Improving the System Performance of High Altitude Platforms Serving Suburban Areas

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To My Family
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To My Parents
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ABSTRACT

High Altitude Platforms (HAP) has been evolving to make a new history in wireless communications infrastructure. A number of applications and services have been proposed for HAP based communications which advance HAP over terrestrial and satellite infrastructure for future communications. Providing high speed multimedia mobile communications through HAPs to the users of Third Generation (3G) holds strong position using one of the proposed band, 2GHz. In this study we investigated how to improve the performance of 3G serving from HAP over a territory having suburban characteristics. Two proposed channel models, free space loss and shadowing loss, has been used to analyze the performance of HAP systems at 2GHz frequency band for suburban regions. Three different parameters namely antenna bore point, HAP antenna roll off factor and user antenna roll off factor have proposed to improve the performance of HAP systems while considering suburban regions. A scenario has introduced consisting of an ideal suburban and rural region to serve 3G services while emphasizing on suburban region. The number of HAPs required to serve the defined suburban region is restricted to at least three due to elevation dependent losses in the scenario. The three proposed parameters have been used to improve the performance of 3G services over the selected suburban region.

Application of the parameters over suburban region gives different performances which can be categorized in different ways. Some of the parameters are more elastic than others for a certain coverage area. We conclude with adaptive application of the parameters for 3G services over suburban area to have improved performance of HAP.

Keywords: 3G, High Altitude Platform (HAP), Roll off factor, Suburban Region, Shadowing Loss.
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1. **INTRODUCTION**

High Altitude Platforms (HAPs) has been acknowledged as a profound field of research to familiar the world with a new infrastructure of wireless communication. The platform for HAPs has proposed at the height of 17-22 km above the ground where airships can fly to provide services to the coverage area [2, 15, 16, 23, 25, 26, 28]. The world of communication is focusing on HAPs with interest because of numerous advantages over satellite and terrestrial communication systems with dynamic nature of application and services. Providing 2G and 3G services have strong recommendation to serve from the stratospheric platform of HAP. Currently 3G services are on peak of demand for multimedia communications and different innovative features. HAP system can provide 3G services which results spectrally efficient and cost effective advantages over terrestrial system [1, 18, 28]. Hence HAP system has such potential to deliver 3G services over a large coverage area.

Several researches have been conducted on different type of territory to serve 3G services through HAPs. Rural, suburban, urban, dense urban and urban high-rise are the major categories of territory on hot topic of research [4, 9, 14, 15]. As stated earlier, a single HAP has capability of providing 3G services over a large coverage area, hence covering a number of territories become under consideration. The verity of territory covered by a HAP system will depend upon the radius of coverage zone. For example, a single HAP system may serve rural, suburban and urban type of territories while covering a large geographical area. One of the major advantages of HAP system is capability of providing higher elevation angle over terrestrial system [7, 14, 15]. As a result HAPs can provide higher probability in case of LOS (LOS) communication to a user than terrestrial systems. A short distance between HAP transmitter and user gives lower free space loss compared with satellite communication systems. Only free space loss is not enough to evaluate the performance of HAP over the territories like suburban, urban, dense urban and urban high-rise etc as like rural territories. Several researches have been performed to model shadowing loss over numerous coverage areas to fit with practical instances. HAP system has very low shadowing loss compare to terrestrial system due to higher probability of LOS communication. A number of shadowing loss models have been proposed for HAP based communications over different type of coverage territories and frequencies to provide services. All proposed models are elevation dependent shadowing loss models [7, 15]. Survey on elevation dependent shadowing loss and free space path loss model indicates that it is not possible to cover a certain territory by a single HAP except rural category. Deployment of multiple HAP initiates with a single HAP which start serving then based on the demand other HAPs set to the platform in purpose of providing quality of service (QoS) [5]. New technologies such as WiMax and Wi-Fi are also the hot topic for implementation through High Altitude Platforms. International Telecommunication Union (ITU) has already allocated
several bands of frequency from 2-66 GHz for HAP based communications [22, 27]. The target frequencies for 3G and 4G services are 2-6 GHz, in particular 2, 3.5 and 5.5 GHz bands are on demand [15, 22].

1.1 History

The history of concept of HAP begins at the time of 1783 by the Mongolfier brothers [6]. However, the direct reference found out in the early age of 1960s with study of airborne craft capability of delivering communications having semi-permanent existence [1, 17]. Similar concept was proposed in an editorial in 1992. The SkyStation International put forward step on the concept of HAP through implementing a 200m long solar powered airship [6]. The aim of the project was to provide 3G and broadband communications. The project was forwarded by International Telecommunication Union-Radio communication sector (ITU-R) on later part. Another project was carried out by Angel Technologies based on a manned stratospheric plane. Unfortunately both of the projects were not successful though could not stop the progress of HAPs. Japan and Korea started their own project at 1998. Japan invested significant amount of budget to develop similar concept of providing telecommunication and remote sensing [6, 17]. The influence on HAP took more time in EUROPE. In Italy a 3 year long project, HeliNet project, was awarded at the time of 1999/2000 which was coordinated by Politecnico de Torino [17]. The three pilot applications of the project, broad band communications, remote sensing and traffic localization, was followed by CAPANINA project coordinated by University of York, UK. At the same time a number of activities led by NASA in USA. They successfully deployed 3G and HDTV in Hawaii [6, 17]. Still there are a number of activities continuing based on the previous development example with COST 297-HOPCOS scientific cooperation action.

1.2 HAPs with Terrestrial and Satellite Communications

Large coverage area, easy to deploy, low cost, coexistence capability etc are the major advantages making HAP more attractive over the other two platforms of wireless communications, terrestrial and satellite communications [1,6,10]. Today the satellite communications is an alternating way of communications at rural and disaster affected areas with increasingly sophisticated solutions. Satellite Communication systems provide large coverage area at a time causes high propagation losses and time delay. The one way delay for a Low Earth Orbit (LEO) is about 5ms whereas for HAP this minimizes to around 0.083ms [1]. On the other hand the terrestrial systems, another major communications system with well established network, always face a negative impact from environmental constrains and propagation of radio waves across all sorts of terrain. That is why a high antenna must have to be mounted to minimize the effect of propagation loss [16, 19, 20].
Terrestrial system has been suffering from high amount of shadowing loss due to lower LOS probability. Overall scenario motivates to deploy HAP as middle ground aiming for providing potential benefits with cost of lower negativity between terrestrial and satellite. The HAP, being the middle ground, could coexist with both the terrestrial and satellite communications. A number of scenarios have been proposed based on intercommunications with terrestrial and satellite.

1.3 Outline of the Thesis

The work has been divided into five distinct parts. Each part of the thesis work bears own characteristics relating with the research questions asked in the subsection 3.2. The first part, namely survey of related works, contains the background knowledge to accomplish the thesis work. A brief explanation about the current trends of research on HAPs was carried out. Only the relevant hot topics have been presented along that part. A description of basic model of HAP, HAP and user antenna radiation pattern and channel modeling has shown concisely into the system modeling part. The role of antenna directivity has shown with a group of side lobe floor in the HAP and User antenna radiation pattern part. Free Space Path Loss (FSL) model and Shadowing loss model have explained relating with elevation angles into the channel modeling part. The modeled system has evaluated and analyzed into the performance analysis part. Different parameters of the modeled system are picked up to improve system performance based on analyzation. An ideal scenario has also been considered for evaluating the performance of HAP. The result part contains the outcomes throughout the system designed of our thesis work then described with a precise manner according to related topic. Finally, the whole thesis work is concluded by mentioning some future work.
2. SURVEY OF RELATED WORKS

Throughout a deep survey of related works the references has found to be supportive for our thesis work. These references were selected because of clear statements as well as updated understanding with innovative concepts in different field of research. We selected the references based on knowledge of integration or coexistence performance, compatibility of different services, multiple HAPs attribute and cellular performance, types of antennas, different losses and different types of service area characteristics.

A number of surveys have been performed by several groups and governments to deploy HAPs. A deep Research and development activities have been conducting by the EU FP6 CAPANINA Project and the COST 297 Action in Europe. There are government-funded projects in Japan, Korea and USA [2]. Some commercial projects are under processing in Switzerland, USA, China, and UK [2]. There are two experiments carried out at Kauai Island and Hawaii respectively, USA [17]. In the second experiment, a successful video communications established using cellular telephony systems. The reference paper [24] describes about the advantages of HAP of different type, manned and unmanned etc. The paper also focuses on the technical challenges and critical issues of energy source, platform station keeping, modulation, coding, antennas design, propagation, diversity, interference and handoff issues. References [1], [6] contain detail general information related to HAP.

In references [10], [21], [22], [26], [27] and [28], the performance of coexistence or integration techniques with terrestrial and satellite for delivering different type of services from high altitude platforms were investigated. Reference [10] gives networking solutions for overlapped terrestrial-HAP-satellite coverage through an inter-working scenario. The effect of using two representative scenarios, a macro cellular system operating from a high altitude platform LOS system and a terrestrial non-LOS System, were investigated in [21]. Discussion of different hybrid system architectures of HAPs and providing a potential mapping of services to the components were described in reference [22]. In references [26] and [27], the coexistence performance of HAP and terrestrial WiMaX systems has evaluated for single cell and multiple cell structure. The performance was carried out using the CINR with right-edge and left-edge in case of single cell structure with fix separation and variable separation distances between HAP and terrestrial WiMax. In addition the performance was evaluated in terms of spacing distance and gain for varying HAP spacing radius, in terms of CINR for varying HAP antenna beam width and in terms of mean CINR for varying user antenna beam widths. In reference [26] different antenna beam widths and beam width roll off were used for the HAP transmitting antenna. Finally, the paper [26] was concluded that delivering WiMaX from HAPs is stable and effective while considering interference. In reference [27]
system performance was evaluated for different cellular reuse schemes. There, a single HAP scenario was considered with different frequency reuse pattern for multiple cell configurations.

There is a huge possibility to provide different types of services through proposed structures of HAP. General Packet Radio Service (GPRS), 3G, Wideband CDMA (W-CDMA), WiMaX and mobility based services are on the top of list that could be provided to users through HAPs. A comparison between GPRS system using only microcellular structure and using both microcellular and macro cellular structures is evaluated in reference [21]. References [10], [18], [22], [23] and [28] are showing the scopes of providing 3G services via HAP. Mobility and multimedia services are on demand for new generation telecommunication systems, so 3GPP consortium has the Multimedia Broadcast and Multicast Service (MBMS) concept into 3G or beyond-3G networks with spectral efficient and cost effective way. The frequencies allocated for HAP in different bands are shown in Table 1. There is 2 GHz band suitable for 3G mobile services. However, 2-6 GHz frequency bands can be used for 3G services [15]. Costs in terms of resource utilization, signaling traffic load, number and location of customers, reliability, possible retransmission paths, user mobility and QoS are the major terms to look after incase of deploying 3G. The overall system capacity can be improved by deploying multiple HAPs for broad band services is shown in reference [5].

So far several types of cellular structures have been proposed with wide range of advantages. Capacity enhancement, frequency reuse, reduce interference, larger coverage area are some of the advantages of cellular structures. In [4] system capacity enhancements were investigated by using multiple HAPs. There were two constellations, named `Fixed Radius’ and `Constant Arc length’, proposed for multiple HAP scenarios. The paper says increasing the number of HAPs provides higher bandwidth efficiency and a narrower beam width of user antenna increases the capacity for single cell performance. The CIR performance and cumulative distribution function (CDF) of multiple cells are also investigated. Multiple cell deployment per HAP also increases system capacity but at a time causes higher inter cell interference. In [27] HAP cellular system performance was evaluated in terms of CIR and CINR for both downlink and uplink communications. HAP system performance for coexistence scenario was also evaluated in terms of CIR and CINR for both downlink and uplink communications. Through the simulation results it is concluded that the internal co-channel interference was dominant when delivering WiMaX via HAPs and HAP system can effectively share the spectrum with terrestrial WiMaX systems. Reference [16] presented a method for predicting co-channel interference based on curve-fit approximations for radiation patterns of elliptic beams. Those elliptic beams illuminate cell edges with optimum power and estimating optimum beam widths for each cell of a regular hexagonal cell design. The method also shows the channel overlap in the coverage area.
<table>
<thead>
<tr>
<th>Frequency Band (GHz)</th>
<th>Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>47.9–48.2</td>
<td>Global</td>
</tr>
<tr>
<td>47.2–47.5</td>
<td>North and South America and also some countries</td>
</tr>
<tr>
<td>31.0–31.3</td>
<td>North and South America and also some countries</td>
</tr>
<tr>
<td>27.5–28.35</td>
<td>Europe, Africa, Russia and Middle East, Asia and Pacific countries</td>
</tr>
<tr>
<td>2.160–2.170</td>
<td>Europe, Africa, Russia and Middle East, Asia and Pacific countries</td>
</tr>
<tr>
<td>2.110–2.160</td>
<td>Global</td>
</tr>
<tr>
<td>2.010–2.025</td>
<td>Europe, Africa, Russia and Middle East, Asia and Pacific countries</td>
</tr>
<tr>
<td>1.885–1.980</td>
<td>Global</td>
</tr>
</tbody>
</table>

Table. 1. Frequency allocation for the HAP based communications [20]

The characteristic of an ideal antenna is to illuminate only the area to be covered for corresponding service providing. The power should be uniform across the coverage with zero power falling outside the coverage as like a special filter [16, 19, 20]. It is very difficult to have such kind of antenna beam shape which only illuminates the service area. A very low side lobe, directive and steep roll-off in the main beam is required for avoiding interference [23, 16]. Though, too high directivity of antenna suffers from excessive power roll-off at its edge. On the other hand, too low directivity is suffers from excessive power fall outside the cell coverage. So that causes rise in marginal link budgets particularly at cell edges. In the reference paper, [16], the half power beam width was chosen to have a main lobe distribution considering the effects. The most practicable antennas for this application are likely to be aperture types because of its well established beams with low side lobes, steep roll-off in the main lobe and minimization of interference. The horn antenna may give strong side lobe suppression with a higher directivity and narrower beam width.

Channel modeling for HAP communications is well established in different aspects incase of high frequencies. But only free space path loss model and shadowing loss model have been established for the applications below 10 GHz frequency bands. Different types of channel modeling have shown in reference [1] with a clear understanding. In reference [4] interference mitigation schemes were presented and performances were evaluated using a new interference mitigation approach. A frequency sharing scheme, adaptive beam forming scheme (ABS), is introduced and interference mitigation effects were examined. An empirical model presented in reference [7] to analyze the losses due to propagation of 2 GHz signal from outdoor to indoor for high elevation angles of HAP. Results of the model show
propagation loss decreases and penetration loss increases at higher elevation angles. In reference [9] a measurement carried out by transmitting signal from a helicopter and receiver was placed in different places such as office building, a shopping mall, and a residential house. The building entry loss and time delay spread were measured. Another model designed in reference [14] as designed in [9]. This time received signal measured at the user end by placing at different places while signal transmitting from a remote controlled air ship and the measured data was presented as a function of elevation angle. An elevation dependent shadowing loss model has been introduced in reference [15]. In the model, LOS probabilities were calculated first and shadowing loss added based on elevation angles. Then three frequencies, 2, 3.5 and 5.5, were used to verify the statistical elevation dependent shadowing loss model. Finally the theoretical and practically measured data were verified in the paper.

To provide services through HAP, references [14] and [15] introduced different model for individual areas like suburban, urban, dense urban, city. The parameters for elevation dependent shadowing model for different type of geography had listed in a tabular format.

Most of the references begin with certain modeling of HAP. Sometimes it was based on single HAP base station with single and multiple cells. Sometimes it was multiple HAPs base station with single and multiple cells. The referenced papers give a good overview of HAP communication systems. The results of the references indicate the possibility of HAP deployment in stand alone or co-existence format.
3. PROBLEM STATEMENT, RESEARCH QUESTION AND MAIN CONTRIBUTION

In this chapter we present the problem statement, formulate the research questions and state the main contributions of the thesis work.

3.1 Problem Statement

References [10], [15], [18], [22] and [23] described about the implementation of 3G services through HAPs. Some related works evaluated the performance using different types of parameters example with HAPs antenna beam width and user antenna beam width. Our study on previous work shows that only free space loss used as channel model in all cases. There, previous work, also mentioned about some shadowing loss models depending on type of territory to be served by the HAP system. Throughout a deep study we have found some problems which have not asked and answered yet to advance the research of HAP. The research for providing 3G services from HAP over suburban regions have not been evaluated yet. Both free space path loss and shadowing loss model can be used to evaluate the performance of HAP through the conceptual models provided into the references. The performance of the model can be improved using parameters, HAP antenna roll-off, user antenna roll-off and antenna bore point, of the system model.

3.2 Research Questions

Based on our background knowledge of High Altitude Platforms we tried to answer the following research questions throughout our thesis work. The questions play an innovative role in the research field of HAP. The questions are as follows-

1. How does HAP system perform for 3G services over suburban areas?
2. What is the impact of Free Space Path Loss (FSL) on CINR or CNR in the study of suburban regional communications?
3. What is the impact of Shadowing Loss (SL) on CINR or CNR in the study suburban regional communications?
4. Which parameters play vital role in improving the performance of 3G services over the suburban regions?
5. How does different bore point of antenna can be used to adapt with left edge and right edge in the modeling?
6. Which type of HAP or user antenna roll off can give better performance for left edge and right edge in the modeling?
3.3 Main Contribution

A system model has to be designed to answer the questions asked in the previous section. In the modeling of antenna radiation patterns for HAPs and user antenna have to be defined. The structure of the channel model has to be modeled which will be used to analyze the performance of HAP for providing 3G services. The elevation dependent modeling of HAP may require more HAP to serve same area of coverage. In that case interference measurement is also an important task to maintain in a certain level. Different parameters of system model, such as HAP antenna roll off, user antenna roll off and HAP antenna bore point, could be used to mitigate the interference of a serving HAP being in an acceptable spacing radius. A high roll off rates of HAP antenna might cause sharp fall of power at the edge of coverage area. Whereas a lower values of roll off suffers from huge power fall outside the coverage. High user antenna roll off should give better performance than a lower value of roll off. This may occur because less interference signal will enter to the main lobe of the user antenna. Different HAP antenna bore point may provide adaptability to service area by multiple HAPs scenario. So, we have to design a scenario where different HAPs will provide 3G services to a certain area of type suburban and others will be rural. Both the free space path loss model and shadowing loss model will be implemented in the scenario.
4. **SYSTEM MODELING**

The system modeling of HAP based communication will be introduced in this chapter. HAP architecture, different parameters, relationship between the parameters, HAP and user antenna pattern modeling and channel modeling are highlighted. We will gather adequate knowledge in this chapter for understanding the way of problem solution.

4.1 **Basic Model of HAP**

A number of system models have been proposed by researchers of HAP based communications system. The models are applicable based on the demand of the system to be analyzed. In general we can have two kinds of HAP systems, single HAP and multiple HAP systems [23]. We can also have cellular based communications where several beams are formed by each HAP antenna [16,26,27]. A basic model of HAP has shown in Fig. 1. There are two HAPs flying at the same platform maintaining a spacing radius while covering same service area. Use of similar frequency causes interference at user end due to superpose of signal from interfering HAP.

![Basic model of HAP](image)

**Fig. 1. Basic model of HAP**

The system model has shown in Fig. 2 used in our thesis work. A single HAP is covering a certain service area flying at a platform of height 17 to 22 km. The boundary of the coverage area is usually named as edge of coverage (EoC) which maintains a constant distance, called coverage radius, from the centre of the coverage area. The HAP always maintains a spacing radius while serving from its platform [6]. The point at the ground straight from the HAP is called the sub-platform point (SPP) and the distance with the centre of the service area is the spacing radius. The serving HAP antenna can maintain different roll off beam width at the EoC of the coverage area.
area. The mostly used roll off beam width values are 3 dB and 10 dB [16, 19]. The angle to maintain the required roll off beam width indicates as subtended angle. Different spacing radius may use depending upon the geography of the coverage area to be serve and the way to provide services. The spacing radius and subtended angle has relation with elevation angle [7]. The following discussions focus on nature of the relations.

Relation between elevation angle at the EoC and the spacing radius has shown in Fig. 3 for a 30km of coverage area. There, relationship has plotted for three distinct heights of HAP platform. Most researchers use the values 17km, 20km and 22km of the HAP platform height for their research purposes. An increasing elevation angles at the EoC, to the x-axis, has proportional impact on spacing radius, to the y-axis. The figure also illustrates a higher spacing radius is required for a lower platform height of HAP to maintain same elevation angle at EoC. The zero crossing of spacing radius means the HAP is at the centre of the coverage for a corresponding elevation angle at EoC. All the curves meet to a point indicating that the HAP is at 30km far from centre of coverage while maintaining 90 degree elevation angle. A negative value has identified to the axis of spacing radius when the HAP has been considered on the right edge.

The relationship between the elevation angle at the EoC and the subtended angle has shown in Fig. 4. Proportionally increasing then decreasing change in subtended angle has maintained with proportionally increasing elevation angle at EoC. On both axes the units are in degrees. The three different HAP platform heights, 17km, 20km and 22km, have also been used in Fig. 4. The zero crossing of the curves in Fig. 3 for the values of elevation angle at EoC gives the peak of the curves in Fig. 4. The subtended angle decreases smoothly when the HAP spacing
radius counts on the left side from the centre of the coverage area. But rapid decrease of subtended angle occurs for a small change in elevation angle at the EoC when the HAP spacing radius counted to the right side.

Fig. 3. Relation between elevation angle at EoC and spacing radius

### 4.2 HAP and User Antenna Radiation Pattern

Antenna always plays a vital role in wireless communication systems. Aperture and patch antennas are the most common type of antennas used in experimental works [16, 20]. Antenna beams should be formed following a proper guideline. An ideal antenna beam should illuminate the coverage area uniformly. Ideally there should be zero power outage from the coverage area so that it may not interfere to the other systems [16, 19, 20]. There is always an advantage of low side lobes and steep roll-off in the main lobe. Still high directivity of an antenna causes excess power loss at the edge of coverage and low directivity causes excess power fall outside the coverage [19]. A Gain distribution of antenna has shown in Fig. 5 over coverage area assuming the HAP at the centre of the coverage. A 3 dB roll-off factor was used for having the gain distribution over the coverage area.

Directivity of an antenna main lobe is convenient to express in terms of a cosine function with a power of $n_H$ [3]

$$A_H = G_{Hbore}(\cos \theta)^{n_H}$$ (1)
where $\theta$ is the deviation of angle from the bore point of the antenna, $G_{\text{Hbore}}$ is the antenna bore sight gain and $n_H$ is roll-off factor of the radiation pattern.

The bore sight gain of an antenna is often expressed as (2) when side lobe level considered very low.

$$G_{\text{Hbore}} = \frac{32 \log 2}{2\theta_{3\text{dB}}^2}$$

where $\theta_{3\text{dB}}$ is the 3dB beam width assuming the antenna pattern is circularly symmetric. The 3dB beam width can be expressed in terms of cosine function and $n_H$ as stated in (3)

$$\theta_{3\text{dB}} = 2\cos^{-1}(\sqrt{n_H/0.5})$$

![Fig. 4. Relation between elevation angle at EoC and subtended angle](image)

We get the antenna directivity in terms of deviation of angle $\theta$ and roll-off factor $n_H$. 

$$A_H = (\cos \theta)^{n_H} \frac{32 \log 2}{2(2\cos^{-1}(\sqrt{n_H/0.5}))^2}$$
Three sample HAP antenna radiation masks have shown in Fig. 6. A side lobe floor of 30 dB has used in the pattern plotting. The three different antenna masks achieved for three different values of $n_H$, respectively 5, 8 and 12. The figure clearly demonstrates the increase of antenna directivity for higher values of roll-off factor. So that antenna beam width decreases with an increasing roll-off factor. Some beam width values has shown for corresponding roll-off factor in the legend of figure.

As like HAP the user antenna radiation pattern can be mathematically express as

$$A_U(\theta) = G_{\text{Ubore}} \left( \max \left[ \cos(\theta)^{n_u}, S_f \right] \right)$$

where $\theta$ is the deviation of angle from the bore point of the antenna, $G_{\text{Ubore}}$ is the antenna bore sight gain, $n_u$ is roll-off factor of the radiation pattern and $S_f$ is the side lobe floor level.

User antenna radiation mask is illustrated in Fig. 7. The figure shows three different side lobe floor levels of -30dB, -25dB and -20dB respectively. The user antenna should be highly directive to suppress interference from surrounding systems where the same frequency is used.
4.3 Channel Models

A channel modeling is one of the major tasks in mobile communication. It is practical to model the channel of wireless communication to provide a guaranteed QoS. The propagation mechanisms, such as multipath propagation and shadowing, affect the message conveying signal. How much signal has affected, it depends upon the time of propagation and frequency of the message carrying signal [15, 21]. The model of the channel may define according to type of environment and statistical nature of territory to be served. In this section we are focus on the HAP channel models applicable for providing 3G services.

![Radiation Pattern of HAP Antenna](image)

Fig. 6. HAP antenna radiation mask

4.3.1 Free Space Path Loss Model

The free space path loss (FSPL) model is the most common model has been using for every mobile communication system. There were no additional channel models proposed before shadowing loss model for the frequency bands of below 10 GHz. The shadowing model was proposed through [21] while limiting with 2-6 GHz frequency bands. This FSPL occurs even then when the transmitter and receiver in a LOS path [26, 27]. So, this loss exists when there is no other loss occurs in the link. It can be define by the ratio between power at a transmitter and receiver pair, commonly named SNR. The amount of loss is depends on time because of time varying nature of channel [23]. Mathematically, FSPL can be expressed as
\[ FSPL_{tt} = \left( \frac{4\pi d}{\lambda} \right)^2 = \left( \frac{4\pi f}{c} \right)^2 \]  

(6)

where \( d \) is the distance between the transmitter and receiver, \( f \) is the operating frequency, \( \lambda \) is the wavelength of the message conveying signal and \( c \) is the speed of light.

In dB scale we can express the FSPL as (7) considering the link distance in kilometer (km) and frequency in gigahertz (GHz) [15].

\[ FSPL_{tt}(dB) = 20\log(d_{km}) + 20\log(f_{GHz}) + 92.4 \]  

(7)

Fig. 7. User antenna radiation mask

4.3.2 Shadowing Loss Model

The shadowing loss model has been proposed recently in [15]. The only FSL was not enough to describe the channel model. The model selected for the mobility based applications which will operate at the frequencies 2 to 6 GHz from HAP [14, 15]. The frequencies, especially 2 GHz, 3.5 GHz and 5.5 GHz, are specially proposed for 3G and 4G services. We have discussed briefly about the way of modeling and use of the model in this subsection.
Fig. 8 shows a scenario of LOS and NLOS communication through HAP. The buildings were deployed according to the statistical model ITU-R Recommendation P. 1410 due to universal acceptance [19]. There is no information required about building shapes and distribution to model buildings for a specific service area. The overall loss calculation has divided into two ports. First the LOS probability was calculated in terms of elevation angle for the building distribution considered. After that the loss due to diffraction added with LOS result. Uniform Theory of Diffraction (UTD) was used to calculate the diffraction loss [15]. The shadowing loss can be approximated as [15],

\[
Loss_h = 20 \log(d_{km}) + 98.4 + \text{normrnd}(\text{mean, STD}) + \text{normrnd}(0,10)
\]

where \(d_{km}\) is the distance in km and \(\text{normrnd()}\) is a normal distribution function in MATLAB. The function \(\text{normrnd}(\text{mean, STD})\) use to generate random number using the normal distribution of a specific mean and standard deviation (STD).

The mean and STD used to get the random numbers can be expressed as a function of elevation angle. The relation of mean and STD with elevation angle has expressed as,

\[
\text{mean, STD} = \frac{a + \theta}{b + c\theta}
\]

where \(\theta\) is the elevation angle and \(a, b, c\) are empirical parameters defined in table 2.

The mean and STD is plotted in Fig. 9. The three distinct frequencies 2 GHz, 3 GHz and 5.5 GHz are used to get mean and STD with the help of empirical
parameters \(a\), \(b\) and \(c\). Then the mean and STD will be used in (8) to have random numbers as well as loss. The blue line used for 2 GHz, red line for 3.3 GHz and green line for 5.5 GHz to represent mean and standard deviation. The solid lines are for mean values and the lines with dot for variance have shown in the figure. The x-axis shows the elevation angle and the y-axis shows the mean and standard deviation of shadowing loss in dB. The elevation angles between 10 to 90 degrees are taken into consideration to specify our work for suburban regions. The recommended elevation angles for suburban areas are between 60 to 90 degrees should be maintained all across the coverage area [7, 14, 15]. The empirical parameters tabulated in the Table. 2 for the three different frequency bands are applicable for all type of environments.

Fig. 9. Parameters of Normal Distribution for frequencies 2 GHz, 3.5 GHz and 5.5 GHz

<table>
<thead>
<tr>
<th>Operating frequency 2 GHz</th>
<th>(10^0 \leq \theta &lt; 90^0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>(a)</td>
</tr>
<tr>
<td>Mean</td>
<td>-94.20</td>
</tr>
<tr>
<td>STD</td>
<td>-89.55</td>
</tr>
</tbody>
</table>

Operating frequency 3.5 GHz

| Parameters | \(a\)        | \(b\)        | \(c\)         |
| Mean       | -92.90      | -3.14       | 0.0302        |
| STD        | -89.05      | -8.63       | 0.0921        |

Operating frequency 5.5 GHz

| Parameters | \(a\)        | \(b\)        | \(c\)         |
| Mean       | -94.80      | -2.955      | 0.0285        |
| STD        | -89.54      | -8.474      | 0.0900        |

Table. 2. Parameters for (9) applicable to all environments
5. **Problem Solution**

In chapter 5, we discussed the HAP system modeling, HAP and user antenna radiation pattern and channel models. This chapter contains the way of solving the problems with brief description. Five subsections have been used to illustrate the solution of the problem. The subsections start with a brief introduction to the concept of different bore point of the antenna that can be implemented. Then the subsection followed by an introductory analysis of HAP and user antenna roll-off factors to be implemented. Implementation of the parameters, discussed in the previous subsections, has carried out in the next subsection named implementation. An ideal scenario has been developed to verify the overall study in the proceeding subsection based on real data. Finally the results are tied up with brief discussion on the outcomes from the previous subsections.

5.1 **Bore point analysis**

A bore point is a reference point of electromagnetic measurement on the amplitude pattern of an antenna. An antenna is said to be “bore pointed” when the electromagnetic axis and the mechanical axis are parallel. The angular difference between the electromagnetic and the mechanical axis is called the error of bore point [1]. A bore point plays an important role in the performance analysis of HAP based communication. Different bore points give different distribution of gain over the coverage area. The analysis of bore point may give a better solution based on demand for a specific scenario. Moreover, by varying the bore point of an antenna it is possible to fine-tune the CNR or CINR over a target service area [6].

The gain performance along the x-axis over the centre of the coverage area is shown in Fig. 10. The HAP is assumed to be on the same line of the x-axis. Three different spacing radii, 10 km, 20 km and 30 km, is used to illustrate the performance of gain over the coverage area in Fig. 10 (a), (b) and (c), respectively. The performance can be analyzed for varying HAP spacing radius and gain distribution as captured in Fig. 10 (a), (b) and (c). The bore points, at centre of cell, at half of subtended angle and at sub platform point (SPP), have been performed over each spacing distances of HAP. The figures show that different bore point can give different characteristic of gain distribution over the coverage at different spacing radii.
Fig. 10. Bore point analysis at spacing radius of 10 km (a), 20 km (b) and 30 km (c)
The characteristics have been discussed subsequently for all mentioned three spacing radii with each of the bore points. First, the observation on the bore point at centre of cell for three different spacing radii in Fig. 10 (a), (b) and (c) indicates that the gain falls more sharply on the left edge than the right edge. The gain at the EoC is higher on the right edge than the left edge for all spacing radii. The sharpness of falling of gain from the bore point to the EoC decreases at both edges with increase in spacing radius. Secondly, the observation on the bore point at half of subtended angle for the three different spacing radii indicates that the gain falls more sharply on the left edge than the right edge as like bore point at centre of cell. This bore point helps to maintain equal gain at both EoC for all considered spacing radii. The sharpness of falling of gain from the bore point to the EoC increases at left edge with increase in spacing radius. But the sharpness of falling of gain decreases at right edge with increase in spacing radius. Finally, the observation on the bore point at sub platform point for three different spacing radii indicates that gain falls less sharply on the left edge than the right edge. The gain at the EoC is higher on the left edge than the right edge for all spacing radii. The sharpness of falling of gain from the bore point to the EoC decreases at left edge but the sharpness of falling of gain increases at right edge with increase in spacing radius.

![Wind Velocity at High Altitude](image)

*Fig. 11. Wind Velocity at High Altitude*

The comparison between the three proposed bore points illustrate that the bore point at the centre of cell always provides least gain at the left edge of coverage for all the spacing radii. The bore point at the centre of cell always provides best gain at the right edge of coverage. But the bore point at the SPP provides opposite gain performance than bore point at centre of cell at both edges of coverage. The comparison between proposed bore points show that the bore point at the half of the subtended angle always provide moderate gain over the coverage area. The gain at the EoC diverges for the increase of spacing radius between the three analyzed bore points.
5.2 Antenna Roll off Analysis

The concept of roll-off has already been introduced in subsection 4.2. Here antenna roll-off can be best understood through (4) and (5). Analysis on antenna roll-off is mostly related to antenna radiation pattern as well as beam width of the pattern. The relation between the roll-off factor and antenna beam width has been clearly illustrated in Fig. 6. The analysis of the figure shows the beam width increases as the value of roll-off factor increases. The decrease in beam width means higher in directivity of the main lobe. The value of roll-off can be achieved by taking partial derivative of (4) with respect to $n$ which can be written like [16],

\[
\frac{dA_n}{dn} = \frac{3.84\sqrt{0.5}(\cos \theta)^n}{\sqrt{1-0.5^{2/n}n^2(\cos^{-1}(\sqrt{0.5}))^2}} + \frac{4(\cos \theta)^n \log 2 \log (\cos \theta)^{n_H}}{(\cos^{-1}(\sqrt{0.5}))^2}
\]

The value of $n$ can get by setting the partial derivative in (10) equal to zero then solving for $n$ gives.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage Radius</td>
<td>30 km</td>
</tr>
<tr>
<td>Transmitter Height</td>
<td>22 km</td>
</tr>
<tr>
<td>Transmitter Power</td>
<td>40 dBm</td>
</tr>
<tr>
<td>Antenna Efficiency</td>
<td>80 %</td>
</tr>
<tr>
<td>User Roll-Off Rate</td>
<td>48</td>
</tr>
<tr>
<td>User Bore sight Gain</td>
<td>18 dBi</td>
</tr>
<tr>
<td>Side lobe Level</td>
<td>-30 dB</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>7 MHz</td>
</tr>
<tr>
<td>Frequency</td>
<td>2 GHz</td>
</tr>
<tr>
<td>Noise Power</td>
<td>-100.5 dBm</td>
</tr>
</tbody>
</table>

Table. 3. Parameter specification of the system for simulation

Now the HAP antenna radiation pattern can be set to 3 dB or 10 dB by putting the value of $\theta$ at the EoC in (4) and using the value of $n$ [5, 16]. A 3 dB fit of antenna radiation pattern to the boundary has clearly shown in Fig. 5. Again by varying roll-off factor in (4) by iterative manner we can fix the 3 dB or 10 dB at the EoC. A higher value of roll-off factor requires setting 3 dB rather than 10 dB at the EoC which causes higher gain at the EoC. Setting of 10 dB at the EoC gives potentially less interference to the neighboring systems compared to 3 dB fit [6, 26].

A highly directive user antenna main lobe is required to have a quality of communication to a certain HAP station. A highly directive user antenna main lobe
can be achieved for higher values of roll-off factors. So, higher value of antenna roll-off can suppress interference originated from the nearby systems [4].

![CNR Contour of a HAP](image)

Fig. 12. CNR contour in a general case

### 5.3 Implementation

The parameters described in the last two subsections can be implemented to HAP systems. Specification of the parameters is tabulated in Table. 3. This subsection shows the implementation of the model and a general contour to give idea of representing the implementation.

The CNR is often used to measure the quality of reception [5, 18, 22]. The term CNR is defined as the received carrier strength relative to the strength of the received noise. The thermal noise has been used in this work to calculate the CNR. The term always measured in a decibel (dB) scale by the engineers and researchers. A high CNR provides better quality of reception. Generally, it means higher communications accuracy and reliability then the reception of low CNR values [23]. CNR is defined as,

\[
CNR = \frac{C}{N} = \frac{P_T A_T (\varepsilon) A_U (\phi) FSPL}{N}
\]

where \(N\) is the thermal noise power which can be calculated as,
\[ N = KTB \]  

where \( T \) is the temperature, \( B \) is the bandwidth and \( k \) is the Boltzmann constant of value \( 1.38 \times 10^{-23} \text{m}^2\text{kg} \text{s}^{-2} \text{K}^{-1} \).

Fig. 13. CINR contour for an ideal scenario

The CINR is the term which measures the quality to the received signal in the presence of noise as well as interfering signal [16, 23]. The interference may occur from nearby systems which operate on the same frequency or co-channel cell. CINR can be defined as,

\[
CINR = \frac{C}{N + I} = \frac{P_T A_T(\epsilon) A_U(\phi) FSPL_T}{N + \sum_{i=1}^{N} P_{Ti} A_{Ti}(\epsilon) A_{Ui}(\phi) FSPL_{Ti}}
\]

(13)

Here,

- \( P_T \) is the power of transmitted antenna
- \( A_T(\epsilon) \) is the gain of the transmitter antenna according to (4)
- \( A_U(\phi) \) is the gain of the user antenna according to (5)
- \( FSPL \) is the free space path loss according to (6) or (7)
- \( N \) is the thermal noise power according to (12)
- $P_{Ti}$ is the transmit power of $ith$ interfering transmitter
- $A_{Ti}$ is the gain of the $ith$ interfering transmitter
- $FSPL_{Ti}$ is the free space path loss for $ith$ interfering signal according to (6) or (7)

![CINR Contour for Suburban Region at the Centre](image)

Fig. 14. CINR contour for an ideal scenario with shadowing

A coverage region of 30 km has been used in the HAP system modeling for implementation. The 30 km coverage region has been chosen to maintain the sequence of research with related works. We considered a 30 km by 30 km area for simulation. A regular grid line has been taken into consideration over the considered area using 1 km separation distance basis for both horizontal and vertical axis. The 1 km separation distance has been selected because of negligible variation of signal level over that distance [26, 27]. Then the user is located on the grid to calculate the performance at that position in terms of CNR or CINR values. The user used to move one point to another point after each iteration and perform the same task to calculate. All the time only one user has to be taken into consideration. So, the mutual interference between the users has been completely ignored. The user antenna bore point always maintained to the direction of serving HAP.

Fig. 12 shows an outcome by implementing a single HAP at a certain spacing radii. The description of contour shows in terms of CNR values. A set of parameters has to take into consideration to build up a simulation platform. The parameters used in the simulation as listed in Table. 3. The platform height is selected at 22 km altitude as having lowest wind speed all over the year. Fig. 11 shows the wind speed curve as a function of altitude. In the figure, the wind speed condition is plotted in a
group of four seasons over Cape Kennedy, Florida, USA. The other parameters, transmitter power, antenna efficiency, user roll-off rate, user bore sight gain, side lobe level and bandwidth, have been chosen based on the level of standard used by researchers. Here the HAP is assumed to maintain a 60 degree elevation angle at the EoC on the left side from the centre. A spacing radius of 17.2 is required according to Fig. 3 to maintain a 60 deg elevation angle at the EoC. The negative values in both axes of distance away from centre represent the opposite side of coverage area from the centre. A subtended angle of 95 degree maintained according to Fig. 4. The bore point at the half of the subtended angle has been used to get the contour of Fig. 12.

<table>
<thead>
<tr>
<th>Territory</th>
<th>Suburban Density (Per square kilometer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia &amp; New Zealand</td>
<td>&lt; 1,150</td>
</tr>
<tr>
<td>Canada</td>
<td>&lt; 1,400</td>
</tr>
<tr>
<td>Japan</td>
<td>&lt; 2,800</td>
</tr>
<tr>
<td>United States</td>
<td>&lt; 1,050</td>
</tr>
<tr>
<td>Western Europe</td>
<td>&lt; 2,400</td>
</tr>
<tr>
<td>Outside United Kingdom</td>
<td>&lt; 2,050</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>&lt; 4,600</td>
</tr>
<tr>
<td>Overall</td>
<td>&lt; 1,850</td>
</tr>
</tbody>
</table>

Table. 4. Suburban density of some important territories [12]

5.4 An Ideal Scenario

HAPs have been proposed for several services over different type of regions, urban, dense urban, urban high-rise, suburban and rural etc. HAPs have capability of serving about 203 km radius of area being at an altitude of 21 km [1, 3]. So, HAPs could cover a big area of having different terrestrial characteristics as mentioned before. In this subsection we have considered an ideal scenario while covering territories of different characteristics. Whole scenario has designed based on real data [8, 11, 12].

The ideal scenario consists of two different types of territory to be served by a HAP system. The suburban and rural areas have been taken into consideration to serve 3G services from HAP base stations. The Kansas City, Missouri, USA has been selected as an ideal suburban city where a HAP system has been deployed to provide 3G services. The population density of the city is about 593.9 per square kilometer [11, 12]. The requirement of population density for being in a list of suburban territory has tabulated in Table. 4 [12]. The population density of Kansas City satisfies the condition of being a suburban area. Other territories can be used while satisfying the condition of being a suburban according to Table. 4.
The overall simulation area has been selected 30 km by 30 km as like the implementation subsection. Similar simulation procedure and system model has been considered simulating the proposed ideal scenario. The additional parameter specifications tabulated in Table. 5 with the parameter specifications of Table. 3. A suburban region has been taken into consideration at the centre of the simulation area. Terrestrial radius of the Kansas City is about 16 km [11, 12]. A 16 km of coverage radius has been selected for suburban to maintain approximation with practical scenario. A characteristic of rural area has been used for simulation outside the suburban coverage. The requirements of maintaining elevation angle over the suburban area of coverage are between 60 degrees to 90 degrees [7, 15]. In case of rural areas the requirement goes down to 60 degrees. So, as a requirement HAPs must have to maintain at least 60 degree over the suburban coverage area. It is impossible for a single HAP system to serve the suburban area maintaining the elevation condition. Thus, at least three HAPs are required to cover the whole suburban area to fully maintain the elevation condition. As per requirement a three HAP system must be in 120 degree a part from each other at the stratosphere. The stratospheric platform has selected at the altitude of 22 km as like before. The HAP deployment technique has followed by the concept of “Fixed Radius” constellation [5]. A FSPL channel model is considered for rural areas and a shadowing loss channel model included with the FSPL for suburban areas.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rural</th>
<th>Suburban</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage area</td>
<td>&gt; 16 km</td>
<td>&lt; 16 km</td>
</tr>
<tr>
<td>Channel Model</td>
<td>FSPL</td>
<td>FSPL, Shadowing loss</td>
</tr>
<tr>
<td>Elevation Angle</td>
<td>&lt; 60°</td>
<td>90°-60°</td>
</tr>
<tr>
<td>No of HAPs</td>
<td>&gt; 3 stations</td>
<td></td>
</tr>
<tr>
<td>Platform Height</td>
<td>22 km</td>
<td></td>
</tr>
<tr>
<td>Spacing Radius</td>
<td>~17 km</td>
<td></td>
</tr>
<tr>
<td>Constellation</td>
<td>Fixed Radius</td>
<td></td>
</tr>
<tr>
<td>Service</td>
<td>3G</td>
<td></td>
</tr>
</tbody>
</table>

Table. 5. Parameter specification for the ideal scenario

The overall simulation is carried out into two parts. The simulation result carried out in Fig. 13 while only the FSPL channel model is using for both suburban and rural areas. In Fig. 14 the result illustrated by using FSPL channel model for rural and in addition shadowing loss model for suburban. The black circle in both figures indicates the edge of suburban area. The small black circle is for representing the serving HAP and diamond symbols are representing the interfering HAPs. The bending of CINR contour in Fig. 13 is clearly indicating about interference from nearby HAPs. CINR performance is higher in the side of serving HAP and decreases away from the serving HAP. In Fig. 14 the CINR performance is similar to Fig. 14.
for the coverage of rural areas. However the performance over suburban area randomly varied over the suburban area due to shadowing loss effect. The performance of CINR over suburban area at the side of serving HAP is mostly at an acceptable condition. The performance of CINR is worst away from the serving HAP due to interference dominate the carrier signal originated from the nearby HAPs.

Fig. 15. Performance of different antenna bore point

5.5 Results and Discussion

So far a model has designed, different probable solutions have proposed and the implementation procedure has also illustrated. Implementation of the proposed solutions, antenna bore point, HAP antenna roll off factor and user antenna roll off factor, gave some outcomes which we are going to interpret in this subsection. The discussion has been followed by the outcomes of implementation where both strong and weak parts enlightened for further improvement.

The performance of different antenna bore points is shown in Fig. 15 for a single HAP scenario. The figure shows the CNR performance over the coverage area being at a spacing radius of about 17.2 km, as Fig. 12, along the x-axis over the centre of the coverage area. Analyzation on the left side from the HAP position clearly indicates antenna bore point at the SPP as the best performer, keeping antenna bore point at half of subtended angle as middle performer and antenna bore point at the centre of cell as poor performer. The bore point at the centre of cell gives best performance in case of right side of the coverage area from the HAP position.
The other bore point at half of the subtended angle performs moderate and the bore point at SPP gives worst performance among the three bore points.

Different HAP antenna roll-off factor performances along the x-axis over the centre of coverage is shown in Fig. 16 by maintaining spacing radius of about 17.2 km. The CNR performance increases with increase in HAP antenna roll-off factor on the right side of the coverage from the position of HAP. But the fluctuation between the use of different HAP antenna roll-off factor decreases at the EoC. A higher value of HAP antenna roll-off factor causes degradation of the CNR performance on the left side of from the position of HAP. Even the fluctuation of the performance degradation increases drastically at the EoC.

Performance of different user antenna roll-off factors is shown out in Fig. 17 using the concept in Fig. 13. So in that case CINR performances has considered along the x-axis and over the centre of the coverage area. A deep inspection of the CINR performance indicates that the CINR increases with increase of user antenna roll-off over the left part of suburban area. But an increase in user antenna roll-off performs negatively over the coverage area outside the left part of suburban area. The fluctuation of decreasing CINR is high at right side of EoC compared with the left side of EoC.
Fig. 17. Performance of different user antenna roll-off factors
6. CONCLUSIONS

In the thesis work a picture of providing 3G services over a suburban area has been illustrated. CINR performances of the designed system have cumulated to identify outperformer. Diverse usability of the outperformed parameters has been shown. Modeling of radio wave propagation, well known as channel model, over free space always been a vital part. Heterogeneous channel models performance also analyzed base on terrestrial characteristics. Thus we got a set of results through which characteristics of specified parameters sparking.

The results of the work clearly illustrate that different antenna bore point, HAP antenna roll-off and user antenna roll-off can serve 3G services over suburban regions. Now, selection of appropriate parameters will depend on overall HAP system modeling. The antenna bore point at the SPP could be used to provide a better quality of CNR on the left part of HAP. On the other hand the antenna bore point at the centre of the cell could be used on the right side of the HAP. An antenna bore point at the half of the subtended angle could be selected for a moderate requirement of performance. A higher value of antenna roll-off may be required on the right side of the HAP while a lower value of antenna roll-off may provide better quality of CNR on the left side of HAP. In case of user antenna roll-off, a higher value could give higher CINR at the side of SPP over part of suburban area otherwise a lower value of user antenna roll-off outperform over the coverage area. So in short, the proposed parameters could be used adaptively with left and right coverage area for better QoS.

There are diverse ways to extend the work in future. The thesis work has been confined within the suburban and somewhat rural cases. The work has multiple dimensions to extend. The work can be extended to improve 3G services for other regional characteristic such as urban, dense urban and urban high-rise etc. The multiple cell concepts can be easily incorporated to analyze the performance instead of the single cell concept. Coexistence performance of HAPs with terrestrial systems can be shown for different bore point cases. More channel models can be designed based propagation characteristics of radio waves considering heterogeneous territoru such as urban, urban high rise etc.
7. **References**


[19] “Propagation data and prediction methods required for the design of terrestrial broadband millimetric radio access systems operating in a frequency range of about 20-50 GHz,” RECOMMENDATION ITU-R P.1410-2, 2005, ITU.


**APPENDIX**

Fig. 18. HAP communication system

Fig. 19. A configuration of equipments for experiment
Fig. 20. Elevation and azimuth for antenna radiation pattern

Fig. 21. A onboard transponder with transmitter (left) and receiver (right)
Fig. 22. Two scenarios for building deployment for different no of ray interactions with same area covered

Fig. 23. Location of buildings with respect transmitter to receiver