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An intelligent SOP navigation system with two mobile receivers

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A Thesis

entitled

An Intelligent SOP Navigation System with Two Mobile Receivers

By

Praneeth Nelapati

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the

Master of Science Degree in Electrical Engineering

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The University of Toledo
August 2011

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An Abstract of
An Intelligent SOP Navigation System with Two Mobile Receivers
By
Praneeth Nelapati
Submitted to the Graduate Faculty as partial fulfillment of the requirements for the
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In this thesis an Intelligent Signals of opportunity (SOP) system is proposed. The intelligence integrated in the system is based on Self Cloned Evolutionary Neural Networks. Signals of Opportunity (SOP) are highly efficient and effective alternative for the Global Positioning System (GPS). The conventional SOP system has one fixed base receiver and one mobile receiver. SOP helps navigation by precisely measuring the time difference between the signals arriving at two points, namely base station and mobile unit. The principal difficulty involved in establishing the SOP is the time and cost required for setting up the base stations. A novel approach proposed in this thesis eliminates the need for fixed base receiver and replaces it with the mobile receiver.

The proposed system was simulated for both the Amplitude Modulated and Frequency Modulated Systems. It has been demonstrated that improved SOP system is 94.9 % more efficient than the conventional method for the Amplitude Modulated (AM) signals. It is 91.43% more efficient over conventional system for Frequency Modulated (FM) signals. The intelligence built into the system identifies the most appropriate signal available in a given locale. In an urban area, where the available signal resources are abundant, the SOP

system signal selection process is time consuming and thus blocks the navigational service occasionally. To overcome the problem, intelligence is built into the system using Evolutionary Neural Network which trains based on the past analysis of the system. To make the learning in the neural network faster than a conventional evolutionary algorithm, an algorithms based on selective cloning is used.

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Chapter 1

Introduction

The Global Positioning System (GPS) is a widely used navigation system that provides accurate positioning with a high degree of reliability [8]. GPS system is equipped with 24-32 satellites in the higher orbits of the earth, and at least three to four satellites monitors any location on the earth during any instant of time [11]. A GPS receiver calculates its position by precisely timing the signals sent by these satellites, with accuracy up to 3 meters. GPS module being compact and highly efficient has found applications in both the military and civilian domains [9].

The primary application of a GPS system/unit is to help the soldiers identify their location in unknown territories. Other applications include Target Tracking, Missile and Projectile Guidance, Search and Rescue, Reconnaissance and Map Creation [8]. The military invests enormous budget in GPS program. The U.S Department of Defense (DoD) estimated that, so far \$8 billion have been spent on the GPS program and this investment may rise to \$ 22 billion by the year 2016 [22]. Though the GPS was initially designed for military use, it has found several applications in civilian domain. Civilian applications include vehicle routing or providing service for surveying.

It is estimated that the complete market value of GPS by the year 2013 will be \$ 75 billion. However, the GPS system has been facing some threats. Advances in missile

technology have enabled the missiles to destroy long range targets thus making GPS system vulnerable to such attacks. Under such an attack, entire investment on the GPS program will go futile. GPS being a very complex system, the time required to replace the existing system will be prohibitive and very expensive. Cost of its replacement will exceed the total investment which has already been made. Thus the destruction of GPS system can play havoc for the civilian and military applications. Therefore, it is very pertinent for national security and civilian communication to have an alternative to GPS system.

1.1 Alternate Navigational Systems

Apart from the GPS, several alternatives have become available for navigation.

Navigation using the Signal of Strength: This is the most basic approach used for navigation that uses signal properties. The path loss model is used to estimate the distance between the transmitter and the receiver based on the signal loss. The path-loss model is a model designed taking into consideration the geographical terrain and other factors affecting the signal propagation. The signal loss is recorded based on the difference between the power of transmitted and the power of the received signals. Using the path loss model, the loss of signal power is used to determine the distance of separation between the transmitter and the receiver. This method for locating the receiver has the following drawbacks:

1. The signal noise is probabilistic in nature and hence the loss estimated by the path-loss model may not be always accurate.

2. Large errors in estimation of the position are likely due to multi path effect and fading of signals.

Navigation using the Time of Arrival: This approach includes a time stamp of the transmitted signal. The time of transmission at the transmitter end and the time of reception at the receiver are recorded. The distance travelled by the signal is determined based on the propagation time of the signal. Precise synchronization of transmitter and receiver clocks is required to avoid any errors in positioning.

Navigation using Angle of Arrival: In the angle of arrival technique, an array of antennas measure the angle of signal reception from various transmission sources and using the triangulation technique, coordinates of the required location are determined [4]. The inherent drawback of this technique is that as the distance between the transmitter and the antenna unit increases, the accuracy of the position determined is reduced. The reason behind this is that the signal to noise ratio (SNR) deteriorates with increasing distance of separation, creating sensitivity problems for the antenna unit.

Navigation using Time Difference of Arrival: The simplest TDOA navigation system consists of two receivers sharing a communication link [1]. The time of reception of the signal is recorded at both the receivers. This information is shared through the communication link to determine the location of the receiver. Decca Navigator system and LORAN are the two examples of the TDOA system.

Decca Navigator System: The system contains three slave stations positioned at the vertices of an equilateral triangle with a master station at the center of it. Hyperbolic patterns are created with the comparison of the phasor of the signals transmitted from

each of the slave station with the signal from the master station. The receivers are located using the intersection of hyperboles from different patterns.

LORAN: Multiple transmitters which are synchronized in time are used for location of the receivers [21]. The receiver compares the time difference of arrival of these signals to determine its position [20].

1.2 Navigation using Radio signals

Recent research indicated that the radio signals have distinct navigation properties.

Kim from Air Force Institute of Technology (AFIT) established the correlation efficiency of certain radio signals for Time Difference of Arrival (TDOA) measurement [13]. He tested the potential of AM and FM signals to be used in the navigation. He used fixed and varying correlation methods on different AM and FM sources modulated either with a voice or a song signals with a standard reference signal as a benchmark [13]. The FM signals exhibited strong ability to produce distinct auto correlation peaks showing greater potential as a navigation signals as compared to the AM signals.

Tim from MIT has built passive Signals of Opportunity radiolocation system using Amplitude Modulated broadcast signals [24]. The system determines the range vector between the base station receiver, whose location is known, and the rover whose location is to be determined. He achieved position accuracy up to 15 meters for baseline lengths (distance of separation between transmitter and the rover) extending till 35 kilometers [24].

He used software radio as an alternative for receiver system. The software radio is used to simulate the received AM signals and to perform all the signal processing tasks like digitization and filtering in the computer. The signal reception data is stored in the receivers and are later processed to derive the results. He observed that the AM positioning is highly efficient in the outdoors and its performance is not affected in the wooded areas, where GPS performance is greatly deteriorated in the wooded areas.

Ryan Eggert from Air Force Institute of Technology (AFIT) used National Television System Committee (NTSC) signals for TDOA system and evaluated their navigational potential [12]. The NTSC signals are used in high and low multipath environments for recording the time difference of arrival data. The TDOA measurement using NTSC signals are observed to have an error range of 1 to 200 meters, with the mean error varying between 10 to 40 meters [12].

Jonathan A. McEllroy from Air Force Institute of Technology (AFIT) developed a simulation environment that mimics the real world AM broadcasting environment to evaluate the ability to navigate using the AM signals [10]. He chose the software radio to eliminate the hardware limitations in signal processing. The average position of error is observed to be a dependent on the Signal to Noise Ratio (SNR) of the signal. Multipath fading is determined to be a major source of error [10].

Fischer from Air Force Institute of Technology (AFIT), described the process of marking the potential of signal for navigation as compared to GPS. He put forward the theory of Navigation Potential (NP) [7].

The research in this area evolved to introduce and establish a navigational system based on any available radio signal, known as Signals of Opportunity (SOP) system [2].

SOP system uses the concepts of Time Difference of Arrival (TDOA) between the signals and corresponding locations of the radio sources for navigation.

Chapter 2

Conventional Signals of Opportunity System

In this chapter, the concepts of a Signals of Opportunity (SOP) system are discussed. The hardware requirements of the transmitters and receivers in the system are discussed. A Signal of Opportunity (SOP) System is a potential navigational system that can be used as an efficient alternative to the GPS [17].

2.1 Advantages

Signals of Opportunity system have the following advantages giving them an edge over other existing navigational system.

2.1.1 Availability

Any radio signal can be SOP signal, like an AM signal or a digital TV signal. So there is no lack of availability of signal resources for SOP system.

2.1.2 Flexibility of Choice:

In general any populated area has a spectrum of signals ranging from simple telecast signals to highly encrypted data signals. The reason that SOP system can operate on any signal gives the system a choice to select any of these signals for navigation. The wide range of signal options makes SOP system flexible.

2.1.3 Tolerable to Timing Errors:

In GPS system, the distance between a GPS satellite and a GPS receiver is so large that even a time synchronization error of a micro second may lead to a positional error of hundreds of meters. In SOP system, the transmitter and receiver are not separated by more than a few kilometers; therefore, small timing errors do not affect the performance of the system significantly.

2.1.4 Cost Effective

SOP system makes use of existing signal infrastructure in a given area and therefore minimizes the cost. The SOP technology can be quickly implemented because it does not require the installation of signal infrastructure.

2.1.5 Performance

SOP system has performance comparable to any GPS based Navigation Systems.

2.2 Blocks of SOP System

Fig. 2.1 shows the three building blocks of SOP system.

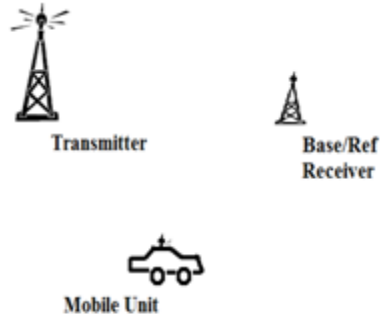


Fig. 2.1 Basic blocks of SOP system

2.2.1 Transmitter

Multiple Transmitters are required for proper functioning of the system.

The SOP transmitter can be any existing signal source in an area, provided that the receivers are capable of processing the signal properties like frequency, modulation and power.

For a simple SOP system, the transmitter should have a stable carrier. The frequency deviation of the carrier should be very narrow, otherwise the receiver system will not be able to lock on to the signal.

The height of the transmitter is a crucial factor in urban areas. The height of the transmitter ensures that the signals have a direct Line of Sight (LOS) with the receivers ensuring minimum signal to noise ratio (SNR). The greater the height, greater is the probability that the signals in clearing the human made structures. The transmitter with lower height has higher probability for the absence of the LOS forcing the SOP receiver to switch to other sources, even though the transmitter possesses good navigational

properties. The height of the transmitter increases the geographical range within which the signals can be used for navigation.

2.2.2 Base/ Reference Receiver

A base or reference receiver is used for providing a reference signal for time difference of arrival calculation at the mobile receiver.

The base receiver is positioned to avoid all the human structure interferences and minimize any kind of atmospheric turbulences. The important attributes of a base receiver are antenna specifications, transmission bandwidth and power source. The antenna should have high sensitivity. The transmission bandwidth between the base receiver and mobile receiver should not be overlapping with other transmissions present in the area. However, installation of new transmission sources with overlapping bandwidth in the future can cause problems to the transmission link. To avoid such issues, the data being transmitted must be encoded so that the mobile receiver can extract the data signal from other interfering signals.

In military applications, the transmission link in enemy territories is preferred to have overlapping bandwidth with existing radio transmissions, as the presence of base receiver will be unnoticed. The power source is a very important component for the base receiver as the signal processing equipment and the strength of the transmission is entirely dependent on it. For commercial applications, low maintenance power sources like solar power sources are highly beneficial as they are highly scalable to meet the increasing power requirements.

2.2.3 Mobile Receiver

The mobile receiver is the user whose position is to be determined. The mobile unit can be either equipped with an Omni directional antenna or a set of directional antennas, with higher sensitivities. The mobile receiver is equipped with the following processing blocks [10].

- Signal processing block
- TDOA calculation block

The locations of the SOP transmitters and the base receiver are determined by surveying and constitute the apriori knowledge which is stored in the memory of the system. The SOP system calculates the relative position of the user or mobile receiver with respect to the SOP transmitters and the base receiver and then integrates them with the stored data to know the actual position of the mobile receiver.

The hardware required for the mobile receiver system and the base receiver system is sophisticated. The receiver system should have a highly sensitive omni-directional antenna that could receive signals with low power. The antenna system for the mobile system has to be more sensitive than the antenna of the base station. This is because the locations of all the transmitters with respect to the base station are known and hence a proper antenna system (even a directional antenna in some cases) for the base station can be installed. The antenna system and the receiver systems have to be equipped with the ability to process a wide range of frequencies. This requires large number of processing elements for various spectrums, increasing the complexity of the hardware. A cost

effective alternative is to use a computer simulator that processes all the signals digitally. The GNU radio is one such example of such a simulator.

2.2.3.1 GNU Radio

The GNU radio is a software radio that enables the host mobile unit to possess all the hardware processing abilities for a broad range of spectrum. The software tool eliminates the additional disturbances due to electromagnetic interference of the hardware. The following are the advantages with the GNU radio:

- The signals being generated in the computer are free from the noise added by the physical components like transistors, resistors, capacitors and other conducting materials.
- The capacitive and inductive effects that restrict the time of stabilization and operation of the circuits are nullified.
- The transition capacitances and the inductances that are generated due to close spacing between the conductors are eliminated.
- Reliability: The wearing effects of hardware components result in decreasing efficiency which is absent in the software radio, making it more reliable.
- Cost Effective and Portability: The hardware circuitry for a wide range of frequencies requires redundant processing elements for each frequency bands, increasing the cost and making the hardware bulky to install.

- Flexibility: The software approach offers more flexibility by allowing updates from time to time without excessive cost. The hardware is to be upgraded each time a new technology is to be implemented.

The GNU software radio requires hardware equipment that receives the real time signal and feeds it to the processor and converts the simulated signals and transmits them. This module is called Universal Software Radio Peripheral (USRP). The Ethernet or a USB connects the USRP to the processor. The USRP module has four Analog to Digital Converters and four Digital to Analog converters. It is equipped with transmitters, receivers and transceivers. The receivers are capable to receive signals up to 4 GHz.

2.3 Basic Signals of Opportunity System

A simple SOP system has two transmitters and a stationary base receiver to locate the position of the mobile receiver (assuming its altitude is zero, as the altitude of the unit can be found using sonar technology or using an equivalent technology) [16].

Fig. 2.2 shows the general mobile network model. Assume that the mobile unit is closer to the transmitter 1 than the base receiver. When the transmitter starts to transmit the signals, because of the closer vicinity, the mobile unit receives the signals first when compared to the base receiver. Let δ be the delay of the signal taken to reach the base receiver, when compared to the mobile unit. Fig. 2.3 shows the range of the base station and mobile unit from the transmitter. Let r_1 and r_2 be the radii associated with the base receiver and mobile unit with transmitter 1 as the center.

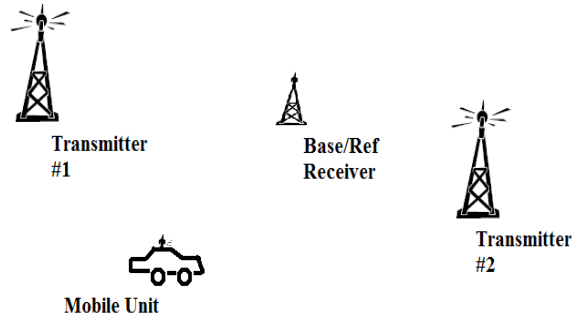


Fig. 2.2: Mobile Network Model

Thus, radial difference between base receiver and mobile unit with transmitter 1 as the center is given by the following equation:

$$r_2 - r_1 = \delta * c \quad (2.1)$$

where c = velocity of light.

Since the radius r_2 , distance between transmitter 1 and base receiver is known, the distance between transmitter 1 and mobile unit r_1 , is given by the following equation

$$r_1 = r_2 - \delta * c \quad (2.2)$$

Fig. 2.4 shows the range hyperboles of mobile unit in reference to transmitter 1. Using the same procedure, we plot range hyperboles of the mobile unit w.r.t the transmitter 2. The point where both the range hyperboles intersect is the location of the mobile unit.

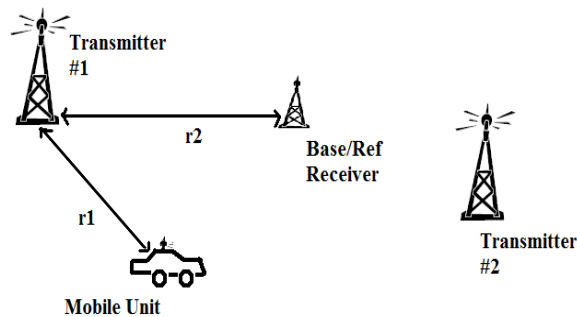


Fig. 2.3: Mobile unit Network: Range of the Base station and Mobile unit

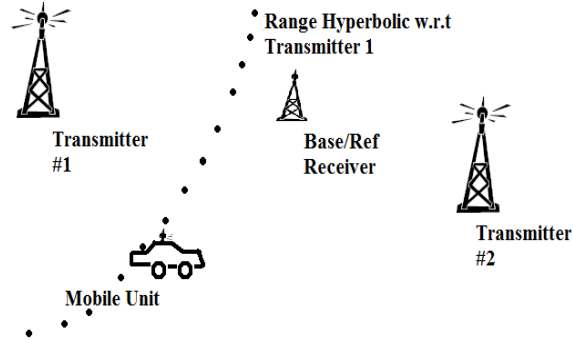


Fig. 2.4: Mobile unit Network: Range hyperboles of the Transmitter 1

Fig. 2.5 shows the intersection of range hyperboles of transmitter 1 and transmitter 2 to locate the mobile unit.

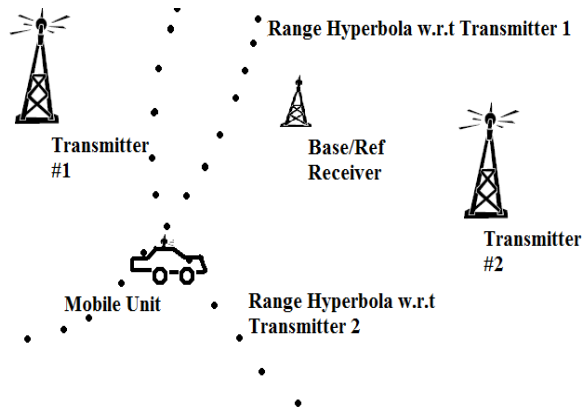


Fig. 2.5: Mobile unit Network: Location of Mobile unit

The time delay δ can be estimated as

$$\delta = t1 - t2 \tag{2.3}$$

$t1$ =clock time of the mobile unit, when the signal is received.

$t2$ =clock time of the base receiver, when the signal is received.

If $\delta > 0$, then the mobile unit received the signals later than the base receiver.

If $\delta < 0$, the mobile unit received signals earlier than the base receiver.

2.3.1 Correlation

The inherent assumption in this explanation is that the transmitter starts transmitting when the base and the mobile receiver are in the vicinity. However, in the real world, the transmissions are continuous in nature and the carriers are periodic. The base station being in the vicinity of the transmitter, will be receiving the transmissions continuously. When the mobile receiver enters the transmission zone of the transmitter and receives its first transmissions from the source at t_1 , it is a difficult job at the mobile receiver to identify the time t_2 at which the same portion of signal is received by the base receiver. One approach is to synchronize both the receiver clocks, so that the time difference of arrival (TDOA) of the signal at the base station and the mobile unit can be determined without ambiguity.

However, synchronizing the mobile unit clock and the base receiver clock is extremely critical. Even though, the clocks are perfectly synchronized, this approach has another principal disadvantage. If the transmissions are periodic, then it is very difficult for the receiver to append the timing information to the amplitude/power levels of the signal.

To avoid such confusion, there is an alternate approach: Correlation of signals [13]. Correlation or Cross-correlation measures the similarity of two signals and is a function of relative time between the two signals [18]. For two continuous signals $x(t)$ and $y(t)$, the cross correlation $R_{xy}(T)$ is

$$R_{xy}(T) = \int_{-\infty}^{\infty} x(t)y(t-T)dt, \quad T \in (-\infty, \infty) \quad (2.4)$$

The term „T” refers to the shift in time scale for the signal $y(t)$. The cross correlation shifts the signal $y(t)$ with different magnitudes (in time) and compares it with the signal $x(t)$.

For discrete signals, $x[n]$ and $y[n]$, the cross correlation $R_{xy}[Q]$ is defined as

$$R_{xy}[Q] = \sum_{n=-\infty}^{\infty} x[n]y[n - Q] \quad Q \in (-\infty, \infty) \quad (2.5)$$

where n and Q are discrete integers.

2.4 Limitations of SOP System

The conventional SOP system has the following limitations:

- The base receiver has to be a fixed station. So, one can only use this navigational technique when a base station is available in an area. The requirement for base station installations makes the system expensive.
- Different signals have different navigational properties. For instance, Digital Television signals have been delivering high accuracy for the Indoor Positioning, while AM signals are highly effective in open areas or rural areas. Therefore, the SOP system has to screen all the available signals present in the area to narrow down on the signal with the highest navigational potential. This is computationally very expensive and time consuming.
- The signal path from the transmitter to the base receiver is different from the signal path from the same transmitter to the mobile receiver. These two paths

may be in different environmental conditions and thus experience different noise distortions (the noise spectral densities [15] of the two paths are not same). The SOP system has to properly accommodate for these noise effects in both these paths for accurate results.

- In the military applications, the role of navigation while in the enemy territory is of great importance. It is very difficult to collect any information regarding the transmitter stations in that enemy zone. However, even if the information is attained, it is highly impossible to install large number of base stations in the enemy land and also if installed, it is highly impossible to maintain the base stations.

2.5 Conclusion

The chapter discussed the basic building blocks of the SOP system. The mathematical background of the functionality of SOP system was described. The limitations of the conventional SOP system are highlighted.

Chapter 3

Improved Signals of Opportunity System

In this chapter, SOP system with two mobile receivers is being proposed. Its feasibility and functionality is established within mathematical framework. Its comparative advantages over the conventional SOP system with single mobile receiver are discussed.

3.1 Advantages of Improved SOP

Signals of Opportunity systems are highly efficient navigational tools with a drawback; they require a large number of resources, including time and man-power for the installation of the base stations.

The improved SOP system being proposed replaces the need for a base receiver with a second receiver in the mobile unit.

The disadvantages of a conventional SOP system discussed in the previous chapter are rectified in the improved SOP system.

3.1.1 Portability and Availability

The conventional SOP system cannot be used for navigational purpose in an area that is devoid of a base station. As the improved SOP system does not need a base station receiver for operation, it can be readily used in areas with rich signal resources. This allows for immediate availability of the navigation technology in any given area.

3.1.2 Higher Efficiency

Noise has a significant effect on the performance of a navigation system. The accuracy of the system depends on the extent of signal restoration from noise. The conventional SOP system is susceptible to considerable noise degradation. The reason for this is that there exist three different signal paths; path from transmitter to the mobile unit; path from the transmitter to the base station; and path from base station to mobile unit. The noise in the three paths are different and hence the correlation between the base station signal and the mobile unit signal is prone to error. However, in the improved SOP system, both the signal paths are from the transmitter to the mobile unit. Therefore both the signals pass through the same environment and there is a high probability that the disturbances affecting both these signals are similar. Therefore the noise does not have a significant effect in the correlation process.

3.2 Mathematical Justification

In this section the mathematical feasibility of the proposed SOP architecture is illustrated. Fig. 3.1 shows the architecture of the proposed SOP system with two mobile receivers. The fixed receiver has been replaced with the mobile receiver. Thus there are

two mobile receivers in the mobile unit. Fig. 3.2 shows the geometrical representation of the SOP architecture.

The symbols in Fig. 3.2 are summarized below.

$AE = h =$ Height of the transmitter

$\theta =$ Angle of arrival.

$D =$ Receiver 1.

$C =$ Receiver 2.

$AB = y_1;$

$BC = x \sin \theta;$

$AC = y = AB + BC;$

$Y =$ signal path from the transmitter to the receiver C.

$DB = x \cos \theta =$ perpendicular from point D (receiver 1) to AC;

$ED = d =$ Distance between the transmitter and the mobile receiver

$CD = x =$ Distance between the two mobile receivers

$AD = t =$ signal path from the transmitter to the receiver D.

Initially, when the transmitter transmits the signal, it is received at different instances of time by the two mobile receivers. Since, the location of both the receivers is unknown, a direct application of TDOA (Time Difference of Arrival) does not provide a solution.

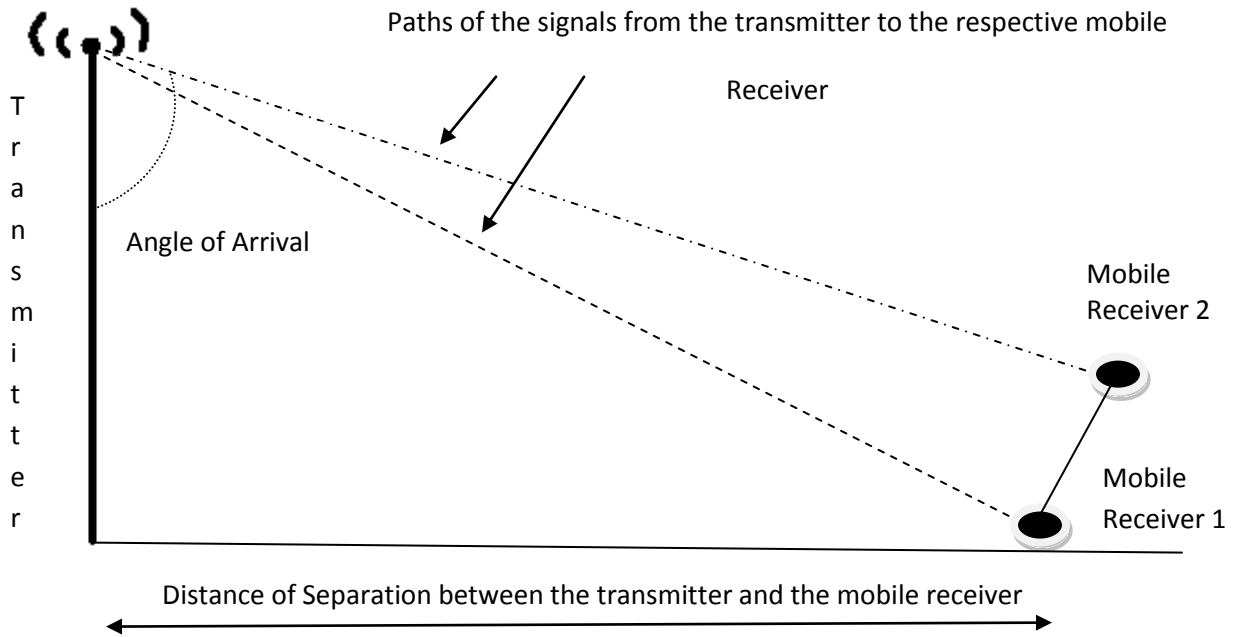


Fig. 3.1: Proposed Architecture of SOP with Two Mobile Receivers

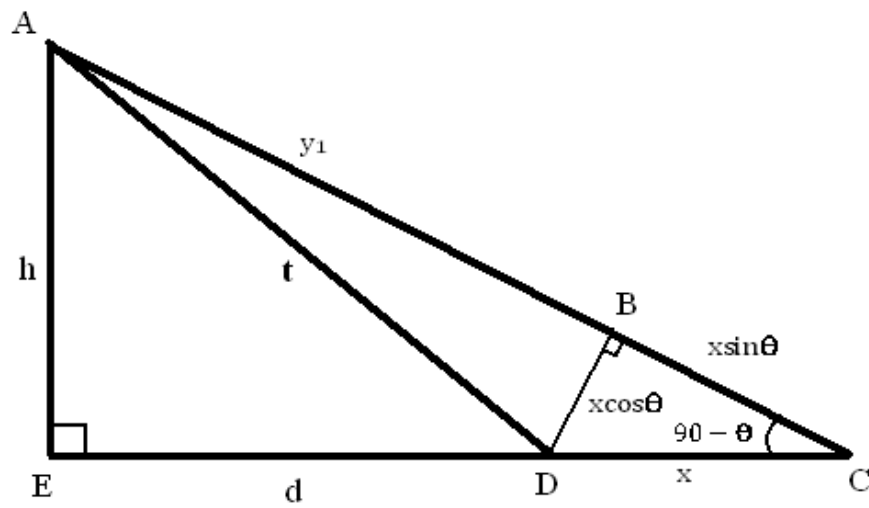


Fig. 3.2 : 2D Geometrical Representation of Proposed SOP Architecture with Two Mobile Receivers

Therefore, the Angle of Arrival (AOA) of the transmitted signal is calculated. Using the angle of arrival, the three dimensional SOP structure is transformed into a two dimensional model to reduce the computational complexity. By mathematical analysis, the distance between the transmitter and mobile unit d is calculated.

As shown in Fig. 3.2, Height h of the transmitter can be expressed by equation (3.1).

$$h=(d+x) \cot \theta \quad (3.1)$$

Squaring equation (3.1) on both the sides,

$$h^2=(d+x)^2 \cot^2 \theta \quad (3.2)$$

From triangle AEC,

$$h^2=y^2-(d+x)^2 \quad (3.3)$$

Substituting the above equation of h in equation (3.2),

$$y^2-(d+x)^2=(d+x)^2 \cot^2 \theta \quad (3.4)$$

Thus the distance from the transmitter to the mobile receiver C is given by equation (3.5)

$$y^2=(d+x)^2(1+\cot^2 \theta) \quad (3.5)$$

$$y=y_1+x \sin \theta \quad (3.6)$$

$$y=(d^2+h^2-x^2 \cos^2 \theta)^{1/2}+x \sin \theta \quad (3.7)$$

$$y^2=((d^2+h^2-x^2 \cos^2 \theta)^{1/2}+x \sin \theta)^2 \quad (3.8)$$

$$(d+x)^2(1+\cot^2 \theta)=d^2+h^2-x^2 \cos^2 \theta+x^2 \sin^2 \theta+2x \sin \theta(d^2+h^2-x^2 \cos^2 \theta)^{1/2} \quad (3.9)$$

Substituting (3.2) in (3.9) gives (3.10)

$$d^2+d^2 \cot^2 \theta+x^2+x^2 \cot^2 \theta+2dx+2dx \cot^2 \theta=d^2+(d+x)^2 \cot^2 \theta+x^2 \sin^2 \theta$$

$$+2x\sin \theta(d^2 + (d+x)^2\cot^2 \theta - x^2\cos^2 \theta)^{1/2} \quad (3.10)$$

$$x^2(1 - \sin^2 \theta) + 2dx(1 + \cot^2 \theta) = 2x\sin \theta (d^2 + (d+x)^2\cot^2 \theta - x^2\cos^2 \theta)^{1/2} \quad (3.11)$$

$$x^2(\cos^2 \theta) + 2dx(1 + \cot^2 \theta) = 2x\sin \theta (d^2 + (d+x)^2\cot^2 \theta - x^2\cos^2 \theta)^{1/2} \quad (3.12)$$

The quadratic equation (3.12) is solved to obtain the distance d of the mobile unit from the transmitter.

3.2.1 Angle of Arrival:

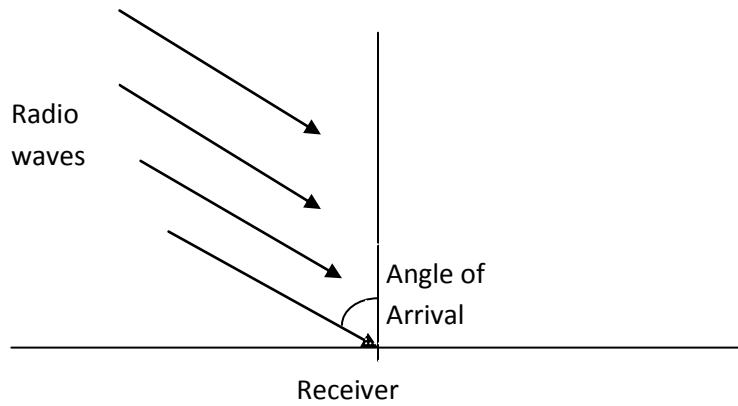


Fig. 3.3: Angle of Arrival

Angle of Arrival (AOA) is the angle of incidence of the radio waves on the receiving antenna system [4]. Fig. 3.3 shows the AOA for a receiver. The knowledge of Angle of Arrival (AOA) enhances the performance of a system in various ways.

- The antenna system can be aligned in the AOA direction to maximize the signal reception. This is an essential function required in any system using directional antennas, as any improper alignment of the antenna may lead to complete cut-off of the signal reception.

- AOA measurement is used in locating the source of the radio frequency. This makes AOA significant in applications like anti jamming and self tracking telescopes.
- The latter property makes AOA relevant in the SOP system. The improved SOP system uses the AOA technique to replace the base receiver with the mobile receiver without compromising on the efficiency of overall system.

AOA measurement is usually obtained by using an antenna/sensor array than a single antenna/sensor. However, AOA measurement can be made using a single antenna system. The procedure includes rotating the antenna system completely in both the horizontal and the vertical planes while recording the signal powers received in each position. The direction of antenna in which the maximum signal power is received is the direction of the signal source [5]. This process is time intensive and prone to errors as the signal properties can change over the time of measurement.

3.3 Rayleigh Effect

The biggest challenge in the calculation of the AOA is in the case of Rayleigh fading, Rayleigh fading is caused when the LOS signal is absent at the receiver. Therefore the received signal is the vector sum of the reflected and refracted waves. The reflected and refracted waves, commonly referred as multipath signals do not reveal the actual AOA, resulting in errors in the improved SOP approach. The following are the techniques that can eliminate these errors:

1. The Rayleigh effect is caused by the human infrastructure and vegetation in a given area. In this kind of environments, the received signal strength fluctuates. The signal strength increases in the presence of LOS (Rician fading) and decreases in the absence of LOS (Rayleigh fading) component at the receiver. If the received signal is observed in a small interval of time, there is at least one instant where the LOS signal is present. Therefore when the signal strength is high, the presence of LOS component can be detected and the location of the mobile unit is determined at that particular instant.

The mobile unit is equipped with a memory unit that records all the signal data. During the process of AOA calculation at a given instant, the mobile unit compares the signal power with the past data to verify whether the received signal has the LOS wave.

2. An alternative method to measure AOA involves the calculation of the present location based on the last known location. The mobile unit is equipped with a compass that indicates the direction in which the mobile unit is travelling. Fig 3.4 shows the vector representation.

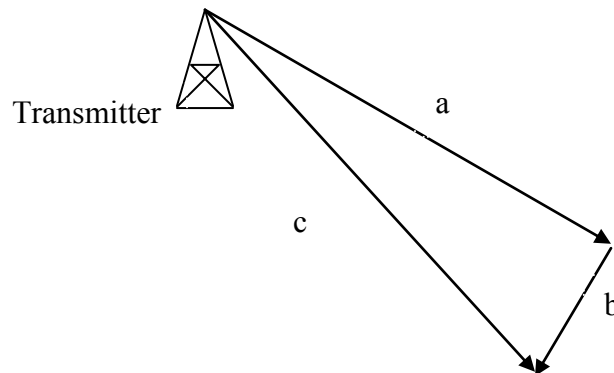


Fig. 3.4: Vector representation

The vector 'a' represents the distance of separation of the transmitter and the last known position. The direction of vector is stored with the help of the compass. The vector 'b' can be found by comparing the compass readings of the last known location and the time elapsed between the two calculations and the speed of the mobile unit. Using the vectorial addition,

$$c=a+b$$

The vector 'c' that represents the LOS signal is determined and hence the AOA.

3.4 Conclusion

In this chapter, improved SOP system with two mobile receivers is proposed, with a mathematical framework to predict the location of the mobile receiver with respect to the transmitter. The need for the base station is eliminated in this method. It has been further shown that the AOA can be estimated in the absence of LOS signal at the mobile unit.

Chapter 4

Modeling of Mobile Environment

In this chapter, a model for the mobile environment is presented. This model will be simulated in MATLAB environment, to test and verify the feasibility and efficiency of improved SOP as proposed in chapter 3.

4.1 Noise Sources

Noise is the main source of signal degradation in any communication system resulting in either loss or errors in transmission. The position accuracy of the SOP system is affected by the signal degradation as the correlation between the two received signals yield deviations from the original value. Sources of noise should be given main focus to simulate the effects in the mobile environment.

Noise in a radio-communication environment is categorized as internal and external. Internal noise refers to the disturbances offered by the system components, while external noise is caused by sources outside the system. Alternatively, noise can also be classified into two categories; Man made noise and Natural noise.

4.1.1 Man made Noise

The noise originating from any technical advances put forward by humans like TV or radio transmissions, automobile radiations can be classified in this category. The man made disturbances result from any electrical equipment used in the vicinity of the source. However, there are two types of interferences caused in the radio environment that are dominant.

4.1.1.2 Adjacent Channel Interference

The Adjacent Channel Interference is the disturbance caused to the signal by the signals in the adjacent frequency channels. The interference is usually transmitted by the same transmitter source as the required signal or the transmitter in its close vicinity; hence the interfering signal has comparable power to the required signal. The interference can be caused due to

- *Lack of frequency control at the transmitter:* This can be eliminated by using stable frequency generators like crystal oscillators.
- *Improper filtering:* The real world band pass filters do not have crisp upper and lower cutoffs. The frequency response is usually smoothed at the lower and upper cutoff boundaries, allowing a little overlap with the adjacent frequency bands. In real time frequency allocations, the frequency bands are separated by small unused frequency spectrum known as guard bands.

4.1.1.2 Co-Channel Interference

Co-Channel Interference is the interference caused when two transmitters are using the same frequency spectrum. This effect is eliminated by using a large separation distance between the two transmitters using the same frequency band.

As ample measures are taken in the real time to avoid adjacent channel interference and co-channel interference, they are not considered in the simulation model.

4.1.2 Natural Noise

Natural noise is due to any disturbances of the nature due to the natural behavior of the particles associated with it. Three important factors contributing to it in the communication arena; thermal noise, shot noise and atmospheric noise.

4.1.2.1 Atmospheric Noise

Atmospheric noise (alternatively referred as static noise) is usually caused by electrical disturbances in the atmosphere like lightening. This causes electric interference with the communication signals.

4.1.2.2 Thermal Noise or Static Noise

Thermal Noise is caused due to random movement of electrons in any conducting material [14]. The temperature of the conducting material is responsible for the kinetic energy of the electrons in random directions. This movement results in varied electron densities at various locations in the conductor producing fluctuating voltages. The voltage or thermal noise power is a function of time and temperature of the conductor. The effect

of thermal noise power increases with the increase in the bandwidth. The thermal noise power is given by eq. (4.1)

$$P_n = KBT \quad (4.1)$$

P_n =thermal noise power

B =bandwidth of signal

T =temperature of the conductor

K =Boltzmann's constant.

4.1.2.3 Shot Noise

Shot noise is a phenomenon observed with D.C. or Direct Current. The D.C current is theoretically constant in a conductor. Observations indicate a small fluctuation over the mean current value. The fluctuation is caused by the randomness in the motion of the electrons i.e., the current or electrons crossing a particular point in a conductor is not consistent.

The shot noise effects and thermal noise effects are difficult to discriminate as both are connected to the randomness of the electrons. The thermal noise accounts for the randomness of electrons irrespective of the direction, while the shot noise is caused by variations in the electrons in the direction of current. When all the carriers are allowed to pass in accordance with current direction, the resulting fluctuation depicts shot noise.

These noise effects are quite difficult to model exactly in the computer simulation environment as the computers cannot create pure randomness. The computers generate

pseudo random numbers, which possess approximated properties of the random numbers [24]. Some of the computers generate true random numbers with the input being noise from the atmosphere. However, such systems need additional equipment like antenna system, converters and signal processing equipment. This makes the equipment difficult for transportation.

Alternatively, Additive White Gaussian Noise Model is used that reproduces the effects of atmospheric, thermal and shot noises.

4.2 Additive White Gaussian Noise

Additive White Gaussian Noise is a channel model that consists of white noise spectral density and Gaussian distribution Amplitude model.

4.2.1 White Noise

White Noise is a random signal with a uniform power spectral density. The uniform power spectral density indicates equal noise power at all frequencies in the entire bandwidth. This assumption that noise affects all the frequencies equally is non-realistic. The use of white noise for simulation is very effective in simulation and testing environments as it can provide distortions in all the bandwidth with equal power, so that simultaneous assessment of the systems at different frequencies is possible. Properties of White noise

1. It is a zero mean random process.

2. The auto correlation of a white noise random signal, continuous in time is a delta function at the time shift of zero and absolutely null at any other time shifts, stating that the white noise is non periodical.

4.2.2 Gaussian Distribution

A probability distribution function is used for estimating the probability of a functional value to fall in a given range of values. A Normal or a Gaussian distribution function is a continuous bell shaped probability distribution that has clustered random variables converging at a mean value. The mathematical function that defines the properties of the bell shaped Gaussian distribution is

$$f(x) = 1/\sqrt{2\pi\zeta^2} \exp(-(x-\mu)^2/2\zeta^2) \quad (4.2)$$

Where,

μ =mean of the Gaussian distribution.

ζ^2 =Variance

ζ =standard deviation

1. The area under the Gaussian curve defines the probability. The area under the Gaussian curve with limits of negative infinity to infinity is one, indicating that the random process always produces finite value.

2. The standard deviation of the distribution defines the spread in the curve. The larger the deviation, flatter is the peak of the curve.

4.3 Multipath Propagation

Multipath propagation occurs when the transmitted signal arrives at the receiver in two or more paths. Multiple paths include the Line of Sight (LOS) propagation, reflected waves from water bodies, human structures and natural obstructions like mountains, refracted waves due to rain drops and ionosphere particles. The communication systems with wires are also prone to this multipath effect, when source to drain impedance mismatch is present. The multipath effect distorts the signal reception. The signals from multiple paths arrive at different time instants at the receiver antenna due to difference in the distance travelled by each wave. This time elapse causes a vector sum of the signals at the receiver.

Let the transmitted signal be T.

$T = A \sin \omega t$ be the transmitted signal with angular frequency ω , and Amplitude A .

The received signal R can be represented as

$$R = A_1 \sin(\omega t + \theta_1) + A_2 \sin(\omega t + \theta_2) + A_3 \sin(\omega t + \theta_3) + A_4 \sin(\omega t + \theta_4) \dots \dots \dots + A_n \sin(\omega t + \theta_n) \quad (4.3)$$

$$R = A_1 \sin(2\pi f t + \theta_1) + A_2 \sin(2\pi f t + \theta_2) + A_3 \sin(2\pi f t + \theta_3) + A_4 \sin(2\pi f t + \theta_4) \dots \dots \dots + A_n \sin(2\pi f t + \theta_n) \quad (4.4)$$

$\theta_1 \theta_2 \theta_3 \theta_4 \dots \theta_n$ are the phasors of various multipath signals.

The multipath effect can be described for two instances; one in the presence of Line of Sight propagation (LOS) and other in the absence of the Line of Sight propagation.

1. Rician Fading: This type of fading involves a Line of Sight (LOS) wave and set of reflected or refracted waves. The amplitude of the received signal follows the Rician distribution and hence derived its name. The Rician fading is characterized by two parameters, K-factor and omega. K-factor is the ratio between the direct signal or LOS power to the power in all the other paths. Omega is the scaling factor that corresponds to the power in the LOS path. The probability density function of the received Rician amplitude is given by

$$f(x) = \frac{2(K+1)x}{\Omega} \exp\left[-K - \frac{x(K+1)x}{\Omega}\right] I_0\left[2x \sqrt{\frac{K(K+1)}{\Omega}}\right] \quad (4.5)$$

$I_0(.)$ represents the Bessel function of zeroth order.

2. Rayleigh Fading: Rayleigh fading is a special case of Rician fading where the Line of Sight (LOS) signal ceases to exist and only the scattered waves exist. Rayleigh fading is most common in highly populated urban areas, where huge manmade structures are the obstructions in signal paths, the line of sight component is absent in the received signal resulting in low signal power and SNR.

The use of a propagation model helps to simulate such effects. The Langley Rice model is used for this purpose.

4.4 Langley Rice Propagation Model

A Langley Rice propagation model is a propagation model specifically intended to account for all the radio-signal distortions for the frequency range of 20 MHz to 40 GHz. Alternatively known as ITU Irregular Terrain Model (ITU-ITR), it estimates the median signal loss of a radio wave in a radio environment. The model is tested for a signal range of 2000 Km and for antenna heights between 0.5 m to 3000 m. The two variations of the Langley Rice model include the area predictions and point to point predictions [19].

The refraction and diffraction are important factors that define the signal at the receiver's end. The refraction can be defined as the bending of the signal or a wave at the boundary separating highly dense and less dense mediums. This effect is clearly seen in long distance transmissions; the refracted waves from the troposphere are significant at the receiver. The diffraction of radio waves explains the bending of the waves at the edges of objects which are in comparable dimensions of the wavelength. The diffraction effect allows part of the signal to be absorbed; part of the signal being allowed to pass through and the rest of the signal being refracted.

The Langley Rice model does not implicitly specify the transmitter and receiver; it describes the signal relationship between two terminals, either terminal capable of being designated as a transmitter or a receiver. The model considers effective earth radius to compensate for the bending of the waves. It also accounts for the conductivity of the surface as it defines the ratio of the absorption portion of the signal and reflected signal. The effective antenna heights and the interdecile range define the irregularities of the terrain. The interdecile range compensates the effective height of the particular area

based on its nature. The incorporation of this factor allows for the area to be viewed as a plain smooth surface. The effective heights of the antennas are also affected by the curvature of the earth. If the two terminals are far away from each other, so that the curvature of the earth cannot be ignored, the effective antenna height is a fraction of the actual antenna height. The model also accommodates diffraction losses. As this model considers all the effects on a radio wave, it is used in the simulation to create the real time effects on the communication link.

4.5 Conclusion

In this chapter, real time factors affecting the RF propagation like noise and other interferences are discussed. These effects are incorporated in the simulation environment for SOP.

The Signals of Opportunity (SOP) system utilizes the available signal resources in an area for functioning. The SOP system scans all the signal resources in the area for a signal that satisfies the minimum requirements. The time for the entire signal selection process is directly proportional to the number of signal resources available. In an urban area, where the available resources are abundant, the selection process is elaborate blocking the navigational service occasionally. To overcome this problem, an intelligent system can be implemented for the SOP system that improves the time to select the signals for navigation.

Chapter 5

Performance Analysis of Proposed SOP with Two Receivers over Conventional SOP

In this chapter, SOP proposed with two mobile receivers is compared with the SOP system with one fixed base receiver. The comparison is done for both amplitude modulated and frequency modulated signals. The chapter presents the simulation results of the comparison of the two SOP systems.

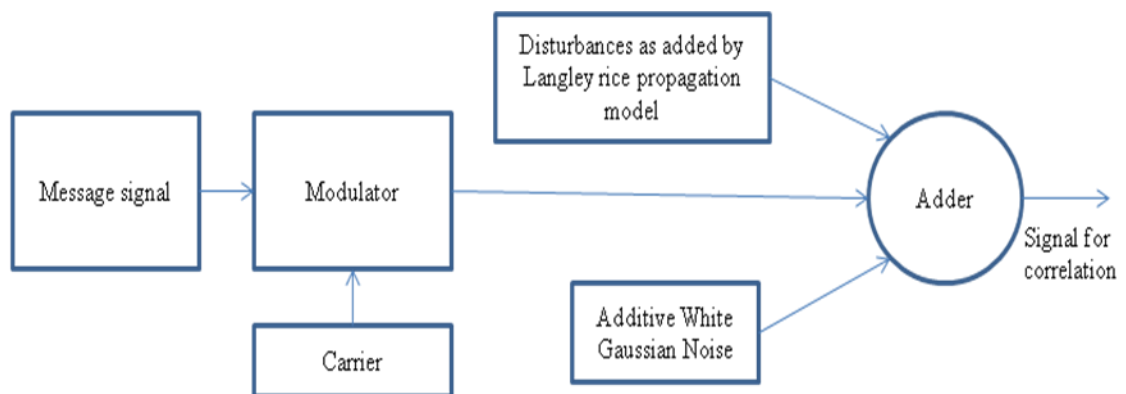


Fig: 5.1 Simulation model for generating the signals at Base Receiver or Mobile Unit

Fig 5.1 shows the simulation model used for generating the received signals at the base receiver and mobile unit. The message signal and carrier are given as the inputs to the modulator block that generates the AM or FM signal that is used for transmission. The

Langley Rice propagation model and the Additive White Gaussian Noise (AWGN) blocks add the disturbances to the signal as a function of distance. The received signal is used for correlation. These two blocks also add disturbances to the retransmitted signal at the base station.

5.1 Message Signal

The message signal is chosen to be a sinusoidal waveform with frequency in the audio range of 300 Hz to 3000 Hz. Fig. 5.2 shows the message signal of 3 KHz with amplitude of 1 V. The sinusoidal frequency used for comparison of both SOP systems is of 3 KHz frequency.

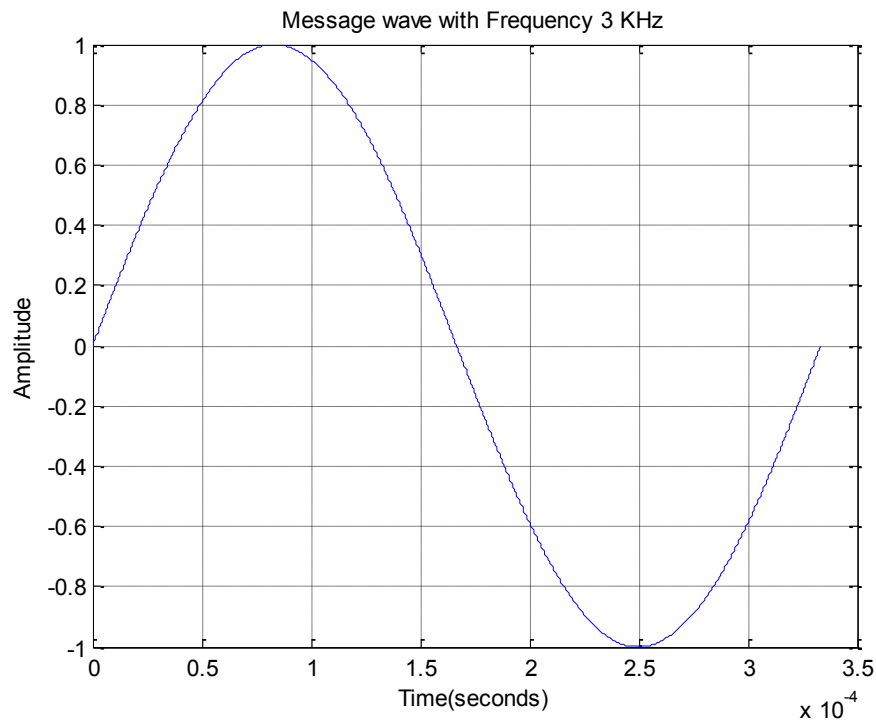


Fig. 5.2: Message signal with Frequency 3 KHz

5.2 Amplitude Modulated Signal

The simulations include the testing of efficiencies of the conventional SOP and the improved SOP system for the two signal resources; Amplitude Modulated wave and the Frequency Modulated wave. The Amplitude Modulated signal uses a carrier in the short wave frequency range (30 MHz) for the simulation. The carrier amplitude is maintained at 10 V during the modulation. The modulation index of the wave is 0.1. Fig. 5.3 shows the AM wave, modulated with the message signal shown in the Fig. 5.2.

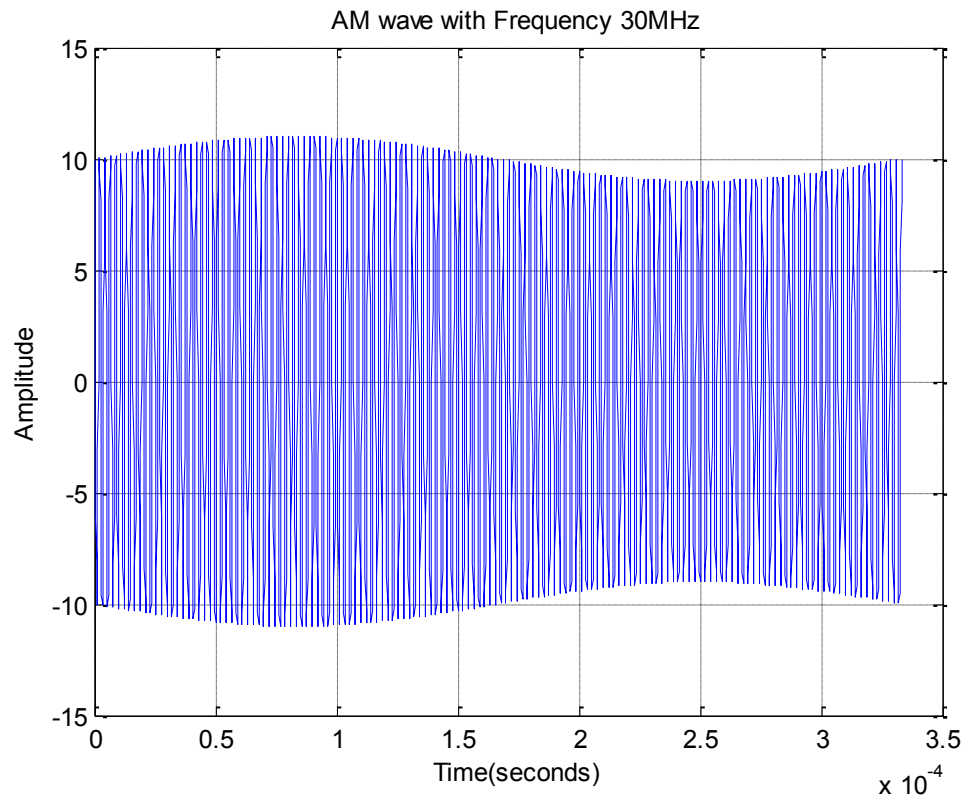


Fig. 5.3: AM short wave with a frequency of 30 MHz

5.3 Frequency Modulated Signal

A 90 MHz carrier is used to frequency modulate the message signal as shown in Fig. 5.4. The geographical area is represented as a coordinate axes, where the location is designated by the x and y co-ordinates. The transmitter for both the techniques; SOP and the improved SOP systems, is assumed at the coordinates (0, 0). The transmitter is assumed to transmit both AM and FM signals and the mobile receiving system and base receiver system have the capability of switching to either of the signals.

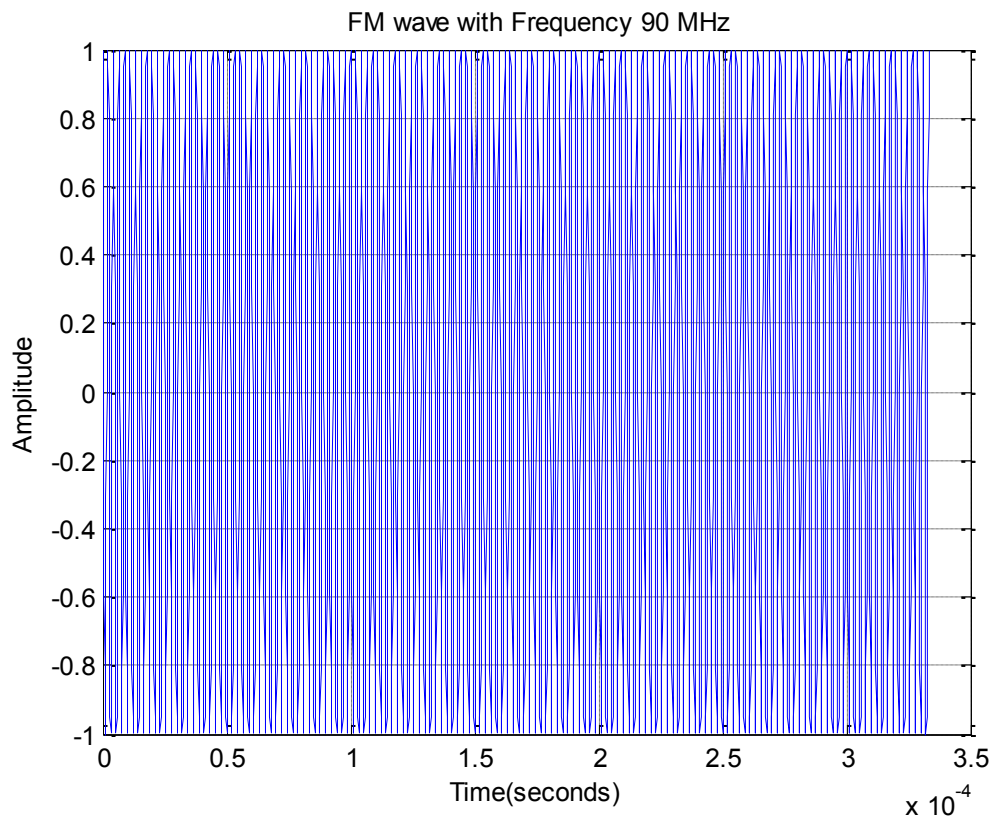


Fig. 5.4: FM wave with carrier frequency of 90 MHz

5.4 Improved SOP System

The simulations for the SOP system are performed for both the signal sources; AM and FM. The simulation environment is identical for both AM and FM. For the purpose of explanation, all the intermediate steps are illustrated for AM. The final results for FM are shown; since the same explanation is applicable for the FM.

The mobile unit receiver 1, which is the only mobile receiver in the conventional SOP system, is located at the coordinates (4, 4). The mobile unit receiver 2 is at the coordinates (4.004, 4.004). The base station is located at (10, 10).

5.4.1 Rician Fading Effect

The Rician fading effect is used to describe the multipath effect for the AM and FM modules. The multipath effect is due to the multiple paths taken by the signal to arrive at the receiver at different times.

5.4.2 Noise Signal at Receiver 1

The Langley Rice model is used to predict the loss incurred by the signal in the given distance propagated by the signal. The free space and the diffraction losses for the signal under consideration is calculated and being applied to the signal.

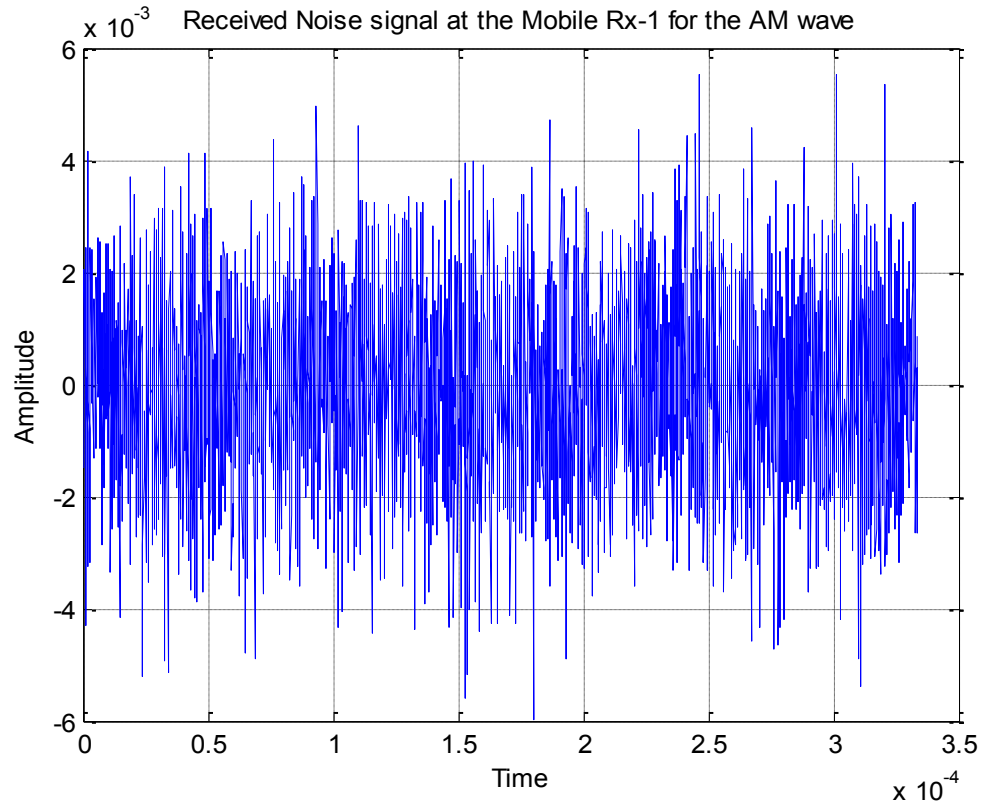


Fig. 5.5: The Received Signal at the Mobile receiver for the AM wave distorted due to Rician fading and Noise.

Fig. 5.5 shows the received noisy signal due to the multipath effects (Rician Fading) and the various disturbances, at the mobile receiver 1.

5.4.3 Noise Signal at Receiver 2

Fig. 5.6 shows the signal received at the second receiver located at the coordinates (4.004, 4.004). The amplitude fluctuation is in the range of [-3.4, 4.75] mV. The reason for these similarities in the signal reception for both the receivers is because of the similar environments experienced by both the receivers at any instant.

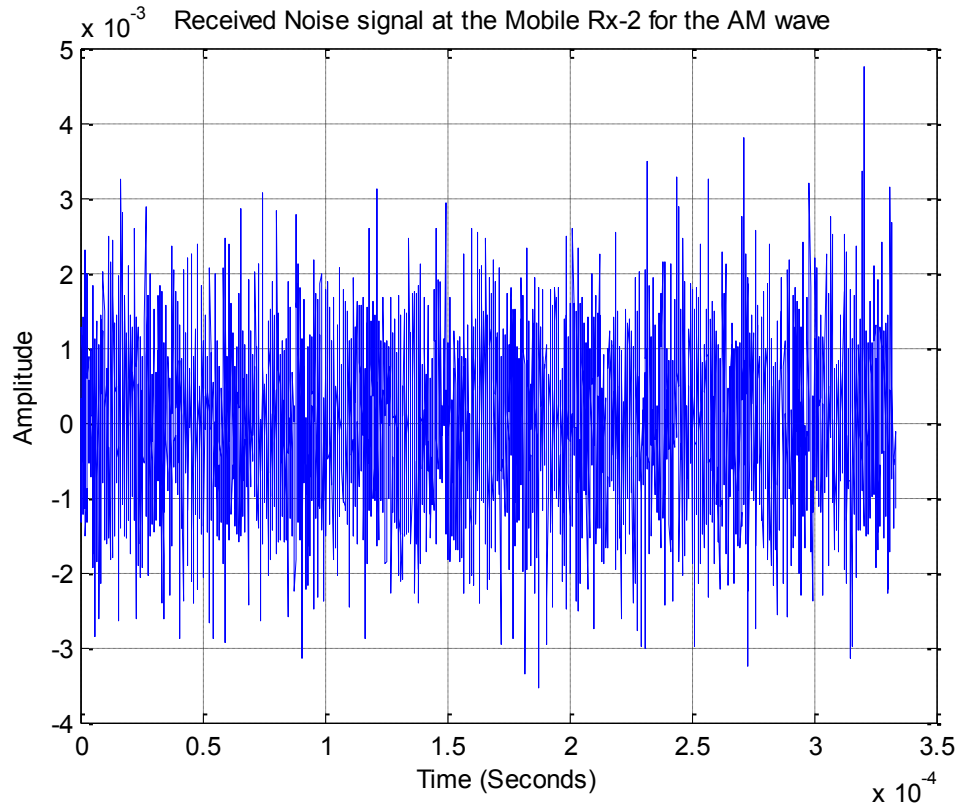


Fig. 5.6: Received AM Noise signal at the Mobile Receiver 2

This kind of relation allows for effectively countering the noise effects on the navigation.

5.5 Correlation for Ideal Environment

The correlation between the received signals at the two receiving stations is the most important factor in the SOP system. It determines the accuracy of the navigational system in predicting the location.

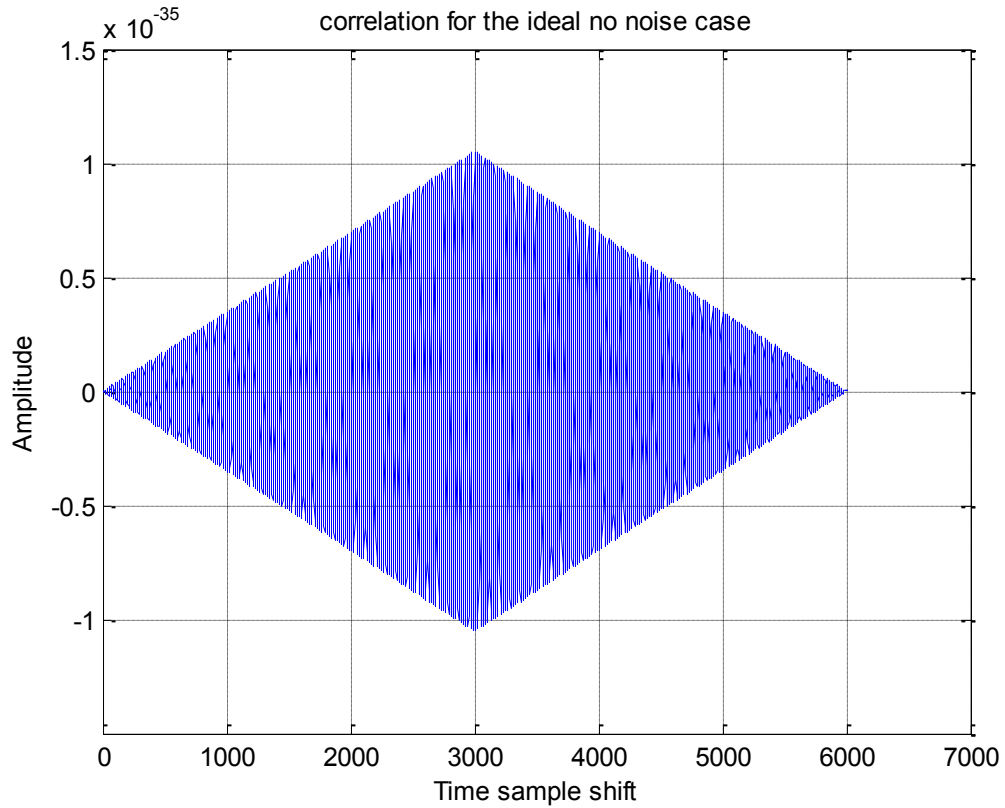


Fig. 5.7: Correlation curve for the ideal no noise case for any received signals

All the other modules in SOP system are based on the output of the correlation function. The comparison of the correlation outputs of both the SOP systems will portray the efficiencies of both the techniques. Fig. 5.7 shows the correlation output for the ideal case with no noise. For effective comparison, all the received signals for the correlation are time adjusted to start at $t=0$. The peak of the correlation curve which represents the maximum similarity between the signals occurs at the time shift of 3001 samples.

5.6 Correlation for Noise Environment for Improved SOP System

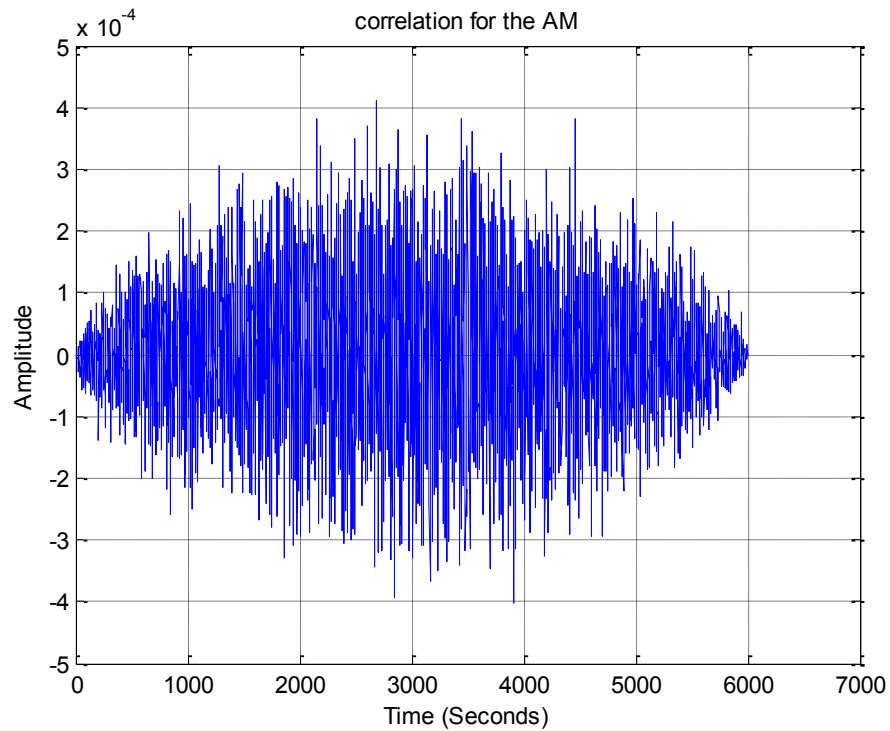


Fig. 5.8: Correlation curve of the signals with noise received at two mobile receivers in improved SOP

Fig. 5.8 shows correlation graph between the received signals at the two mobile receivers. The maximum correlation amplitude is in the range of 4mV. The correlation peak occurs at time shift of 2987 samples.

5.7 Conventional SOP System

5.7.1 Noise Signal at Base Receiver

Fig. 5.9 shows the signal affected by the multipath and atmospheric disturbances at the base station in the conventional SOP system. The fluctuation of the signal is in the range of $[-6, 6]$ micro volts.

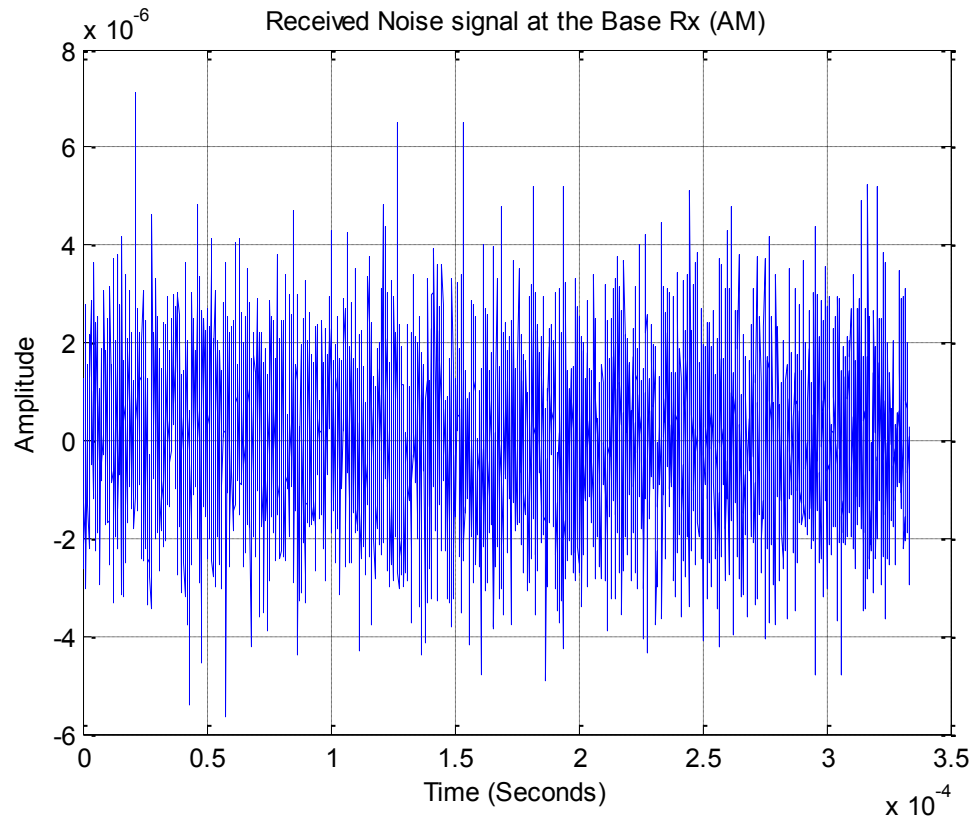


Fig. 5.9: Received AM Noise signal at the Base Receiver/Station in the conventional SOP

5.7.2 Noise Signal at Receiver

The received base station signal is now to be transmitted to the mobile unit for the computation of correlation between the two signals. The base station does not add any power to the received signal for retransmission and also does no signal processing to it. These assumptions are made only to compare the systems in similar conditions.

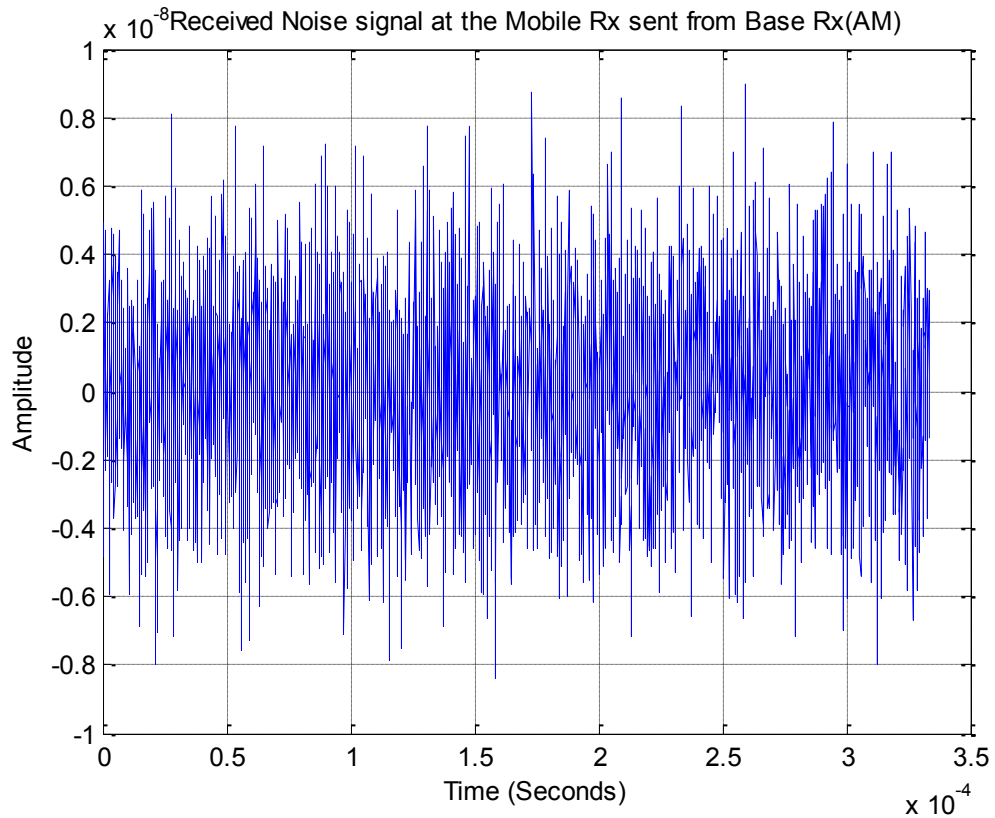


Fig. 5.10: Received Signal at Mobile unit, as transmitted from the Base station

Fig. 5.10 shows the transmitted base station signal affected by the multipath and atmospheric disturbances at the mobile unit. The fluctuation of the signal is in between $[-8, 8]$ nano volts.

5.8 Correlation for Noise Environment for SOP System in the Presence of Noise

Fig. 5.11 shows the correlation of the mobile unit signal and the received signal from the base station. The correlation peak is 3.2×10^{-13} units.

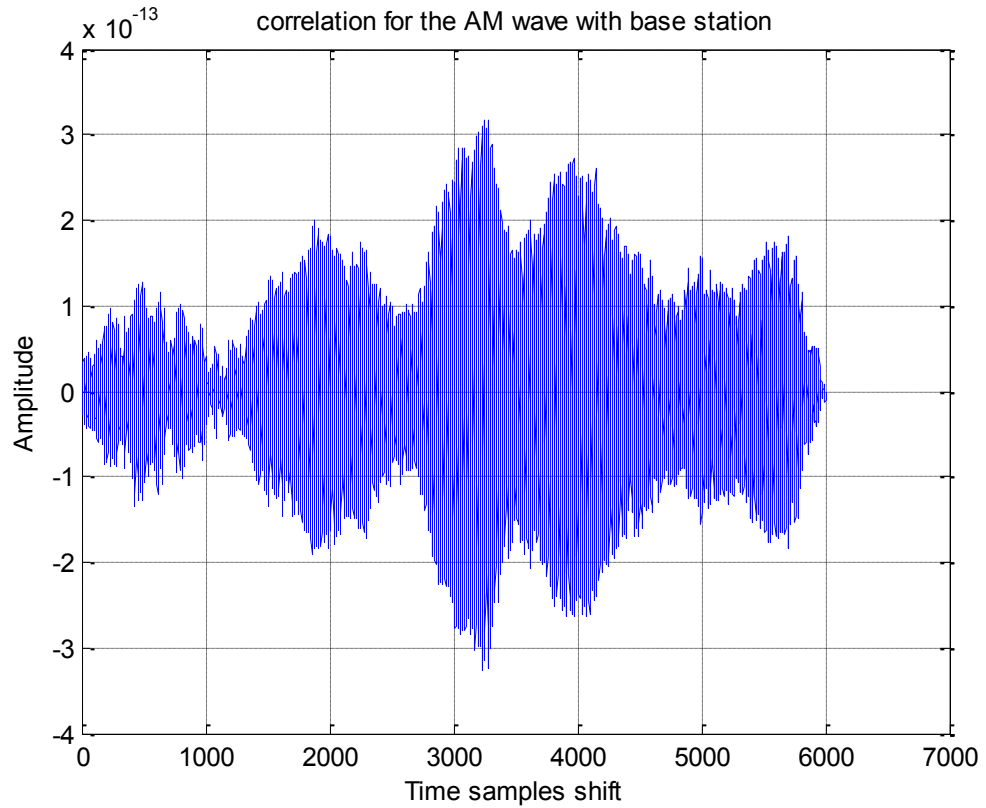


Fig. 5.11: Correlation graph for the AM SOP system with Base Station

The drop in the correlation peak suggests the decrease in the similarity of the same transmitted signal, travelling through various paths. The correlation maximum occurs at time shift of 3277 samples as against the ideal case of 3001 samples. The improved SOP system has correlation peak at 2987 samples as shown in Fig. 5.8, which is only 14 time samples away from the 3001 samples of ideal correlation with no noise. The margin of error for the conventional SOP system is more with 276 samples. This is because; the mobile receivers are close enough to experience similar environment effects.

5.9 Correlation for Noise environment for Improved SOP System with FM Carrier

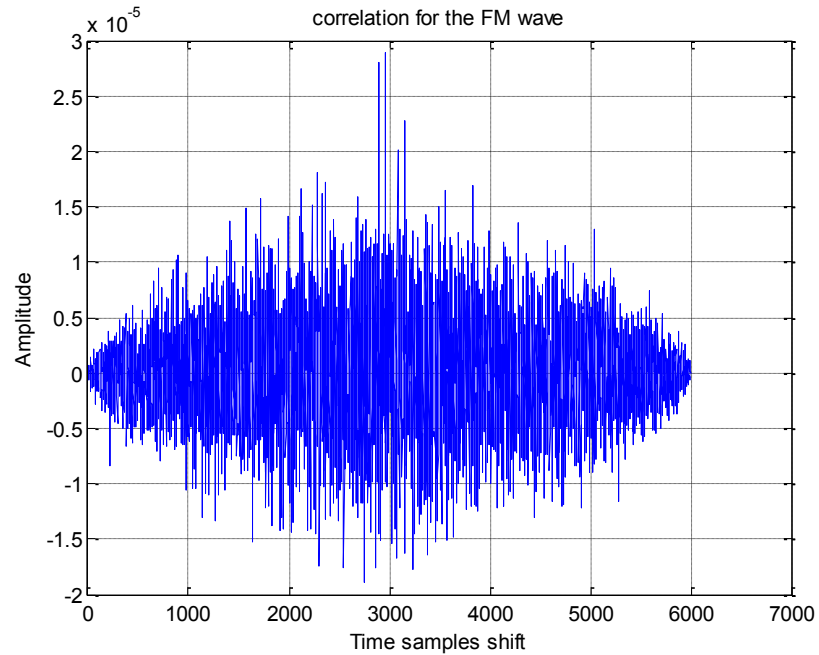


Fig. 5.12: Correlation graph for the improved SOP system for FM carrier

Fig. 5.12 shows the correlation curve for the FM wave for the improved SOP system. The procedure and conditions assumed for the FM wave are similar. The correlation for the improved SOP system has its peak at 2954 samples, with the maximum value of 2.75×10^{-5} .

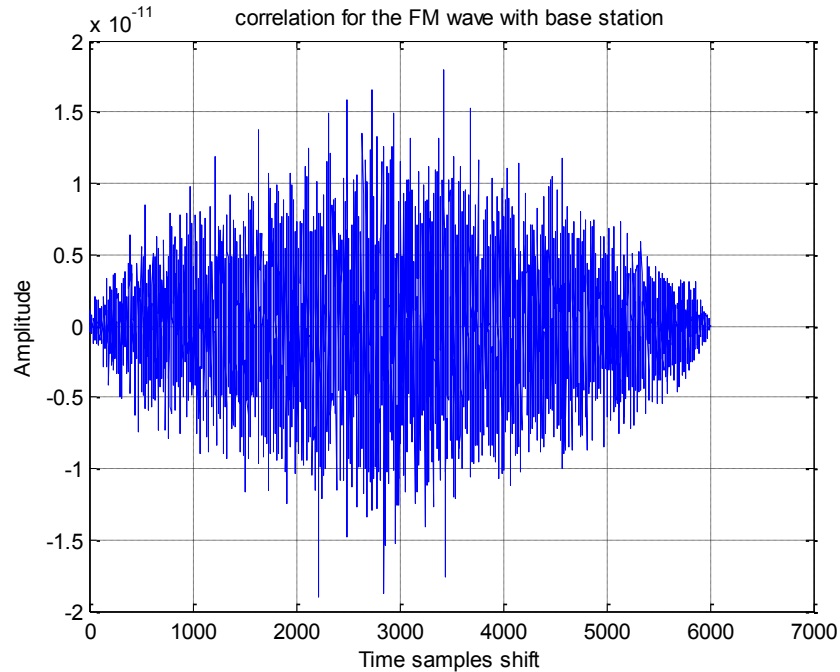


Fig. 5.13: Correlation graph for the conventional SOP system for FM carrier

5.10 Correlation for Noise environment for SOP system with FM Carrier

The correlation peak for the conventional SOP system occurs at 2465 samples as shown in Fig. 5.13. The correlation curve for the FM signal with the base station has maximum value of 2×10^{-11} . The correlation peak occurs at 2465 samples as against the ideal case of 3001.

The efficiency of the SOP system in case of AM wave is:

$$(3001-3277)-(3001-2987) / (3001-3277) \% = 94.9\%$$

The efficiency of the SOP system in case of FM wave is:

$$(3001-2465)-(3001-2954) / (3001-2465) \% = 91.23\%$$

5.11 Conclusion

The improved SOP system is shown to have 94.9% more correlation efficiency than the conventional SOP system for AM and 91.23% more efficient for the FM.

Chapter 6

An Evolutionary Neural Network to identify the appropriate SOP signal in the region

In this chapter, the evolutionary neural network which identifies the most appropriate navigational signal in the region is proposed.

The SOP system has a number of signal resources in a highly populated area. The SOP system has to scan the corresponding signals periodically to select the navigational signal for a particular instant. To scan such large number of signals for testing their efficiency is very time consuming. It can result in abrupt interruption to the service. If the SOP system is incorporated with an intelligent system that can determine the signal of navigation based on the past experience, then it can identify the appropriate signal without causing considerable delay.

6.1 Intelligent System

Data classification and pattern recognition systems are of great significance in the real world. A neural network is a very efficient tool to classify the patterns appropriately. The neural network stores the knowledge in the form of interconnection strength (weights) between the neurons. The architecture of the neural network depends on the classification

problem. The neural network can be trained with back propagation algorithm or an evolutionary technique. However the back propagation algorithm may converge to a set of sub optimal solutions which it cannot escape, so it cannot always guarantee an optimal solution. On the other hand, evolutionary techniques, for instance genetic algorithm, using crossover and mutation operators ensure that the obtained solution is an optimal one. For this reason a neural network trained with genetic algorithm is a better choice for selecting appropriate signal.

6.2 Generation of Data Set

In selecting the most appropriate signal for navigation in a given location, five signal parameters; AM signal carrier frequency, FM signal carrier frequency, speed of the mobile unit, message signal frequency and signal power are considered. All these parameters are collectively considered to find the most appropriate signal. The simulation was run with these 5 input parameters with different values and correlation graphs were generated. The time shift at which the correlation is maximum is recorded for both AM and FM signals in the region. The smaller time shift in the correlation graph represents the more appropriate signal for navigation. This generated data was used for training the neural network. Table 6.1 shows an instance of data set. It has five input parameters and one output, that represents either AM or FM.

Table 6.1: Sample Extract from the data set.

Mess freq	Speed	AM freq	FM freq	Power	AM	FM
500	20	29000000	99000000	7000	1	0
500	20	29000000	99000000	10000	1	0
500	20	30000000	1E+08	1000	0	1
500	20	30000000	1E+08	4000	0	1
500	20	30000000	1E+08	7000	0	1
500	20	30000000	1E+08	10000	1	0
500	30	20000000	90000000	1000	0	1
500	30	20000000	90000000	4000	0	1
500	30	20000000	90000000	7000	1	0
500	30	20000000	90000000	10000	1	0
500	30	21000000	91000000	1000	1	0
500	30	21000000	91000000	4000	1	0
500	30	21000000	91000000	7000	1	0
500	30	21000000	91000000	10000	1	0
500	30	22000000	92000000	1000	0	1
500	30	22000000	92000000	4000	1	0
500	30	22000000	92000000	7000	1	0
500	30	22000000	92000000	10000	1	0
500	30	23000000	93000000	1000	0	1
500	30	23000000	93000000	4000	1	0
500	30	23000000	93000000	7000	1	0
500	30	23000000	93000000	10000	1	0
500	30	24000000	94000000	1000	1	0
500	30	24000000	94000000	4000	1	0
500	30	24000000	94000000	7000	1	0
500	30	24000000	94000000	10000	1	0
500	30	25000000	95000000	1000	1	0
500	30	25000000	95000000	4000	1	0
500	30	25000000	95000000	7000	1	0
500	30	25000000	95000000	10000	1	0
500	30	26000000	96000000	1000	0	1

1. AM Signal Carrier Frequency: The Amplitude Modulated Short wave is varied within the range of 20MHz to 30 MHz, with the center frequency of 25 MHz. The Carrier Amplitude is kept constant at 10V throughout the data instances.

2. FM Signal Carrier Frequency: The Frequency Modulated wave is used for the data instances in the range of 90 MHz to 100 MHz. The Center Frequency is positioned at 95 MHz, while maintaining the power of the signal constant.

3. Speed of the Mobile unit: The speed is an important attribute in the process of signal selection as the Doppler effects and the fading of the signals depend on it. The speed of the mobile unit is varied between 10 Kmph to 40 Kmph.

4. Message Signal Frequency: The Message signal is a sinusoidal wave with the frequency varying between 500 Hz to 2500 Hz, i.e. in the audio frequency range.

5. Signal Power: The signal power is a very important factor in determining the reception factors like sensitivity, Signal to Noise ratio. The transmitter signal power is maintained in the range of 1000 W to 10000 W.

From the simulations, 500 data samples were generated, 400 of which are used for training the neural network and the remaining 100 are used for testing the neural network.

6.3 Neural Network

A neural network is a collection of artificial neurons arranged in multiple layers in a feed forward fashion. A neuron is represented with a mathematical model based on

Mcculloch and Pitts (MP) model that takes in multiple inputs to generate a single output. MP neuron sums all the inputs and fires according to the activation function if the input is above a given threshold. Neural networks have been successfully used for data classification. Various algorithms are developed for neural network learning including back propagation and genetic algorithms [23]. Fig. 6.1 shows the neural network for the SOP signal selection.

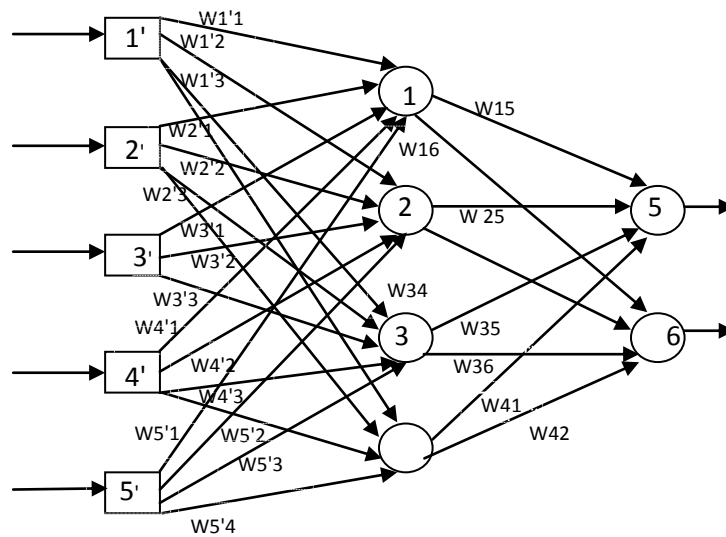


Fig. 6.1: The Neural Network for the SOP Data Classification

It has three layers; one input layer, a hidden layer and an output layer. The input layer has five neurons that correspond to the five input parameters of AM carrier frequency, FM carrier frequency, message signal frequency, signal power and speed of the mobile unit. The hidden layer has four neurons. The output layer has two neurons corresponding to the two signal sources, AM and FM. The neural network is a fully connected one, i.e. the outputs of all the neurons in a layer are presented as inputs to all the neurons in the next layer. The connection strengths between the neurons are the weights of the neural

network. A neural network stores the knowledge in the form of weights. The weights are to be properly adjusted so that the SOP data is classified properly. The learning rules for the network can be analyzed very easily when there are only two layers namely input and output. However complex problems or functions cannot be modeled using two layers. For this reason multiple layers (known as hidden layers) are being introduced in between input and output layer. The numbers of hidden layers increase the computations exponentially without significant additional performance. For most of the classification problems one hidden layer is sufficient. Each neuron in the neural network is an MP neuron, with a net sum function and an activation function. One of the key feature on which the efficiency of a neural network depends on is the activation function of the neuron.

The activation function determines the output of a neuron based on its given inputs. The activation function used for the neural network is the sigmoid function. The sigmoid function can functionally be represented as follows

$$\text{Sigmoid}(x) = 1 / (1 + e^{-x})$$

6.4 Genetic Algorithm

The Genetic Algorithm is a global computational search technique used for extracting optimized solutions. They are inspired from the biological processes in the nature. In the natural world, the best and the fittest survive in an environment i.e. the next generation of species contain the organisms suitable to the environment. In a changing environment, an organism has to change its characteristics to suit to the environment for survival. The

genetic algorithm also evolves the solution set towards the best possible solution. Fig. 6.2 shows the flow chart of the genetic algorithm. The stages in the genetic algorithm are [23]:

1. Encoding: The process of translating a problem domain into a chromosome is called encoding. The problem domain is represented as a chromosome. From the initial population of chromosomes, the genetic algorithm tries to find the optimal chromosome, which is the best possible solution to the problem. The neural network of Fig. 6.1 has 34 weights and 7 thresholds. The chromosome which represents the neural network has 34 parameters or genes. Fig. 6.3 represents the chromosome for the neural network of Fig. 6.1. The chromosome is made up of six groups, each group representing the weights and threshold of a particular neuron in the hidden layer and output layer. The chromosome has 34 genes in total.

2. Fitness Function: Fitness function measures the performance of a chromosome. The fitness function for the SOP classification is the inverse of mean square error.

3. Creation of Initial Population: Create an initial population of 100 chromosomes.

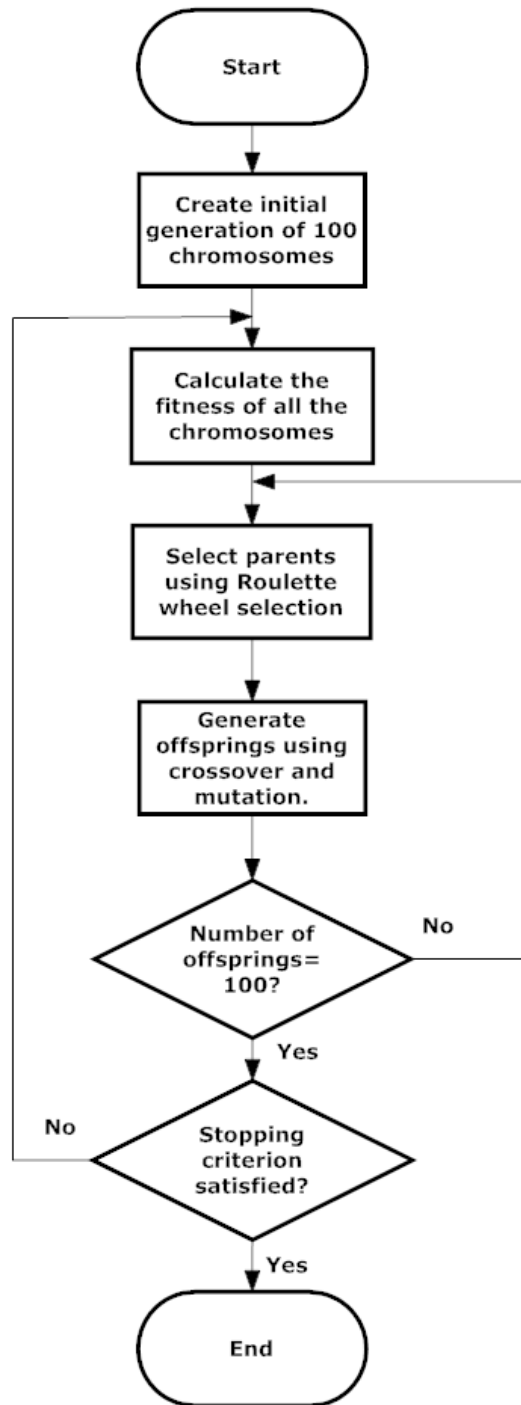
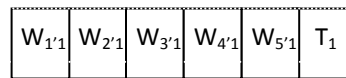
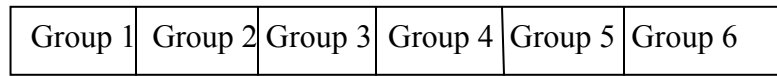
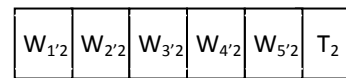


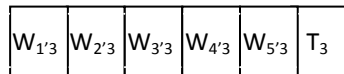
Fig. 6.2: Flow chart of genetic algorithm



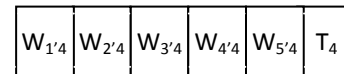
Group 1



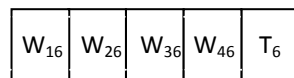
Group 2



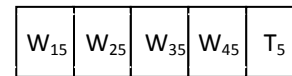
Group 3



Group 4



Group 6



Group 5

Fig. 6.3: chromosome of the Genetic Algorithm

4. Selection: The chromosomes are selected from the initial population to produce offsprings. The selection is based on the fitness of the chromosomes and is implemented using a roulette based selection. Fig. 6.4 shows the Roulette wheel. The sectors in the wheel are based on the fitness ratio, i.e. the ratio of fitness of the chromosomes to the sum of fitness of all the chromosomes. The chromosomes with higher fitness are more likely to be selected for reproduction

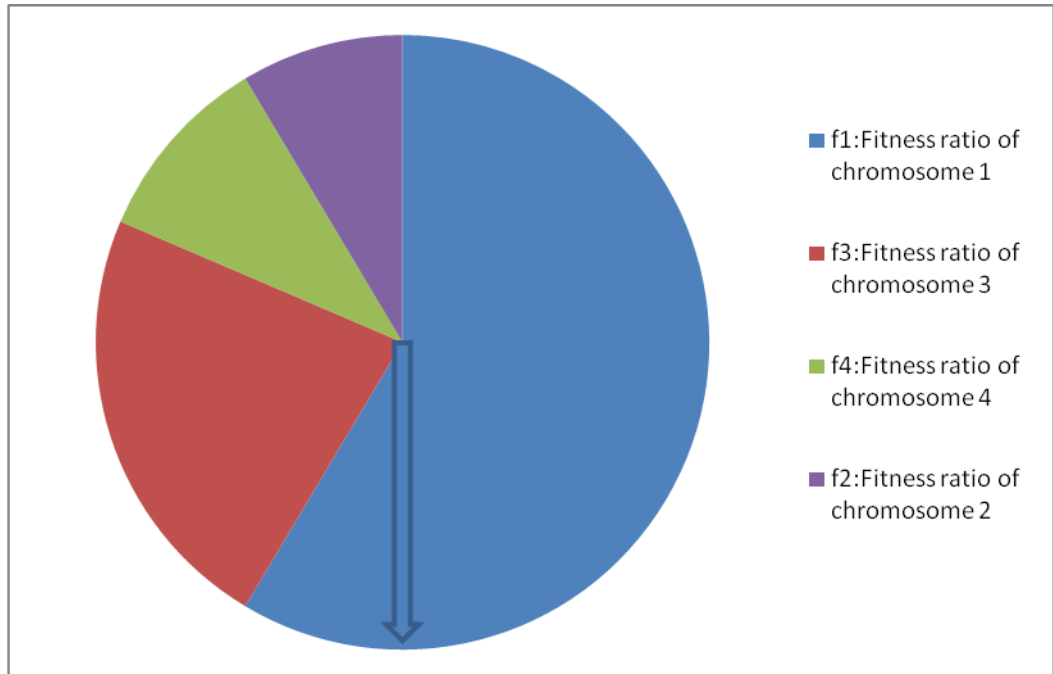


Fig. 6.4: Roulette Wheel

5. Creation of offspring: The selected chromosomes are then allowed to reproduce by cross breeding. The crossover and the mutation operators are being used to generate the next generation of offspring chromosomes. The crossover operator interchanges the genes of the chromosomes [23]. The mutation operator expands the search space ensuring that the solution obtained at the end is optimal (and not localized). For this training, scattered crossover operator and Gaussian mutation are used.

6. Stopping criterion: The stopping criterion is attained if a preset number of generations are achieved or there is no improvement in mean fitness of the population in the successive generations.

6.5 Performance of the Genetic Algorithm

The neural network was trained using the genetic algorithm discussed in section 6.4. Fig. 6.5 shows the convergence of the genetic algorithm. The mean classification error of the chromosomes in the initial population is 0.35. The best chromosome in the initial generation had an error of 0.02.

After training the genetic algorithm converged in 35 generations. The average of the mean classification error is 0.2. The best chromosome achieved an error of zero.

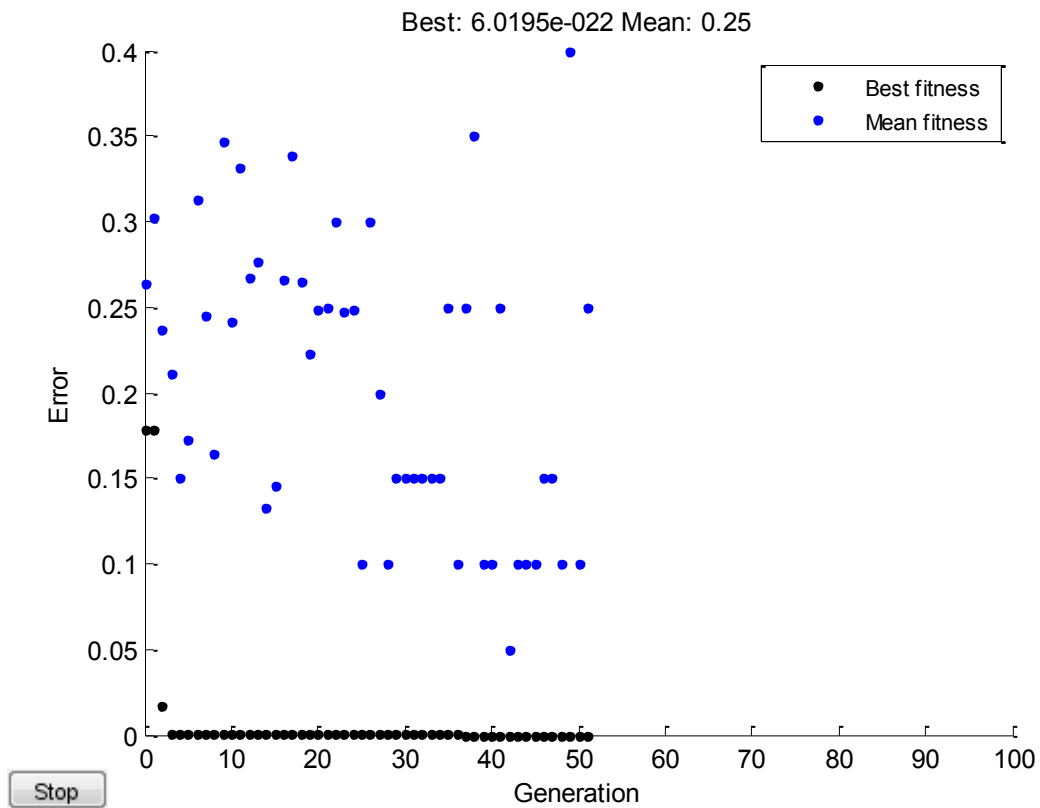


Fig. 6.5: Convergence of GA

The test data set for the neural network consist of 100 data samples that are not part of the training data set. The testing of the neural network is to identify the accuracy of the network in predicting for new data instances which are not used in the training of the neural network.

Fig. 6.6 shows the data points that are classified by the neural network. The neural network using the GA successfully classified 78 instances of the total 100 sample. The error in the classification of these samples is zero. The remaining 22 data instances are misclassified. This results in the overall training error of 0.22.

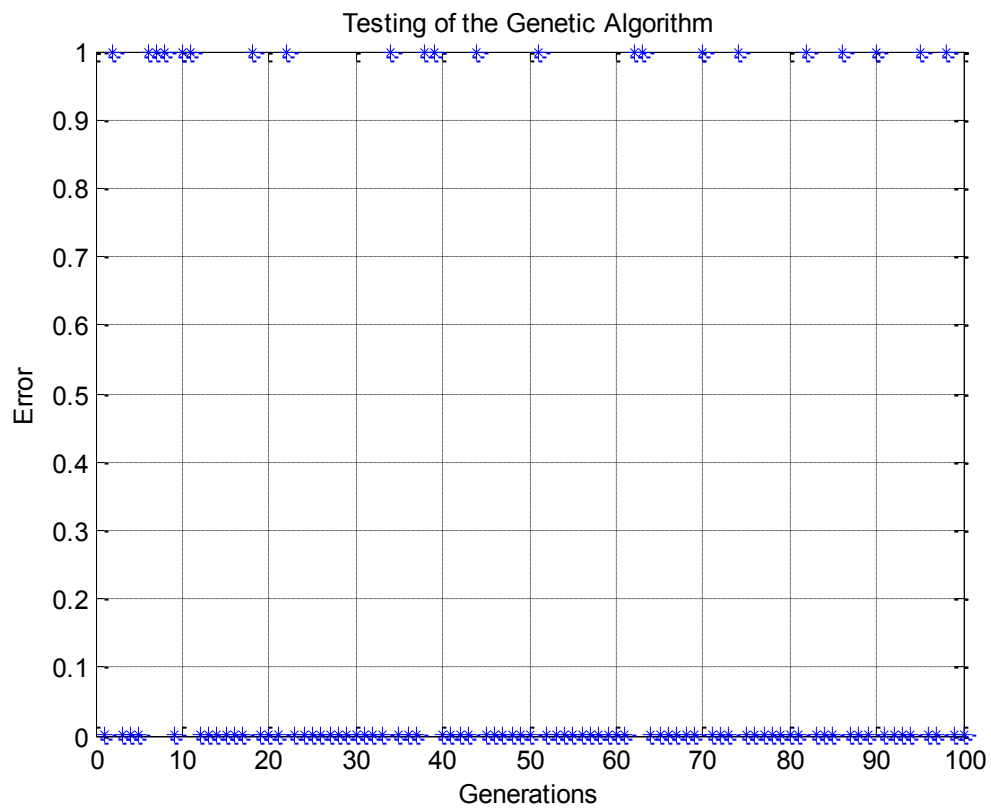


Fig. 6.6: Training of the Neural Network

6.6 Conclusion

In this chapter, an evolutionary neural network to identify the navigational signal in a locale was presented. The neural network with the genetic algorithm worked with 78% efficiency. The performance of the genetic algorithm can be further improved using selectively cloning described in chapter 7.

Chapter 7

Selectively Cloned Genetic Algorithm

In this chapter, an improved version of genetic algorithm which uses selective cloning is presented. The selectively cloned genetic algorithm compares the fitness of parents and offspring to create the new generation of chromosomes.

7.1 Effects of Inappropriate Crossover Operator

The crossover operator has a significant effect on the performance of the genetic algorithm. Improper crossover operator can destroy the essential schema instances being passed from one generation to the next.

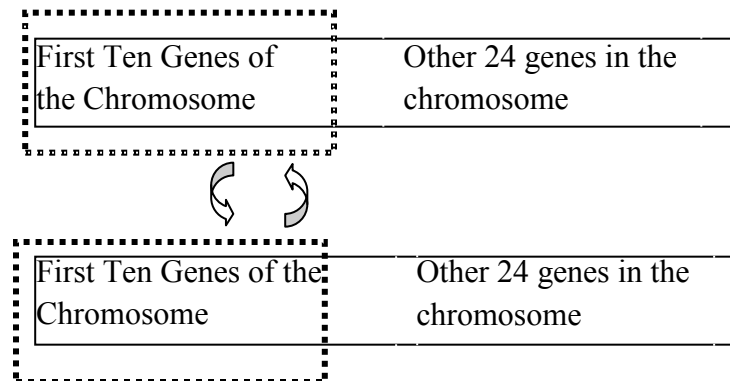


Fig. 7.1: Random Crossover Operator that interchanges first ten genes of the chromosomes

To observe this effect, a random crossover operator is chosen which implies the position and the length of crossover operator are chosen randomly. Fig. 7.1 shows the crossover operator that interchanges the first ten genes of the parent chromosomes. This crossover operator is used to generate the next generation of chromosomes for the SOP data classification. Fig. 7.2 shows the destructive effect of this crossover operator. The initial generations had some best individuals that minimized the error to approximately zero. However, after the application of the crossover operator, the error started increasing and finally converged at 0.25.

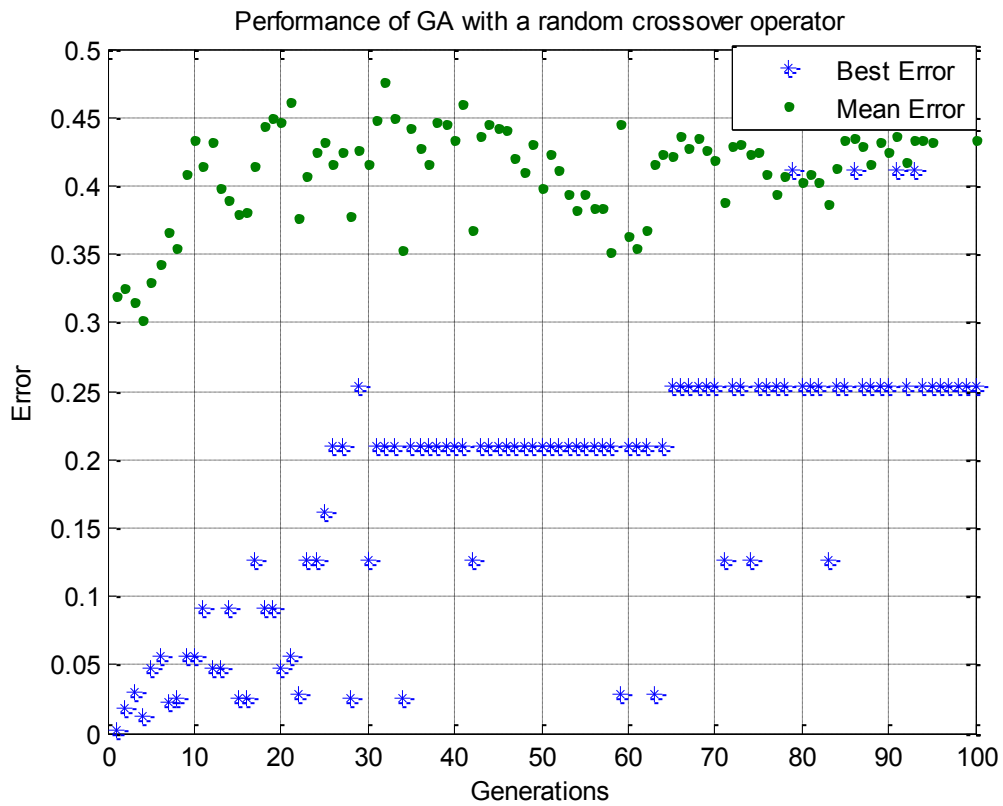


Fig. 7.2: Effect of Improper random crossover operator

Fig. 7.3 shows the effect of using randomly chosen single point crossover operator for

every generation. The best error is at 0.01 initially. It has increased to a value of 0.2 in 100 generations. The mean error never converged in the first 100 generations [23].

One of the possible solutions to overcome this problem is to randomly check for various crossover lengths and positions and then decide the best crossover operator. This is computationally intensive. Even after the application of the proper crossover operator, not all the offsprings have better fitness than their parent chromosomes.

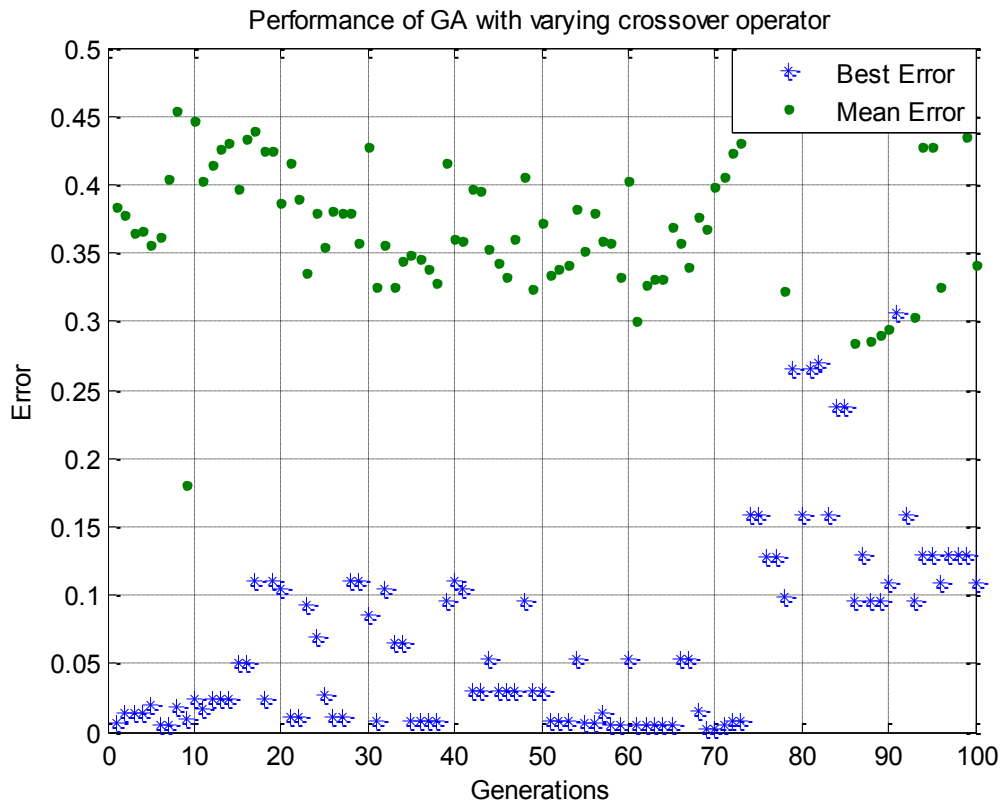


Fig. 7.3: Effect of Improper varying crossover operator

7.2 Selective Cloning

Selective cloning is a technique of selecting the parent over the offspring, when the fitness of the parent is superior to the fitness of the offspring. This approach can

guarantee a definite and a faster convergence. The selective cloning is based on the schema theorem. A schema is a set of bit strings of ones, zeros and asterisks, where each asterisk can assume the value of one or zero. For instance consider a schema $A \{0 * * 1\}$. The instances of schema A are $\{0001, 0101, 0011, \text{ and } 0111\}$. According to the schema theorem, one can predict the presence of a schema in next chromosome generation. For faster convergence, the fittest schema traces must be increased from generation to generation.

Let the fitness function be directly proportional to the instances of given schema „A’ in any generation. The negative effect of random crossover can be corrected using selective cloning. In case of selective cloning, when a random crossover length and position are chosen, the crossover operator can still break some of the schema instances of A and may leave the rest undisturbed. Thus, the offspring that contains the instances of A are of higher fitness and hence passed to the next generation. The offsprings that do not contain instances of A show poor fitness than the parents and hence instead of passing the offspring to the next generation, the parents are passed on to the next generation (cloning).

This approach guarantees the increase in population containing instances of A from generation to generation and thus guarantees definite increase in fitness of the generation and hence convergence, irrespective of crossover operator length and positioning. Thus, by using this technique we can choose any crossover operator to obtain an optimal solution. The mutation operator ensures that search space is not narrowed down [23].

7.2.1 Mathematical Justification

This section explains mathematically why selective cloning ensures higher fitness of

successive generations and is independent of the choice of random crossover operator.

Let 'm' be the total chromosome population in any generation.

The fitness criterion is directly proportional to the number of instances of schema H.

In the *i*th generation,

$m_H(i)$ = Total chromosome population containing instances from schema H.

$m_H'(i) = m - m_H(i)$ = Total chromosome population that do not contain instances from schema H.

Then by applying crossover and mutation operators, offsprings are generated.

$M_H(i)$ = Total chromosome population containing instances from schema H in offsprings.

$M_H'(i) = m - M_H(i)$ = Total chromosome population that does not contain instances from schema H in offsprings.

The crossover and mutation operators work in such a way that, some of the offspring of $m_H(i)$ population may lack instances from schema H and remaining possess the instances from schema H as given in equation 1. For example, consider two chromosomes 1001000 and 111100. The schema 1001 is the instance of H. If the crossover operator exchanges first 3 genes of the parents, the offsprings are 1001100 and 1001000. One of the offsprings possesses the schema instance 1001 and other lacks it. The Fig. 4 shows the creation of new generation of offsprings.

$$m_H(i) \rightarrow a * M_H(i) + b * M_H'(i) \quad (7.1)$$

Where $a + b = 1$, and $a, b \in [0, 1]$.

a = fraction of the total offspring population, where both the parents and the offsprings have the instances of schema H.

b = fraction of the total offspring population, where the offsprings lack the instances of schema H

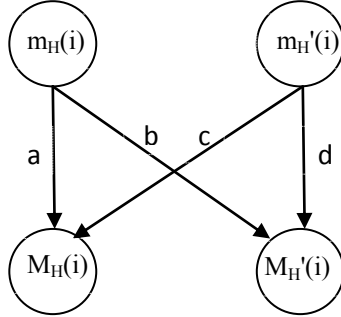


Fig. 7.4: Creation of next generation of chromosomes

$$m'_H(i) \rightarrow c * M_H(i) + d * M'_H(i) \quad (7.2)$$

Where $c+d = 1$, and $c, d \in [0,1]$.

c = fraction of the total offspring population, where the parents lack the instances of schema H and the offspring have the instances of schema H.

d = fraction of the total offspring population, where both the parents and the offspring lack the instances of schema H.

Now in selective cloning approach, the fitness of offspring is compared with the fitness of parents:

Thus

$b * M'_H(i)$ population has less fitness when compared to its parents and hence parents are passed on to the next generation.

$c * M_H(i)$ population has higher fitness than their parents and hence the offspring replace their parents in the next generation.

Therefore using the selective cloning, instances of schema H in next generation is given by equation (7.3).

$$m_H(i+1) = m_H(i) + c * M_H(i) \quad (7.3)$$

The worst case scenario is that when $c=0$, which is a rare case, and then there is no increase in the instances of schema H in next generation as shown in equation 4 [23].

$$m_H(i+1) = m_H(i) \quad (7.4)$$

Whenever $c > 0$, the instance of schema H in the next generation is given by equation (7.5).

$$m_H(i+1) \geq m_H(i) \quad (7.5)$$

This ensures that selective cloning ensures fitness improvement and so convergence.

7.3 Performance of Selectively Cloned Genetic Algorithm

The neural network is trained using the SCGA and its performance is analyzed. The SCGA converged within 10 generations as compared to the GA which converged in 35 generations. Fig. 7.5 shows the convergence graph for the fixed crossover point that exchanges first ten chromosomes as shown in Fig. 7.1, for successive generations. The mean classification error is as high as 0.2 initially with the best chromosome reducing the classification error to approximately zero. However occasional fluctuations are present, but the frequency of such fluctuations is very low.

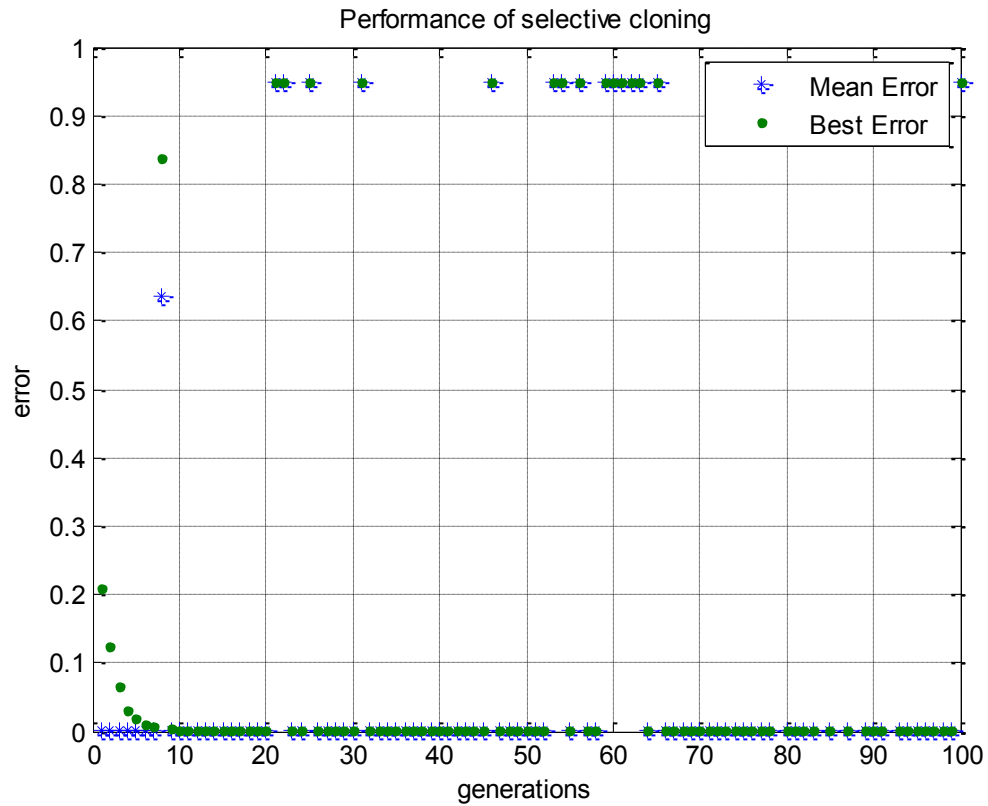


Fig. 7.5: Convergence of SCGA with random crossover operator

Next step is to study the impact of a random crossover point chosen for each successive generation on SCGA. Fig. 7.6 shows the performance of the SCGA with the single point crossover operator varied every generation. The mean classification error is as high as 0.2 initially with the best chromosome reducing the classification error to approximately zero. The SCGA converged within 10 generations.

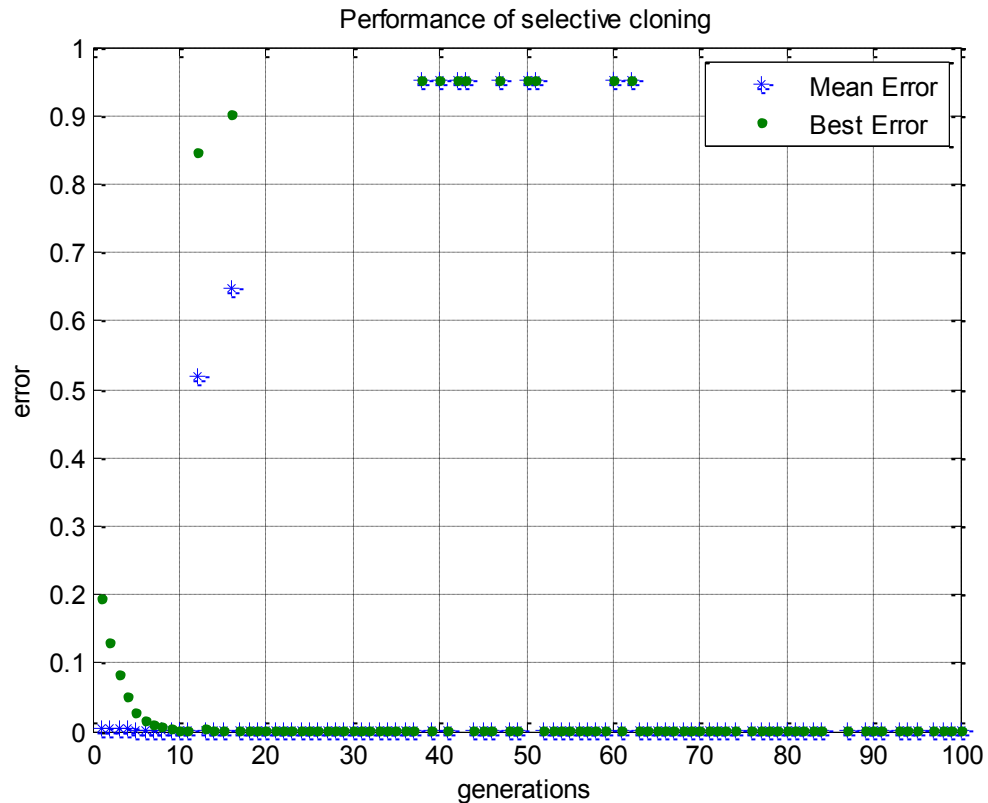


Fig. 7.6: Convergence of SCGA with varying crossover operator

The testing set of the evolutionary algorithm consist of 100 data samples used for the testing of the conventional GA. The testing of the neural network is to identify the accuracy of the network in predicting for new data instances which are not used in the training of the neural network

The neural network using the GA successfully classified 78 instances of the total 100 sample with classification error of 0.08. However, the rest of the 22 instances are misclassified with an error of 0.38. This results in the overall training error to be 0.21.

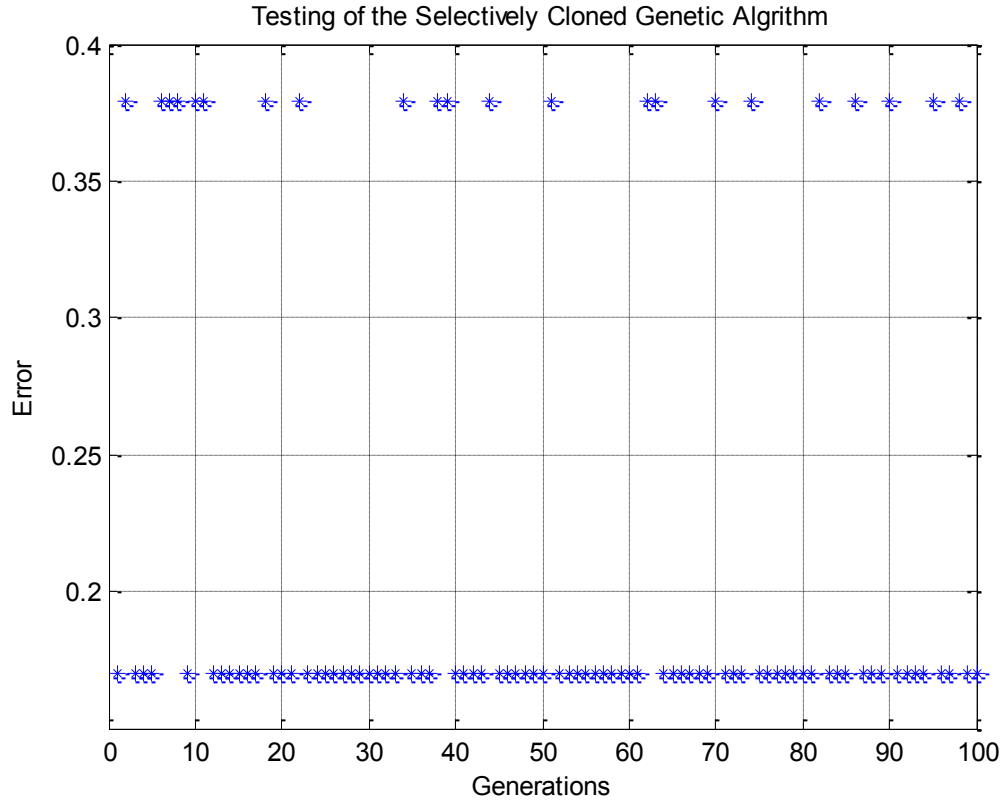


Fig. 7.7: Training of the Neural Network

7.4 Comparison of SCGA and GA

Table 7.1 shows the comparison of the GA and SCGA techniques. The SCGA converged faster than the conventional GA by 25 generations. The convergence efficiency, C_{Gen} (in terms of generations) is defined as

$$C_{Gen} = \frac{\text{converging generations of GA} - \text{converging generations of SCGA}}{\text{converging generations of GA}} = 71.4\% \dots (7.5)$$

The training efficiency, C_{Tr} (in terms of generations) is

$$C_{Tr} = \frac{\text{Mean Training error of GA} - \text{Mean training error of SCGA}}{\text{Mean Training error of GA}} = 4.8\% \dots \dots \dots (7.6)$$

Table 7.1: Comparison of GA and SCGA

	SCGA	GA
Convergence	10	35
Mean-Training Error	0.21	0.22

7.5 Conclusion

The chapter presented a modified genetic algorithm called selectively cloned genetic algorithm. The mean training error is reduced in SCGA to 0.21 as compared to 0.22 in GA. The improvement in error is 4.8%. The convergence rate is improved. SCGA converged in 10 generations and GA converged in 35 generations. The convergence is improved by 71.4%.

Conclusion & Future Work

A novel Signals of Opportunity (SOP) system with two mobile receivers was presented with mathematical framework, which eliminates the base station. The SOP system was shown to have more efficiency, flexibility and faster installation than the conventional SOP system with a base station. The SOP system was embedded with an evolutionary neural network that reduces the signal selection time without compromising on the navigation standards.

The research for the improved SOP system can be extended to achieve the following:

- The correlation patterns for AM and FM sources for improved SOP could be studied for better results.
- The comparison of both SOP systems for other sources like UHF or X-band will help in assessing the system more accurately.

References

1. **Chunpeng Yan Fan**, “Asynchronous differential TDOA for non-GPS navigation using signals of opportunity”, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, May 2008, 5312-5315.
2. **Mike Richardson**, “Passive Urban Surveillance Using Signals of Opportunity”, (http://www.seastdc.com/events/2009_conference/downloads/pdf/communications_and_control/CC014_presentation.pdf)
3. **Rong Peng and Mihail L. Sichitiu**, “Angle of Arrival Localization for Wireless Sensor Networks”, *3rd Annual IEEE Communications Society Sensor and Ad Hoc Communications and Networks (SECON)*, Sept 2006, 1, 374-382.
4. **Akhdar, Carsenat, Decroze, Monediere**,” A simple technique for angle of arrival measurement”, *IEEE Antennas and Propagation Society International Symposium*, July 2008, 1-4.
5. **Jari Yli-Hietanen, Kari Kalliojarvi, Jaakko Astola**,” Analysis of robust time-delay based angle-of-arrival estimation methods”, *14th International Conference on Digital Signal Processing*, 2002, 1, 239-242.

6. **Jason G. Crosby**, "Fusion of Inertial Sensors and Orthogonal Frequency Division Multiplexed (OFDM) Signals of Opportunity for Unassisted Navigation", Dissertation, , Air Force Institute Of Technology, March 2009.
7. **Fisher**, "The Navigation Potential of Signals of Opportunity-Based Time Difference of Arrival Measurements", Ph.D. dissertation, Graduate School of Engineering and Management, Air Force Institute of Technology (AETC),Wright-Patterson AFB OH, March 2005.
8. **Bradford W. Parkinson, James J. Spilker**, "Global positioning system: theory and applications", publication American Institute of Aeronautics and Astronautics, 29-54.
9. **Ahmed El-Rabbany**, "Introduction to GPS: the Global Positioning System", publication Artech House, 2002, 1-20.
10. **Jonathan A. McEllroy**, "Navigation Using Signals of Opportunity in the AM Transmission Band", THESIS by Air Force Institute of Technology, September 2006.
11. **Wright, Stallings, Dunn**, "The effectiveness of global positioning system electronic navigation", *IEEE Proceedings SoutheastCon*, April 2003, 62- 67.
12. **Eggert, R.J. and J.F. Raquet**. "Evaluating the navigation potential of the NTSC analog television broadcast signal", ION GNSS 17th International Technical Meeting of the Satellite Division, 2436–2446. Institute of Navigation, Inc., Long Beach, CA, September 2004.
13. **Kim**, Second Lieutenant USAF, B. S.," Evaluating the Correlation Characteristics of Arbitrary AM and FM Radio Signals for the Purpose of Navigation". Master's thesis,

Graduate School of Engineering and Management, Air Force Institute of Technology (AETC), Wright-Patterson AFB OH, March 2006.

14. **B. P. Lathi**, “Signal Processing and Linear Systems”, Oxford University Press, Inc., New York, NY, 1998.

15. **P. Misra, P. Enge**, “Global Positioning System: Signals, Measurements, and Performance”, Massachusetts: Ganga-Jamuna Press, 2001.

16. **Enright M.A., Kurby C.N.**, “A signals of opportunity based cooperative navigation network”, Proceedings of the IEEE 2009 National Aerospace & Electronics Conference (NAECON), July 2009, 213 – 218,.

17. **Chun Yang, Thao Nguyen, Venable D., White M., Siegel R.**, “Cooperative position location with signals of opportunity”, Proceedings of the IEEE 2009 National Aerospace & Electronics Conference (NAECON), 18 – 25, July 2009.

18. **Wierwille, Walter W.** , “A Theory and Method for Correlation Analysis of Nonstationary Signals”, IEEE Transactions on Electronic Computers, vol. EC-14 , issue 6, pp 909-919, Dec. 1965

19. **A. G. Longley and P. L. Rice**, "Prediction of tropospheric radio transmission loss over irregular terrain. A computer method-1968", ESSA Tech. Rep. ERL 79-ITS 67, U.S. Government Printing Office, Washington, DC, July 1968.

20. **Sherman c. Lo, Benjamin b. Peterson, Per k. Enge, Peter Swaszek**, “Loran data modulation: extensions and examples”, *IEEE Transactions on Aerospace and Electronic Systems*, April 2007, 43(2), 628-644.

21. **Gregory Johnson, Ruslan Shalaev, Richard Hartnett, Peter Swaszek, Mitch Narins**, "Can LORAN Meet GPS Backup Requirements?", *IEEE Magazine on Aerospace and Electronic Systems*, February 2005, 20(2), 3-12.
22. **Yogendran**, "GPS - The different arguments..?", (<http://www.gisdevelopment.net/technology/gps/techgp0017pf.htm>).
23. **Devinder Kaur, Praneeth Nelapati**, "Performance Enhancement of Selectively Cloned Evolutionary Algorithm for Data Classification", *International Journal of Computational Intelligence Systems (IJCIS)*, December 2010, 6(3), 723-732.
24. Wikipedia, (http://en.wikipedia.org/wiki/Random_number_generation) as retrieved on 21 March, 2011.