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The Effect of Platform Instability on the User Terminal and Backhaul Link Performance of HAPS-UMTS

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Abstract

High Altitude Platform Stations (HAPS) are a new, promising means of providing Third Generation (3G) mobile services, broadband services and TV broadcasting. One of the potential problems of the system, where aircraft technology is used, is the platform positional instability due to rotation and stratospheric winds. This may produce fluctuations in the signal level and thus degrading the performance level. In this work, a study of the effect of positional instability of HAPS (aircraft category) on the link level performance of an International Mobile Telecommunications (UMTS) served by HAPS is presented. The analysis is performed in three different climatic conditions of Malaysia, which is a tropical country. Then two types of radio links have been analyzed – firstly, the end user link which connects aerial station and end user and then, backhaul link that establishes communication between HAPS and Ground Transmission Gateway (GTG). A platform instability model obtained through measurements of rotation and stratospheric winds. Finally, the effect of instability was given in received signal level variation and link availability or percentage outage of the link. Obtained results showed that, the link availability of the backhaul link meets the ITU-R recommendations. Lately, it can be said that, the results of the service obtained can be used to design the communication network with higher level of user satisfaction.

Keywords: About; HAPS, UMTS, Link Performance.

INTRODUCTION

The increasing demand for broadband mobile communications has led to the successful and rapid deployment of both terrestrial and satellite wireless networks. Besides the high data rates, current wireless networks can be inexpensive, support reconfigurability and provide time and space varying coverage at low cost [1]. In parallel with these two well established methods for providing wireless communication services, in recent years another alternative has attracted the attention of the telecommunications community. It is based on quasi-stationary aerial platforms operating in the stratosphere, known by different names as High Altitude Platform Stations (HAPS) or Stratospheric Platforms (SPFs), and located 17–22 km above the Earth's surface [2]. The most important advantages of HAPS systems are their easy and incremental deployment, flexibility, reconfigurability, low-cost operation, low propagation delay, high elevation angles, broad coverage, broadcast/multicast capability, broadband capability, ability to move around in emergency situations, etc. But there are also some crucial disadvantages, such as the monitoring of the station, the immature airship technology, and the stabilization of the on-board antenna. A very interesting feature is that for the same bandwidth allocation terrestrial systems need a huge number of base stations to provide the needed coverage, while GEO satellites face limitations on the minimum cell size projected on the Earth's surface and LEO satellites suffer from handover problems. Therefore, HAPS seem to be a very good design compromise [3].

The growing exigencies for mobility and ubiquitous access to multimedia services call for the development of new-generation, wireless telecommunications systems. So, it is very interesting and challenging to examine and evaluate a mixed infrastructure comprising HAPS, terrestrial and satellite systems which could lead to a powerful integrated network infrastructure by making up for the weakness of each other. In this respect, 3g networks are starting steps to fulfill the vision for optimal connectivity anywhere, anytime, providing higher bit rates at low cost. HAPS can play an important role in the evolution of 3g systems [4].

Even though satellite systems possess many attractive features, some of their advantages are negated by the large propagation delays in the case of MEO and GEO satellites, and the unreliability of the satellite channel and the high complexity in the case of LEO satellite systems. To this end, HAPS systems can be employed since they represent a solution preserving most of the advantages of satellites, while avoiding some of their drawbacks. It is rather difficult and economically inefficient to cover remote and impervious areas with cellular networks, xDSL, or fiber networks. However, HAPS constitute a real asset to wireless infrastructure operators to provide telecommunication services in these areas. Each station can employ a communications payload equipped with a phased antenna array. For the case of cellular communications, cells of various sizes and shapes may be created on the ground and subsequently moved in order to accommodate spatially and time varying traffic [5].

One of the open research issues is whether the platforms can provide reliable services without temporal outages due to rotation and sudden gusts of stratospheric winds that could cause platform positional instability. In this work focus is given on examining the impact of the platform movement due to stratospheric winds on the link level performance of a propulsion enabled HAPS UMTS- System [6].

The main problem of this research, which due to rotation and rapid burst of stratospheric wind the platform might not provide acceptable or stable services to the system. This could cause platform positional instability which hampers system level performance. This instability also made the job of designing antenna for HAPS much more complicated. The positional instability can be analyzed into horizontal or vertical displacement and inclination. A study of the wind statistics and the respective HAPS instability model [7] shows that the most important components are the horizontal and vertical displacement. In case of inclination, it can be easily compensated as the digital beamforming antenna will be affixed to a gimbaling system (at the specific position of the aircraft) that will limit the movement of the antenna to less than one degree with respect to the ground [8]. So, rotation and horizontal and vertical displacements are the main area of concern. As in the stratospheric region wind is a strong reason for deviation of the aerial platform, this was taken into account, along with rotational movement, in the study to find out the issues on whether the platform can provide reliable services without temporal outages. Then, the impacts of platform positional instability of HAPS on UMTS- terminal and on backhaul link at 28/31 GHz band were analyzed for different scenarios, different geographical locations and also for different positions of both aerial station and ground receivers [9].

This paper organized starting with introduction then, overview operations, functionality were presented in the second section. Third section describes the obtained results and detailed discussion of obtained findings. Lastly, conclusion is well handled.

PLACEMENT ISSUES AND SPECTRUM ALLOCATION

HAPS are located at 17–22 km above the Earth's surface because these altitudes are well above the air lanes. The wind conditions in the stratosphere are normally predictable (the average wind velocities are shown in Figure 1) and, further, the zone of 17 to 22 km suffers from a relatively mild turbulence.The most preferable altitudes fall from 19 to 22 km, while from 17 to 19 km the velocities are also low. Generally, wind velocities increase over the altitude of 25 km [10]. Besides, as the altitude increases the air density is reduced, making the placement of the vehicle very difficult. For example, at 12 km (the maximum altitude of airplane lanes) the density is about 25 percent compared to that at the sea level, while at 24 km it is only about 3.6 percent.

HAPS can provide quasi-stationary communication relay platforms, but several points should be examined carefully in the design of the system. The ITU has specified that HAPS, in case of airship, should be kept within a circle of 400 m radius, with height variations of ±700 m [11], so that services are available almost all the time. It is easier for airships than for aircraft to be quasi-stationary, but it is rather difficult to remotely control the airship's position as it is drifted by winds or pressure variations. GPS can play an important role in the precise positioning of high-altitude aerial vehicles, although it is not a trivial task. In this work, the operating flight altitude is 20 km, as provided by Qucomhaps.

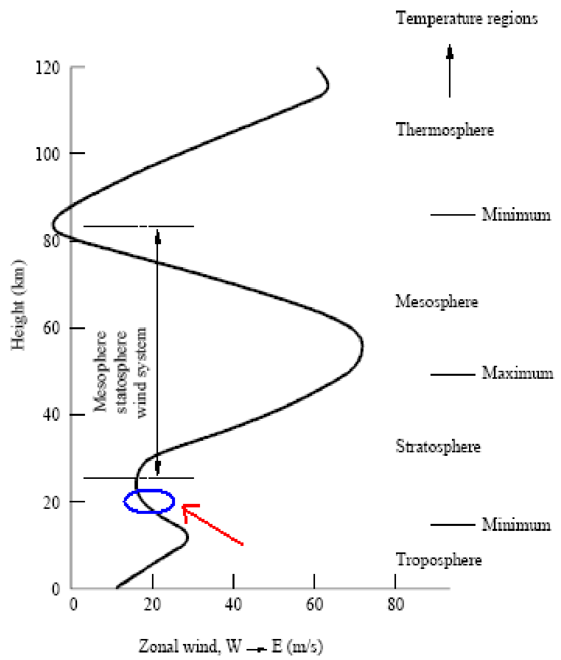

Figure 1: Altitude with respect to the wind velocity [9].

Other issues to be examined are the aerodynamics (the behavior of large semi-rigid structures and the thermodynamic behavior of large gas volumes cannot scale from small prototypes), the feasibility and requirements of inter-platform links and links to satellites (again, the effect of the platform's movement should be considered), and the link budget for platform-to-ground links and vice versa [12]. The choice of energy source is also of fundamental importance. Solar energy has considerable appeal solving this problem.

The ITU has allocated specifically for HAPS backhaul services 600 MHz at 47/48 GHz (shared with satellites) worldwide. But in Asia the 28/31 GHz band is assigned [13].

SYSTEM PERFORMANCE

In [4] and [14] focus was given on examining the impact of the platform movement on a airship due to stratospheric winds on the system level performance of a propulsion enabled HAPS UMTS- . A 12.2-kb/s speech service and three Cell Types were implemented and different user mobility models and session durations for each Cell Type were applied. Some typical wind velocity profiles have been obtained by the High Resolution Doppler Imager (HRDI) on the National Aeronautics and Space Administration's Upper Atmospheric Research Satellite [15]. The HRDI is providing direct global scale observations of horizontal wind fields in the stratosphere, mesosphere and lower thermosphere (10–115 km). So, the raw data sets (Level 3A files), where measurements were taken every 65 s (referred as observation periods), were used. After obtaining small (time) scale statistics the platform movement was modeled at an altitude of 20 km.

In order to counterbalance the horizontal displacement, the HAPS was equipped with a propulsion mechanism. The ideal position and the position error can be determined through an on-board GPS system. The propulsion employed in the simulation was based in an on-off system with a reaction latency of 20 s [16].

The antenna system is one of the most important performance factors in a HAPS configuration. In [17] the required functions for a successful broadband HAPS antenna were summarized in the rules:-

- Use of high radio frequency in order to secure a sufficient bandwidth.
- Directional antenna with a high gain to cope with attenuation in high frequencies.
- A multibeam antenna that accommodates 100 beams or more, both for transmission and for reception, to cover views as wide as 120° or more from the stratosphere with a high gain and to achieve effective use of the frequencies involved.
- Reduced weight, size, and power consumption of the mission payload.
- Must operate reliably in the stratospheric environment.

Considering the movement of HAPS, it is necessary to compensate this movement by mechanical or electronic steering. A serious constraint is the available payload aperture. As the size of cells decreases, their number increases and also the required payload aperture increases. The structure size of an antenna array was calculated in [18] as a function of the radius of the central cell (broadside cell), for a platform at 21 km operating at 2.2 GHz. The size of the antenna array is also determined by the altitude of the platform for a specified radius of the central cell. As the altitude of the platform increases, the size of the array also increases. However, the higher the operating frequency, the smaller the array.

Two types of multibeam antennas meeting the above requirements were described in [19], [20]: a Multibeam Horn (MBH) antenna of the mechanical-drive type for operation at 48/47 GHz, and a Digital Beamforming (DBF) antenna of the electronic-scanning type for operation at 31/28 GHz. Basic specification of the antennas are shown in Table 1.

The DBF antenna has much more flexibility then MBH antenna [19]. Here a beam is formed by a combination of the array antenna and spatial digital signal processing. It is an "intelligent" next-generation antenna, referred to as a "smart antenna" or a "software antenna." The antenna supports automatic acquisition, tracking, interference separation, and so on by performing spatial parallel processing of signals received from the ground-user stations, thereby forming an antenna pattern. Since there is no mechanical drive component, this antenna is considered to be suitable for multi-element, large-scale, multibeam formations. This antenna is flexible, accurately steerable, accommodates a number of ground-user stations, provides a maximum gain continuously to a specific user, supports efficient frequency reuse performance by (WCDMA), removes undesired incoming interfering waves, reduces the interference to other systems (such as satellite systems), and also can estimate the Direction of Arrival (DOA) of authorized or unauthorized electromagnetic waves.

Table 1: Main Specifications of the multibeam antenna prototypes [15].

Item	MBH antenna	DBF antenna
Frequency band	Tx 47.2-47.5 GHz Rx 47.9-48.2 GHz	Tx 27.5-28.35 GHz Rx 31.0-31.3 GHz
Antenna type	Seven corrugated horns	16 (4x4) patch array
Number of beams	Seven fixed beams	Nine fixed beams, three tracking beams
Bandwidth	300 MHz or more	4 MHz
EIRP	6.3 dBW or more	11~15 dBW
G/T	-15.4 dB/K or more	-13 ~ -17 dB/K
Compensation for platform fluctuation	Position sensor and three axis gimbal control mechanism	Adaptive beamforming with spatial digital signal processing
Transmission bit rate	56 Mb/s	4 Mb/s
Weight	150 kg or less	74.2 kg
Others	Frequencyreuse:7, Isolation between co-channel beam 30dB	Sampling rate: 32 MHz Resolution: 12 bits

END USER OR GATEWAY RECEPTION MODELING

In case of end user, received power of user (UMTS-) terminal is computed at different user locations in the ground for different aircraft positions. On the other hand, for backhaul link, received power of gateway is determined at different aircraft position and also for different polarization, namely circular, horizontal and vertical, of the transmitting HAPS antenna.

For these, the free space loss is calculated using the following formula [21],

Ls = 32.45 + 20 log d (in km) + 20 log f (in MHz) (1)

here,

Ls = Free Space Loss in dB

d = Distance between transmitter and receiver in km

f = Operating frequency in MHz.

Then, the received power at receiver is calculated by [16],

Pr = Pt + Gt + Gr – Ls –A (2)

Pr = EIRP + Gr – Ls - A (3)

here,

EIRP = Effective Isotropic Radiated Power in dBm.

Pr = Power at receiver in dBm,

Pt = Transmitted power in dBm,

Gt = Gain at tranmitter,

Gr = Gain at receiver dB,

A = Attenuation due to rain in dB,

Carrier to Noise Ratio (CNR) is calculated for each received power for both end user link and backhaul link. Noise is calculated using [20]

N = k * T * B * F (4)

here,

N = Noise

k = Boltzmann’s Constant

T = Temperature in Kelvin

B = Channel Bandwidth

F = Receiver noise figure.

Availability of the link in computed in percentage of time based on the CNR for backhaul link. It shows how much time the link will be unavailable in a total calendar year.

END-USER LINK

The HAPS network architecture is described using Figure 2 and Figure 3. In Figure 2, four positions of the HAPS circular corridor have been highlighted – A, B, C, and D. The black numbers indicate the ground distances from center of the HAPS rotation circle in ground to a particular position where the user might be situated. The blue numbers refer to the aerial distance between the haps and the particular user location. Figure 3 delineates the situation of user receiving different signal strength at different location of HAPS.

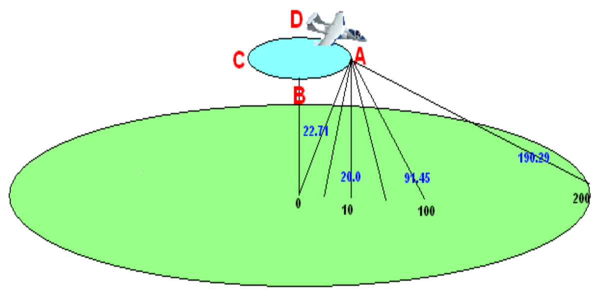

Figure 2: HAPS movement for user at different locations.

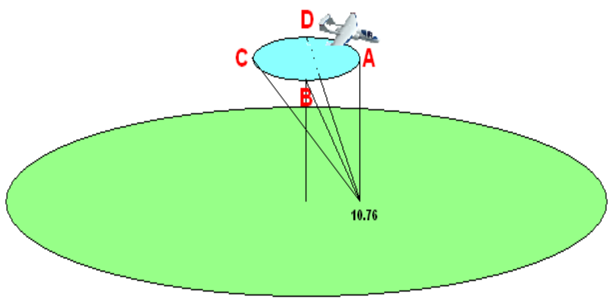

Figure 3: HAPS movement for user at specific location

At first the different values of CNR, that the receiver will get, at different positions has been determined for a single instance of HAPS position. The summarized result is shown in Figure 4.

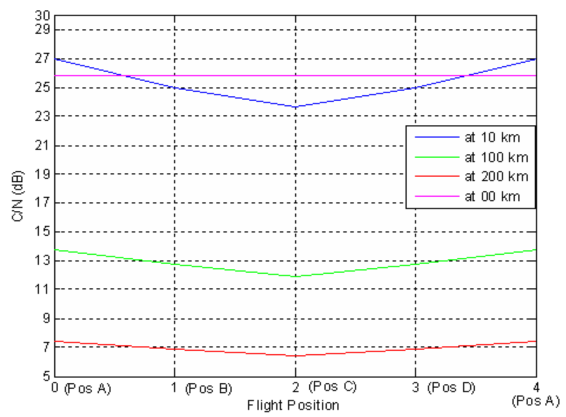

Figure 4: Comparison of CNR when receiver at different ground positions.

Here, it can be noted that when the receiver is at 00 km, which means at center of the HAPS circle in ground, there is no fluctuation in the received signal for all the flight positions from A to D. It has a constant value of around 26 dB. Then, when receiver is at 10 km from center, it experiences the most fluctuations of about 3 dB due to circular rotation of HAPS. At flight position A, it has best value of 27 dB and at flight position C it faces lowest CNR o 24 dB.

After that, in case of receiver at 100 km, the total fluctuation of CNR among different flight positions decreases to 2 dB. But there is a significant decrease of the total signal strength, which is now about 13 dB. Then, for 200 km, the total fluctuation of CNR among different flight positions is now less than 1 dB. Subsequently, the total signal strength went down to around 7 dB. Lastly, it should be noted that, the difference in CNR between the center of the circle and edge of the circle (at 200 km from center) in all flight positions is approximately 20 dB.

The effect of horizontal and vertical fluctuation of HAPS is summarized in Figure 5, Figure 6, Figure 7 and Figure 8. To describe the phenomena properly 4 ground distances have been chosen, namely 00 km, 10 km, 100 km and 200 km respectively.

In Figure 5, the effect is analyzed when the receiver is at 00 km ground distance, which means at the center of the HAPS rotational circle in ground. As the receiver is at center, there is no fluctuation in received signal for change in altitude or radius. Here, fluctuation in altitude generates more CNR variation then variation in flight path radius. But, both of these values are well below 1 dB.

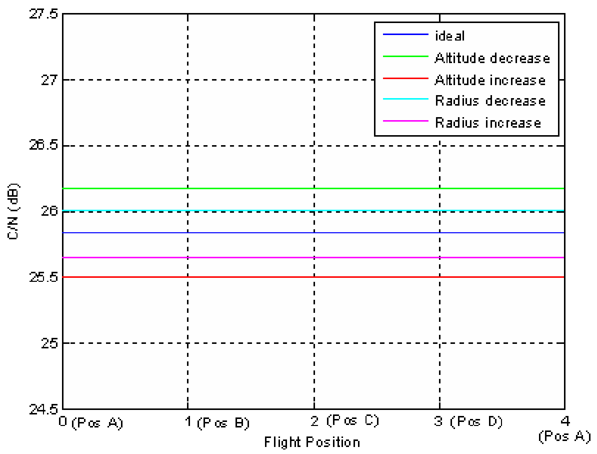

Figure 5: Altitude and radius fluctuation when receiver at 00 km.

In case of Figure 6 the receiver is at 10 km ground distance that means 10 km from center of the circle at ground. Throughout the circulation, altitude variation produce CNR difference of around 3.5 dB- lower value in position C and higher value in position A. Radius fluctuation is not significant in position A, but reaches the same value of 3.5 dB in position C. So, at 10 km ground distance, the receiver will face significant CNR variation in received signal.

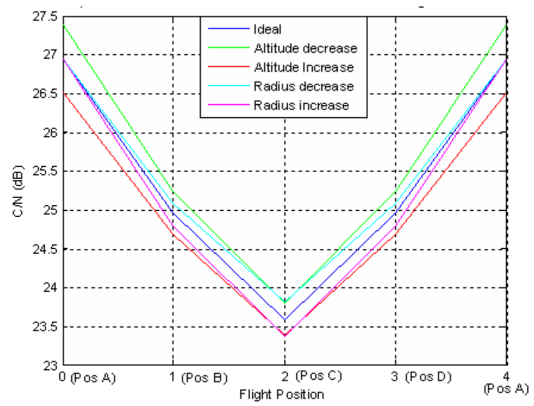

Figure 6: Altitude and radius fluctuation when receiver at 10 km.

Figure 7 describes the situation when receiver is at 100 km ground distance, which means 100 km from the center of the circular corridor at ground. It is clear that, at this distance the altitude and radius fluctuation don't have significant impact on CNR. The highest variation in CNR is approximately 1.5 dB from position A to C.

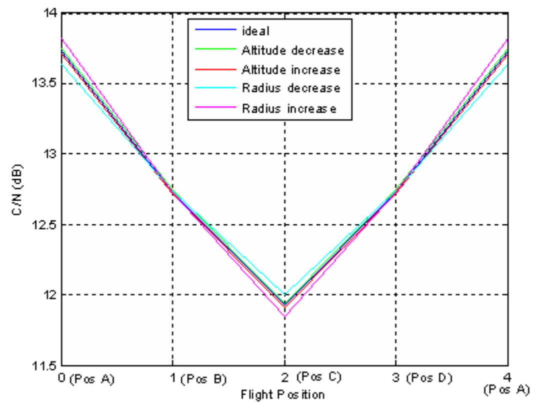

Figure 7: Altitude and radius fluctuation when receiver at 100 km.

Then, Figure 8 demonstrates the effects when receiver is at 200 km ground distance, which means at the edge of coverage area. Here, the effect is almost similar as for 100 km. The only difference is that the overall CNR fluctuation is less than 1 dB.

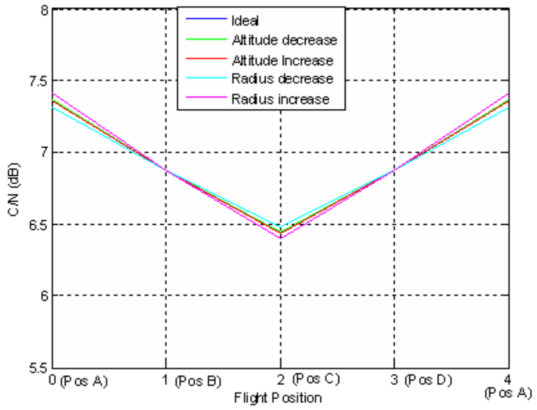

Figure 8: Altitude and radius fluctuation when receiver at 200 km.

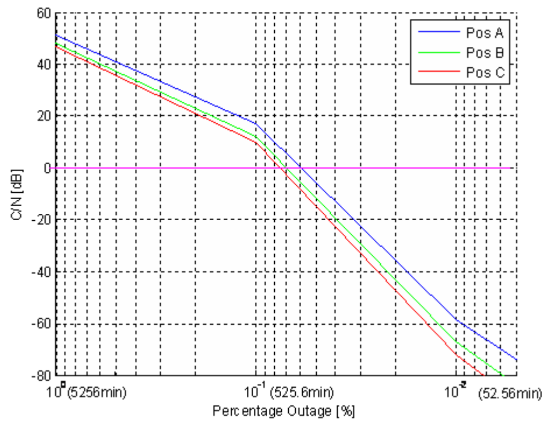

Figure 10: site 1 backhaul result for different flight position (Circular Pol.)

From the above results, a number of points can be extracted. Firstly, the radius and altitude fluctuation creates significant CNR variation if the receiver is closer to the center of HAPS circular corridor in ground, except the center itself. Then, when the receiver is located at long distances from center the effect of fluctuation don't have significant impact on the received signal, only the rotational effect remains. Lastly, when the receiver is close to the center, altitude fluctuation has higher impact than radius fluctuation in variation of CNR.

BACKHAUL LINK

The link availability of backhaul link is determined according to the parameters of 3 different places. The calculated network structure for backhaul link is shown in Figure 9. Here, the GTG is located at 35.35 km ground distance from center.

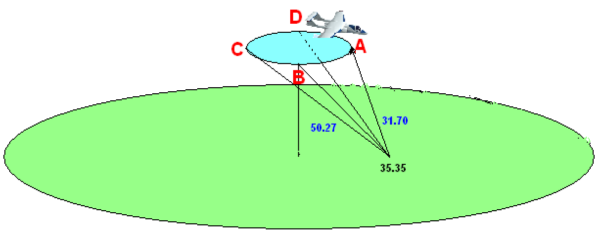

Figure 9: HAPS movement for backhaul link.

Then, Figure 11 shows backhaul link availability for 3 different polarization computed in flight position A. Here also, all the polarization can provide minimum availability of 99.9%. Vertical polarization gives the best CNR, Horizontal polarization gives the lowest CNR and circular polarization gives a value between these two. There is a difference of 10 dB between received signal of horizontal and vertical polarization at 99.9% availability.

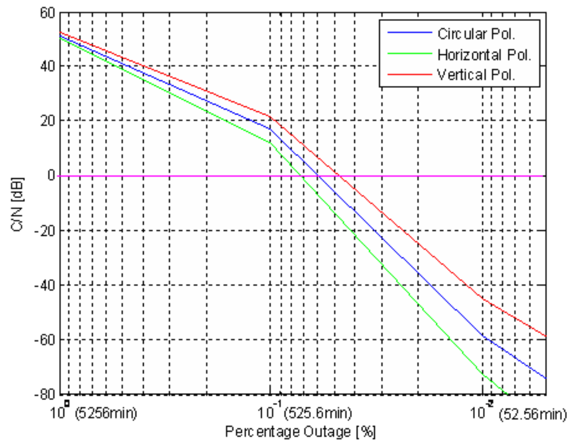

Figure 11: site1 backhaul result for different Polarization (Pos. A)

Figure 10 shows the link availability of first site for 3 different flight positions – A, B and C using circular polarized antenna. It is evident that, here the link can provide 99.9% of availability as it is well over the 0 dB CNR value. So, the percentage of outage here is 0.1%, which means the link will be unavailable for 525.6 minute in a total calendar year. Now, the highest CNR variation is 8 dB which occurs between position A and C. Position B gives a value in between these two.

Site 2 will give a measure of best possible performance of the link. In, Figure 12, the link availability is shown for 3 different flight positions – A, B and C using circular polarized antenna. It is clear that here the link can provide 99.91% of availability as it is well over the threshold CNR value. So, the percentage of outage here is 0.09%, which means the link will be unavailable for 473.04 minute in a total calendar year. Now, the highest CNR variation is 7 dB which occurs between position A and C.

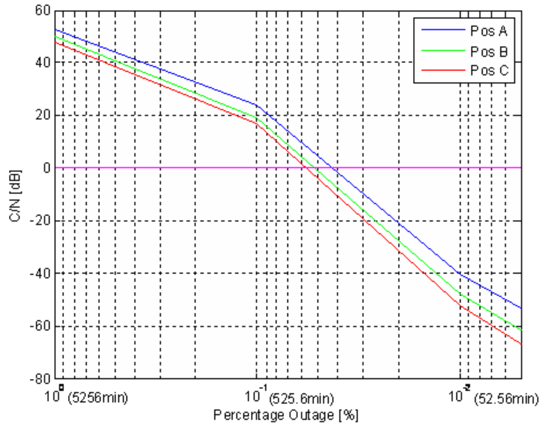

Figure 12: Site 2 backhaul result for different flight position (Circular Pol.)

Now, Figure 13 shows backhaul link availability for 3 different polarization computed in flight position A. Here, all the polarization can provide minimum availability of 99.92%. So, the percentage outage in this case is 0.08%, where thee link will be unavailable 420.48 minute in a year. In these case also, vertical polarization gives the best CNR, Horizontal polarization gives the lowest CNR and circular polarization gives a value between these two. There is a difference of 9 dB between received signal of horizontal and vertical polarization at 99.92% availability.

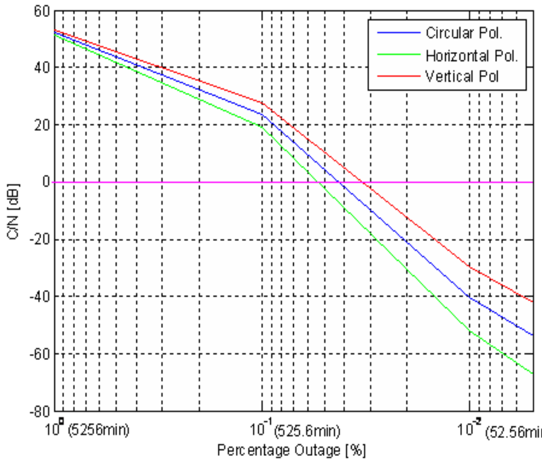

Figure 13: site 2 backhaul result for different Polarization (Pos. A)

Site 3 is the place which experiences most rainfall. It will give a measure of worst possible performance of the link. In, Figure 14, the link availability of site 3 is shown for 3 different flight positions – A, B and C using circular polarized antenna. It is shown that here the link can provide 99.8% of availability as it is well over the 0 dB CNR value. So, the percentage of outage here is 0.2%, which means the link will be unavailable for 1051.2 minute in a total calendar year. Here, the highest CNR variation is 7 dB which occurs between position A and C.

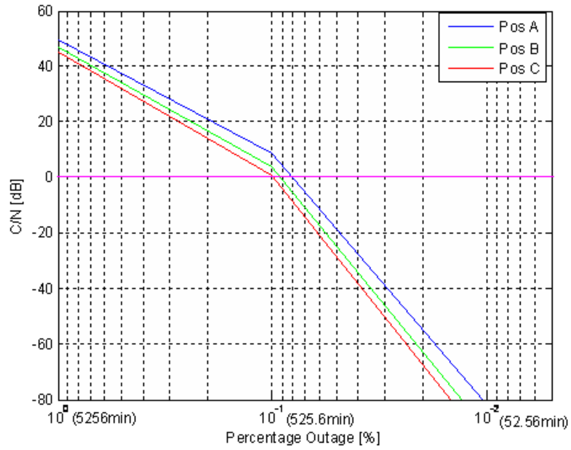

Figure 14: Site 3 backhaul result for different flight position (Circular Pol.)

Now, Figure 15 shows backhaul link availability for 3 different polarization computed in flight position A. Here, all the polarization can provide minimum availability of 99.8%. So, the percentage outage in this case is 0.2%, where thee link will be unavailable 1051.2 minute in a year. In these case also, vertical polarization gives the best CNR, Horizontal polarization gives the lowest CNR and circular polarization gives a value between these two. There is a difference of 9 dB between received signal of horizontal and vertical polarization at 99.8% availability.

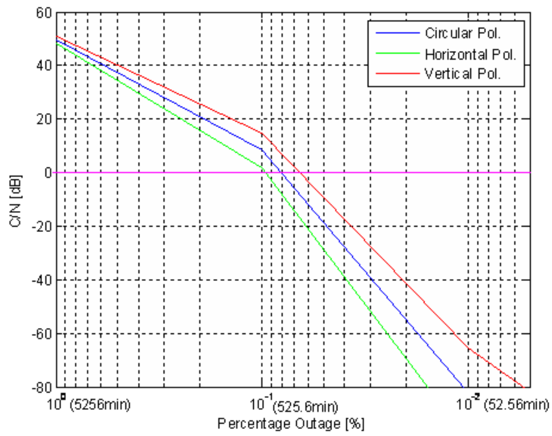

Figure 15: Site 3 backhaul result for different Polarization (Pos. A)

As Site 2 and 3 are the places where two most diverse rainfalls are experienced, so it can be said that, in this scenario link availability between 99.8% and 99.92% can be provided. This also indicates that, the duration of backhaul link unavailability will be between 473.04 minute and 1051.2 minute. This clearly satisfies the ITU-R recommendation of minimum 99.4% [3].

In case of antenna polarization, vertical polarization always gave better result than other two. So, polarization diversity can be used for better performance. If the atmosphere normal, then either horizontal or circular polarization can be used. Then in case of heavy rain or other natural disturbances, it can be switched to vertical polarization.

CONCLUSION

One of the primary obstacles of improving HAPS service quality is its instability. The CNR variation from center to the edge of servicing area is around 20 dB for UMTS- end user. Moreover, if a user is located at a fixed position it can suffer from maximum 3 dB variation in the received signal due to the rotation and fluctuation. Furthermore, users close to the center suffer more variation in signal than users located at long distances and altitude fluctuation degrades the signal more than radius fluctuation. The backuhaul link also suffers from a number other effects besides the above stated ones, such as rain attenuation. In this case, signal levels were determined in three different places with different rainfall statistics – Site 1, 2 and 3. It is observed that even in the worst case condition (in Site 3) the link can provide 99.8% link availability, which means the link may be down for around 1051 minute in a total year. This statistics is higher than that of 99.4%, which is proposed by ITU-R. On the other hand, in best case condition, (in Site 1) calculation showed that, even 99.91% of link availability can be achieved. Last but no least, research on different antenna polarization reveled that, vertical polarization, which gave the best performance, can be used with either circular or horizontal polarization in polarization diversity to obtain optimum system performance. Lastly, it can be said that, the result of the service obtained can be used to design the communication network with higher level of user satisfaction. These findings might also be useful for the design team of HAPS to come up with more robust aerial stations and better ways of stabilizing mechanism.

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