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Optimising Interference Management in LTE Networks: A Case Study of Bandung City Using Soft Frequency Reuse

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ABSTRACT

This paper explores the implementation of the Soft Frequency Reuse (SFR) algorithm to optimize interference management in LTE networks. Using Bandung City as a case study, the research evaluates performance metrics such as SINR and throughput across dense urban, urban, and suburban areas. The study employs the Cost-231 propagation model and proportional SINR-based resource allocation to optimize network planning. Results demonstrate that SFR effectively balances resource allocation and interference mitigation under varying traffic conditions, providing practical insights for network operators. These findings validate SFR's capability to improve LTE network performance across diverse environments.

1. Introduction

Multi-cell systems are distinguished by a more dense arrangement of e-NodeBs to enhance network capacity in response to rising user demand, particularly data traffic. With the imminent widespread adoption of Orthogonal Frequency Division Multiple Access (OFDMA) in these networks, it is presumed that users within a cell maintain orthogonality, while inter-cell interference, particularly limiting for users at cell boundaries, serves as the primary source of interference. (Al-Ashwal et al., 2023; Daldoul et al., 2020; Joo et al., 2020; Lian & Brandt-Pearce, 2020). Inter-cell interference coordination (ICIC) is a method to enhance network performance by distributing resources among cells to optimise spatial reuse and reduce interference inside the network. (Du et al., 2022; Hernandez-Solana et al., 2022; Z. Liu et al., 2022; H. Wei et al., 2022).

In the context of optimising interference management in LTE networks, the study (Putri et al., 2024)It provides valuable insights that complement our research on soft frequency reuse (SFR) in Bandung City. Both studies emphasise the importance of strategic network planning and optimisation to enhance performance metrics such as SINR and throughput, demonstrating that advanced planning methods like ACP and SFR are crucial for managing interference and improving overall network efficiency in urban environments.

Fractional Frequency Reuse (FFR) has been suggested as an inter-cell interference coordination (ICIC) method in OFDMA-based wireless networks (J. Liu, 2022; Luu et al., 2023). The fundamental concept of FFR is to allocate cell bandwidth in a manner that (i) prevents interference between users at the cell edges of neighboring cells, (ii) minimizes the interference experienced and generated by users within the cell, and (iii) utilizes a greater portion of the overall spectrum compared to conventional frequency reuse methods. The implementation of FFR in cellular networks establishes an inherent trade-off between enhanced cell edge user rates and coverage, and the overall network throughput and spectral efficiency. Most prior research has depended on simulations to assess FFR performance, chiefly because of the complexity of hexagonal grid models of e-NodeB locations (Bao & Shi, 2023; Wang et al., 2023).

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The rapid growth of LTE networks is driven by increasing demand for high-speed data services. However, inter-cell interference remains a critical challenge, particularly in urban environments. Fractional Frequency Reuse (FFR) techniques, including Soft Frequency Reuse (SFR), have been widely studied as solutions for managing interference. Despite these advancements, limited research has been conducted on their application in real-world, geographically diverse scenarios.

In this study, we model the locations of e-NodeBs as Poisson Point Processes (PPPs). This technique well represents the diverse architecture of contemporary mobile deployments influenced by topographical, demographic, and economic factors (Jeyaraj et al., 2021). Furthermore, manageable formulas can be obtained from the Poisson model, resulting in broader performance characterization and understanding (Nashwan & Nashwan, 2021) .

Two common FFR deployment modes are Strict FFR and Soft Frequency Reuse (SFR). FFR may be applied in either the uplink or downlink; however, this study concentrates on the downlink, as it typically accommodates links with greater rate demands and diminished interference tolerance. Moreover, in contrast to the uplink, power regulation may be disregarded by presuming uniform power in the downlink (Hikmaturokhman et al., 2023; Novanana & Hikmaturokhman, 2023).

This study addresses the research gap by analyzing the implementation of SFR in Bandung City, a major urban center in Indonesia with dense urban, urban, and suburban areas. The study aims to optimize interference management and resource allocation to enhance LTE network performance. Contributions include (1) a detailed evaluation of SFR in diverse urban scenarios using empirical data, (2) comparative performance analysis of SINR, RSRP, and throughput, and (3) the introduction of a novel proportional resource allocation strategy.

1.1 *Strict FFR*

Strict Frequency Reuse (FFR) is a modification of traditional frequency reuse commonly utilized in multi-cellular networks (Lu, 2022; Musa et al., 2022; Salmeno & Iskandar, 2022). Figure 1 (a) illustrates the strict FFR for a hexagonal grid model deployment with a cell edge reuse factor â = 3. Users in each cell are allocated a common frequency subband and the bandwidth for cell edge users is apportioned among cells according to the reuse factor â. In total, Strict FFR necessitates ±1 subbands. Indoor users do not share spectrum with outdoor users, hence minimizing interference for both indoor and cell-edge users.

1.2 *SFR*

Figure 1 (b) shows the SFR deployment at the cell-edge,for reuse factor â = 3. SFR uses the same cell-edge,bandwidth partitioning strategy as Strict FFR, but allows,interior users to share subbands with edge users in other cells. Users inside a cell typically transmit at lower power than users at the cell edge due to sharing the bandwidth with neighboring cells. While SFR is more bandwidth efficient than Strict FFR, it causes more interference to both cell-interior and cell-edge users (Supriadi & Putri, 2020).

Bandung-Indonesia is the third largest city in Indonesia after Jakarta and Surabaya with a population of 2,389,720 until 2024, and with a population growth rate of 0.502% (Giswara & Indrawati, 2018). Due to the largest metropolis city with an area of 167.7 km^2 , Bandung is in dire need of an LTE network that can reach all areas of Bandung. With 70% of the population using LTE technology, customer traffic is increasing and the need for Internet access is arising. Thus, the interference management is designed for LTE frequency 1800 MHz. By using this SFR method, frequency allocation can be made to improve the SINR of users that could reach all areas of Bandung city under high capacity conditions and therefore, make the LTE network work optimally.

2. Literature review

Recent advancements in interference management focus on adaptive techniques, including machine learning-based frequency reuse and dynamic spectrum allocation (Zhao et al., 2023). However, these methods often lack practical deployment strategies. This study emphasizes the practicality of SFR by integrating capacity and coverage planning in urban settings.While foundational studies on FFR and SFR provide essential insights, this research updates the context with references from 2020-2024, emphasizing their relevance in modern network scenarios. The proposed methodology highlights the adaptability of SFR to evolving traffic conditions, distinguishing this work from earlier approaches.

In this paper, the authors propose a fractional frequency reuse (FFR) system to manage inter-cell interference in cellular networks by splitting the frequency bandwidth into two orthogonal bands. Users near the center of a FFR cell use a band with a frequency reuse (FR) factor of one (full FR), while users near the cell edge use a band with a FR factor greater than one (partial FR). The study highlights the importance of full FR coverage, which distinguishes between full FR and partial FR regions within a FFR cell, on system performance. The authors previously investigated optimizing full FR coverage to maximize system throughput and found that, under a specified target outage probability, the optimal full FR coverage is a non-increasing function of base station power when all base station powers are scaled equally. Interestingly, this paper demonstrates that as the power of a single base station increases, the optimal full FR coverage in that cell also increases. These findings provide valuable insights into designing full FR coverage in relation to base station transmit power, enhancing the understanding of the relationship between key FFR system parameters and base station power (Seo et al., 2023) and In this paper (Adu et al., 2020; Chang et al., 2020) , In this paper, the authors address the challenge of decreasing power system inertia due to the increasing penetration of Renewable Energy Sources (RESs). They propose a Fast Frequency Response (FFR) technique for wind turbines equipped with Doubly Fed Induction Generators (DFIG). The method involves controlling the DC-link of a DFIG unit to partially exchange energy during frequency transients, thereby providing FFR to help maintain grid stability. This control is achieved by adjusting the DC-link voltage, with supercapacitor units connected to the DC-link providing the necessary energy for FFR services. The authors perform a detailed analysis to determine the minimum DC-link voltage required for the proper operation of the grid side converter and the factors affecting its value. They also propose a procedure to estimate the optimal value for FFR controller gain and a DC-link protection scheme that decouples the FFR controller design from the grid characteristics. This method can be applied to any RES using a converter with a sufficient energy buffer to provide FFR service. The findings suggest that in real-world environments, these methods can optimize system capacity and performance, providing a suitable model for practical applications (J. Wei & Tian, 2021). In a soft frequency reuse scheme or algorithm, each eNb uses the entire system bandwidth for transmission. Within a cell, there are two subband frequencies provided at different power levels within U. UEs at the cell center share the entire bandwidth with neighboring cells and transmit less power at the center than edge cell users. The Soft-Frequency-Bandwidth scheme is more bandwidth efficient than Strict-FrequencyReuse since it utilizes the entire system bandwidth. The drawback of this scheme is that it creates more interference not only within the cell but also to edge users.

In (Nema et al., 2023) In this paper, the authors address the challenge of reduced system inertia and high Rate-of-Change-of-Frequency (RoCoF) caused by the bulk integration of Renewable Energy Sources (RES) into power grids. They propose an improved Fast Frequency Response (FFR) through the optimal utilization of a Battery Energy Storage System (BESS). The method involves designing a compensator for BESS to provide FFR, deploying BESS in fractions rather than integrating the entire capacity at once during grid frequency events. Optimal parameters for the BESS compensator with an inverter are determined using various performance indices estimated by multiple metaheuristic optimization algorithms. The system frequency dynamics are analyzed with and without the BESS response, and numerical analysis reveals that the proposed BESS compensator improves system performance by 80.9% during grid frequency events.

In (Wang et al., 2020), the authors address the challenge of monitoring all operating parameters in large-scale engineering systems due to the numerous technical indicators and constraints on sensor installation. They propose a fault feature reduction (FFR) based approach for optimal sensor placement to enhance fault detection and diagnosis. The method involves analyzing fault-symptom relationships using fault tree analysis and constructing a Boolean matrix to represent these relationships. By eliminating redundant fault features, the authors determine the best sensor configurations. The proposed approach is validated on three large-scale systems, including a diesel engine and two chemical systems, demonstrating its effectiveness in meeting real-world monitoring requirements and showing improved performance compared to existing techniques. This approach can be applied both at the design phase and during the lifecycle of the system to optimize sensor placement.

In (Sathya et al., 2021) presents a novel methodology for managing resources and interference in dense small cell networks. The methodology, RAPTAP, is inspired by sociological theories and involves a two-stage approach. The first stage uses a centralized scheduling algorithm (RAPTA) that formulates a Mixed Integer Non-Linear Programming (MINLP) problem to optimize resource block allocation and power transmission. Due to the complexity of solving the MINLP problem, a heuristic algorithm (RAPTAP) is derived to perform these tasks in polynomial time. The results demonstrate that RAPTAP achieves a 60.67% improvement in service quality compared to traditional algorithms, with only a marginal 4% drop in overall system throughput compared to the optimal RAPTA algorithm. However, the study notes that the heuristic approach, while effective, may not always achieve the absolute optimal performance, indicating a trade-off between computational efficiency and optimality. RAPTAP and FFR both aim to manage interference and optimize resource allocation in wireless networks. FFR divides the available spectrum into different frequency bands and assigns them to different cells to minimize interference. Similarly, RAPTAP uses a socio-inspired approach to dynamically allocate resources and manage interference. While FFR is more static in its allocation, RAPTAP's heuristic algorithm allows for more adaptive and real-time adjustments based on network conditions. This adaptability makes RAPTAP particularly effective in dense small cell environments where traffic conditions can change rapidly.

This research primarily contributes a novel analytical methodology for assessing coverage probability and average rate in strict FFR and SFR systems. These measurements are crucial, particularly for cell-edge users, as contemporary mobile networks must deliver high data rates and assured quality of service irrespective of geographic location, rather than merely meeting a minimal SINR requirement. Consequently, it is applicable for uses such as voice traffic. This research demonstrates that, when compared to an actual deployment of urban e-NodeB, the grid model establishes an upper bound on real performance due to its idealization of network topology, whilst the Poisson model framework offers a lower bound. Moreover, the analytical expression for the SINR distribution simplifies to a straightforward function of the primary FFR design parameters when examining a specific scenario pertaining to perturbation-limited networks. The system policy demonstrates that although strict FFR offers superior coverage probability for edge users compared to SFR at low power control factors, SFR systems can enhance coverage performance by augmenting the power control factor for cell-edge users, thus improving overall coverage efficacy. The efficacy of per-cell frequency reuse is estimated without sacrificing the spectral efficiency linked to stringent FFR. This paper proposes an approach for the best allocation of frequency subbands to edge users for SFR and FFR, contingent upon a designated TFR threshold potentially associated with network traffic load. Numerical results indicate that the SINR proportional resource allocation strategy elucidates the selection of FFR parameters that optimize the sum-rate for universal or cell-wise reuse, while effectively distributing sub-bands to enhance coverage for edge users based on their traffic load or coverage needs. In the subsequent section, we elucidate the system model and its assumptions.

3. Method

The SFR method is characterized by the use of a frequency reuse factor (FRF) of 1 for cell center areas and FRF > 1 for areas near cell borders. In the SFR method, 1/3 of the available bandwidth is allocated to users at the cell edge with stronger sending power. The other subcarriers are assigned to users in the cell center with low transmit power. Users at the cell edge can only use subcarriers at the cell edge, while users at the cell center can access the entire available bandwidth with low priority to be able to access subcarriers at the cell edge compared to users at the cell edge. The maximum power and number of subcarriers provided are divided into 2 for cell center and cell edge. The subcarrier at the cell center is called the minor subcarrier, while the subcarrier at the cell edge is called the major subcarrier. Therefore, the major subcarrier has stronger power than the minor subcarrier. However, the number of major subcarriers has a smaller number than minor subcarriers .

$P_C / P_E = \alpha$ ……………………………………………………………………………………1)

$P_C + P_E = P_{MAX}$ …………………………………………………………………………………....2)

P_C = Total power for users in the center cell, P_E = Total power for users at the cell edge, P_{MAX} = Maximum transmit power, and α = Power Splitting Factor.

In the SFR method, the total number of available subcarriers in a cell is called Ntotal. Then, the number of subcarriers allocated to users at the cell center (Ninner) and at the cell edge (Nouter) is calculated by Equations 1 and 2 .

$Ninner = [\,Ntotal\,\left(\frac{rinner}{R}\right)^2]$ ……………………………………………………………………..3)

$Nouter = \min\left[\frac{Ntotal}{3}\right], Ntotal - Ninner$ ………………………………………………………….4)

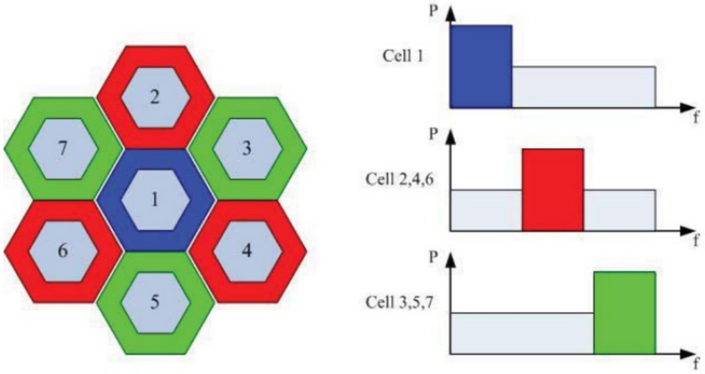
N_{total} = Total number of subcarriers, N_{inner} = Number of subcarriers in cell center, N_{outer} = Number of subcarriers in cell edge, r_{inner} = radius for cell center, and R = cell radius.

This research was conducted by dividing into three areas which are dense urban, urban, and sub urban.

3.1. *SFR Algorithm*

The cell splitting mechanism is comparable to that of the stringent FFR system. However, a Macrocell User Equipment (MUE) in a cell's center zone may use subbands of cell edge zone MUEs from surrounding cells in the cluster. For a cluster of N cells, the entire number of subchannels available in a cell is divided into N subbands, with one sub band assigned to each edge. Figure 1(i) depicts a mobile network with a soft FFR deployment. Figure 1(ii) depicts the deployment of the soft FFR scheme with FRF of 3 for edge zone MUEs. The entire frequency range is divided into three sub bands: A, B, and C, which correspond to the cell-edge zone UEs of macrocells 1, 2, and 7. The center-zone MUE device of macro cell 1 may use subbands B and C (i.e., the subbands of cell-edge zone MUEs of macro cells 2 and 7).

In this scheme in Figure 1., MUEs in both center and peripheral zones are subject to perturbations from stage 1 macrocells as in Figure 1. A power control factor (ε) was included for MUEs in edge zones to reduce inter-cell interference. This occurs when MUE device m is in the middle zone. If MUE device m is in the center zone, the transmit power from the tagged macrocell e-NodeB (referred to as MeNBs) MeNB is P_m^k on subchannel k, however if the MUE device is in the edge zone, the transmit power is εP_m^k $(\varepsilon > 1)$. The optimal number of subchannels assigned to center zone MUEs is the same as in the stringent FFR situation, and the total number of subchannels allotted to edge zone MUEs is as follows: $K_{edge} = \min(K_{band}/N, K_{band} - K_{center})$. One of the biggest advantages of soft FFR is that it has better spectral efficiency than strict FFR.



(a) (b)

Figure 1. SFR Scheme

3.2. *Proposed Method*

Using the common macrocell frequency allocation scheme, a frequency allocation scheme for hybrid macrocell networks is presented. The proposed allocation techniques could enhance the cohabitation of the two types of networks. These proposed allocation strategies are deemed fixed due to unrequired coordination or macrocell signaling. In this analysis, the assumption is made that the network is incorporates macrocells from an LTE system. The macrocells are positioned in the central zone, and the MUEs are evenly dispersed within them. The suggested SFR system divides the macrocell's coverage into two portions, namely core and periphery zones, each of which contains three sectors as shown in Figure 2. The core cells are labelled Z1, Z2, and Z3, whilst the periphery cells are labelled X1, X2, and X3. To achieve the segmentation of the outer regions X1, X2, and X3, the macrocell needs to use three sectorized antennas, each with a sector width of 2π/3.

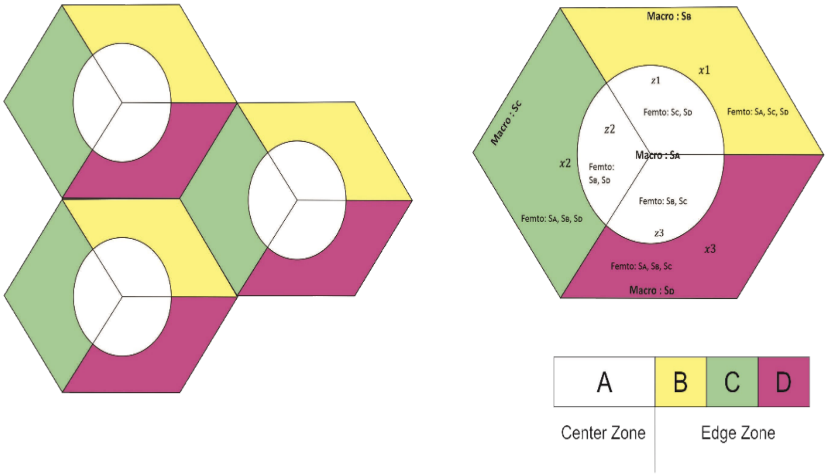


Figure 2. The proposed scheme

Figure 2 illustrates the SFR frequency allocation, with green and red frequencies representing cell-center and cell-edge subcarriers.

The research models e-NodeB deployment using Poisson Point Processes (PPP) to reflect the variability of urban infrastructure. The SFR method divides cell coverage into center and edge zones, with proportional SINR-based resource allocation ensuring optimal performance.

Key Assumptions

1. Propagation model: Cost-231
2. Uniform user distribution across the study area
3. LTE operating frequency: 1800 MHz

Resource Allocation

The proposed strategy assigns:

- Higher power to cell-edge subcarriers for better SINR.
- Full bandwidth access for cell-center users with lower priority on edge subcarriers.

3.3. *Transmit power allocation at SFR*

Tables 1–4 provide detailed data on power, bandwidth, and subcarrier allocations. Frequency planning for the SFR interference management scheme is described in Table 1. Table 1 shows the allocation for the 15 MHz bandwidth. The frequency division pays attention to the 3GPP standard bandwidth allocation, with a total bandwidth of 15 MHz. All available bandwidth is maximally utilized.

Table 1. SFR Transmit Power and Bandwidth Allocation

Cell	Area	Power (Watt)	Bandwidth Channel (MHz)	Frequency (MHz)
1	Cell Centre	10	10	1805 – 1815
2			10	1800 – 1805 & 1811 – 1815
3			10	1800 – 1810
1	Cell Edge	30	5	1800 – 1805
2			5	1806 – 1810
3			5	1811 – 1815

Table 2 presents the total subcarriers allocation data for LTE network planning using SFR method.

Table 2. Total Subcarriers Data Allocation

Area	Bandwidth	Resource Block (RB)	Subcarriers	Total Subcarriers	Total Subcarriers per Sector
Cell Centre	10 MHz	50 RB	600	9000 KHz	9000 KHz
Cell Edge	5 MHz	25 RB	300	4500 KHz	4500 KHz

For subcarrier allocation for these three different areas (Dense, Urban and Sub Urban) using the SFR method based on the equations 1 and 2 are presented in Table 3 while the parameters of power, bandwidth, and subcarrier allocations are presented in Table 4.

Table 3. Subscriber Allocation for Each Area Type

Method	Area	Radius (m)	Subcarrier Allocation	
			N_{inner}	N_{outer}
SFR	Dense Urban	193 m	5967	Min. (4500 – 7533)
	Urban	306 m	5967	Min. (4500 – 7533)
	Sub Urban	493 m	5980.5	Min. (4500 – 7519.5)

Table 4. Power, Bandwidth, and Subcarrier Allocations

Parameters	Area	Value
Power (W)	Cell center	10
	Cell edge	30
Bandwidth (MHz)	Cell center	10
	Cell edge	1 sector = 5 MHz

Next, The model classification was determined based on the type of service required in each area. Throughput calculations were then performed to estimate both network-wide and per-cell throughput. These values served as the basis for calculating the number of required sites in the service area, resulting in 176 sites. Additionally, cell radius calculations were conducted for each geographic scenario. From the calculation, the cell radius for Dense Urban is 0.55 km, Urban is 0.59 m, and Sub Urban is 0.59 km.

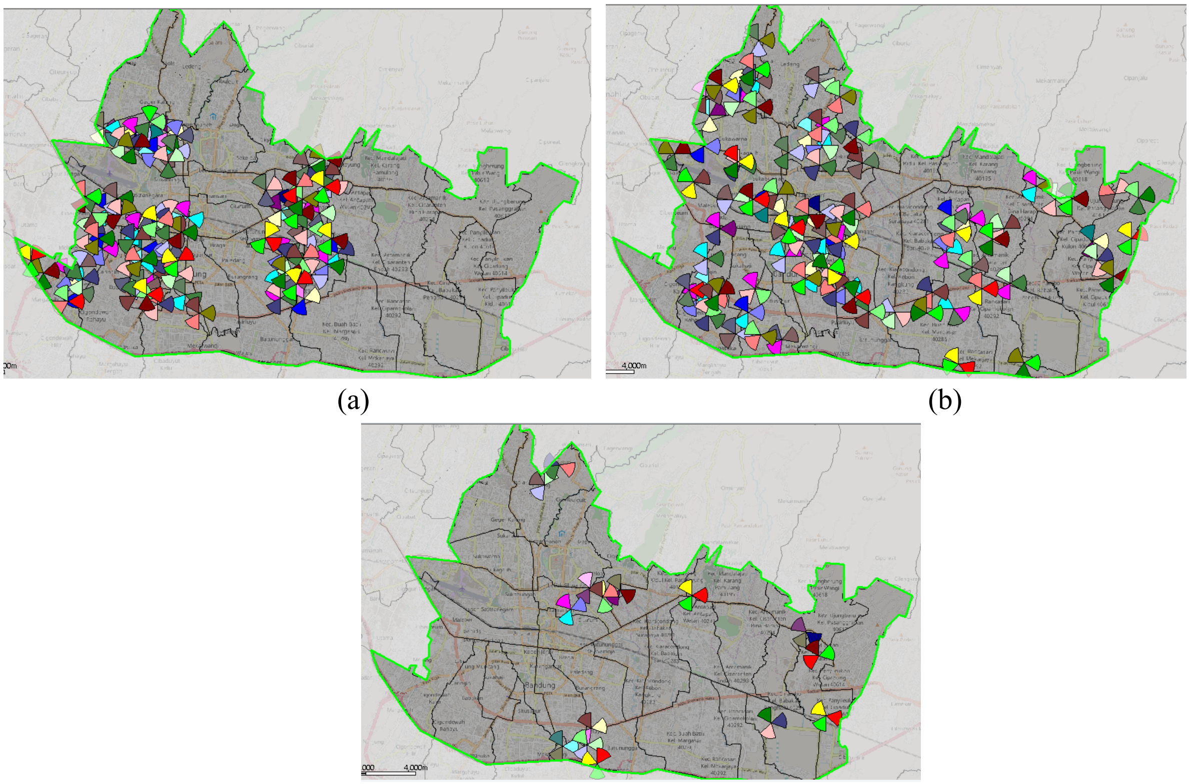
Simulations were conducted for three geographic scenarios:

- Dense urban (radius: 0.55 km)
- Urban (radius: 0.59 km)
- Suburban (radius: 0.59 km)

These radius values align with the propagation model used and reflect differences in infrastructure density and user distribution. The simulation results provide insight into how network planning must adapt to meet specific geographic and service demands.

4. Result and Discussion

Network design with the SFR method in capacity planning is implemented to 176 number of sites. The sites are spread across all sub-districts in Bandung City. The site conditions are depicted as in Figure 3.



(a) (b)

(c)

Figure 3. (a) Dense Urban Sites (b) Urban Sites (c) Sub Urban Sites

Figure 3 depicts the site deployment conditions across dense urban, urban, and suburban areas in Bandung City. These site layouts were derived from simulation results, which consider signal propagation, user density, and geographic characteristics. The dense urban area's higher e-NodeB density aims to address higher traffic demand and mitigate interference in a highly populated region. In contrast, the urban area balances node placement and traffic load, resulting in optimal throughput. The suburban area's sparse deployment reflects lower user density, leading to reduced SINR values but acceptable service coverage. These geographic insights validate the necessity of customized network planning for varying urban scenarios.

Table 5 presents the SINR and RSRP test results. Dense Urban has stronger signals and better signal quality than other environments, although interference challenges remain. Urban shows a slight decrease in both signal strength and signal quality, which is expected due to a more balanced number of e-NodeBs and users. Sub Urban has the weakest signal with the lowest signal quality, in keeping with peripheral environments that have less communications infrastructure. The drop in quality in Sub Urban may impact the user experience, especially for services that require a strong signal such as video streaming or video calling.

Table 5. SINR and RSRP Parameter Test Results

Parameter	Dense Urban	Urban	Sub Urban
RSRP (dBm)	-94.39	-99.86	-107.96
SINR (dB)	26.64	23.02	17.44

Furthermore, observations were also made on two other parameters, namely throughput and the number of connected users. Table 6 presents the final throughput data obtained in the planning area.

Table 6. Throughput Parameter Test Results

Parameter	Dense Urban (Gbps)	Urban (Gbps)	Suburban (Gbps)
Downlink Throughput	1.9021	1.08988	0.4309
Uplink Throughput	0.1207	0.6154	0.218

Table 7 shows the value of the number of connected users.

Table 7. User Connected Parameter Test Results

Parameter	Dense Urban	Urban	Sub Urban
Connected User	45,356	165,755	10,666
Percentage Connected User	33.7 %	19.7 %	26.1 %
Rejected User	2,490	18,714	4,403
Percentage Rejected User	66.3 %	80.3 %	73.9 %
Total User	47,846	184,469	15,069

Tables 5–7 summarize SINR, RSRP, and throughput results. Key findings include: Dense urban areas exhibit the highest SINR (–26.64 dB) but lower throughput due to interference from densely packed e-NodeBs.Urban areas achieve the highest throughput due to balanced infrastructure and traffic load. Suburban areas face reduced signal quality (–17.44 dB SINR) due to limited infrastructure.

Based on the test results of these three different areas, the highest average Throughput is found in urban areas for both downlink and uplink. This indicates that the network infrastructure in urban areas is generally better compared to dense urban and sub urban areas. It is likely due to the high user density in urban areas which encourages service providers to increase network capacity. Although dense urban areas are very densely populated, the average Throughput in these areas is actually lower compared to urban areas. This is due to several factors, such as higher signal interference due to the density of buildings and users, or limited network infrastructure capacity that cannot keep up with the high demand. As expected, sub-urban areas have the lowest average speed due to the lower population density. Thus, investment in network infrastructure is not as intensive as in urban and dense urban areas.

Urban areas have the highest number of connected users in absolute terms. Although the percentage of connected users in urban areas is not the highest, the total number of users who successfully connected is much higher compared to other areas. Suburban areas have the highest percentage of connected users. This indicates that a higher proportion of users are successfully connected in this area compared to the urban and dense urban areas. However, the total number of connected users in the sub-urban area is much lower because the total number of users is also smaller. Urban areas have the highest number of rejected users in absolute terms, and the percentage of rejected users is also quite high. This may be due to the very high network load in urban areas due to the large number of users. The results of this test have several important implications. Suburban areas have a relatively better quality of service as measured by the percentage of users who successfully connect. However, the network capacity in these areas may be more limited to accommodate a larger number of users. Urban areas experience very high network load, resulting in frequent connection denials. Service providers need to increase the network capacity in these areas to meet the growing demand. Furthermore, service providers need to consider the differences in population density and service requirements in different types of areas when planning network development.

SFR is compared with Strict FFR and FFR-3. The results confirm that SFR provides superior SINR and throughput under high traffic conditions while maintaining lower interference levels. Poisson Point Processes (PPP) modelling effectively simulates the diverse deployment of e-NodeBs in Bandung City. This approach enhances the generalizability of the findings to other urban centres with similar characteristics.

5. Conclusion

This study demonstrates the effectiveness of SFR in optimising LTE network performance across diverse urban scenarios. Urban areas achieve the highest throughput due to balanced infrastructure and traffic, while dense urban areas face interference challenges. The findings emphasise the need for tailored resource allocation strategies and validate SFR’s capability to optimise interference management in modern LTE networks.

Future work will explore the integration of SFR with advanced machine learning techniques to enhance its adaptability to dynamic traffic conditions further.

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