ELIMINATION OF INTERFERENCE AND MULTIPATH SIGNALS IN SATELLITE PERSONAL COMMUNICATION SYSTEMS USING ADAPTIVE ANTENNA ARRAYS

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CERTIFICATION

This work has not been presented elsewhere for the award of a degree, or any other purpose.

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DEDICATION

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ABSTRACT

Two of the problems of Satellite Personal Communications Systems are interference and multipath signals. These problems result in pronounced link degradation and affect overall capacity. To get rid of these problems, an adaptive antenna array on handheld/mobile systems is adopted. Adaptive antenna arrays have the ability to adapt to the changing environment and null out the interference and multipath signals. This technique performs better than omni-directional antennas currently used by manufacturers of these handhelds. The Kalman adaptive filtering technique has been studied and used in the simulation of the adaptive antenna arrays. The sidelobes that accommodated the interference and multipath signals were eliminated by appropriate the filtering technique to enhance better performance of the systems. Superposition approach on multipath signal was used by combining Signal of Interest with multipath signal. The resulting adaptive antenna array responses achieved, provided better services compared to omni-directional antennas currently used by the manufacturers of these mobile/handhelds units of Satellite Personal Communication Systems.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Satellite communication networks are now an indispensable part of most major telecommunication systems. For some decades, several proposals have come forth for personal communication services implemented by means of multiple satellite systems. It has come of age where more than one has been launched. The advantages offered have enabled this technology to mature within some decades [Richharia, 1999]. The challenges surrounding these systems are many. However, the rewards are equally great. These challenges imposed include the choice of suitable modulation techniques to support reasonable capacity, resistance to channel impairments, isolation of users from each other, to networking ideas such as access techniques, analysis of delivery time, and allocation of channel. The overall expectation is to derive a communication system that will provide data and voice links to virtually anywhere at anytime.

Satellite personal communication system (satPCS) has been touted to provide communication services to vast region of the Earth, particularly African continent that lacks adequate infrastructure for commercial telephony services compared to other parts of the globe. These infrastructures include electricity, cost of manpower capacity and other socio-economic problems. In Nigeria, these have been problems militating against the service providers and hence downgrading the efficiency of the quality of the services provided. Whether this is indeed the backdrop for such systems will depend on many factors, not the least important of which is cost. Also of extreme importance is the ability to integrate satPCS with the land-mobile and fixed networks. It is a safe bet that mobile user satellite systems, judging from geometric growth of

PCSs, will enjoy an equally rapid growth into markets yet to come. Satellite personal communication services are comparable to moving cellular technology into space [Tuck, 1994].

The present terrestrial cellular system has numerous technical problems associated with it. Moving cellular into space poses additional complications for the designers of systems. Some of these complications include cost, capacity, soft-handoff, power control, multipath fading and shadowing effects. Most existing cellular systems use simple arrays or antennas transmitting in a fixed or all directions (omni-directional). This imposes a lot of interference between the subscribers. Interference on voice channels causes cross-talk, where the subscriber hears interference in the background. On control channels, interference may lead to missed or blocked calls due to errors in digital signaling. With the rapid increase in cellular subscription, an approach to increase capacity is to reduce interference: a cost effective method of achieving this is *diversity* in the channel. Based on the observation that on fading the signal to noise ratio, SNR, at the receiver is a random variable, the idea is to transmit the same signal through separate fading channels. Many techniques have been advocated for obtaining the independent channels needed by diversity: spatial diversity, selection diversity, polarization diversity, frequency diversity and time diversity. However, the most popular technique that is being used is spatial diversity.

Space diversity (sometimes called antenna diversity) is widely used in wireless systems [Thiele, 1981]. It consists of receiving the transmitted signal through L spacing of separate antennas, whose spacing is wide enough to the carrier wavelength to obtain sufficient decorrelation. This technique can be easily implemented, and does not require extra spectrum occupancy. The focus of this M. Eng project is to look at the impact of using adaptive antenna arrays on handheld communicators for satPCS.

This thesis starts with an overview of some satPCSs including IRIDIUM, GLOBALSTAR and ODYSSEY. Next, an analysis on the tradeoffs between the different constellations, minimum elevation angle, inclined orbit and capacity is presented. In addition, details related to the network architecture, i.e. channel assignment strategies, handoff and compatibility are examined. Subsequently the focus moves toward antenna diversity. Here, an overview of adaptive antenna array is presented including one of the popular algorithms. Later, simulation of a linear adaptive algorithm is conducted to demonstrate the self-steering capacity of an adaptive antenna array. The M. Eng thesis demonstrates how an adaptive antenna can be used to eliminate both interference and multipath fading, and its application to handheld communicators.

1.2 SPECIFIC OBJECTIVES OF THE RESEARCH

The Specific objectives are to:

(a) develop an adaptive antenna array technique for mobile units capable of combating interference and multipath signals in satellite personal communication systems; and

(b) adapt and use Kalman filtering technique to eliminate the effects of interference and multipath signals in satellite personal communication systems.

1.3 CONTRIBUTION OF THE RESEARCH TO KNOWLEDGE

The research established how Kalman filter algorithms could be used to reduce effects of interference and multipath signals in satellite personal communication systems using adaptive antenna arrays on mobile units

CHAPTER TWO

LITERATURE REVIEW

2.1 PERSONAL COMMUNICATION SATELLITES

Wireless personal communication is known to be the fastest growing fields in the engineering sector. However, the wireless industry has not reached an advanced stage after Guglielmo Marconi first demonstrated radio's ability as a means of communication more than a century [Rappaport, 1995]. Nigeria, like rest of the world, is still at infancy stage and cannot stand on its feet to sort through the options of either technological transfer or imitation of existing information technology. As a country of huge resources and diverse topography setup, personal communication satellites in conjunction with terrestrial communication could be used to solve the problems confronting our current telecommunication sector.

Like United States of America, "information superhighway" is more like an unmarked country road. As a result, everyone is scrambling to find a way to mesh disparate technologies into forms that will yield a workable roadmap. This thesis is expected to be one of the ways of solving the problems in conjunction with handheld terminal industries.

2.2 HISTORICAL PERSPECTIVES

AT&T Bell Laboratories first developed Advanced Mobile Phone Service (AMPS) back in the late 1970s. Ameritech first deployed this system in late 1983 in Chicago; a total of 40MHz of spectrum in the 800MHz band was allocated by the Federal Communications Commission (FCC) [Rappaport, 1995].

There are currently two digital cellular communications standards in various stages of technical development, namely, Global System for Mobile communication (GSM), and Code Division Multiple Access (CDMA). Both GSM and CDMA are currently adopted in Nigeria.

2.3 SATELLITE CELLULAR INTEGRATION

The integration of satellite cellular with the terrestrial cellular that will provide subscribers with continuous coverage anywhere and anytime is a technology that has been provided by systems known as "Big LEOs"—that is, the Low-earth orbiting satellites. It will continuously revolutionize the way we communicate and perceive the world. The technology involved is, in general, a migration of terrestrial cellular technology into space. Anyway, these personal communication satellites are designed to complement present terrestrial networks and not to compete with them. In other words, this can be seen as an integration of satellite and cellular *technology*.

The general consensus is that an integration of the satellite and terrestrial cellular systems would suit best the urban and suburban regions, while satellites are more suitable for rural areas and inaccessible terrain. Nigeria has 90% of its population residing in rural areas.

An integrated system will not only provide the subscribers with one-number service and unrestricted roaming, but satellites can be used as a backup for terrestrial systems when needed. In order for the integration to work, some factors have to be considered:

a. The air interface - modulation, multiple access, link budgets,
b. Radio resources management – user mobility, handoff management, both between satellite and routing strategies,
c. *Terminal technology*, and

d. Networking features.

The development detail of the concepts, the planning of services, as well as the production of the hardware can be achieved in Nigeria by technology transfer from the advanced countries just like the Asian countries.

On the regulatory front, initial frequency bands were set aside at the 1992 World Administrative Radio Conference (WARC-92), an initiative of the International Telecommunication Union.

2.4 GEOMETRICAL ANALYSIS

There are, in general, four types of satellites [Kolawole, 2002]:

- Geostationary satellite (GEO),
- High elliptical orbiting satellite (HEO),
- Middle-earth orbiting satellite (MEO), and
- Low-earth orbiting satellite (LEO).

An HEO satellite is a specialized orbit in which a satellite continuously swings very close to the earth, loops out into space, and then repeats its swing by the earth. It is an elliptical orbit approximately 18,000 to 35,000 km above the earth's surface, not necessarily above the equator. An MEO is a circular orbit, orbiting approximately 8,000 to 18,000 km above the earth's surface, again not necessarily above the equator. The LEO satellites orbit the earth in grids that stretch approximately 160 to 1,600 km above the earth's surface. A *geostationary* orbit is a non-retrograde circular orbit in the equatorial plane with zero eccentricity and zero inclination. The satellite remains fixed in an apparent position relatives to the earth; about 35,784 km away from the earth if its elevation angle is orthogonal (90 degree) to the equator. Figure 1 shows the coverage area and apex angle to cover the earth's surface. A detailed derivation is discussed in section 2.4.1.

The advantages of going from GEOs to LEOs are:

(a) Shorter delays (better transmission quality), (b) Ability to reuse frequency and increase capacity, (c) Smaller and lighter radio handsets since less power is required, (d) Handsets can use low power and non-directive antennas, (e) World-wide coverage, (f) provision of position location. In contrast, LEOs are not without their own disadvantages; for instance, (a) large number of satellites at high cost, (b) complex network operations for: (i) satellite monitoring, (ii) control replenishment, and (iii) individual satellite spending a large percentage of time over areas with little traffic; (c) relative complex satellites: (i) on-board switching, routing, (ii) handoff, (iii) cross-links (iv) power management during orbit. Consequently, MEO constellations look for a better position between LEOs and GEOs. They require a limited number of satellites for global coverage by employing intermediate elevation angles ($\alpha \geq 20^0$). Also, the propagation delay and attenuation due to free space are also intermediate.

The analysis of a number of mutually linked factors of the optimum satellite constellation is identified by:

a. The extent and distribution of the expected user population,

b. Types of mobile terminals,

c. Service quality and availability specifications,

d. Minimum elevation angle,

e. Type of service(s),

f. Maximum transmission delay, and so on.

The orbit affects satellite performance. Transmission of the signal through the atmosphere is affected by the elevation; that is, the angle between the radio frequency (RF) link and the horizontal plane [Gordon, 1993].

A sufficient number of network nodes and corresponding links between them can achieve a high degree of connectivity within a LEO satellite network. The higher the degree of connectivity, the more alternatives for routing are given, and therefore the better the traffic flow distribution. Moreover, LEO satellite enhances the flexibility of the network to cope with link or node failures. On the other hand, construction and positioning of more gateways and/or satellite means higher fixed costs, and the permanent supply of large capacity means high recurring costs. These factors show that optimization of the whole system is a central task in the initial state of system planning.

2.4.1 GEOMETRIC COVERAGE AREA

The amount of coverage is an important feature in the design of earth observation satellites. Coverage depends on altitude and look angles of the equipment, among other factors [Kolawole, 2002]. To establish the geometric relationship of the coverage, consider the Fig. 2.1 below.

Consider the angle of view from the satellite to the earth terminal as α; then the apex angle is 2α. The view angle has a mathematical physical function given by

$$\alpha = Sin^{-1}\left(\frac{R_e}{h_a + R_e}\right) = Sin^{-1}\left(\frac{R_e}{r}\right) \qquad (2.1)$$

Using empirical values (Re = 6,378 km, r = 42,162 km), the apex angle $2\alpha = 17.33^0$. In practice, an antenna of 18^0 or 19^0 beamwidth is used to allow for directional misalignment.

Using the notations in Fig. 2.1 as a guide, the coverage area A_{cov} from which the satellite is visible with an elevation angle if at least θ can be established as

$$A_{cov} = 2\pi R_e^2 (1 - \cos\gamma), \tag{2.2}$$

where γ is the central angle.

The apex angle required at the satellite to produce a given coverage A_{cov} must satisfy

$$2\pi(1 - \cos\alpha) = \frac{A_{cov}}{h_o^2} \tag{2.3}$$

However, for small angles, that is, α << 1, we can approximate the global beamwidth to

$$2\alpha \approx \frac{d_{cov}}{h_o} \tag{2.4}$$

where d_{cov} is the coverage diameter.

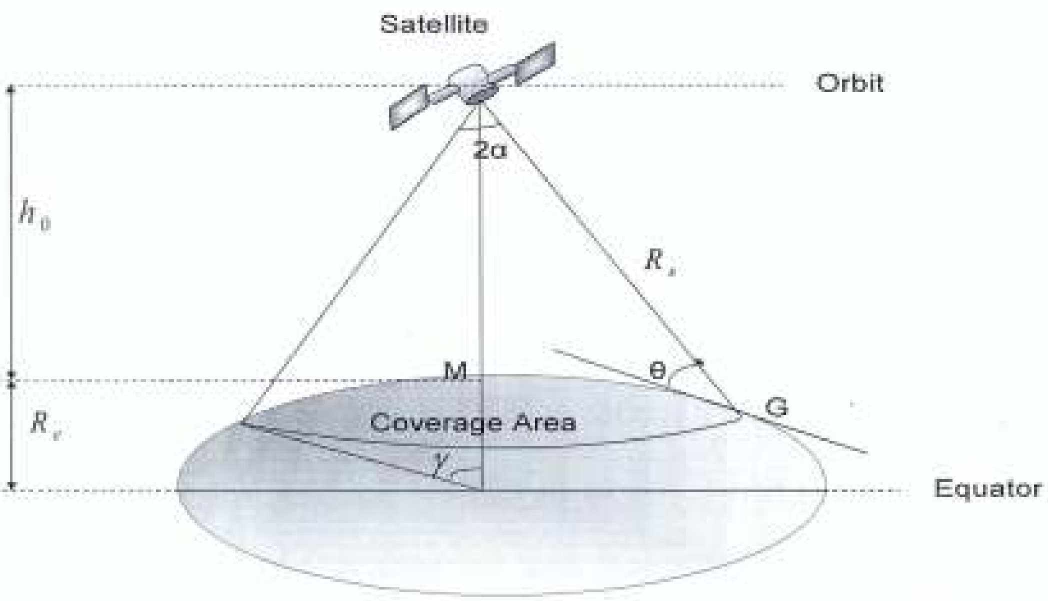


Fig.2.1: An illustration of coverage area and apex angle [Kolawole, 2003]

In order to provide communications among areas serviced of satellites, a terrestrial earth station must be provided at a location where satellites are visible.

Fig. 2.2 shows the number of required satellites versus the orbit height for the example of system of Table 2.1; the chosen values are also given.

Table 2.1: System parameters of some of the proposed/available constellations [Richharia, 1999].

System	Height (Km)	Nominal α (°)	Number of Satellites	Number of Orbital planes	Inclination
Iridium	780	10	66	6	90
GLOBALSTAR	1400	10/15	48	6	47/52
ICO Global Com	10,300	N/A	10	2	45
Teledesic	700	N/A	840	21	98.2
Odyssey	10,354	200	12	3	55
Starsys	1,000	N/A	24	6	53

Besides the number of satellites, the minimum number of orbits Ω is also important. At least for great orbit heights, one launcher has to be used for each orbit. In order to determine the necessary number of orbits, it is sufficient to consider the satellite coverage of the equatorial coverage depicted in Fig. 2.1. The orbital height versus Number of satellites is shown in Fig. 2.2.

2.5 ORBITS AND CHARACTERISTICS OF MOBILE SATELLITE SERVICES.

As stated in section 2.4, GEO satellites are located in orbit farthest from the earth. The communication link time delay is about 250 msec (one way). Most of the non-geostationary satellites are located in LEO orbits. Middle –earth orbit (MEO) systems utilize the advantage of a gap between the GEO and LEO and place the satellites in inclined orbits.

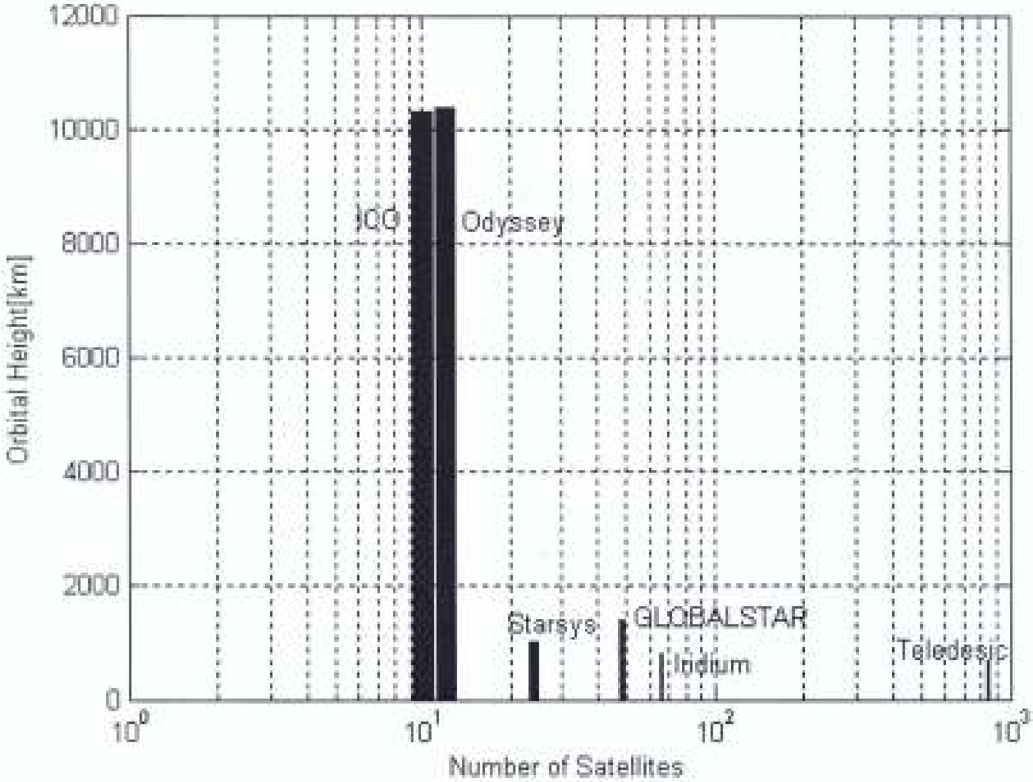


Fig. 2.2: Orbital Height Vs Number of Satellites

2.5.1 TELEDESIC

Formally called Calling Network is a broadband "big LEO" system for the fixed service. The systems offer broadband optic fiber-like communications for application in Ka-Band (frequency range of 17.7-21.2 GHz) such as broadband internet access and video conferencing. Low propagation delay makes the system well suited for supporting delay-sensitive protocols and capacity-on-demand systems, allowing a user to request and release capacity as needed.

A number of fixed and mobile services are offered worldwide, beginning from 16 kbps to primary rate ISDN at 2.048 Mbps, and above. The basic user terminal consists of a 20cm diameter antenna supporting up to 64 kbps; advanced terminals support up to 2.048 Mbps [Richharia, 1999].

The system architecture consists of small terminals which may be connected directly to each other or to public networks via a constellation of regenerative, intelligent, highly autonomous satellites interconnected to each other via inter-satellite links. A *Constellation* is a group of similar satellites working together in partnership to provide network of useful service [Kolawole, 2002]. The constellation of satellites provides better coverage particularly in the LEO system. Each satellite in an orbital plane maintains its position in relation to the other satellites in the plane. Each satellite in an LEO constellation, for example, acts as switching node and is connected to nearby satellites by *inter-satellite links*.

In Teledesic, each satellite's beam covers up to 64 supercells; the actual effective supercell coverage depends on the satellite's orbital position and its relative distance to other satellites. Each cell in the supercell is allocated a timeslot, and each satellite focuses on the cell in the supercell at that allotted time.

The concept behind these hundreds of satellites is that even outside most advanced urban areas, most of the world will never get access to these technologies through conventional wire line means. Teledesic is designed using a decentralized network, which provides better system reliably compared to other centralized systems.

The Ka-Band mobile link was chosen to achieve sufficient bandwidth for the high bit rates Teledesic requires. In order to overcome the delay problems, a LEO constellation with an elevation angle of about 40° has been selected to overcome the shadowing effects. Each satellite has an inter-satellite link with its eight adjacent neighboring satellites. All communication within the network is treated as streams of short, fixed length (512 bits) packets based on Asynchronous Transfer Mode (ATM) technique.

Teledesic uses steerable antennas and regional mapping to reduce the number of handoffs required as a result of the satellite's motion and the Earth's rotation. The earth's surface is mapped to approximately 20000 supercells, each of which is again divided into 9 cells. The supercell is a square 160km on each side. A satellite footprint encompasses a maximum of 64 supercells, or 576 cells, corresponding to one supercell per beam. The channel resources are associated with each cell and are managed by serving satellites. The multiple access method chosen by Teledesic is a combination of space, time and frequency divisions multiple access [Tor, 1996].

2.5.2. IRIDIUM

The Iridium was one of the world's first systems designed for voice communication from non-geostationary orbits. It is designed to provide global communication and each satellite has a special feature where each satellite has four crosslink per satellite. The first batch of low earth orbit satellites for provision of voice service to hand-held terminals (Iridium) was launched in 1997 and several broadband FSS personal communication system was equally proposed [Richharia, 1999]. The originators of the Iridium system, which offers voice and data communication at up to 4.8 kbps, can be credited for the advent of the LEO/MEO era. The company was the first to propose a high-risk commercial LEO satellite system in the year 1990 [Richharia, 1999].

The Iridium system is intended to provide voice services to satellite/terrestrial dual mode handheld terminals. The terrestrial component could be any of the more established cellular systems. The handset would use a cellular system when within its coverage, but, when outside, switch to the Iridium system. Other value-added services on offer are a position-determine service, facsimile, paging, two-way messaging and duplex 2.4kbps data-bearers.

The Iridium constellation form a network's switching algorithm allows some of the beams to be switched off as it approaches the pole but maintains a sizeable proportion of the beams at any given time. The system originally consists of a constellation of 77 satellites which matches the number of electrons around the element called Iridium. It was reduced to 66 satellites after the system was refined. The polar constellation consists of 66 satellites in six 780 km altitude orbital planes, each plane containing six equidistant satellites. Each Iridium satellite is capable of transmitting/receiving 48 spot beams, each with a capability of 230 duplex conversations. Higher-latitude coverage is denser being a polar constellation and hence spot beams are switched off as the satellite moves away from the equator.

The network architecture of the iridium system is shown in Fig. 2.3 below. The ground segment consists of various types of handsets, capable of providing voice, data, paging or facsimile services connected via the Iridium constellation to 15-20 gateways dispersed throughout the world. A duplex TDMA mode is used for multiple access; such a scheme is shared in the up-and downlinks by using different timeslots on the carrier.

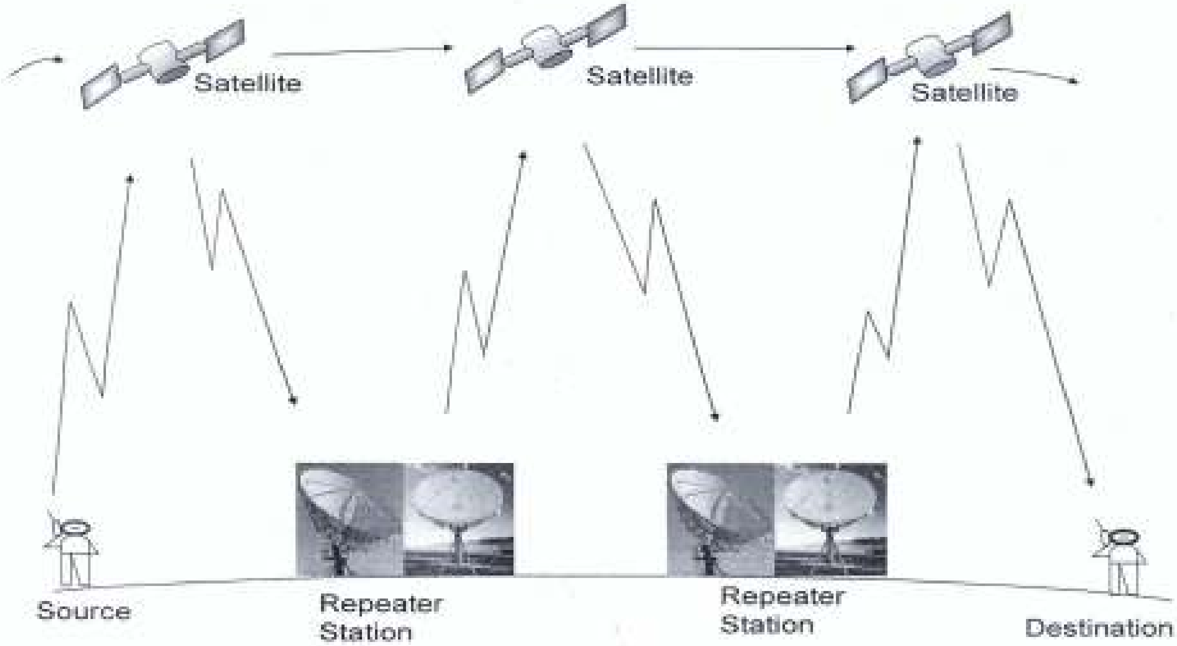


Fig. 2.3: Iridium Architecture

Iridium has the architecture that provides a space network that links the entire iridium system to the Public Switched Telephone Network (PSTN). It uses GSM based telephony architecture to provide digitally switched telephone network and global dial tone call and receive calls from any place in the world [Swan, 1993]. This system has a built-in roaming feature and each subscriber is assigned a single phone number throughout the entire world, thus the subscriber will only receive one bill no matter what country he or she visits whenever placing or receiving a phone call. The Iridium system is fully digital and utilizes high-quality voice-coded (vocoding) messages at 4.8 kbps with Forward Error Correction (FEC) coding. The vocoding technique used is called Vector Sum Excited Linear Prediction (VSELP). Besides this, Iridium also provides data communication at 2.4 kbps paging, two way messaging and position location services. Fig. 2.3 illustrates some of the sixty-six satellites that make up of the constellation. Table 2.2 summarises the frequency assignment adopted by Iridium.

Sixty-six operational satellites are configured in six-near polar orbital planes, in which 11 satellites circle in one plane [Swan, 1993]. The satellites are phased approximately in co-rotating planes up to one side of the earth. The first and the last planes rotate in opposite directions, creating a 'seam'.

TABLE 2.2: Iridium's Frequency & Cannel Assignment [Source: Motorola, 1992]

	Frequency-Band	Frequency Assignment (GHz)	Max. Number of Channels per satellite
Mobile-to-Satellite	L-Band	1.616-1.6265	3840
Gateway-to-Satellite	Ka-Band	27.5-30.0 18.8-20.2	3000
Satellite-to-satellite	Ka-Band	22.55-23.55	6000

2.5.3 ORBCOM

ORBCOM is the first successful test of low data rate commercial low earth orbit satellite system [Richharia. 1999]. The fully deployed constellation is conceived to consist of up to 36 'micro' satellites weighing about 38.5 kg each in LEO orbit. There were 8 satellites each in 45° inclined planes at an altitude of 775 km, and 4 satellites at an altitude of 739 km in two planes at an inclination of 70°. The constellation has been built up gradually--initially with two satellites giving intermittent service in the U.S.A as they passed over that country up to 8 times a day, each passing lasting about 10 minutes [Richharia, 1999].

The ORBCOM satellites operate simultaneously in two frequency bands. The VHF frequency band is used for the transmission and reception of all message traffic, while the UHF frequency band is used for the transmission of time signals, standard frequency, and satellite ephemeris (position) information required for enhanced position determination. Each satellite has 20 uplink messaging channels operating on the 148-149.9 MHz frequency range, 19 downlink message channels operating in the 137-138 MHz frequency range, one downlink channel operating in the UHF band at 400.1 MHz, and an inter-satellite link to receive GPS time/position information in the L-band at 1575.42 MHz. Table 2.3 outlines the channel requirements. Transmit polarization for both the VHF band and UHF band downlinks is circular. The subscriber terminal transmit polarization is linear. The ORBCOM satellites located in the same plane are spaced so as to eliminate mutual visibility at any point on the earth. This allows all satellites in the same plane to employ the same frequency plan with no interference. A Time Division Multiple Access, TDMA approach is used to overcome intra-system interference [Lian, 1997].

TABLE 2.3: ORBCOM's channel requirement [Lian,1997]

Link description	Frequency (MHz)	Channels	BW/Channel (KHz)	Total Bandwidth
Downlink				
Subscriber Term Regional Gateway Time/Frequency	137.2-138.0 137.0-137.050 400.075-400.125	18 1 1	15 50 50	270 50 50
Uplink.				
Regional Gateway GPS sat	148.850-148.900 1575.42(Rx only)	1	50	50

2.5.4 GLOBALSTAR

GLOBALSTAR is very similar to Iridium. It has a constellation of 48 LEO satellites in circular orbits with 1389 Km altitude from the equator to 70° latitude, and provide 100% global coverage. It observed as much as 50% of the earth surface at a time. As a result, services are provided with a somewhat smaller constellation, about 48 satellites. Each satellite is less complex than the Iridium satellites, since GLOBALSTAR does not use inter satellite links (ISLs).

Six satellites are equally spaced in its constellation in an orbit and occupy each of the 8 planes. In order to eliminate the problem of long term blockage and shadowing effects, an attempt to provide double coverage with large angular separation is designed. Each orbital plane has an inclination angle of 50°, and each satellite has a 7.5° phase shift to the satellite in the adjacent orbital plane [Mazzella et. al., 1993].

The system uses CDMA, but the satellites do not have on-board processing capabilities. Each satellite projects 16 beams to the earth. GLOBALSTAR employs spatial diversity by transmitting signals through two satellites. This Qualcomm technique reduces the amount of power required for transmission, thus, each handset communicates through two satellites. The two CDMA signals are combined in each handset receivers that add the two CDMA signals constructively. This technique provides the most robust service when two satellites are available. The double path provides a 'soft' handoff from beam to beam and satellite to satellite as the constellations move overhead.

The GLOBALSTAR satellite spot antennas are also designed to compensate for the difference in the satellite-to user link losses between the 'near' and the 'far' users so that the power flux density of the 'far' users is about the same as the 'near' users [Mazzella et. al., 1993]. Table 2.4: shows the four segments proposed for GLOBALSTAR

TABLE 2. 4: GLOBALSTAR's Frequency Assignments

Link	Communication paths	Frequency Assignment (GHz)
User	Mobile-to-satellite Satellite-to-Mobile	1.610-1.6265 2.4835-2.500
Feeder	Gateway-to-Satellite Satellite-to-Gateway	5.091-5.250 6.700-7.075

2.5.5 ODYSSEY

ODYSSEY employs orbiting satellites in medium elliptical orbit (MEO) or intermediate circular orbit (ICO) for mobile satellite service [Lutz, 1993]. The cost effectiveness is achieved because of a smaller number of earth stations and less complex operations are required and minimum speech is achieved. Ability to operate in MEO region makes the system to have little radiation effect, thus requiring less shielding on the satellite. The system's lifespan is longer (12 years) compared to LEOs of about 5-7 years.

ODYSSEY required satellites for full global coverage. With 12 satellites, at least two satellites would be visible from any part of the world. ODYSSEY also provides the highest elevation angles of all the mobile satellite systems proposed for voice service. The constellation provides continuous global coverage with a high degree of dual satellite visibility. This means a mobile subscriber has at least one satellite in view about 20° elevation angle at all times, and two satellites in view above 20° elevation angle more than 88% of the time, virtually guaranteeing like completion [Baird, 1996]. Table 2.5 shows the frequency assignments for ODYSSEY.

TABLE 2. 5: ODEYSSEY's Frequency Assignments

Link	Communication paths	Frequency Assignment (GHz)
User	Mobile-to- Satellite Satellite-to-Mobile	1.610-1.6265 2.4835-2.500
Feeder	Satellite-to-Satellite	17.7-21.2

2.5.6 OTHERS

There are still numerous proposed constellations, which are not mentioned including American Mobile Satellite Corporation (AMSC) located in geostationary orbit, Archimedes, Ecco, Ellipso, VTAsat, African, Aces, Starsys, EMS, LLM, GEMnet, and Inmarsat,

TABLE 2.6: Selected LEOs, MEOs and GEOs [Lian, 1997]

	Organization	Orbital Type	No. Orbital Plane	No. of Satellites	Access Method
Iridium	Motorola	LEO	6	48	TDD/TDMA/ FDMA
GLOBALSTAR	Loral/Qualcom	LEO	8	66	CDMA
ODYSSEY	TRW	MEO	3	12	CDMA
Teledesic	Teledesic Co	LEO	21	840-924	FDMA/ATDMA
Ellipso	MCHI	HEO/MEO	2/1	10/6	CDMA
ICO	ICO Global	MEO	2	10	TDMA
Archimedes	ESA	M-HEO	6	5-6	FDMA/TDM/ COFDM
ECCO	Const. comm./ Telebras	LEO	1	11	CDMA
ORBCOM	Orbital comm.	LEO	6	36	FDMA
Starsys	Starsys Global Pos.	LEO	6	24	CDMA
VITA sat	VITA/Final Analysis	LEO	1	2	FDMA
GEMnet	CTA comm. System	LEO	5	38	FDMA
AMSC-1	AMSC	GEO	-	2	FDMA/TDMA
MSAT	AMSC	GEO	-	2	FDMA
Mobile sat	Optus COM	GEO	-	2	FDMA
EMS	EMS	GEO	-	1	CDMA/FDMA

2.6 SUMMARY

This chapter is expected to serve as a background to subsequent discussions. Most of the proposed Satellite personal communication systems use low frequencies (L-and S- bands); as a result, there will be some practical limitations with the spacing of adaptive antenna elements on a handheld unit, which invariably could still be solved to enhance its efficiency.

2.7 MANAGEMENT OF NETWORK RESOURCE

This section is essentially to examine how link budgets, channel assignments, handoff and call set-up are handled in satPCS. It must also be noted that some of the problems experienced by terrestrial networks on voice and control channels may be linked to satPCS if interference and multipath present are not handled properly, which may result in cross talks or blocked/dropped calls. To overcome these problems, this thesis aims at using adaptive arrays on hand held terminals. However, before discussing the issue of interference and multipath, there is a need to look at voice and control channeling in this chapter.

2.7.1 PERSONAL COMMUNICATION NETWORK

At present, in populated areas such as cities, terrestrial cellular mobile systems are far more cost-effective than satellite mobile systems. However, satellite systems offer the only viable system solution for providing mobile communications to remote areas [Richharia, 1999]. In Nigeria where 90% of their population reside in the rural areas, satellite mobile communication system is expected to provide the best solution to telecommunication problem.

The early design objective of most cellular services was to provide a large area of coverage by using a single, high powered transmitter with an antenna mounted on a tall tower or pylon.

The drawback of this method is that it eliminates the possibility of reusing the same frequency within the same coverage area. In order to avert the problem of congestion and utilize the spectrum more effectively, a better cellular concept needs to be developed.

It has already been discussed that satellite based personal communication systems are a migration of terrestrial cellular technology into space. The *footprint* generated by the multi-beam antennas and the satellite has the same concepts compared to cells in a terrestrial system. Unlike the terrestrial cells, which are stationary, satellite multi-beam antenna cells depend on the speed of the satellite; hence, the satellite systems will experience more handoffs compared to terrestrial systems. Hence, trunking efficiency, grade of service, and overall capacity of LEOs and MEOs would be affected by routing and Doppler shift.

Trunk means a collection of circuits grouped together to carry traffic between two locations [Richharia, 1999]. Trunking in cellular terms means ability to accommodate a large number of users in a limited radio spectrum. Trunking exploits the statistical behavior of users so that a fixed number of channels or circuits may accommodate a large number of users in a cell. Thus, trunked radio systems are designed to handle a specific grade of service. The grade of service is a measure of the ability of the user to access a trunked system during the busiest hour and is usually given as the likelihood that a call is blocked [Rappaport, 1995].

Consequently, the satellites used to provide cellular coverage will have highly directive multi-beam antennas, or adaptive antenna arrays, to increase the number of footprints/cells to reuse frequency, thus increasing overall capacity.

(i) BEAMS OF ANTENNA

Having multi-beam coverage enables the possibility of frequency reuse if sufficient angular separation could be achieved between coverage. However, adjacent beams must use different frequency bands from one adjacent beam to another in order to avoid inter-beam interference, and this is a drawback as it obliges the earth terminals to change frequency as the satellite passes overhead. The advantages of a multi-beam satellite antenna include high antenna gain within each individual but a more complex payload and greater antenna size.

(ii) INTER-SATELLITE LINKS

This is the link between two satellites in the same orbit. Higher frequencies are more suitable for inter-satellite links (ISL) and may become useable as the orbit congestion arises at the lower frequencies. Satellite network often required communication between satellites via an inter-satellite link (ISL). As a communication link, an ISL has the advantage of the possibility of extending the coverage area of a geostationary satellite network by linking satellites directly in space [Kolawole, 2002]. The effective coverage of such a network is the sum of the coverage available from each satellite separately [Richharia, 1999]. The maximum separation between two satellites is decided by the permitted propagation delay and unobstructed visibility between satellites. In another architectural concept, ISLs are used to form a cluster of co-related satellites, each satellite in the cluster having different function. For example, the satellites of a mobile satellite service and a fixed satellite service network could be linked and clustered together, and cells from one service could be directly connected to the other via an ISL. Radio frequency links that use omni-directional antennas obviate the task of locating the satellite but has low throughput. Directional antennas, on the other hand, allow high throughput but require a location determination system of some agility to find the destination satellite. Phased array antennas are well adapted for agility and are highly directional. This will be discussed later.

(iii) HANDOVER

This is also known as handoff. There are generally two types of handover; the cell is switched between two spot beams of different satellites, or the cell is either switched between two spot beams of the same satellite. If the signal quality deteriorates during a call, the call is *handed over* to a new satellite or a new beam on the same satellite; if necessary, the handover process is repeated until the call is completed. For packet networks, the routing strategy can be more dynamic [Richharia, 1999]. Mobile handover between spot beams occurs when the satellite remains in view but the communication needs to be supported by another spot beam. This either happens when the mobile user moves from one spot beam (cell or footprint) to another or because of the motion of the satellite, the stationary user needs to be transferred to another spot beam. This type of handover could also be experienced when both the satellite and the user are in motion.

Mobile handover between satellites occurs when the satellite is moving out of visibility and the communication needs to be switched to another satellite. In the case of an earth station handover, the satellite moves out of visibility and communications need to be switched to another earth station which provides the same coverage for the satellite. Alternatively, the communication can be handed over to a new satellite in visibility of the same station.

There are numerous reasons for handover to occur. First, they take place whenever the network needs to free up some of its resources in area with high traffic load, usually by handovers between antenna footprints. Secondly, they occur because the satellite is moving out of visibility of the user and in order to preserve the communication link, a handover is required.

In satellite communication system based on a non-geostationary constellation, the network has to cope with the motion of the satellite as well as that of the mobile user. Location of the mobile provides the network with the necessary information to route calls. In a satellite system, this information is based on the terminal location (that is, its longitude and latitude). Since the orbital parameters are known, it is always possible to identify the proper satellite (LEOs and/or MEOs) and spot beams in order for the calls to be routed.

Not all existing constellations use handover strategies. For instance, Odyssey's system does not provide for handovers. The constellation has long visibility periods for each satellite, and each satellite has a built-in overlap of 10 minutes for every user. Furthermore, the ODYSSEY satellites have a built-in antenna steering capability, thus no spot beam handovers are really necessary.

GLOBALSTAR is designed with the objective of minimizing handovers between spot beams. The system uses active phased antennas which have dedicated low noise amplifiers for receiving and dedicated higher power amplifiers for transmitting for every antenna element. The phased array uses passive phase shifters for beam steering and a beam forming network. This characteristic allows the system to decrease the need for handovers, thus a communication link starting in a beam can be supported by that beam until the satellite moves out of visibility.

Iridium has by far one of the most complicated network designs. This system together with its intersatellite links will allow all the handovers (mobile handover between types of two different spot beams and between two different satellites) to be implemented. This will significantly complicate the network structure and requires complex on-board processing, which might add to the delay of the communication link. However, because of Iridium's low altitude, it is anticipated that this additional delay will not cause significant degradation in voice communications quality.

(iv) DOPPLER EFFECTS

Doppler effects result due to the relative radiation velocity between the satellite and the user, or between the satellites in the case of intersatellite links. Doppler shift is a frequency shift of the transmitted carrier at the receiver end of the link. The frequency of satellite transmissions received on the ground increases as the satellite is approaching the ground observation and reduces as the satellite moves away. The Doppler shift effect can be compensated for with either a sufficient frequency gap between carriers or by frequency tracking at the receiver end. The Doppler shift can be used for Moving-Target Indication (MTI) [Lian, 1997] and for position determination purposes.

For most of LEO constellations, the Doppler shift can reach values as high as ±50kHz (on satellite to mobile link) and ±35kHz (on mobile to satellite link) with Doppler rates up to 500Hz/s. In the gateway/satellite link, knowledge of the satellite ephemeris is used to compensate the Doppler shift in a closed loop through the satellite at the gateway.

(v) CHANNEL ASSIGNMENTS

Channel assignment refers to the allocation of specific channels to cell sites and mobile unit [Lee, 1989]. One of the major issues in implementing an efficient mobile satellite service is to maximize the channel throughput with limited bandwidth while providing high quality service. In the case of handover, every time a mobile user with a call in progress passes from one cell (footprint) to the adjacent one, new channel is required in order to prevent call termination.

The difference between LEO, MEO and GEO satellites is the size of the cells, which in essence, is dependent on their footprints. In the case of GEOs, the cells are larger in diameter compared to the LEOs. The latter case will allow the frequency to be reused more often. Thus, allowing more traffic to be handled by the network. However, the limiting factor is co-channel interference.

Co-channel interference results from the frequency-reuse method used for increasing the efficiency of spectrum usage in co-channel cells [Lee, 1989]. Unlike thermal noise, co-channel interference cannot be overpowered by increasing the carrier transmitter power. As a result, a minimum reuse distance is required between cells using the same set of frequencies [Kolawole, 2002].

(vi) CALL SETUP

Basically, there are two types of call setup; fixed to mobile, and mobile to fixed [Cullen et al., 1993]:

1. The mobile to fixed call setup procedure:
    a. Dialing of number by the mobile user;
    b. Channel request message to the Primary Earth Station/ controller (PES/c) is sent by mobile terminal;
    c. The PES/c randomly accesses, returns an immediate assignment message to the mobile terminal; and
    d. The mobile replies with a paging response.

2. The fixed to mobile call setup procedure:

a. Dialing the mobile user's number by fixed user, then connected to the PSTN;

b. Transferring of the signal to the PES/c by PSTN;

c. The PES/c will page the number terminal via the appropriate satellites and coverage zones through the last known location of the user;

d. A channel request message to the PES/c (Random Access Channel, RACH) is sent by the paged mobile terminal;

e. The PES/c that was 'randomly accessed' then returns an immediate assignment message to the mobile terminal;

f. The mobile replies with a paging response which includes its international mobile subscriber identity/space (IMSI/S) number.

These call setups are general techniques; however, there is need to explain the call setup of Iridium and ORBCOM.

(v) (i) IRIDIUM'S CALL SETUP

As stated earlier, Iridium has 66 LEO satellites and uses inter-satellite links. Besides having 66 satellites and 12 spares, the Iridium system has numerous gateways to monitor the activity of its subscribers, such as billing and so on. In order for the call to be made, the Iridium subscriber turns the mobile on.

Once it is on, it enters a standby mode where it hooks onto the strongest spacecraft signaling channel. To place a telephone call, the Iridium user will dial the number and depress the send button to start the call mode. The unit sends its owned phone number, registration number, and the number being called directly to the satellite. The satellite passes the information to the regional gateway. The regional gateway looks into the database and then sends this information to the home gateway of the user to verify the validity of the caller. After this is done, the regional gateway determines the proper routing to the destination. Both the caller and the destination information are sent to the regional gateway, which provides the final routing to the satellite. It is expected that the total setup procedure does not exceed 30 seconds.

A public telephone user can also directly dial an Iridium subscriber unit's number. This call will enter the Iridium system through the caller's closest regional gateway. The iridium user's home gateway will validate that the user is still current and provide the user's last known location. The remainder of the call setup follows the previous setup in section 2.7.1.6.

(v) (ii) ORBCOM'S CALL SETUP

The ORBCOM is designed for paging services. There are two methods of processing messages. First, a subscriber will initiate the message which will flow from his/her terminal through the satellite and a regional gateway to the Network Master Control center (NMCC), where it is either printed out for delivery by mail or routed based on pre-determined protocols through packet switched networks. Emergency messages will be passed directly through to service providers or to ORBCOM's customer service activity where each message will be individually managed until confirmed as clear.

Secondly, an off-network message may enter the system through the service operation center via several different media. The service operation center will enter the message into the system computers, which in turn will forward it to the NMCC. NMCC provides proper structure and addressing and routing it to the designated subscriber via the appropriate Regional Gateway and satellite based on the subscriber's last known position.

2.8 ROUTING

Several routing protocols developed for serving the needs of packet switched networks are applicable to this type of architecture.

2.8.1 CENTRALIZED ROUTING SCHEME

A central site, such as a ground station, maintains a database of the current location of all satellites and users in the network. The database is updated continually, as users signal their location regularly. Satellite orbital parameter may be obtained from the satellite that broadcasts or from the satellite control centre. The database is queried on a call-by-call basis to establish a route; alternatively the route lookup table can be transferred to each mode regularly.

2.8.2 DISTRIBUTED ROUTING SCHEME

Each satellite maintains its own database. This scheme is more resistant to failures because of the distributed architecture, but the satellites are more complicated, requiring significant on-board memory and computing power. To simplify this scheme, the routing tables may be maintained at ground sites.

2.8.3 FLOODING

In the *flooding* scheme, each message contains a destination header and is transmitted to all visible nodes. The message is forwarded by all receiving nodes unless addressed to it; the process is continued until the message is received at the destination. On received at the intended destination, a "confirmed" message is flooded to all, thereby freeing up the nodes.

It is possible to combine flooding with other schemes for improving the overall performance. Flooding can be used during the call establishment phase; once the best routing is obtained, the call can be routed by selected route [Richharia, 1999].

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 ADAPTIVE ANTENNA ARRAYS IN SATELLITE PERSONAL COMMUNICATION SYSTEMS

In satPCS, interference and multipath fading remain the problems to reliable reception of signals. These are the problems confronting most of the Satellite Personal Communication Systems (satPCS), which are not desirable. Also multipath can be caused by scattering surfaces like the ground, buildings and vehicle, rain, cloud is shown in fig 3.1.

Most of the antenna used in transmitting and receiving signals by handheld terminals is ideally circularly polarized and isotropic in nature, with a single low gain antenna element. However, these single element units are particularly less susceptible to noise (interference and multipath) effects because they receive signals from all directions. Adaptive antenna array mounted on the handheld terminal is an approach that is best suited to combat the problem. Therefore, one of the major focuses in this chapter is to discuss the adaptive array which is expected to reject interference and track the satellite automatically as it moves across the sky.

3.2 ADAPTIVE ANTENNA ARRAYS: DEVELOPMENT

An array of antenna elements is a spatially extended collection of M similar radiators or elements, where M is a countable number bigger than 1, and the term "similar radiators" means that all the elements have the same polar radiation patterns, orientated in the same direction in 3-dimensional space. The elements do not have to be spaced on a regular grid, neither do they have to have the same terminal voltages, but it is assumed that they are all fed with the same frequency and that one can define a fixed amplitude and phase angle for the drive voltage of each element.

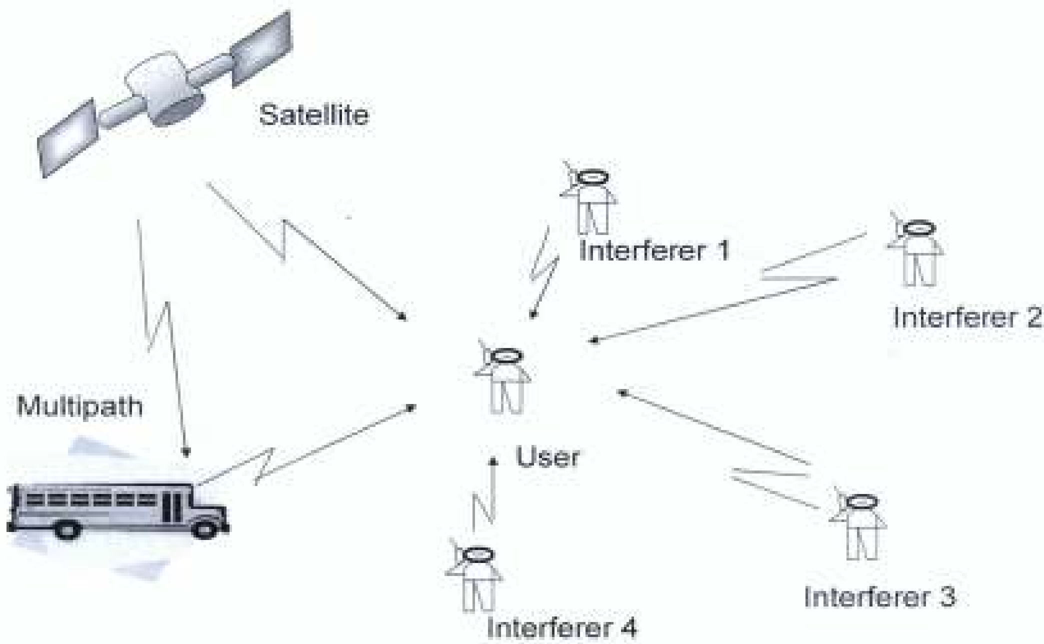


Fig. 3.1: SatPCS user affected by Interference and Multipath

3.3 ADAPTIVE ANTENNA ARRAYS: ASSUMPTION AND ARCHITECTURE

In Fig. 3.2, adaptive antenna arrays are considered to be self-adapted to various incoming signal conditions so as to maximize the signal from a particular source or to null out interfering signals. A variety of configurations are possible [Collins, 1985]. As an illustration, let consider the self-phasing array, shown in the Fig. 3.2, which is designed to bring all the signals received by the various elements from a particular source into phase. To analyze the antenna array, it is necessary to make some assumptions. We first assume that there is a direct path for the signal from the satellite and there is also some form of interference, where the interfering signal is uncorrelated with the wanted or desired signal. Also, multipath components due to reflection, scattering and diffraction, which are incident on the antenna array, must exist. These incident waves are assumed to be plane waves. It is equally assumed that the transmitter and any object which results in multipath components are in the far field of the receiver's antenna. Next, we assume that all the array elements are placed closely enough such that there is no significant amplitude variation due to the difference in propagation path length for any two elements. Further, we will assume that there is no significant difference in the Direction-of-Arrival (DOA) of a particular plane wave at any two elements. Finally, we assume that each of the antenna elements has the same pattern and the same orientation.

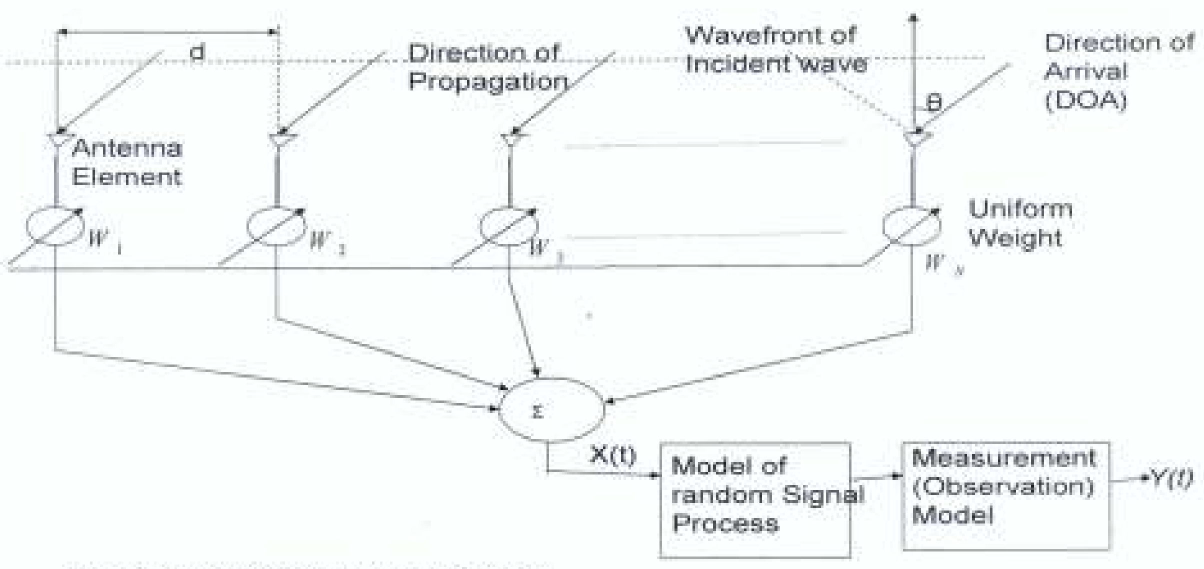


Fig. 3.2: An Adaptive Antenna Array

Fig. 3.2 shows an example of an adaptive antenna array. X(t) is the Fourier Transform of adaptive antenna array. The algorithm of the models is derived in section 4.4.1 as based on the Kalman filtering algorithm. The figure shows plane waves arriving at the antenna elements at angle θ. The signals are then down-converted to an intermediate frequency and sampled by an Analog to Digital converter (A/D). The A/D converter converts the electrical signal from analog to digital form. Then, this input signal is multiplied with an adjustable weight w_i, (where i = 1, 2 ...N) and all the signals are summed to produce an output, X_t.

Adaptive filtering has also been widely applied to multiple data sequences that result from antenna arrays, where the antennas are arranged in some spatial configuration. Each element of the array of antenna provides a signal sequence. By properly combining the signals from the various antennas it is possible to change the directivity pattern of the array [Proakis et. al., 1992].

Adaptive antenna arrays differ from conventional arrays in the sense that they are adaptive. An adaptive array is actually a phased array antenna that is capable of adjusting the phasing of elements automatically, thus controlling its own pattern. They adjust their pattern automatically to the signal environment to reduce the level of interference. This is accomplished by optimizing the signal-to-interference-plus-noise ratio (SINR) at the array output.

There are several advantages of using an adaptive antenna array as opposed to a conventional array. Adaptive arrays are capable of sensing the presence of interference noise sources and are able to suppress the interference while simultaneously enhancing desired signal reception without prior knowledge of the signal/interference environment. An adaptive array is used to complement other interference suppression techniques so that the actual suppression achieved is greater than that obtained solely through conventional means. An adaptive array also offers enhanced reliability compared to conventional array. The response of operational elements in the array can be automatically adjusted until the array sidelobes are reduced to an accepted level. Unlike when the conventional array fails, the sidelobe structure of the array pattern may be significantly degraded as the sidelobes increase.

Interference signal suppression is obtained by appropriately steering the beam pattern nulls and reducing sidelobe levels in the direction of interfering sources, while desired signal reception is maintained by steering the main beam. Since an adaptive array is capable of forming deep nulls over a narrow angle region, very good interference suppression can be realized. Thus, interference suppression by null steering is a principal advantage of adaptive arrays.

3.3.1 ADAPTIVE ALGORITHMS

The problems of interference and multipath of handheld units for satellite personal communication system (satPCS) could be overcome by mounting adaptive arrays on a handheld unit. As submitted in chapter 2, adaptive antenna arrays have the ability to combat the interfering signal. In this chapter, computer simulations are carried out to see the effectiveness of antenna array against interference.

(i) N-ELEMENT LINEAR ARRAY: UNIFORM AMPLITUDE AND SPACING

[Balanis, 1982; Kolawole, 2003; Lian, 1997 and Skolnik, 1981.]

Fig.3.2 illustrates how Kalman filter algorithms work and shows N- elements array of identical characteristics. The first pulse is taken as the phase centre, *f*(t). Then second pulse is advanced by τ and denoted by *f*(t- τ), the third is advanced by 2τ and denoted by *f*(t-2τ), and so on. Thus, for N=5, as an example in figure 6, we write

$$f_T(t) = a_o f(t) + a_1 f(t-\tau) + a_2 f(t-2\tau) + a_3 f(t-3\tau) + a_4 f(t-4\tau) \qquad (3.1a)$$

where $a_0, a_1 \ldots a_5$ are the weights/gains of each element of the array. In adaptive antenna array, the weights/gains of each element are taken to be the same and equally spaced not more than $\lambda/2$ to avoid grating lobes appearing on the antenna pattern. The purpose of the weight is essentially to determine the radiation pattern or array factor of the adaptive antenna.

Now, if the first pulse is Fourier transformed and be represented by $f_\Delta(\omega)$, then (3.1a) is written as:

$$f_T(\omega) = a_0 f_\Delta(\omega) + a_1 f_\Delta(\omega)e^{-j\omega\tau} + a_2 f_\Delta(\omega)e^{-j2\omega\tau} + a_3 f_\Delta(\omega)e^{-j3\omega\tau} + a_4 f_\Delta(\omega)e^{-j4\omega\tau} \quad (3.1b)$$

By letting $a_0 = a_1 = \ldots = a_4$

$$f_\tau(\omega) = a_0 f_\Delta(\omega)\left[1 + e^{-j\omega\tau} + e^{-j2\omega\tau} + e^{-j3\omega\tau} + e^{-j4\omega\tau}\right] \quad (3.2)$$

Multiply equation 3.2 by $e^{-j\omega\tau}$

$$f_\tau(\omega)e^{-j\omega\tau} = a_0 f_\Delta(\omega)\left[e^{-j\omega\tau} + e^{-j2\omega\tau} + e^{-j3\omega\tau} + e^{-j4\omega\tau} + e^{-j5\omega\tau}\right] \quad (3.3)$$

Subtracting (3.3) from (3.2):

$$f_\tau(\omega)\left[1 - e^{-j\omega\tau}\right] = a_0 f_\Delta(\omega)\left[1 - e^{-j5\omega\tau}\right]$$

or

$$f_\tau(\omega) = a_0 f_\Delta(\omega)\left[\frac{1 - e^{-j5\omega\tau}}{1 - e^{-j\omega\tau}}\right] \quad (3.4)$$

Since $\sin\theta = \dfrac{e^{j\theta} - e^{-j\theta}}{2j}$

$$f_\tau(\omega) = a_0 f_\Delta(\omega)\left[\frac{e^{-j5\omega\tau/2}\sin(5\omega\tau/2)}{e^{-j\omega\tau/2}\sin(\omega\tau/2)}\right] \quad (3.5)$$

$$f_\tau(\omega) = a_0 f_\Delta(\omega)\left[e^{-j5\omega\tau/2} e^{+j\omega\tau/2}\left(\frac{\sin(5\omega\tau/2)}{\sin(\omega\tau/2)}\right)\right] \quad (3.6)$$

$$f_\tau(\omega) = a_0 f_\Delta(\omega)\left[e^{-j2\omega\tau}\left(\frac{\sin(5\pi f\tau)}{\sin(\pi f\tau)}\right)\right] \qquad (3.7)$$

Since $\omega = 2\pi f$

Equation 3.7 represents the antenna array equation of five elements equally spaced as shown in Fig 3.3. Note that $f_\Delta(\omega)$ is the radiation pattern or gain factor of the first element of the array. Fig 3.3 is the pattern of antenna array of five elements equally spaced.

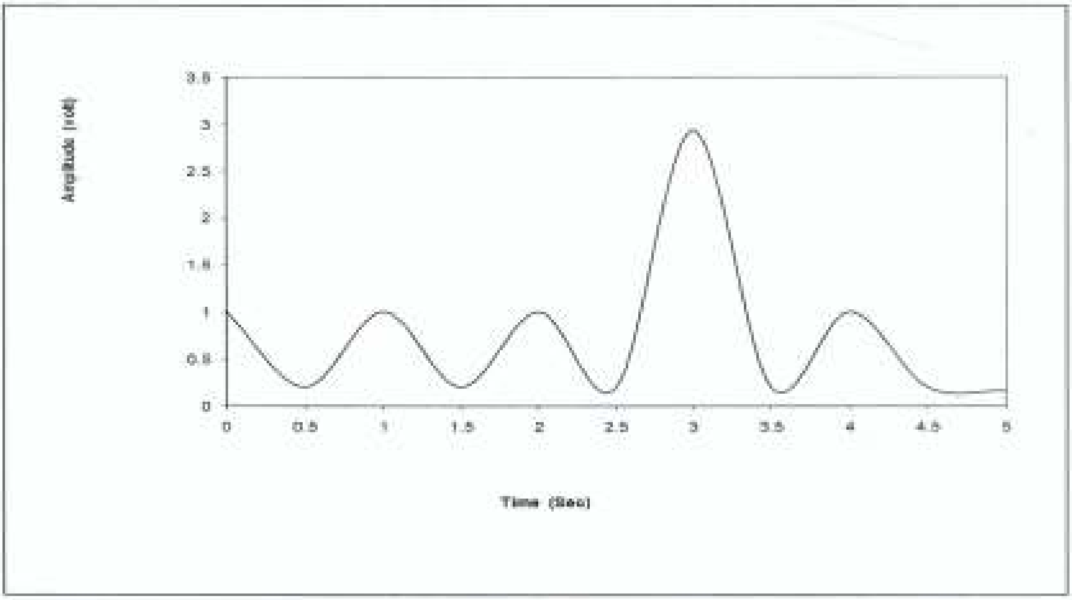


Figure 3.3: Electric field response of adaptive antenna array of five elements using frequency of 1MHz

The Figs. 3.4, 3.5 and 3.6 show the field responses of some of existing service providers of satPCS. For consistency, the weight/gain of each element a_0 and its gain factor, $f_\Delta(\omega)$, for the "service providers" are the same. Figs. 3.3, 3.4, 3.5 and 3.6 are comparable, except that the absolute values of responses of Fig. 3.4, 3.5 and 3.6 were taken, since the responses in rear sides are the same as the responses in the front side.

From the simulation and analysis carried out in section 3.3 on the antenna array, the higher the frequency that is, moving from LEOs to GEOs, the sidelobes became apparent and given rooms for interferers to make a remarkable effect on the Signals of Interest (SOI) received from the satellite (see Figs 3.4, 3.5 and 3.6). The amplitudes and phases of the signals at each element are weighted uniformly, as expected when dealing with satPCS antenna arrays on handheld terminals. Time varying weights are not desirable because they may modulate the desire signal.

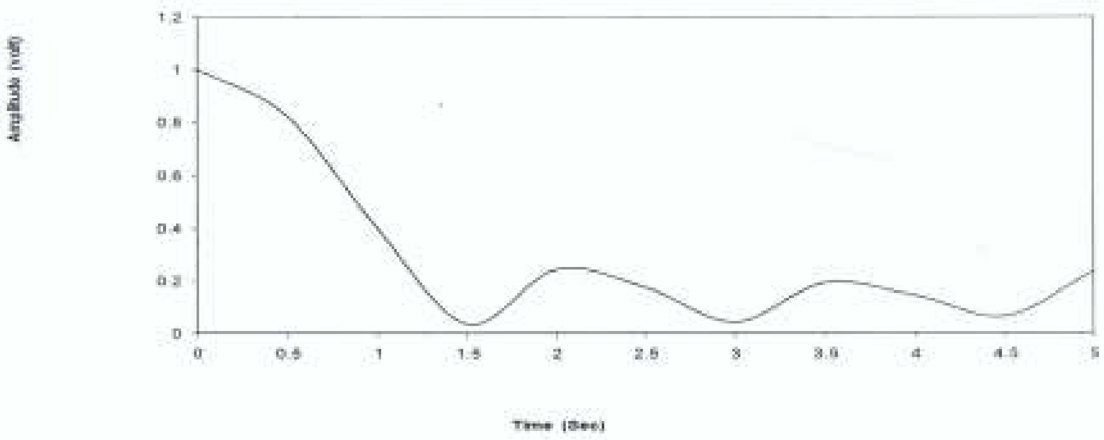


Figure 3.4: Electric field response of ORBCOM (f= 0.1376 GHz)

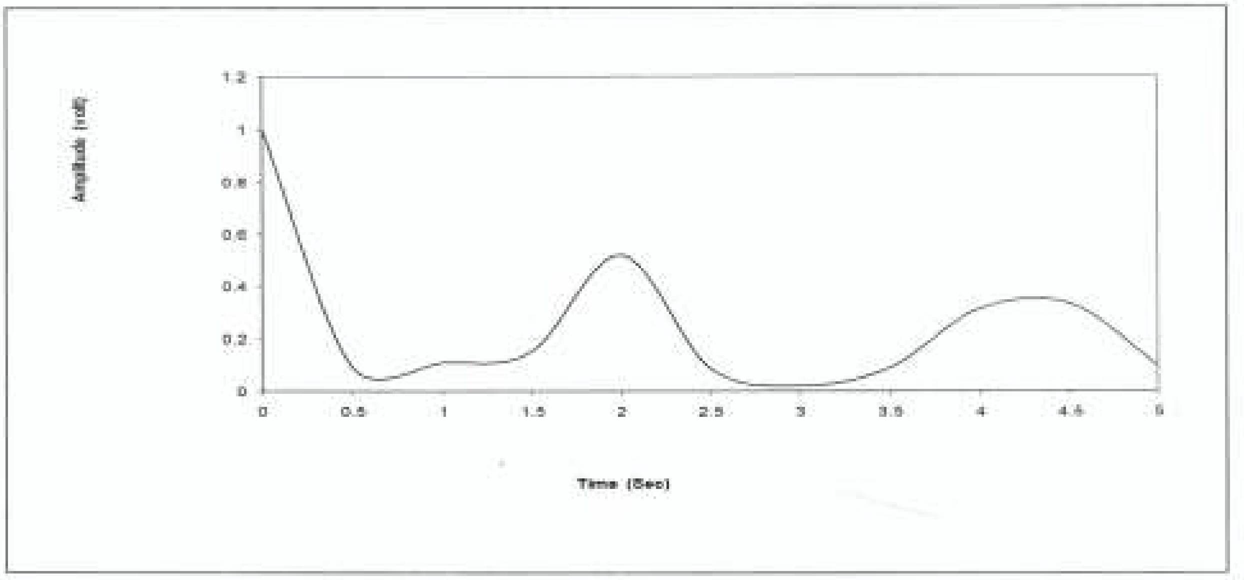


Figure 3.5: Electric field response of GLOBALSTAR (f= 2.49 GHz)

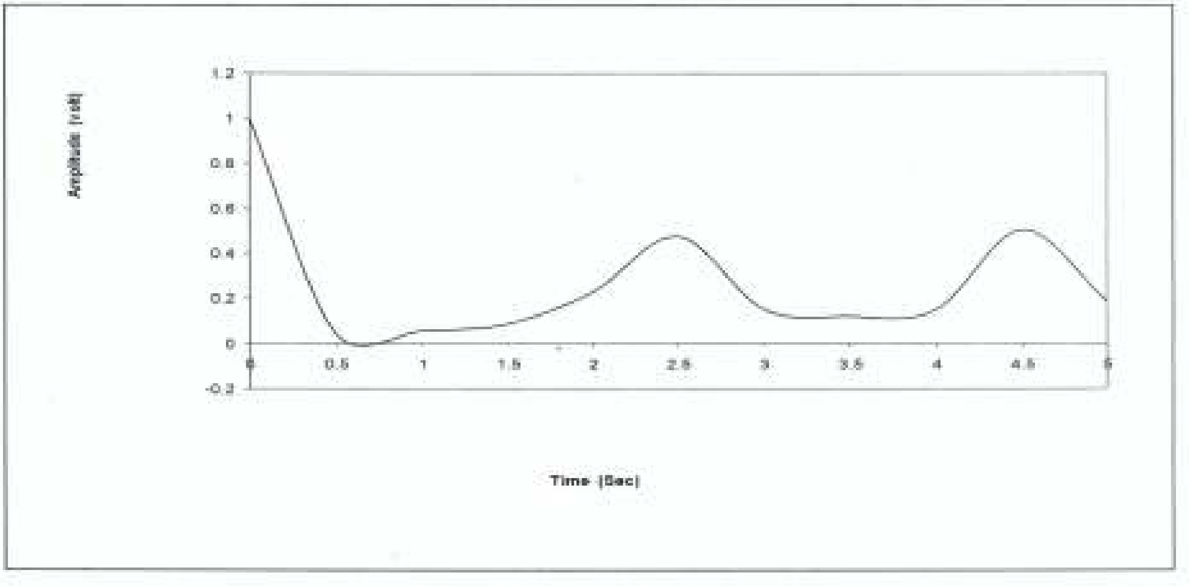


Figure 3.6: Electric field response of AMSC-1 (f= 1.57 GHz)

(ii) GRATING NULLS

Grating nulls are undesirable because interference null by the array at one angle may cause additional nulls (grating nulls) to appear at other angles. If the desired signals fall in a grating null, this will result in a low signal to interference plus noise ratio (SINR). To illustrate better this concept, we will reuse Fig. 3.2.

The output of all the elements is summed to produce an output, X(t). Element 1 will be taken as the reference signal with zero phase. The incremented difference in the phase of the signals with respect to adjacent element is: $\varphi = \frac{2\pi d}{\lambda}\sin\theta$, where θ is the direction of the incoming signal. For this analysis, we will further assume that the amplitudes and phases of the signals at each element are weighted uniformly. As a result, the antenna gain for each element can be normalized to unity. The sum of all the signals from the individual elements when the phase difference between elements is φ, can be written as

$$Y = \sin 2\pi f_c t + \sin(2\pi f_c t + \varphi) + \sin(2\pi f_c t + 2\varphi) + ... + \sin(2\pi f_c t + (N-1)\varphi) \quad (3.8)$$

where, $2\pi f_c$ is the angular frequency of the signal.

The sum can be written

$$Y = \sin[2\pi f_c t(N-1)\varphi]\frac{\sin(N\varphi/2)}{\sin(\varphi/2)} \quad (3.9)$$

The first factor is a sine wave of frequency $2\pi f_c$ with a phase shift $(N-1)\varphi/2$ (if the phase reference was taken at the centre of the array, the phase shift would be zero), while the second term represents an amplitude factor of the form: $\frac{\sin(N\varphi/2)}{\sin(\varphi/2)}$. The field intensity pattern is the magnitude of equation 3.9, or

$$|Y| = \left| \frac{\sin\left\{ N\left(\frac{\pi d}{\lambda} \sin\theta \right) \right\}}{\sin\left(\frac{\pi d}{\lambda} \sin\theta \right)} \right| \tag{3.10}$$

The pattern has nulls (zero) when the numerator is zero. The latter occurs when $\frac{N\pi d}{\lambda} \sin\theta = 0, \pm\pi, \pm 2\pi, ..., \pm n\pi$.

The value of the field intensity is apparently indeterminate when both the numerator and denominator are zero. With the help of L'Hospital's rule, it is found that $|Y|$ is a maximum whenever $\frac{d}{\lambda} \sin\theta = \pm n\pi$.

These maxima all have the same value equal to N. The maximum at sin θ =0 defines the main beam. The other maxima are called grating lobes, which are typically undesirable. In the case when the spacing is a half-wavelength (i.e. d=λ/2), the first grating lobe does not appear in real space since that requires that sin θ>1, which cannot happen. Grating lobes appear at ±90° when d=λ.

Therefore, an antenna with isotropic elements has a similar pattern in the rear of the antenna as in the front. In order to avoid any ambiguity, the backward radiation is usually eliminated by placing a reflecting screen behind the array. Thus, only the radiation over the forward half of the antenna needs to be considered. The radiation pattern is equal to the normalized square of the amplitude:

$$G(\theta) = \frac{|Y|^2}{N^2} = \left[\frac{\sin\left\{ N\left(\frac{\pi d}{\lambda} \sin\theta \right) \right\}}{N \sin\left(\frac{\pi d}{\lambda} \sin\theta \right)} \right]^2 \tag{3.11}$$

(iii) PRACTICAL LIMITATION

In chapter 2, Tables 2.2, 2.3, 2.4 and 2.5, the data presented for satPCS examples show that most of the satellite constellations for personal communications broadcast at L- and S-Bands. At these bands the wavelength is in the range of 10 to 20 centimeters. As mentioned previously, the spacing between the antennas is typically 0.5λ. Consequently, this will be a challenge for the handheld unit designers since they have to be concerned with the implementation and design of the handheld unit. Thus, the size of the array becomes the limiting factor in terms of the number of elements that can fit on the handheld unit. In order to mount a linear array on the handheld unit, the maximum number of elements that can conveniently fit limits the antenna to a two element array. If multiple elements were used on a handheld unit at L-Band, this might result in a bulky handheld unit. Advances in nanotechnology could make this constraint a reality [Kolawole, 2009]. Currently, the size of the handheld unit is a major factor in consumer satisfaction. However, in the case of higher frequencies, such as S-Band, a four element array may fit onto handheld unit.

(iv) DEGREES OF FREEDOM

The more antenna elements in an array, the more degrees of freedom the antenna possesses in combating interference and multipath fading. For instance, an N-element antenna array has (N-1) degrees of freedom in its pattern. This puts a limit on the number of things an array can do at a particular time.

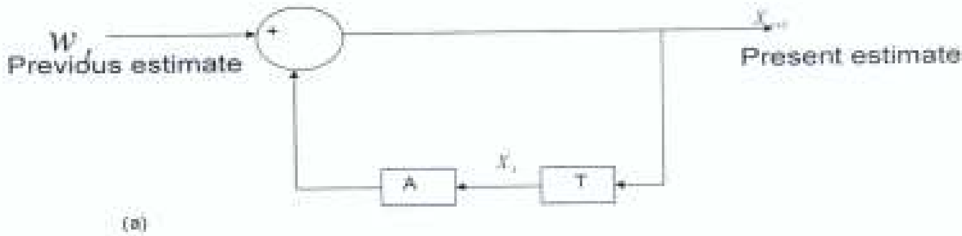
3.4 THE KALMAN FILTER ALGORITHM

The main function of the Kalman filter is to provide an estimate of the current state of a dynamical system. Also, the filter can serve as the basis for predicting future values of some prescribed variables or for improving previous estimates of parameters of interest [Haykin, 1989].

The Kalman filter is a recursive estimator used to estimate the state of a linear time-varying state equation, in which the states are driven by noise and observations are made in the presence of additive noise. Many approaches can be used to derive the Kalman filter, each with its own criterion of optimality. Some of these approaches are: Bayes approach- an application of the recursive Bayes estimation; the innovations approach- building upon the principle of orthogonality; and the calculus- based techniques [Moon, 1999]. In this project, the Bayes approach is used to derive the algorithm for the simulation of the Kalman filter. Detailed derivation of Bayes approach is given in Appendix B.

3.4.1 MODELS FOR RANDOM PROCESSES [Moon, 1999; Bozic, 1994; Kalman, 1960]

In this section the models (random and measurement) in Fig 3.2 are considered in detail. The Kalman filter is an application of sequential estimation to a discrete- time state- variable system driven by noise, with noisy observations. The models are shown in Fig 3.7, comprising model of random signal process and measurement (observation) model.



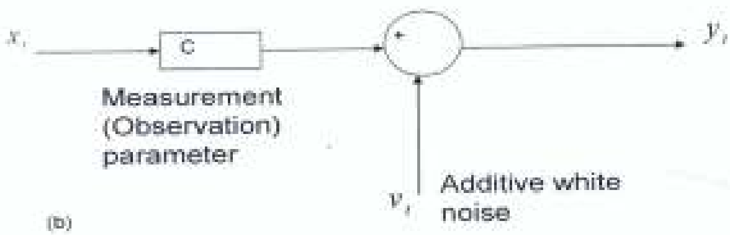


Fig. 3.7: (a) Random Signal process model,
(b) Measurement (observation) model

Using Fig. 3.7 as a guide, the state and measurement equations are represented as

$$\begin{Bmatrix} X(t+1) = A(t)X(t) + W(t) \\ Y(t) = C(t)X(t) + V(t) \end{Bmatrix} \tag{3.12}$$

where,

$A(t)$ = system parameter

T = Unit time delay

$C(t)$ = measurement (observation) parameter

$W(t)$ = Gaussian White Noise

$V(t)$ = Additive noise

$X(t+1)$ = Present estimate

$X(t)$ = Previous estimate

$Y(t)$ = Filter output/ measurement estimate

As indicated, the state- variable system may be time-varying. The following assumptions are made about this system:

- For convenience, all processes are assumed to be real.
- For the Bayesian approach to the Kalman filter, we assume that W_t is Gaussian of centered zero mean, where W_t is the state noise process.
- The observation noise V_t is assumed to be stochastic. It is additive noise of the measurement model.
- There is some initial condition, or a *priori* density, on the random variable X_0, and is taken as Gaussian.

The important property of Gaussian random signals is that they remain Gaussian after passing through a linear system [Mohanty, 1989]. The summary of the Kalman filtering problem is that given a sequence of measurements $y_0, y_1 \ldots$ at time t=0, t=1... determine a sequence of estimates of the state of the system $X(t)$ in a computationally feasible, recursive manner. This forms the basis of the algorithms that are needed for simulation. Fig 3.7 in Fig 3.2, and following developed equations from (3.9) to (3.12) form the basis of the algorithms for simulation whose results are detailed in chapter 4.

3.5 SUMMARY

Satellite personal communication systems experience some of the problems that occur in the terrestrial systems. The most commonly encountered are interference and multipath already discussed in this chapter. This chapter equally shows the technique of combating the interference with the help of adaptive antenna arrays, which can be processed using Kalman filtering technique. The limiting factors: i.e. grating nulls, spacing of the elements and number of degrees of freedom, that affect the performance of adaptive antenna arrays are discussed.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 SIMULATION ASSUMPTIONS

All the simulations for this thesis were carried out on Excel programme (Spread Sheet). The entire antenna arrays modeled is dipole arrays. In essence, five sets of arrays are used. The Fourier transform of the entire pulses were taken to derive the array pattern as demonstrated in section 3.3.

In satellite based personal communication system, there is the problem of interference from both correlated and uncorrelated signals. Interference in this context will be constrained to uncorrelated signals, which are a result of interference arriving from other users within the coverage areas or from other satellites. Multipath signals are considered as correlated signals because they are principally phase shifted versions of the Signal of Interest (SOI). They occupy the sidelobes of the antenna array pattern (see Fig 3.3). Multipath arrives at the receiver via different paths due to refection from scattering surfaces such as vehicles, building, cloud and ocean (see Fig 3.1).

The simulation is divided into two parts; the first simulation has been demonstrated in section 3.3, and presents how the center frequency of each service provider is used to determine the antenna array pattern (see Figs 3.4 3.5 and 3.6). The second part of the simulation is demonstrated next, using the Kalman filter algorithm (equation 3.12) to eliminate the correlated signals due to interference and multipath.

4.2 SIMULATIONS AND RESULTS

4.2.1 ADAPTIVE ANTENNA ARRAY PATTERNS

The antenna patterns were achieved by taking the absolute values of the response at the respective period of each measurement. The absolute values were taken because of the responses in the rear side of the main lobe are the mirror versions in the front side of the main lobe. Hence, figures 8, 9 and 10 are the responses of the signals of the selected service providers. Two methods may be used to achieve processing; the one used is the response of the Fourier transform of the pulses at the output of the adaptive antenna arrays on the handheld terminals, and as a function of the period of measurement (equation 3.7). Here, a_0 is the weight of the antennas, which determines the gain/array factor; $f_\Delta(\omega)$, the Fourier transform of the first antenna array [Kolawole, 2003] and $e^{-j\omega t}$ only determines the phase shift of the pattern. The second method involves the use of Direction of Arrival (DOA) as in equation 3.10. The DOA may be varied fractionally, say between 0° and 5°, to determine the scanning effect of the array pattern.

4.2.2 KALMAN FILTER ALGORITHM IN ADAPTIVE ANTENNA ARRAYS

The Kalman filter algorithm was defined in section 3.4. These simulations attempt to show that adaptive antenna array is effective in combating both interference and multipath fading. This section presents a concrete description of the type of problem currently being studied. The estimated values of Y(t) at t_0 when t_0= t(0)= 1 as the initial condition and assuming w(t) to be probability (Gaussian) distribution function of mean centered zero and the additive noise of the measurement (observation) process assuming to be stochastic, hence, the filter response is determined. The measurement behavior as the system parameter A(t) increases s estimated; it conveys all the information of the measurement of the random variables $x(t_0),\ldots,x(t)$ about y(t). The statistical estimate of the random variables Y(t) is a function of the random variables $x(t_0),\ldots,x(t)$.

The statistical dependence (correlation) between the random signals observed at different times as a result of the presence of a dynamic system and the observer provides a better performance of the Kalman filter [Kalman, 1960].

Figs 4.1, 4.2, 4.3 and 4.4 show the simulated results of the adaptive antenna output when processed using Kalman filter algorithm model (Fig. 3.7) under various levels of additive noise W(t). Equation 3.12 provides the recursive estimation characterized by Kalman filter algorithm. Fig 4.1 shows the response where the sidelobes where eliminated. Figs. 4.2, 4.3 and 4.4 show the responses of the Kalman filter output when the additive noise is varied and resulted to sine function. Higher the additive noise on the measurement (observation) model, results in a little change in the amplitude of the estimation but no effect on the periods and waveform patterns. Given that W(t) is Gaussian White Noise of mean centered zero, the waveform patterns remain constant without much effect on the variations of W(t).

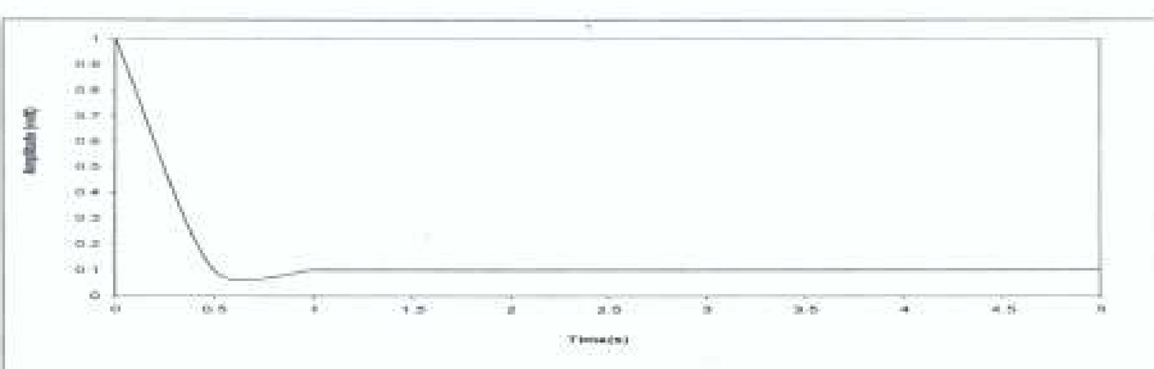


Figure 4.1: Kalman filter output

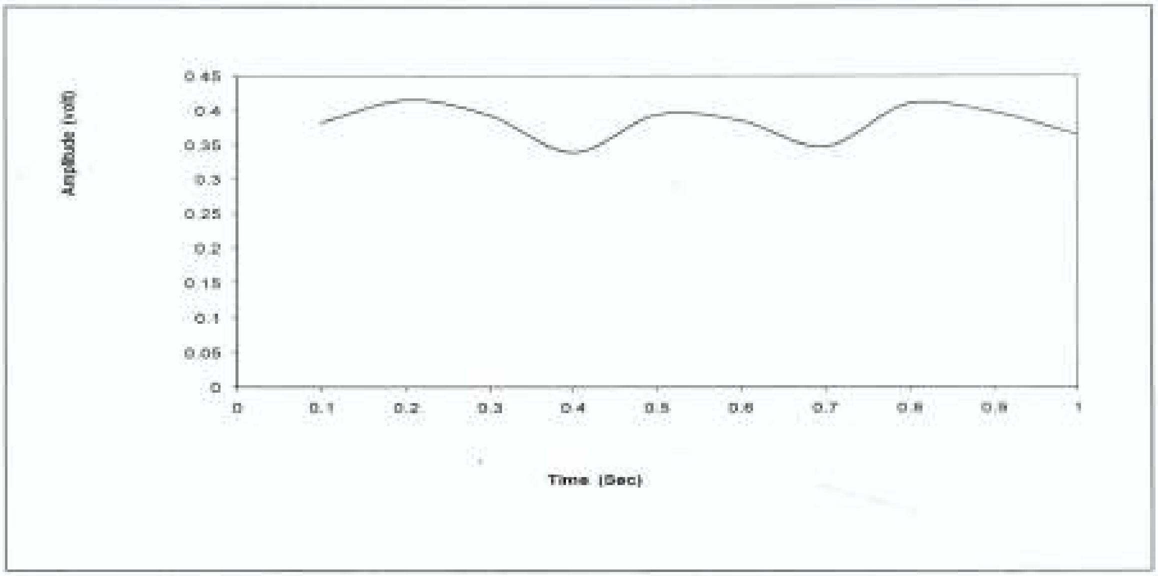


Figure 4.2: Kalman filter Electric field response when V(t)= 0 volt

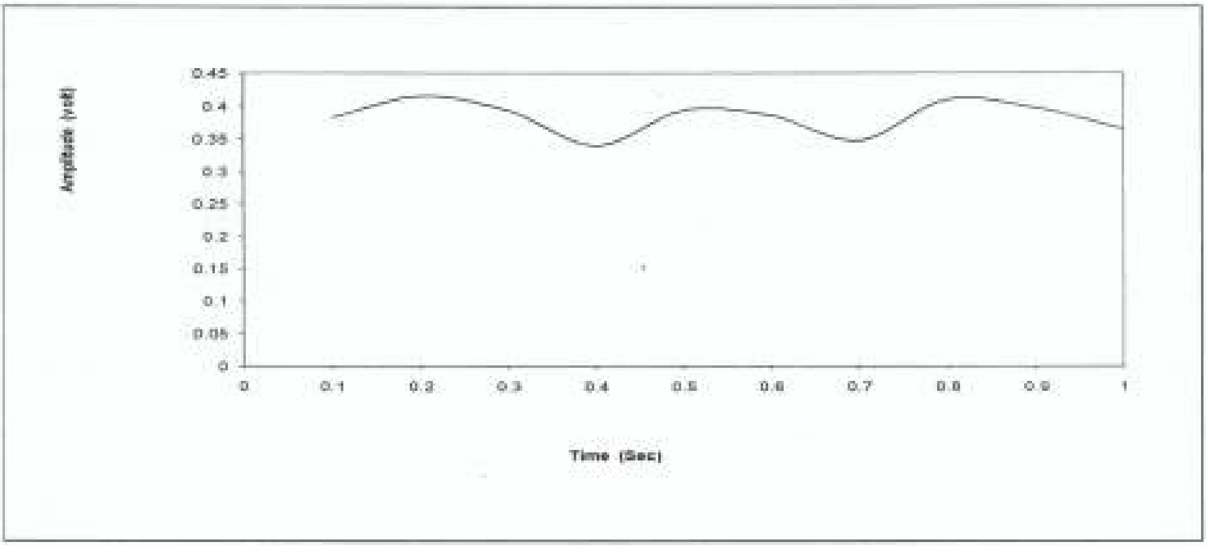


Figure 4.3: Kalman filter Electric field response when V(t)= 0.5 volt

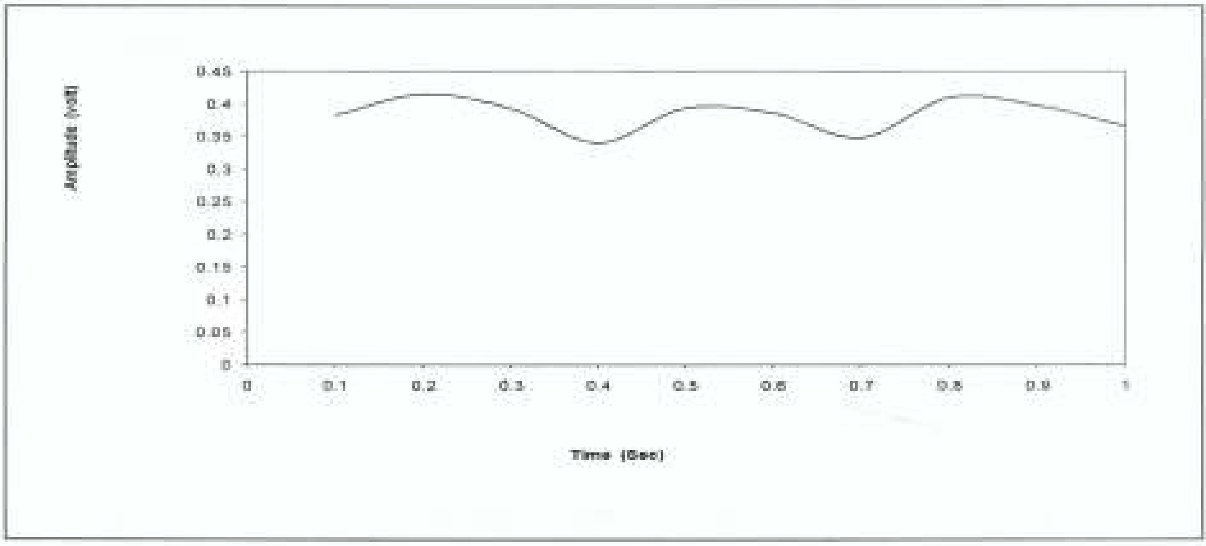


Figure 4.4: Kalman filter Electric field response when V(t)= 2.0 volt

4.2.3 MULTIPATH IN THE PRESENCE OF SIGNAL OF INTEREST

Numerous techniques can be used to eliminate the effect of multipath in satPCS. [Gabriel, 1984] proposed the use of the Burg maximum entropy method and the maximum likelihood method. [Shan, 1985] uses a preprocessing scheme for the sensor outputs that will restore the rank of the signal covariance matrix so that the multipath signal will be completely coherent with "Signal of Interest". The second method is based on combining measurements and overlapping the sub-arrays. These two methods are mostly used when more than two antenna elements are required.

The elimination of multipath is achieved by making the signal of interest uncorrelated with the multipath arriving from the scattering due to physical structures such as building, vehicles, cloud and ocean. In this thesis, a unit step delay introduced to the multipath signal before processing and superimposed with the signal of interest as shown in Fig. 4.5.

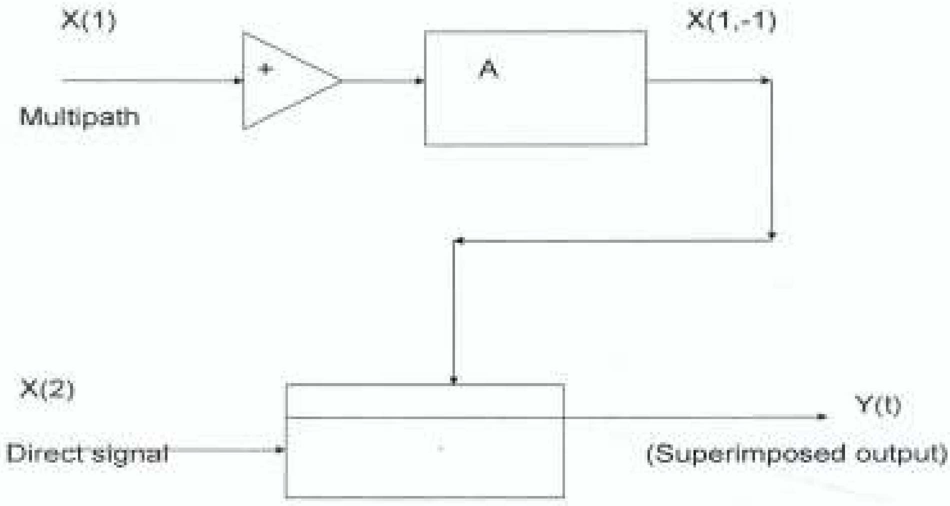


Fig. 4.5: Superposition of multipath with direct signal

This superposition method allows the system model of the handheld unit to determine which of the arriving signals are stronger, and then to switch to the antenna for a given time interval. In the case where there is no direct Line-of-Sight (LOS) present, numerous multipath signals might be incident on the handheld terminals. When this occurs, the antenna with the strongest incident signal will be selected to receive the strongest component.

CHAPTER FIVE

CONCLUSION

om the simulations of the antenna arrays carried out, it was noticed that a Kalman filter based aptive antenna array can eliminate an uncorrelated signals residing in the antenna sidelobes ccessfully; however, in the case of multipath, the signal is delayed by unit step before it is perimposed with the direct signal for better processing.

an be observed that the Kalman filter perform better and feasible under LEOs satPCSs rational centered frequencies as a result of shorter time required by LEO satellites to move oss the sky. The variation of the weights as a result of movement of the handheld rs/mobile units may affect the effectiveness of the system as we are moving from LEOs ugh MEOs to GEOs. However, a mobile user of any of the systems might experience the e problem since the environment is changing too rapidly for the weights to converge. This blem could be overcome by adopting blind adaptive algorithms to compensate for the weights ation. Blind adaptive algorithms are algorithms that exploit the characteristics of the signal elope and utilize this information to adapt the weights to the changing environment. reover, since some of the satellite constellations utilize CDMA as the multiple access nique, pseudo noise, PN codes can be utilized to monitor the adaptive array weights. As a lt, this thesis has demonstrated that the Kalman filter algorithms can be used as a blind ptive algorithm, but not inherently blind.

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APPENDIX A

GLOSSARY OF TERMS

Adaptive Antenna Array	An array that has ability to adapt to the changing environment and null out the interference.
Antenna	The transitional structure between free-space and a guiding device.
Array	The new antenna formed by multiple elements of identical characteristics.
Array antenna	An aggregate of radiating elements in an electrical and geometrical arrangement which results in the desired radiation characteristics.
Communication satellite	An electric relay station orbiting in space that picks up messages transmitted from the earth station and retransmits them to a distant location on earth or other satellites in space.
Constellation	A collection of identical satellites designed to provide multiple coverage.
Code Division Multiple Access (CDMA)	A multiple access based on spread spectrum principles using orthogonal codes to avoid interfering with one another.
Downlink	The communications channel from a satellite to an earth station.

Filter	An electrical or microwave device designed to allow a selected range of signal frequencies to pass while obstructing those outside the range.
Footprint	An area on earth illuminated by a satellite antenna
Geostationary satellite (GEO)	A satellite placed in the geostationary orbit, at about 35,000 km from the earth's surface.
Grating lobe	An unwanted sidelobe caused by two radiating, or receiving antennas or elements that are separated by more than one half wavelength.
High Elliptical Orbiting Satellite (HEO)	An elliptical orbit satellite approximately 18,000-35,000 km above the earth's surface.
Inter-satellite link (ISL)	The link between two satellites in the same orbit.
Kalman filter	A recursive filter extremely useful in processing measurements to obtain the optimal estimate, utilizing a digital computer.
Ka Band	Frequency range from 18 to 31 GHz.
Ku Band	Frequency range from 10.9 to 17 GHz.
L- Band	Frequency range from 0.5 to 1.5 GHz. Also refers to the 950 to 1450 MHz for cellular radio communications.
Low-Earth Orbiting Satellite (LEO)	A satellite that orbits the earth in grids, stretching approximately 160-1600Km above the earth's surface.
Middle-Earth orbiting	A satellite located on the orbit between the lower

Satellite (MEO)	orbits and the geostationary orbits; circular and orbits approximately 8,000-18,000Km above the earth's surface.
Orbit	A path relative to a specified frame of reference, described by the centre of mass of a satellite in space, subject to gravitational attraction.
Omni-directional antenna	An antenna that radiates uniformly in all directions
Satellite personal Communication systems (SatPCS)	A communication that can provide communication services to vast regions of the earth surface through satellite.
Satellite	An electronic communication system stationed in an orbital plane above the earth. Also known as a spacecraft.
Uplink	The pathway from earth-to-satellite telecommunication.

APPENDIX B

KALMAN FILTER: THE BAYES APPROACH

For the Bayesian approach, it is assumed that the noise processes are Gaussianly distributed. Then the Bayes estimate of X_t amounts to finding the conditional mean of X_t, given the observations.

The key equations in the Bayes derivation are the propagation step [Moon et al, 1999]

$$f(X_{t+1} \mid y_t) = \int f(X_{t+1} \mid X_t) f(X_t \mid y_t) dX_t \qquad \text{(B1)}$$

From which the estimate is propagated using the state update equation into the future; and

$$f(X_{t+1} \mid y_{t+1}) = \frac{f(y_{t+1} \mid X_{t+1})}{f(y_{t+1} \mid y_t)} f(X_{t+1} \mid y_t) \qquad \text{(B2)}$$

which is the measurement update.

In summary, we have the following: starting from an initial estimate $\hat{X}_{0|-1}$, with an initial covariance of $p_{-1|-1}$, for each observation y_t, t= 0, 1 ..., the estimate of the state is updated using the following steps

- State estimate extrapolation : $\hat{X}_{t+1|t} = A_t \hat{X}_{t|t}$ (B3)
- Error covariance extrapolation: $P_{t+1|t} = A_t P_{t|t} A_t^T + Q_t$ (B4)
- Kalman estimate update: $K_{t+1} = P_{t+1|t} C_{t+1}^T \left(C_{t+1} P_{t+1|t} C_{t+1}^T + R_{t+1} \right)^{-1}$ (B5)
- State estimate update: $\hat{X}_{t+1|t+1} = \hat{X}_{t+1|t} + K_{t+1} \left(y_{t+1} - C_{t+1} \hat{X}_{t+1|t} \right)$ (B6)
- Error covariance update: $P_{t+1|t+1} = \left(I - K_{t+1} C_{t+1} \right) P_{t+1|t}$ (B7)

In the interest of reducing computations, the Kalman gain and error covariance update are sometimes written as:

$$K_{t+1} = P_{t+1|t+1} C^{T}_{t+1} R^{-1}_{t+1} \tag{B8}$$

$$P^{-1}_{t+1|t-1} = P^{-1}_{t+1} + C^{T}_{t+1} R^{-1}_{t+1} C_{t+1} \tag{B9}$$