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**19-21 September 2017, Yogyakarta, Indonesia**

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# Performance Analysis for MIMO LTE on the High Altitude Platform Station

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*Abstract*—High Altitude Platform Station (HAPs) is a new communications infrastructure that uses air balloon to carry high data rate service and wide bandwidth. One technique to make it happen is Long Term Evolution (LTE), LTE support capacity increasing, expand coverage area, data rate increasing, multi-antenna, and can be integrated with other systems. To improve the performance of LTE in capacity building, coverage area, and data rate, it can use the multi-antenna techniques both on receiver or transmitter or often called multiple input multiple outputs (MIMO). Type of MIMO technique in this paper is spatial Multiplexing.

In this study, an estimation that has been used is the Linear Minimum Mean Square Error (LMMSE). Channel estimation is used to find out information about the channel condition between the transmitter and the receiver so that the performance of Bit Error Rate (BER) increase and expand the coverage area of the same BER compared without estimation. The system performed channel estimation has a better performance than the without estimation system with improved SNR of 20dB. Based on the simulation to get the same BER value in the system with channel estimation and without estimation, on the system with estimation it is necessary to lower elevation angle to be 10° and still there was improvement of SNR of 3 dB compared to the system without any estimation. With lowered elevation angle from 90° to 10°, the area of coverage was greater becomes 215.77km from the original 0.032km

Keywords: HAPs, LTE, MIMO, BER, Capacity, Coverage.

## I. INTRODUCTION

The development of technology has opened up a new wireless infrastructure used to complement the satellite and terrestrial networks. High Altitude Platform Station (HAPs) is a communications infrastructure that uses air balloon as a solution between terrestrial and satellite communications systems with medium coverage and the low cost of launching and maintenance **[1].**

HAPs can improve the area coverage and capacity with existing systems is a challenge. Due to the addition of system capacity and coverage area requires a considerable cost. One solution to make it happen is by using the channel estimation to extend coverage. In order HAPs can contribute to other services, so in this study were selected HAPs as a medium to provide services to the technology Long Term Evolution (LTE) standardized by the Third Generation Partnership Project (3GPP).

LTE uses Orthogonal Frequency Division Multiplexing (OFDM) technology for downlink **[2]**, **[4].** OFDM technology is a technology that uses multi carrier and brings the data in parallel and the bandwidth is divided into multiple subcarriers. To improve the performance of LTE in an increase in capacity, coverage, and data rate, it can use MIMO techniques. MIMO is a technique using multiple transmitter antenna and receiver antennas which are used to overcome the problem of multipath fading and increase the capacity of the system to be serviced. MIMO support the achievement of a high transmission rate **[2][8].**

Based on the channel model, it can be explained sequence data transmitted $x_1$, $x_2$, $x_3$, and $x_4$, normally performed data transmission at first time slot is $x_1$, and second time slot is $x_2$. Because it uses MIMO then in the first time slot can send $x_1$ and $x_2$ in the first antenna and the second antenna simultaneously (in the case of MIMO 2x2). Then in the second time slot to transmit data $x_3$ and $x_4$ in the first antenna and the second antenna simultaneously and so on. In the second data, transmission symbols can be combined and delivered in one-time slot so that if amount transmits the data, only need the amount divided by two-time slots.

In many channel estimation methods which can be used as the least squares method (LS) and linear minimum mean square error (LMMSE) **[5].** But the channel estimation using the LMMSE method has better performance and stable compared with the LS method such studies **[6-8].** Thus, in this study, channel estimation method used is LMMSE the MIMO system on HAPs.

So our contributions in this research are to Analyze the coverage of HAPs, BER performance and Addition of antennas from 2x2 to 4x4.

## II. THEORETICAL BASIC

### *A. HAPs*

HAPs system is air balloon working in the stratosphere layer of about 17-22 km. HAPs are considered to have some unique characteristics compared with terrestrial communication and satellite systems. For comparison between terrestrial communication systems, HAPS, and Low Earth Orbit satellite service (LEO) can be seen in Table I.

### *B. LTE*

Third Generation Partnership Project (3GPP) introduced the 3rd generation LTE in mobile communication standards, which the LTE Release 9 describe the standard of mobile communication throughput up to 300 Mbps on the downlink using OFDM technology and 75 Mbps on the uplink using the modulation Single Carrier Frequency Division Multiple Access (SC -FDMA).

TABLE I
COMPARISON OF TERRESTRIAL, HAPS DAN SATELLITE SERVICE. **[8]**

| | Terrestrial | HAPs | Satellite |
|---|---|---|---|
| Coverage | < 1km | Until 200km | >500km |
| Area Service | Spot Area | Regional | Global |
| Data Rate | 155Mbps | 25-155Mbps | < 64Mbps |
| Spreading System | Fixed | Flexible | Complex |
| Cell of Size | 0.1-1km | 1-10km | <50km |

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## III. SYSTEM MODEL

### A. *Signal Model*

In wireless communication, using two or more antenna can decrease the effect of multipath fading. Multipath fading will cause decreasing data rate and increasing bit error rate. Generally, in this study the assumption of the channel model used is flat. On systems using OFDM technology, the bandwidth of the channel is divided into multiple subcarriers so that the selective frequency is considered to be flat. Additionally, fading that was used based on the time was slow fading.

We assume that the system model for M transmitters and N receivers that we call it Multi Input Multi Output (MIMO) system is defined in Equation 1.

$$y = Hx + n \tag{1}$$

Where $x \in C^M$ is the transmitted vector, $H$ is the channel matrix, $n \in C^N$ is the noise vector, and $y$ is the received vector. So that the signals received at the first antenna in the first time slot and the second timeslot can be seen Equation 2.

$$y_1 = h_{11}x_1 + h_{12}x_2 + n_1 = [h_{11} \quad h_{12}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \tag{2}$$

$$y_2 = h_{21}x_1 + h_{22}x_2 + n_2 = [h_{21} \quad h_{22}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$$

### B. *Channel Model*

In HAPs communication, the channel used is Ricean Channel. In Ricean channel, there was the contribution of the Line Of Sight (LOS) component and the components of the non-LOS (contribution of Rayleigh channel). The normalized ricean channel model can be seen in Equation 3.

$$H_{ric} = \sqrt{\frac{K}{K+1}} H_{LOS} + \frac{1}{\sqrt{K+1}} H_{Ray} \tag{3}$$

By looking at the relationship between K as the ratio of LOS power and scattering power and also elevation angle on the 2.4 GHz frequency has been measured by iskandar on paper references **[8]**, it can be presented in Table II, it can be presented in Table II.

In this study, the channel used is Ricean Channel, the transmitting antenna was assumed stationary and the arrangement of the antenna reference point was in the middle, so that the angle of the downlink direction (β) can be ignored. HAP also assumed as stationary so it does not result in additional doppler effect in the receiver. Henceforth, the Doppler Effect is defined as the effects of the train velocity. To calculate the doppler frequency is defined in Equation 4.

$$fd = \frac{v}{c} f_c \cos\alpha \tag{4}$$

Where *v, c,* and $f_c$ denote the train velocity (in *m/s*), the velocity of light (in *m/s*), and the carrier frequency (in *Hz*) respectively.

TABLE II
RELATIONSHIP BETWEEN K FACTOR AND THE ELEVATION ANGLE

| Elevation Angle (°) | 10 | 30 | 60 | 70 | 90 |
|---|---|---|---|---|---|
| K Factor (dB) | 1.41 | 2.33 | 6.35 | 9.21 | 16.77 |

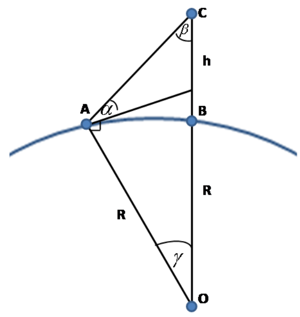


Fig. 1 HAPs system Geometry

### C. *HAPs System Geometry*

The High Altitude Platforms communication system channel model that analyzed the scenario at height h position shown in Fig.1. To calculate the value of β can be calculated mathematically with the principles of trigonometry comparison shown in Equation 5.

$$\frac{OA}{\sin\beta} = \frac{OC}{\sin(90+\alpha)} = \frac{R}{\sin\beta} = \frac{R+h}{\sin(90+\alpha)} \tag{5}$$

$$\sin\beta = \frac{R}{R+h}\sin(90+\alpha)$$

By the formula of trigonometry $\sin(90+\alpha) = \cos\alpha$,so it can be shown in equation 6. Using the Equation 6, so that the equation to find the length of AB as shown in Equation 7.

$$\cos(90-\beta) = \sin\beta \tag{6}$$

$$(90-\beta) = \cos^{-1}\left(\frac{R}{R+h}\cos\alpha\right)$$

$$AB = \left(\cos^{-1}\left(\frac{R}{R+h}\cos\alpha\right) - \alpha\right)R \tag{7}$$

So to calculate the coverage of HAPs can be calculated by Equation 8.

$$coverage = \left(\cos^{-1}\left(\frac{R}{R+h}\cos\alpha\right) - \alpha\right)2R \tag{8}$$

Where R is the radius of the Earth, for which a value of 6400 km is assumed. In Equation 8, as a function of platform altitude h (in km), R and user elevation angle α (in degrees).

### D. *Channel Estimation*

Training symbols can be used for channel estimation, usually providing a good performance. The Linear Minimum Mean Square Error (LMMSE) technique is widely used for channel estimation when training symbol is available **[3],[8-9]**. Consider the simulated LMMSE solution in **[8]** can be written as in Equation 9.

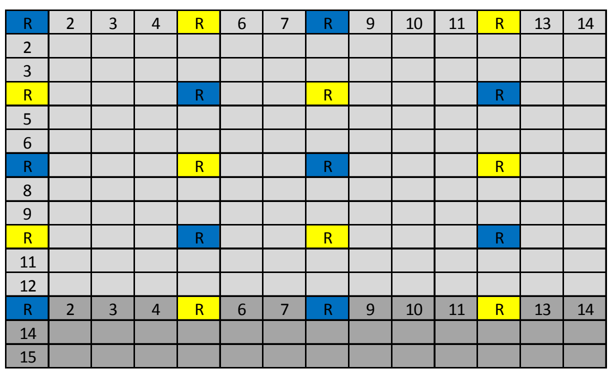


Fig.2 *Cell Signal Reference* (CSR) of LTE position for MIMO channel estimation [8]

$$\hat{H}_{LMMSE} = \left(R_{H\tilde{H}}\ R_{\tilde{H}\tilde{H}}^{-1}\right)\tilde{H}$$
$$\hat{H}_{LMMSE} = R_{H\tilde{H}}\left(R_{\tilde{H}\tilde{H}} + \frac{\sigma_z^2}{\sigma_x^2}I\right)^{-1}\tilde{H} \quad (9)$$

Where $\sigma_z^2$ is the variance of noise and $\sigma_x^2$ is the variance of the signal. After find channel estimation with signal reference in LTE, and then output data compensated with equalizer.

### *E. LTE*

In the LTE system, one (1) frame consists of 10 (ten) subframe. Where 1 (one) subframe consists of two (2) time slots. One (1) time slot consists of 7 (seven) OFDM symbol (if using a normal CP) or 6 (six) symbol (if using extended CP). One (1) user consists of two adjacent RB in the time domain. One Resource Block (RB) consists of twelve (12) subcarrier at 1 (one) time slots. One (1) Resource Element (RE) consists of one (1) subcarrier in one symbol.

In the LTE one sub frame consists of two slots each one slot of 0.5ms which consists of 7 symbols. One slot is composed of 7680 samples with the normal cyclic prefix (assuming the sampling frequency of 15.36 MHz) **[10].** For illustration Cell, Specific Reference (CSR) can be seen in Fig. 2.

Based on Fig. 2 the blue color shows the reference signal of antenna 1 and yellow color shows the reference signal of the antenna 2. In the transmission conditions on the antenna 1, the first reference signal antenna used and the reference signal of antenna 2 in set to zero.

TABLE III
PARAMETER OF SIMULATION

| Parameter | Explanation |
|---|---|
| Bandwidth | 10 MHz |
| Number of Subcarriers | 600 |
| Number of IFFT | 1024 |
| Length of CP | 80 and 72 |
| Frequency Spacing | 15 kHz |
| Duration of Slot | 0.5ms |
| Number of symbol per slot | 7 |
| Number of transmitter antenna | 2and 4 |
| Number of receiver antenna | 2and 4 |
| Modulation | QPSK,16QAM |
| Velocity | 60kmph |
| Number of samples | 7680 samples |
| Frequency of sampling | 15.36 Mhz |
| Duration time symbol | 66.67$\mu s$ |
| Duration guard time | 5.21$\mu s$ and 4.69$\mu s$ |

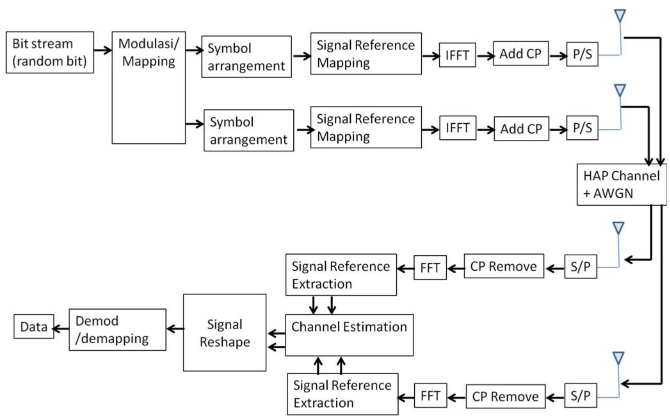


Fig. 3. Block Diagram of transmitter and receiver HAPs

## IV. SIMULATION DESIGN AND IMPLEMENTATION

In the design and implementation, it is necessary to determine the simulation parameter are used. For the simulation system parameters of the LTE downlink system can be seen in Table III. In the simulation system, there are three main parts, i.e. a transmitter, channel, and receiver, each of which is shown in Fig. 3.

## V. SIMULATION RESULT AND PERFORMANCE ANALYSIS

### *A. Comparison of Doppler shift, K factor and elevation angle*

In this study, the Doppler effect is defined as the effects of the train velocity. So the relationship of Doppler shift, K factor and elevation angle in Table IV in the HAPS communication system downlink direction with the carrier frequency ($f_c$) of 2.4 x $10^9$Hz, train velocity (v) is 3, 30.120, and 350 kmph, the elevation angle ($\alpha$) is from 10° to 90° with 10° range and the velocity of light ($c$) 3 x $10^8$ m/s using the Equation 4. Doppler shift affects the signal changes that has been generated more quickly and the threshold level changes of the signal was getting sharper. For the relationship of doppler shift, K factor and elevation angle can be seen in Table IV.

TABLE IV
RELATIONSHIP OF DOPPLER SHIFT, K FACTOR AND ELEVATION ANGLE.

| Elevation Angle [°] | K Factor [dB] | Velocity (kmph) 3 | 30 | 60 | 120 | 350 |
|---|---|---|---|---|---|---|
| 10 | 1,41 | 65,66 Hz | 656,55 Hz | 131,31 Hz | 262,62 Hz | 765,97 Hz |
| 20 | 1,99 | 62,65 Hz | 626,50 Hz | 125,30 Hz | 250,60 Hz | 730,92 Hz |
| 30 | 2,33 | 57,74 Hz | 577,44 Hz | 115,49 Hz | 230,98 Hz | 673,68 Hz |
| 40 | 2,66 | 51,09 Hz | 510,85 Hz | 102,17 Hz | 204,34 Hz | 595,99 Hz |
| 50 | 4,61 | 42,88 Hz | 428,75 Hz | 85,75 Hz | 171,50 Hz | 500,21 Hz |
| 60 | 6,35 | 33,36 Hz | 333,64 Hz | 66,73 Hz | 133,46 Hz | 389,25 Hz |
| 70 | 9,21 | 22,84 Hz | 228,40 Hz | 45,68 Hz | 91,36 Hz | 266,47 Hz |
| 80 | 12,15 | 11,62 Hz | 116,23 Hz | 23,25 Hz | 46,49 Hz | 135,60 Hz |
| 90 | 16,77 | 0,01 Hz | 0,05 Hz | 0,12 Hz | 0,21 Hz | 0,62 Hz |

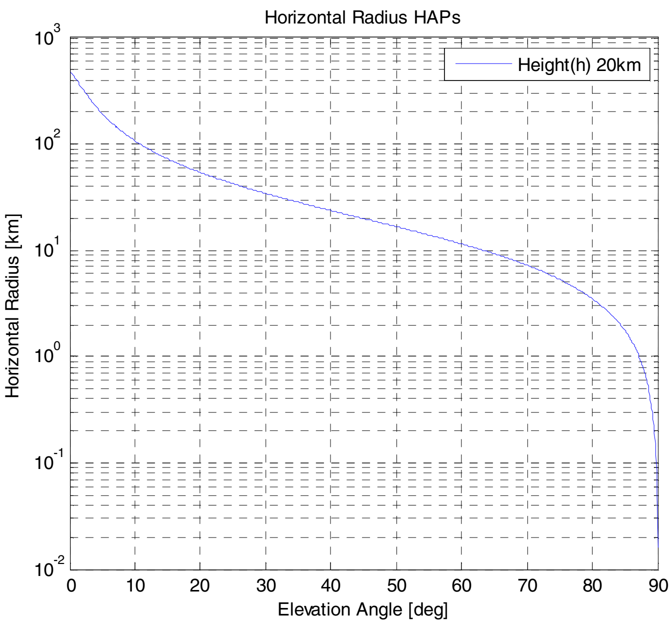


Fig. 4 Radius of HAPs Coverage

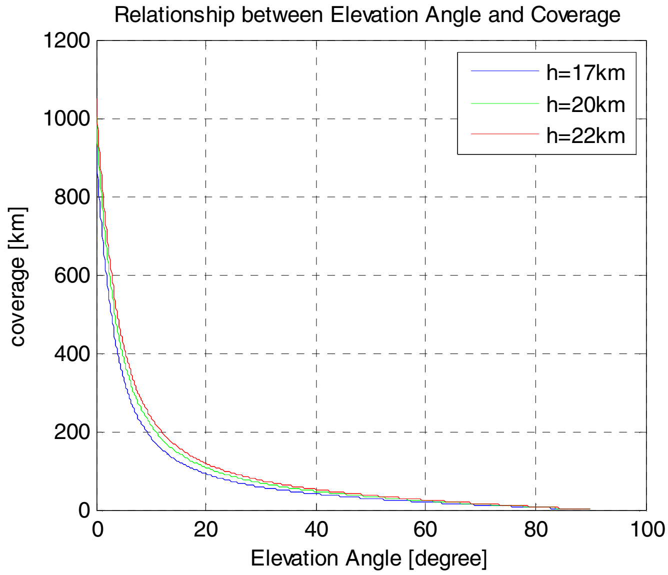


Fig. 5 Relationship coverage area HAPs and elevation angle at height 20 km

TABLE II
COVERAGE OF HAPS (KM) BASED ON THE ANGLE OF ELEVATION.

| Elevation Angle (°) | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
|---|---|---|---|---|---|---|---|---|---|
| Heigh 17km | 184 | 92 | 59 | 41 | 28 | 20 | 12 | 6 | 0.03 |
| Heigh 20km | 216 | 108 | 69 | 47 | 33 | 23 | 15 | 7 | 0.08 |
| Heigh 22km | 236 | 119 | 76 | 52 | 37 | 25 | 16 | 7.8 | 0.04 |

### B. Relationship between elevation angle and coverage

Based on the equation 7, the relationship horizontal radius distances of HAPs with a height of 17 km to 22km [1], [4] and the corresponding elevation angles in Table II. In Equation 7 is used increases as the user elevation angle is decreased, as shown in Fig. 5.

Based on the simulation results in Fig.5, the diameter of data relationships HAPs coverage area (in kilo meters) and elevation angle can be presented in Tables II. So by looking at the Table II relationship K factor, elevation angle, position, and diameter of the HAPS altitude is greater the coverage area of the elevation angle, the greater the K factor. The greater the elevation angle, the smaller the diameter of the area of coverage. But the higher the position, the greater the diameter HAPS area coverage. So it can be concluded that the elevation angle and the K factor value is proportional, but the value of the angle of elevation is inversely proportional to the diameter of the HAPS coverage area.

### C. Relationship between BER and coverage

Based on Fig. 6 it can be seen that the system has a large coverage, it also has a large BER. That's because the further coverage served the multipath will be even greater. Based on Fig. 6 it can be seen that at 25dB SNR with elevation angle of 90°, the system without any channel estimation has a BER of $0.5 \times 10^{-2}$ while the system was estimated to have BER of $2.3 \times 10^{-4}$ So the system performed channel estimation has a better performance than the without estimation system with improved SNR of 20dB.

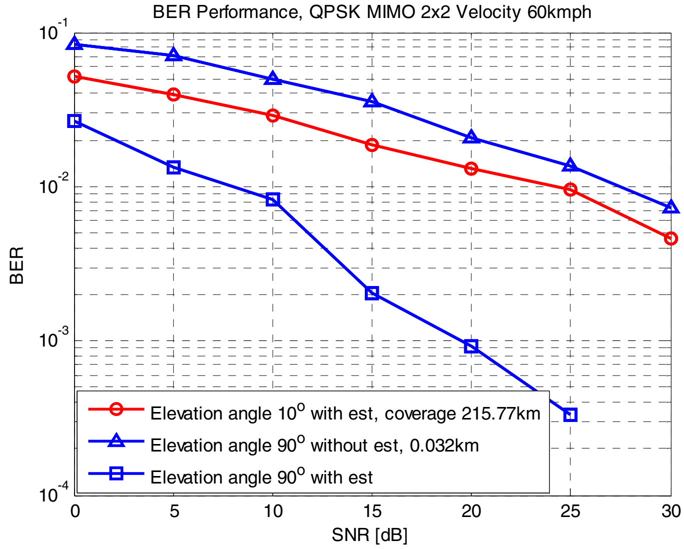


Fig 6. Comparison of BER performance in the system with channel estimation and without channel estimation

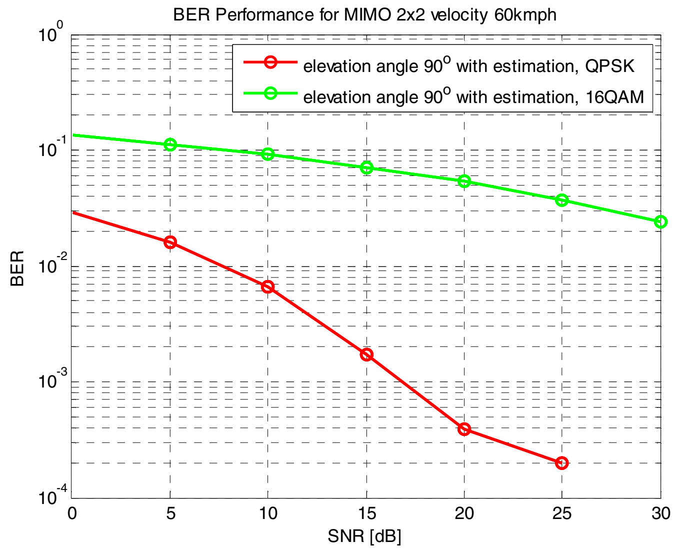


Fig 7. BER performance for MIMO with velocity 60kmph, elevation angle 90°

In addition, based on Fig. 6 can be seen also that the system with channel estimation at the elevation angle of 10° have better BER performance compared with the system without estimation for the elevation angle of 90°. Thus, to get the same BER on the system with estimation it is necessary to lower elevation angle to be 10° and still there was improvement of SNR of 3dB compared to the system without any estimation. With lowered elevation angle from 90° to 10°, the area of coverage was greater becomes 215.77km from the original 0.032km.

Based on Fig 7, it can be seen that the BER performance in the elevation angle of 90° with a high modulation level can produce larger BER compared to a lower modulation level. In addition, at higher modulation level requires more power than the lower modulation level. So based on this study, to large coverage area is better using a lower modulation level than using higher modulation level.

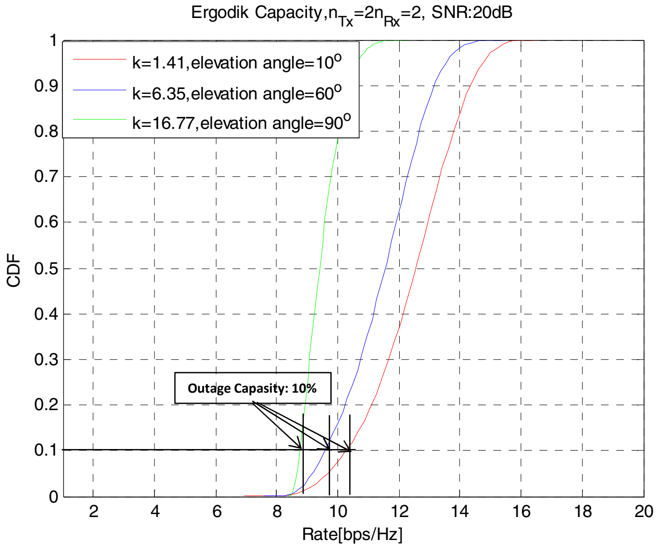


Fig 8. CDF rate MIMO 4x4 with SNR 10dB

### *D. Relationship between K Factor and Capacity with MIMO 4x4*

Based on Fig. 8, the ergodic capacity showed by the median of CDF curve. The outage capacity if on the probability expression is p %., So that the information rate that can be quaranteed. By the channel realitation is (100-p)%. The Outage capacity is expressed by $p(C \leq C_{out})$ is 10%. So that the system can be said have relied on 1- $p(C \leq C_{out})$ or 90%. So that based on figure V.4 the outage capacity for each K factor for 1.41 dB, 6.35dB and 16.77dB are 10.3bps/Hz, 9.58bps/Hz, and 8.75bps/Hz respectively.

## VI. CONCLUSION

To get the same BER with the system without estimation, then the system that was estimated needs to scale the elevation angle to be 10 and still there is the improvement of SNR of 3dB compared to the system without any estimation. By lowering the elevation angle from 90 ° to 10 °, the area of coverage to be greater, it becomes 215.77 km from 0.032 km. This paper study the effect modulation in the BER, the higher modulation level so the influence of the BER becomes worse (larger) than the lower modulation level. Because high modulation level has a higher BER than the lower modulation level. So the lower modulation level can be used extend the area of coverage.

In ergodic conditions, the capacity decreases with the addition of the K factor equivalent to the HAP elevation angle being 10.3bps/Hz, 9.58 bps / Hz, and 8.75 bps / Hz at elevation angle of 10 ° (K = 1.41 dB) , the elevation angle of 60 ° (K = 6.35 dB) and the elevation angle of 90 ° (16.77 dB) on the same SNR. So the smaller the elevation angle or the smaller the K factor, the capacity served is also more and more.

## VII. ACKNOWLEDGE

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