5G Capacity Design Based on User Demand in Single High Altitude Platform Network

Desain Kapasitas Seluler 5G Berdasarkan Permintaan Pengguna pada Jaringan High Altitude Platform Tunggal

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ABSTRAK

HAPS (High Altitude Platform Station) adalah alternatif teknologi telekomunikasi sebagai pelengkap sistem eksisiting yaitu terestrial dan satelit. Salah satu aplikasi yang dapat digunakan dalam sistem HAPS adalah teknologi seluler 5G. Namun, interferensi merupakan salah satu masalah dalam mencapai kapasitas maksimum. Teknik multispot beam dan power control keduanya digunakan untuk mengatasi masalah tersebut. Teknik multispot beam ini berfungsi seperti pada sistem antena BTS terestrial. Akan tetapi antena multispot beam pada sistem HAPS ditempatkan berdekatan pada satu wahana atau platform HAPS. Oleh karena itu sinyal interferensi dari tiap pengguna akan menempuh jarak lintasan yang hampir sama dengan sinyal yang diinginkan. Berbeda dengan sistem BTS terestrial di mana setiap pengguna mendapat kontrol daya dari BTS yang berada di setiap sel. Panjang lintasan yang diambil oleh setiap sinyal pengguna berbeda sehingga nilai shadowing juga berbeda. Paper ini bertujuan untuk mengevaluasi kapasitas 5G seluler dalam sistem HAPS tunggal di mana bandwidth yang digunakan adalah 0,1 GHz dan 1 GHz. Hasil simulasi menunjukkan bahwa probabilitas outage menggunakan bandwidth 0,1 GHz menghasilkan kapasitas dalam sistem HAPS tunggal, maksimum 550 pengguna dan jika menggunakan 1 GHz maka maksimum jumlah pengguna adalah 5500 pengguna dalam referensi sel.

ABSTRACT

HAPS (High Altitude Platform Station) is an alternative technology to an existing communication systems named terrestrial and satellite systems. One of the applications that can be employed in HAPS system is cellular 5G technology. However, interference is one of problems in achieving maximum capacity. Multispot beam and the power control are both used to overcome the problem. This multispot beam antenna works like a base station on a terrestrial system. The multispot beam antenna lies at a close distance on the platform. Thus the path passed by the signal of each user has a nearly equal length of trajectory. Almost the same trajectory causes the shadowing experienced by each user almost the same value. This is in contrast to the terrestrial system in which each user gets the power control of the BTS residing in each cell. The length of the path taken by each user's signal is different so the shadowing value is also different.This paper aims at evaluating the capacity of 5G cellular in single HAPS system in which the bandwidths used are 0.1 GHz and 1 GHz. Simulation result shows that outage probability using 0.1 GHz bandwidth resulting the capacity in single HAPS system, which is maksimum 550 users in reference cell can achive 10-15 and it also happen when using 1 GHz with maksimum 5500 users in reference cell.

1. Introduction

Nowadays, telecommunication service globally employs wireless communication system with two alternatives, which are terrestrial and satellite communication systems. Terrestrial communication system has an advantage on the improvement of system capacity by doing antenna sectorization or decreasing the size of the cell. However, this system needs big amount of Base Transceiver Station (BTS) to provide coverage needed and it has limited communication on line of sight (LOS) between the user and BTS. On the other hand, in the second alternative, satellite communication system can reach wider range area and it has better LOS communication compared with terrestrial communication system. Nevertheless, this satellite communication system consists of propagation delay and larger pathloss caused by that satellite height. Therefore, it needs new alternative that can handle those problems. The new alternative for wireless communication system is High Altitude Platforms Station (HAPS). HAPS combines the adavantages of terrestrial and satellite communication system. It has wide range area and low propagation delay, enables to provide LOS communication, and needs smaller infrastructure, development and implementation costs.

Cellular communication system has encountered long development since 1990s. It currently enters the fifth G namely 5G generation. 5G is different with the previous generation, which is LTE. This fifth generation does not use multi-access scheme of Orthogonal Frequency Multiple-Access (OFDMA), but it employs Non-Orthogonal Multiple-Access (NOMA). The development of 5G technology aims at creating cellular telecommunication technology that contains improvement on capacity, throughput and data rate (~1000x of throughput improvement over 4G, cell data rate ~10 Gb/s, signaling loads less than 1~100%) [1]. In addition, downlink user experienced data rate is 100 Mbit/s and uplink user experienced data rate is 50 Mbit/s in 5G. The minimum requirement for control plane latency is 20 ms. Proponents are encouraged to consider lower control plane latency, e.g. 10 ms. The minimum requirement for the reliability is 1-10-5 success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms in channel quality of coverage edge for the Urban Macro-URLLC test environment, assuming small application data (e.g. 20 bytes application data + protocol overhead). The requirement for bandwidth is at least 100 MHz. The RIT/SRIT shall support bandwidths up to 1 GHz for operation in higher frequency bands (e.g. above 6 GHz) [2].

The implementation of 5G HAPS system is expected to be supporting the availibity of global connectivity in the future. 5G system will support HAPS (High Altitude Platform Stations) where UAVs(Unmanned Air vehicles) will act as intermediate transceiver stations and thus this implementation will increase the effective range of communication [3]. One of important aspects to be examined in HAPS system before being implemented is the system capacity. This study will discuss 5G capacity in single HAPS systems with bandwidth 0.1 GHz dan 1 GHz. The model of HAPS system is created based on the previous study analyzing LTE reverse link capacity [4].This study is divided into four parts compiled as follows: Section I is the introduction, Section II introduces multi beam HAPS system model. In Section III interference analysis and system capacity in terms of outage probability is defined. Simulation result on the capacity is then presented in Section IV. Finally, conclusions of the paper are given in Section V.

2. HAPS System Model

HAPS is a telecommunication platform at manned or unmanned flying aircraft or airship or balloon which operate at 17 km to 22 km altitude. HAPS must be located above aviation airline with sufficiently low wind speed to keep it

$$G(\theta) = \begin{cases} 34.8 - 3(\theta/1.57)^2, & for\ 0^0 \le \theta \le 4.53^0 \\ 9.8, & for\ 4.53^0 \le \theta \le 5.87^0 \\ 55.95 - 60\log(\theta), & for\ 5.87^0 \le \theta \le 37^0 \\ -38.2, & for\ 37^0 \le \theta \le 90^0 \end{cases} \tag{1}$$

where $G(\theta)$ is antenna gain of a spotbeam in dBi with boresight angle θ.

HAPS coverage area is assumed to consist of 6 cells. Cells are defined as an area illuminated by the main lobe of the HAPS antenna. HAPS coverage area can be calculated using HAPS heights and minimum elevation angle for HAPS. The smaller or the minimum elevation angle value, the larger HAPS coverage area. The minimum elevation angle in this study is 10˚. In each cell there are multiple N users active at the same time. The reference cell is just below HAPS. The i^{th} user in j^{th}cell is denoted by index (i, j) where $1 \leq i \leq N$ and $1 \leq j \leq 7$.

Since the simulation becomes too complex if each user has different shadowing probabilities, the shadowing probability is considered the same for users who are in the same area.

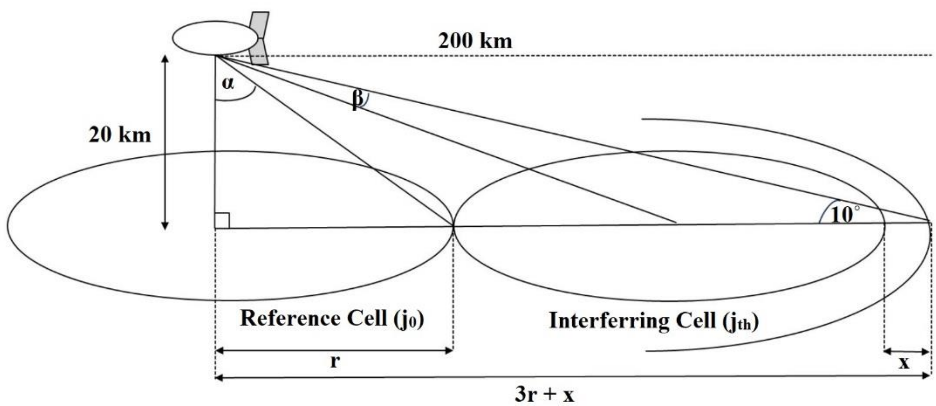

Fig 1. Geometry model of system with HAPS.

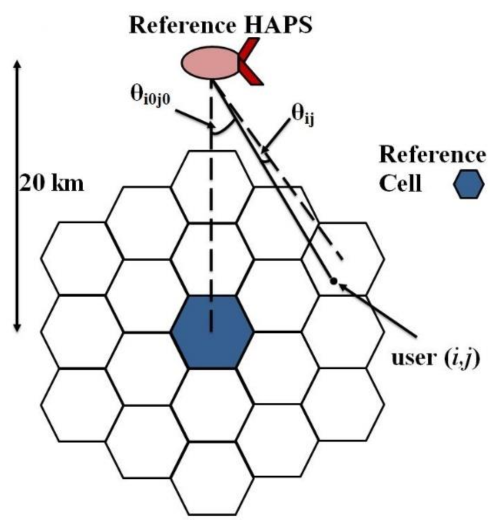

Fig 2. Single HAPS system model.

3. Interference and Probability Outage Analysis

The total interference is derived from the user residing in the cell around the reference cell within the HAPS coverage area.The user gets the power control of each multispotbeam antenna from a cell. This multispotbeam antenna works like a base station on a terrestrial system. The multispotbeam antenna lies at a close distance on the platform. Thus the path passed by the signal of each user has a nearly equal length of trajectory. Almost the same trajectory causes the shadowing experienced by each user almost the same value.

This is in contrast to the terrestrial system in which each user gets the power control of the BTS residing in each cell. The length of the path taken by each user's signal is different so the shadowing value is also different.

Users in the reference cell as well as users in other cells may experience a power control error (PCE). PCE can be modeled as a lognormal distribution $\gamma = e^{\delta}$ where δ is a Gaussian random variable with mean zero and standard deviation σ_δ. σ_δ value is 1 dB for unshadowed user and between 2-4 dB for shadowed user. If the power received on the base station with perfect power control is P_0, the power received in the presence of PCE is P_0e^{δ}.

Interference from users outside the reference cell is attenuated according to the characteristics of the spotbeam antenna. Users residing in each cell require increased power to recall the power received on each antenna because the antenna gain distribution in a cell is uniform. If user *(i, j)* has an off-boresight angle *Pij* relative to the cellbeam antenna of the cell, the gain of power obtained is proportional to $1/G_j(\theta_{ij})$, where $G_j(\theta_{ij})$ is the spotbeam antenna gain to *j*. The power gain will affect the reference cell as a power discrimination factor. The power discrimination factor because the spotbeam antenna is written with the equation,

$$\beta^2_{ij} = G_{j0}(\theta_{ij0})/ G_j(\theta_{ij}) \quad (2)$$

Based on the central limit theorem, if the number of *N* users is large, the total interference component can be approximated as a Gaussian random variable with the mean equation [6].

$$\mu_I = \psi\left[g_1\left(N - 1 + \textstyle\sum_{(i,j,k)} \gamma^2_{ijk}\right) + g_2 \textstyle\sum_{(i,j,k)} \left(\frac{r'_{ijk}}{r_{ijk}}\right)^2 \gamma^2_{ijk}\right] \quad (3)$$

where g_1 is the expected power control imperfection for shadowed user and unshadowed user with standard deviation σ_s and σ_{us} expressed by equation,

$$g_1 = E\left[e^{\delta}\right] = Ae^{\alpha^2\sigma_s^2} - Ae^{\alpha^2\sigma_{us}^2} + e^{\alpha^2\sigma_{us}^2} \quad (4)$$

and g_2 can be expressed by equation,

$$g_2 = \frac{E\left[\chi^2_{ijk}\right]}{\left(\frac{r'_{ijk}}{r_{ijk}}\right)^2} = A^2e^{\alpha^2\sigma_\xi^2} + \frac{A(A-1)e^{\alpha\mu_\xi + \frac{\alpha^2\sigma_\xi^2}{2}}}{1+K} \quad (5)$$

$$+A(1-A)e^{-\alpha\mu_\xi + \frac{\alpha^2\sigma_\xi^2}{2}}(1+K) + (1-A)^2$$

A is shadowing probability, which is 0.3, and α = (ln10/10).

Standard deviation is expressed by equation [6],

$$\sigma_I^2 = \psi\begin{bmatrix}\left(h_1 - \psi g_1^2\right)\left(N - 1 + \sum_{i,j,k} \gamma^4_{ijk}\right), \\ +\left(d_2 - \psi c_2^2\right)\sum_{i,j,k}\left(\frac{r'_{ijk}}{r_{ijk}}\right)^4 \gamma^4_{ijk}\end{bmatrix} \quad (6)$$

where $h_1$is expressed by equation

$$h_1 = E\left[\left(e^{\delta}\right)^2\right] = Ae^{2\alpha^2\sigma_s^2} + Ae^{2\alpha^2\sigma_{us}^2} + e^{2\alpha^2\sigma_{us}^2} \quad (7)$$

and h_2 is expressed by equation

$$h_2 = E\left[\chi^4_{ijk}\right] = A^2e^{4\alpha^2\sigma_\xi^2} + \frac{A(A-1)e^{2\alpha\mu_\xi + 2\alpha^2\sigma_\xi^2}}{1+K} \quad (8)$$

$$+A(1-A)e^{-2\alpha^2\mu_\xi + 2\alpha^2\sigma_\xi^2}(1+K)^2 + (1-A)^2$$

The quality of the 5G transmission in the HAPS system is expressed in the ratio of energy per bit to the total spectral power of noise E_b/N_0

$$\frac{E_b}{N_0} = \frac{C}{I+\eta} \tag{9}$$

where C is the received signal power, I is the total interference, and η is the AWGN noise power.

The ratio of received signal power to total interference coupled with AWGN noise can be expressed in equation

$$\frac{C}{I+\eta} = \frac{\beta_{i_0 j_0} EIRP_{i_0 j_0} G_{j_0}(\theta_{i_0 j_0})}{\sum_{(i,j)\epsilon V} \beta_{ij} EIRP_{ij} G_{j_0}(\theta_{ij}) + \eta} \tag{10}$$

where β_{ij}^{-1} is attenuation on the link between the user *(i, j)* to the reference HAPS. Attenuation includes pathloss and channel fading. $EIRP_{ij}$ is the effective isotropic transmitter power of the user *(i, j)* and $G_{j0}(\theta_{ij})$ is the antenna gain for the reference cell.

The E_b/N_0 limit value for a given performance requirement $(E_b/N_0)_{req}$ is determined based on channel characteristics, coding schemes, and modulation methods used. Outage probability P_{out} in this study is defined as the probability of failure to achieve value $(E_b/N_0)_{req}$ and can be written as

$$P_{out} = \Pr\left\{\frac{E_b}{N_0} \leq \left(\frac{E_b}{N_0}\right)_{req}\right\} \tag{11}$$

The 5G uplink capacity in the HAPS system is defined as the number of active users simultaneously on N cell. Outage probability for uplink 5G can be expressed

$$P_{out} = \Pr\left\{\frac{e^{\delta_{i_0 j_0 k_0}}}{I/P_0 + \eta/P_0} \leq (E_b/N_0)_{req}\right\} = \Pr\{I/P_0 \geq \varsigma\} \tag{12}$$

where equation for ς is

$$\varsigma = \left[\frac{e^{\delta_{i_0 j_0 k_0}}}{(E_b/N_0)_{req}} - \frac{1}{E_b/\eta_0}\right] \tag{13}$$

E_b/η_0 is the ratio of energy per bit to the AWGN spectral density. Based on Gaussian distribution with mean value $\mu_I$dan standard deviation σ_I^2, outage probability conditional to power control error of the reference user can be expressed by the equation [4].

$$P_{out}|\delta = \frac{1}{2} erfc\left(\frac{\varsigma - \mu_I}{\sqrt{2\sigma_I^2}}\right) \tag{14}$$

where $erfc(\gamma)$ is expressed by equation

$$erfc(\gamma) = 1 - \int_0^{\lambda} \frac{2}{\sqrt{\pi}} \exp(-x^2)\, dx \tag{15}$$

4. Simulation Result

In this study, bandwidth resource block in 4G LTE is used because bandwidth resource block in 5G has not been standardized yet. Fig. 3 shows the bandwidth resource block 4G LTE.

Table 1 is used as parameter in this study. Based on interference analysis and outage probability, MATLAB simulation for single HAPS was done. Bandwidth used is 0,1 GHz and 1 GHz. When we use 0.1 GHz so we can get 550 user in reference cell for each user using 180 KHz meanwhile we will get 5500 user in reference cell if we use 1 GHz. In Fig 4. And Fig 5. are showed the effect of changing the standard deviation value to number of user. For both bandwidth it will give more user when we use σ_s = 0 dB or the perfect power control. For 1 GHz bandwidth and σ_s = 10, the number of user still high while in 0.1 GHz it is almost 0 user. Another graphics showed the comparison between outage probability and number of user. When we use many user in HAPS system, it means

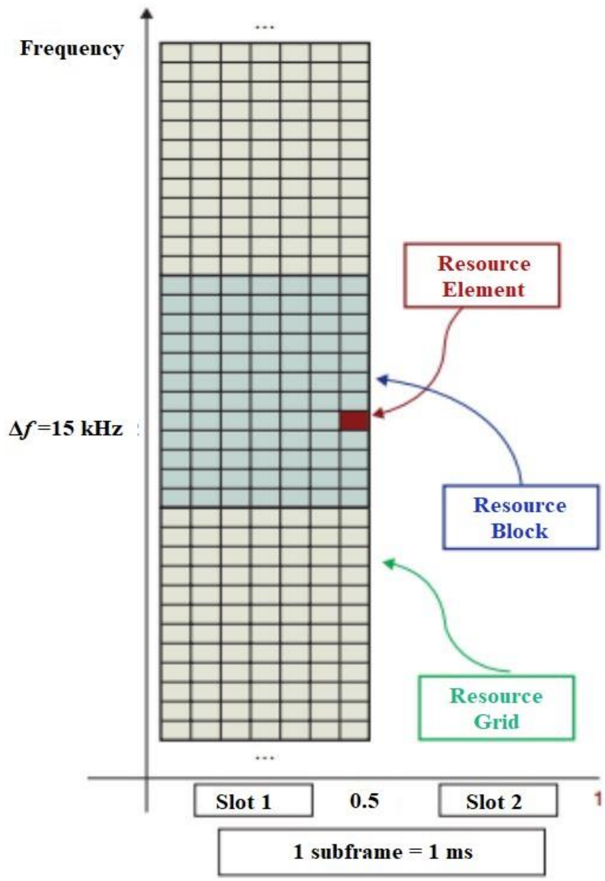

Fig 3. Resource Block for 4G LTE [4].

Table 1. Simulation Parameter of 5G Technology.

Parameter	Value
Spectrum	6 GHz - 100 GHz
Bandwidth	100 MHz and 1 GHz
Bandwidth Subcarrier	180 kHz
Data Rate Downlink	100 Mbit/s
Data Rate Uplink	50 Mbit/s

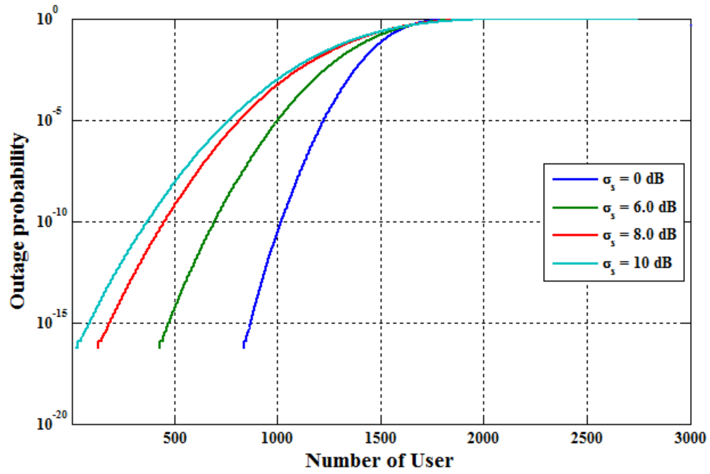

Fig 4. Effect of PCE Standar Deviation in 0.1 GHz.

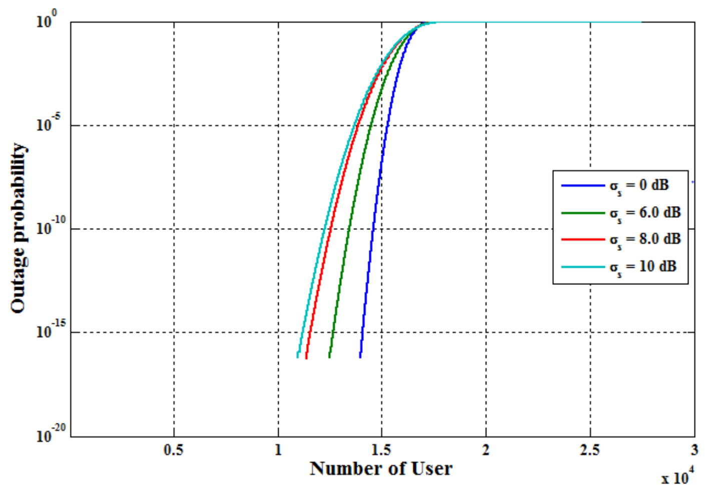

Fig 5. Effect of PCE Standar Deviation in 1 GHz.

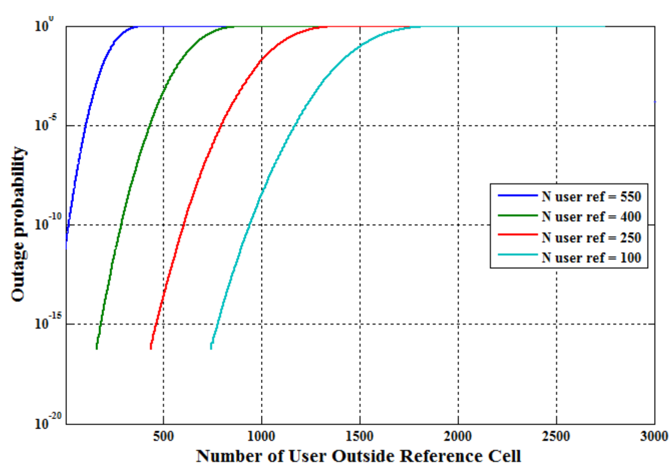

Fig 6. Single HAPS with Bandwidth 0.1 GHz.

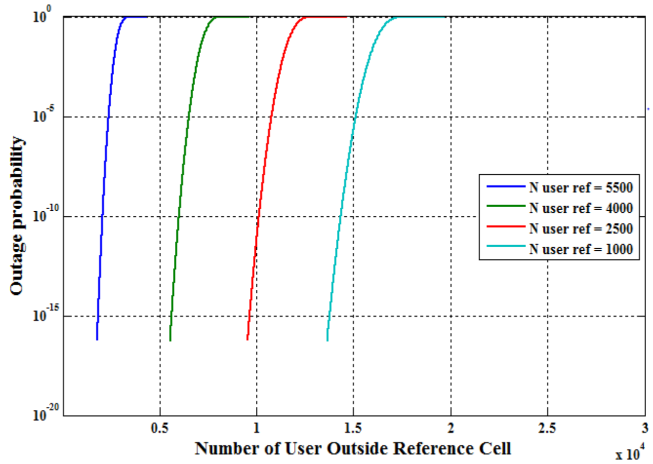

Fig 7. Single HAPS with Bandwidth 1 GHz.

The other side in Fig 7. ,the trend shows that to have the same outage probability value when the active user in reference cell bigger, we need less user active outside the reference cell. For probability of outage Pout = 10^{-15}, single HAPS system with 1 GHz can support 2000 active users outside reference cell if there are 5500 users active in reference cell. From Fig.7, it will show the same outage value if there are 5100 active users outside reference cell if there are 4000 users active in reference cell. This is little bit different if we compare with 0,1 GHz bandwidth. However, this system still can achive good outage probability value even many interference from user in reference cell or outside the reference cell.

5. Conclusion

From simulation above, it can be seen that using the 1 GHz or 0,1 GHz bandwidth in single HAPS system results in nearly stable probability outages in both bandwidth. So it means that this system is suitable enough if used in 5G bandwidth which will have more user in the implementation. Since there is no clear specification for spectrum 5G in HAPS so this study will need further research with the exact specification HAPS for 5G.

6. Acknowledgment

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