Multipath Propagation Model for High Altitude Platform (HAP) Based on Circular Straight Cone Geometry

J. L. Cuevas-Ruíz
ITESM-CEM
México D.F., México
jose.cuevas@itesm.mx

A. Aragón-Zavala
ITESM-Qro
Querétaro Qro., México
aaragon@itesm.mx

G. A. Medina-Acosta
UPC-Campus Nord
Barcelona, Spain
agni_medina@tsc.upc.edu

J. A. Delgado-Penín
UPC-Campus Nord
Barcelona, Spain
delpen@tsc.upc.edu

***Abstract*—A geometric model that describes a multipath propagation for a fixed wireless communication system between a High Altitude Platform and a fixed terrestrial user is presented. The model describes the propagation of the reflected signals that are able to reach the receiver as a consequence of all the scatterers located inside the system coverage area. The establishment of a particular geometry characterizing the system coverage area allows the behavior of the multipath phenomenon effects to be modeled accurately.**

***Keywords*—channel modeling, multipath channels, radio propagation, communication systems**

I. INTRODUCTION

In a wireless communication system the signals are subject to various impairments that may cause the received signal to be severely attenuated. In a fixed communication system the signal is attenuated mainly due to free space loss and multipath. Multipath occurs when a radio signal is split by obstacles (i.e. buildings, cars, trees, etc) into two or more signals causing the reception of multiple copies of the same signal at the receiver, which originates fluctuations in the amplitude and phase of the resulting signal, causing constructive and destructive interference plus an additional delay [1-2].

A HAP refers to a technology intended to provide wireless broadband telecommunication services (i.e. internet, cellular services) with either airships or aircrafts, which are located in the stratosphere at 20-25 km of altitude having a fixed position with respect to the ground. [3-5]. The aim of this paper is to show that a three-dimensional (3-D) multipath propagation model allows a better perspective of the real spatial distribution of scatterers in the vicinity of the user as part of a HAP-user link, compared to two dimensional models. With a 3-D model, it is possible to characterise multipath effects that are generated inside the coverage area of a HAP system. The 3-D model is a more realistic scenario since all scatterers are supposed to be distributed inside a volume determined by their heights and size of the individual objects, which are statistically modelled. This volume is modelled by a straight circular cone, making sure it is more likely to find scatterers near the user and not necessarily close to the HAP. The paper is organized as follows: in section I an introduction to the channel model is given and their general characteristics are mentioned. Section II describes the channel model mathematically. In Section III the volume where the scatterers could be located is computed. The values for the power delay profile calculated by simulation using the proposed channel model are shown in Section IV. In section V several values for coherence bandwidth are calculated and simulated using a QPSK modulation scheme. Conclusions and future work are mentioned in Section VI.

II. GEOMETRIC MODEL DESCRIPTION

In [6] a methodology to characterize small-scale fading in a system based on HAPs is shown using an ellipsoid. However circular straight-cone geometry could be a better approximation to simulate the multipath propagation, since this geometry represents the coverage area of a HAP-based system more accurately, as shown in Fig.1. The energy from the scatterers is not considered significant close to the platform, as [6] suggests, but more concentrated close to the base of the cone.

A scheme describing the spatial distribution of a wireless communication system between a HAP and an user located on the ground is shown in Fig. 1 where: T_x is the base station (HAP) located at an altitude z_o above ground level; R_x is the receiver located at a distance x_o with respect to the origin, and r_o represents the direct propagation path.

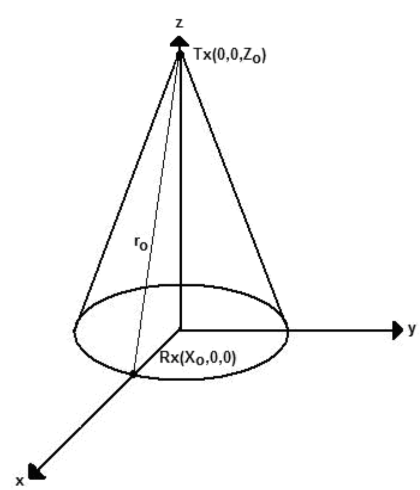


Figure 1. Spatial distribution of a fixed wireless communication system based on a HAP coverage area.

Based on this scheme it is possible to obtain the length of the direct propagation path as follows

$$r_o = \sqrt{(x_o)^2 + (z_o)^2} \ . \qquad (1)$$

The propagation time of the signal in line of sight (LOS) is established by

$$\tau_o = \frac{r_o}{c} \ . \qquad (2)$$

In (2) c is the speed of light, taken as $3x10^8$ m/s.

Therefore a reflected wave that reaches the receiver with a propagation excess delay τ should cover a path $K(\tau)$ defined by

$$K(\tau) = r_o + \tau c \ . \qquad (3)$$

Equation (3) indicates that this reflected wave should cover, at least, the length already established for a direct propagation path, plus an additional distance depending on the delay.

Assuming that the coverage area is given by a circular straight cone, the maximum propagation path $K(\tau_M)$ that a reflected wave will travel to reach the receiver is

$$K(\tau_M) = r_o + 2x_o \ . \qquad (4)$$

Thus, the maximum additional distance that a reflected wave will travel is the diameter of the base of the cone, as shown in Fig.2, and defined as

$$d = \tau c = 2x_o \ . \qquad (5)$$

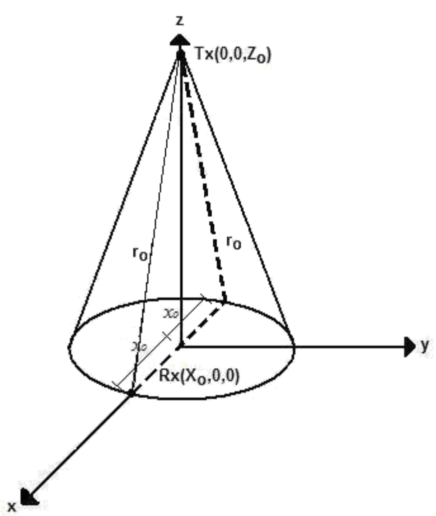


Figure 2. Maximum propagation path of a reflected wave $K(\tau_M)$ (dotted line) depending on the geometry of the coverage area (cone) of the HAP system.

III. SCATTERERS IN THE SYSTEM COVERAGE AREA

All scatterers located inside the cone will generate a total path length smaller than $K(\tau_M)$ and therefore experience smaller delays than τ_M. Hence, the reflected signal (echo) with a scatter S located at any point (x, y, z) inside the cone can be considered. On the other hand, due to the dispersed waves produced mainly by high buildings, trees, poles and other obstructions above a certain height h, the scatterers can be assumed uniformly distributed only within a thin solid area that spans from ground level to h, as shown in Fig. 3.

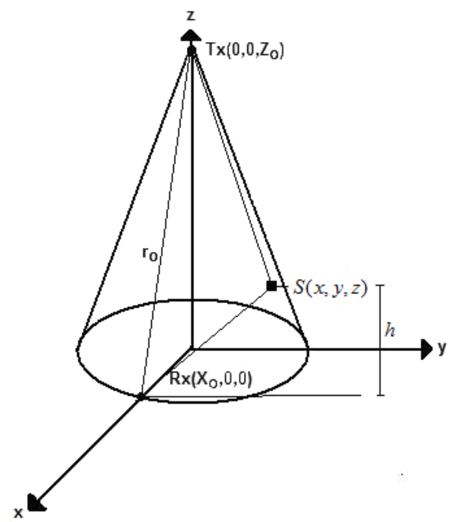


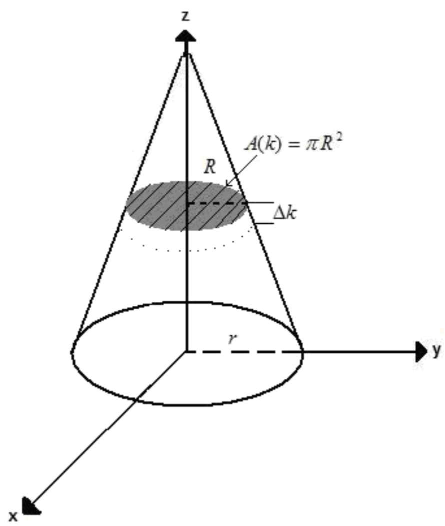
Figure 3. Spatial distribution of a fixed wireless communication system in presence of a scatter S delimited by a height h.

As a consequence, the volume $V(\tau)$ that contains the obstacles originating the dispersed waves with a delay smaller than τ_M is defined by all the points (x, y, z) that satisfy the following criteria (for $0 < z < h$)

$$\sqrt{(x - x_o)^2 + y^2 + z^2} + \sqrt{x^2 + y^2 + (z - z_o)^2} < K(\tau_M) \ . \qquad (6)$$

Once these points are established, which satisfy the uniform distribution of the scatterers located inside the cone, the total volume of the cone $V(G)$ is computed to obtain the volume of interest $V(\tau)$ delimited from 0 to h. A way to find this total volume consist of making a horizontal cut on the cone up to a height k, producing a transversal section from which it is possible to obtain the area $A(k) = \pi R^2$. When this area is multiplied by a height Δk, the volume $V(k) = A(k)\Delta k$ is obtained for that slice, as shown in Fig. 4a.

To sum a n number of slices when $n \to \infty$, an approximation of the volume of the cone is produced. The total volume for the coverage area of the HAP system can therefore be found by adding all the elements from 0 to z_o. A relationship between the radius of the transversal area R, the height k and the system coverage area is required, to define an equation that specifies the total volume $V(G)$. This volume can be obtained by using the theorem of similar triangles, as shown in Fig. 4b.



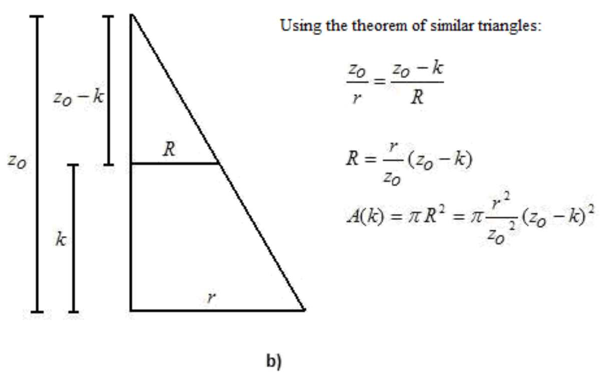


Figure 4. a) Area of the transversal section $A(k)$ and the height differential Δk. b) Relationship between the radius R and the height k and system coverage area using the theorem of similar triangles.

The diameter of the base of the cone was defined as $d = \tau c = 2x_0$, so the radius is given by $r = \tau c / 2 = x_0$. Finally, $V(G)$ can be written as

$$V(G) = \int_0^{z_0} \pi \frac{\left(\frac{\tau c}{2}\right)^2}{z_o^2} (z_o - k)^2 \, dk = \pi \left(\frac{\tau c}{2}\right)^2 \frac{z_0}{3} \qquad (7)$$

The volume $V(\tau)$ that contains all scatterers uniformly distributed is given by

$$V(\tau) = \int_0^{h} \pi \frac{\left(\frac{\tau c}{2}\right)^2}{z_o^2} (z_o - k)^2 \, dk = \pi \frac{\left(\frac{\tau c}{2}\right)^2}{z_o^2} \left(z_0^2 h - z_0 h^2 + \frac{h^3}{3} \right) \qquad (8)$$

IV. SIMULATION RESULTS

The cumulative distribution function CDF can be calculated using the ratio between the volume $V(\tau)$ and the volume that corresponds to the maximum excess delay of the system $V(\tau_M)$ as follows

$$F_{PS}(\tau) = \frac{V(\tau)}{V(\tau_M)}. \qquad (9)$$

At this point it is necessary to know the maximum excess delay τ_M of the system. Recommended values from other authors show excess delays τ_M of $150ns$ and $500ns$ [6-7]. Therefore, the analysis was considered to be performed using $150ns$, $200ns$, $300ns$ and $500ns$ for excess delay.

Once the value of the maximum excess delay of the system has been determined, the CDF is evaluated using (9). A value for the h parameter still needs to be assigned, which represents the height of the highest obstruction inside the system coverage area. This obstruction delimits the volume $V(\tau)$ described in (8), which for simulations effects has been taken as $h = 225$m corresponding to the highest building in Mexico City. This parameter can be adjusted according to different scenarios.

The losses for each delay (echo) $P(\tau)$ can then be computed assuming free-space propagation, with the distance depending on the excess delay as follows: $d = \tau_n c$, where τ_n is the excess delay of each existing echo component in each τ_M interval, and λ is the wavelength, as shown in (10). The system operating carrier frequency, for simulation purposes, was considered following the ITU-R recommendation related with IMT-2000 for HAPs.

$$P(\tau) = \left(\frac{\lambda}{4\pi\tau c}\right)^2. \qquad (10)$$

Fig. 5 shows an approximation of the power delay profile of the system, where times of arrival for different paths of the echoes versus their received power for each of the four τ_M described before are shown. While an echo presents a longer delay, it will also present higher power attenuation. In other words, an echo that takes more time to arrive at the receiver presents a higher path loss and/or more attenuation due to reflections from the scatterers.

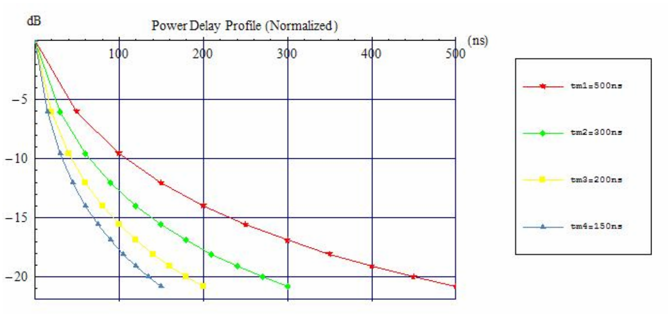


Figure 5. Normalized curve of the Power Delay Profile.

V. COHERENCE BANDWIDTH

The coherence bandwidth can now be computed having the curve for the power delay profile. The coherence bandwidth is a statistical measure of the range of frequencies over which the channel can be considered "flat"; i.e. a channel which passes all spectral components with approximately equal gain and linear phase. In other words, coherence bandwidth is the range of frequencies over which two frequency components have a strong potential for amplitude correlation. If the coherence bandwidth is defined as the bandwidth over which the frequency correlation function is above 0.9 [1], then the coherence bandwidth is approximately

$$Bc = \frac{1}{50\sigma_\tau}. \quad (11)$$

Where σ_τ is the so called *rms* delay spread.

Table I shows the results of the coherence bandwidth considering the response obtained from the power delay profile for each τ_M.

TABLE I. COHERENCE BANDWIDTH OF THE SYSTEM

τ_M	Coherence Bandwidth	(rms) Delay Spread
500ns	220.082KHz	90.8752ns
300ns	366.803KHz	54.5251ns
200ns	550.205KHz	36.3501ns
150ns	733.607KHz	27.2626ns

Considering the response of the power delay profile of four different values of τ_M

An additional simulation, using the power delay profile results from the previous section was performed to build a multipath fading channel using MATLAB. QPSK modulation was used to estimate the bit error rate (BER) after the modulated signal was affected by the proposed channel.

The channel conditions that were simulated are described as: a) LOS condition (Rice distribution, k =12), b) LOS condition (Rice distribution, k =5), and c) NLOS condition (Rayleigh distribution).

A Tape Delay Line Model was used to simulate each one of the scenarios described before and the parameters are given in Tables II, III and IV.

TABLE II. TAPE DELAY LINE MODEL FOR A LOS CONDITION

Tap No.	Tap delay	pdf	Pot (dB)	K
1	0ns	RICIAN	0	12
2	100ns	RAYLEIGH	9.5	-
3	200ns	RAYLEIGH	14	-
4	300ns	RAYLEIGH	17	-
5	400ns	RAYLEIGH	19	-
6	500ns	RAYLEIGH	21	-

TABLE III. TAPE DELAY LINE MODEL PARAMETERS FOR A LOS CONDITION

Tap No.	Tap delay	pdf	Pot (dB)	K
1	0ns	RICIAN	0	5
2	100ns	RAYLEIGH	9.5	-
3	200ns	RAYLEIGH	14	-
4	300ns	RAYLEIGH	17	-
5	400ns	RAYLEIGH	19	-
6	500ns	RAYLEIGH	21	-

TABLE IV. TAPE DELAY LINE MODEL PARAMETERS FOR A NLOS CONDITION

Tap No.	Tap delay	pdf	Pot (dB)	K
1	0ns	RAYLEIGH	0	-
2	100ns	RAYLEIGH	9.5	-
3	200ns	RAYLEIGH	14	-
4	300ns	RAYLEIGH	17	-
5	400ns	RAYLEIGH	19	-
6	500ns	RAYLEIGH	21	-

The bit error rate (BER) for the LOS and NLOS channel conditions before described are given in Fig. 6.

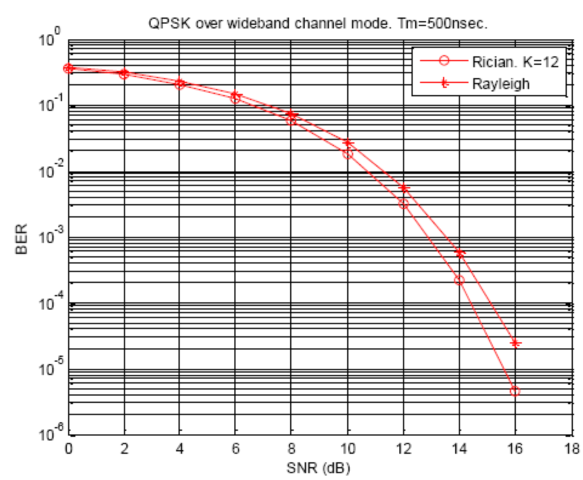


Figure 6. Channel characterization using the Power Delay Profile (500ns) considering different data rates.

VI. CONCLUSIONS

In this paper a 3-D multipath model based on circular straight cone geometry is proposed. This model can be used to describe the coverage area of a wireless communication system for a link between a HAP station and terrestrial users. By performing a geometrical analysis, it is shown that is possible to model the presence of multipath. Therefore, from the proposed model, results to characterize the presence of the reflected components inside the coverage area are obtained. First, the CDF shows the delays generated by the scatterers and the probability that they are present in the system. Later, the power delay profile shows the power of each of the present echoes in the system, where a higher echo delay component produces a higher level of attenuation. On the other hand, for coherence bandwidth results, it can be said that for a higher excess delay in the system, the coherence bandwidth decreases: i.e. only a small available spectrum can be considered as linear. Finally the previous results were characterized to build a multipath fading channel, which was tested using a QPSK modulation scheme to obtain the BER for the system under different conditions.

REFERENCES

[1] B. Sklar, "Rayleigh Fading Channels in Mobile Digital Communications Systems Part I: Characterization", IEEE Journal on Selected area in Communications, Vol. 35, No.11, July 1997.

[2] B. Sklar, "Rayleigh Fading Channels in Mobile Digital Communications Systems Part II: Mitigation", IEEE Journal on Selected area in Communications, Vol. 35, No.11, July 1997.

[3] Recommendation. ITU-R P.681-6.

[4] J. L. Cuevas, J. A. Penin, "HAPS Links Performance Analysis Using Time Flow Simulation", EUROCON 2005 Belgrade, Serbia and Montenegro, Nov 2005.

[5] S. Liu, Z. Niu, and Y. Wu, "A Blockage Based Channel Model for High Altitude Platform Communications", IEEE Journal on Selected area in Communications, Vol. 2, April 2003.

[6] F. Dovis, R. Fantini, M. Mondin, and P. Savi, "Small-Scale Fading for High-Altitude Platform (HAP) Propagation Channels", IEEE Journal on Selected area in Communications, Vol. 20, April 2002.

[7] M. Döttling, A. Jahn, J. Kunisch, and S. Buonomo, "A Versatile Porpagation Channel Simulator for Land Mobile Satellite Applications", IEEE Journal on Selected area in Communications, Vol. 1, May 1998.