Technical Analysis of Fiber To The Home (FTTH) XG-PON and 1.4 GHz 5G Fixed Wireless Access (5G FWA) as Indonesia Affordable Access Network Option

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The Hutuo, Dutulanaa, and Bulota areas in Gorontalo represent suburban regions with increasing demand for high-speed triple-play services. This study evaluates the technical feasibility and deployment readiness of Fiber to the Home (FTTH) and Fixed Wireless Access (FWA) technologies in these areas. The assessment is conducted using Link Power Budget analysis for FTTH and SS-SINR evaluation for FWA as the primary performance parameters. The FTTH Link Power Budget calculation yields downstream attenuation values of 23.08 dB (ODC 1) and 22.35 dB (ODC 2), with respective maximum values of 23.99 dB and 23.161 dB well within the acceptable threshold of 28 dB as specified by the ITU-T G.987.2 standard. For 5G NR-based FWA, the SS-RSRP measurements across bandwidths of 30 MHz, 50 MHz, and 80 MHz are -80.46 dBm, -75.14 dBm, and -69.41 dBm, respectively, all of which comply with established Radio Key Performance Indicator (KPI) benchmarks.

1. Introduction

Despite the availability of Fiber to the Home (FTTH) technology in Indonesia, the fixed broadband penetration rate remains relatively low at 20.87% (Kementrian Komunikasi dan Informatika, 2024). In response to this, the Indonesian government is promoting the adoption of Fixed Wireless Access (FWA) using 5G technology, planned for deployment within the 1.432–1.512 GHz frequency band through a spectrum auction in 2025 (KOMDIGI, 2025). FWA, with a targeted speed of 100 Mbps, represents a new broadband access solution in Indonesia designed to accelerate the expansion of fixed broadband penetration. This technology is expected to complement existing infrastructure by serving areas currently underserved by fiber optic or FTTH networks, while also offering more affordable service options with competitive broadband speeds(Budiman, 2025).

FTTH is an access network solution that directly connects end users' residences to the fiber optic infrastructure, enabling ultra-high-speed internet connectivity and substantial data capacity. XG-PON (10 Gigabit Passive Optical Network) represents an advanced evolution of the Gigabit Passive Optical Network (GPON), offering significantly higher network capacity with data transmission speeds up to 10 Gbps. This technology is particularly well-suited to meet the increasing demand for high-bandwidth applications and data-intensive services (Alamsyah et al., 2022).

Conversely, 5G Fixed Wireless Access (FWA) operating in the 1.4 GHz band offers a more flexible and cost-effective solution, particularly for challenging-to-serve regions. The Ministry of Communication and Digital

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(Kemkomdigi) has selected the 1.4 GHz band with an 80 MHz bandwidth to optimize the deployment of 5G FWA technology, as this spectrum range enables the provision of high-capacity broadband services. In the context of network planning for Gorontalo, the adoption of this technology must align with prevailing regulatory frameworks—particularly Kemkomdigi's spectrum allocation guidelines for the 1.4 GHz band—and address the capacity requirements of the local population (KOMDIGI, 2025)

The FTTH network design in this study employs XG-PON technology, involving the creation of cable routes and the specification of network components based on key performance parameters such as Link Power Budget (LPB), Rise Time Budget (RTB), Bit Error Rate (BER), Signal-to-Noise Ratio (SNR), and Q-Factor. Performance simulations are conducted using specialized network planning software. Meanwhile, the 5G FWA network is designed to operate at 1.4 GHz with bandwidths of 10, 30, 50, and 80 MHz. The evaluation parameters for the FWA system include Secondary Synchronization Signal-to-Interference-plus-Noise Ratio (SS-SINR), Secondary Synchronization Reference Signal Received Power (SS-RSRP), and throughput, with corresponding performance simulations also conducted using software tools. The FTTH network planning utilizing XG-PON and the 5G FWA network deployment at 1.4 GHz are specifically targeted for suburban regions, namely Hutuo, Dutulanaa, and Bulota in Gorontalo, Indonesia.

2. Literature Review

2.1. Previous Research

a. Techno-economic 5G New Radio Planning Using 26 GHz Frequency at Pulogadung Industrial Area (Rianti, D., Hikmaturokhman, A., & Rachmawaty, 2020). This study reviews the technical and economic aspects of implementing 5G New Radio (NR) networks using 26 GHz frequencies in the Pulogadung Industrial Area. The main objective of this study is to analyze the economic potential and feasibility of using 26 GHz frequencies in an industrial context. With a detailed technical approach and in-depth cost evaluation, this study provides important guidance in planning 5G NR networks for the industrial sector.
b. 5G New Radio (NR) Network Planning and Analysis for Bandung City Center (Usman et al., 2023). This study examines the optimal network planning strategy and performance evaluation of 5G NR networks in the Bandung urban area. Using a comprehensive approach, the author describes the steps involved in planning, frequency spectrum allocation, and the implementation of 5G NR technology to improve the quality of connectivity and telecommunications services in Bandung's city center.
c. Design and Analysis of Fiber To The Home Access Network Using Gigabit Passive Optical Network Technology for Triple Play Services in Taman Asri Indah Housing Complex (Putri et al., 2023). This study reviews the implementation of FTTH networks using XG-PON technology in Green Cagar City housing, focusing on manual calculations of LPB, SNR, and BER parameters, and on simulations using the Optisystem application.
d. Design of Fiber to the Home Access Network Using 10 Gigabit Capable Passive Optical Network (XG-PON) Technology at Private Housing Cluster Plemburan Yogyakarta (Alamsyah et al., 2022). This study reviews the implementation of FTTH networks using XG-PON technology in the Private Housing Cluster Plemburan Yogyakarta area, focusing on manual calculations of the parameters and simulations using the Optisystem application.
e. The 5G Fixed Wireless Access Network for Urban Residential Market: A Case of Indonesia (Adityo et al., 2021). This study examines the coverage of the 5G Fixed Wireless Access (FWA) network in Citra Raya Cakupa housing. The focus of this study provides an overview of the economic analysis of Fixed Wireless Access (FWA) technology at 3.5 GHz (mid-band) and 28 GHz (mmWave) frequencies. Based on the analysis in the journal, the 3.5 GHz frequency requires 67 gNodeBs, while the 28 GHz frequency requires 107 gNodeBs. Implementing 5G FWA in Citra Raya Cikupa housing will be more economical

with the 28 GHz frequency, as it offers lower CAPEX and OPEX costs. Based on the analysis results, this study is expected to help network operators design a more effective 5G FWA network.

2.2. Fiber To The Home (FTTH)

Fiber to the Home (FTTH) is a system that sends optical signals from the service provider's central office directly to the user via fiber-optic cables. This technology is developing alongside the increasing demand for Triple Play Services, namely services that combine internet, telephone, and television in one package (Hantoro, Gunadi Dwi, 2015).

2.3. XG-PON

XG-PON is an access technology in the fiber-optic-based broadband category, defined by ITU-T G.987 and ITU-T G.652. One of the advantages of XG-PON is its ability to provide high bandwidth, with downstream speeds reaching 10 Gbps and upstream speeds reaching 2.5 Gbps, which improves service quality for customers.

Table 1. Parameter FTTH XG-PON

Parameter	Downstream	Upstream
Speed	9,95328 Gbit/s	2,48832 Gbit/s
Wavelenght	1575-1580 nm	1260-1280 nm
Sensitivitas receiver	-28 dBm	-27 until -7 dBm
Power Transmitter	2-6 dBm	2-7 dBm
Optical Fiber G.652 D	0,35 dB/km	0,5 dB/km

An international organization that regulates international telecommunications, namely ITU (International Telecommunication Union). This organization has issued recommendations for 2023, namely ITU-T G.987 (ITU-T G.987.2, 2023) and ITU-T G.652 for FTTH XG-PON technology, summarized in Table I (ITU-T G.652, 2000).

The following is an illustration showing Segments A to D (Hantoro, Gunadi Dwi, 2015).

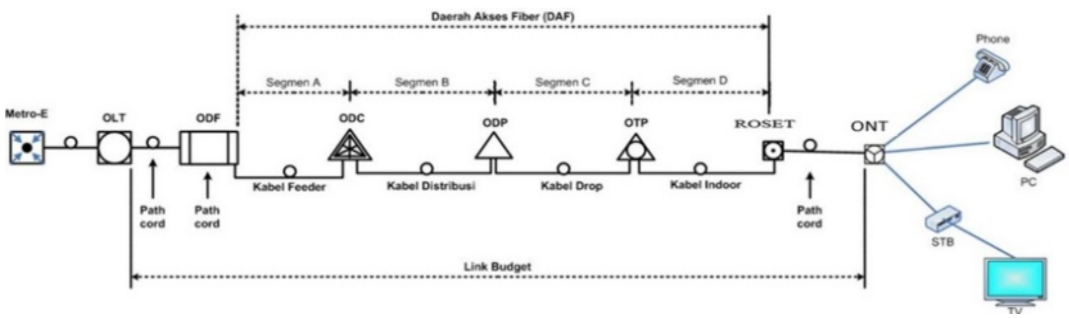


Figure 1. Segment A to D

2.4. Fifth Generation (5G) Networks

Mobile operators around the world will soon face a major challenge in providing capacity to handle the ever-increasing data traffic, much of which is driven by video. Adding more base stations in high-traffic areas will reach a point where it is no longer economically sustainable.

The 5G NR standard was developed by the International Telecommunication Union (ITU) and announced through the International Mobile Telecommunication program in 2020 (ITU-R, 2020). IMT-2020 aims to integrate the capabilities of mobile communication systems and applications to be more efficient, as shown in Figure 2, which illustrates the vision of 5G NR technology, which is divided into three parts.

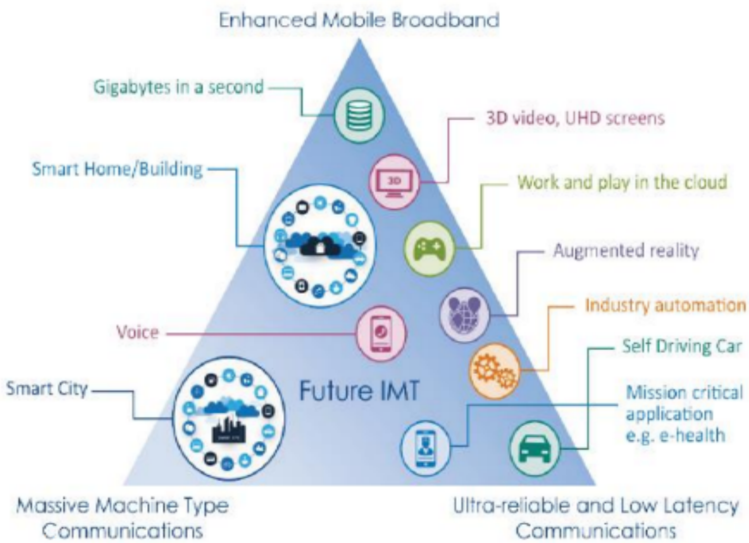


Figure 2. Services 5G (ITU Regional Office for Asia and the Pacific, 2020) :

a. eMBB (Enhanced Mobile Broadband)
   To meet users' needs for accessing multimedia content, services, and data via mobile broadband, demand for mobile broadband continues to increase. eMBB provides solutions for various use cases, including wide-area coverage and hotspots with different requirements.
b. (Ultra-Reliable Low Latency Communication)
   URLLC meets the needs of users who require high throughput, low latency, and high availability. Examples of URLLC applications include remote medical surgery, transportation security, and others.
c. mMTC (Massive Machine Type Communication)
   mMTC supports a large number of connected devices, generally for low-speed, low-delay data transmission. Devices involved in mMTC must have low power consumption and efficient operational and acquisition costs.

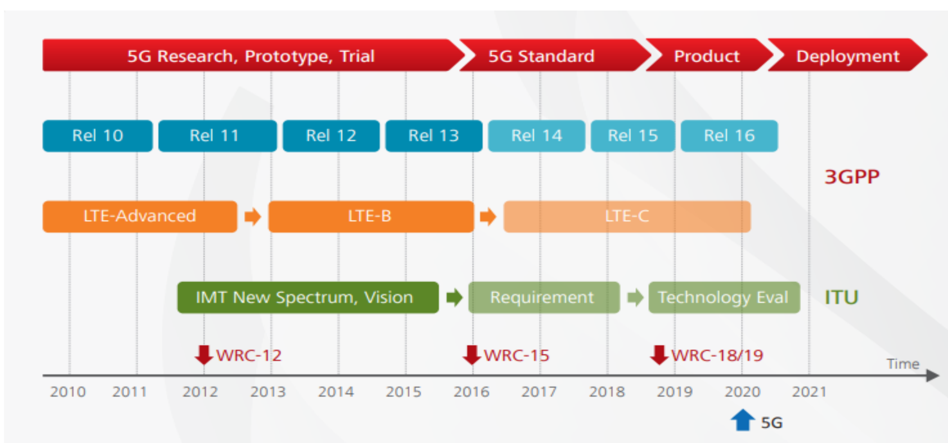


Figure 3. Roadmap 5G (Huawei, 2013)

2.5. *Architecture*

In 4G networks, operators need to deploy radio access networks and core networks on the same technology generation (e.g., LTE radio access uses the EPC (Evolved Packet Core) to build a 4G network). However, 5G introduces a new concept for integrating network elements from different technology generations with varying configurations. (GSMA, 2018), namely:

a. Standalone Mode
5G radio is connected to the 5G core network and uses both control and user paths. This solution provides a simple method for operators to build a 5G network as an independent network alongside the existing 4G network.

b. Non-Standalone Mode
5G radio is combined with LTE base stations (eNBs) and connected to the 4G core (EPC) via the standard S1-U interface for user traffic. Control-plane communication (e.g., for session mobility management) between the network and fixed devices uses LTE radio and 4G core. In this model, 5G radio acts as a secondary service cell to increase throughput and capacity.

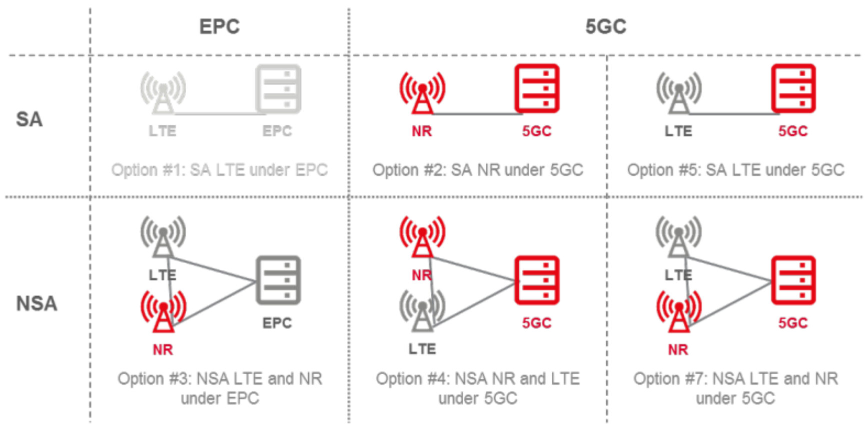


Figure 4. SA and NSA 5G (GSMA, 2018)

2.6. Frequency Range

In the context of wireless communication technology, the need for spectrum is an important factor in the development of 5G. The GSMA has divided the spectrum into three categories, each more suitable for different 5G application scenarios (Hikmaturokhman et al., 2018).

a. Low Band
The spectrum in the low band category is highly suitable for covering a wide area, especially for users in rural areas. However, its weakness lies in its insufficient bandwidth. In this spectrum, 5G technology leverages the legacy 1G/2G/3G/4G networks, which provide a wider network coverage across urban, suburban, and rural areas. The frequency range below 1 GHz spans a wide area and is well-suited to supporting comprehensive IoT services.

b. Middle Band
Cellular communications generally use spectrum bands between 1 GHz and 2.6 GHz. When 5G is ready for implementation, several frequency bands above 2.6 GHz can be used. Although frequency bands in this range offer advantages in coverage and capacity, several factors are considered insufficient to meet the 5G vision for data rates without the need for spectrum aggregation or carrier aggregation.

c. High Band
In this range, ultra-high broadband speeds are applied. Although the spectrum in this category provides a very wide channel to meet high data rate needs, its coverage is limited to small areas in urban areas and inside buildings. Higher spectrum is still needed for services in rural areas. Spectrum above 6 GHz is also

vulnerable to natural conditions and has difficulty penetrating buildings, making indoor antenna installation necessary to serve customers inside.

This specification is part of 3GPP Release 17. According to 3GPP, the frequency bands for 5G NR have been defined, providing a list of frequency bands in which 5G NR can operate. This specification divides the frequency bands into FR1 and FR2, as described in the following Table (ETSI, 2022):

Table 2. 5G New Radio (NR) frequency range specifications

Band	Frekuensi (MHz)	Type
FR1	450 - 6000	Sub 6 GHz
FR2	24250 - 52600	mmWave

2.7. Fixed Wireless Access

Fixed Wireless Access (FWA) will be implemented in Indonesia at 1.4 GHz with an 80 MHz bandwidth. FWA will compete with previous technology, namely Fiber to the Home (FTTH). Each of these technologies has differences in cost, performance, and implementation speed. While FTTH technology has been implemented in Indonesia, FWA is expected to emerge as a technology with several advantages. These advantages include avoiding the distance limitations of fiber optic (areas not covered) and high cable costs, and rapid implementation. The advantages of FWA technology and competitive access are driving a revolution towards wireless access infrastructure.

Figure 5. Architecture FWA (Schnaufer, 2018)

2.8. KPI Target Parameters

The following is the table below which is used as a reference parameter for testing the feasibility of the design made:

Table 3. NR KPI Target Parameters (ITU-R, 2020), (Nugraha et al., 2022)

Objective	Parameter	Target KPI
Coverage Test	RSRP	>= -85 to -115 dBm
Quality Test	SINR	> 5 dB
Capacity Test	5G Throughput	>= 100 Mbps

2.9. Radio Planning Parameters

The parameters used in radio planning include SS-RSRP, SS-SINR, and Throughput.

a. Secondary Synchronization - Received Reference Signal Power (SS-RSRP)

The SS-RSRP value standard is determined by the Key Performance Indicator (KPI) based on the following table:

Table 4. SS-RSRP Value Category for 5G (Nugraha et al., 2022)

Category	value limit SS-RSRP
Excellent	≥ -85 dBm
Good	-100 to -85 dBm
Fair	-115 to -100 dBm
Poor	< -115 dBm

b. Secondary Synchronization – Signal to Noise and Interference Ratio (SS-SINR)
The standard SS-SINR values required by the KPI are shown in the following Table.

Table 5. SS-SINR Value Category for 5G (Nugraha et al., 2022)

Catgory	value limit SS-SINR
Excellent	16 until 30 dB
Good	10 to 15 dB
Fair	5 to 10 dB
Poor	< 5

c. Throughput
The desired throughput standard, which is more than 100 Mbps, has been recommended by the ITU for IMT-2020, as shown in the following Table.

Table 6. ITU 5G NR Standard Recommendations (ITU-R, 2020)

Parameter	IMT-2020
User Experienced Data Rate	100 Mbps
Spectrum Efficiency (bps/Hz)	30
Mobility (km/h)	500
Latency (ms)	1

3. Method

3.1 Design Flowchart

3.1.1 FTTH

Figure 6 illustrates the process of designing an FTTH network architecture using XG-PON technology to provide triple-play services to users. This network design requires accurate data, careful calculations, and compliance with ITU-T G.987.2 standards to ensure customers can use the network properly. The first step in finalizing this design is to determine the location for implementing FTTH XG-PON. The locations used are Hutuo, Dutulanaa, and Bulota, Gorontalo. Data collection is conducted to determine how many houses will be built. Based on the data obtained, it can be used to determine the device type, the number of devices, the device's technical specifications, and the length of the fiber-optic cable used. The design of this FTTH network begins by determining the fiber optic feeder cable path from the OLT to the ODC. To create a cable path using Google Earth software. Then continued with the placement of the XG-PON components. The feasibility parameters of a network include Link Power Budget, Bit Error Rate, Signal-to-Noise Ratio, and Q-Factor. The network scheme is also modeled using software.

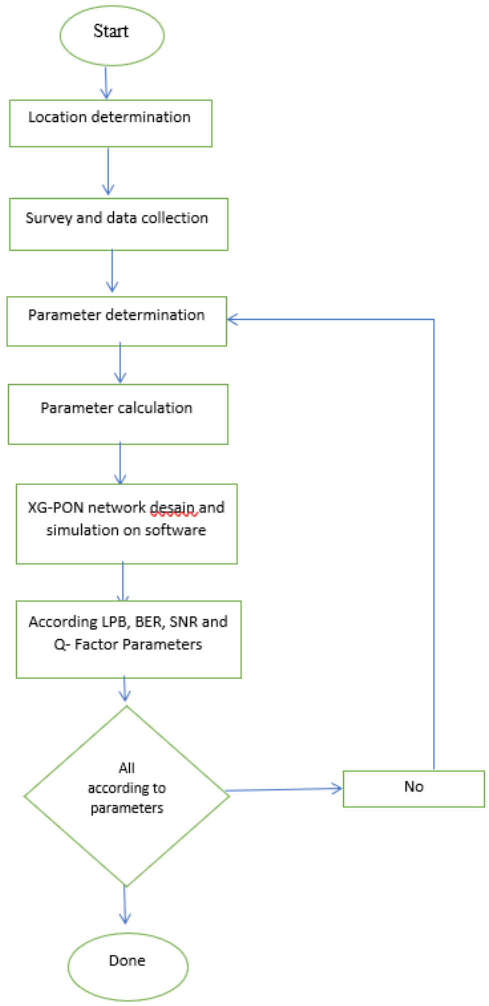


Figure 6. Illustrates the process of designing FTTH

3.1.2 FWA

The stages of this research are to plan a 5G NR FWA network at 1.4 GHz, considering the site's coverage area. The final result of this research project is the number of sites needed to cover the areas of Hutuo, Dutulanaa, and Bulota in Gorontalo. The first stage is to determine the area where the 5G NR FWA network will be planned, namely the Hutuo, Dutulanaa, and Bulota areas, Gorontalo. The area was chosen as a case study area because the main target of 5G NR FWA technology is directed at suburban conditions (KOMDIGI, 2025). The data needed for classification include area, geographic location, and area description, because the service area is classified based on user density (capacity planning). After determining the path loss for Downlink using the Uma (Urban Macro) NLOS propagation model recommended in 3GPP 38.901, the cell radius can be set to the maximum distance between the gNodeB and a User Terminal (UT). The known cell radius will be used to calculate the site coverage area and the number of sites needed for the Hutuo, Dutulanaa, and Bulota areas in Gorontalo, as the final result of this coverage planning calculation. Furthermore, to calculate Capacity Planning, a Bass Model calculation is needed. Once the population density and traffic demand requirements are known, the number of sites required can be calculated. Furthermore, analysis and planning simulations are carried out using Atoll Software. This stage is the most important in this study, because the simulation will display the coverage area and the parameters to be compared with the results of the coverage link budget calculation.

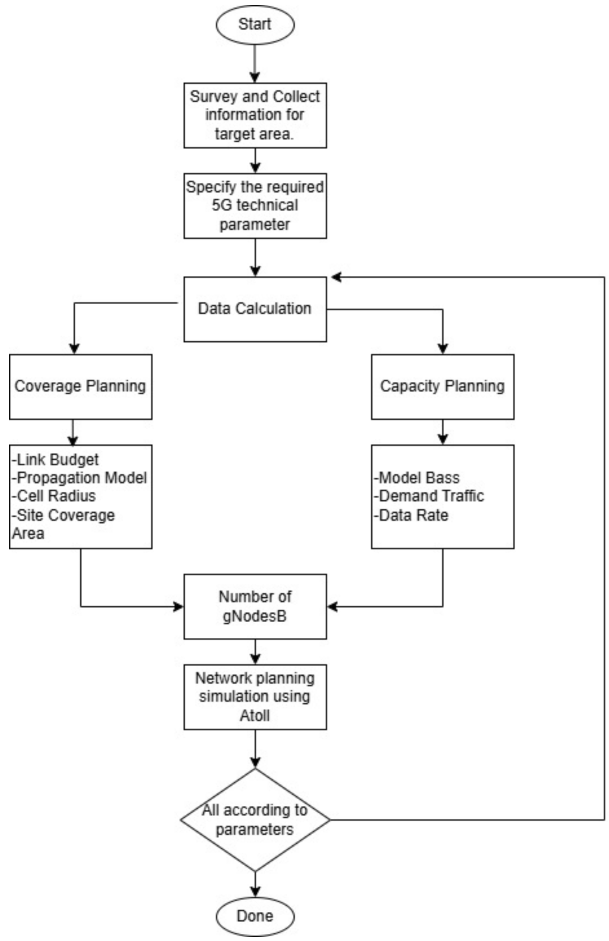


Figure 7. Ilustrates the process of designing an FWA

3.2 Demain Traffic

In this design, the initial development phase targets coverage for 2505 homepasses with a target bandwidth per user of 100 Mbps. According to the Eq. (15), (17) dan (18) then the traffic demand obtained is:

Table 7. Demain Traffic

Years	Users	Demand Traffic (Mbps)
1	716	2127
2	1270	3772
3	1595	4738
4	1857	5516
5	2045	6074

3.3 Network Planning

3.3.1 Design Area Coverage

In the FTTH XG-PON and Fixed Wireless Access (FWA) 5G NR Network Design at a frequency of 1.4 GHz, where there are 2505 houses with an area of 3.69 km2 according to the Figure 8.

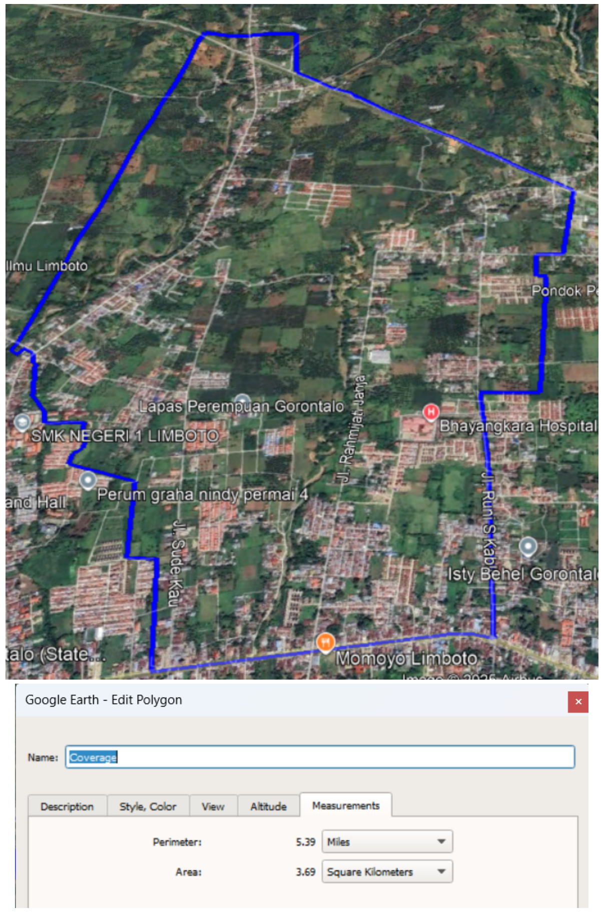


Figure 8. Design Area FTTH and FWA

3.3.2 FTTH

The OLT for the XG-PON access network in the Hutuo, Dutulanaa, and Bulota areas is located in the Tower owned by company X. Then, the distance of OLT to ODC 1 is 2,047 km, for ODC 1 to the furthest ODP 2,745 km and ODC 1 to the nearest ODP 172 m, for ODP to the furthest ONT 30 m and ODP to the nearest ONT 15 m. While the distance from OLT to ODC 2 is 0.65 km, the distance from ODC 2 to the furthest ODP is 2,258 km, and the nearest ODP to the nearest ONT is 20 m (138 m furthest), using an aerial cable path.

In this study, testing was conducted on the network to be implemented using software version 7.0 and manual calculations. The following input parameters are used:

Table 8. Input Parameters

No	Parameter		Spesification	
		Type	LASER	
1	*Transmitter*	Wavelength	*Downstream*	1577 nm
		Input Power	*Downstream*	3 dBm
2	*Bandwidth*	Modulation	*NRZ (non return to zero)*	
		Bite Rate Downstream	10 Gbps	
		Bite Rate Upstream	2.5 Gbps	

No	Parameter		Spesification
3	*Receiver*	*Responsivity*	1 A/W
		Sensitivity	-28 dBm
		Gain	2.5 Gbps
		Modulasi	APD
4	*Optical Fiber*	*Downstream*	0,35 dB/km
5	*Connector*	*SC*	0,25 dB
6	*Splitter*	*1:04*	7,3 dB
		1:8	10,5 dB
7	*Splice*		0,25 dB
8	*number of splices*		4
9	*number of connections*		14
10	*Avalanche Photodiode Gain (M)*		10
11	*Electron Charge*		1,69 x 10^{-19} C
12	*Noise Figure*		M^x, with x = 0,7 = $10^{0,7}$
13	*Planning Area*		3.69 km^2
14	*Konstanta Boltzman's*		1,38 x 10^{-23} J/K
15	*Temperature*		298 K = 300 K

3.3.3 FWA

Antenna budget calculation aims to predict the total path loss, or maximum attenuation, of the signal received between wireless networks in O2O or indoor-to-indoor scenarios. In this study, testing was carried out on a network that will be implemented with Atoll Version 3.4.0 and manual calculations.

a. Coverage Planning

The following input parameters are used:

Table 9. Parameter Perhitungan Coverage

Parameter	Downlink
gNodeB Transmiter Power (dBm)	49
Resource block bandwitdh (30,50,80 Mhz)	78, 133, 217
Subcarrier Quality	936, 1596, 2604
gNodeB Antenna gain (dBi)	15
gNodeB cable loss (dBi)	0
Foliage loss (dB)	12
Body block loss (dB)	8
Interference margin (dB)	13
Rain/Ice margin (dB)	0
UT antenna gain (dB)	0
Bandwitdh (Mhz)	30, 50, 80
Konstanta boltzman (mWs/K)	1.38×10^{-23} mWs/k
Temperature (Kelvin)	293
Thermal noise power (dBm) Bw 10, 30, 50, 80 Mhz	159.161 | 156.94 | 154.90
UT noise figure (dB)	9
Demodulation theshold SINR (dB)	-1,1
Planning Area	3,69 km^2

Parameter	Downlink
Slow Fading Margin	6
Penetration Loss	13

b. Capacity Planning:

Capacity planning is a preparation method that considers network quality and capacity, producing information on the estimated resources needed to support traffic with a certain quality of service (QoS), such as throughput, coverage area, and cellular network requirements. In addition, other factors that can affect network design include:

1) Predicting the number of market users: The estimated number of users is a parameter that can help project traffic demand.
2) Projecting traffic demand: Cellular traffic demand can affect user density per kilometer and network performance.
3) Throughput (Data Rate): IMT-2020 has a data rate specification required for 5G of 100 Mbps.

4. Results and Discussion

4.1 *Network Feasibility Testing*

4.1.1 FTTH

In this test, it is tested using input parameters that meet ITU-T G.987.2. The first step in determining the feasibility of FTTH development is calculating the Link Budget. Link Power Budget is calculated with the condition that the power we design exceeds the power requirement threshold. Standard > -28 dBm (Alamsyah et al., 2022) Link Power Budget can use the following formula

$$\alpha_{tot} = L.\alpha_{kabel} + Nc.\alpha_c + Ns.\alpha_s + Sp \quad \text{...1)}$$

$$P_{rx} \equiv P_{tx} - \alpha_{tot} - SM \quad \text{...2)}$$

P_t = Optical source output power (dBm)
P_r = Maximum detector power sensitivity (dBm)
SM = *Safety margin, ranging from 2-3 dB*
α_{tot} = Total system attenuation (dB)
L = Fiber optic length (Km)
α_c = Connector attenuation (dB/unit)
α_s = Splice attenuation (dB/splice)
α_{serat} = Fiber optic attenuation (dB/Km)
Ns = Number of splices
Nc = Number of connectors
Sp = Splitter attenuation (dB)

The next step is to calculate the SNR value. Signal-to-Noise Ratio (SNR) is the ratio of signal power to interference power, at the same point, with a minimum value of 22 dB (Alamsyah et al., 2022), (K, Muhammad Hafizh, Dhoni Putra Setiawan, 2025). The higher the S/N value, the better the system performs. S/N can be formulated as follows:

$$SNR=10\log\frac{(Pr\,x\,R\,x\,M)^2}{(2\,x\,q\,x\,Pr\,x\,R\,x\,M^2\,x\,F(M)x\,Be)+\frac{4\,x\,K_B\,x\,T\,x\,Be}{R_L}} \quad ...3)$$

P_{in} = Power received by the receiver (Prx in watts)
R = Responsitivity (A/W)
M = Avalanche Photodiode Gain
q = Electron Charge (1,69 x 10^{-19} C)
F(M) = Noise Figure
Be = Receiver Electrical Bandwidth
K_B = Boltzmann's Cosnstant (1,38 x 10^{-23} J/K)
T = Room Temperature
R_L = Resistance (Ω)

The next step is to calculate the Q-factor value. Q factor is a quality factor that determines the good and bad of a system, with a minimum value of 6 (Putri et al., 2023). Q factor can be expressed by the following formula:

$$Q = \frac{10^{\frac{SNR}{20}}}{2} \quad ...4)$$

SNR = *Signal to Noise Ratio*

The next step is to calculate the BER value. BER is the bit-error rate when transmitting digital signals. In optical communication networks, the BER value must be ≤ 10^{-9} (Alamsyah et al., 2022). BER can be formulated as follows:

$$BER = P\,e\,(Q) = \frac{1}{Q\sqrt{2\pi}}exp^{-\frac{Q^2}{2}} \quad ...5)$$

Description:
Q = *Quantum noise,* π = *3.14*

Table 10. Manual calculation results ODC 1

ODC 1	Prx	SNR	*Q-Factor*	BER
Nearest downstream	-23,08 dBm	29,19 dB	14,40	2,599 x 10^{-47}
Farthest downstream	-23,99 dBm	28 dB	12,559	1,785 x 10^{-36}

Table 11. Manual calculation results ODC 2

ODC 2	Prx	SNR	*Q-Factor*	BER
Nearest downstream	-22,35 dBm	30,12 dB	16,03	3,959 x 10^{-58}
Farthest downstream	-23,161 dBm	29,09 dB	14,22	2,998 x 10^{-46}

Overall in Table 10 and 11, it still meets the standards that have been determined, namely Prx downstream > -28 dBm, SNR > 22, Q-factor > 6, BER ≤ 10^{-9} (Alamsyah et al., 2022). The throughput required in the initial design of 2505 houses with a target per user of 100 Mbps, the first step is to find potential users using the Bass Model with formula (15), the next step is to find traffic demand using formula (17) and (18). So that the traffic demand for the next 5 years is 6074 Mbps with an estimate of 2045 users.

Simulation Results:

Design on Google Earth, where to find out the location of the device, cable length, cable design, and the number of devices used in the design of the XG-PON FTTH network development in the sub-districts of Hutuo, Dutulanaa and Bulota, Gorontalo Regency. The OLT device is located on Company X Tower at coordinates 0°38'16.32 “N 122°59'33.24” E. According to the Figure 9.

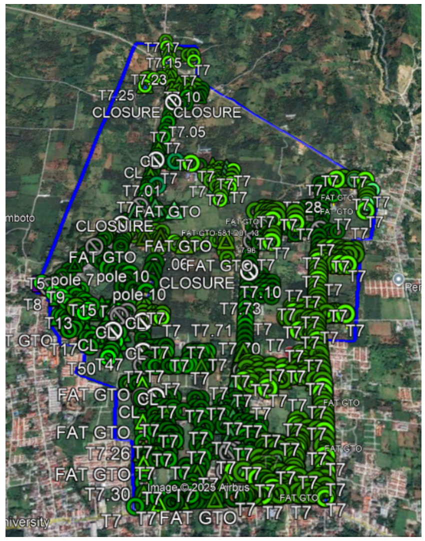
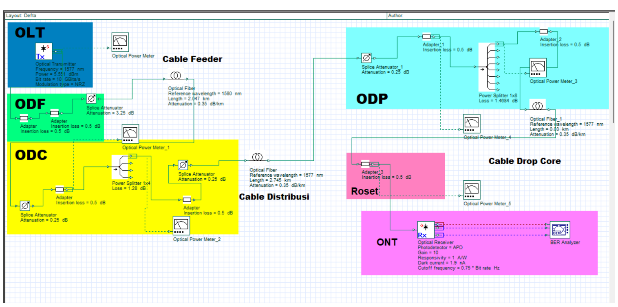
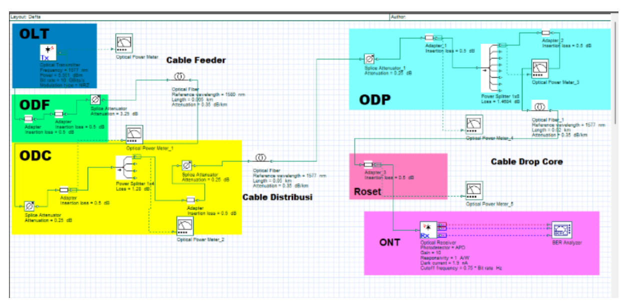


Figure 9. Design FTTH

FTTH XG-PON simulation design design at ODC according to the Figure 10. While in ODC 2 according to the Figure 11.

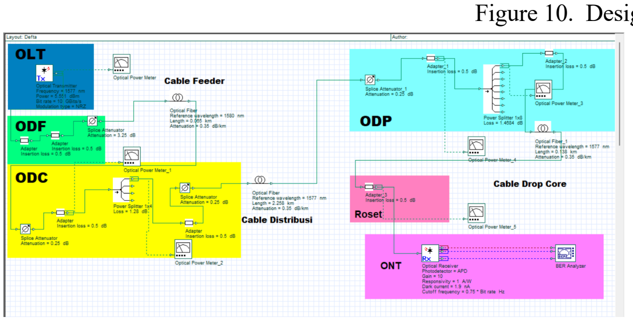


(a) Farthest in ODC 1

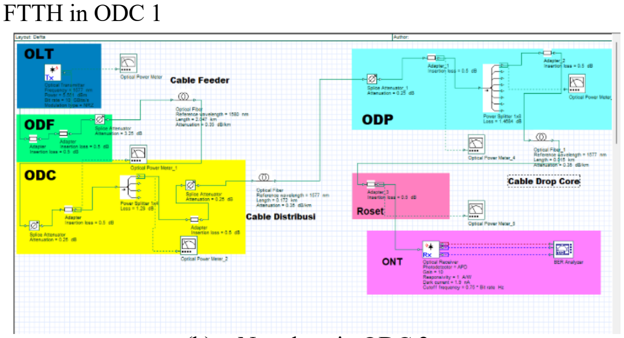


(b) Nearest in ODC 1

Figure 10. Design FTTH in ODC 1



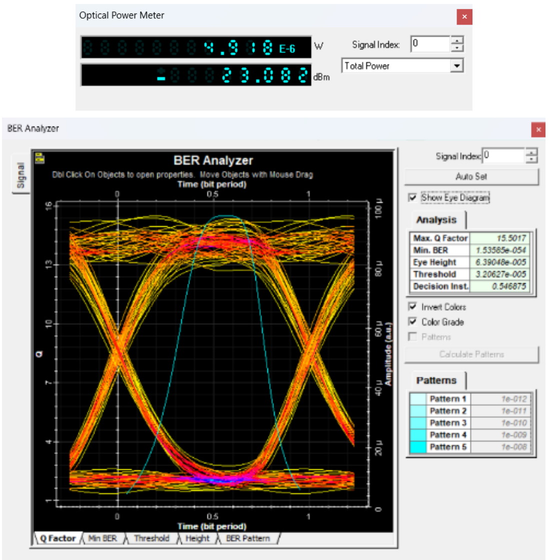
(a) Farthest in ODC 2



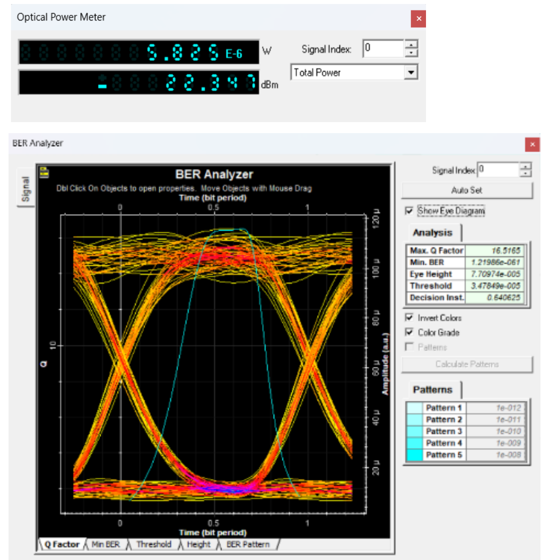
(b) Nearthest in ODC 2

Figure 11. Design FTTH in ODC 2

In this test, it was tested using simulation on software.



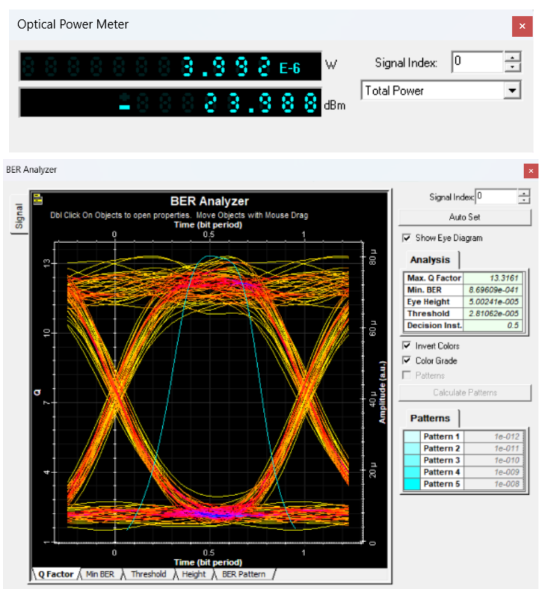
Nearest Downstream ODC 1



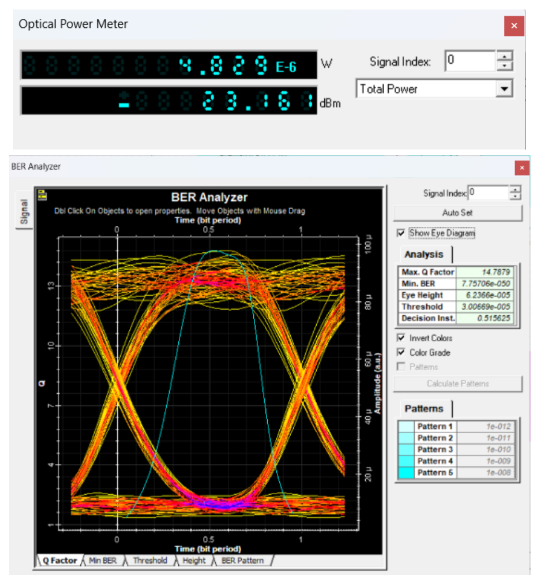
Nearest Downstream ODC 2

Figure 12. Result Simulation Nearest ODC 1 and ODC 2

In Figure 12, at ODC 1, the transmit power for the nearest downstream is - 23.082 dBm, the Q-factor value is 15,5017, and the BER value is 1,52585 x 10^{-54}. While at ODC 2, the transmit power for the nearest downstream is - 22.347 dBm, the Q-factor value is 16.5165, and the BER value is 1.21986 x 10^{-61}.



Farthest Downstream ODC 1



Farthest Downstream ODC 2

Figure 13. Result Simulation Farthest Downstream ODC 1 and ODC 2

In Figure 13, at ODC 1, the transmit power for the Furthest downstream is - 23.988 dBm, the Q-factor value is 13,3161 and the BER value is 8,69609 x 10^{-41}. While at ODC 2, the transmit power for the nearest downstream is - 23.161 dBm, the Q-factor value is 14,7879, and the BER value is 7,75706 x 10^{-50}.

4.1.2 FWA

a. Coverage Planning

Fixed Access Wireless network planning generally involves two approaches: coverage planning and capacity planning. Coverage planning is network planning focused on the area to be covered by the network. Coverage planning can be influenced by parameters such as emissive capacity, receiving capacity, path loss, device sensitivity, radio link budget calculations, and cell radius. Radio link budget calculation is used to determine the maximum path loss allowed between the gNodeB antenna and the UE antenna, while propagation modeling is used to determine the cell radius (Nugraha et al., 2022).

b. Urban Macro (UMa) Propagation Model

The number of sites in Hutuo, Dutulanaa, and Bulota sub-urban, Gorontalo, is determined by determining the propagation model. The propagation model is based on the link budget for the 5G NR FWA network, as specified in 3GPP 38.901. The propagation model used in this study is the Urban Macro (UMa) NLOS model. UMa with Base Station O2O (Outdoor to Outdoor) installed on the roof of the customer's house. First, determine the Thermal Noise and Subcarrier Quantity values, and calculate these values using the following equation (Fahira et al., 2020), which is then entered into the link budget table:

$$N_{thermal} = 10 \times \log (K \times T \times B) \qquad (6)$$

K = Konstanta Boltzman(1.38×10^{-23} mWs/k)

T = Temperature ($293^{o}\ K$)

$$S_{cq} = R_B \ x \ S_{RB} \qquad (7)$$

Resource Block = 24, 78, 133, 217

Subscarrier Per Resource Block = 12

Then, calculate path loss value with the following equation (Huawei Technologies Co., 2018):

Pathloss (dBm) = gNodeB transmit power (dBm) – 10 log10 (subcarrier quantity) + gNodeB antenna gain (dBi) – gNodeB cable loss (dB) – penetration loss (dB) – foliage loss (dB) - body block loss (dB) – interference margin (dB) – rain/ice margin (dB) – slow fading margin (dB) + UT antenna gain (dB) – thermal noise figure (dBm) – UT noise figure (dB) – demodulation threshold SINR (dB)

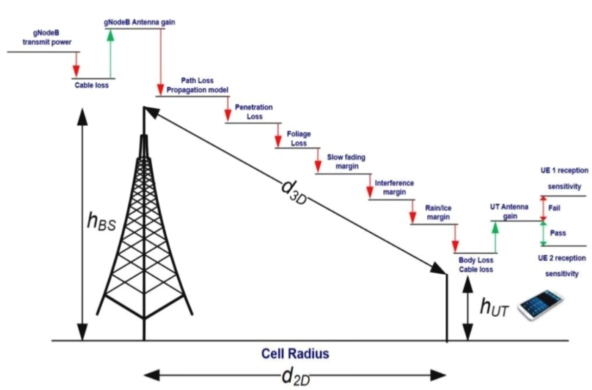


Figure 14. Factors Affecting Link Budget (Huawei Technologies Co., 2018)

The next step is to find the h_{BS}value; h_{UT} value and d_{BP} value, calculate these values using the following equation (Fahira et al., 2020):

$$h_{BS} = h_{Bs-} hE \qquad (8)$$

$$h_{UT} = h_{UT-} hE \qquad (9)$$

$$d_{BP} = 4\, x\, h_{Bs}\, x\, h_{UT}\, x\, f_c \,/\, c \qquad (10)$$

Table 12. Result Calculation

Parameter	Value	Description
Hbs	25 m	Height of Base Station
Hut	2 m	Height of User Terminal
hE	1 m	Effective Environment Height
H'bs	24 m	Effective Height of Base Station
H'ut	1 m	Effective Height of User Terminal
C	1,4 GHz	Frequency
F	3×10^8 m/s	Speed of Light
D'bp BW 10,30, 50, 80 Mhz	448 m	Distance of Break Point

In the UMa model for the Line of Sight (NLOS) case, it has the formula (ETSI, 2020).

$$PL_{UMa-NLOS} = 13.54 + 39{,}08 log_{10}(d_{3D}) + 20 log_{10}(f_c) - 0.6\,(h_{UT} - 1.5) \qquad (11)$$

PL = Path loss value (dBm)

d_{3D} = The result of the calculation between h_{BS} and h_{UT} and the value of d_{2D}

f_c = Carrier frequency (GHz)

d_{BP} = Break point distance (m)

h_{BS} = Height of the Base Station antenna (m) (10 m < h_{BS} ≤ 150 m)

h_{UT} = Height of the User Terminal antenna (m) (1.5 m ≤ h_{UT} ≤ 22.5 m)

Determine the d_{2D} value using the following equation (Fahira et al., 2020):

$$d_{2D} = \sqrt{((d_{3D})^2 - (h_{BS} - h_{UT})^2} \qquad (12)$$

To determine the area to be covered by one gNodeB using three sectoral cells (Fahira et al., 2020):

$$C_A = 2{,}6\, x\, d_{2D}{}^2 \qquad (13)$$

Last, after getting the value of the coverage area, you can continue calculating the number of gNodeBs for that area (Fahira et al., 2020):

$$\text{Number of gNodeB} = \frac{Large\ of\ Area\ (km)}{C_A(km)} \qquad (14)$$

Large of Area = Large Area (km)

C_A = Large Coverage area (km)

Table 13. Result of the Manual Calculation Coverage Planning

Parameter	Value Downstream
d_{3D} BW 30, 50, 80 Mhz (m)	973.57 | 745.80 | 562.72
d_{2D} BW 30, 50, 80 Mhz (m)	973.30 | 744.80 | 562.250
Coverage Area BW 30, 50, 80 Mhz (km2)	2.463 | 1.442 | 0.821
Number of gNodeB BW 30, 50, 80 Mhz	2 | 3 | 5 site
Pathloss	133.55 | 129.01 | 124.24

Table 14. Number of gNodeB

Bandwitdh (Mhz)	Number of gNodeB Downstream
30	2
50	3
80	5

c. Capacity Planning

The first step is to determine the model's base value. The Bass Model is used in planning 5G networks to predict user numbers and market potential. In calculating the Bass Model, there are several factors to consider, such as the number of connected users, data speed, and traffic demand (Adityo et al., 2021). Where the initial construction was 2505 houses, in this case, Indonesia is included in "Developing Asia," therefore, the value of p = 0.0267 and q = 0.3356 (M. Luiz, 2018). Therefore, the Bass Model calculation is used in formula (15).

$$N_t = \text{M x } \frac{1 - e^{-t(p+q)}}{1 + \frac{p}{q} e^{-t(p+q)}} \quad \ldots 15)$$

N_t = Estimate of market user number
M = Market volume
p = Innovation adoption rate, where 0 ≤ p ≤ 1
q = Imitation adoption rate, where 0 ≤ q

The result manual calculation Bass Model:

Table 15. Manual Calculation Bass Model

Years	User
2025	715
2026	1267
2027	1593
2028	1855
2029	2041

Then determine the data rate value according to the 3GPP Standard. Factors that affect system capacity are site usage, frequency spectrum, and sectorization. The frequency used in this study is 1.4 GHz, with bandwidths of 30, 50, and 80 MHz. Using the Time Division Duplex (TDD) approach with modulation for uplink up to 256 QAM (8 Multiple layers) and downlink (8 Multiple layers) up to 256 QAM. Thus, based on capacity planning needs, the following Table 18 shows the number of gNodeBs needed in Hutuo, Dutulanaa, Bulota Districts, Gorontalo Regency.

For 5G New Radio, the estimated data rate can be calculated using equation (16).

Data Rate = $10^{-6} \Sigma_{j=1}^{j} (V_{layer}^{(j)} \, x \, Qm^{(j)} \, x \, f^{j} x \, R_{max} \, x \, \frac{N^{BW(j)\,\mu} \, x \, 12}{T_S^{\mu}} \, x \, 1 - \, OH^{(j)}))$ ....16)

J	= Number of carrier components
R_{max}	= 948/1024.
$V_{layer}^{(j)}$	= Number of layers in MIMO
$Qm^{(j)}$	= Modulation level
f^{j}	= Scale factor (1, 0.8, 0.75, and 0.4)
T_S^{μ}	= Average OFDM symbol duration in the subframe for numerology
$N^{BW(j)}$	= Maximum bandwidth allocation
$OH^{(j)}$	= The overhead control channel value, calculated as: 0,14 for frequency range FR1 for downlink (DL) 0,18 for frequency range FR2 for uplink UL 0,08 for frequency range FR2 for Downlink (DL) 0,10 for frequency range FR2 for uplink (UL).

Table 16. Manual Calculation Data Rate

Bandwidth (Mhz)	Site Capacity/ Throughput (Gbps)	Site Capacity/ Throughput 3 Sector (Gbps)
10	0.4109	1.2327
30	1.33542	4.0062
50	2.277077	6.83123
80	3.7175	11.14569

Then determine the value of traffic demand in the next 5 years. Traffic demand is the density of network users per kilometer in the studied area. φ(t) represents the percentage of active users in the time span where $\varphi(t)$=100% to calculate peak traffic needs, assuming N_{dh} is 9 hours a day with N_{md} 30 days, with a monthly average need of 100 GB/user/month. To determine traffic needs, this calculation uses formula (18).

$p = \frac{N_t}{Large\ Area}$ ....17)

$G(t) = p \, x \, \frac{8}{N_{dh} \, x \, N_{md}} \, \varphi(t) \, x \, D_k$ ....18)

Description:

N = Value in Model Bass

$G(t)$ = Traffic demand forecast.

p = User density in the selected area.

N_{dh} = Number of hours counted as busy time each day

N_{md} = Total number of days in a month.
$\varphi(t)$= Calculation of peak traffic based on the percentage of active users at a specific time.
D_k = Total traffic demand for each month.
The result manual calculation Demand Traffic:

Table 16. Manual Calculation Demand Traffic

Years	Demand Traffic (Mbps)
2025	2127
2026	3772
2027	4738
2028	5516
2029	6074

The final step is to determine the number of gNodeB sites. The gNodeB capacity calculation determines how many sites are needed at the research location. In calculating the gNodeB capacity, the following formula is used (19):

$$\text{Site gNodeB} = \frac{G(t)}{\text{Average site Capacity}} \quad \ldots 19)$$

The result Manual Calculations Capacity Planning:

Table 17. Result Manual Calculation Capacity Planning

No	Parameter	Spesification
1	Frequency	1.4 Ghz
2	Environment	Outdoor
3	Sector	3
4	Average site Capacity (Mbps) Bandwidth 30,50,80 Mhz	4006,2 | 6831,23 | 11145,69
5	Total gNodeB Bandwidth 30,50,80 Mhz	2 | 1 | 1
6	Large Area km2	3,69 km2

In this planning, the simulation uses the optimal number of gNodeBs, as specified in the ITU formula in Table 18 below. Final Gateway = Maximum (Number of Gateways (coverage), Number of Gateways (capacity))

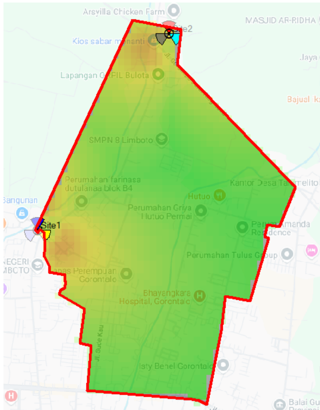
Table 18. Number of gNodeB.

Bandwitdh (Mhz)	Number of gNodeB
30	2
50	3
80	5

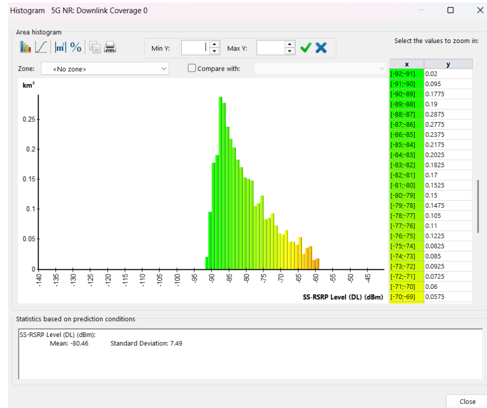
1. Fixed Wireless Access (FWA) Design
   In the 5G NR FWA design at 1.4 GHz frequency, the location of gNodeB sites 1, 2, 3, 4, and 5 are sequentially at coordinates °38'15.79"N 122°59'32.9"E, 0°39'6.41"N 123°0'6.71"E, 0°38'34.67"N 123°0'14.55"E, 0°38'15.23"N 123°0'3.11, 0°37'48.52"N 123°0'1.09"E. Where gNodeB sites 1 and 2 are existing sites of Company x, sites 3, 4, and 5 are new gNodeB sites, considering the density of the area in the region, and

have an empty land area where there will likely be housing growth in the area in the next 5 years, according to the Bass Model calculation.

2. Secondary Synchronization Simulation - Reference Signal Received Power (SS-RSRP)

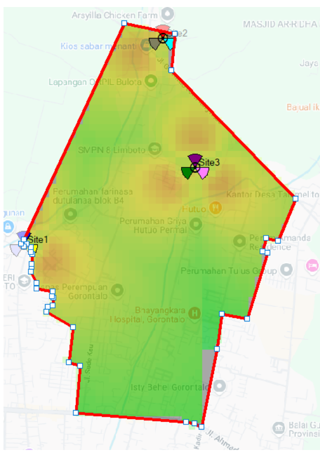


Design SS-RSRP 30 MHz

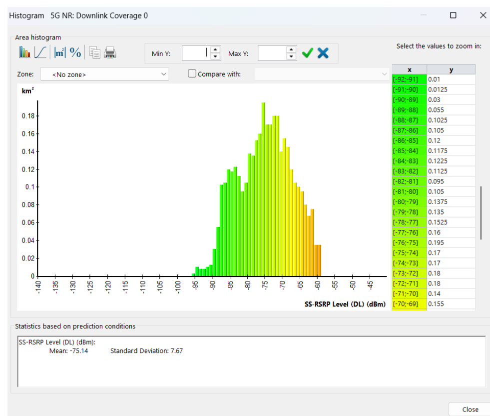


Result SS-RSRP 30 MHz

Figure 15. SS-RSRP 30 MHz

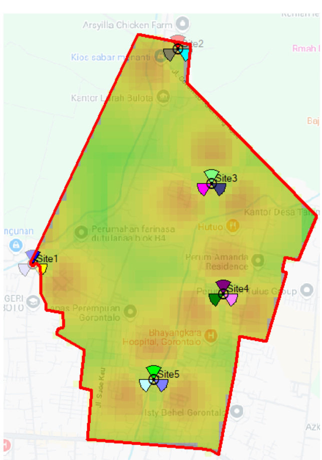


Design SS-RSRP 50 MHz

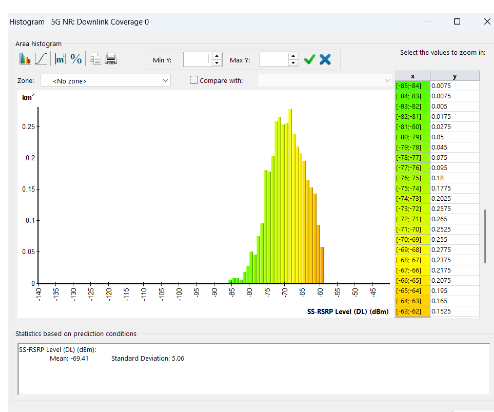


Result SS-RSRP 50 MHz

Figure 16. SS-RSRP 50 MHz



Design SS-RSRP 80 MHz



Result SS-RSRP 80 MHz

Figure 17. SS-RSRP 80 MHz

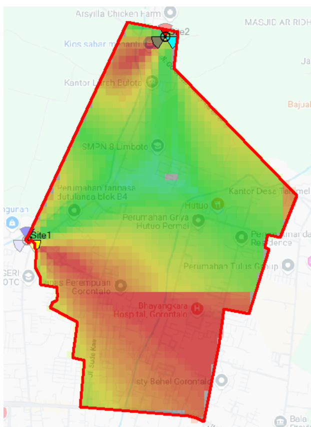
Figures 16, 17, and 18 above show the results of the SS-RSRP parameters from the coverage planning carried out. The table below shows the average SS-RSRP value obtained as follows.

Table 19. Average SS-RSRP

Bandwitdh (Mhz)	SS-RSRP (dBm)	Coverage Area (%)
30	-80.46	100
50	-75.14	100
80	-69.41	100

Based on the Radio KPI (Key Performance Indicator) standard shown in the table. 4. These results show very good signal quality. In this study, the area covered was 100%.

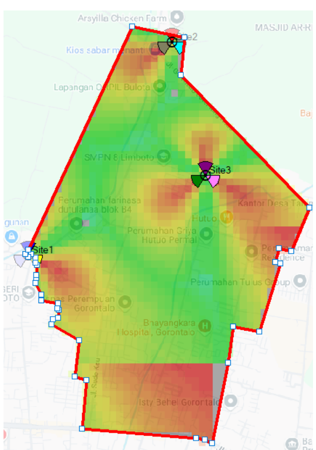
3. Secondary Synchronization - Signal to Noise and Interference Ratio (SS-SINR)

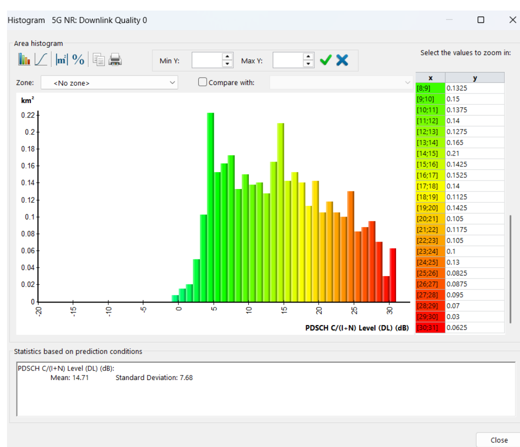


Design SS-SINR 30 MHz

Result SS-SINR 30 MHz

Figure 18. SS-SINR 30 MHz

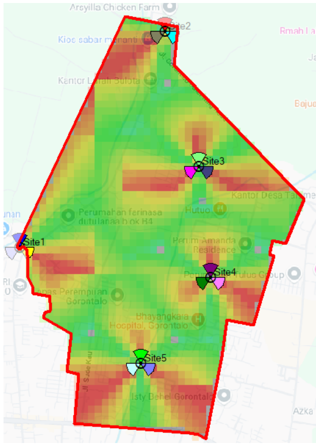




Design SS-SINR 50 MHz

Result SS-SINR 50 MHz

Figure 19. SS-SINR 50 MHz



Design SS-SINR 80 MHz

Result SS-SINR 80 MHz

Figure 20. SS-SINR 80 MHz

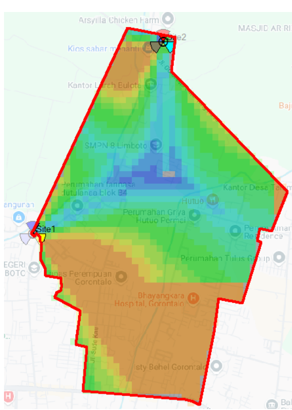
Figures 19, 20, and 21 above show the results for the SS-SINR parameters, with the average values listed in the table below.

Table 20. SS-SINR Parameters

Bandwitdh (Mhz)	SS-SINR (dB)	Coverage Area (%)
30	16.47	99.8
50	14.71	99.1
80	14.51	99.4

Where it is included in the good category according to the Radio KPI (Key Performance Indicator) standard in Table 5. In addition, with better signal quality, network performance improves, enabling more stable, reliable data communication.

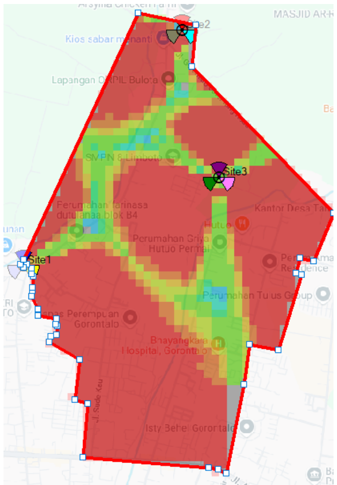
4. Throughput

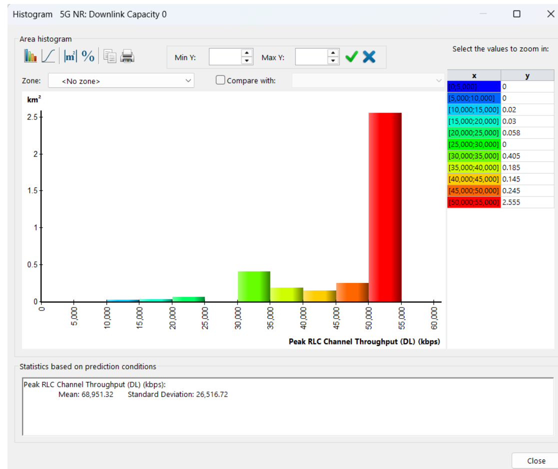


Design Throughput 30 MHz

Result Throughput 30 MHz

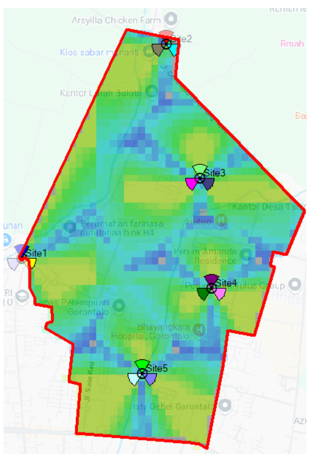
Figure 21. Throughput 30 MHz

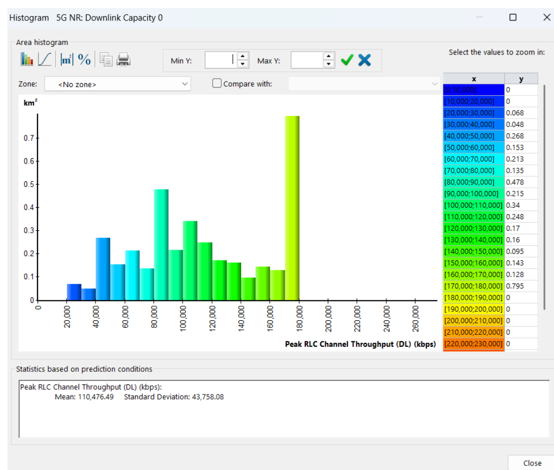




Design Throughput 50 MHz Result Throughput 50 MHz

Figure 22. Throughput 50 MHz





Design Throughput 80 MHz Result Throughput 80 MHz

Figure 23. Throughput 80 MHz

The image above shows the histogram of the results for the throughput parameters obtained from the simulation. The average throughput obtained is in accordance with the following table.

Table 21. Average Throughput

Bandwitdh (MHz)	Throughput (Kbps)	Throughput (Mbps)	Coverage Area (%)
30	41.944	42	99.8
50	68.951	69	99.1
80	110.476,5	110	99.4

From Figures 22, 23, and 24 above, it can also be seen that the coverage area dominates the entire region. However, with bandwidths of 30 and 50 MHz, the throughput is below 100 Mbps, whereas with a bandwidth of 80 MHz, the throughput is above 100 Mbps. These results indicate that most of the Hutuo, Dutulanaa, and Bulota areas in Gorontalo have achieved very good, if not optimal, throughput and provide services with optimal data rates, with dominant throughput coverage at 80 MHz. Meanwhile, at 30 and 50 MHz bandwidth, the average throughput was not good, as it remained below 100 Mbps, providing services at less than optimal data rates. According to the ITU parameters Table. 6.

4.2 Based on FTTH and FWA Network Planning

The development of FWA 5G NR technology with a frequency of 1.4 GHz is faster than the development of FTTH XG-PON, because the actual implementation of FTTH network development uses more poles for network distribution, so it takes longer than FWA which is distributed without using poles, this also affects the speed or not of the licensing process for the location of the pole planting. In accordance with KOMDIGI's wishes, the deployment of FWA 5G NR at 1.4 GHz will later aim to increase penetration and accelerate the spread of Fixed Broadband technology in Indonesia

5. Conclusion

In FTTH XG-PON, the manual calculation of the downstream Link Power Budget attenuation produces the following values: the nearest downstream at ODC 1 with a value of 23,08 dB and Prx -23,08 dBm. While ODC 2 has a value of 22.35 dB and Prx -22.35 dBm. The furthest downstream at ODC 1 with a value of 23,99 dB and Prx -23,99 dBm. While ODC 2 has a value of 23.161 dB, and Prx -23.161 dBm. Based on the calculation results, the downstream Link Power Budget attenuation still meets the ITU-T G.987.2 standard at -28 dBm. The results of the network design simulation using OptiSystem obtained the following BER values: the nearest downstream on ODC 1 is 1,52585 x 10^{-54}.while ODC 2 is 1.21986 x 10^{-61}. The furthest downstream on ODC 1 is 8,69609 x 10^{-41} while on ODC 2 is 7,75706 x 10^{-50}. Where the BER value still meets the value of $\leq 10^{-9}$.).

In Fixed Wireless Access he 5G New Radio FWA network planning using a 1.4 GHz frequency with the Urban Macro (UMa) NLOS propagation model provides a solution to the lack of fixed broadband network penetration and supports communication activities, as well as economic and social development in the areas of Hutuo, Dutulanaa, and Bulota, Gorontalo. Network planning is done using two main analyses: coverage planning and capacity planning, yielding bandwidths of 30, 50, and 80 MHz, respectively, requiring gNodeB antennas of 2, 3, and 5, respectively. The results of the network design simulation using Atoll are shown below: SS-RSRP and SS-SINR values. The SS-RSRP values at 30, 50, and 80 MHz bandwidths are sequentially 80.46, -75.14, and -69.41 dBm. The SS-SINR values at 30, 50, and 80 MHz bandwidths are 16.47, 14.71, and 14.51 dB, respectively. The SS-RSRP value is in the "very good" category, and SS-SINR indicates good signal quality based on the radio's Key Performance Indicator. These results indicate that most of the Hutuo, Dutulanaa, and Bulota areas in Gorontalo have achieved very good, if not optimal, throughput and provide services with optimal data rates, with dominant throughput coverage at 80 MHz. Meanwhile, at 30 and 50 MHz bandwidth, the average throughput was not good, as it remained below 100 Mbps, providing services at less than optimal data rates.

The development of FWA 5G NR technology with a frequency of 1.4 GHz is faster than the development of FTTH XG-PON, because the actual implementation of FTTH network development uses more poles for network distribution, so it takes longer than FWA which is distributed without using poles, this also affects the speed or not of the licensing process for the location of the pole planting. In accordance with KOMDIGI's wishes, the deployment of FWA 5G NR at 1.4 GHz will later aim to increase penetration and accelerate the spread of Fixed Broadband technology in Indonesia.

6. Acknowledgements

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