1 Visibility between satellites

In the following pages we are going to discuss the methodology to obtain the maximum angle between two satellites on the same plane. By doing this, the upper limit of the distance between the satellites will be established. This is necessary to compute some of the constellation parameters. However, this distance is expected to be larger than the maximum distance allowed in order to achieve global coverage

To compute the angle we have to make some assumptions:

- The satellites have antennas pointing to each other.
- The atmosphere attenuation is neglected over $113km$. Below that altitude the signal is fully attenuated.
- The antenna have enough power to reach that distance.

These hypothesis converts the problem into simple geometric calculation because we are neglecting all the physics related to it. Remember that the aim of this code is to obtain a first approach. Nevertheless, the second assumption has an explanation, for frequencies below $3GHz$ the attenuation caused by clouds, oxigen, and other atmospheric gases can be neglected in the upper layers of the ionosphere (over $113km$)[1]. In fact, there are other origins for the attenuation (as specified in the next section), but for this approximation they will be neglected.

The figure [?] shows the geometric approximation we are talking about. It can be easily seen that the distance to the tangent point is the same for both satellites. Thus, the semi-angle can be calculated with one of the triangles and then multiple it. Applying simple trigonometric relations:

$$cos\frac{\varphi}{2} = \frac{R+h}{R+h_{atm}} \tag{1.1}$$

$$\therefore \varphi = 2acos\frac{R+h}{R+h_{atm}} \tag{1.2}$$

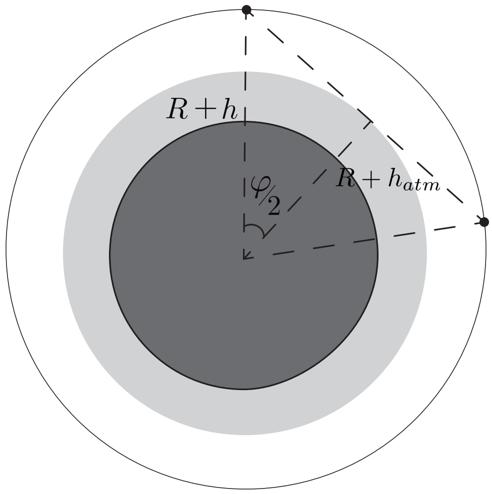

Figure 1.1: Situation we are dealing with. In grey, the atmosphere

Hence, the distance is obtained by the *cosine rule*:

$$d = (R+h)\sqrt{2(1-cos\varphi)} \tag{1.3}$$

The results of applying this simple equations are shown in the following figure:

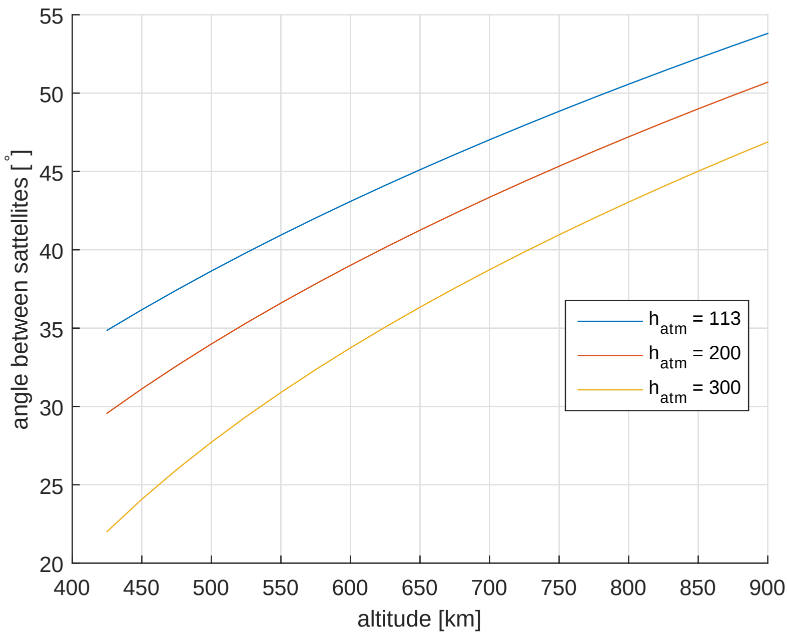

Figure 1.2: Some values of the angle between satellites for different altitudes

2 Satellite to Satellite Communications

2.1 Satellite signal propagation

Introduction

Satellite communication and propagated satellite-to-satellite signals are affected by the environmental conditions in which these operate. Some of these atmospheric effects will be important depending on the altitude of the satellites.

Ionospheric Effects

The ionosphere region is located between 60 and 1000 km of height. This atmospheric layer is especially affected by the extreme ultra-violet and X-ray radiations coming from the Sun, thus removing outer electrons from the atoms and creating an ionised-gas based region that will reflect incident radio signals. These conditions cause a variety of effects on propagating electromagnetic signals which must be taken into account.

Refraction (bending) and dispersion are important issues to be considered. The first will cause the radars of the satellites to see the other satellite displaced from where it really is. The higher the frequency of the radio, the less the bending. Dispersion, on the other hand, will cause signal delay in wideband communication systems.

Scintillation

The ionospheric layer contains irregularities regards the density of the gas, and scintillation must be faced. Scintillations manifest themselves as a combination of variations of amplitude, phase, and polarisation angle. Signal angles of arrival can also be changed.These are more intense in equatorial regions, falling with increasing latitude away from the equator but then rising at high latitudes where auroras take place. The effects are also found to decrease with increasing frequency, and generally not noticeable above frequencies of 1 - 2 GHz.

Faraday Rotation

The combination of plasma in the ionosphere and the Earth's magnetic field can induce a rotation of the polarised radio signal which is travelling through this atmospheric layer. A rotation of 90 degrees may cause a total loss of signal. At high frequencies, i.e 4 GHz, the rotation will rarely exceed a few degrees.

3 References

[1] Muhammad Zubair, Zaffar Haider, Shahid a Khan, and Jamal Nasir. Atmospheric influences on satellite communications. *PRZEGLĄD ELEKTROTECHNICZNY (Electrical Review)*, 87(5):261–264, 2011.