources relative to the 900 MHz scenario, degrading SINR in areas with unfavorable site geometry. Nevertheless, the 1800 MHz SINR distribution is generally sufficient to support high-order modulation across the majority of the coverage footprint.

The 2100 MHz band records the lowest mean SINR at 17.61 dB (Very Good category), with 34.3% Bad and 3.8% Poor area the worst SINR performance in this study. The 21-site deployment generates substantial co-channel interference, but the inter-site distance is not yet small enough to confine this interference effectively. The result is a broad interference footprint with high spatial variability (std. dev. 11.55 dB). This transitional network density—where interference has grown but coverage localization has not yet improved—is a well-recognized challenge in LTE urban planning [4][5].

The 2300 MHz band outperforms 2100 MHz in SINR with a mean of 23.70 dB and 62.86% Excellent area. Despite having the highest site density (33 sites), which increases the number of potential interference sources, the smaller inter-site distances reduce the effective interference range per cell. The TDD frame structure of Band 40 also contributes to interference isolation through time-domain separation. These combined effects produce a SINR distribution superior to 2100 MHz and even competitive with 1800 MHz—despite operating 500 MHz higher in frequency.

## D. Throughput Analysis

Throughput is examined as a supporting metric that integrates the effects of RSRP, SINR, and available bandwidth. Table VII summarizes the mean peak RLC channel throughput results.

TABLE VII
COMPARATIVE THROUGHPUT SIMULATION RESULTS

| Indicator | 900 MHz | 1800 MHz | 2100 MHz | 2300 MHz |
|---|---|---|---|---|
| Mean Throughput (Mbps) | 93.53 | 120.28 | 91.31 | 43.63 |
| Std. Deviation (Mbps) | 7.79 | 61.80 | 53.12 | 15.45 |
| Excellent (≥ 14 Mbps) % | 100 | 99.8 | 92.3 | 90.0 |

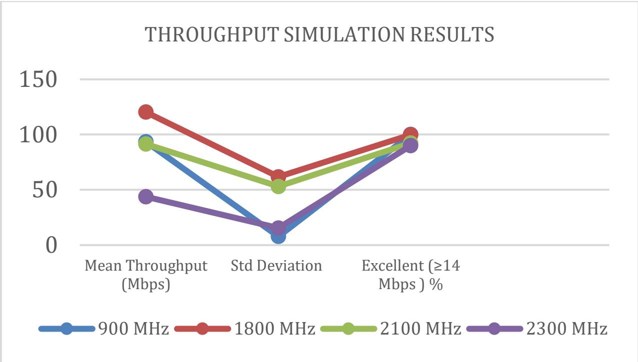



Fig. 3. Comparison of mean peak RLC channel throughput across 900 MHz, 1800 MHz, 2100 MHz, and 2300 MHz LTE frequency bands

The 1800 MHz band delivers the highest mean throughput at 120.28 Mbps, benefiting from its 20 MHz bandwidth (100 PRBs) combined with sufficiently high SINR to maintain 64-QAM modulation across a large fraction of the coverage area. The 900 MHz band, despite achieving the best RSRP and SINR, is limited to 93.53 Mbps by its narrower 10 MHz bandwidth (50 PRBs). The 2100 MHz band achieves 91.31 Mbps—comparable to 900 MHz—due to its 20 MHz bandwidth, though its inferior SINR produces throughput degradation at cell edges. The 2300 MHz band records the lowest mean throughput (43.63 Mbps), a consequence of the TDD frame structure allocating a portion of time slots to uplink, effectively reducing downlink resource availability relative to FDD bands. The high standard deviation of throughput at 1800 MHz (61.80 Mbps) and 2100 MHz (53.12 Mbps) reflects the spatial heterogeneity of SINR in those deployments, consistent with the SINR variability observed in Table VI.

### *E. Coverage Trade-off and Frequency Propagation Behavior*

The simulation results, taken together, reveal a consistent and interpretable pattern of frequency-dependent coverage behavior. Table VIII provides a consolidated comparison across all metrics.

TABLE VIII
CONSOLIDATED COVERAGE PERFORMANCE SUMMARY ACROSS FREQUENCY BANDS

| **Metric** | **900 MHz** | **1800 MHz** | **2100 MHz** | **2300 MHz** |
|---|---|---|---|---|
| MAPL (dB) | 138.67 | 133.38 | 133.55 | 130.70 |
| Cell Radius (km) | 2.548 | 0.933 | 0.820 | 0.633 |
| Sites Required | 4 | 17 | 21 | 33 |
| Mean RSRP (dBm) | −59.96 | −83.19 | −87.51 | −84.86 |
| Mean SINR (dB) | 36.57 | 20.07 | 17.61 | 23.70 |
| Mean Throughput (Mbps) | 93.53 | 120.28 | 91.31 | 43.63 |
| Coverage Role | Anchor | Capacity | Fill | Dense Urban |

The 900 MHz band is unambiguously the most infrastructure-efficient option for area coverage. Its low path loss—predicted by Okumura-Hat enables a single site to cover 16.88 km², making it the natural coverage anchor in multi-band deployments. This is consistent with findings by Silalahi et al. [5], who demonstrated that LTE 900 MHz implementation substantially reduces the site count required to achieve target RSRP thresholds in urban areas, and with Alfaresi et al. [8], who validated Okumura-Hata applicability in urban LTE scenarios.

The 1800 MHz band emerges as the most balanced performer. It achieves acceptable RSRP coverage (mean −83.19 dBm), competitive SINR (mean 20.07 dB), and the highest throughput (120.28 Mbps). This profile makes 1800 MHz the natural capacity layer in a multi-band architecture, a role supported by Dharmi and Putra [9] who reported that 1800 MHz coverage planning with appropriate shadowing margin produces reliable urban coverage with manageable site density.

The 2100 MHz band presents the most challenging coverage profile in this study. Its RSRP is the weakest, its SINR variability is the greatest, and its site density (21 sites) places the network in a regime where inter-cell interference is elevated but coverage localization is insufficient. Network planners deploying 2100 MHz for primary urban coverage should consider either increasing site density or employing interference management mechanisms to reduce SINR variability.

The 2300 MHz TDD band demonstrates that site density can compensate for the propagation disadvantages of higher frequencies. With 33 sites, it outperforms 2100 MHz (21 sites) in both RSRP and SINR, despite operating 200 MHz higher. This finding reinforces the relevance of link budget-based coverage planning: the relationship between MAPL, cell radius, and site count directly governs the achievable coverage quality, independent of frequency in isolation. Operators planning 2300 MHz TDD deployments in urban areas should anticipate significantly higher site counts than for lower bands, but can expect spatially uniform signal quality once the density threshold is achieved [4][13].

Across all four bands, no simulated scenario produces a no-coverage pixel in the study area, confirming that the MAPL-derived site counts are appropriate for ensuring baseline coverage in the dense urban environment of Padang City. The path loss models used Okumura-Hata and COST-231 Hata—are validated for similar urban macro-cell environments in multiple independent studies [10][14] and produce internally consistent results in this simulation framework.

## IV. Conclusion

This study has presented a simulation-based comparative coverage analysis of 4G LTE networks operating at 900 MHz, 1800 MHz, 2100 MHz, and 2300 MHz in the urban core of Padang City, West Sumatra, Indonesia. Link budget calculations and Atoll radio propagation simulations were conducted over a 33.26 km² study area using standardized LTE parameters, operator-sourced hardware data, and calibrated empirical propagation models.

The primary finding is that MAPL and by extension, cell radius and required site count is governed by the combined effect of operating frequency, propagation model behavior, and band-specific penetration loss. The 900 MHz band achieves the widest coverage (cell radius 2.548 km, 4 sites), the best mean RSRP (−59.96 dBm, 95.9% Excellent), and the highest SINR (mean 36.57 dB), making it the most infrastructure-efficient band for area coverage provisioning. The 1800 MHz band provides the best throughput (mean 120.28 Mbps) and a well-balanced coverage profile, establishing it as the preferred capacity-coverage layer in multi-band urban deployments.

The 2100 MHz band exhibits the weakest coverage in this study, with the lowest mean RSRP (−87.51 dBm), highest RSRP spatial variability (std. dev. 10.87 dBm), and worst SINR distribution (34.3% Bad area). Its 21-site deployment is in a transitional interference-limited regime that warrants consideration of increased site density or interference management for urban applications. The 2300 MHz TDD band, despite operating at the highest frequency, outperforms 2100 MHz in both RSRP and SINR by virtue of its denser 33-site deployment, demonstrating that site density is a primary lever for overcoming high-frequency propagation limitations.

These results confirm a fundamental frequency-coverage trade-off in LTE deployment: lower bands offer wider coverage per site at the expense of narrower bandwidth, while higher bands require more sites but can achieve competitive signal quality under sufficient deployment density. A multi-band LTE strategy with 900 MHz as the coverage anchor, 1800 MHz as the capacity layer, and 2100 MHz/2300 MHz serving dense sub-areas is the most effective approach for complex urban environments such as Padang City. Future work should incorporate drive test measurement data for propagation model validation and extend the analysis to include indoor coverage scenarios and multi-band interference coexistence.

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