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Optimization of Enhanced Mobile Broadband Solution for Rural and Remote Areas: A Case Study of Banten, Indonesia

Optimisasi Jaringan Seluler Pita-Lebar untuk Kawasan Rural dan Terpencil Studi Kasus Banten, Indonesia

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A B S T R A K

Penelitian ini menawarkan solusi untuk akses broadband futuristik di daerah terpencil dan pedesaan dengan pilihan: optimasi LTE; dan perkembangan jaringan pita lebar yang diasumsikan sebagai 5G. Teknologi yang digunakan pada sistem 5G masa depan ialah pemanfaatan frekuensi tinggi, UE-Specific Beamforming, dan Skema Carrier Agregation (CA). Lima klasifikasi dalam implementasi jaringan futuristik: Skenario 1, Single Carrier (SC) LTE 1,8 GHz; Skenario 2, CA LTE 1,8 GHz + 2,6 GHz; Skenario 3, SC 5G 15 GHz; Skenario 4, SC 5G 28 GHz; Skenario 5, CA LTE 1,8 GHz + 5G 15 GHz. Redaman hujan diperhitungkan demi mendapat hasil realistis. Pada wilayah Leuwidamar, Skenario 5 memiliki jumlah BS paling sedikit. Sedangkan di Panimbang, Skenario 3 dan 5 memiliki jumlah BS yang paling sedikit. Namun, jika performansi energi diperhitungkan, Skenario 3 merupakan solusi terbaik. Selanjutnya, jika kita mengimplementasikan Discontinues Transmission (DTX), Skenario 3 dapat memberi kita penghematan energi yang mengesankan, dengan masing-masing penghematan sebesar 97% dan 94% pada daerah Leuwidamar dan Panimbang. Maka, hasil studi menyarankan untuk menggunakan jaringan SC 15 GHz sebagai optimisasi jaringan prospektif masa depan di Leuwidamar dan Panimbang, menimbang tercapainya salah satu target teknis teknologi 5G, yaitu ketersediaan 50 Mbps dimana saja dan kapan saja.

Keywords:
eMBB
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Case Study
Rural Area
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A B S T R A C T

Our work compared the performance of future broadband network solutions: with Optimized LTE system; and a new enhanced Mobile Broadband (eMBB) system, in which assumed to be prospective 5G network. The proposed eMBB system implements three key-techniques: high frequency, a UE-Specific Beamforming, and Carrier Aggregation (CA). We propose five solutions: Case 1, Single Carrier (SC) LTE 1.8 GHz; Case 2, CA LTE 1.8 GHz + 2.6 GHz; Case 3, SC 5G 15 GHz; Case 4, SC 5G 28 GHz; Case 5, CA LTE 1.8 GHz + 5G 15 GHz. Rain attenuation is considered to aim realistic solution. In the remote area (Leuwidamar), the Case 5 gives the least number of BS, with only 1.6 times densification of the current network. For the rural area cases (Panimbang), it is offered by Case 3 and Case 5 with the same number of BS. However, the best solution in terms of energy performance for both areas is Case 3. With DTX implementation, Case 3 gives an impressive amount of energy saving, with 97% in Leuwidamar and 94% saving in Panimbang. Thus, provided that our assumptions about eMBB techniques are fulfilled the Single Carrier 15 GHz link network is the most efficient.

1. Introduction

Future 5G Network is expected to provide a fast and reliable connection for anything, anyone, anytime and anywhere (Members of the 5G Infrastructure Association, 2015). A vast number of studies has been carried out

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to prepare 5G to be commercially available in 2020: from technical aspects, business schemes to regulations. However, most research focuses on providing such network in the urban or dense-urban area, not rural. In fact, compared to an urban area, rural area has its own particular challenges that need to be addressed: high revenue gap (high-cost yet low-ARPU); and the area's physical geographic challenge which might raise the difficulty of network planning (Anand, Pejovic, Belding, & Johnson, 2012). Consequently, only few telecommunication industry players have been involved to deploy a rural connectivity. On the other hand, a communication access is important and accounted as one of the human rights (Sandle, 2016). Thus, we need to find an effective broadband telecommunication services solution in a rural area which benefits both subscribers and network providers. A research by Chiaraviglio et al., (2017) shows that analyzing and reducing network's Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) is the main key for an effective 5G rural communication access.

Based on studies, there are several possibilities to suppress the network's CAPEX. Firstly, a capital cost can be reduced by utilizing a new architectural network, such as deploying cells using UAVs. Giant companies e.g. Google and Facebook, are using UAVs and put the telecommunication equipment into the air. The UAVs systems successfully avoiding a tower or any other fix building cost, in which at the same time able to provide a wide coverage of communication access. Although the investment cost might be so much lower, the sustainability and safety still investigated. However, both flying objects have a possibility to fall unexpectedly when a hardware failure occurs, and it would be a huge concern for people (Katikala, 2014). There is a second option to decrease CAPEX, which met by increasing the inter-site distance (ISD) resulting in a small number of cell per area. A study by Stare, Giménez, & Klenner, (2016) shows a possibility of using Ultra High Frequency (UHF) to deliver a television and mobile broadband services. By providing a broadband service in UHF, we can deploy the nodes with a high ISD and suppress CAPEX per area. Moreover, there is also a possibility to increase the ISD by applying a Massive MIMO Beamforming techniques. A study shows it could give a 5 dB additional link budget, and maintaining a small number of cell needed per area (Frenger, Olsson, & Eriksson, 2014). Combined with a Discontinuous Transmission (DTX) ability, the Massive MIMO Beamforming network can save up to 50% energy consumption per area, provided that the DTX technique enables a deep-sleep mode and saving more energy. Moreover, this DTX ability could be useful to decrease OPEX since we able to save a high amount of energy consumption.

Aside from the applied solutions e.g. UAVs network, the previous discussion shows that there are also numerous simulation studies of providing an effective rural 5G system. Most simulations studies, however, take a general assumption or condition for performance evaluation. To decide which solution suits best for a realistic case, we need to have deeper investigation i.e. evaluating important properties of the studied area. In this paper, we analyze several solutions to provide a broadband access network in practical rural/remote area by investigating the studied area's condition and studying its network and energy performances. The network dimensioning and network performances are evaluated in MATLAB. In addition, we study the difference between taking simplified network model and realistic network model for planning a practical area. This research takes an example of Banten Province, Indonesia. As we focus on rural and remote area, we decided to take two different geographic characters: Coastal lowland in Panimbang District as a rural area, and hilly topography area in Leuwidamar District as a remote area. The analysis of proposed technical solutions for both areas hopefully would benefit policymakers to prepare future enhanced Mobile Broadband (eMBB) strategic regulations for rural areas in Indonesia.

To find the most suitable solutions to deploy the future broadband network, we need to investigate the current condition of Banten. Based on a study, people in Banten currently access information by using mobile phones, computer, fixed line phone, television and radio (R&D Center for Post & ICT Resources, 2016). The fixed line cable / ADSL user is less than 5% in Banten. The fiber network mostly limited to cities. Both terrestrial television signal and radio signal also hardly reach a remote area. The satellite signals, however, mostly suffer from a latency and have limited capacity, which only able to reach downlink up to 20 Mbps (Cosseboom, 2015), where the 5G aim to have 50 Mbps everywhere (Team & NGMN Alliance, 2015). On the other hand, Banten has a well-established mobile communication infrastructure in which some of the areas are covered by the LTE services. For this reason, it is interesting to do a quantitative analysis of upgrading current LTE network to be a prospective eMBB network, provided that we could suppress the investment cost by upgrading a brownfield area.

2. Key Elements of Future eMBB Techniques

The future eMBB technology would be supported by several cutting-edge mechanisms which enable to serves a high traffic demand with a good performance. We evaluate three key techniques that would likely to help eMBB to operate: Millimeter-wave; User-Equipment (UE)-Specific Beamforming; and, Carrier-Aggregation. We also add one additional mechanism to enable energy efficient solution i.e. DTX in Ultra-Lean Design Network.

2.1. Millimeter-wave

The lack of bandwidth availability in frequency below 6 GHz, is the main constraint of providing a high capacity and a high bitrate which able to serve a vast future traffic demand. One of the possible solutions is to utilize the high frequency. Some prospective frequencies to operate the future 5G for eMBB are 28 GHz, 38 GHz, 60 GHz and 73 GHz, with the wavelength 10 mm, 7 mm, 5 mm and 4 mm respectively, hence millimeter-wave / mmWave (Niu, Li, Jin, Su, & Vasilakos, 2015). In addition, there is also a proposal to use microwave frequency in 15 GHz to serve prospective 5G network (Okvist et al., 2015).

To deploy a network in high frequency, there are several challenges that need to be addressed. Operating in high frequency gives high propagation loss and significant attenuation from blockage. For that reason, mmWave is probably more suitable for small cells such as microcells or picocells since the distance between receiver and transmitter will not be so far. However, we could combat the high attenuation and propagation loss in wide range cells by using beamforming techniques. For the mmWave system, we have an advantage of smaller wavelengths, which enables us to design a smaller antenna aperture. By having a smaller antenna aperture, we can make an array antenna which consists of tens or hundreds of antenna with a compact size. The array antennas increase the antenna gain and consequently mitigate the high propagation loss. Further details will be discussed in Section 2.2.

2.2. UE-Specific Beamforming

Using a high frequency for a mobile communication network is challenging because of the strong distance-dependent attenuation and a high penetration loss from obstacles such as buildings and trees. However, because of the small wavelengths, we can pack more arrays into a small antenna size which leads to a higher antenna gain. Moreover, a large number of antenna elements enable the antenna beam to be narrower. Such narrow beam could be steered to a specific user in order to maximize the signal strength which in the same time decrease the interference, hence UE-Specific Beamforming (Yu, 2016). An illustration can be seen in Figure 1. To calculate antenna gain g_{MB}, we use a simple mathematical equation in which dependent on elevation θ and azimuth φ half-power beamwidth (HPBW) as expressed by:

$$g_{MB} = \frac{A_{Sphere}}{A_{MainBeam}} = 4\pi r^2 \frac{4}{\pi r^2 \sin\theta \sin\varphi} = \frac{16}{\sin\theta \sin\varphi} \quad \text{1)}$$

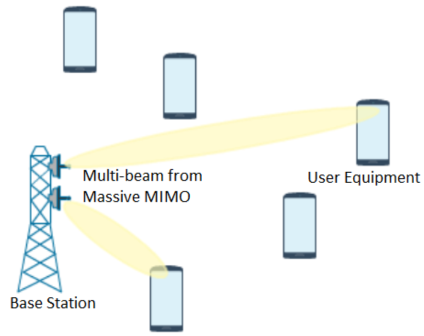


Figure 1. UE Specific Beamforming Illustration

2.3. Carrier Aggregation (CA)

CA is a mechanism that enables the utilization of wide bandwidth by combining several Carrier Components (CC) in order to increase user capacity and system throughput (Jeanette Wannstrom, 2013). From current 3GPP standard, the CA scheme is able to combine five CC in maximum e.g. if one CC is 20 MHz, then the maximum aggregated bandwidth for the system is 100 MHz. There are three types of CA, as illustrated in Figure 2. The most simple scheme is the Intra-Band Contiguous when we aggregate CC within the same operating frequency. However, such allocation scenario is not common. Most operators have licenses in different bands, thus the Intra-Band Non-Contiguous and Inter-Band CA scheme are more popular. The Intra- and Inter-band has different performance in terms of coverage. Intra-band CC's coverage is almost identical and overlaid to each other, while for the Inter-band CC which operated in a higher frequency will have smaller coverage due to a higher propagation loss (Shen, Papasakellariou, Montojo, Gerstenberger, & Xu, 2012).

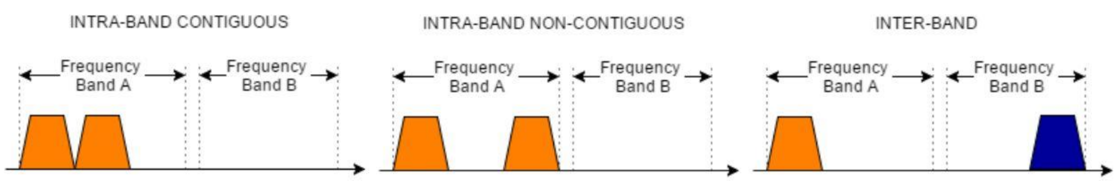


Figure 2. Carrier Aggregation Illustration

2.4. Ultra-Lean Design

In terms of power, the current Base Station (BS) designed to be always-on, while in the future ultra-lean design, the BS would be always-available, i.e. no need to be always active all the time including during the idle mode. The main idea of ultra-lean design is to minimize any transmissions which not related to data delivery, such as synchronization signals, control channel, etc (Forssell, 2015). Cell discontinuous transmission (Cell DTX) is one of technology that enables ultra-lean design system. It allows BS to change into a sleep mode when there is no traffic data that needed to be served. The DTX is not completely turning off the BS, it still needs an amount of energy to activate some important components. In practical, there is a term called DTX Capacity which represents a capability of Cell DTX to deactivate some components. The current LTE system allows us to have a sleep duration maximum 0.2 ms because of its plenty of mandatory signals that need to be submitted. However, a study of future 5G shows that we could achieve a sleep duration up to 99.6 ms hence having a deeper sleep compared to LTE system (S Tombaz, Han, Sung, & Zander, 2014).

3. Performance Evaluation Method

The evaluation method of this study is divided into three steps, as depicted in Figure 3. Firstly, we forecast the future traffic demand that needs to be satisfied. The forecasting accounts a realistic data such as a number of users, population density, and government spatial planning. Secondly, we dimension the network for each proposed solution case to satisfy futuristic traffic demand. In network dimensioning phase, we set and define the user distribution, the BS specifications, and analyze the radio environment map (REM) for each solution case. Lastly, we analyze the energy performance for proposed solution cases by using power consumption model.

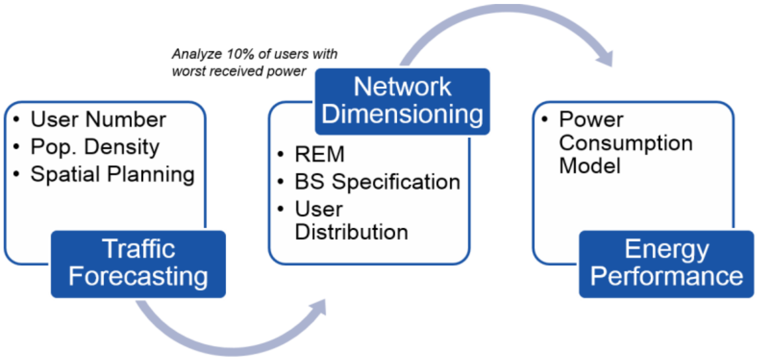


Figure 3. Evaluation Framework

3.1. Traffic Forecasting

We estimate the futuristic traffic demand by evaluating several important data such as the population growth, the device capability in which depicted the number of devices that capable to receive 2G/3G/4G, the user type, and the average subscription for each type. The realistic data were gathered from Central Bureau Statistics, network providers public reports, and internal operator data. We adopt traffic modeling from EARTH project to calculate overall traffic requirement (Auer & Blume, 2012). The average traffic demand can be calculated by:

$$r_{av} = \sum_{k} r_k s_k \text{ in [GB/month/subscriber]} \quad \text{2)}$$

where r_k is the monthly data demand and s_k is the ratio of subscribers of the type k device. We consider three type of users which are the mobile phone user, mobile PC user, and tablet user. Those types have a different data demand and a different ratio of subscribers for the Panimbang (rural) and Leuwidamar (rural) areas.

3.2. System Model

To evaluate the network performance, we use a user downlink throughput as the main parameter. The user throughput from a particular BS may vary within a certain amount of time. BS tend to offer a high throughput for a low traffic, and vice versa. The feasible load model calculates the load or cell resource allocation as the fraction of time-frequency resources in an OFDM system in which scheduled for data transmission for a given cell (S Tombaz et al., 2014). The Feasible load η_k of BS k for N_k users in time T is depicted by the following equation:

$$\eta_k = \frac{\sum_{i=1}^{N_K} \Omega_i / r_i}{T} \quad \text{3)}$$

Where Ω_i is the traffic demand of user i as calculated in Equation 4, and r_i is the data rate as depicted in Equation 5.

$$\Omega_i = (r_{av})_i \frac{8 \times 10^3}{30 \times 12 \times 3600} Mbps \quad \text{4)}$$

$$r_i = W_{RB} \min\left[\log_2\left(1+\frac{g_{MB}g_{ik}P_k}{\sum_{j\neq k}^{M}\eta_j g_{SB} g_{ij} P_j + N_0}\right), v_{\max}\right] \quad \text{5)}$$

The Ω_i is affected by average data rate r_{av} and the sum of the busy hour for a certain amount of time. In this study, we assume the busy hour is spread over 30 days and 12 hours each day. The user i's data rate r_i depends on the bandwidth allocation W_{RB}, a main lobe antenna gain g_{MB}, the i to k channel gain g_{ik}, and the BS k's power transmit P_k. The rate also affected by the sum of interference which depends on the load of interferer BS η_j, the side lobe antenna gain g_{SB}, a channel gain between user i to BS j, the BS j's power transmit P_j. The rate is also affected by the noise floor N_o. The v_{max} is the maximum spectral efficiency in practical.

Aside from the throughput performance, we also evaluate the average area energy performance in which calculated by Equation 6 (Auer & Blume, 2012). In practical, the user traffic in a day is variated between 16% of users active during the peak hour to 2% of users active during the low traffic hour. Thus the energy consumptions are varied within a day. To capture a practical case, we classify the BS power consumption into active mode Pactive and Sleep mode Psleep. The power during active mode Pactive and sleep mode Psleep is set differently between LTE and future 5G network, and are shown in Equation 7 and 8 respectively. The active mode is when PtxLTE or PBS5G is > 0, means that the BS has a traffic that needs to be served. The sleep mode is when it equals to 0, means that the BS does not has any traffic to be served. In LTE power consumption equation, the NTRX denotes the number of the transceiver, Ptx is the transmit power, Δp is the consumption of power amplifier which needed to mitigate a feeder loss. The Po represents the power of active cooling and the signal processing equipment which not related to transmitting traffic load. In future 5G power model, the Pactive has a slightly different calculation. It considers the additional impact of power amplifier efficiency ε. Instead of accounting the number of the transceiver, the future 5G power model accounts the RF chains N. The Ptxs denotes the transmit power, and PB is the fixed power consumption in a BS. For both systems, we adopted the DTX model that depicted by additional δ where 0 < δ < 1 in which represents the DTX ability. The minimum value for δ in LTE system is 0.84, and for the 5G system is approximated as 0.29. The reason is that in LTE system the primary transmissions required is very short with only 0.2 ms, while the future 5G system could achieve longer DTX period up to 99.6 ms, hence such system could save more energy during the sleep mode (Sibel Tombaz et al., 2015).

$$P_{area} = \frac{1}{24}\frac{\sum_{t=1}^{24}\sum_{i=1}^{N_{BS}} P_{active}\eta_i^t + P_{sleep}(1-\eta_i^t)}{A}[kw/km^2] \quad \text{6)}$$

$$P_{BS}^{LTE} = N_{TRX} \times \begin{cases} \Delta_p P_{tx} + P_0 & \text{if } P_{tx}^{LTE} > 0 \\ P_0 & \text{if } P_{tx}^{LTE} = 0 \text{ (without cell DTX)} \\ \delta P_0 & \text{if } P_{tx}^{LTE} = 0 \text{ (with cell DTX)} \end{cases} \quad \text{7)}$$

$$P_{BS}^{5G} = N_S \times \begin{cases} \frac{P_{tx}^{s}}{\varepsilon} + NP_c + P_B & \text{if } P_{tx}^{5Gs} > 0 \\ P_B & \text{if } P_{tx}^{5G} = 0 \text{ (without cell DTX)} \\ \delta P_B & \text{if } P_{tx}^{5G} = 0 \text{ (with cell DTX)} \end{cases} \quad \text{8)}$$

3.2.1 Radio Environment Model

We use a propagation model that suitable for mmWave path loss calculation in the rural area. The model is modified with an empirical result from an experimental study of US's rural areas (MacCartney & Rappaport, 2017). We use the CIH-RMa NLOS model since generally the distance from BS to UE is quite far, thus it is more likely to be a non-line-of-sight connection. The propagation is calculated as follows:

$$PL_{NLOS}^{CIH-RMa}(f_c, d, h_{BS}) = 32.4 + 20\log_{10}(f_c) + 30.7\left(1 - 0.049\left(\frac{h_{BS} - 35}{35}\right)\right)\log_{10}(d) + X_{\sigma NLOS} \quad \text{......9)}$$

Where d is the distance between BS to UE ($d \geq$ 1m), f_c is the operating frequency, h_{BS} is the BS transmitter height and σ_{NLOS} is the standard deviation of the shadow fading in which recommended as 6.7 dB. For the antenna modeling, we use the horizontal antenna pattern for a three sectoral cell site model which expressed in Equation 10. The θ_{3dB} represents an azimuth HPBW of an antenna, and the A_m is a maximum difference of antenna's main lobe and side lobe which is 20 dB(NGMN Alliance, 2008).

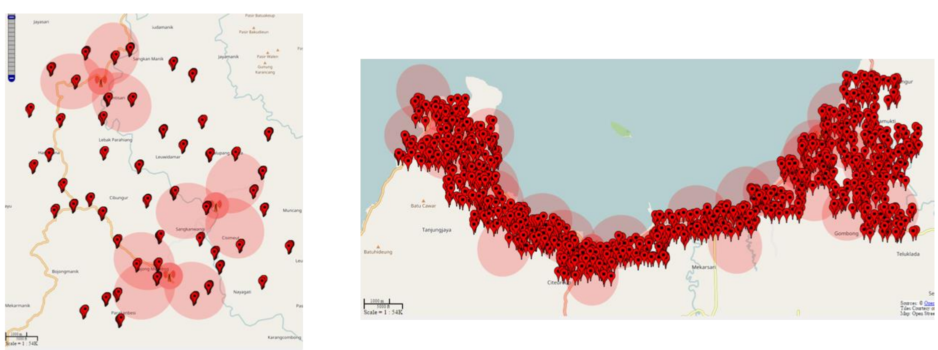
$$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{dB}}\right)^2, A_m\right] \quad \text{......10)}$$

To mimic a real situation in Indonesia, we account a rain attenuation which highly important to be considered, especially when we operating a network in high frequency. The most widely acceptable rain model is from ITU-R Recommendation which illustrated in Equation 11:

$$\gamma_R = kR^{\alpha} \quad \text{......11)}$$

Where R is the rain rate (mm/h), k and α are the coefficients which dependent on functions of frequency. To find a suitable rain rate, we adopt the result of an observation of Jakarta's rain attenuation impact for different frequencies (Mirfananda & Suryanegara, 2016). The authors account the rain attenuation of a heavy rain with a rain rate 100 mm/h. The study shows that such a heavy rain gives a 6 dB/km loss in 15 GHz link and a 14 dB/km loss for 28 GHz link.

3.3. Simulation Scenario



a. Leuwidamar (Remote) b. Panimbang (Rural)

Figure 4. User Distribution

We have two types of the studied area with a different characteristic. The first one is Leuwidamar that represents a remote area. As a remote area, Leuwidamar has sparsely distributed users which spread among 50 small villages. The second one is Panimbang which characterizes the rural area. Users in Panimbang are distributed more uniformly along the coastal road. As we use a brownfield area, the Leuwidamar has three existing BS to cover 176 km^2 area, and Panimbang has eight existing BS to cover 132 km^2 area. The BS location, each sector's azimuth direction, and the village distribution are modeled in MATLAB as shown in Figure 4. User Distribution

As previously discussed in Section 2, we consider four techniques to dimension the prospective eMBB network, in which assumed to be 5G for this research. We propose five systems to be evaluated:

3.3.1. Case 1: Single Carrier (SC) LTE 1.8 GHz

We intend to evaluate how current LTE system serves futuristic traffic demand. This scenario will be the baseline of comparison to others. The motivation of using 1.8 GHz link is because it is the frequency used for LTE in Indonesia. We occupy a 20 MHz bandwidth, provided that the operators in Indonesia currently have a license for up to 20 MHz bandwidth usage for LTE.

3.3.2. Case 2: Carrier Aggregation (CA) LTE 1.8 GHz + 2.6 GHz

The CA was recently introduced in LTE-A standard, thus it is important to be considered for the coming networks. Some prospective frequencies for CA (e.g. 800 MHz, 2.1 GHz, 2.3 GHz and 3.5 GHz) are fully allocated in Indonesia, including the 2.6 GHz that we use for our study. However, the 2.6 GHz is one of the popular frequencies that used for LTE service in some countries. Thus, we evaluate the performance of aggregating 1.8 GHz LTE with 2.6 GHz LTE system as one of the future solutions.

3.3.3. Case 3: SC 5G 15 GHz

In the future, we probably face a capacity limited scenario in a rural area. Thus, evaluating a mid-solution between low frequency and mmWave is needed. A study shows that a microwave link might provide a wide bandwidth up to 100 MHz for the mobile communication network (Sibel Tombaz et al., 2015).

3.3.4. Case 4: SC 5G 28 GHz

Most 5G studies evaluate 28 GHz link performance for the future mobile network. Such a high frequency is generally operated for the dense-urban area since it able to occupies up to 850 MHz Bandwidth (National Instruments, 2016). Since mmWave may serve a very high traffic demand and has a high potential for the future 5G network, we need to investigate the 28 GHz link performance in a rural or remote area as well.

3.3.5. Case 5: CA LTE 1.8 GHz + 5G 15 GHz

A backward-compatibility is expected to be available on the future 5G services. Evaluating the carrier aggregated link between existing LTE system and the future 5G system is important. The reason we choose to aggregate LTE network with the 15 GHz link is that it can give us wide enough bandwidth with no dramatic propagation loss.

Table 1. Parameter Setup

Details	Case 1	Case 2	Case 3	Case 4	Case 5
Frequency	1.8 GHz	1.8+ 2.6 GHz	15 GHz	28 GHz	1.8 + 15 GHz
Bandwidth	20 MHz	20 + 40 MHz	≤ 100 MHz	≤ 500 MHz	20 + ≤ 100 MHz
Tx Antenna Gain	18 dBi	18 dBi	24 dBi	27 dBi	18 / 24 dBi
Az. HPBW	65°	65°	20°	10°	65° / 20°

The parameters used for all proposed scenarios are shown in Table 1. Parameter Setup The frequency used for each scenario is different. We also assume a different bandwidth on each link, provided that the higher frequency has a higher probability to offer a wider bandwidth. The antenna gain and HPBW is different between the LTE and the 5G system. Thanks to the antenna arrays, the higher frequency can give us a higher antenna gain and a narrower beam.

4. Result and Discussions

There are four results that discussed in this section. First is the traffic forecasting from 2017 to 2023 that define the futuristic traffic demand. The second one is the discussion of how radio environment and future technologies affect user performance. The third discussion is comparing a simplified and realistic model. The last discussion is the performance comparison of the five proposed solutions.

4.1 Traffic Forecasting

By combining the population growth data statistic, the device capability record, several types of user, and the average subscription for each type of users, the forecasting of the futuristic traffic demand is illustrated in Figure 5. We consider a three type of users: a mobile phone user, a tablet user, and a mobile PC user. Those three users are differed on the amount of subscription per month, and a percentage of users in a population. To accounts all user types, we calculate an average subscription r_{av} by using the Equation 3. As we can see in Figure 5, the average monthly demand is increasing up to 16 GB/Month/User for Leuwidamar and 18 GB/Month/User for Panimbang in 2023. The reason for the increase is, firstly, the traffic demand from each user might increase, and secondly, the growth of the number of subscribers per area. The increase of the subscribers might be caused by the growth of population or an increase of the user penetration. In Panimbang area, the traffic demand is higher. Aside from a higher average subscription, Panimbang also has a higher number of users, compared to the Leuwidamar area. By having this forecast, we able to dimension a future network that serves the demand while maintaining the performance, which in this research is evaluated by having 50 Mbps downlink throughput for 95% of users, as the minimum requirement.

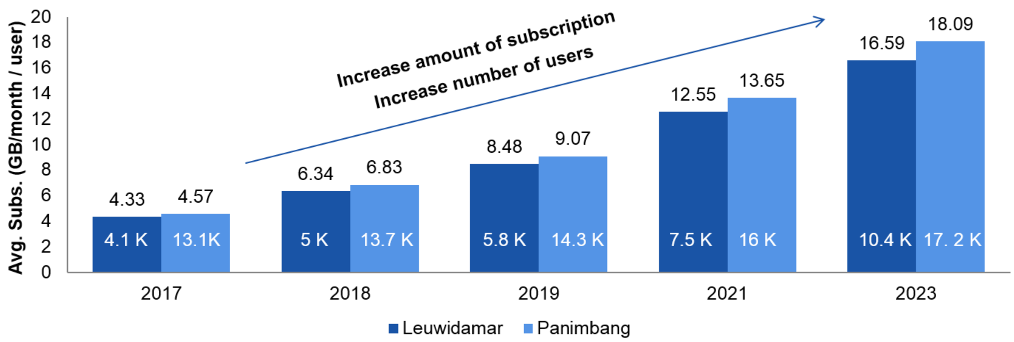


Figure 5. Traffic Forecasting

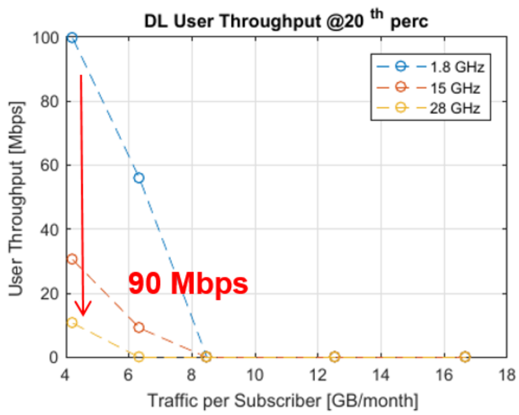
4.2 Network Dimensioning Solutions

In this section, we first discuss the impact of changing properties on the radio environment to the downlink user throughput. It followed by evaluating the impact of changing some technical aspects to the user performance. The aim of both evaluations is to understand the impact of some parameters and find the most effective way to meet the future requirements. After understanding how the network model works, we calculate the number of BS needed for each solution as one additional metrics to compare each other solution. Lastly, we evaluate the difference of using realistic model network compared to a simplified hexagonal model network.

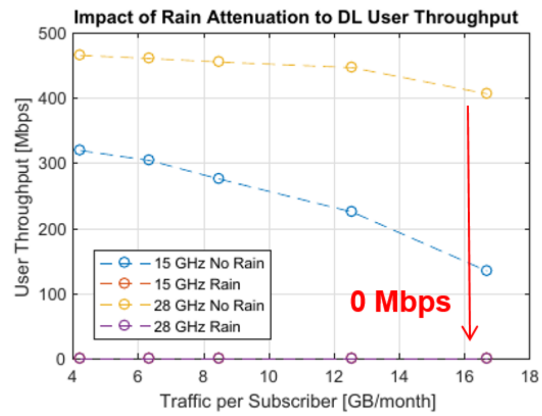
4.2.1 Impact of Radio Environment and Technology Aspects

We use a current Leuwidamar network with 3 BS spread over a 176 km^2 area as the baseline to compare properties, such as the impact of changing operating frequency, the effect of rain attenuation, an impact of implementing a variety of bandwidth, changing of an antenna's beamwidth, and the effect of carrier aggregation implementation compared to a single carrier network performance. We use the same number of BS, same user distribution, and some other properties which act as the control variables.

The impact of frequency changing and effect of the rain attenuation to the downlink user throughput is depicted in Figure 6a and Figure 6b respectively. In terms of changing operating frequency, the path gain decreases dramatically by increasing the frequency from 1.8 GHz to 28 GHz, thus the downlink user throughput has decreased as well. The 28 GHz offer the least throughput because the link signal suffers from a very high loss. For the rain attenuation impact analysis, the average signal power attenuates significantly with 25 dB decrease in 15 GHz link and 58 dB decrease in 28 GHz link. This highly affects the downlink user throughput. For this scenario, whenever we have a heavy rain, the system is no longer working. The main reason is that both operating frequencies have a high rain attenuation, which is 6 dB/km in 15 GHz and 14 dB/km loss in 28 GHz link. Thus, the edge-cell users will highly suffer from a high loss and cannot be served by BS.



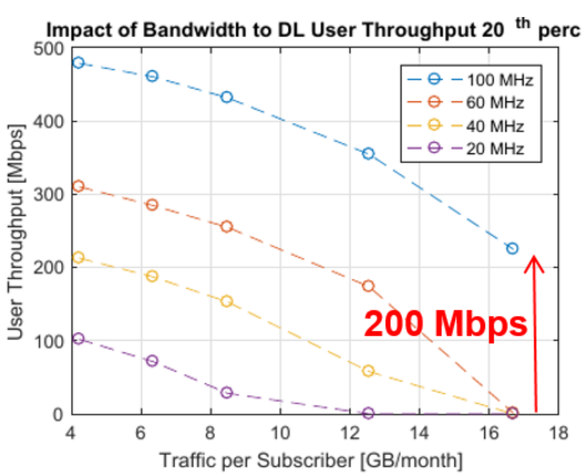
a. Impact of Operating Frequency to Downlink User Throughput



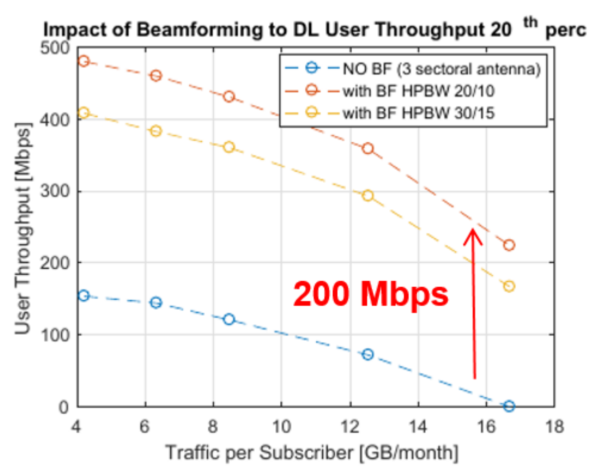
b. Impact of Rain Attenuation in 15 GHz and 28 GHz link to Downlink user Throughput

Figure 6. Impact of Radio Environment

Next, we investigate the impact of three key techniques application: the wide bandwidth availability, the impact of UE-Specific Beamforming and CA scheme. To evaluate the impact of bandwidth availability, we simulate a Single Carrier 15 GHz system in Leuwidamar Network. As we can see in Figure 7a, when we increase the bandwidth, the downlink user throughput increases up to 200 Mbps by having a 100 MHz bandwidth. The reason is that the wider bandwidth will give us a less interference and a higher capacity. However, we must note that there is an extra SNR loss when we enlarge a bandwidth due to an increase of a noise power. Yet, at the same time, it can decrease the interference and increase the throughput performance.



a. Impact of Bandwidth to Downlink User Throughput



b. Impact of Beamforming Ability to Downlink User Throughput

Figure 7. Impact of Technology Aspects

To mitigate the high loss in a high frequency, we exploit the UE-Specific Beamforming for the additional antenna gain. The antenna gain is dependent on azimuth and elevation HPBW, as calculated by Equation 10. We evaluate the performance of a normal three-sectoral antenna with 65° HPBW which used as a baseline comparison. Then we vary the antenna's beamwidth which uses in UE-Specific Beamforming: the 30°/15° HPBW antenna, and the 20°/10° HPBW antenna. Compared to the three-sectoral antenna, UE-Specific Beamforming techniques have a better throughput, which mainly caused by the stronger signal and a less interference. Thus, as illustrated in Figure 7b, the user throughput rises to more than 100 Mbps by implementing the 30°/15° HPBW antenna and reach more than 200 Mbps while using the 20°/10° HPBW antenna. The reason behind this is the narrower beamwidth will give us a higher gain, with a 4 dB increase of 10° narrower beamwidth in this scenario. Hence, the downlink user throughput also linearly increasing with a narrower beamwidth.

Another way to have a higher capacity is by using CA Scheme. We compare the SC LTE 1.8 GHz system, SC LTE 2.6 GHz System and CA scheme for LTE 1.8 and 2.6 GHz. Compared to the SC performance, the CA network has a significant increase with additional 15 dB SINR which mainly caused by the decrease of interference. The reason is that all users are distributed into two different systems and leads BS to offer more capacity. Consequently, our user throughput performance will also increase, as depicted in Figure 8. It shows that the 50 Mbps requirement is met when we use CA scheme, while it is not met when we use SC scenario. The resource allocation in CA is set based on a threshold of the user's received power. Users which have a well-received power, i.e. above the threshold, will be allocated to a higher frequency since it has a higher capacity until the BS is fully loaded. For those who received lower than the threshold, users will be allocated to the lower frequency network. Note that for the further Case 2 and Case 5 Solution, we implement an optimal threshold to maximize 5th percentile of user performance.

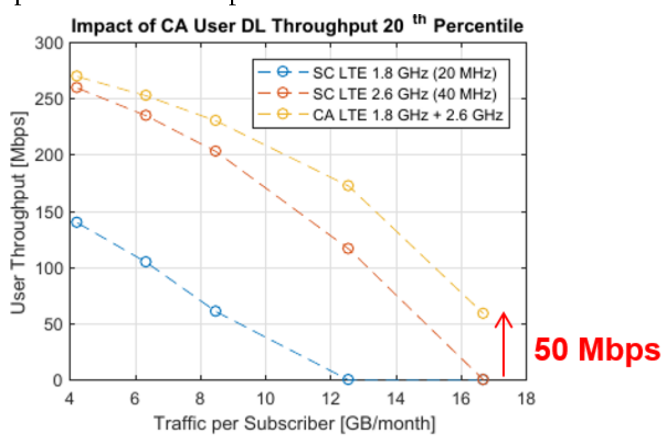


Figure 8. Impact of Carrier Aggregation

4.2.2 BS Dimensioning for Proposed Cases

After we understand the impact of changing frequency, rain attenuation, bandwidth, antenna's beamwidth and CA scheme, we can optimize the networks for five proposed solutions, and calculate the number of BS needed for each solution. Note that we maintain the user downlink throughput to be 50 Mbps for the 5th percentile of users for all cases and maximize the ability of 5G technology to have the least number of BS. As shown in Table 2, for Leuwidamar Area, the Case 1 has 36 BS with twelve times densification to serve futuristic traffic demand. The reason for such a high number is that we only have 20 MHz bandwidth and it is not enough to serve the forecasted traffic. For Case 2, we have 7 BS only with 2.3 times densification. The reason is that we have more capacity in 2.6 GHz link by having a 40 MHz bandwidth, which is a twice of the capacity in the Case 1. For Case 3, we also need to have 7 BS to meet the future requirement. Although we have a 100 MHz bandwidth, we need to add more BS since it is a coverage limited scenario. Note that we account a rain attenuation, so the dimensioning result is working during a heavy rain. Similar to the Case 3, the Case 4 is a coverage limited scenario. Moreover, the 28 GHz link has a smaller coverage compared to the 15 GHz link coverage, thus we need 21 BS with 7 times densification. Lastly for the Case 5, we only need to have 5 BS with 1.6 times densification. The Case 5 has the least number of BS since the 5G 15 GHz link can provide a high capacity for users located close to BS, and offer a low-frequency network for the cell edge users.

For Panimbang area, Case 1 also gives us the highest number of BS. The Case 3 and Case 5 do not need additional BS which leads them to have the smallest number of BS needed. Another interesting thing to see is the Case 4 network dimensioning result. While Leuwidamar needs a high amount of BS, Panimbang only needs to have 11 BS with 1.37 times densification. This is because the Leuwidamar has a wider area and a sparse user distribution, whereas Panimbang has a smaller area and a denser user distribution.

Table 2. Network Dimensioning Solution

Case/Area	Leuwidamar (Remote)	Panimbang (Rural)
Existing BS	*3 BS / 176 km2*	*8 BS / 132 km2*
Case 1: SC LTE 1.8 GHz	36 BS (12×)	81 BS (10.12×)
Case 2: CA LTE 1.8 + 2.6 GHz	7 BS (2.3×)	12 BS (1.5×)
Case 3: SC 5G 15 GHz	7 BS (2.3×)	8 BS (no add)
Case 4: SC 5G 28 GHz	21 BS (7×)	11 BS (1.37×)
Case 5: CA LTE 1.8 + 5G 15 GHz	5 BS (1.6×)	8 BS (no add)

4.3 Importance of Realistic Model

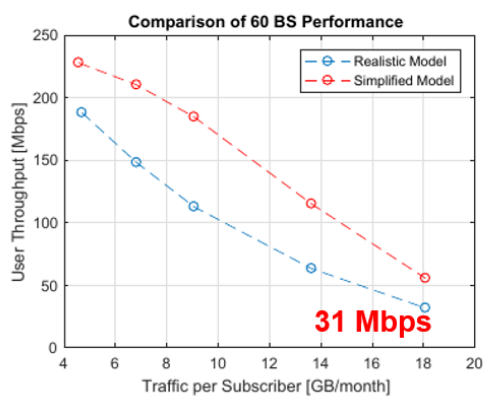
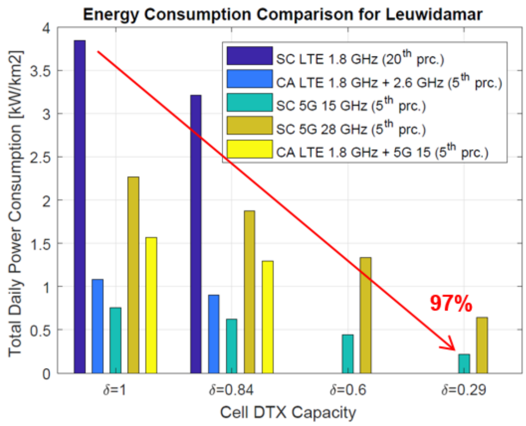


Figure 9. Performance Comparison of Simplified and Realistic Model

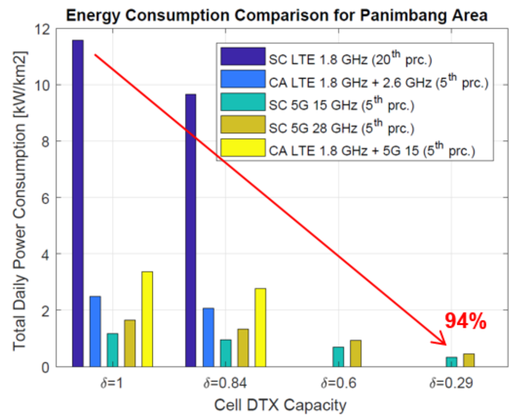
To plan a future network, most studies take a general simplified network model e.g. 120° hexagonal site pattern. In this research, we compare the simplified and realistic model with the same user number, the same traffic demand, and the same system network. The difference is only on BS location and the user distribution. The simplified model uses 120° hexagonal site pattern network, and the realistic model is following the practical Panimbang's BS distribution. Our study shows that the 50 Mbps requirement is met when we deploy 60 BS in a simplified model, while for a realistic case we need to deploy 81 BS. We also compare the performance of both models when having the same number of BS. As we can see in Figure 9, when we have 60 BS, the realistic model does not meet the requirement, while the simplified model fulfilled it. Thus, it is important to consider a realistic network layout, since it gives us a different result.

4.4 Energy Performance

As previously discussed, there are some solutions that have the same number of BS. To give a better suggestion, we evaluate the energy consumption to study the energy performance of each solution. Thus, we can give a suggestion which has the best network and energy performance.



a. Energy Performance of Leuwidamar



b. Energy Performance of Panimbang

Figure 10. Energy Performance Comparison for Different Solutions

In Leuwidamar's Cases, the Case 1 has the highest number of BS needed, thus it consumes the highest energy among other solutions, as we can see in Figure 10a. The main reason is that the energy consumption is linearly correlated to the number of BS. Although the Case 5 has the least number of BS, which is 5, it consumes a high enough energy. The reason is that when we apply CA scheme, we have added 45% of power to generate the second system (Sibel Tombaz et al., 2015). The Case 2 and Case 3 has the same number of BS, yet the Case 2 consumes more energy since it also implements the CA scheme. In Panimbang's Cases, Case 1 also consumes the most power, because of the enormous amount of BS needed for such system. The Case 3 and Case 5 has the same number of BS, and yet the Case 5 consumes a higher power compared to the Case 3 since the Case 5 uses a CA Scheme. In result, for the Leuwidamar and Panimbang areas, The Case 3, SC 5G 15 GHz is suggested to be the best solution for both areas, since it gives us the least energy consuming solution. Moreover, if we have the DTX Capability, the energy consumptions can be decreased significantly. Especially for the 5G networks, when we can achieve a deeper sleep mode. By utilizing DTX capability, Leuwidamar's Case 3 can save up to 97% of power, and the Panimbang's Case 3 can save up to 94% of power consumption, compared to each respective Case 1 LTE network.

5. Conclusions

Several solutions perform differently in different areas, and a suggested solution might be different as well. The study shows that it is important to consider a realistic network model, over a simplified model, to reach the most suitable solutions for a particular area. In Leuwidamar and Panimbang scenarios, a vast amount of BS needed if we keep using the current LTE 1.8 GHz network, in which more than 10 times BS densification of the current network.

For the futuristic network, the wide bandwidth availability, UE-Specific Beamforming, and Carrier Aggregation scheme are successfully decreasing the required number of BS. For both area, it is suggested to deploy Case 3 (SC 5G 15 GHz) system network, considering that our assumptions of 5G eMBB techniques are fulfilled, and on the same time has a high efficiency of energy consumption compared to other solutions. The high efficiency of energy is also supported by DTX capability which uses in the ultra-lean design network.

The motivation of comparing the number of BS and the energy consumption is to have a wide understanding of how much the system will cost compare to each other. For the future work, it is highly recommended to analyze the economic aspect for the proposed solutions. Moreover, it is also interesting to investigate the future 5G eMBB network deployment in a heterogeneous network for a rural area.

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