Extra Buffer, Less Suffer: A Quantitative Descriptive Analysis of Last-Mile Mobile Internet Performance in Bacolor, Pampanga

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***Abstract*: This quantitative descriptive study investigates the engineering, infrastructure, and operational challenges affecting last-mile mobile data delivery for DITO, Smart, and Globe in Bacolor, Pampanga. Utilizing a dual-sampling methodology, empirical data was gathered from 82 mobile data consumers and 18 telecommunications engineers, triangulated with objective benchmark drive-test metrics. Findings reveal that while baseline connectivity is functional, network performance is highly variable and susceptible to severe peak-hour congestion. Benchmarking indicated that Smart delivered the fastest throughput (46.55 Mbps), Globe provided the strongest overall signal quality, and DITO achieved the widest LTE coverage (38.54% optimal RSRP). However, all providers experienced significant service degradation during peak evening hours, driven by high user density, backhaul bottlenecks, and limited spectrum capacity. Furthermore, environmental barriers specifically indoor signal loss and frequent power interruptions, exacerbated last-mile delivery issues. The study concludes that mitigating these bottlenecks requires a multi-faceted engineering approach. Key recommendations include expanding macro and microcell infrastructure, augmenting fiber backhaul capacity, integrating resilient hybrid backup power systems at cell sites, and streamlining local government permitting processes to accelerate digital expansion.**

***Keywords*: Drive-test benchmarking, Last-mile mobile connectivity, Network performance, Peak-hour congestion, Telecommunications infrastructure.**

1. Introduction

Communication is a crucial element in the development of culture and human society. It entails the sharing of ideas, information, attitudes, or emotions between two or more individuals (Biswa, 2018). Technology has greatly facilitated interpersonal communication. The advancement of technology has significantly enhanced individuals' lifestyles and has influenced every facet of existence. The evolution of communication strategies has significantly progressed from the earliest methods to contemporary forms. In the contemporary world, people possess instantaneous access to an astonishing variety of technologies and services that provide communication with nearly anybody, anywhere, at any time (Biswa, 2018). Additionally, prior to the development of the internet and various data networks, telecommunication had a straightforward definition, primarily encompassing the telephone or telegraph, which facilitated long-distance communication via voice and telephone services (Biswa, 2018). Today, the internet and mobile phones have emerged as fundamental necessities. Discussions surrounding telecommunication now predominantly emphasize the utilization of mobile devices and internet connectivity in everyday life. This shows that the contemporary mode of communication has become indispensable for nearly all individuals who depend on modern techniques just to stay connected.

As previously mentioned, telecommunication is very much incorporated into this contemporary world. Abbott (2019) described telecommunications as the relaying of information in its original form and content. Apart from that, it is characterized by multiple network segments—the backbone, middle mile, and last-mile—that illustrate the data's progression from a source, such as a data center or the internet, to the end user (Beranek, 2023). Among all the segments of telecommunication, the last mile is considered the weakest because it is often heavily affected by external factors such as physical distance, obstruction, and even environmental conditions. In the context of telecommunications, last mile is the last part of a network that connects an internet service provider's (ISP) core network to each subscriber. The last mile might be anywhere from a few hundred meters to several kilometers long, depending on where it is (What Is Last-Mile Connection? Understanding Its Role in Internet Infrastructure, 2025).

The last mile remains a significant obstacle to the delivery of dependable and superior mobile internet services in many nations, including the Philippines. It often relies on wireless technologies, such as cellular towers, microwave links, or roadside tiny cells, in contrast to the backbone and middle mile infrastructure, which are typically anchored by high-capacity fiber networks. According to Navigating the Highways of Connectivity: Understanding 'Any Mile' of Network

Infrastructure (2025), these technologies are more vulnerable to problems like signal loss, tower capacity overload, geographical barriers, and environmental interruptions.

In the Philippines, the provision of last-mile mobile data is primarily managed by the three major telecommunications companies: DITO, Smart, and Globe. These entities, classified as mobile network operators (MNOs), deliver mobile communication services and oversee a complex infrastructure encompassing support systems, core networks, and radio access networks. MNOs are responsible for delivering diverse services to mobile subscribers, managing spectrum allocations, and ensuring network security (Telecom Trainer, 2023). Despite these operators' maintenance of nationwide infrastructure and standardized service provisions such as 4G, LTE, and 5G, the last-mile segment of the network, where radio signals directly interact with user devices, is the critical point at which consumers perceive mobile data quality. Therefore, even when end users have the same service provider and data plan, the quality of service they experience can differ significantly depending on where they are located (Brewer et al., 2022).

In semi-urban and rural areas, characterized by reduced tower density and potential signal obstructions such as structures, elevated landscapes, or dense vegetation, the variability in internet service quality among providers is especially pronounced (The Last-mile Internet Connectivity Solutions Guide, n.d.). These constraints make the last mile a crucial factor in the practical performance of mobile internet, which in turn affects user experiences related to speed, latency, and reliability. Consequently, a thorough understanding of last-mile dynamics is essential for identifying the underlying causes of variable mobile internet performance and for developing effective strategies for improvement (Brewer et al., 2022).

Considering these challenges associated with last-mile connectivity, it becomes essential to examine how such conditions manifest in specific local environments. With that, Bacolor Pampanga is chosen as the research setting. It has 21 barangays with significantly varying population density (Bacolor at a Glance, 2017). The municipality of Bacolor covers 71.70 square kilometers (27.68 square miles), accounting for 3.58% of Pampanga's total area. Furthermore, the population as of the 2020 Census was 48,066. This accounted for 1.97% of the total population of Pampanga province, or 0.39% of the entire Central Luzon area. Based on these numbers, the population density is calculated as 670 people per square kilometer or 1,736 people per square mile, implying that the municipality is moderately dense (Bacolor, Pampanga Profile – PhilAtlas, 2020). In terms of topography, Bacolor has an average elevation of 8 meters and is classified as non-forest with flat terrain and a downward sloping area (Bacolor at a Glance, 2017).

Apart from that, geographic orientation plays a major role in the quality of signal received. A strong mobile phone signal requires line of sight, so essentially any object can obstruct a cellular signal, reducing reception.

This may include vegetation, as forested areas can interfere with cellphone reception, as well as terrain such as hills, mountains, or ridges, all of which can contribute to poor cellular signals (Wilson Connectivity, n.d.). Also, flat terrain and a downward sloping area are susceptible to extreme weather conditions such as flooding and heavy rain. Mobile signals travel via radio waves that can be affected by rain. Raindrops in the air function as tiny barriers, absorbing and scattering the waves. As such, rain absorbs the signal's energy, diminishing its power (Why Does Your Mobile Signal Get Weaker on Rainy Days? Why Does Your Mobile Signal Get Weaker on Rainy Days? 2025).

Considering the elements that affect mobile data quality and reliability across the country, particularly in rural and semi-urban areas like Bacolor, it is imperative to have a deeper understanding of how things actually are on the ground. With that, the objective of this quantitative descriptive study is to measure and analyze the current performance of mobile data networks in Bacolor, Pampanga using measurable network indicators such as download speed, upload speed, latency, signal strength, and connection stability. More so, the study aims to quantitatively describe the condition of last-mile mobile data delivery and identify patterns in network performance that may indicate engineering, infrastructural, operational, and environmental factors affecting mobile internet service, ultimately providing data-driven recommendations to improve overall mobile network performance.

Peltola and Hämmäinen (2018) found a strong link between population density and signal strength. The higher the population density in each location, the lower the mobile data signal quality produced, regardless of the number of telecommunication towers. Additionally, more sparsely inhabited rural areas have frequently been left behind as telecommunication service providers concentrate on providing services in densely populated areas that offer a reasonably quick return on investment (Auer, Kronestedt, & Lindqvist, 2025). These significantly affect the reliability and quality of signal received by residents or anyone in the area who depends on strong mobile data delivery, much like in Bacolor.

This quantitative descriptive study aims to identify and analyze the engineering, infrastructural, and operational challenges affecting last-mile mobile data delivery of DITO, Smart, and Globe in Bacolor, Pampanga.

Specifically, the study seeks to answer the following questions:

1. What is the current level of last-mile mobile telecommunications connectivity in Bacolor, Pampanga?
2. What are the factors affecting peak-hour network congestion in mobile data connection reliability?
3. What is the geographical distribution of signal availability and mobile network coverage within selected areas of Bacolor, Pampanga?
4. What environmental or infrastructural conditions are associated with variations in mobile data performance?

5. Based on the measured performance data, what engineering insights can be identified to improve last-mile mobile internet delivery?

The research only examined the three primary mobile network operators: DITO, Smart, and Globe. All other operators were excluded from the research. It was restricted to mobile data services alone, excluding fixed broadband (fiber, DSL, cable) and satellite internet. This was to eliminate misunderstanding regarding the performance of mobile internet compared with fixed internet. The technical scope included download speed, upload speed, latency, signal strength, and connection stability. This study did not examine differences related to user devices, types of cellphones, operating systems, SIM card conditions, or individual user behavior.3. Materials and Methods

2. Methodology

In this study, quantitative descriptive research served as the optimal framework for identifying core characteristics, usage frequencies, and emerging trends within a specific population. To ensure the validity and reliability of the findings, a meticulously structured research design was employed. By utilizing standardized data collection instruments, this methodology provided a holistic perspective on complex research problems. A distinct advantage of the descriptive approach was its ability to capture data within the respondents' natural environment, thereby preserving data integrity and facilitating the analysis of large-scale populations (Ghanad, 2023).

The study utilized a dual-sampling strategy to gather both technical and user-centric data. Purposive sampling was employed to select telecommunications engineers and network specialists, ensuring that qualitative engineering insights were derived from respondents with specific technical expertise in last-mile delivery. Simultaneously, convenience sampling was applied to mobile data consumers within Bacolor, Pampanga, allowing for a broad and accessible collection of real-world performance data and user-perceived reliability metrics.

The primary data collection instrument for this study was a structured survey/questionnaire integrated with a 5-point Likert scale. The Likert scale served as a cornerstone instrument for quantifying attitudes and perceptions through a structured, multi-point rating system (Mohn, 2024). This instrument was designed to translate subjective user experiences regarding mobile data reliability into quantifiable data. The Likert scale allowed respondents to rate their level of agreement or satisfaction, ranging from Strongly Disagree to Strongly Agree, across various dimensions of network performance such as connection stability, peak-hour accessibility, and perceived signal strength. By utilizing this standardized format, the study ensured that consumer feedback could be statistically analyzed alongside objective engineering metrics.

A validated survey instrument utilizing a 5-point Likert scale was distributed to the convenience sample of mobile data consumers through Google Forms. This instrument measured perceived network reliability and the degree of mobile data performance experienced by end-users. Concurrently, structured questionnaires were administered to the purposively sampled telecommunications engineers. This expert feedback was critical in identifying underlying infrastructural hurdles, backhaul capacity limitations, and specific environmental challenges unique to the Pampanga region. By combining active network probes, environmental assessments, and targeted surveys/questionnaires, the study produced a comprehensive dataset required to formulate actionable engineering insights for improving last-mile mobile internet delivery.

To ensure the integrity of the research and the protection of its respondents, this study strictly adhered to established ethical standards in both quantitative research and engineering management. All data collection involving human subjects, specifically mobile data consumers and telecommunications professionals, complied with the provisions of the Philippine Data Privacy Act of 2012 (Republic Act No. 10173), which required explicit informed consent, voluntary participation, and the right to withdraw at any time without prejudice. To guarantee confidentiality, all personally identifiable information was sanitized from the final dataset, and raw data was securely stored exclusively for academic use.

Furthermore, recognizing the high sensitivity of infrastructural data associated with DITO, Smart, and Globe, strict boundaries were maintained with the purposively sampled engineers to ensure that no proprietary corporate information or critical network vulnerabilities were exposed. Finally, the researchers maintained absolute technical objectivity during the physical network benchmarking phase, ensuring that all empirical metrics related to signal strength, latency, and peak-hour congestion were recorded and reported exactly as measured, entirely free from manipulation or bias toward any specific telecommunications provider.

This descriptive quantitative study utilized descriptive statistical techniques, including averages, charts, and tables, to summarize user experience and perceived network reliability. These methods were used to examine temporal variations in network congestion and to compare network speed and coverage between peak and off-peak hours. Quantitative data gathered from both technical network benchmarking and structured survey instruments were processed and analyzed using descriptive statistics and comprehensive data visualization techniques.

3. Results and Discussion

This section presents the consumer survey, telecommunications engineer feedback, and the operator benchmark comparison for last-mile connectivity in Bacolor, Pampanga.

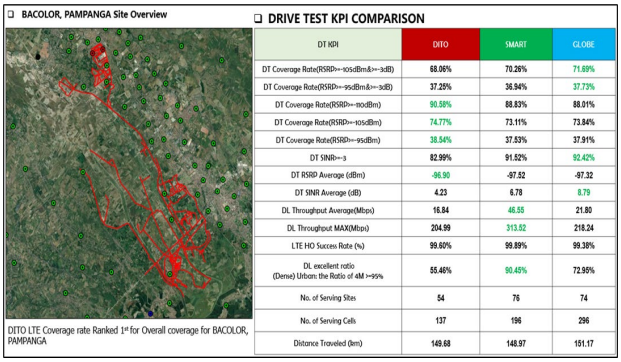


Fig. 1. Drive Test KPI Comparison of DITO, Smart, and Globe in Bacolor

Figure 1 showcases that conducting a benchmark comparison test provides an objective evaluation of the actual performance of the three major operators in Bacolor, Pampanga. This assessment generates valuable insights into the strengths and weaknesses of each telecommunications provider within the area. By analyzing and interpreting the results, stakeholders can identify which operator demonstrates superior service quality and where improvements are needed. Ultimately, this process supports evidence-based decision-making and guides future enhancements in mobile connectivity for Bacolor, Pampanga.

Coverage: DITO has the widest reach, but Globe and Smart are close behind.

Signal Quality: Globe gives the clearest signal, Smart is also strong, while DITO's signal is weaker.

Speed: Smart is the fastest by far, Globe is moderate, and DITO is the slowest.

Reliability (handover): All three are very reliable when switching towers, with Smart slightly better.

Urban Areas: Smart performs best in crowded places, Globe is decent, and DITO struggles.

Infrastructure: Globe has the most cell sites, Smart has a good balance, and DITO has fewer.

In Bacolor, Smart is the best overall thanks to its speed and reliability. Globe comes second with strong signal quality and wide infrastructure. DITO has good coverage but still needs improvement in speed and consistency

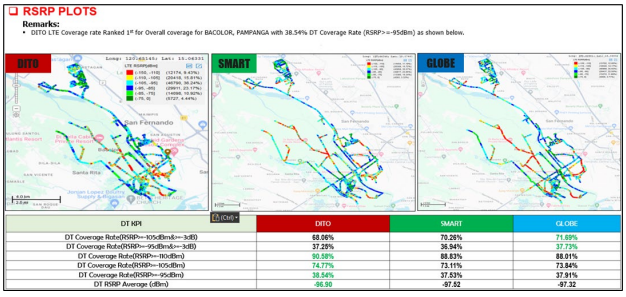


Fig. 2. Reference Signal Received Power (RSRP) Plots of DITO, Smart, and Globe in Bacolor

Figure 2 implies that in Bacolor, DITO provides the widest overall LTE coverage, meaning more areas get a usable signal. Globe delivers slightly stronger signals in the best spots, while Smart lags a bit in coverage strength but remains competitive.

DITO – Best reach
Globe – Strongest signals in good areas
Smart – Solid but slightly behind in coverage strength

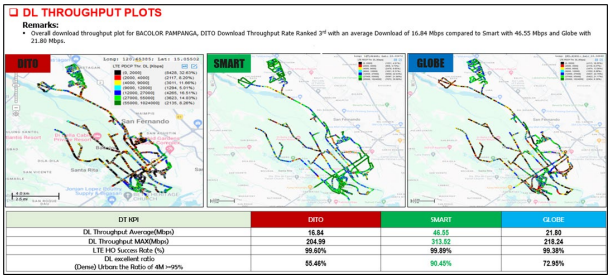


Fig. 3. DL Throughput Plots of DITO, Smart, and Globe in Bacolor

Figure 3 shows that in Bacolor, Smart clearly provides the fastest and most consistent internet speeds, especially in busy areas. Globe is a solid second choice, offering moderate speeds with good reliability. DITO ranks last in speed and consistency, though it still provides usable service.

Smart – Best for speed and reliability
Globe – Good balance, but slower
DITO – Usable, but behind the others

The study also gathered responses from a sample of 100 individuals, including 82 mobile data consumers and 18 telecoms engineers. The dual-sampling method guarantees that the analysis encompasses both user-perceived service performance and expert-level technical insights, consistent with the purposeful and convenience sampling strategy outlined in the methodology.

Table 1. Overall Network Experience Indicators

Overall Satisfaction	
Overall Satisfaction with Respondent's Mobile Network (Mean)	3.71
Quality Index (Mean)	3.43
Coverage Index (Mean)	3.69
Speed Index (Mean)	3.56

Table 1 implies that respondents indicate a moderately high level of satisfaction with their mobile network services. A score of 3.71 on a 5-point scale indicates that users encounter satisfactory service levels, however there is potential for enhancement, especially during periods of high demand or peak

hours.

The quality, encompassing video streaming performance, voice-call clarity, and latency, scores 3.43, signifying a more inconsistent user experience. This indicates that application-level performance (e.g., streaming, video conferencing) is generally less reliable than baseline connectivity.

The Coverage Index is robust at 3.69, indicating adequate signal availability and overall coverage throughout Bacolor's barangays. This corresponds with respondents indicating largely stable signal availability while several geographic weak points are addressed in subsequent sections.

A Speed Index score of 3.56 indicates moderate consumer satisfaction with network throughput. Users indicate improved speeds at off-peak hours, with significant decline during nighttime peak times.

The overall performance on all four parameters (Table 1) ranges from 3.43 to 3.71, which is in the middle to upper end of the Likert scale. This implies that Bacolor's mobile internet infrastructure is functional and largely reliable; nonetheless, users encounter reductions in quality and speed, particularly during peak-hour congestion period.

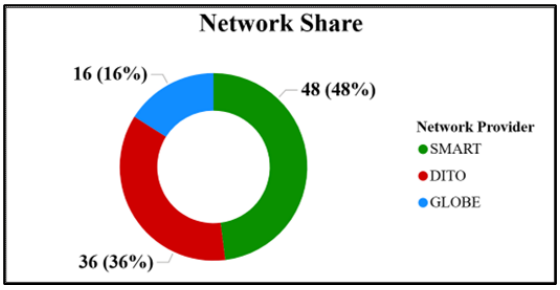


Fig. 4. Network Distribution among Respondents

Figure 4 shows that Smart holds the largest share among the respondents, followed by DITO, which reflects increased uptake due to competitive pricing and promotional data offerings. Globe comprises the smallest portion of the sample.

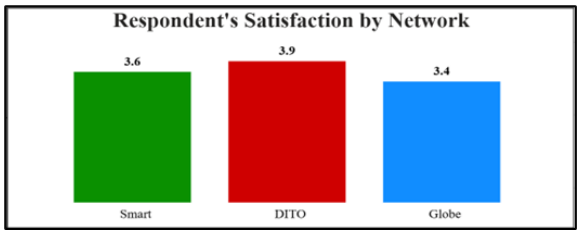


Fig. 5. Mean Satisfaction Scores across the Three Major Providers

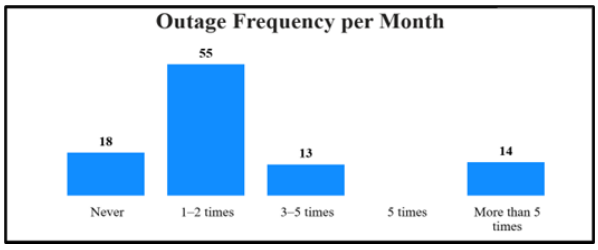


Fig. 6. Distribution of Mobile Data Outages Experienced per Month

Respondent satisfaction (Figure 5) and outage frequency (Figure 6) show an association between service reliability and user perception. DITO has the highest satisfaction score, 3.9, followed by Smart at 3.6 and Globe at 3.4. When outage frequency is considered, this trend becomes more pronounced: 55% of respondents report only 1–2 outages monthly, but 27% report three or more, indicating municipal instability.

DITO-like networks with fewer outages have greater satisfaction ratings. Smart and Globe users are less satisfied, matching the percentage of responders who experience greater disruptions. In Bacolor's mobile data context, reliability is vital to user experience, as outage frequency dramatically affects satisfaction.

Table.2. Barangay-Level Connectivity Assessment

Connectivity Heatmap

Barangay	Coverage Index	Speed Index	Quality Index
Balas	2.87	3.10	2.47
Cabalantian	3.36	3.41	3.18
Cabambangan	3.61	3.00	3.28
Cabetican	4.67	4.38	4.58
Calibutbut	4.14	4.14	3.95
Concepcion	3.83	2.50	4.33
Dolores	3.67	3.39	3.35
Duat	3.67	4.00	3.00
Macabacle	3.17	3.50	3.00
Magliman	3.67	3.40	3.73
Maliwalu	4.08	3.25	3.42
Mesalipit	4.67	4.50	3.67
Parulog	3.67	3.00	3.67
Potrero	4.33	3.83	3.78
San Antonio	5.00	5.00	5.00
San Isidro	3.54	3.66	3.08
San Vicente	3.60	3.50	3.47
Sta. Barbara			
Sta. Ines	3.78	4.50	4.00
Talba			
Tinajero			
Total	3.69	3.56	3.43

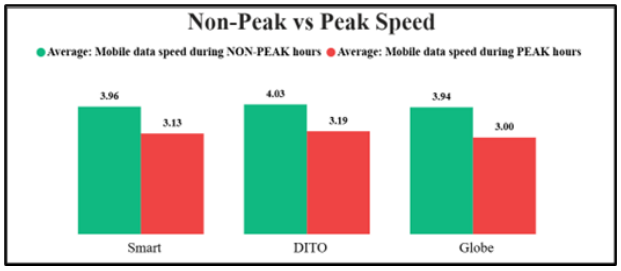


Fig. 7. Average Mobile Data Speed between Peak and Non-Peak hours

Bacolor's mobile connectivity performs well during off-peak hours but poorly during peak traffic. Figure 7 shows that all networks, Smart, DITO, and Globe, have remarkable non-peak

speed user experience (3.94–4.03), while peak speed user experience drop to 3.00–3.19. This shows that evening congestion limits providers.

The Connectivity Heatmap (Table 2) shows positive coverage and speed user experience at the barangay level, albeit with significant variation. San Antonio, Mesalipit, Potrero, and Cabetican consistently score well in coverage, speed, and quality. In contrast, Balas, Cabambangan, and Concepcion have lower numbers, indicating lower indoor penetration, throughput, or quality.

The Respondents' responses show that Bacolor's last-mile connectivity is functional yet inconsistent, depending on location and time. Standard load works well, but peak hours strain the system, affecting reliability and user experience.

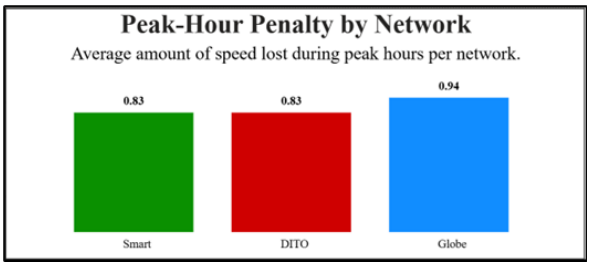


Fig. 8. Average Drop in Likert Speed Rating from Non-Peak to Peak (1–5 Scale)

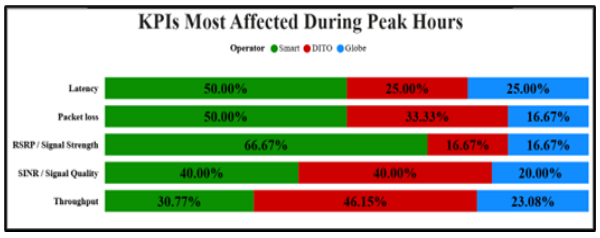


Fig. 9. Key Performance Indicators Most Impacted During Peak Periods, Such as Latency, Packet Loss, and Throughput, Based on Telecom Engineer Feedback

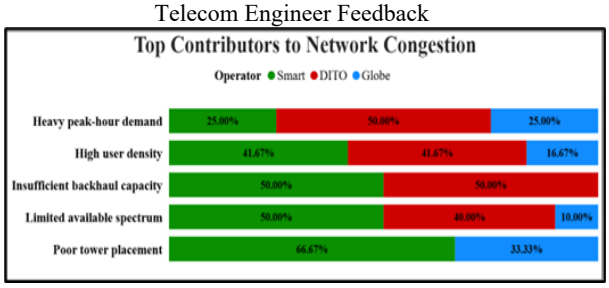


Fig. 10. Engineer-Identified Factors Causing Congestion

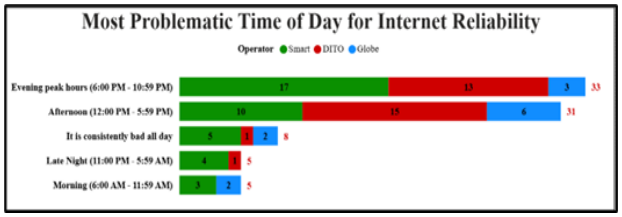


Fig. 11. Consumers' Time of Day when Poor Mobile Data Performance is Experienced

Survey results show that peak hour congestion affects all Bacolor networks, with users experiencing performance decreases under heavy traffic. The Peak Hour Penalty chart (Figure 8) shows that networks lose nearly 1 point in perceived speed during peak hours, with SMART and DITO losing 0.83 points and Globe 0.94. No matter the provider, traffic demand during the day significantly impacts throughput.

Technical response from telecom engineers supports these findings. Engineers consider latency, packet loss, signal strength (RSRP), SINR, and throughput the most critical KPIs during congestion windows (Figure 9). The degradations indicate cell site overload, signal quality loss, and link instability under excessive demand.

The Top Contributors to Network Congestion chart (Figure 10) shows the engineering causes of these trends. Engineers blame congestion on high user density, insufficient backhaul capacity, limited spectrum, and inefficient tower placement, which limit network performance during peak usage.

Consumer input matches engineering findings. According to the Most Problematic Time of Day for Internet Reliability (Figure 11), mobile data speed is worst in the evening (6 PM–10:59 PM) and afternoon. Heavy home use, streaming, gaming, and video calls increase network load during these times.

Peak hour congestion in Bacolor is caused by user-side traffic surges and infrastructure-level capacity restrictions, affecting throughput stability, latency, and service reliability.

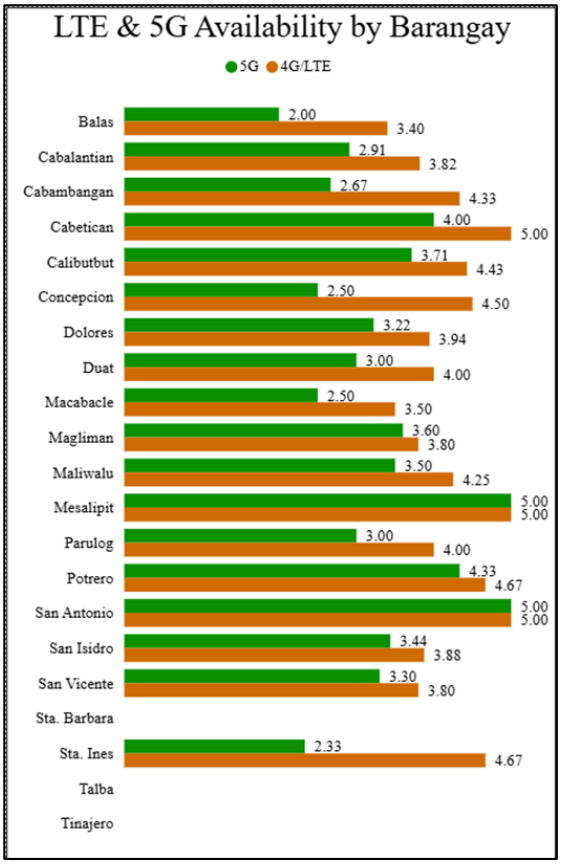


Fig. 12. Comparison of LTE and 5G Availability across Barangays

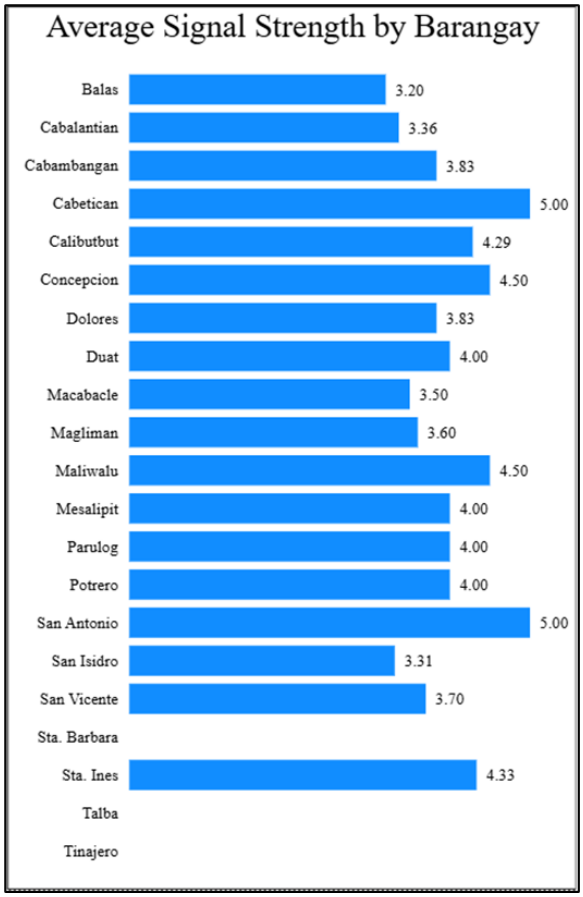
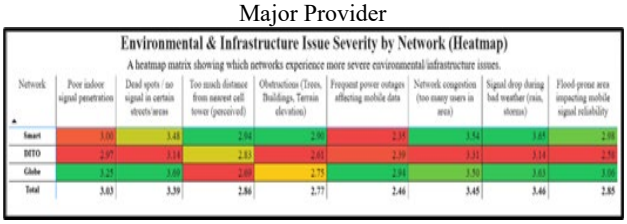


Fig. 13. Each Barangay's Average Signal Strength on a 5-Point Likert Scale

Survey results indicate strong mobile coverage in Bacolor, with significant variation across barangays based on 5-point Likert scales for LTE/5G availability and signal quality. Figure 12 demonstrates that Cabetican, Mesalipit, San Antonio, Potrero, and Sta. With reliable tower presence and advanced network infrastructure, Ines consistently rank 4–5 in LTE and 5G. Lower availability ratings in barangays like Balas, Cabambangan, Macabacle, and Cabalantian indicate weaker last-mile coverage or restricted 5G reach. According to the Average Signal Strength by Barangay chart (Figure 13), high-performing places like San Antonio, Maliwalu, Cabetican, and Concepcion score between 4.0 and 5.0, while lower-performing barangays like Balas and San Isidro score closer to the mid-range. Research shows that Bacolor has unequal coverage, with certain barangays having great connectivity and others having weaker reception and restricted access to next-generation technology.

Table 3. Common Environmental and Infrastructure Issues per Major Provider



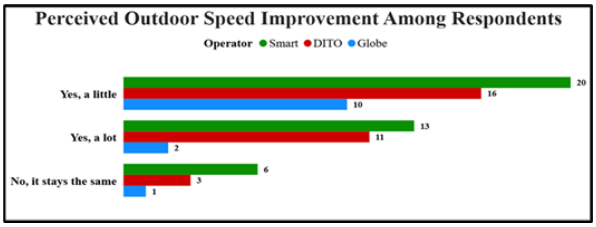


Fig. 14. Respondent's Service Improvement when Moving Outdoors

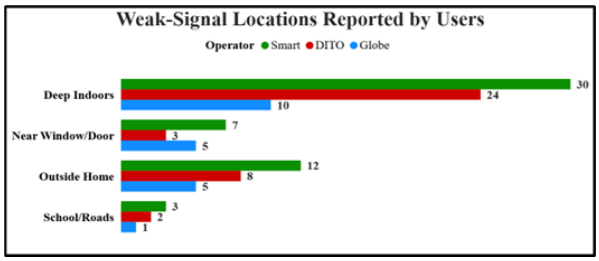


Fig. 15. Areas where Users Most Frequently Experience Weak Signals

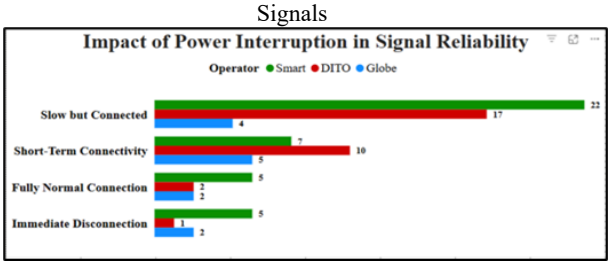


Fig. 16. Degradation of Mobile Signal Reliability During Power Interruption

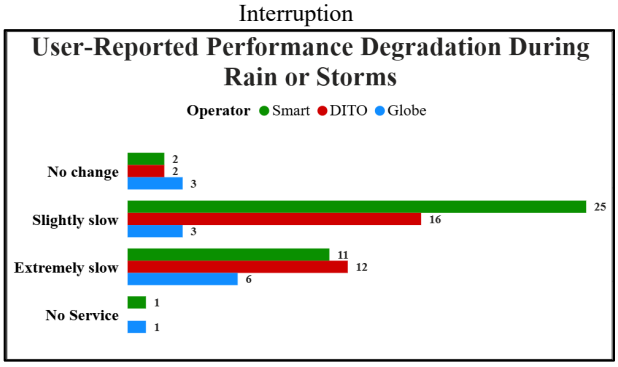


Fig. 17. Respondents' Mobile Data Usage Experience During Bad Weather

Results indicate that environmental and physical constraints impact last-mile mobile data performance in Bacolor. The Environmental & Infrastructure Issue Severity Heatmap (Table 3) shows that all networks encounter moderate challenges with indoor penetration, dead spots, impediments, and user-area congestion, with issue severity grouping around mid-Likert scores. Consumer feedback (Figure 14) shows that indoor conditions severely reduce signal penetration, since most respondents report faster speeds outdoors. The User-Reported Performance Degradation During Rain or Storms chart (Figure 17) highlights environmental sensitivity, as weather caused slow or severely slow connectivity for many users. Weak signal reporting (Figure 15) indicates structural concerns, with deep

indoor spaces being the most problematic and outside zones with uneven coverage following. Figure 16 illustrates how power supply volatility impacts real-time mobile performance, with brownouts often causing delayed or short-term connectivity. These findings indicate that environmental conditions, weather, and infrastructural limitations impact the reliability and consistency of last-mile mobile experiences.

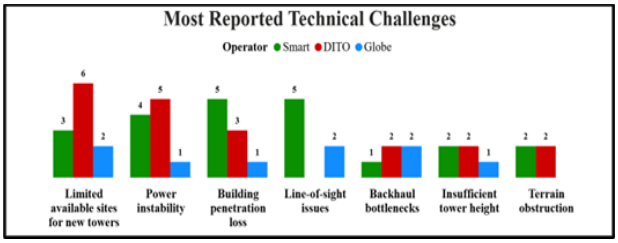


Fig. 18. Summary of Key Engineering Issues Affecting Network Performance

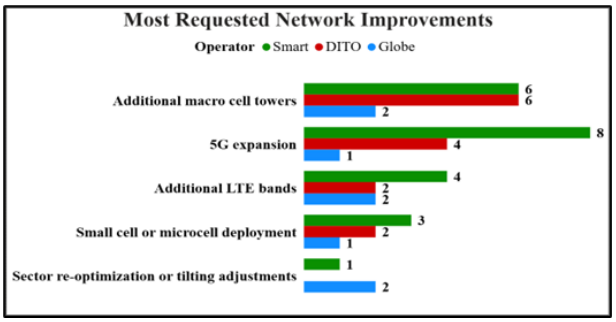


Fig. 19. Network Upgrades Engineers Believe are Most Needed

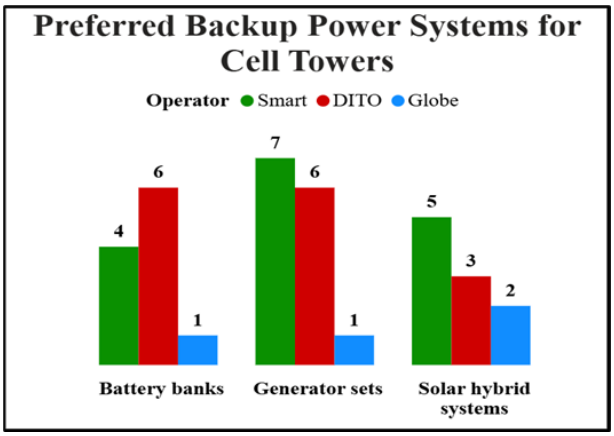


Fig. 20. Backup Power Solutions Most Favored by Engineers

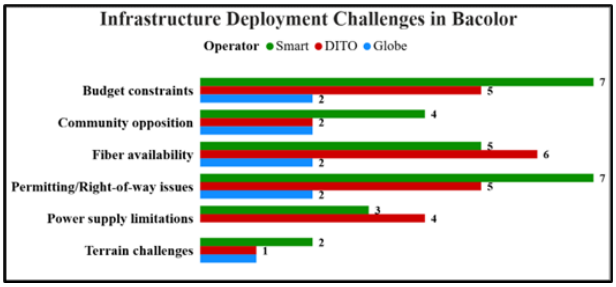


Fig. 21. Major Barriers to Infrastructure Expansion

Findings reveal Bacolor telecom engineers' top engineering difficulties and improvement goals. Figure 18 reveals that restricted tower site availability, power instability, building penetration loss, line-of-sight concerns, and backhaul congestion are the top technical challenges affecting network performance. According to the Most Requested Network Improvements chart (Figure 19), engineers prioritize macro cell towers, 5G extension, LTE bands, and small-cell deployment to improve coverage and capacity. Based on the Preferred Backup Power Systems chart (Figure 20), engineers prioritize generator sets and battery banks to prevent service disruptions during outages. In Figure 21, the Infrastructure Deployment Challenges chart identifies budget constraints, permitting/right-of-way limits, fiber availability gaps, and power supply concerns as important obstacles to infrastructure development. The study highlights the need for capacity enhancements and favorable infrastructure and policies to enhance last-mile delivery and enable scalable mobile network expansion.

4. Conclusion

This study examined the technical, environmental, and user-experience elements affecting last-mile mobile data performance within Bacolor Pampanga, employing a dual-sampling methodology involving 82 mobile users and 18 telecommunications engineers. To augment the survey and engineering perspectives, the study incorporated benchmark testing data facilitating an objective evaluation of the three principal operators, Smart, DITO, and Globe, concerning coverage, signal quality, speed, reliability, and infrastructure accessibility.

Benchmarking data revealed differences in operator performance. Smart provided the fastest mobile data speeds, averaging 46.55 Mbps. Globe followed with 21.80 Mbps, and DITO had an average of 16.84 Mbps. In contrast, DITO achieved the widest LTE coverage, with 38.54% of Bacolor areas experiencing strong signal conditions (RSRP $\geq$ –95 dBm), while Globe and Smart closely followed with slightly lower coverage strength. Globe demonstrated the clearest and strongest signal quality, whereas Smart, despite competitive coverage, excelled primarily in speed and consistency. All three operators maintained strong reliability during tower handover, with Smart showing a slight advantage in maintaining stable connections. These results emphasize that coverage and speed do not always align, and each operator maintains different performance strengths:

Smart: Fastest and most reliable speeds
DITO: Best in LTE reach
Globe: Strongest overall signal quality

Survey results aligned with these benchmark findings. Users consistently reported strong coverage and acceptable speeds during non-peak hours but experienced notable declines during evening peak periods. This drop in performance was

attributed to network congestion, constrained spectrum resources, and backhaul capacity limitations, all of which affected throughput and service stability. Environmental and infrastructural conditions further shaped user experience, including poor indoor penetration, frequent power interruptions, terrain obstructions, and weather-induced signal degradation during storms and typhoons.

Feedback from telecommunications engineers validated these challenges, identifying limited tower sites, backhaul bottlenecks, spectrum insufficiency, tower height issues, and power instability as the most critical technical obstacles. These engineering-reported limitations directly mirrored user-reported problems such as slow speeds indoors, weak coverage in specific barangays, and inconsistent performance during rain or brownouts.

The benchmark data and survey results, when considered collectively, offer a comprehensive perspective on Bacolor's mobile connectivity environment. While Bacolor typically experiences favorable mobile service, the quality of user experience exhibits considerable variation, contingent upon barangay location, time of day, and prevailing environmental factors. Smart distinguishes itself as the most consistently high-performing provider, delivering superior speed and stability; Globe offers excellent signal quality, supported by a robust infrastructure; conversely, DITO demonstrates the most extensive LTE coverage, though it necessitates enhancements in both speed and consistency.

The research findings indicate that mobile connectivity within Bacolor is significantly influenced by the interaction of technological factors, environmental conditions, and infrastructural elements. To improve last-mile performance, specific capacity enhancements are essential, alongside more robust backhaul and power systems, a broader deployment of towers and small cells, and supportive local government unit (LGU) policies that facilitate telecommunications infrastructure development. Consequently, bolstering these key areas will contribute to ensuring dependable, equitable, and future-proof connectivity for Bacolor's inhabitants in Pampanga.

A. RECOMMENDATIONS

To strengthen last-mile mobile internet delivery and ensure more reliable user experience in Bacolor, Pampanga, several improvements are recommended:

1) Improve Network Capacity and Coverage

To improve last-mile mobile performance in Bacolor, network service providers should expand their tower infrastructure. This can be done by building more macro cell towers and using microcells or small-cell systems in barangays with limited coverage, like Balas, Cabambangan, and Concepcion. Increasing the number of towers will not only extend service but also reduce network congestion and improve overall stability. Furthermore, continuing the 5G rollout, especially in areas where testing showed performance problems, will support greater capacity, higher data speeds, and better service quality.

2) Enhance Spectrum Resources and Strengthen Backhaul Efficiency

To boost site capacity and better manage traffic, it is advisable to allocate or reform more LTE spectrum bands. However, these spectrum enhancements need to be backed by upgrades to the fiber backhaul infrastructure. This will help to alleviate peak-hour congestion, increase data speeds, and ensure that the growing demand across all barangays is handled efficiently.

3) Implement Network Optimization Strategies

Regular network optimization is crucial for maintaining consistent performance, involving load balancing, antenna adjustments, sector reconfiguration, and adaptive resource management. These methods are essential for alleviating congestion-related issues, keeping key performance indicators (KPIs) within acceptable limits, and effectively managing user demand during both peak and non-peak times.

4) Strengthening Power Resilience for Telecommunications Infrastructure

Considering the frequent power outages documented in Bacolor, it is imperative that every cell site be furnished with backup generator sets, battery banks, and solar hybrid systems. This is crucial for maintaining service during electrical failures and inclement weather. Furthermore, collaboration with local power cooperatives is essential to mitigate both the duration and frequency of brownouts. Consequently, this will help to diminish service interruptions stemming from power instability.

5) Address Environmental Barriers to Signal Performance

To mitigate environmental challenges, including indoor signal degradation, physical impediments, and variations in terrain, antenna tilt adjustments, sectorization alterations, and line-of-sight clearance procedures are crucial. Moreover, routine inspections are recommended to identify performance degradations resulting from factors such as vegetation growth, the erection of new structures, and seasonal environmental shifts.

6) Streamline Infrastructure Deployment Processes

Local government units (LGUs) should work closely with telecommunications providers to simplify permitting and right of way (ROW) procedures for tower construction, fiber installation, and small cell deployment. Establishing LGU level digital infrastructure ordinances can accelerate telecommunications expansion and encourage equitable network distribution across Bacolor.

7) Maintain Continuous User Feedback and Performance Monitoring

A sustained monitoring system, such as a user reporting dashboard, should be implemented to track service outages, congestion hotspots, weak signal zones, and environmental impacts on performance. Consumer education programs may also improve public understanding of how device capabilities, indoor environments, and weather conditions affect mobile data reliability.

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