Channel Propagation Characteristics on the Performance of 4G Cellular Systems from High Altitude Platforms (HAPs)

Kabiru Yusuf[1], Dahiru Sani Shuaibu[2], Suleiman Aliyu Babale[3]

[123] Department of Electrical Engineering, Bayero University Kano, Nigeria.

***Abstract*:** In this paper, we investigated the effect of different channel propagation characteristics on the performance of 4G systems from high altitude platforms (HAPs). The use of High-Altitude Platforms for communication purpose in the past focused mostly on the assumption that the platform is quasi stationary. The technical limitation of the assumption was that of ensuring stability in the positioning of the platform in space. The use of antenna steering and other approaches were proposed as a solution to the said problem. In this paper, we proposed a channel model which account for the motion of the platform. This was done by investigating the effect of Doppler shift on the carrier frequency as the signals propagate between the transmitter and receiver while the High-Altitude Platform is in motion. The basic free space model was used and subjected to the frequency variation caused by the continuous random shift due to the motion of the HAPs. The trajectory path greatly affects the system performance. A trajectory of 30km, 100km and 500km radii were simulated. An acute elevation angle was used in the simulation. The proposed model was also compared to two other channel models to illustrate its performance. The results show that the proposed model behave similar to the existing models except at base station ID 35 and 45 where the highest deviation of 20dBm was observed. Other stations that deviated were less than 2dBm.

***Keywords*:** High Altitude platform (HAP), 4G cellular system, Doppler shift, Propagation model, Base station, elevation angle and velocity of HAP.

1. Introduction

Constant growth of interest in highspeed wireless communication causes the search for new solutions and new concepts for network access [1]. High Altitude Platforms (HAPs) are considered a part of this trend. More than half of the world's populations do not have access to mobile broadband services as of 2017 according to a recent International Telecommunication Union (ITU) report [2]. This calls for the need to develop improved ways of service delivery to ensure optimum system capacity, spectral efficiency and wider coverage. The report also detailed that 74% of African population have no access to broadband services most of which are located in rural and remote areas. It was estimated that a minimum of 60,000 base stations were required to cover over 36 million people living in rural areas who are either grossly served or totally underserved [2]. The traditional terrestrial system of communication is not cost effective in order to curtail the problem of grossly served areas and totally underserved areas considering the user density in the areas as well as the disperse nature of the communities. High Altitude Platform Station is an alternate approach for telecommunication infrastructure solution for rural and remote areas based on stratospheric airborne platform [3]. HAPs have the potential to provide line-of-sight links to a large number of users, situated over a large geographical area, and using considerably less communications infrastructure than that required if delivered by a terrestrial network [4]. The High-Altitude Platforms are said to be a radio communication station situated in the stratospheric layer of the atmosphere at an altitude of about 17-22km above the sea level. It has a better signal quality due its relative short distance as compared to satellite networks. The HAPs network has wider footprint coverage as compared to the terrestrial systems. It can be easily deployed in relatively short time as compared to terrestrial and satellite systems and therefore a good option for providing communication network access to areas affected by disaster.

2. Related Work

The High-altitude platforms are classified generally into two, namely, lighter than air platforms and heavier than air platforms [1]. The lighter than air platforms are mostly airships which are considered as the most welcome solution. They are characterized by many advantages, but the most important are long term work time (up to one and a half years) and large capacity [1]. The heavier than air platforms on the other hand include unmanned planes that are hydrogen powered or solar powered. Manned planes are also available for this category; however, the operation is limited to few hours. This solution is much appreciated in providing communication infrastructure to communities affected with disaster.

(a) (b)

Figure.1: (a) Manned Plane Proteos; (b) Unmanned airship Zeppelin N2

In this research, a channel model which account for the relative motion of the HAPs while communicating with ground BTS is proposed. The system is assumed for a full loading of BTS while communicating with HAP. Also, the effect of reducing the path of flight trajectory for the HAP is investigated.

So many works have been carried out in the trend of High-Altitude platforms as an infrastructure used as part of communication networks. [1] Clearly brings out a clear comparison between High Altitude Platforms used for communication and the existing terrestrial and satellite systems. The advantage in terms of low propagation delay, signal quality due to shorter transmission distance when compared to satellites was stressed. GSM cell with a diameter of 35km provides coverage to the area of about 970 square kilometers. In the second case the overall system capacity is limited. High Altitude Platforms are relatively cheap, easy to deploy and have significant capacity. System based on a single HAP can cover the area with a diameter of about 60km (HAP altitude 17km, minimum elevation angle 30 degrees) up to 420km (HAP altitude 22km, minimum elevation angle 5 degrees). It gives up to about 140 thousand square kilometers [1]

High Altitude Platforms are said to be radio stations that are positioned to operate in the stratospheric layer of the atmosphere. The altitude lies between 17km and 22km [7-10]. The concern of radio Engineers in the channel design is to design a channel model that will depict the signal power level as it propagates in the operating environment. The free space model is mostly used in the previous literatures. However, the need to enhance the communication services requires the improvement in channel conditions. Reference [2] proposed a scheme for beam pointing from a high-altitude platform (HAP) for contiguous coverage delivery within an extended service area. The scheme, which illuminates cells, considers the broadening of beams on the ground from the HAP-based antenna array. The atmosphere around the Earth's surface is divided into several layers [5]. This characterization of layers is based on wind speed and density, pressure and temperature [5]. Number of air molecules per unit area decreases with an increase in altitude because of weakening of gravitational pull, air is denser closer to Earth's surface than that of higher altitude [3]. More than half of atmospheric molecules are present inside 5.5 km radius from Earth's surface so air pressure decreases rapidly with first few kilometers in altitude, afterwards it decreases monotonously [4].

Wind speed is a great factor that affects the positioning of HAP in space. Figure.1 illustrates the variation of wind speed across different altitude levels. It can be observed that the wind speed increases from 0-10km altitude. At an altitude of about 17km the wind speed tends to drop and maintain a minimal value between 17-22km levels. The chosen altitude for HAPs operation is thus between 17-22km. In the channel design procedure, it is crucial to study the environment as that will define the expected impairments along the communication channel.

2.1 The Free Space Propagation Model

The general free space propagation model is given by equation [1, 24- 25]

$$l_{fsl} = 20\log(f) + 20\log(d) + 92.4 \quad (1)$$

Where: l_{fsl} is the basic free space loss

f = the carrier frequency in GHz

d = the distance between transmitter and receiver measured in km

2.2 Steve Chukwuebuka Arum's Model

This model is extension of the free space by a normal distributed random variable X_σ to account for random impairments due to shadowing. [2]

$$L(\theta,\varphi)_{dB} = 92.4 + 20\log(d(\theta,\varphi)) + 20\log(f) + X_\sigma \quad (2)$$

2.3 Jaroslav Holis Model

This model was used by Jaroslab Holis and Pavell Phechac. However, the model was further modified by introducing the random parameter to account for the random impairments. [12]

$$L = 20\log(f) + 20\log(d) + 92.4 + L_m \quad (3)$$

where L_m is express in equation (4)

$$L_m = A\ln p + B \quad (4)$$

Where p is the percentage outage probability, A and B are defined in equation 5 and 6

$$A = 0.002\theta^2 + 0.15\theta - 0.7 - 0.2f \quad (5)$$

$$A = 0.002\theta^2 + 0.15\theta - 0.7 - 0.2f \quad (6)$$

The factor L_m is added to the free space model in order to account for the losses due to atmospheric absorptions and other losses in the propagation environment. The factor as defined is a function of elevation angle.

Where: l_{fsl} is basic free space loss

f = transmission frequency

d = distance between transmitter and receiver

θ = the elevation angle

L_m = the component to account for random impairments

p = the percentage outage probability in the range of 1-20%

3. Research Work

3.1 System Model

The proposed method takes the Doppler frequency into account and the equation is given as:

$$F_D = \frac{F_T V\cos\theta}{c} \quad (7)$$

Where: F_D = Doppler shift frequency measured in GHz

F_T = transmitted carrier frequency measured in GHz

V = Velocity of the moving terminal (HAPs) Measured in km/hr

C = Speed of Electromagnetic waves $3.0 \times 10^8\, m/s$

θ = Elevation angle between the sending and receiving terminal

The received frequency equation is thus given by the equation (8) as follows:

$$F_R = F_T \pm F_D \quad (8)$$

Where: F_R = Received frequency in GHz, the $\pm$ indicates, the direction of the motion, either moving toward each other or away from each other.

Now we can substitute equation (7) into equation (8) to have equation (9) as follows:

$$F_R = F_T \pm \frac{F_T V\cos\theta}{c} \quad (9)$$

Equation (9) can further be simplified to

$$F_R = F_T\left(1 \pm \frac{V\cos\theta}{c}\right) \quad (10)$$

the free space model is given by the following equation:

$$L = 20\log(f) + 20\log D + 92.5\ dB \quad (11)$$

Where: f= carrier frequency measured in GHz

D= separation distance between transmitter and receiver

In the proposed model we take Doppler shift into consideration to investigate the system performance. We also apply the three coordinates distance formula in order to obtain the varying distances. Figure 3 shows the arrangement for the calculating the distances between the HAPs and the Base station on the ground floor. Figure 4 shows the HAPs and the Base station cells

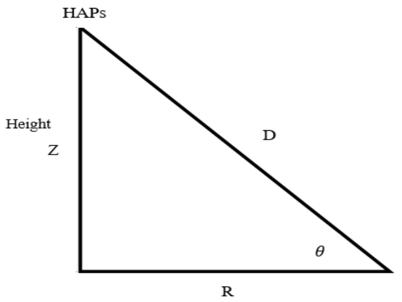


Figure.2: A triangular representation of the system

Figure.2 illustrates a scenario of the transmitter and receiver from which we can observe that the distance is giving as D. The height (Z) of the platform above the ground station is also shown. If we assume (X_1, Y_1) and (X_2, Y_2) to be the coordinates of the extremes defined by distance R, we can find R using distance formula as follows:

$$R = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \qquad (12)$$

The distance, D can be calculated by applying Pythagoras's theorem in the system triangle using equations (13) and (14)

$$D^2 = R^2 + Z^2 \qquad (13)$$

We can further show that the distance D can be calculated using equation (14) by substituting equation (12) into (13)

$$D = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + Z^2} \qquad (14)$$

The proposed model is thus given as follows:

$$L = 20\log\left(F_T \pm \frac{F_T V\cos\theta}{c}\right) + 20\log\left(\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + Z^2}\right) + 92.5 + E \qquad (15)$$

The above equation represents the proposed mathematical model of the channel. All parameters in the model are earlier All parameters are defined in previous sections. The last parameter (E) is to take account of atmospheric absorptions, rain attenuation, tracking losses and other environmental attenuation factors. It is random in nature and therefore in the simulation we introduce a random variable to take care of that. It is assumed that the ground stations are at the same height and are at ground level.

4. Simulation Parameters

The proposed model was simulated using MATLAB software using the following parameters as given in table 1: The 3D geometry of the Haps and the Base stations are give in Figure 4

Table 1: Simulation parameters of the proposed model

Item	Specification
Operating Frequency	3.5GHz
Antenna Transmit Power	34dBm
Trajectory Radius	30,50 and 500km
Receive Antenna Gain	12dBm
Antenna Efficiency	0.75
HAPs Speed	120km/h
HAPs Altitude	20km
Outage Probability	20%
Speed of E-M wave	108,000km/h

Figure 4 shows the system presentation of the HAPs in relation to the ground base stations. The circular ring with reddish small circles is assumed to be the HAPs moving in a circular path whereas the hexagonal cells are used to represent the ground base stations.

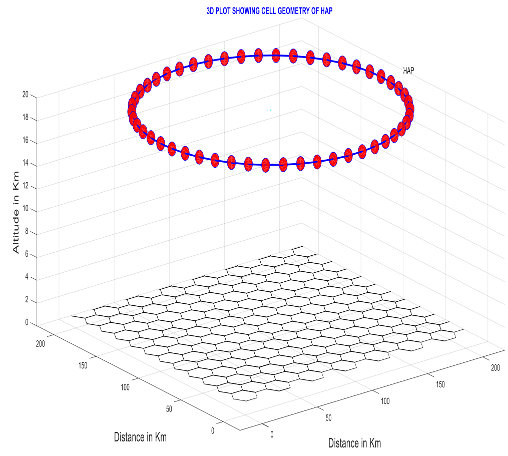


Figure.3: Assumed System Geometry of the HAPs

5. Result and Discussion

5.1 Doppler Frequency Versus Hap Velocity

The Doppler frequency as defined in equation (7) is a function of carrier frequency, Haps velocity and separation angle between the transmitter and receiver. We investigate the relationship between the parameters and the frequency. The Haps velocity was found to be directly proportional to the Doppler frequency. Figure.4 shows the relationship. At a HAPs velocity of 120km/h the Doppler shift of 200Hz was observed. Also, at 180km/h about 300Hz was observed.

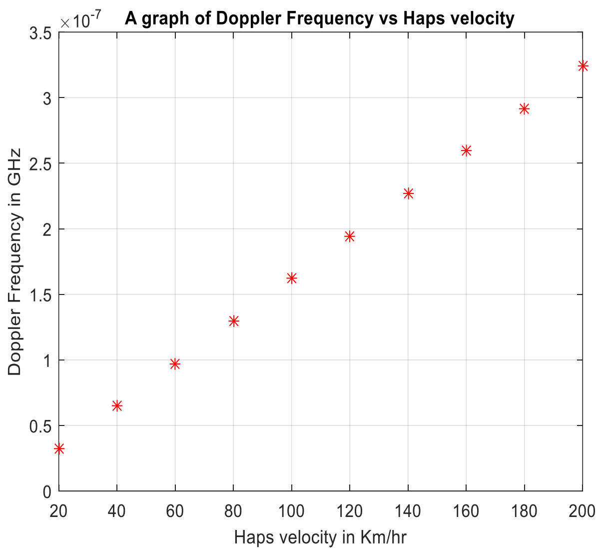


Figure.4: A graph of Doppler frequency against Haps Velocity

5.2 Doppler Frequency Versus Separation Angle

The effect of separation angle between the transmitter and receiver in relation to the Doppler frequency was simulated. The graph shows a dynamic behavior as cosine function is not purely linear in nature and it is the cosine of the angle was used in the equation. The cosine of angle is maximum when the angle is zero and this is practically not realizable. The behavior of the Doppler frequency with respect to the angle is shown in theFigure.5 . The smallest value was obtained at 3.14 which is the value of pi.

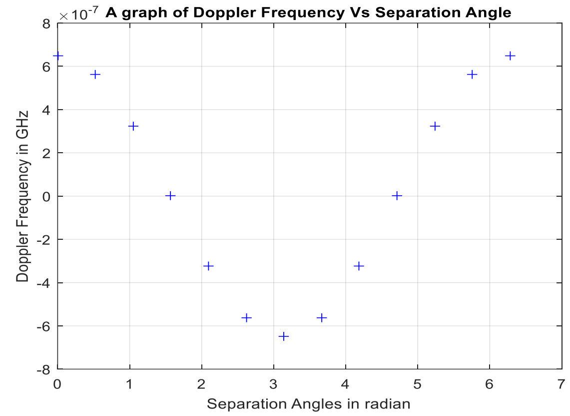
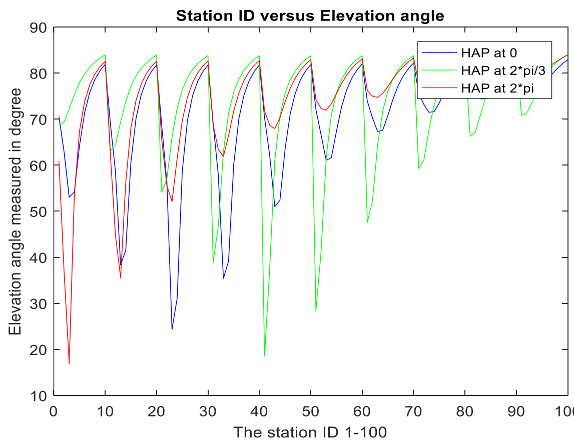


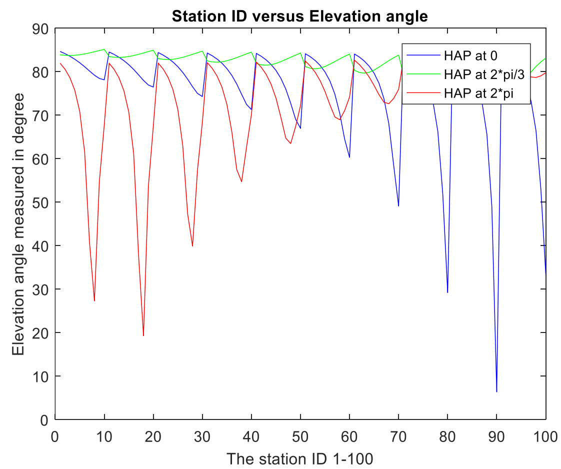
Figure.5: A graph of Doppler Frequency vs Separation Angles

5.3 Ground Stations ID and Elevation Angles

The receiving stations on the ground are allocated specific IDs for easy analysis. Knowing that the HAPs motion will cause a constant change in elevation angle, we therefore simulate to see how the angle varies at different points as the platform moves on its trajectory. The elevation angle was computed for each base station at 0°, 2pi/3 and pi. Also, the same reading were obtained when the trajectory radii was 30km, 100km and 500km. Figure.6 (a) is when the radii was 30km it could be seen that the elevation angles were closer here when compared with Figure.6 (b) of 100km radii and Figure.6 (c) of 500km radii.



(a)



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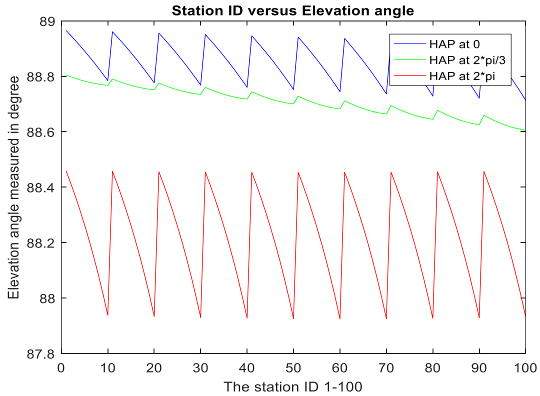


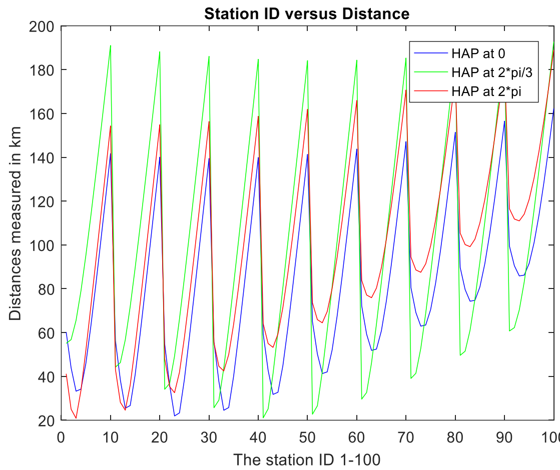
(c)

Figure.6: Station ID versus elevation angle; (a) at a radius of 30km, (b) at a radius of 100km, (c) at a radius of 500km

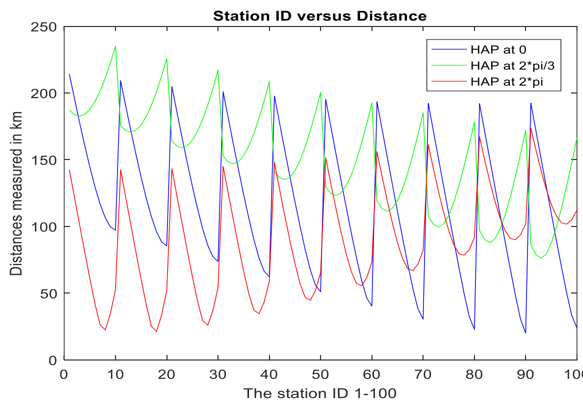
Figure.6 shows how the elevation angle changes with trajectory radius. In each of the graphs, three different HAPs positions were sampled and plotted. In Figure.6 (a) , where the radius is small, we observed that most stations are within the coverage of the serving platform. However, in Figure.6 (c) where the radius is relatively large, the three graphs are seen to diverge far from one another. This shows that with considerably small trajectory path, a better performance can be achieved

5.4 Ground Station ID versus Measured distances

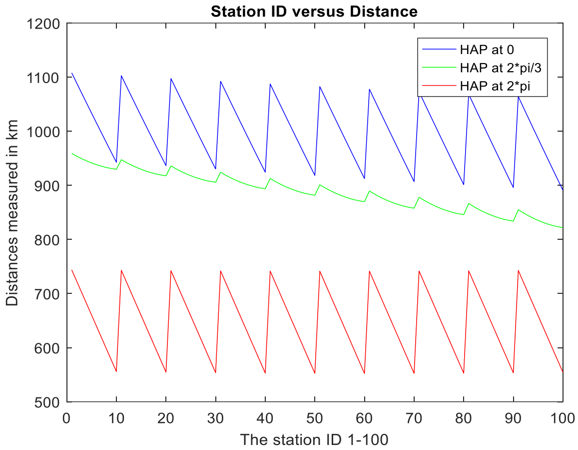
The distances of all stations from some defined points on the circular path of the platform were obtained and plotted. The results for different radii are given Figure.7



(a)



(b)



(c)

Figure.7: Station ID vs measured distance; (a) at a radius of 30km, (b) at a radius of 100km, (c) at a radius of 500km

The results above show that each HAPs position will result to different distances from stations. It can be observed that although each line on the graph represents a fixed position on the HAP trajectory but yet it keeps changing with ID positions. Secondly increase in trajectory radius makes the signals to be more diverge.

5.5 Comparison of power received by different Channel Models

For the purpose of validating the proposed channel, different Channel Models are simulated to predict the power strength at different locations. The transmitted signal will undergo a continuous change in a propagation environment depending on the impairments encountered. Wireless channels are generally time dependent and random in nature. Figure.8 show the power received using the proposed model alongside three other channels when the radius of the Haps is 30km. The result is obtained when the Haps is at 2pi/3 location.

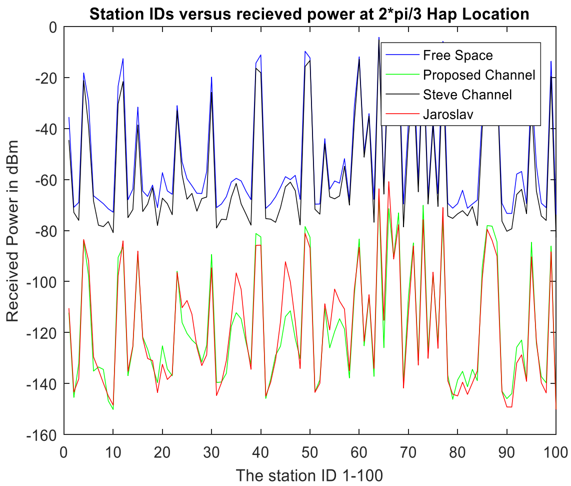


Figure.8: Station ID versus received power at a radius of 30km

With reference to the Figure.8 , the blue color represents free space model which appears to over predict the signal loss. It is so because it only takes account for change in elevation angle but not frequency shift. Steve model also predict closely to the free space model with a little deviation from the free space model. The proposed model and Jaroslav model predict similar condition with a little variation. A notable difference is at base station ID 35 and 45 where a variation of the received signal is up to 20dBm. The rest of 98 remaining base stations have a variation below 2dBm. The radius of the trajectory of the Haps was further increases to 500km inFigure.9 . The variation of the received signal can be seen to have improved by around 10dBm average between free space and Steve Model. Also, the Jaroslav model and proposed model have a variation of 15dBm on average this shows that the radius of the trajectory has direct impact on the performance of the models.

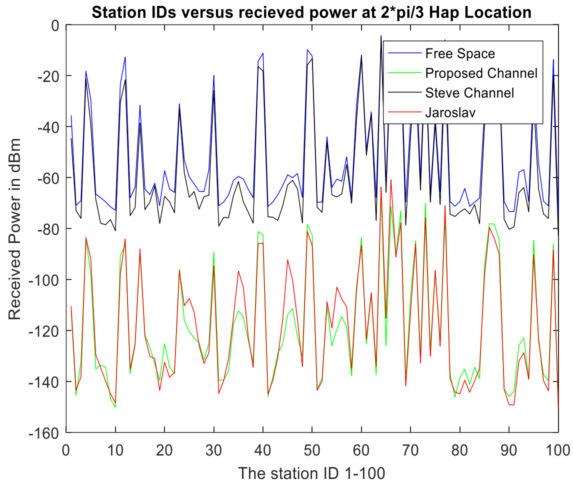


Figure.9: Station ID versus received power at a radius of 500km

5.6 Station ID versus Directivity

The directivity is an important factor in the computation of the received power. The directivity of the antenna helps to determine how the main beam of an antenna is directed. Figure.10 depicts the variation in directivity as the HAPs moves on its trajectory. It could be seen that the directivity is high in almost all the base stations except for some few that happen to be at the edge of the area under consideration.

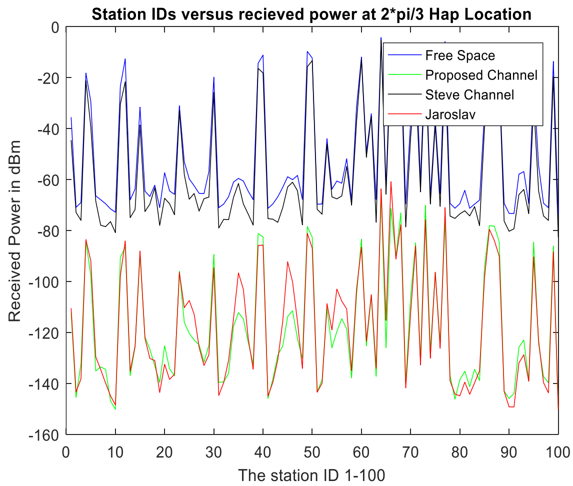


Figure.10: Station ID vs Transmit Antenna directivity

6. Conclusion

Channel model has been proposed in this work, the proposed channel takes the effect of the Doppler shift into consideration. This is because in Haps there is always a relative motion between the receiver and the transmitter. This relative motion causes the frequency to change. At

120km/h a Doppler shift of 200Hz was observed. The proposed model was compared to Jaroslav model and the two models were observed to have a similar performance in received signal quality with a little variation at base station ID 35 and 45 where a difference of 20dBm was observed and all other variations for the remaining base stations are below 2dBm for 30km radius of the Haps.

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