The Mechanics of Low Orbiting Satellites Implications in Communication

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THE MECHANICS OF
LOW ORBITING SATELLITES

Implications in Communication

May 20, 1985

by

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for
Senior Project

Submitted to
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Foreword

Low orbiting satellites provide a new challenge for communications technology. Because low orbiting satellites circle the earth instead of staying in one spot in space, communication networks must adopt a different operational procedure. This purpose of this report is to describe the geosynchronous and low orbiting schemes, the orbital phenomena, and the modes of operation demanded by the low orbiting satellites.

Summary

Low orbiting satellite communication networks will be competing with geosynchronous satellites for a share of the communications market. In world-wide communications that do not require immediate real time transmissions, low orbiting satellites are competitive with geosynchronous satellites because the system is reliable and low in cost.

Since satellites are a clear example of Newtonian laws, the distinct patterns they make in their orbiting process are predictable. Newton's law states that an object will remain in uniform motion unless acted upon by a force: a satellite remains in motion around the earth because there is no atmosphere to slow it down. A satellite stays in orbit because the pull of gravity inward is balanced by centrifugal energy outward. The rate which a satellite orbits the earth and the lifetime of the satellite depend on its altitude. Low orbiting satellites trace unique paths over the surface of the earth -- the satellite is accessible for communication if the path of the satellite comes within 1500 kilometers of a ground station.

Unless there are 50 to 80 low orbiting satellites, the system is not useful for exclusive real time communication and thus requires a different operating structure. The low orbiting satellite will use a combination of two modes for communication: the transponder mode, and the store and forward mode.

1. Introduction

Low orbiting satellites provide a new challenge for communications technology. With the availability of the space shuttle, the cost of launching small low orbiting communications satellites is substantially lower than launching geosynchronous satellites. Because low orbiting satellites circle the earth and are not stationary in the sky, communication networks must adopt a different operational procedure. An understanding of orbital mechanics and the modes in which low orbiting satellites operate is critical in the development of a new system of communication. This report describes the geosynchronous and low orbiting schemes, the orbital phenomena, and the modes of communication demanded by low orbiting satellites.

2. Description of Geosynchronous and Low Orbiting Schemes

The low orbiting satellite will compete with the geosynchronous satellite for a share of the communications market. The geosynchronous orbit is the only orbit capable of providing continuous contact with ground stations via a single satellite. For this reason, the geosynchronous satellite network provides an effective link for the kinds of transmission that require immediate "telephone-type" communication. A huge market exists, however, for the types of data communication, such as electronic mail and data collection services, that do not require this immediate real time mode. In this market, there are two factors which make a low orbiting satellite communication network more appealing than a geosynchronous satellite network: its reliability, and its low cost.

2.1 Low Orbiting Networks are Reliable. The structure of the low orbiting network lends itself to a relatively fail-safe world-wide communications system. Appendix 1 shows the world extent of coverage. If one satellite in a network consisting of 10 to 100 satellites breaks down, the network operation will continue virtually unimpaired. In a geosynchronous communications network, only three satellites are used for world coverage; if one satellite breaks down -- the whole network breaks down.

2.2 Low orbiting Networks are Low in Cost. The exorbitant cost of developing and launching a world wide geosynchronous satellite communications network is a strong factor behind developing the low orbiting satellite communications network. Our estimations show one small low orbiting satellite can be manufactured and launched at a cost of about $250,000, whereas one geosynchronous satellite starts at a cost of $85 million. A world wide low orbiting network will effectively operate with 10 satellites -- at a starting cost of $2.5 million. A world wide geosynchronous network requires 3 satellites -- at a starting cost of $255 million.

3. Description of the Orbital Process

Since satellites are a clear example of Newtonian laws, the distinct patterns they make in their orbiting process are predictable. Newton's law states that an object will remain in uniform motion unless acted upon by a force: a satellite remains in motion around the earth because there is no atmosphere to slow it down. Newton's laws of motion and gravitation are the basis for describing the movements of satellites.

3.1 Satellites Must Overcome the Force of Gravity. A satellite stays in orbit around the earth when the centrifugal force outward is equal and opposite to the gravitational force inward. The force of gravity diminishes with increasing altitude according to the inverse-square law first enunciated by Newton. If a satellite is launched vertically, it will rise to some height depending on its initial speed then fall back to earth under the force of gravity. If the satellite is projected not vertically up the gravitational field, but horizontally -- at right angle to it, the satellite can remain orbiting as the moon does around the earth. The critical speed of about 5 miles a second necessary to establish an orbit, is independent of the size or mass of the satellite. The speed (or energy) is not lost in space since there is no (or little) atmosphere to slow it down.

3.2 Orbits Are Not All Circular. Although it is simplest to talk about circular orbits, real ones are usually elliptical to some degree. In the case of very high ellipticity (or eccentricity), a satellite may come within a few hundred kilometers of the earth and then rise thousands of kilometers out into space at its far point. Elliptical orbits are sometimes referred to as "egg-shaped," but this is not quite true since eggs are usually more pointed at one end than the other. An ellipse is perfectly symmetrical about both axes.

3.3 Orbiting Rates Depend on Altitude. The rate at which a satellite circles the earth varies according to the height at which it orbits. At greater distances from the earth, less speed is necessary to counter the weakening gravitational pull, so the period of revolution steadily increases: at 300 km up, the period is one and one half hours; at 35,900 km up, the period is 24 hours. The geosynchronous satellite is in an orbit whose period of revolution is exactly that of the earth. Satellites in this orbit around the equator appear to be stationary in the sky because they circle the earth at the same rate that the earth rotates.

3.4 Orbiting Lifetimes Depend on Altitude. The lifetime of a satellite is determined by how much atmosphere the orbiting satellite encounters. The density of atmosphere may change by a factor of 10 when the distance from the center of the earth changes by 1%. (Figure 1 demonstrates that the lifetime increases with altitude.)

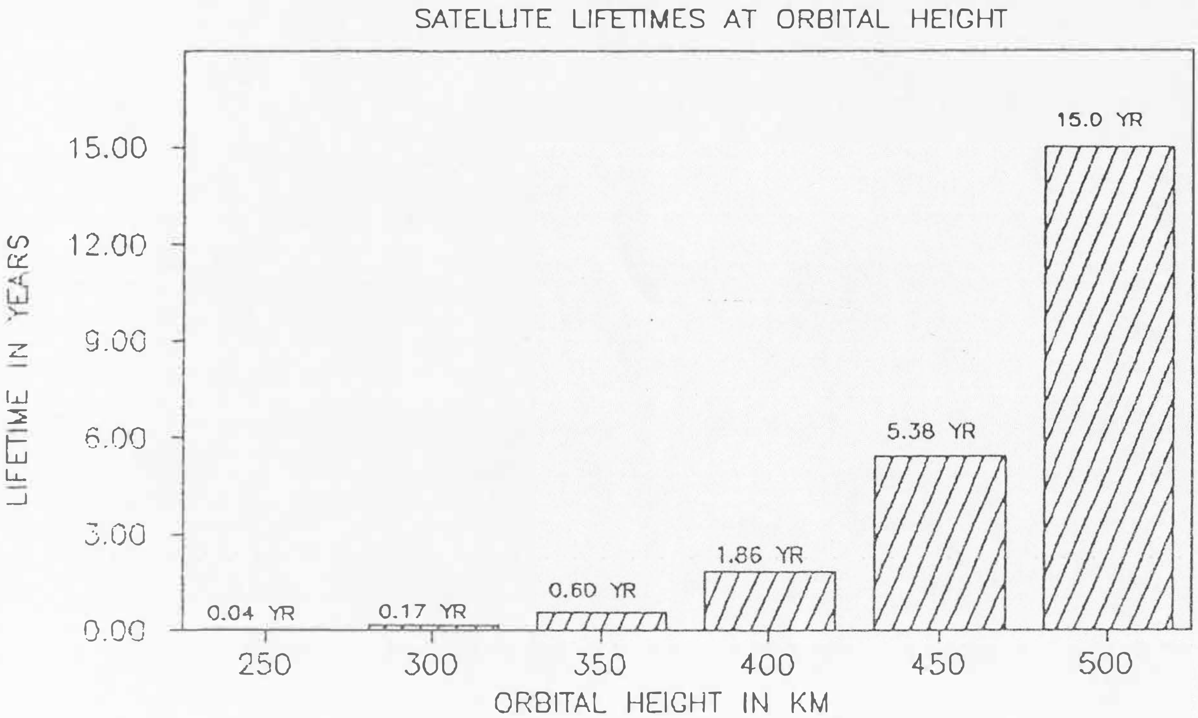

Fig 1. Satellite Lifetimes at Orbital Height

The parameters which affect the lifetime of the satellite are the cross section presented to the atmosphere and the mass of the satellite. The greater the area, the greater the drag and hence the shorter the life of the satellite. Greater mass in the satellite however, increases the momentum which makes it more difficult to slow down and therefore increases the life of the satellite. It is possible to put cold gas thrusters on the small low orbiting satellites and boost them to an orbital height which insures an extended life.

3.5 <u>Orbiting Paths determine Accessibility.</u> The ground track of a satellite -- the path it traces over the surface of the earth -- determines the regions on the earth from which it can be observed. The satellite is accessible for communication if the path of the satellite comes within 1500 kilometers of a ground station. The simplest path traced is by the equatorial satellite: it remains above the equator and retraces the same path at regular intervals determined by its period. In space, the path of a satellite always stays in a single plane; and the earth rotates inside it. Once the plane of the orbit is moved off the equatorial plane, the ground tracks take on an extraordinary appearance. Figure 2 shows the spiral pattern traced on the earth by a low orbiting satellite in a plane inclined 57 degrees to the equatorial plane.

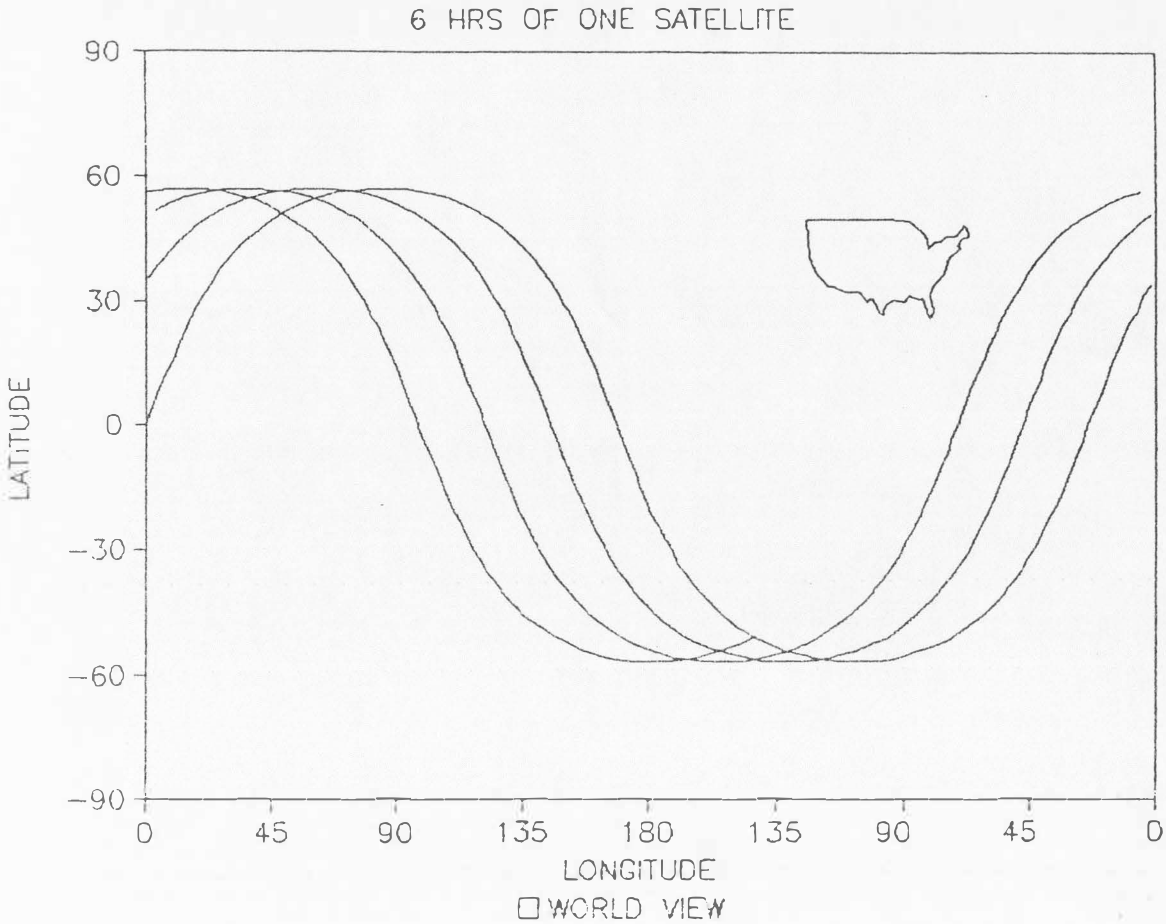

Fig 2. The Spiral Pattern of a Low Orbiting Satellite at 57 degrees and 500 km

4. Description of Operational Modes

Unless there are 50 to 80 low orbiting satellites, the system is not useful for real time communication and thus requires a different operating structure. The low orbiting satellite will use a combination of two operating modes: transponder mode, and store and forward mode.

4.1 Transponder mode. In the transponder mode, the satellite transmits messages like a mirror -- it is given a message from one ground station, and immediately retransmits the message to the receiving station. The transponder mode requires both transmitting and receiving stations to be in range of the satellite at the same time. The range of low orbiting satellites is about 1500 km, this is demonstrated in figure 3 where one satellite has passed within the approximate range of a Salt Lake City ground station 5 times in a 24 hour period.

The transponder mode offers real time communication like that demanded by telephone communications. Discontinuity creates a problem when using low orbiting satellites for real time communication. Appendix 2 shows that even with 50 low orbiting satellites there is still a possibility of communication discontinuity. Appendix 3 demonstrates that the number of low orbiting satellites required for an continuous real time communications network is between 50 and 80.

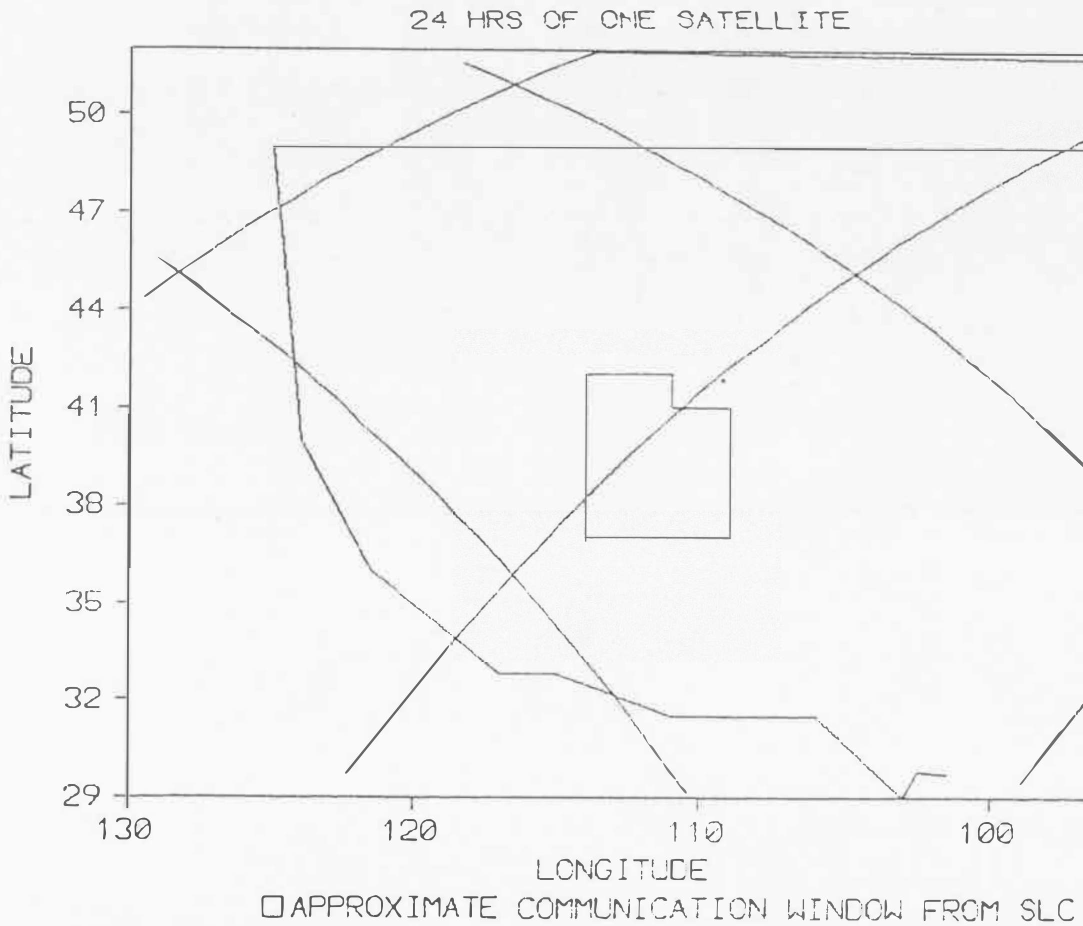

Fig 3. Satellite at 57 degrees and 500 km passing over SLC demonstrates approximate range

4.2 <u>Store and Forward Mode.</u> The store and forward mode transfers messages like a mail carrier -- the message is picked up from the transmitting station, carried a distance, then transferred down to a receiving station. The simplest example of this operation mode is demonstrated in figure 4.

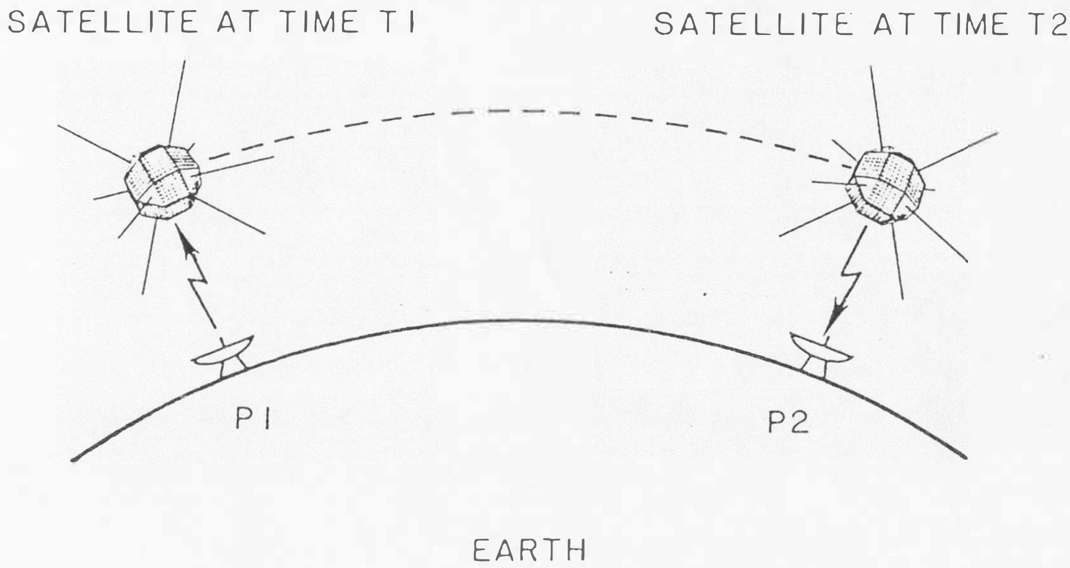

Fig 4. Simple Store and Forward Operation

Since a low orbiting satellite may take 8 to 10 hours to pass over a final receiving station, the store and forward mode will be modified by using intermediate ground stations and satellite to satellite message transferring to speed up the transfer time. Appendix 4 illustrates these modified store and forward modes of operation. Using a low orbiting network of 10 satellites under the modified conditions, the time required to transfer a message anywhere in the world will be under two hours.

The low orbiting satellite will use a combination of transponder mode and store and forward mode. Where a higher density of receivers is available, much of the data will be transmitted in the transponder mode. Where the receivers are dispersed internationally, the data will be transmitted in store and forward mode.

5. Summary

Low orbiting satellite communication networks will be competing with geosynchronous satellites for a share of the communications market. In world-wide communications that do not require immediate real time transmissions, low orbiting satellites are competitive with geosynchronous satellites because the system is reliable and low in cost.

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The rate which a satellite orbits the earth and the lifetime of the satellite depend on its altitude. Geosynchronous satellites orbit the earth at 35,900 kilometers: this altitude gives the satellite a period of 24 hours which, if it is orbiting around the equator, allows the satellite to appear stationary in the sky. Low orbiting satellites trace unique paths over the surface of the earth -- the satellite is accessible for communication if the path of the satellite comes within 1500 kilometers of a ground station.

Unless there are 50 to 80 low orbiting satellites, the system is not useful for exclusive real time communication and thus requires a different operating structure. The low orbiting satellite will use a combination of two modes for communication: the transponder mode, and the store and forward mode.

Appendix 1

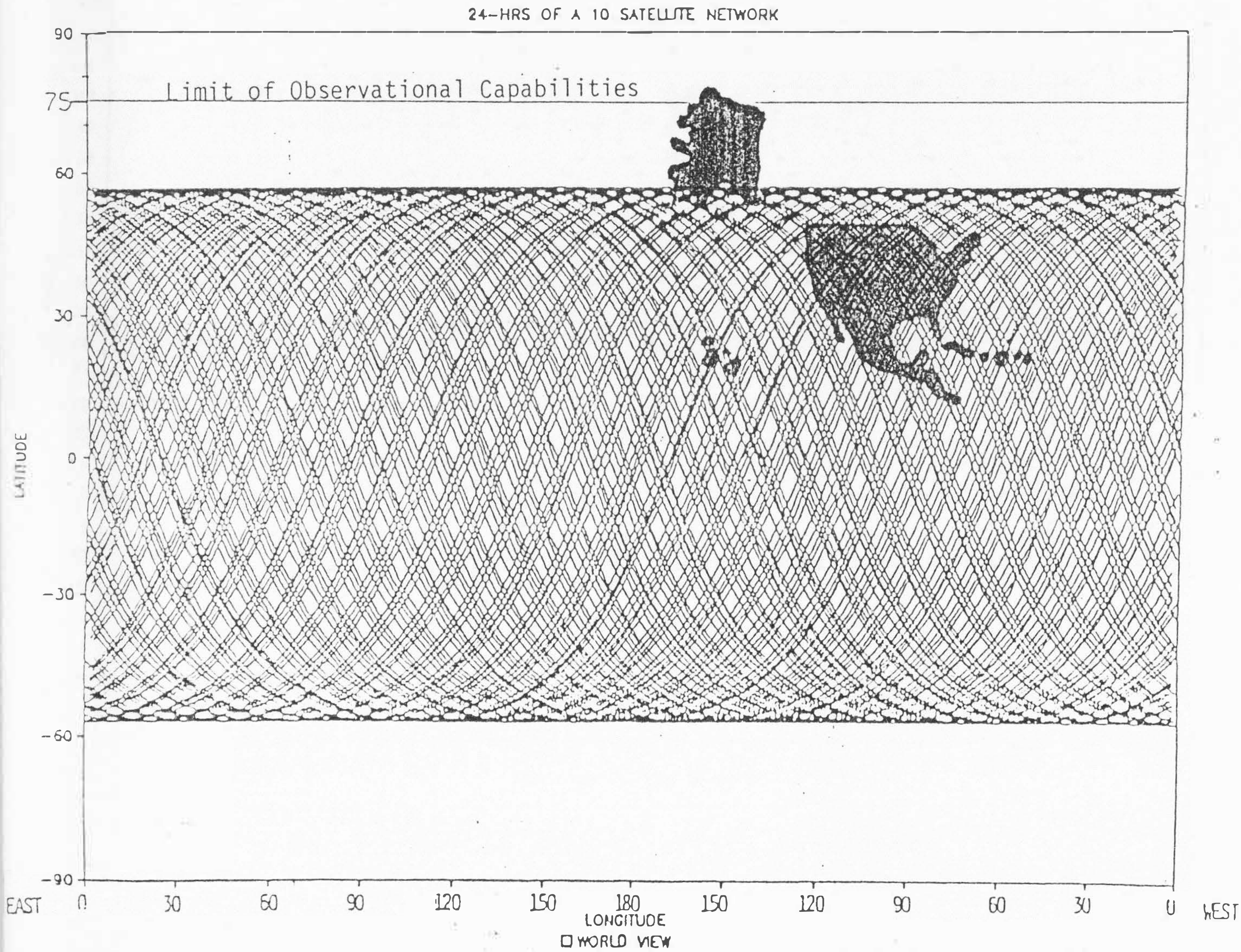

Fig 1. Low Orbiting satellite density

This figure represents ten satellites orbiting the earth over a 24 hour period. (Note the density of traces which cover the entire circumference of the globe.)

Appendix 2

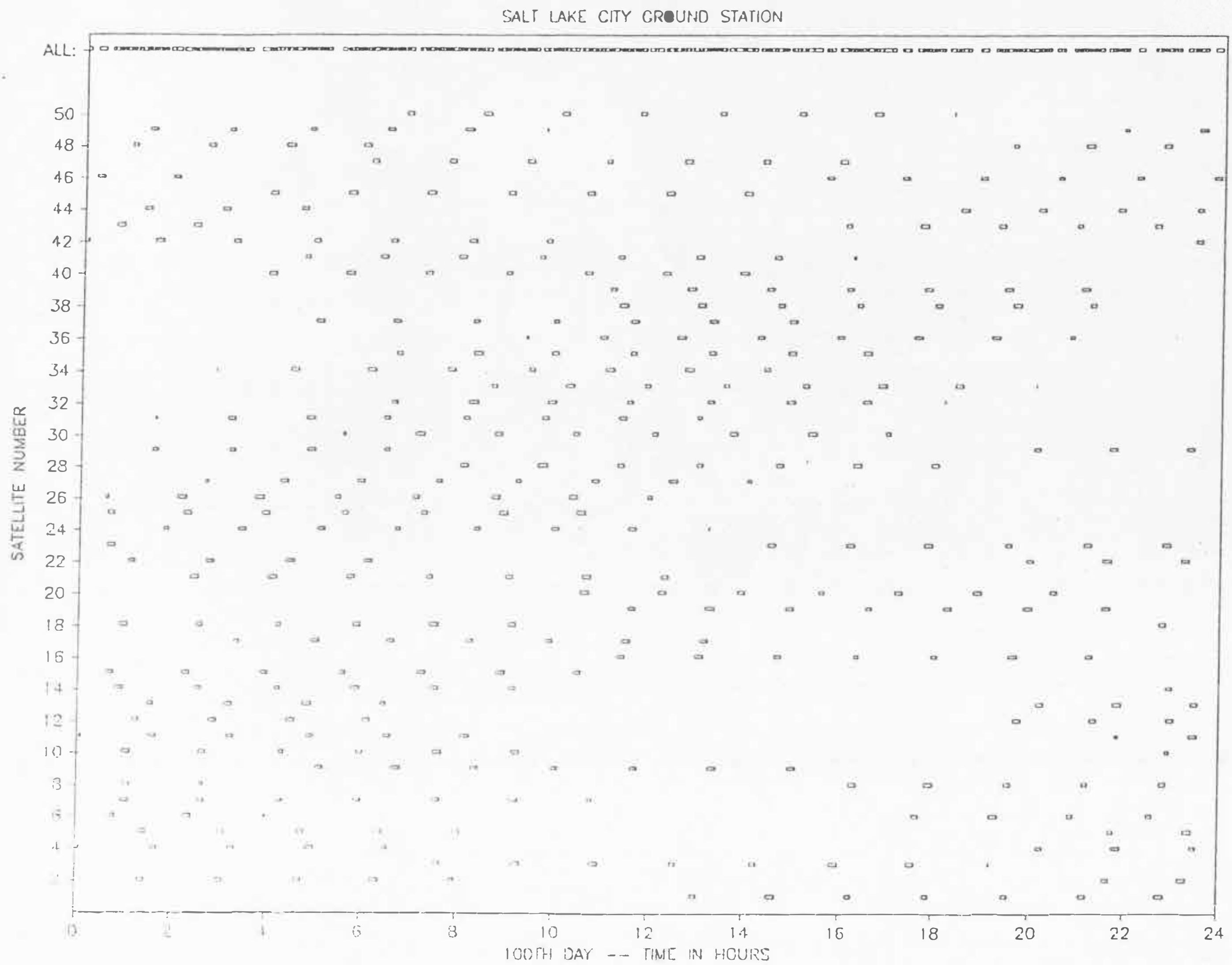

Fig 1. Low Orbiting Satellite Continuity

This figure represents a network of 50 satellites over a 24 hour period. The satellites are numbered on the vertical column and time is represented horizontally. Each time one of the satellites comes within range of a ground station in SLC a small rectangle is presented. The length of the rectangle represents the amount of time the satellite is in view. The top row, marked "ALL", is a composite of all the rectangles. Note: spaces still exist for this 50 satellite network.

Appendix 3

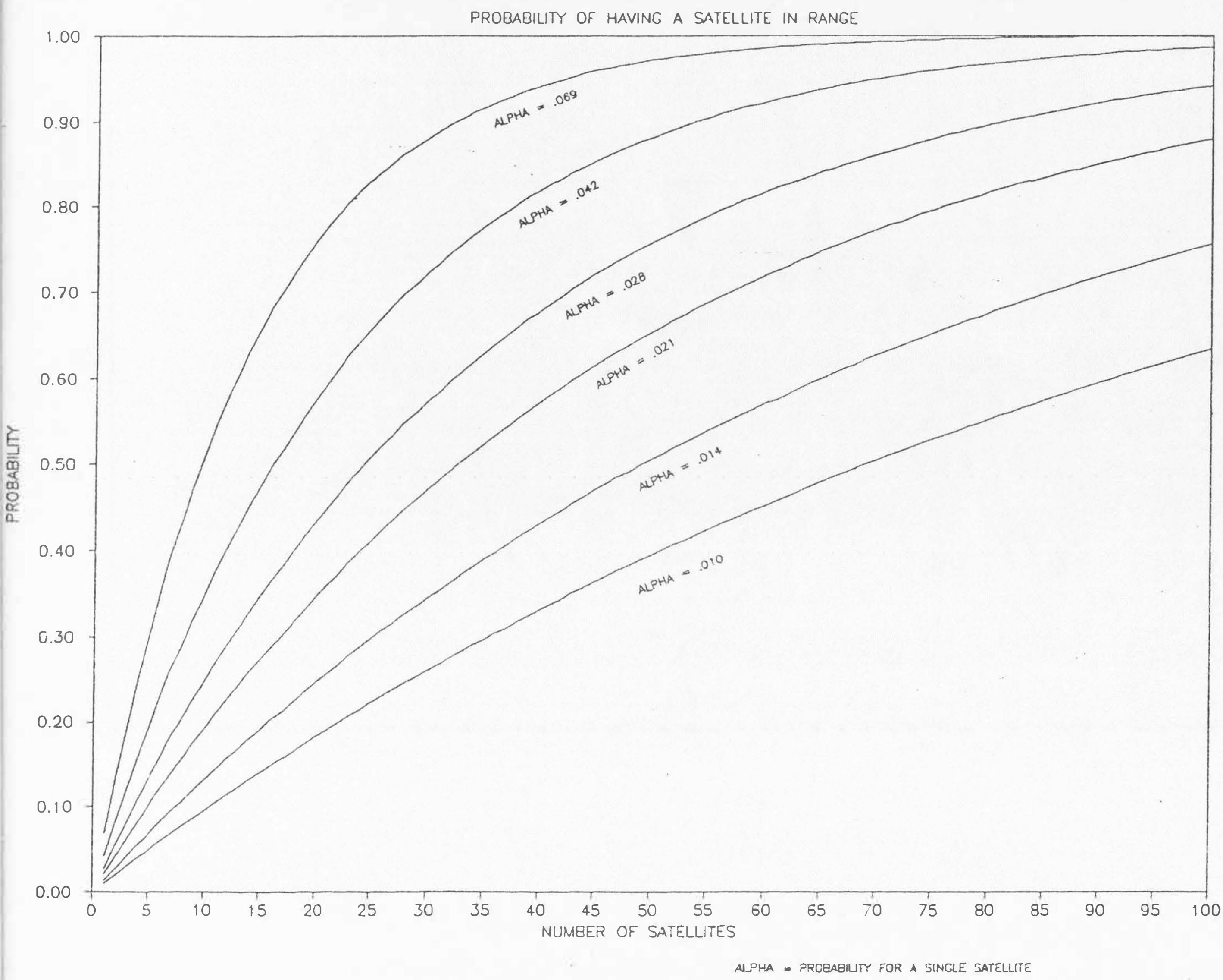

Fig 1. Low Orbiting Satellite Probability

This figure illustrates the probability of having a satellite in range as a function of the number of satellites in a network. Alpha is the probability that a single satellite will be in range. There is some discrepency on what value should be selected for alpha. Alpha depends on several factors: the communication range of the satellite, the required time for data transmission, and in the case of transponder mode -- the location of the receiving party. For transponder mode, alpha may be between .04 and .08; for very long transmission requirements (10 minutes) alpha may be between .01 and .02.

Appendix 4

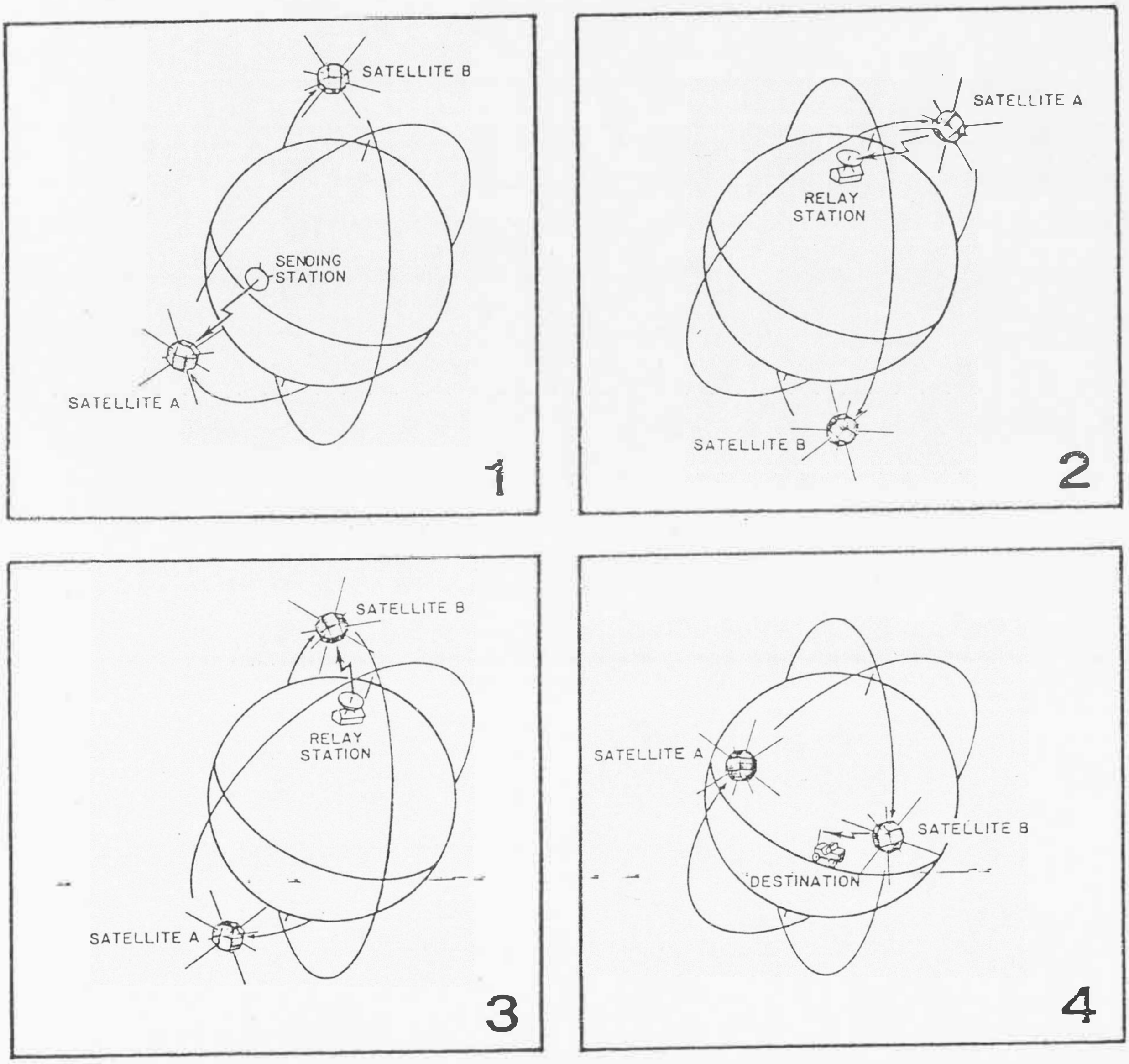

Fig 1. Modified Store and Forward #1

Satellite "A" receives data and downlinks it to an intermediate relay station; satellite "B" passes over the relay station, receives the data, and passes it to its destination.

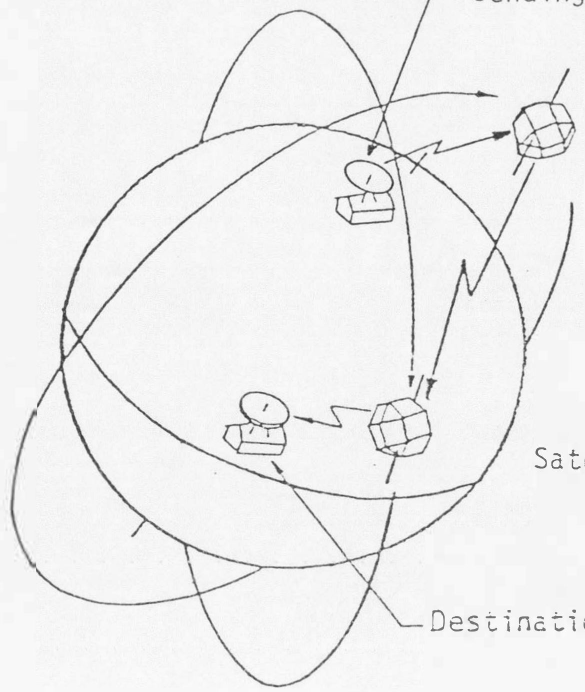

Fig 2. Modified Store and Forward #2

Satellite "A" receives data and sends it to Satellite "B" which then sends the data to its destination.