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AUTOMATIC TRACKING AND IDENTIFICATION SYSTEMS IN NAVIGATION

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M.Sc. Thesis

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NAVİGASYON AMAÇLI KULLANILAN OTOMATİK İZLEME VE TANIMA SİSTEMLERİ

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KEY ACRONYMS

ADS	:Automated Dependent Surveillance
AIS	:Automatic Identification System
AMPS	:Advanced Mobile Phone Service
AS	:Antispoofing
BPSK	:Binary Phase Shift Key
C/A	:Coarse / Acquisition or Clear / Acquisition code
CDMA	:Code Division Multiple Access
CDU	:Control Display Unit
COMMSTAs	:Coast Guard groups and Communications Stations
D8PSK	:Digital Eight Phase Shift Keying
DGPS	:Differential Global Positioning System
DNSS	:Defense Navigation Satellite System
DOP	:Dilution of Precision
DOT	:Department of Transportation
DR	:Distance Ratio
DR	:Dead Reckoning
DSC	:Digital Selective Calling
DSSS	:Direct Sequence Spread Spectrum
ECDIS	:Electronic Chart Display Information System
ECEF	:Earth Centered Earth Fixed
ECI	:Earth-Centered Inertial
FCC	:Federal Communication Commision
FOC	:Full Operational Capability
GLONASS	:Global Navigation Satellite System
GMDSS	:Global Maritime Distress and Safety System
GMSK/FM	:Frequency Modulation using Gaussian Minimum Shift Keying
GNSS	:Global Navigation Satellite System
GP&C	:Global Positioning & Communication
GPS	:Global Positioning System
I/O	:Input / Output
IC	:Integrated Circuits
IMO	:International Maritime Organization
ITU-R	:International Telecommunication Union Recommendation
JPO	:Joint Program Office
LADGPS	:Local Area DGPS
LORAN	:Long Range Navigation
MCS	:Master Control Station
MID	:Maritime Identification Digits
MMSI	:Maritime Mobile Service Identity
NASA	:National Aeronautics and Space Administration
NI	:Nominal Increment
NS	:Nominal Slot

NSS	:Nominal Start Slot
NTS	:Nominal Transmission Slots
OCS	:Operational Control Segment
OSD	:Office of the Secretary of Defense
P Code	:Precision Code
PDOP	:Position Dilution of Precision
PLL	:Phase Lock Loop
PPS	:Precise Positioning Service
PpS	:Pulse per Second
PR	:Power Ratio
PRN	:Pseudorandom Noise
PVT	:Position, Velocity and Time
RAM	:Random Access Memory
RHCP	:Right-Hand Circularly Polarized
RR	:Report Rate
RSS	:Relative Signal Strength
SA	:Selective Availability
SI	:Selection Interval
SOG	:Speed Over Ground
SOLAS	:Safety of Life at Sea
SPS	:Standard Positioning Service
SS	:Set of Slots
STDMA	:Self-Organized Time Division Multiple Access
SV	:Space Vehicle
TAI	:International Atomic Time
TDMA	:Time Division Multiple Access
TOA	:Time of Arrival
TP	:Throughput
TT&C	:Telemetry, Tracking and Command
TTAC	:Telemetry, Tracking, and Control Centers
U	:Update Rate
U.S.	:United States
UERE	:User-Equivalent Range Error
USCG	:U.S. Coast Guard
USNO	:United States Naval Observatory
UTC	:Coordinated Universal Time
VHF	:Very High Frequency
VTS	:Vessel Trafic Services
WADGPS	:Wide Area DGPS

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NAVİGASYON AMAÇLI KULLANILAN OTOMATİK İZLEME VE TANIMA SİSTEMLERİ

ÖZET

Navigasyon (seyir), bir aracı veya insanı bir yerden baska bir yere ulaştırma olarak tanımlanabilir. Hepimiz günlük hayatımızda navigasyonun farklı türleri ile karşılaşmaktayız.Fakat bunların çoğu duyu organlarımıza ve etrafımızdaki işaretlere dayalı türlerdir ve daha hassas bilgi gerektiren durumlarda yetersiz kalmaktadırlar. Böyle durumlarda navigasyonu gerçekleştirmek için elektronik sinyaller kullanılabilir. Elektronik sinyallerin kullanıldığı navigasyon türüne "Radyo Navigasyon" diyoruz.

Radyo navigasyonu uzayda kurulmuş sistemler ve yeryüzünde kurulmuş sistemler olmak üzere ikiye ayırabiliriz. Bizim tezimizin ikinci bölümünde uzayda kurulmuş sistemler üzerinde durulmuştur. Uzay bazlı sistemlerin temelleri 1950'lere dayanmaktadır. Bu sistemlerden ilkleri Amerika'lılar tarafından geliştirilen Transit ve Ruslar tarafından geliştirilen Tsikada'dır. Bu iki sistemde de iki boyutlu konum bilgisi sağlanıyordu ve gelen sinyalin işlenip yeni konum bilgisinin elde edilmesi yaklaşık on-on beş dakika alıyordu. Bu gibi eksiklerden dolayı yeni sistemlerin geliştirilmesine ihtiyaç duyulmuştur. Amerika Deniz ve Hava Kuvvetleri, uydu yardımıyla konum belirleyecek yeni bir sistem üzerinde çalışmaya başladılar ve GPS' i (Global Positioning System) geliştirdiler. Buna karşılık olarak Rus'larda GLONASS' ı (Global Navigation Satellite System) geliştirdiler. Her iki sistemde de amaçlanan; süreklilik ve her hava koşulunda çalışabilme, küresel kapsama, dinamik ortamlara uygunluk ve yüksek doğrulukta çalışabilme idi.

GPS ve GLONASS'ın altında yatan temel düşünce, uzaya yerleştirilmiş olan uyduları, yeryüzündeki konumumuz için bir referans noktası olarak kullanmaktır. Uzaydaki uyduların konumunu bildiğimiz varsayımı ile bunu yapmak mümkündür. Yeryüzünden yaklaşık yirmi bin km. yukarıda bulunan bu uydulara olan uzaklıklarımızı bularak üç boyutlu konum bilgimizi elde etmek mümkün olacaktır. (Bkz. Şekil 10 - 11 – 12). Uydulara olan uzaklığımızı ise, uydudan gönderilen sinyalin bize variş süresi ile, elektromagnetik dalganın yayılım hızını çarparak buluruz. Görüldüğü gibi uydu sinyalinin bize varış süresini hesaplamak GPS ve

GLONASS sistemlerinin en can alıcı noktasıdır. Zamandaki hassaslık uydularda atomik saatler kullanılarak sağlanır. Atomik saatlerin fiyatı ise elli bin ile yüzbin dolar arasında değişmektedir. Bu ise atomik saatlerin GPS kullanıcılarında kullanılmasını olanaksız kılmaktadır. Bunun sonucunda ise GPS ölçümlerinde daha hesaplamaların başında hatalar işin içine girmektedir. Fakat yapılan çalışmalar sonucunda, üç boyutlu konum bilgisi için gerekli olan üç uydu ölçümünün dışında, dördüncü bir uydudan alınacak sinyalle bu sorunun ortadan kaldırılabileceği görülmüştür.

GPS kullanıcılarına iki türlü hizmet vermektedir. Bunlardan ilki PPS (Precise Positioning Service) diğeri ise SPS'dir (Standard Positioning Service). PPS Amerika Hükümet'i ve ordusu tarafından izin verilen kişiler dışında kullanıma kapalıdır. Normal kullanıcıların bu sisteme erişimin engellemek için SA(Selective Availability) ve AS (Antispoofing) şifreleme sistemleri kullanılmıştır. PPS sisteminin içerdiği hata; yatayda 22 m., düşeyde 27 m. ve zaman transferinde yaklaşık iki yüz nsn.'dir. SPS sistemi ise GPS alıcısına sahip herkesin kullanabildiği bir sistemdir. Bu sistemin içerdiği hata ise; yatayda 100 m., düşeyde 156m. ve zaman transferinde yaklaşık üç yüz kırk nsn.'dir.

GPS'ten elde edilen, yukarda belirtilen doğruluk derecesine sahip konum bilgisi bir çok uygulama da yeterli olmasına rağmen, gerek insan doğasından gelen daha iyisine sahip olma isteği gerekse de daha hassas bilgi gerektiren uygulamalarda yetersiz kalmaktadır. Bu nedenle GPS'in bir adım daha ilerisi olan DGPS (Differential GPS) sistemi geliştirilmiştir. DGPS' te konumu çok iyi bilinen bir referens istasyonu GPS uydularından gelen sinyalleri sanki bir GPS kullanıcısıymış gibi işler ve elde ettiği konum bilgisini kendi konum bilgisi ile kıyaslar . Aradaki fark GPS'ten o bölgeden alınan sinyallerden elde edilen konum bilgisinin içerdiği hata olacaktır. Referans istasyonu bu hataları içeren düzeltme mesajlarını civarına yayınlayarak GPS kullanıcılarının daha doğru bilgi elde etmesini sağlamış olur. DGPS ile elde edilen konum bilgisinin içerdiği hata yatayda ve düşeyde 5m. ile 10 m. arasında olmaktadır.

Konum belirleme sistemlerinde bu gibi gelişmeler yaşanırken, gerek deniz gerekse hava araştırmacıları, kullanımda olan radar sistemlerini iyileştirebilecek veya onların yerini alabilecek yeni izleme sistemleri araştırmaktaydılar. İzleme amaçlı radarlar bir digital işaret gönderirler ve bu işaret herhangi bir cisme çarptığında, o cismi tanımlayıcı bilgilerle vericiye tekrar geri döner. Elde edilen veriler çok fazla doğruluklu değillerdir ve bilgiyi güncelleme oranı radar anteninin dönüş hızına bağlı olarak genelde yavaştır. Bu nedenler GNSS (Global Navigation Satellite System (örneğin GPS, GLONASS)) sistemlerinin hızlı yükselişi ile birleşince, GNSS sistemlerini yeni izleme sistemlerinde kullanma fikri ortaya çıkmıştır. Tezimizin ikinci ve üçüncü kısmı 'bilgisayar, GNSS ve digital radyo işaretlerini' birleştiren sistemlerden ikisini incelemektedir.

Tezin üçüncü bölümünde STDMA (Self Organized Time Division Multiple Access) tekniği incelenmiştir. Bu sistemde kullanıcı GNSS sistemlerinden birisiyle sürekli olarak konum bilgisi elde etmekte ve elde ettiği bu bilgiyi VHF veri bağlantısıyla etrafına yayınlamaktadır. Kullanıcı konum bilgisini ne zaman yayınlayacağını özel bir algoritma olan Self Organizing algoritmasını kullanarak karar verir. Bu algoritmada veri iletimi için seçilecek zaman daha önceki iletim bilgileri ve yeni iletim bilgileri göz önüne alınarak belirlenir. Yani bir merkez kontrol istasyonu tarafından kontrol edilmeye gerek kalmamaktadır.

STDMA tekniğinde veri iletimi bandı adından da anlaşılacağı üzere zamanda çoğullama ile paylaştırılır. Her pozisyon bilgisi bir zaman aralığında (time slot) gönderilir. Her kullanıcının gönderdiği konum bilgisi ancak belirli bilgi bölge de hesaba katılır. Buna o kullanıcının içinde bulunduğu VHF hücresi (VHF Cell) denir. Aşırı yüklenme durumunda VHF hücrelerinin boyutları küçültülür. Bu ise STDMA sistemine, her an değişen kullanıcı sayısına göre uyumlu çalışma özelliği katmaktadır. STDMA tekniğinde VHF bandı kullanıldığından VHF hücreleri ufuk çizgisi (Line-of-Sight) ile de sınırlanmaktadır. STDMA Veri linklerinin kapasitesi oldukça yüksektir. 25 kHz'lik VHF radio kanallarında dakika'da 2000 konum bilgisi iletilebilmektedir.

Tezin dördüncü bölümünde ise DSC (Digital Selective Calling) tekniği incelenmiştir. DSC Uluslararası Denizcilik Organizasyonu (International Maritime Organization – IMO) tarafından onaylanmış yarı otomatik radyo çağrısı kurma sistemidir. Normalde denizcilikteki radyo haberleşmesi sesli bir çağrıdan ve karşı tarafta onu dinleyen kişinin cevabından oluşmaktadır. Yani her hangi bir tehlike anında sizin gönderdiğiniz mesajın karşı taraftan alınabilmesi için o an hatta birilerinin bulunuyor olması ve sizi dinliyor olması gerekmektedir. Bu ise kullanımda olan sistemlerin güvenilirliğini azaltmaktadır.

DSC'de herhangi bir haberleşme hattı ile bağlantı kurulduğunda, o hatta kullanılan frekanslar ve gönderilen sinyaller otomatik olarak izlenmektedir ve gelen mesajların niteliğine göre otomatik olarak cevap mesajları gönderilebilmektedir. Bumesajlar genelde, geminin kimlik kartı diyebileceğimiz MMSI (Maritime Mobile Service Identity) numarasını, konumunu ve konum bilgisinin elde edildiği zamanı, hangi frekansta haberleşileceği ve tehlike nedeni gibi bilgiler içermektedir. Ayrıca DSC mesajları istenilen bir kullanıcıya da yönlendirilebilir ve veri iletimi için HF, MF veya VHF frekansları kullanılabilir. Bu ise kullanıcıların ufuk çizgisi içinde kalma gerekliliğini ortaya çıkarır.

Tezin sonuçlar bölümünde ise incelenen iki tekniğin avantajları ve dezavantajlarından bahsedilmistir. İki teknikte de VHF bandlarında iletim gerçekleştirilmektedir. Bu ise kullanıcıların ufuk çizgisi içinde kalması zorunluluğunu getirmektedir. Bu nedenle, DSC veya STDMA tekniğinin kullanılacağı bölgelerin yeryüzü yapısı uygulamada önemli bir parametre olmaktadır. Yeryüzünün çok yükseltili alçaltılı olduğu bölgelerde ekstra DSC istasyonlarına ihtiyaç duyulmaktadır. Bu ise ek bir maliyet getirmektedir. Yine böyle bir bölgede STDMA tekniğini kullanan sistemlerin VHF hücrelerinin boyutları küçülmektedir. Bu ise kullanıcı sayısını sınırlamaktadır. STDMA tekniğinde kullanılan özel algoritma, bir merkez kontrol istasyonu tarafından kontrol edilerek iletim bandının paylaştırılması gerekliliğini ortadan kaldırmaktadır. Bu algoritma aynı zamanda iletimde meydana gelebilecek çakışmaları önleyebilmektedir ve oluşabilecek çakışmaları da çözebilmektedir. STDMA Veri linklerinin kapasitesi oldukça yüksektir. 25 kHz'lik VHF radio kanallarında dakika'da 2000 konum bilgisi iletilebilmektedir. DSC tekniğinde ise kapasite sorunu vardır. 25 kHz'lik VHF bandlarında dakikada yaklaşık 15, DSC protokolune uygun mesaj gonderilebilmektedir. Bu sorun DSC iletimi için ekstra kanallar kullanılarak bir ölçüde çözülebilmektedir.

AUTOMATIC TRACKING AND IDENTIFICATION SYSTEMS IN NAVIGATION

SUMMARY

Navigation is defined as the science of getting a craft or person from one place to another. Trying to figure out where you are and where you're going is probably one of man's oldest endavours. Most of us confront some form of navigation in our daily lives. They are usually some simple form of navigation. However, in some cases, more accurate navigational information which needs more complex systems for their realization. Signals from one or more radionavigation aids enable a person (user) to compute their position.

Various types of radionavigation aids exist. It can be categorized as either ground-based or space-based . Early developed spaced-based systems (namely the United States (U.S.) referred to as Transit-and the Russian Tsikada system) provide a two dimensional high-accuracy positioning service. However, the frequency of obtaining a position fix varies with latitude. Limitations applicable to both systems are that each position fix requires approximately 10 to 15 minutes of receiver processing and an estimate of the user's position. In the early 1960s, several U.S. government organizations including the military, the National Aeronautics and Space Administration (NASA), and the Department of Transportation (DOT) were interested in developing satellite systems for position determination and developed GPS (Global Positioning Service). Russian government developed GLONASS (Global Navigation Satellite System) in reply to GPS. These navigation system is developed with the desired capabilities (global coverage, continues all weather operation, ability to serve high_dynamicplatforms, and high accuracy).

The whole idea behind GPS is to use satellites in space as reference points for locations here on earth. Assuming that we know where the GPS satellites are, we can use them as reference points. They're floating around 11,000 miles up in space. By very accurately measuring our distance from three satellites, it is possible "triangulate" our position anywhere on earth. The distance from the satellite can be calculated by timing how long it takes for a signal sent from the satellite to arrive at our receiver. It is clear that measuring the travel time of a radio signal is the key to

GPS. Timing is almost perfect on the satellite site. Because they have very precise atomic clocks on board. Atomic clocks cost upwards of $50K to $100K. If our receivers needed atomic clocks GPS would be very costly and unpractical. Designers of GPS came up with the brilliant idea which is to extract timing reference from signals received from the satellites. This made it possible to use much less accurate clocks in GPS receivers.

GPS provides two levels of service. One of them is Standard Positioning Service (SPS) for general public use and the other is encoded Precise Positioning Service (PPS) primarily intended for use by the Department of Defense. SPS signal accuracy is intentionally degraded to protect U.S. national security interests. This process, called Selective Availability (SA), controls the availability of the system's full capabilities. The SPS accuracy specifications, given below, include the effects of SA. SPS provides accuracy's within: 100 meters horizontal 156 meters vertical. SPS Coverage is continuous and worldwide, with a position dilution of precision (PDOP). The PPS is specified to provide a predictable accuracy of at least 22m in the horizontal plane and 27,7m in the vertical plane.

Basic GPS is the most accurate radio-based navigation system yet developed. And for many applications it's sufficiently accurate. But it's human nature to want more. So, Differential GPS which correct the various inaccuracies in the system is developed. Differential GPS involves the cooperation of two receivers. One of them is stationary and another that's moving around making position measurements. The stationary receiver is the key of DGPS. It ties all the satellite measurements into a solid local reference. If two receivers are fairly close to each other (i.e within a few hundred kilometers) the signals that reach both of them will have traveled through virtually the same slice of atmosphere. Therefore they will have virtually the same errors. We have one receiver measure the timing errors and then provide correction information to the other receivers that are not stationary. By this way virtually all errors can be eliminated from the system, even the Selective Availability error. Differential GPS (DGPS) can yield measurements accurate to a few of meters (5m - 10m) in moving applications and even better in stationary situations.

Maritime and aviation surveyers are looking for alternative ways to replace or improve current radar system for navigation or surveillance purposes. The radar system for surveying purpose will send a digital signal back to the transmitter when it detects the radar signal which contain an identifier and altitude. But radar gives very little and usually inaccurate information. The update rate is generally slow, since it is equal to the rotation rate of the radar antenna. And GPS offers surveyers a chance to reach their dreams. In the reminder of this thesis a new approach in navigation "automated tracking of vessles" will be discussed which combines computer, GNSS and digital radio.

In the third chapter of thesis, it is examined the technique which is used in automated tracking is Self Organized Time Division Multiple Access (STDMA). A station with a system which continuously receives its own position from GNSS system and then broadcasts it via VHF data link is used for this purpose. The station determines its own transmission schedule based on the Self Organizing algorithm which schedules transmissions based on the prior knowledge and future activities on the data link. In other words, there is no need for controlling or polling functions via the master control.

The transmission is controlled by the computer and synchronised by an accurate timing signal (UTC), which can be derived from the GPS system. Transmissions from each transponder's VHF-radio are made automatically and with short time-intervals (typically 1-60sec). The capacity of the data link is very high. More than 2000 position reports per minute can be transmitted on a single VHF radio channel (25KHz bandwidth). Transmitted data includes Identity, Position (Lat and Long), Altitude, Heading, Speed etc.. as part of the standard aviation position report. It also handles overload very well, with gracefully reduced VHF cell size as a result. In brief; time division multiple access (TDMA) provides efficient use of the frequency resource and the self-organizing algorithm,makes it possible to handle overload, and a constantly changing population of participating stations.

In the forth chapter of thesis, DSC (Digital Selective Calling) technique is examined. It is a semi automated method of establishing a radio call which was approved by the International Maritime Organization (IMO) for maritime applications. Radio contact is usually established by making a voice call and relying on an aural watch by the called party to hear the call.

Digital selective calling automatically monitors calling frequencies and signals when a communications link is established between marine radios. The advantage of DSC is that it provides faster alerting capabilities and automatic transmission of information. DSC cane be used to send a specific information . The information can include caller's Maritime Mobile Service Identity (MMSI), caller's location, time of location, the requested working frequency and the nature of the distress. Moreover the communication can be established selectively, i.e. , DSC messages can be addressed to a certain user.

In the conclusion section, the advantage and disadvantage of both communication techniques is discussed. DSC is a viable alternative for Automated Dependent Surveillance (ADS). The system reliability and integrity are very good. And the latency on the working channel is also good. Coverage area depends on geographic area. It might be needed more DSC sites in the complex area. And it increases cost of the system. DSC has a capacity problem. 15 DSC polls can be made and responded to per minute based on the DSC protocol. Capacity might be increased by using additional channels for DSC. One more advantage of this system is that there are no monthly or per charge for use regardless of traffic volume. And the shipboard equipment is small and inexpensive. In STDMA, transmissions are normally in broadcast and autonomous mode. That means transmission can be monitored by the all the ships or shore stations within the VHF radio range. The capacity of STDMA is very high. More than 2000 position reports in minute can be transmitted on a single radio channel which is 25 kHz. Each reports obtains identity, position, altitude, speed... In STDMA, the data link can be shared among a large number of stations. The system provides minimizing of the transmission conflicts. And also, there is no need master or control station. STDMA system is capable handling overload case and constantly changing population of participating stations. It seems that STDMA is more useful system for surveillance and tracking purpose with its these feature.

1. INTRODUCTION

Navigation is defined as the science of getting a craft or person from one place to another. Trying to figure out where you are and where you're going is probably one of man's oldest endavours. Most of us confront some form of navigation in our daily lives. They are usually some simple form of navigation. However, in some cases, more accurate navigational information which needs more complex systems for their realization. Navigation and positioning are crucial to so many activities and yet the process has always been quite cumbersome. Over the years all kinds of technologies have tried to simplify the task but every one has had some disadvantage.

One of the earlier navigation system is Omega. Omega navigation system is developed by USA government. It is based on relatively few radio direction beacons. Omega a phase comparison radio navigation technique utilizing very low frequency radio waves. Utilizing low frequencies adventageous in that approximately six shore based transmitters can provide world wide coverage. It provides accuracy within coverage area with a reliability of 95%. Omega is used principally by airlines, military craft and intercontinental businnes craft. But the accuracy is limited and subject to radio interference.

Loran which stands Long Range Navigation is next generation navigation system which means Long Range Navigation. It is the low-frequency hyperbolic radio long-range navigation system which measures time difference between reception of synchronised signals transmitted from ground transmitters. Loran-C, operates in the 100-110 kHz frequency band with an operating range of 600-1,500 nm independent of line-of-sight. Loran-C was originally developed to provide radionavigation service for U.S. coastal waters and was later expanded to include complete coverage of the continental U.S. as well as most of Alaska. Twenty-four U.S. Loran-C stations work in partnership with Canadian and Russian stations to provide coverage in Canadian waters and in the Bering Sea. Loran-C provides better than 0.25 nautical mile absolute accuracy for suitably equipped users within this areas. But the coverage area is limited, accuracy is variable and is affected by local geographic conditions. Moreover it can be jammed.

In the early 1960s, several U.S. government organization were interested in developing a satellite system for position determination . And fortunately they had the funds ($12 billion) it took to build something really good. The result is the Global Positioning System, a system that has changed all prior concept in navigation . GPS is a satellite-based radionavigation system developed and operated by the U.S. Department of Defense (DOD). GPS permits land, sea, and airborne users to determine their three-dimensional position, velocity, and time 24 hours a day, in all weather, anywhere in the world with a precision and accuracy far better than other radionavigation systems available today or foreseeable in the near future.

The whole idea behind GPS is to use satellites in space as reference points for locations here on earth. Assuming that we know where the GPS satellites are, we can use them as reference points. They're floating around 11,000 miles up in space. By very accurately measuring our distance from three satellites, it is possible "triangulate" our position anywhere on earth. The distance from the satellite can be calculated by timing how long it takes for a signal sent from the satellite to arrive at our receiver. It is clear that measuring the travel time of a radio signal is the key to GPS. If their timing is off by just a thousandth of a second, at the speed of light, that translates into almost 200 miles of error! Timing is almost perfect on the satellite site. Because they have very precise atomic clocks on board. However, both the satellite and the receiver need to be able to precisely synchronize their pseudo-random codes to make the system work.

Atomic clocks cost upwards of $50K to $100K. If our receivers needed atomic clocks GPS would be very costly and unpractical. Designers of GPS came up with the brilliant idea which is to extract timing reference from signals received from the satellites. This made it possible to use much less accurate clocks in GPS receivers. Up to now we've been treating the calculations that go into GPS very abstractly. But, to get the most out of the system, a good GPS receiver needs to take a wide variety of possible errors into account.

GPS provides two levels of service. One of them is Standard Positioning Service (SPS) for general public use and an the other is encoded Precise Positioning Service (PPS) primarily intended for use by the Department of Defense. SPS signal accuracy is intentionally degraded to protect U.S. national security interests. This process, called Selective Availability (SA), controls the availability of the system's full capabilities. The SPS accuracy specifications, given below, include the effects of SA. SPS provides accuracy's within: 100 meters horizontal 156 meters vertical. SPS Coverage is continuous and worldwide, with a position dilution of precision (PDOP).

The PPS is specified to provide a predictable accuracy of at least 22m in the horizontal plane and 27,7m in the vertical plane.

Basic GPS is the most accurate radio-based navigation system yet developed. And for many applications it's sufficiently accurate. But it's human nature to want more. So, Differential GPS which correct the various inaccuracies in the system is developed. Differential GPS (DGPS) can yield measurements accurate to a few of meters in moving applications and even better in stationary situations. That improved accuracy has a profound effect on the importance of GPS as a resource. It becomes a universal measurement system which is capable of positioning things on a very precise scale.

Differential GPS involves the cooperation of two receivers. One of them is stationary and another that's moving around making position measurements. The stationary receiver is the key of DGPS. It ties all the satellite measurements into a solid local reference. If two receivers are fairly close to each other (i.e within a few hundred kilometers) the signals that reach both of them will have traveled through virtually the same slice of atmosphere. Therefore they will have virtually the same errors. We have one receiver measure the timing errors and then provide correction information to the other receivers that are not stationary. By this way virtually all errors can be eliminated from the system, even the Selective Availability error.

In the early days of GPS, reference stations were established by private companies. They had usually big projects demanding high accuracy - groups like surveyors or oil drilling operations. But now there are enough public agencies transmitting corrections and providing them for free. The United States Coast Guard and other international agencies are establishing reference stations, especially around popular harbors and waterways. GPS technology far beyond its original design goals. These days many people use it for different purposes. (i.e. Farmers, scientists, sportsmen, soldiers, surveyors, hikers, sailors, dispatchers, lumberjacks, fire-fighters ...). GPS makes their work more producutive, safer or easier.

First application of GPS is the simple determination of a position. Knowing the precise location of someone or something, might be critical. An interesting application was measuring the growth of the world's tallest mountain the everest. GPS data collected strengthened past work that the mountain itself is getting taller. But also revealed that as the Khumbu glacier moves toward Everest's Base Camp.

Most important application of GPS is navigation. GPS was originally designed to provide navigation information for ships and planes. It was orginally designed for navigation on the water, but it also useful on the land and in the air. For example a

New Zealand commercial fishing company uses GPS so they can return to their best fishing holes without wandering into the wrong waters in the process. And flying a single-engine Piper Cub or a commercial jumbo jet requires the same precise navigation information and GPS provides it all.

Maritime and aviation surveyers are looking for alternative ways to replace or improve current radar system for navigation or surveillance purposes. The radar system for surveying purpose will send a digital signal back to the transmitter when it detects the radar signal which contain an identifier and altitude. But radar gives very little and usually inaccurate information. The update rate is generally slow, since it is equal to the rotation rate of the radar antenna. And GPS offers surveyers a chance to reach their dreams. On the other hand GPS is not the only satellite navigation system. The other satellite navigation system GLONASS which is operated by Russia's Ministry of Defense and is quite similar to GPS. The GLONASS System is explained also in the next section of this study. From now on, we will call all of the navigation system as Global Navigation Satellite Systems (GNSS). GNSS is the feasible method for surveying purposes. In the reminder of this thesis a new approach in navigation "automated tracking of vessles" will be discussed which combines computer, GNSS and digital radio. Many applications of which are currently being implemented..

The main differences in automated tracking is in the alternative ways which they use in realizing ship-to-shore ship-to-ship data transfer. One of the methods that can be used for this purpose is AMPS (Advanced Mobile Phone Service). AMPS is a standard system for analog signal cellular service in the United States and is also used in other countries. It is introduced by AT&T in 1983 and it is currently the most widely deployed cellular system in the United States. AMPS allocates frequency ranges within the 800 and 900 Megahertz MHz spectrum to cellular telephone. Each service provider can receive signals from cellular phones by using 824-849 MHz band and transmit signal by using 869-894 MHz. Transmit and receive bands are divided into 30 kHz sub-bands. These subbands are called as channels. The division of the spectrum into sub-band channels is achieved by using frequency division multiple access FDMA. A cell is an area which is covered by the signals received from a transmitter. When a user moves out of the cell's area into an adjacent cell, it begins to pick up the new cell's signals. The signals in the adjacent cell are sent and received on different channels to prevent interference.

Another approach in establishing a communications link makes use of the Newcomb L-Band Satellite System. Newcomb satellite system was developed for the Coast

Guard R&D Center. This system uses small satellite terminals in the RDSS band (1610 – 1625.5 MHz). The use of small transceivers which includes embedded GPS receivers, it made possible to collect inputs from notebook or notepad PCs and relay this data through Geostationary Satellites to the Vessel Traffic Management Center. Control is accomplished using the special software which retrieves data via Internet or dial-up interface for real time tracking and monitoring. Report rate may be changed from 10 seconds to 12 hours. Newcomb Communications has also installed similar systems on US Army Vehicles, and this system has the potential to be used all modes of transportation.

The communication links may utilize Digital Selective Calling (DSC). It is a semi automated method of establishing a radio call which was approved by the International Maritime Organization (IMO) for maritime applications. Radio contact is usually established by making a voice call and relying on an aural watch by the called party to hear the call. Digital selective calling automatically monitors calling frequencies and signals when a communications link is established between marine radios. The advantage of DSC is that it provides faster alerting capabilities and automatic transmission of information. DSC cane be used to send a specific information . The information can include caller's Maritime Mobile Service Identity (MMSI), caller's location, time of location, the requested working frequency and the nature of the distress. Moreover the communication can be established selectively, i.e. , DSC messages can be addressed to a certain user.

DSC is used to listen for distress calls, to initiate radiocommunications with other vessels, to announce urgent maritime information broadcasts and also to track vessels. Distress alerting and safety calling on terrestrial frequencies (HF, MF and VHF) is transmitted by DSC. For distress and safety purposes a number of frequencies have been assigned. For instance; 2.137,5 kHz in MF band, 4.207,5 kHz, 6.312 kHz, 8.414,5 … in the HF bands, and 156,525 MHz which are channel 70 in the VHF band. Special types of DSC radios which is built to ITU-R Recommendation M.825 can be used as a ship transponder. This transponder usually consists of a transmit/receive subsystem, DSC processor subsystem, and operator console which is used to identify and track vessel. A more comprehensive study of Digital Selective Calling will be presented in the next section of this studying.

Another technique which is used in automated tracking is Self Organized Time Division Multiple Access (STDMA). A position sensor is needed for STDMA too. A station with a system which continuously receives its own position from GNSS system and then broadcasts it via VHF data link is used for this purpose. This concept works regardless of ground infrastructure. The station determines its own transmission schedule based on the Self Organizing algorithm which schedules transmissions based on the prior knowledge and future activities on the data link. In other words, there is no need for controlling or polling functions via the master control. This algorithm substantially reduces possible transmission conflicts. And if they happens, it resolves the conflict quickly. In STDMA system, data link is shared by dividing time into slots using Time Division Multiple Acces (TDMA). The position report fits into one time slot.

The main component of the system is the transponder as in DSC. STDMA transponder is called as Automated Identification System (AIS) Transponder in maritime applications. The transponder consists of three parts; GPS satellite navigation receiver, computer, VHF radio transmitter/ receiver. The transponder is normally connected to a display unit showing maps/charts with positions of the transponder equipped mobile units. The transmission is controlled by the computer and synchronised by an accurate timing signal (UTC), which can be derived from the GPS system. Transmissions from each transponder´s VHF-radio are made automatically and with short time-intervals (typically 1-60sec). The capacity of the data link is very high. More than 2000 position reports per minute can be transmitted on a single VHF radio channel (25KHz bandwidth). Transmitted data includes Identity, Position (Lat and Long), Altitude, Heading, Speed etc.. as part of the standard aviation position report. Maritime version has similar content suited to maritime demands. The STDMA system works very well in this dynamic environment, ensuring safe delivery of safety critical information to surrounding stations. It also handles overload very well, with gracefully reduced VHF cell size as a result. In brief; time division multiple access (TDMA) provides efficient use of the frequency resource and the self-organizing algorithm,makes it possible to handle overload, and a constantly changing population of participating stations. More comprehensive study of Self Organized Time Division Multiple Access will also be presented in the next section of this thesis.

All of techniques mentioned above have resulted in novel navigational presented applications. They all depend in one way or other on the GNSS. Developing of the GPS system provided developing of the new surveillance and tracking sytem. These developments can be regarded as a typical example of the advance in technology in that one step in the science triggers many applications, which were difficult, if not impossible, at the outset. After this brief introduction, we will now proceed to investigate modern maritime navigational system in more detail.

2. GENERATION OF POSITION INFORMATION

2.1 A review the use of GPS in the context of VTS (Vessel Trafic Services)

Navigation is defined as the science of getting a craft or person from one place to another [1]. It is definitly that every one of us conducts some form of navigation in our daily lives. For all of us, these skills require utilizing common sense, our eyes, and landmarks. However, in some cases where a more accurate knowledge of either our position, transit time to a desired destination is required, navigation aids other than landmarks are used.

Signals from one or more radionavigation aids enable a person (user) to compute their position. It is important to note that it is the user's radio navigation receiver that processes these coming signals and computes the position . The receiver performs the necessary computations for the user to navigate to a desired location. In some cases , the receiver may only process the received signals with the navigation computations performed by a separate processor.

Various types of radionavigation aids exist. It can be categorized as either ground-based or space-based . The accuracy of ground-based radionavigation aids changes according to their operating frequency. Highly accurate systems generally transmit at relatively short wavelengths and the user must remain within line-of-sight. The other systems which broadcasts at lower frequencies are not limited to line-of-sight but are less accurate.

Satellite based system provides continues, accurate, worldwide, three dimensional position and velocity information to the user which has appropriate receiving equipment. This system provides service to unlimited number of users. Global Navigation Satellite Sytem (GNSS) has been included by both the commercial and recreational maritime communitie. Navigation is enhanced on all part of waters; from riverways to oceanic travel. Some of nations are developing local area differential GPS networks to increase system accuracy for harbor, harbor approach and river usage. One area in which differential GNSS will play a larger role is in vessel traffic services (VTSs). The combination of a datalink and differential GNSS receiver permits broadcast of the vessel's position to a control center. VTSs are used for collision avoidance and to expedite the flow of traffic during periods of restricted visibility. VTSs can be used in conjunction with the electronic chart display information system (ECDIS). ECDIS displays a vessel's position in relation to charted objects, navigation aids, land as well as unseen hazards.

2.2 What is GPS (Global Positioning Service)

GPS (Global Positioning System) provides accurate, continuous, worldwide, position and velocity information to the user. GPS is fully operational and meets the criteria established in the 1960s for optimum positioning system. Early developed spaced-based systems (namely the United States (U.S.) referred to as Transit-and the Russian Tsikada system) provide a two dimensional high-accuracy positioning service. However, the frequency of obtaining a position fix varies with latitude. Limitations applicable to both systems are that each position fix requires approximately 10 to 15 minutes of receiver processing and an estimate of the user's position. These attributes were suitable for shipboard navigation because of the low velocities, but not for aircraft and high-dynamic users [2].

In the early 1960s, several U.S. government organizations including the military, the National Aeronautics and Space Administration (NASA), and the Department of Transportation (DOT) were interested in developing satellite systems for position determination. When Transit became operational in 1964, it was widely accepted for use on low dynamic platforms. However, it is determined by the Navy that it is need to enhance Transit or develop another satellite navigation system with the desired capabilities (global coverage, continues all weather operation, ability to serve high dynamicplatforms, and high accuracy).

Several variants of the original Transit system were proposed by its developers at the Johns Hopkins University Applied Physics Laboratory. Concurrently, the Naval Research Laboratory (NRL) was conducting experiments with highly stable space-based clocks to achieve precise time transfer. This program was denoted as Timation. Modifications were made to Timation satellites to provide a ranging capability for two-dimensional position determination.

At the same time the Air Force conceptualized a satellite positioning system denoted as System 621B. It was envisioned that System 621B satellites would be in elliptical orbits at inclination angles of 0°, The +x axis is permanently fixed in a particular direction relative to the celestial sphere, the +z axis is taken normal to the xy-plane in the direction of the north pole and 60°. Numerous variations of the number of satellites (15 to 20) and their orbital configurations were examined. System 621B was to provide three-dimensional coverage and continuous worldwide service. The use of pseudorandom noise (PRN) modulation for ranging with digital signals was proposed. The concept and operational techniques were verified at Holloman AFB and White Sands Missile Range using an inverted range in which pseudolites (i.e., ground-based satellites) transmitted satellite signals for aircraft positioning [3].

In 1969, the Office of the Secretary of Defense (OSD) established the Defense Navigation Satellite System (DNSS) program to consolidate the independent development efforts of each military service to form a single joint-use system. The OSD also established the Navigation Satellite Executive Steering Group, which was charged with determining the viability of a DNSS and planning its development. From this effort, the system concept for NAVSTAR GPS was formed. The NAVSTAR GPS program was developed by the GPS Joint Program Office (JPO) .

As it is mentioned before, all of GPS criteria is based on 1960s. The satellite constellation consists of 24 satellites arranged in 6 orbital planes with 4 satellites per plane. A worldwide ground control/monitoring network monitors the health and status of the satellites. This network also uploads navigation and other data to the satellites. GPS can provide service to unlimited number of users since the user receivers operate passively . The system utilizes the concept of one-way time of arrival (TOA) ranging. Satellite transmissions are referenced to highly accurate atomic frequency standards onboard the satellites, which are in synchronism with an internal GPS system time base. The satellites broadcast ranging codes and navigation data on two frequencies . It is broadcasted using a technique which is called code division multiple access (CDMA). There are only two frequencies in use by the system. One of them is called L1 (1575.42 MHz) and the other L2 (1227.6 MHz). Each satellite transmits on these frequencies, but with different ranging codes than those employed by other satellites. These codes were selected because of having low cross-correlation properties with respect to one another.

The navigation data provides the means for the receiver to determine the location of the satellite at the time of signal transmission.The ranging code enables the user's receiver to determine the propagation time of the signal . According to this, it is calculated satellite-to-user range. Utilizing this technique to measure the receiver's three-dimensional location requires that Time of Arrival ranging measurements be made to four satellites.. However, it is used crystal clock usually in navigation receivers to minimize the cost, complexity, and size of the receiver. Therefore GPS time is different from System base time and it cause error on desired measurements. GPS provides two services:

- **Standard Positioning Service (SPS):** SPS is designated for the civil community. There are no restrictions on SPS usage . It is available for all users worldwide. SPS provides predictable accuracies of 100m (2 drms, 95%) in the horizontal plane and 156m (95%) in the vertical plane. UTC time dissemination accuracy is within 340 nsec 4(95%) [4]. SA is usually a prime error source in a SPS-derived position fix. However, it can be posibble to mitigate it by using some techniques.

- **Precise Positioning Service (PPS):** PPS is slated for U.S. authorized military and select government agency users. Access to the GPS PPS is controlled through cryptography. Descriptions of these services are presented in the following sections. The PPS is specified to provide a predictable accuracy of at least 22m (2 drms, 95%) in the horizontal plane and 27.7m (95%) in the vertical plane. UTC time dissemination accuracy within 200 nsec (95%). Velocity measurement accuracy is specified as 0.2 m/sec (95%) .

PPS is primarily intended for military and select government agency users. Civilian use is permitted but only upon special U.S. Department of Defense (DOD) approval. It is controlled to access PPS position information by two cryptographic features denoted as Antispoofing (AS) and Selective Availability (SA).

- **AS:** is a mechanism intended to defeat deception jamming. It is possible to be replicate and changed the navigation data, satellite ranging codes by adversary. Deception jamming denotes this. The intention of AS is to protect the PPS from deception jamming.

- **SA:** is implemented to deny full system accuracy to SPS users. SA "dithers" the satellite's clock, thereby corrupting TOA measurement accuracy. Further, SA induces errors into the broadcast navigation data parameters [5]. PPS users remove SA effects through cryptography [6]. The PPS reached full operational capability (FOC) in spring 1995.

2.3 What is Global Navigation Satellite System (GLONASS)

GLONASS is a Russian space-based radionavigation system that provides the capability for three-dimensional position and velocity determination as well as time dissemination on a worldwide basis. The system consists of a 24 satellite constellation, a ground monitoring network, and various types of user equipment. The constellation consists of 3 orbital planes with 8 satellites per plane. The ground network consists of a number of satellite monitoring and data uploading facilities located throughout Russia. GLONASS is operated by Russia's Ministry of Defense. The program was instituted in the mid-1970s . The intend of GLONASS is similar to GPS. PVT determination is performed using PRN ranging signals. But, the satellite transmissions differ from GPS. GLONASS employs frequency division multiple access (FDMA). In FDMA each satellite propagates on a different freyuency. It allows the same ranging codes to be broadcast from each satellite.

GLONASS provides separate civil and military services. The predictable accuracies of the civil service are 100m (2 dnns, 95`%) in the horizontal plane and 150m (95 %) in the vertical. Civil velocity accuracy is specified at 0.15 m/sec (9S%) [7]. The time dissemination is within 5 msec of UTC. Presently, GLONASS has not employed an SA feature. Therefore, actual measured civil accuracies are 26m (2 drms, 95 %) in the horizontal plane and 45m (95 %) in the vertical. Velocity measurement is 0.03 to 0,05 m/sec [7]. Observations by the University of Leeds and 3S Corporation indicate that the military service yields accuracies comparable to the GPS PPS.

2.4 Segments of GPS System

The Global Positioning System (GPS) is comprised of three segments:

- Space (Satellite Constellation)
- Operational Control (Ground control/monitoring network)
- User receiver

The satellite constellation includes the satellites in orbit which provides the ranging signals and data messages to the user equipment . The operational control segment (OCS) tracks and maintains the satellites in space. Furthermore, the OCS updates the satellite clock corrections and ephemerides as well as numerous other parameters essential to determining user position, velocity, and time . The user receiver equipment performs the navigation, timing, or other related functions . More detail about segments is provided text.

2.4.1 Space (Satellite Constellation)

The satellites are positioned in six Earth-centered orbital planes with four satellites in each plane. The orbital radius is approximately 26,600 km. The nominal orbital period of a GPS satellite is one-half of a sidereal day or 11 hr 58 min [8]. The orbits are nearly circular and equally spaced about the equator at a 60° separation with an inclination relative to the equator of nominally 55°. Figure (2.1) depicts the GPS constellation

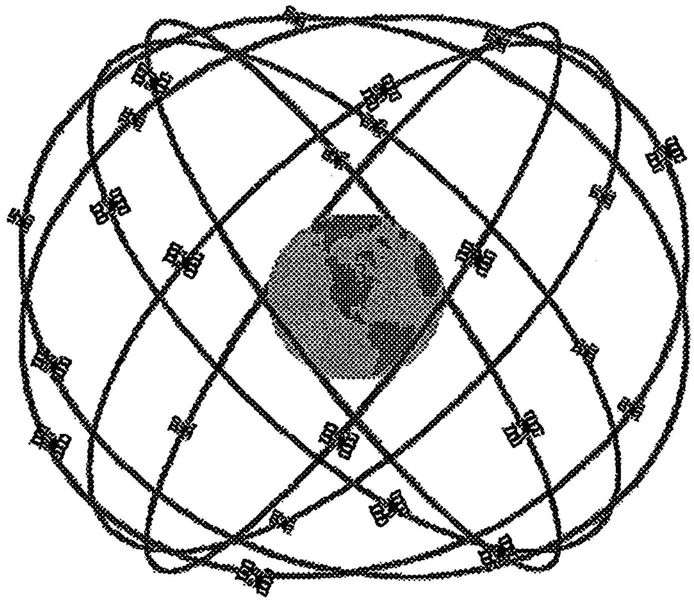

Figure 2.1 GPS nominal satellite constellation

2.4.2 Operational Control

The Operational Control Segments (OCS) has responsibility for maintaining the satellites and their proper functioning.

- Maintaining the satellites in their proper orbital positions (called station keeping) and monitoring satellite subsystem status.
- Monitoring the satellite solar arrays, battery power levels, and propellant levels used for maneuvers and activates spare satellites.
- Updating each satellite's clock, ephemeris, and almanac and other indicators in the navigation message once per day or when is needed.

This functions are accomolished by using three different physical components; the master control station (MCS), monitor stations, and the ground antennas (Figure 2.2).

Monitor Stations

- A monitor station contains a dual-frequency (L1/L2) GPS receiver which provides making pseudorange and delta range measurements to each satellite in view. All collected data are transmitted to the MCS for processing.
- The monitor station contains two cesium clocks referenced to GPS system time.

- The monitor station receiver dual-frequency measurements enable the MCS to determine the ionospheric delay for satellites within the monitor station satellite field of view.

There are five monitor stations located at Colorado Springs, Kwajalein, Ascension Island, Hawaii, and Diego Garcia. These facilities provide approximately 92% tracking coverage of the GPS satellites.

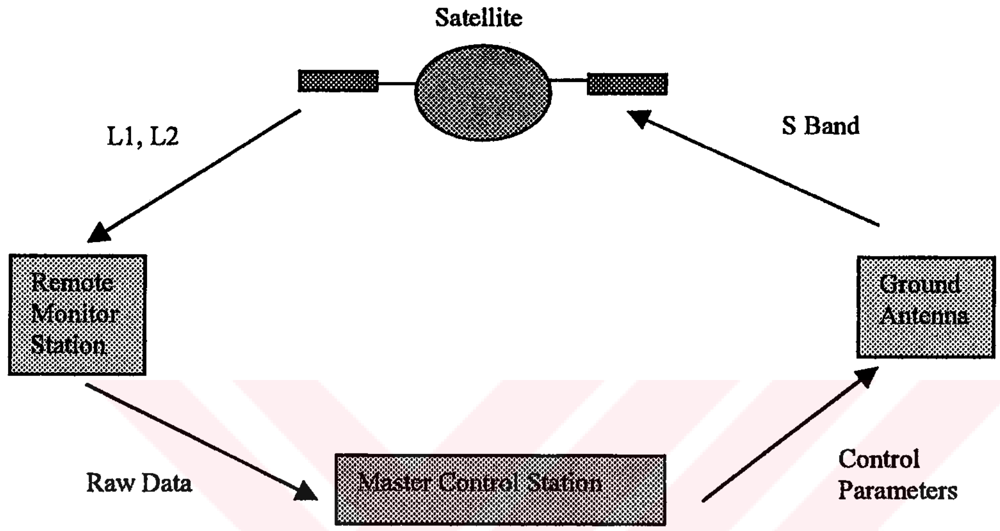

Figure 2.2 Control segment operations

Ground Uplink Antenna Facility

- The ground uplink antenna facility provides commanding and controlling the satellites.

- At the same time, it is provided uploading the navigation messages and other data.

It stores and uploads what is called TT&C which is prepared by the MSC Ground antennas are collocated with monitor stations at Ascension Island, Kwajalein, Diego Garcia, and Cape Canaveral. These locations have been selected to maximize satellite coverage .

Master Control Station (MSC)

MCS performs various of functions to support the operation of GPS as a system.

- One principal activity is the processing of the data collected at the remote monitor stations to form estimates of the GPS satellite clock, ephemeris, and almanac data. Many steps are involved for this processing [9].

- Another important activity is monitoring the reliability of the system. The control segment must take meticulous care to ensure that all clock and ephemeris data uploads and other signal transmissions are correct. The MCS computes the upload navigation messages, monitors the uploading of data, and verifies the correct transmission by the satellite.

2.4.3 User Receiver

The user receiving equipment is called as "GPS receiver". It processes the L-band signals which is transmitted from the satellites and determine user PVT. The GPS set consists of five principal components (Figure 2.3):

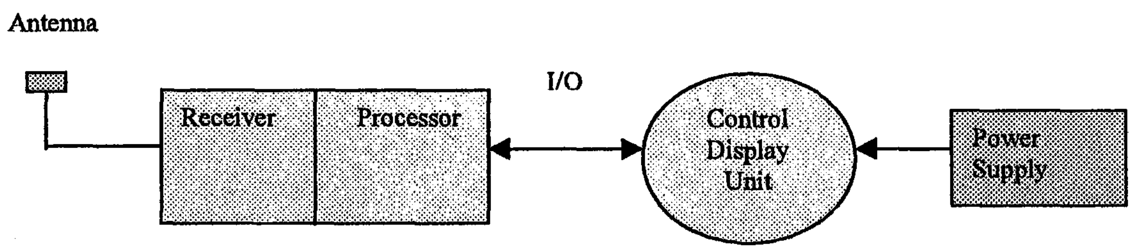

Figure 2.3 Component of GPS receiver

Antenna: Satellite signals are received via the antenna, which is right-hand circularly polarized (RHCP) and provides near hemispherical coverage. Typical coverage is 160° with gain variations from about 2.5 dBic at zenith to near unity at an elevation angle of 10°. (The RHCP antenna unity gain also can be expressed as 0 dBic = 0 dB with respect to an isotropic circularly polarized antenna.). Various type antenna present from thin microstrip to helical coils. Antenna selection are such as antenna gain pattern, available mounting area, aerodynamic performance, multipath performance, resistance to interference and stability of the electrical phase center of the antenna.

Receiver:Two basic receiver types exist today:First type tracks both P(Y)-code and C/A-code. It is generally used by the PPS user. These sets initiate operation with receivers tracking C/A-code on L1 tracking and then switch to tracking P(Y)-code on either L1 or L2. Y-code tracking occurs only with the aid of cryptographic equipment. Second type only track C/A-code. It is generally used by SPS users . These sets track the C/A-code exclusively on L1 since that is the only frequency that the C/A-code is generally broadcast on. Most receivers have multiple channels which provides to each channel tracking the transmission from a single satellite. The desired measurements and demodulated navigation message data are forwarded to the processor.

Navigation / Receiver Processor: A processor is generally required to control and command the receiver through its operational sequence, starting with channel signal acquisition and followed by signal tracking and data collection. In addition, PVT solution from the receiver measurements is formed at this part. Most processors provide an independent PVT solution on a 1-Hz basis. The formulated PVT solution and other navigation-related data is forwarded to the I/O device.

Input/Output Device: The I/O device is the interface between the user and GPS set. I/O devices are of two basic types: integral or external.Generally, the I/O device is a Contol Display Unit (CDU) which permits operator data entry, displays status and navigation solution parameters, etc. Other installations, for instance those onboard an aircraft or ship, may have the I/O device integrated with existing instruments.

Power Supply: It is possible to be integral, external, or a combination of the two power supply. Generally, alkaline or lithium batteries are used for integral or self-contained implementations, airborne, automotive, and shipboard GPS set normally use platform power but typically have built-in power converters (ac to dc or dc to dc) and regulators. There is usually an internal battery which maintains data stored in volatile random access memory (RAM), integrated circuits (ICs) and to operate a built-in timepiece (date/time clock) in the event platform power is disconnected.

2.4.4 GPS Receiver Selection

- Shock and vibration requirements, temperature and humidity extremes, as well as atmospheric salt content.
- If the receiver is to be used by government and/or military personnel, PPS operation may be required.
- The necessary independent PVT update rate must be determined.
- Under what type of dynamic conditions (e.g., acceleration, velocity) will the set have to operate?
- Is a differential GPS (DGPS) capability required? Many of receivers are manufactured with a DGPS capability.
- Does the application require reception of a geostationary satellite-based overlay service (e.g., INMARSAT) broadcasting GPS and/or GLONASS satellite integrity, ranging, and DGPS information?

- If the receiver has to be interfaced with an external system, does the proper I/0 hardware and software exist?

- In terms of data input and display features, does the receiver require an external or integral CDU capability.

- Is portability for field use required?

- Economics, physical size, and power consumption must also be considered.

2.5 Fundamental of GPS

GPS utilizes the concept of time-of-arrival (TOA) ranging to determine user position. This concept entails measuring the time it takes for a signal transmitted by a satellite at a known location to reach a user receiver. This time interval (signal propagation time) is multiplied by the speed of light to obtain the satellite-to-receiver distance.

2.5.1 Two-Dimensional Position Determination

Consider the case of a mariner at sea determining his or her vessel's position from a foghorn. (This example was originally presented in [6]). It is assumed that the vessel is equipped with an accurate clock, the mariner has an approximate knowledge of the vessel's position, the foghorn whistle is sounded precisely on the minute mark and that the vessel's clock is synchronized to the foghorn clock. The foghorn whistle propagation time is the time it took for the foghorn whistle to leave the foghorn and travel to the mariner's ear. This propagation time is multiplied by the speed of sound . That is the distance from the foghorn to the mariner. Let this distance be denoted as R1. Now the mariner knows that the vessel is somewhere on a circle with radius R1 centered about the foghorn (Figure 2.4).

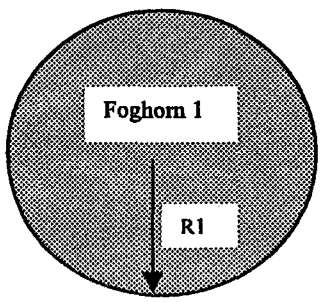

Figure 2.4 Somewhere on this circle

If there is a other vessel and the mariner simultaneously measured the range from a second foghorn which is generated by second vessel in the same way, the vessel would be at range R1 and range R2 (Figure 2.5).

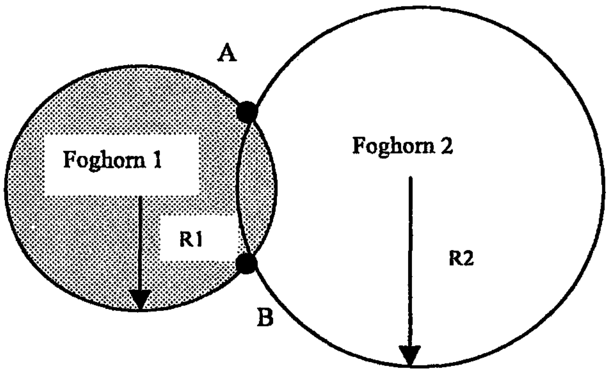

Figure 2.5 Resulting from two source

The vessel relative to the foghorns is at one of the intersections of the range circles. This ambiguity can be resolved by making a range measurement to a third foghorn (Figure 2.6).

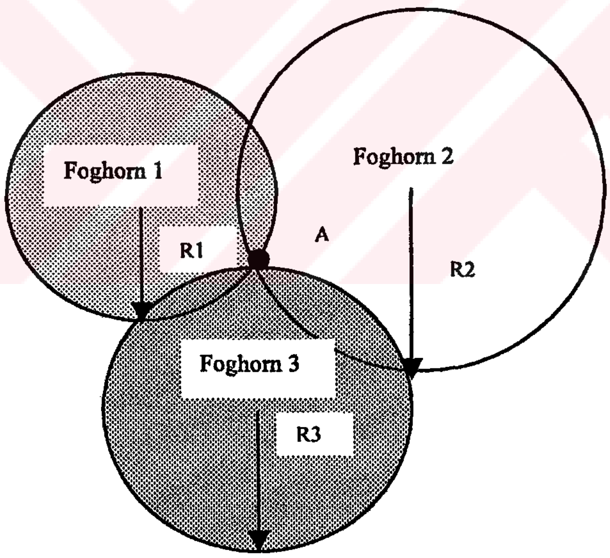

Figure 2.6 Position is determined by third source

It is assumed that the vessel's clock was precisely synchronized with the foghorn time base. However, for many times it is not possible. Therefore measurements would not be perfect. In addition to this , due to errors from atmospheric effects, foghorn clock offset from the foghorn time base, and interfering sounds cause error on measurements (Figure 2.7).

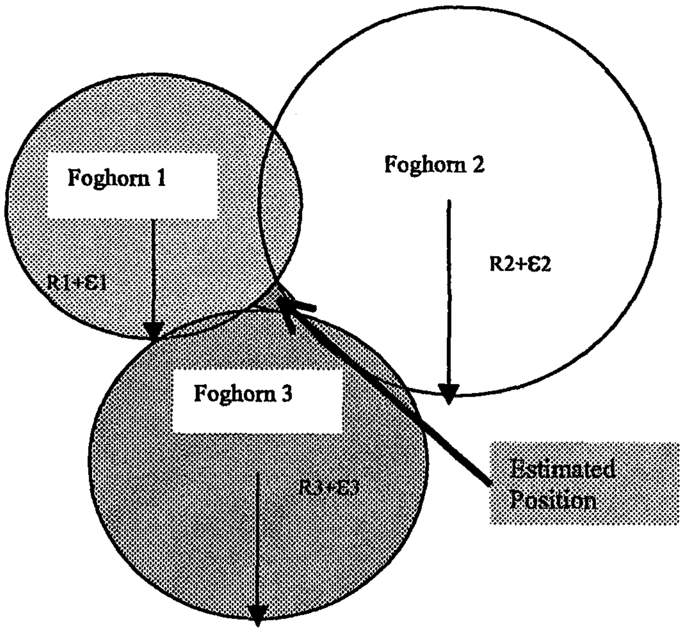

Figure 2.7 Effect of error source

2.5.2 Three-Dimensional Position Determination

There is a few assumption on this scenario. There is a single satellite transmitting a ranging signal. Timing of ranging signal broadcast is controlled by the clock which is onboard the satellite. All of clock are effectively synchronized to an internal system time scale that is GPS system time . The satellite ranging signal contains timing information that enables the receiver to calculate when the signal left the satellite. By noting the time when the signal was received, the satellite-to-user propagation time can be computed. As a result of this measurement process, the user would be located somewhere on the surface of a sphere centered about the satellite (Figure 2.8).

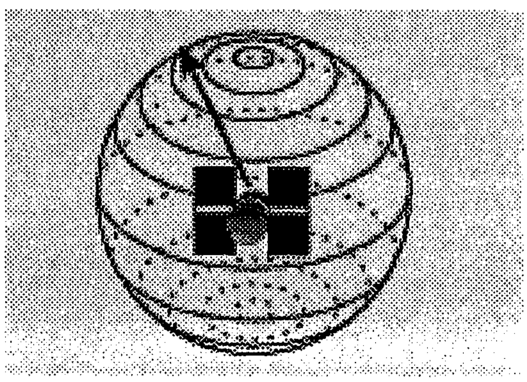

Figure 2.8 Somewhere on sphere

If a measurement was simultaneously made using for second satellite, the user would be located on the second surface of a second sphere. The user would be somewhere on the surface of both sphere (Figure 2.9).

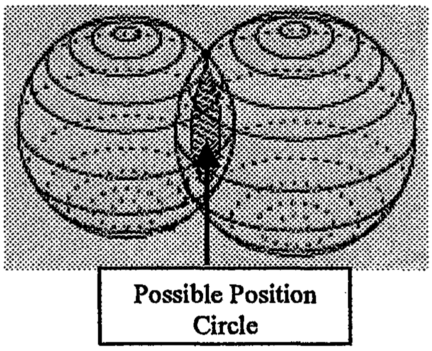

Figure 2.9 Resulting from two source

Repeating the measurement process using for third satellite, it is appeared that third sphere intersects the shaded circle perimeter at two points (Figure 2.10); however, only one of the points is the correct user position. It can be observed that the candidate locations are mirror images of one another with respect to the plane of the satellites. For a user on the Earth's surface, it is apparent that the lower point will be the true position. However, users that are above the Earth's surface may employ measurements from satellites at negative elevation angles.

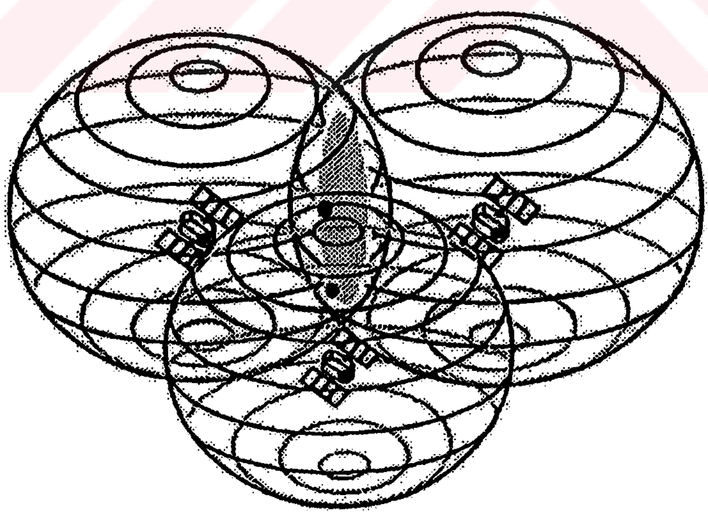

Figure 2.10 Position is determined by third satellite

2.5.3 Reference Coordinate System

If it is wanted to formulate the mathematics of the satellite navigation problem, it should be choosen a reference coordinate system in which the states of both the satellite and the receiver can be represented. In this formulation, it is typical to describe satellite and receiver states in terms of position and velocity vectors measured in a Cartesian coordinate system. There are a few of commonly used Cartesian coordinate systems, including inertial and rotating systems.

- Earth-Centered Inertial (ECI) Coordinate System:

  It is convenient to use an Earth-centered inertial (ECI) coordinate system, for the purposes of measuring and determining the orbits of the GPS satellites. In ECI the origin is at the center of mass of the Earth. In ECI coordinate system Earth's equatorial plane coincide with xy plane. The +x axis is permanently fixed in a particular direction relative to the celestial sphere, the +z axis is taken normal to the xy-plane in the direction of the north pole , y is choosen so as to from a right-handed coordinate system. Due to irregularities in the earth's motion, some problem occur in ECI coordinate definition.

- Earth Centered Earth Fixed (ECEF) Coordinate System:

  It is more conveniant to use a coordinate system which rotates with the Earth to compute the position of a GPS receiver. In ECEF coordinate system +x axis points in the direction of 0° longitude, +y axis ppoints in the direction of 90° longitude. The x and y axis rotate with earth. The z axis is choosen to be normal to the equatorial plane in the direction of north pole.

2.5.4 Time and GPS

GPS disseminates a form of Universal Time Coordinate (UTC). UTC provides time synchronization of user worldwide. UTC is a composite time scale that is comprised of inputs from a time scale derived from atomic clocks and a time scale referenced to the Earth's rotation rate. The time scale based on atomic standarts is called International Atomic Time (TAI) that is based on atomic second. The atomic second defined as the duration of 9.192.631.770 periods of radiation corresponding to the transition between two hyperfine levels of ground state cesium 133 atom. GPS system time and UTC were coincident at 0 hr January 6, 1980.

2.5.5 Pseudorandom Noise Codes (PRN)

GPS satellite transmissions utilize direct sequence spread spectrum (DSSS) modulation which provides the structure for the transmission of ranging signals and essential navigation data . The ranging signals are PRN codes that binary phase shift key (BPSK) modulate the satellite carrier frequencies. These codes have spectral properties similar to random binary sequences, but are actually deterministic. These codes is periodic and can be replicated by a suitably equipped receiver. Each GPS satellite broadcasts two types of PRN ranging codes:

- "short" coarse/acquisition (C/A)-code: It has a 1-msec period and repeats constantly.

- "long" precision (P)-code: The P-code satellite transmission is a 7-day sequence that repeats every midnight Saturday/Sunday. The P-code is encryptted which is denoted as the Y-code. The Y-code is accessible only to PPS users through cryptography.

2.5.6 GPS Satellite Signal

The SVs transmit two microwave carrier signals. The L1 frequency (1575.42 MHz) carries the navigation message and the SPS code signals. The L2 frequency (1227.60 MHz) is used to measure the ionospheric delay by PPS equipped receivers [12].Three binary codes shift the L1 and/or L2 carrier phase (Figure 2.11 depicts GPS Satellite Signal).

- The C/A Code (Coarse Acquisition) modulates the L1 carrier phase. The C/A code is a repeating 1 MHz Pseudo Random Noise (PRN) Code. This noise-like code modulates the L1 carrier signal, "spreading" the spectrum over a 1 MHz bandwidth. The C/A code repeats every 1023 bits (one millisecond). There is a different C/A code PRN for each SV. GPS satellites are often identified by their PRN number, the unique identifier for each pseudo-random-noise code. The C/A code that modulates the L1 carrier is the basis for the civil SPS.

- The P-Code (Precise) modulates both the L1 and L2 carrier phases. The P-Code is a very long (seven days) 10 MHz PRN code. In the Anti-Spoofing (AS) mode of operation, the P-Code is encrypted into the Y-Code. The encrypted Y-Code requires a classified AS Module for each receiver channel and is for use only by authorized users with cryptographic keys. The P (Y)-Code is the basis for the PPS.

- The Navigation Message also modulates the L1-C/A code signal. The Navigation Message is a 50 Hz signal consisting of data bits that describe the GPS satellite orbits, clock corrections, and other system parameters.

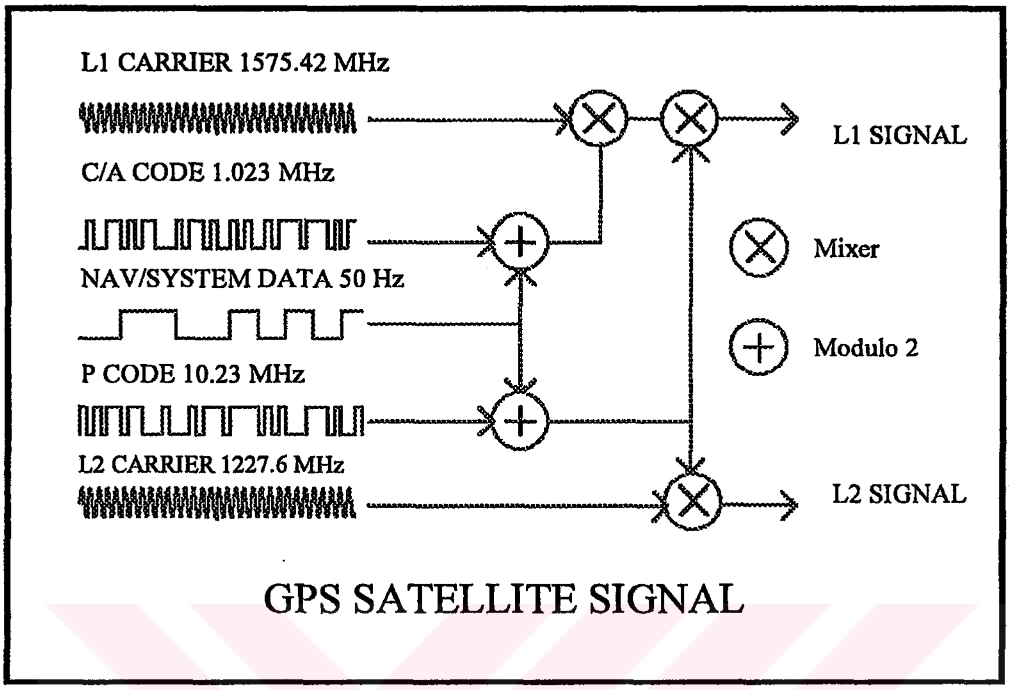

Figure 2.11 GPS Satellite Signal

2.5.7 GPS Data

The GPS Navigation Message consists of time-tagged data bits marking the time of transmission of each subframe at the time they are transmitted by the SV [12]. A data bit frame consists of 1500 bits divided into five 300-bit subframes (Figure 2.12). A data frame is transmitted every thirty seconds. Three six-second subframes contain orbital and clock data. SV Clock corrections are sent in subframe one and precise SV orbital data sets (ephemeris data parameters) for the transmitting SV are sent in subframes two and three. Subframes four and five are used to transmit different pages of system data. An entire set of twenty-five frames (125 subframes) makes up the complete Navigation Message that is sent over a 12.5 minute period.

- Data frames (1500 bits) are sent every thirty seconds. Each frame consists of five subframes.

- Data bit subframes (300 bits transmitted over six seconds) contain parity bits that allow for data checking and limited error correction.

- Clock data parameters describe the SV clock and its relationship to GPS time.

- Ephemeris data parameters describe SV orbits for short sections of the satellite orbits. Normally, a receiver gathers new ephemeris data each hour, but can use old data for up to four hours without much error. The ephemeris parameters are used with an algorithm that computes the SV position for any time within the period of the orbit described by the ephemeris parameter set.

- Almanacs are approximate orbital data parameters for all SVs. The ten-parameter almanacs describe SV orbits over extended periods of time (useful for months in some cases) and a set for all SVs is sent by each SV over a period of 12.5 minutes (at least). Signal acquisition time on receiver start-up can be significantly aided by the availability of current almanacs. The approximate orbital data is used to preset the receiver with the approximate position and carrier Doppler frequency (the frequency shift caused by the rate of change in range to the moving SV) of each SV in the constellation.

- Each complete SV data set includes an ionospheric model that is used in the receiver to approximates the phase delay through the ionosphere at any location and time.

- Each SV sends the amount to which GPS Time is offset from Universal Coordinated Time. This correction can be used by the receiver to set UTC to within 100 ns.

- Other system parameters and flags are sent that characterize details of the system.

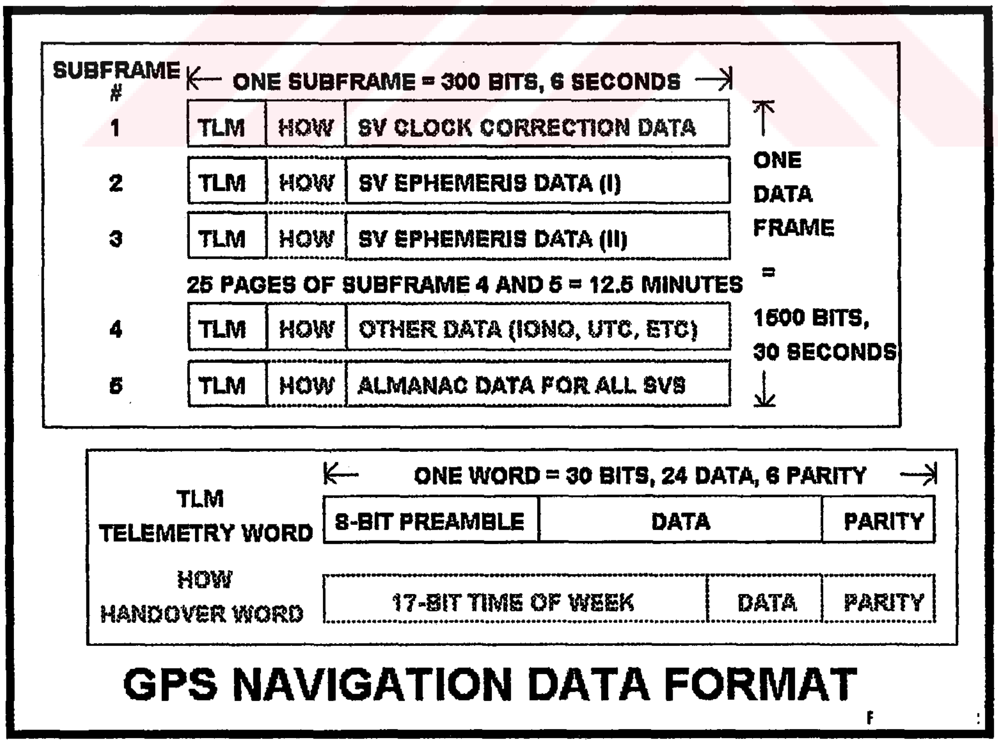

Figure 2.12 GPS Navigation Data Format

2.5.8 Error Source of GPS

The accuracy of GPS measurements are depends on complicated interaction of various factor Generally, it is depends on the quality of the pseudorange and delta pseudorange measurements. To analyze the effect of errors on accuracy, it is assumpted that the error sources can be allocated to individual satellite pseudoranges and can be viewed as effectively resulting in an equivalent error in the pseudorange values. The effective accuracy of the pseudorange value is denoted the user-equivalent range error (UERE). The UERE for a given satellite is considered to be the (statistical) sum of the contributions from each of the error sources associated with the satellite. Usually, the error components are considered independent and the composite UERE for a satellite is approximated as a zero mean Gaussian random variable where its variance is determined as the sum of the variance of each of its components. The accuracy of the position/time solution determined by GPS is ultimately expressed as the product of a geometry factor and a pseudorange error factor.

(error in GPS solution) = (geometry factor) x (pseudorange error factor) (2.1)

The pseudorange error factor is the satellite UERE. The geometry factor expresses the composite effect of the relative satellite/user geometry on the GPS solution error (Dilution of Precision).

2.5.8.1 Pseudorange Errors

Effects of satellite and receiver clock offsets and various error sources "corrupt" the satellite-to-user geometric range measurement. The satellite signal experiences delays as it propagates through the atmosphere. Further, reflections, SA, and hardware effects between the user's antenna phase center and receiver code correlation point may delay the signal. The total time is:

$$\delta td = \delta tatm + \delta tnoise\&re + \delta mp + \delta thw + \delta tsa \quad (2.2)$$

$\delta tatm$ =delays due to the atmosphere

$\delta tnoise\&res$ = receiver noise and resolution offset

δtmp = multipath offset

δthw = receiver hardware offsets

δtSA = degradation

Satellite Clock Error: The satellites contain atomic clocks. All onboarding timing operations is controlled by atomic clock. Deviation from GPS system time is approximately 1msec. It causes 300 km pseoud range error. Ranging errors induced by clock errors are on the order of 3.0m . The master control station (MCS) determines and transmits clock correction parameters to the satellites for rebroadcast in the navigation message .

Ephemeris Prediction Error: Estimates of ephemerides for all satellites are computed and uplinked to the satellites with other navigation data message parameters for rebroadcast to the user. As in the case of the satellite clock corrections, these corrections are estimates and contain a residual error. The effective pseudorange error is on the order of 4.2m .

Selective Availability (SA): The single largest error source for SPS users is SA. SA was formally implemented on March 25, 1990. The degradation is accomplished through manipulation of the broadcast ephemeris data (orbital error component) and through dithering of the satellite clock (clock error component) (Figure 2.13) .

The effective pseudorange error is on the order 70m. SA is generated at the transmitter side. It is spatially correlated. Spatial correlation means that there is a strong relation between the error at one location and the error at a nearby location. This property of SA can be exploited to eliminate the error if DGPS is employed. DGPS removes all errors that are common to both a local GPS ground monitoring station and the user's receiver.

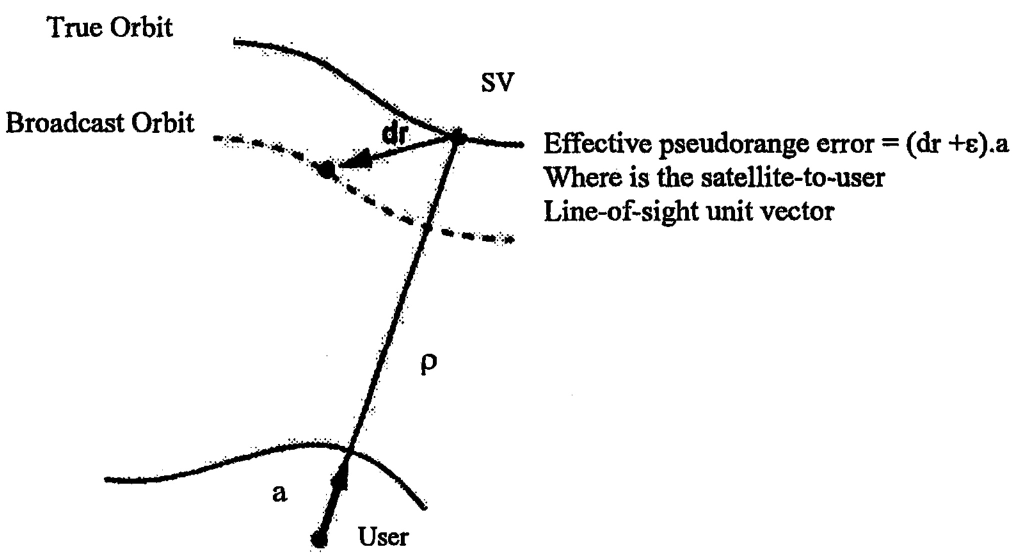

Figure 2.13 Ephemeris error

Another form of SA is the manipulation of the broadcast ephemerides (Figure 2.14). The broadcast ephemeris data contains 15 parameters which means that the error could be induced in various ways. The effective pseudorange error would be the vector sum of the residual ephemeris error and the SA orbital component projected onto the satellite-to-user line-of-sight vector.

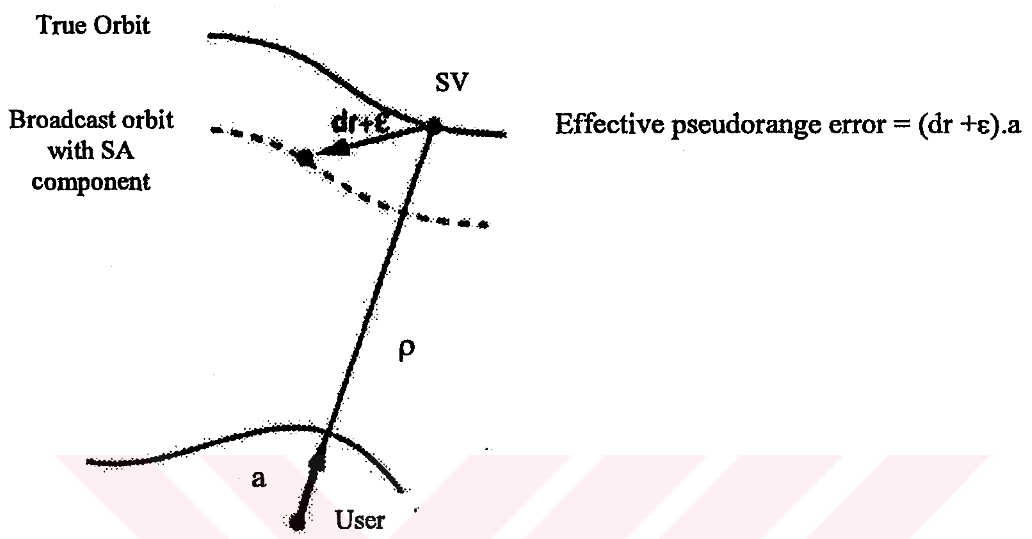

Figure 2.14 Combined effect of SA orbital error component and ephemeris prediction error

Relativistic Efects:Einstein's general and special theories of relativity effects in the pseudorange measurement process. It is necessary for special relativity (SR) relativistic corrections arises any time the signal source or the signal receiver is moving with respect to the chosen isotropic light speed frame, which in the GPS system is the ECI frame.

- The need for general relativity (GR) relativistic corrections arises any time the signal source and signal receiver are located at different gravitational potentials . In order to compensate for both of these effects, the satellite clock frequency is adjusted to 10.22999999545 MHz prior to launch. The frequency observed by the user at sea level will be 10.23 MHz; hence, the user does not have to correct for this effect.

- The user does have to make a correction for another relativistic periodic effect that arises because of the slight eccentricity of the satellite orbit. Exactly half of the periodic effect is caused by the periodic change in the speed of the satellite relative to the ECI frame and half is caused by the satellite's periodic change in its gravitational potential.When the satellite is at perigee the satellite clock to run slower. When the satellite is at apogee the satellite clock to run faster . Error parameter which is related this effect is added to error parameter of satellite's clock and than broadcasted to the user. The effective pseudo range error is on the order of 21 m (70 nsec).

- Due to rotation of the Earth during the time of signal transmission, a relativistic error is introduced . This effect is called Sagnac. The effective pseudorange error is on the order of 2,7 m.

***Atmospheric Effect*:** The propagation speed of a wave in a medium can be expressed in terms of the index of refraction for the medium. The index of refraction is defined as the ratio of the wave's propagation speed in free space to that in the medium by the formula

$$n = \frac{c}{v} \qquad c = 299{,}792{,}458 \text{ m/sec.} \qquad (2.3)$$

If the propagation speed is a function of the wave's frequency, it can be said that the medium is dispersive. In a non dispersive medium, wave propagation is independent of frequency and the signal phase and signal information broadcast at the same speed.

- *Ionospheric Effects*: Ionosfer is a dispersive medium located. It is located the region of the atmosphere between 70 km and 1000 km above the Earth's surface. In the Ionosphere, a portion of gas molecules is ionized by ultraviolet rays from the sun and it is released free electrons. Free electrons influence electromagnetic wave propagation. When viewing satellites elevation changes, it cause changing on error of Ionosferic. For a signal arriving at vertical incidence, the delay ranges from about 10 nsec (3m), at night 50nsec (15m). At low satellite viewing angles (0° - 10°) the delay can range from 30nsec (9m), at night 150 nsec (45m). This delay can be compensated by using some models. An example Klobuchar model removes about 50% of ionosferic delay. It assumes that the vertical ionosferic delay can be approximated by half a cosine function of the local time during day time and by a constant level during nightime.

- *Tropospferic Delay*: Troposphere is non-dispersive for frequencies up to 15 GHz. Within this medium, the phase and group velocities associated with the GPS magnitude larger than P(Y) code. The noise and resolution error are on the order of 20 cm for P(Y) code and 1,5 m for C/A code. PLL measurements error are on the order of 1,2 mm for C/A code and 1,6 mm for P(Y) code.

Multipath and Shadowing Effects: One of the dominant errors in the receiver measurement process is multipath (Figure 2.15). With multipath, a signal arrives at the receiver via multiple paths due to reflections from the Earth and nearby objects . Multipath distorts the PRN code, navigation data, which is modulated onto the carrier, and the phase of the carrier itself . Multipath can cause the receiver tracking loops to lose lock.

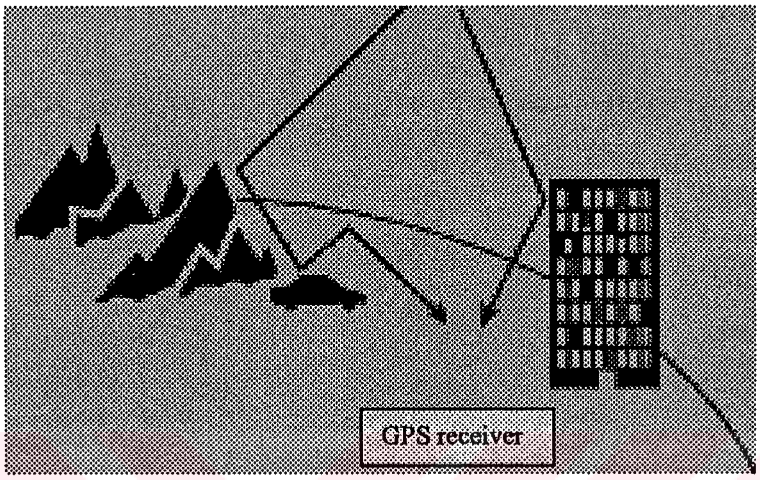

Figure 2.15 The effect of multipath and shadowing

The degradation of the pseudoranges is caused by the distortion of the correlation peak by the presence of the indirect signal . To compensate multipath, antenna sitting is important. It should be placed above the highest reflector. Multipath generally occurs with signals that comes from satellites at low elevation angles. Therefore antenna gain should be designed to attenuate incoming signals at low elevation angles. To reduce multipath, choke ring antenna is designed. These vertical rings shape the antenna pattern such that multipath signals incident on the antenna at the horizon and negative elevation angles are attenuated. Multipath errors vary from 50 cm to 2 m for a choke ring antenna [10]. But in urban environment near a large building with a stationary receiver showed multipath error approximately 100m.

2.5.8.2 Error Budget

Based on the above discussion regarding pseudorange error constituents, we can develop error budgets (Table 2.1 and 2.2) .

Table 2.1: GPS PPS Pseudorange Error Budget [11]

Segment Source	**Error Source**	**GPS 1σ Error (m)**
Space	Satellite Clock Stability	3.0
	Predictability of satellite perturbations	1.0
	Other (thermal radiations, etc.)	0.5
Control	Ephemeris prediction error	4.2
	Other (thruster performance , etc)	0.9
User	Ionospheric delay	2.3
	Trophospheric delay	2.0
	Receiver noise and resolution	1.5
	Multipath	1.2
	Other (interchannel bias, etc.)	0.5
System UERE	**Total**	**6.6**

Table 2.2: SPS C/A Code Pseudorange Error Budget [11]

Segment Source	Error Source	GPS 1σ Error (m) without SA	GPS 1σ Error (m) without SA
Space	Satellite Clock Stability	3.0	3.0
	Satellite perturbations	1.0	1.0
	Selective ability	32.3	
	Other (thermal radiations, etc.)	0.5	0.5
Control	Ephemeris prediction error	4.2	4.2
	Other (thruster performance , etc)	0.9	0.9
User	Ionospheric delay	5.0	5.0
	Trophospheric delay	1.5	1.5
	Receiver noise and resolution	1.5	1.5
	Multipath	2.5	2.5
	Other (interchannel bias, etc.)	0.5	0.5
System UERE	**Total**	**33.3**	**8.0**

2.5.8.3 Geometry Factor

Geometry factor can be named Dilution of Precision (DOP).To understand DOP, it is considered again foghorn example. The user measured the time of arrival of each of the foghorn signals and computes a propagation time which provides determining user's range from each foghorn. In the presence of measurement error, the range rings used to compute the user's location will be in error and result in error in the computed position. The measurement errors depend on the user/foghorn relative geometry. To understand this, it will be better to examine following figure. In figure (2.16.a) , the foghorns are located approximately at right angles with respect to user location.

In figure (2.16.b) , satellites are near more than in first figure and the angle is much smaller. In both cases , the accuracy of the computed location is very different. With the same measurement error variation, geometry (b) gives more error in the computed user's location then in geometry (a). It denotes that measurements error also depend on geometry factor which is termed Dilution of Precision (DOP) in GPS application.

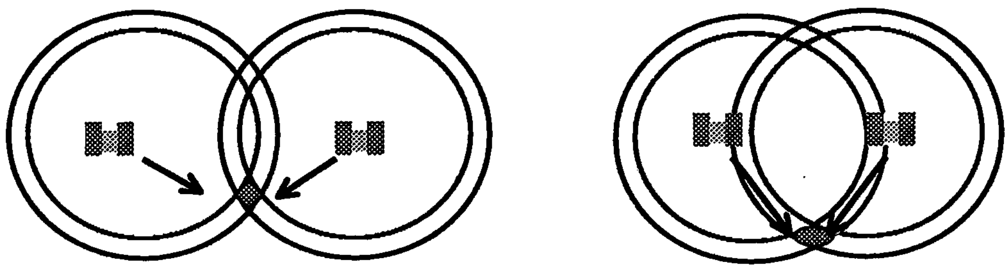

Figure 2.16 **a-)** Low DOP **b-)** High DOP

2.5.9 Differential GPS

The GPS SPS provides accuracy of approximately 100m horizontally and 156m vertically. In many application requires more accuracy. An example, the U.S Coast Guard limited the error 8m horizontally 20m vertically for marine navigation. To provide it, 50 DGPS onshore stations are installed along coastline. That provides accuracies of under 5m to a distance of 400 km offshore.

In DGPS, one receiver is called reference receiver that its precise position is known. The other receiver are called rover which are in line of sight of the reference station.The reference station makes GPS pseudo measurements and determine the 'biases' in the measurements. These biases are computed by differencing the pseudorange measurement for each satellite when it is viewed. Biases includes errors incurred in the pseudorange measurement process and also receiver clock offset from GPS system time is contained by the biases. For real time applications, the reference station transmit biases to all users which are in the line of sight of reference station. Position errors less than 10m are typically realized. Several code based techniques have been proposed to increases standalone GPS accuracy. These techniques usually categorized to be Local Area DGPS (LADGPS), Wide Area DGPS (WADGPS).

LADGPS: station typically serves receivers . LADGPS accuracies are depend on the fact that some of the pseudorange error components are common to all receivers within the local geographic area. If the receiver is close to reference station, the error components attributed to the space and control segments may be entirely removed . Aircraft use VHF datalinks. The station can communicate with the receivers through direct line of sight data links. In maritime services, MF frequency is used. LADGPS is extended up to 400 km. LADGPS is limited by spatial decorrelation of the errors. Following table 2.3 gives estimates of pseudorange error components from various sources for SPS.

WADGPS: attempts to attain meter level accuracy over a large region by using a fraction of the number of reference stations required by LADGPS to attain the same accuracy within the same coverage region. The general approach is to divide the pseudorange error into its component and to estimate each of them for the entire region. The simplest concept is a system having a master control station. It accepts measurements from all other reference station and updates the satellite ephemeris predictions, estimates SA dither and the uncorrected satellite clock drift, tracks varying atmosphering delay. For large ranging system, these architecture places a severe burden on one master control station and on the communications system to produce updates and distribute them to the reference stations. Regional Control Stations is closer to the reference station and less burdened with processing. It can provide timely correction updates. On the other hand provide active or standby redundancy to take over the functions of a neighboring regional control station in some cases.

Table 2.3: SPS C/A Code Pseudorange Error Budget [3]

Segment Source	**Error Source**	**GPS 1σ Error (m)**	**LDGPS 1σ Error (m)**
Space	Satellite Clock Stability	3.0	0
	Satellite perturbations	1.0	0
	Selective ability	32.3	0
	Other (thermal radiations, etc.)	0.5	0
Control	Ephemeris prediction error	4.2	0
	Other (thruster performance , etc)	0.9	0
User	Ionospheric delay	5.0	0
	Trophospheric delay	1.5	0
	Receiver noise and resolution	1.5	2.1
	Multipath	2.5	2.5
	Other (interchannel bias, etc.)	0.5	0.5
System UERE	**Total**	**33.3**	**3.3**

3. STDMA (SELF-ORGANIZED TIME DIVISION MULTIPLE ACCESS)

This part of thesis looks at system which combines GNSS receiver, a computer and a digital radio. In addition looks an algorithm for organization of a digital radio link. This system combines the line-of-sight characteristics of VHF frequencies and a self organizing transmission algorithm. The algorithm is called Self-Organized Time Division Multiple Access (STDMA). The algorithm provides minimizing of transmission conflicts. Self-organizing, which means that controlling, or polling functions, via master control, are not needed. The features, which make the system feasible for surveillance applications, are:

- time division multiple access (TDMA), which provides efficient use of the frequency resource,
- the self-organizing algorithm, which makes it possible to handle overload, and a constantly changing population of participating stations, and,
- strong discrimination of weaker signals, which promotes throughput and cellular operation.

The main idea of this system following [19]:

- *Problem:* In order to allow an efficient use of time division, it is necessary that all units have a common time basis. The time slots must be very accurately defined and synchronised. As regards e.g. aviation applications, the synchronisation requirement applies all over the globe as each unit can be part of a global "mosaic". Mosaic implies here that a user being a great distance off can be relatively close to another user being still further away and so on. For smaller areas a fixed base station can of course act as a "master" and by that synchronise the users. However, over e.g. the oceans this is not possible as the system is to operate autonomously in such areas.

  In STDMA: By receiving time signals from satellites, the positions of which are known, a global time basis can be produced in a very simple and inexpensive way. As the distance between the satellites and the different users varies, certainly the received time will be differing between the users. This, however, does not pose any problem as the own position as well as that of the satellite is known and thus also the distance to the time reference. It is then possible to compensate for the differences in propagation delay and by that bring about a global time basis having an accuracy of about 100 ns. This type of time reference is known and is being used in connection with position determination by means of satellite navigation.

- *Problem:* A certain area will constantly be entered by new users while others will leave the area. Should several users enter the area at the same time, there is a risk of the same vacant time slot being selected by more than one user, which would result in a blocking of the position message.

  In STDMA: In autonomous transmission mode each user periodically (e.g. every fifth to eight minute) changes the independently allocated time slot for transmission. Information concerning slot change is also included in each position report to form the Self-organising TDMA datalink. This prevents two or more users systematically to block each other's transmission. This is of special importance when users arrive from distant areas where a quite different traffic situation prevailed with other or similar time slot allocations.

- *Problem:* A system with many users will of course have a capacity limit. One of the factors that affect the system is the reporting rate. To enable solving time critical situations involving a collision hazard, a high reporting rate is required, which will reduce the number of users.

  In STDMA: By storing and updating information concerning all audible users in the communication system's computers (at each user), the present distance to each user can be calculated. This implies that at autonomous transmission the interval between the messages may be extended if the distance to the nearest user is long and thus not critical. If also information regarding speed and direction is used, the system will be further improved. Users that are moving away from each other are not critical even if the distance between them is short. In a corresponding way the time between the transmissions is shortened in critical situations. By this adaptive reporting the total system capacity as well as the performance can be considerably improved.

- *Problem:* Should a loss of the navigation satellites occur, the possibility to determine the own position will lapse. The reasons for loss of satellites or their signals can be several; e.g. intentional changes of codes in the event of an international crises arising. Another reason can be that the required clear view to the satellites momentarily is blocked by buildings or other such things. As the introduction of this type of guidance system may result in a total dependence on the satellites and on the organisation managing and maintaining these, it is necessary to have an alternative method for position determination.

In STDMA: The position messages are transmitted on the radio channel as asynchronous data packages consisting of start frames, user identity, position, speed etc. followed by a check sum and stop frames. By the fact that the position messages are containing the transmitter position as well as the exact time for the transmission, these messages can be used to determine one's own position. By this method a second order of navigation can be achieved, should it for some reason not be possible to pick up the satellite signals. If position messages from fixed located base stations are used, only one available satellite is required to time synchronise the base stations. Should the base stations have their own accurate external time reference, there is no need for any navigation satellite at all, but the precision will be downgraded. In case of an external time reference being used at the base station, this can be synchronised by using the signals from one and the same TV satellite.

3.1 Definitions

3.1.1 Modes of Operation

The data link can be categorized based on its mode of operation. The mode of operation applies to transmission of repeatable character, such as position information. It means that, while one mode is used for continuously transmitting position reports, another mode can be used for transmission of other information. The figure 3.1 illustrates the different modes of operation:

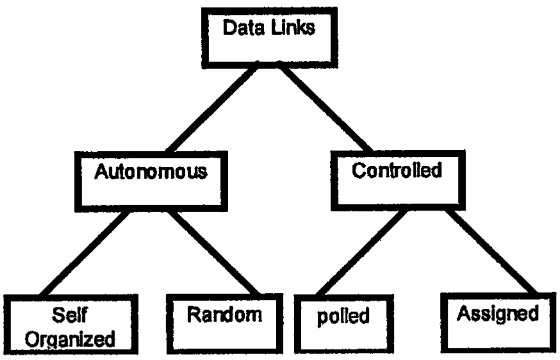

Figure 3. 1 Modes of Operation

Autonomous Mode: In the autonomous mode of operation, each individual station is responsible for organization, and thus determines its own transmission schedule. Two techniques can be distinguished in autonomous mode: self-organized and random mode.

- **Self-Organized Mode:** In the self – organized mode of operation, a station determines its own transmission schedule, based on some intelligent algorithm. This algorithm schedules transmissions on the data link, based on prior knowledge, of future activities. It provides avoiding transmission conflicts, and quickly resolving conflicts when they do occur. In the STDMA system, the primary mode of operation is self – organized mode. It is possible to put it into an assigned mode.

- **Random Mode:** In the random mode of operation, a station determines its own transmission schedule on some algorithm. It is disregarded current and future data link traffic. In this mode, the station will schedule its transmissions purely based on randomization around some given criteria. It will transmit even though other stations might be doing the same simultaneously. Conflict resolution is based on random behaviour which statistically ensures that, at least some transmissions, will be successfully received.

Controlled Mode: In the controlled mode, a master is responsible for scheduling transmissions. Some systems may use a quasi-controlled mode. In quasi-conrolled mode, a station assumes control, based on some criteria, in lack of a master. Even though advocates of such systems may argue that they operate in autonomous mode, they are in fact operating in controlled mode since scheduling is controlled by one station; the current master.

- Polled Mode: In the polled mode of operation, the master station interrogates other stations. One interrogation results in one, or more responses. If a station is not interrogated, it remains silent. The radar system operates in polled mode since the radar interrogates and receives a response in the form of an echo and a secondary radar response.

- Assigned Mode: In the assigned mode the master assigns a transmission schedule to other participating stations. This schedule is generally valid for a limited time, after which the master must re-assign the schedule. The assigned mode is more efficient than polled mode since the transmission of the master results in a transmission schedule, which will operate for quite a while. The STDMA system can operate in assigned mode. The GSM system, for cellular mobile phones, is an example of a system, which operates in assigned mode.

3.1.2 Capacity

Capacity is defined as Measurement of how many stations the system can handle, and how well it handles overload. In a TDMA system, calculating of how many stations can be simultaneously handled is quite easy. Assume that each station has a given report rate (RR), in transmissions per minute. One minute is equivalent to a set of slots (SL). The number of possible stations is then SL/RR. The reality is more complex. A surveillance system can not have restrictions which specifies a maximum number of stations. It must be able to handle overload and to adapt to the traffic, in a controlled and safe manner.

3.1.3 Synchronization

Syncronization defined as the process, in which a station aligns itself in time, with other stations, in order to enable Time Division Multiple Access to the data link. The STDMA system shares the data link by dividing time into slots (Time Division Multiple Access - TDMA). A position report fits into one slot. A set of slots is grouped in a frame. A frame is one minute long. A very accurate source, for synchronization, is the 1PPS pulse from a GNSS receiver . Stations can synchronize their clocks to transmissions from semaphore stations. The semaphore station is responsible for providing timing simply by transmitting some synchronization message at specific intervals.

3.1.4 Report Rate

Report rate defined as the number of transmitted reports per minute. Each station will transmit its position at some given time interval. The report rate may differ between stations. It is depend on factors such as speed or change of course. There are two types of report rates:

- **Nominal report rate**, which is defined as transmission attempts in a given time interval.

- **Net report rate**, which is defined as successfully received transmissions at a receiving station.

Due to slot reuse, and other disturbances, a station may receive less reports than actually transmitted. The net report rate may vary even though the nominal report rate remains fixed.

3.1.5 Net Throughput

Net throughput is defined as the relation between a nominal report rate, output by a transmitter, and the net report rate, from that same transmitter, at a receiver. The net throughput can be derived, by dividing the number of successfully received transmissions, with the number of transmission attempts. This assumes that one transmission occupies exactly one slot.

3.1.6 Time Frame and Time Slots

A TDMA system divides the communication channel in time, by first specifying a frame (Figure 3.2). The STDMA frame is one minute long. The frame is divided into time slot . The start of a frame can be different between stations, but all stations strive to coordinate the frame start to Coordinated Universal Time (UTC). The start of each slot is an opportunity for a station to transmit. The slot start shall be the same for all participating stations. The current time slot, is the slot in which a station currently is receiving or transmitting. All stations are thus always at the same current slot, though they may have numbered it differently because the frame start differs.

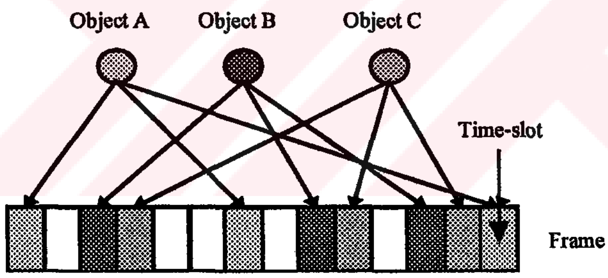

Figure 3. 2 Frame

3.2 Brief Description of STDMA Algorithm

The Self-Organized Time Division Multiple Access (STDMA) algorithm enables a self-organized autonomous mode of operation. Each station continuously broadcasts its position using a transmission packet, which occupies one time slot. The time slot is selected using STDMA. Additionally, the transmitted packet will also contain a Comm State which contains information that states the intention of the STDMA algorithm:

- **Slot Time-out,** which indicates how many more minutes the slot will be occupied.
- **Slot Offset,** a relative offset to the next slot to be used the following minute. The slot offset is ignored unless the Slot Time-out is zero.

Brief description of operation phase is following:

- When a station first powers up, it will begin an initialization phase, which takes one minute. During this time, the data link will be monitored by the station to determine channel activity, other, participating, stations and current slot assignments. After this time, the station enters the Network Entry Phase.

- During the network entry phase the station selects its first transmission slot and prepares to make itself visible on the data link. Firstly, its Nominal Increment (NI) is determined. The NI is equal to the number of slots per minute divided by the desired report rate. To select the first transmission slot, it is selected a Nominal Start Slot (NSS) by the station (Figure 3.3). The NSS is randomly selected from the current slot and NI slots ahead in time. After this, a Selection Interval (SI) is determined which is always 20% of NI and placed so that the NSS is in the middle.

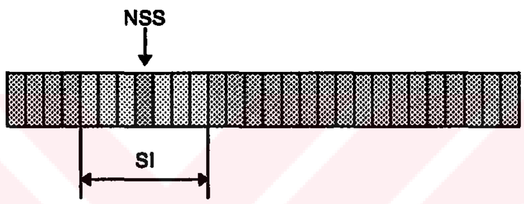

Figure 3. 3 NSS and SI selection

If it is assumed that there is 200 mobile stations and the required update rate is equal to 10, SL is calculated as 2000 by multiplying 200 with 10. Then NI is derived as 200 by dividing SL to U (update rate). SI which is 20 % of NI is 40.

A slot is randomly selected within the SI. This slot is checked to see if it is available for use. If not, the adjacent slot to the left and right is checked. This process is continued until an available slot is found within SI. There shall always be a set of available slots. If the link is approaching maximum capacity, slots are reused from stations at the greatest distance, from the own position.The selected slot becomes the Nominal Transmission Slot (NTS). After reaching the NTS, the First Frame Phase is entered.

- During the first frame phase, the station continuously allocates its nominal transmission slots (NTS) and transmits its position. Each NTS is allocated a unique slot time-out between 4 and 8 minutes. Upon reaching the first NTS, a new Nominal Slot (NS) and NTS is selected for the following transmission (Figure 3.4). The NS is selected by adding NI to the NTS.

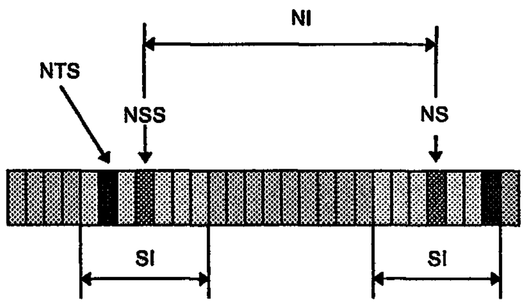

Figure 3. 4 First Frame Phase

A new SI is placed around the NS and the NTS is allocated as described previously. This process is continued until one minute has elapsed and the initial NSS is approached again. Then the station enters the Continuous Operation Phase.

- In the Continuous Operation Phase, the station transmits in the allocated NTS's and decrements the slot time-out. When the time-out reaches zero, a new NTS is selected within the SI as described above. The relative offset (slot offset) is inserted into the position report packet and transmitted so that receiving stations are made aware of the intentions. This phase is maintained until the system is shut down, enters assigned mode or changes reporting rate.

3.3 GP&C SYSTEM

Global Positioning & Communication (GP&C) is the name for a data link technology that is used in aviation, maritime and land mobile applications. The GP&C system is an implementation of a broadcast system using STDMA. The following functions are offered by the GP&C system ;

- Navigation
- Identification
- Surveillance
- Situation awareness
- Communication.

The GP&C system attempts to satisfy communications requirements found in aviation, maritime and land-mobile environments. There is a population of independently moving objects which needs to exchange information. Base stations, which monitor the communication, can also be part of the scenario. Radar and voice radio can be possible solution, but needed communicaiton extends farther than the range of radar. Because of this dedicated paths are required to fly in the aviation environment. This is expensive for the airlines and introduces delays because of heavy air traffic. The GP&C system operates autonomously, allowing two aircraft to exchange information anywhere on the globe. If this information is position information, the aircraft could monitor the traffic and decide its path based on cost and current traffic in the area. The maritime and land-mobile environments have similar needs.

The main component in the system is the GP&C Transponder (Figure 3.5). It is also known as the GNSS-Transponder in aviation applications or as the 4S-Transponder in maritime applications. The transponder consists of three parts [18].

- GPS Satellite Navigation Receiver : Position information is generally provided via a satellite navigation system (i.e GPS or GLONASS). A GP&C transponder contains a GNSS receiver as a position sensor.

- Commmunicaiton Processor (Computer) : The communication processor is a computer. Using of the communication channel is coordinated by the communication processor.

- VHF Radio Transmitter / Receiver transceiver : The GP&C transponder is equipped with a VHF transceiver which is able to operate on channels with 25 kHz spacing. The radio can be keyed and de-keyed within 1 ms.

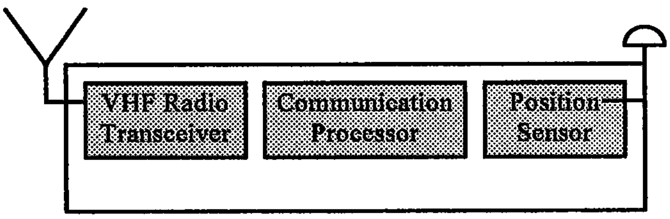

Figure 3. 5 GP&C Transponder

The GP&C transponder is used in mobile units and as base station. The transponder is normally connected to a display unit showing maps/charts with positions of the transponder-equipped mobile units. The function of the system is as follows :

- The navigation satellite receiver is used to give position data, which is communicated by the VHF radio transmitter to base stations and mobile units within radio range.

- The transmission is controlled by the computer and synchronized by a timing reference signal to an universal time.

- Each transponder independently selects a "private" time slot for the transmission without interfering with the transmissions from other transponders.

- Transmitted position reports are received by all other transponders within radio range.

Transmissions from each transponder`s VHF-radio are made automatically and with short time-intervals (selectable , typically 1-60sec). The capacity of the data link is very high. More than 2000 position reports per minute can be transmitted on a single radio channel (25KHz bandwith). Identity, Position, Altitude, Heading, Speed etc.

3.3.1 Analaysis of GP&C System

The analysis of GP&C system is divided to four part

- Characteristic of Transmission
- Propagation
- Synchronization
- Organization

3.3.1.1 Characteristic of transmission

This section looks at factors and behaviour surrounding the transmission and propagation of the radio waves. This part provides a background to the input used in overall analysis of the STDMA system.

Firstly, it is determined factors affecting the range of radio waves. It is assumed a transmitter and receiver are placed in space and the environment at the transmitter is similar at receivers. The only obstructions, between the two stations, are the vessels in which the transmitter and receiver are installed. Figure 3.6 describes this case.

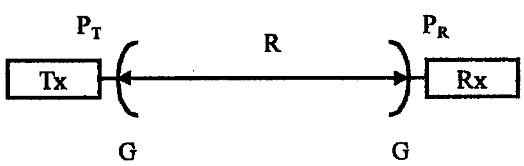

Figure 3. 6 Transmission Scenario

R is the maximum distance between the transmitting and receiving stations and now it is sought [17].

$$\frac{P_R}{P_T} = G_T\, G_R\, \frac{\lambda^2}{(4\pi)^2\ R^2} \tag{3. 1}$$

- P_R = Minimum required power at the receiver
- P_T = Output power at the transmitter
- G_T = Transmit gain
- G_R = Receive gain
- λ = The wave length

It is assumed that the gain at the transmitter is equal to the gain at the receiver because of being the environment identical. Applying the assumption R is obtained.

$$R = \sqrt{\frac{P_T\ G^2\ \lambda^2}{P_R\ 16\pi^2}} \tag{3. 2}$$

The wave length is calculated by the following equation.

$$\lambda = \frac{c}{f} \tag{3. 3}$$

- c = $2.99793 \bullet 10^8$ m/s (the speed of light in space)
- f = The used frequency . The GP&C system operates in the maritime and aviation domain (107 – 174 MHz).

If the λ is putted on equation 3.2 by choosing special (f) value, simple equation can be derived. (f = 150 MHz => λ = 2 meters (approximately))

$$R = \sqrt{\frac{P_T\ G^2}{P_R\ 4\pi^2}} \tag{3. 4}$$

According to the last equation, high transmit power, high gain, low minimum required receive power and low wavelength increase the range. High transmit power results higher temperature. It consumes more energy. The antenna cabling, antenna dimensions, and the position of antenna affects the gain. Low receive power results less tolerant to noise.

In order to illustrate how the distance varies with the gain value, it is needed two assumptions which are $P_R = 10^{-14}$ Watts and $P_T = 5$ Watts (Figure 3.7).

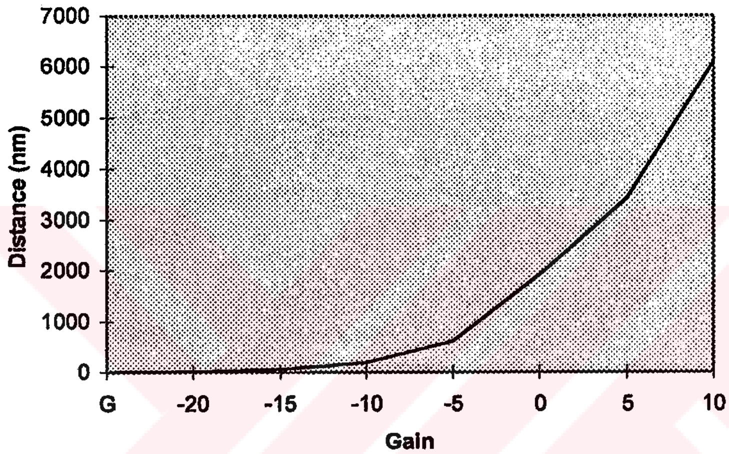

Figure 3. 7 Distance and Gain Diagram

In this analysis is omitted factors such as atmospheric effects, interfering noise, multipath. Secondly, it is determined the range of radio waves with respect to how the radio waves propagate through the atmosphere. VHF radio waves are used in STDMA application. VHF radio waves travels as space waves where most prominent path is direct line between transmitter and receiver. The radio waves have line-of-sight reach. It is also valid VHF radio waves.

It is assumed a transmitter and receiver are placed in space with the earth as an obstruction. Figure 3.8 illustrates this case.

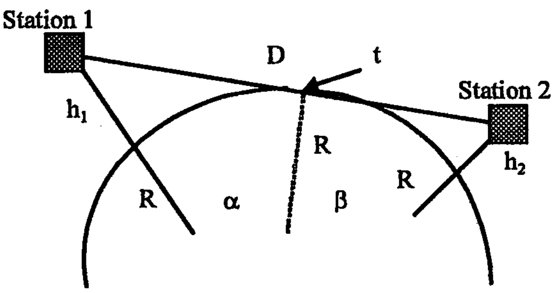

Figure 3. 8 Line of sight case

- D = The direct distance between station 1 and 2 (km)
- t = The point, where a direct line between the two stations, touches the horizon of the earth
- β = The angle between the right side radius line and the dotted line going to t
- h_1 = The height above ground for station 1 (meter)
- h_2 = The height above ground for station 2 (meter)
- R = The earth radius (6370 km)
- α = The angle between the left side radius line and the dotted line going to t

According to the figure (3.8) cosinus of α and β is derived:

$$\cos\alpha = \frac{R}{R+h_1} \qquad (3.5) \qquad\qquad \cos\beta = \frac{R}{R+h_2} \qquad (3.6)$$

and D is:

$$D = (R+h_1)\sin\alpha + (R+h_2)\sin\beta \qquad (3.7)$$

after some simplification,

$$D = 3.6\left(\sqrt{h_1} + \sqrt{h_2}\right) \qquad (3.8)$$

If it is assumed that the height of station 1 and station 2 above ground are same (Figure 3.9), an alternative equation can be derived which is more simple.

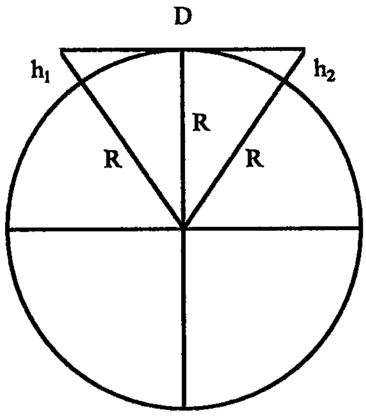

Figure 3. 9 Height of stations are same

In figure 3.9, it can be seen easily that;

$$(R+h)^2 = R^2 + \left(\frac{D}{2}\right)^2 \qquad (3.9)$$

after some simplification

$$D[m] = \sqrt{8Rh} \qquad (3.10)$$

Some effect (i.e. atmospheric condition...) can cause exceeding range beyond line-of-sight. It is called refraction. These calculation doesn't contain effect of refraction. If refraction is considered, it will be enough replacing the constant 3.6 with 4.1 in equation 3.8.

D is calculated in aviation environment and maritime environment by using these equation. For the aviation environment, terminal environment can be considered where the height of station changes between 1000 m. – 3000 m. It is assumed that a base station antenna is positioned 20 m. above ground. The range is expected 130 km. – 213 km. for D.

In maritime environment, altitude can be effected by the height of the antenna above ground. It is assumed that the antenna of ship is positioned at 30 meter and the antenna of base station is positioned at 150 meter. According to this, base station has a range of 64 km and mobile station has a range of 39 km.

These results contain some assumption. It is assumed that globe has a uniform radius and obstruction are not present. In areas with a few obstructions, the resulting range can be longer than calculated. In areas with many obstructions the resulting range can be shorter.

And now it is determined how radio signal are received when transmission from several stations are in conflict. It is assumed that a receiver is placed in the middle of a population of moving objects which are equipped with transceivers. This part is a study of experiments performed in laboraty, land mobile and aviation environments [13]. Used setup in all tests is similar like in Figure (3.10).

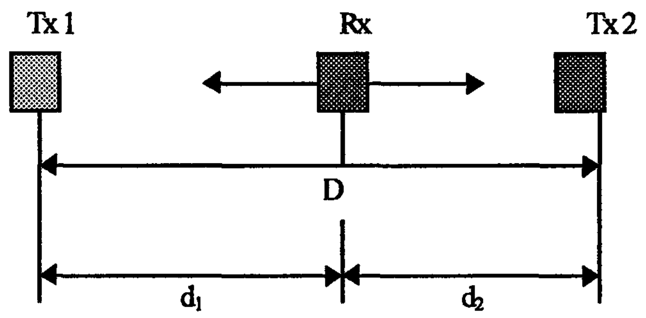

Figure 3. 10 Test configuration

Tx 1 and Tx 2 are transmitter .They are stationary and separated by a distance (D). Rx is a receiver which is allowed to move back and forth between Tx 1 and Tx 2. The two transmitters output position reports once per second, in the same time slots, thus inducing transmission conflicts. While moving from Tx 1 to Tx 2, the number of successfully received position reports are measured at the receiver (Rx).

A successfully received transmission depends on the ratio in power between Tx 1 and Tx 2. This ratio is called power ratio (PR). Power Ratio is expressed in decibels (dB). Tx 1 and Tx 2 use the same nominal transmit power. The power ratio can easily be converted to a distance ratio (DR). This ratio describes the required separation between Rx to Tx 1 and Rx to Tx 2 (d_1/d_2). To convert between DR and PR, following equations are used [13]:

$$PR = 20 \log(DR) \tag{3. 11}$$

$$DR = \sqrt{10^{(PR/10)}} \tag{3. 12}$$

Laboratory Test: In the laboratory test, moving of transmitters is simulated by using attenuators. The used setup in the laboratory is as shown in figure 3. 11.

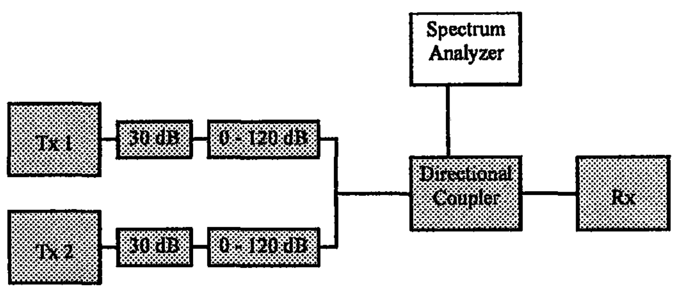

Figure 3. 11 Laboratory test configuration

The result of this testing is following (Table 3.1):

Table3. 1 Laboratory test results

PR	Throughput	DR
3 dB	0%	1.4
4 dB	30%	1.6
5 dB	100%	1.8

It is seen clearly that PR must be at least 5 dB for a 100 % succes rate or DR must be at least 1.8 (d1/d2 = 1.8).

The land-mobile test: It was performed using the same setup which is described above. Two transmitters were positioned at opposite ends of an airport runway. A receiver was installed in a car and then allowed to travel between Tx 1 and Tx 2.

For a 100% success rate, PR must be at least 0.8 dB or DR must be at least 1.1 (d_1/d_2=1.1).

The aviation test: It was performed using the same setup which is described above. Two transmitters were positioned at two different airports. A receiver was installed in an aircraft and then allowed to fly between Tx 1 and Tx 2.

For a 100% success rate, PR must be at least 2.0 dB or DR must be at least 1.25(d_1/d_2 = 1.25)

The difference between the laboratory and the land-mobile and aviation tests might be explained by environmental causes (i.e interfering obstructions, antenna positions ...). These results was obtained by using GMSK/FM (Frequency Modulation using Gaussian Minimum Shift Keying). If D8PSK (Digital Eight Phase Shift Keying) is used, results will be in a PR of 18 dB or a DR of 7.9. In general, a lower power ratio will promote improved throughput.

Therefore, D8PSK is not a feasible modulation method, compared to GMSK/FM [16]. For furher analysis, It is assumed that power ratio is 6 dB and thus the distance ratio is 2.0.

The term garble (Figure 3.12) denotes that neither station is successfully received by Rx. When one station is successfully received, that station is said to have discriminated the other.

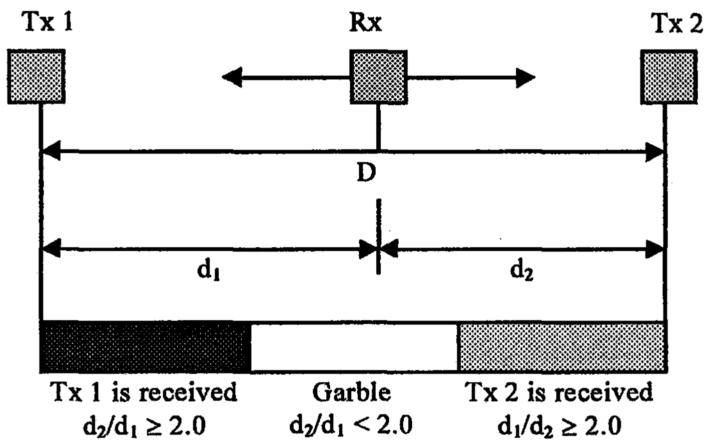

Figure 3. 12 Discrimination zone

3.3.1.2 Propagation

This section examines how propagation affects throughput and cell radius when stations are far apart (more than 370 km) and the slot occupancy is less than maximum. The STDMA system has a built-in guard time in each slot, which allows stations to be 370 kilometers apart. 370 km equates to 200 nautical miles. A buffer which protects data. A station can still receive a transmission farther away. They can be more than 200 nautical miles (nm) apart. But their transmission will cross slot boundaries, thus no longer be protected within a slot and potentially be in conflict with a trans-

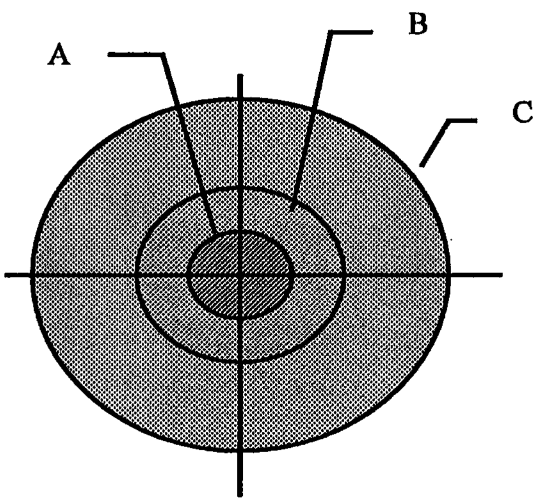

Figure 3. 13 Propagation zones

The total number of transmissions occupy all available slots. Initially 5% of the transmissions are within 200 nm of the receiving station. The througput to receiving station which is positioned in the center is studied. The transmission which inside the 200 nm radius is protected by the guard time as said before. The stations are then slowly allowed to move into the 200 nm radius until 95% of all transmissions are within.

The data link is time divided which means that each transmission is allocated its own time slot. Slots can be 3 states:

- **Ok** :means that a transmission in that slot was received successfully.
- **Garbled** :means that two transmissions which are in adjacent slots were in conflict and neither transmission was received successfully.
- **Discriminated** :means that two transmissions which are in adjacent slots were in conflict. But one of them was successfully received and one was discriminated.

This analysis only looks at conflicts due to propagation. Therefore it is assumed that only one station transmits in each time slot. Conflicts only might be when transmissions overlap slot boundaries at the receiving station. To discriminate, it was assumed before that the power ratio is 6 db and this equates to 2.0 of distance ratio. Based on this, following figures can be drawn which denotes different case of slots.

(d1 / d2) = 2: The station at 200 nm allows the station at 400 nm to overlap into the next slot but not overlap the transmission (Figure 3.14).

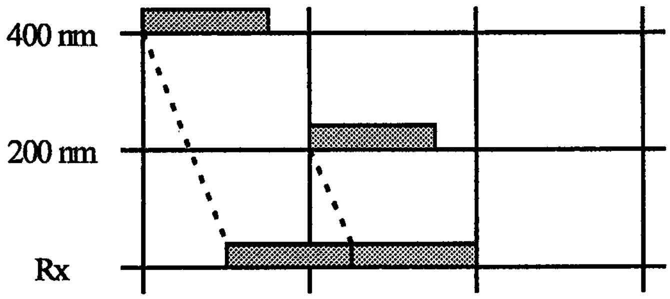

Figure 3. 14 d1/d2 = 2

(d1 / d2) > 2: The station at 100 nm overrides the station at 400 nm, thus discriminating that station (Figure 3.15). Discrimination is the only factor limiting throughput in the non-saturated scenario with respect to propagation time.

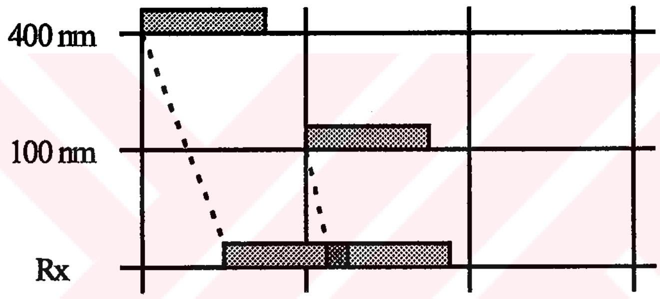

Figure 3. 15 d1/d2 > 2

(d1 / d2) > 2: The previous transmission is at a closer range than the following one and no conflicts exist (Figure 3.16) .

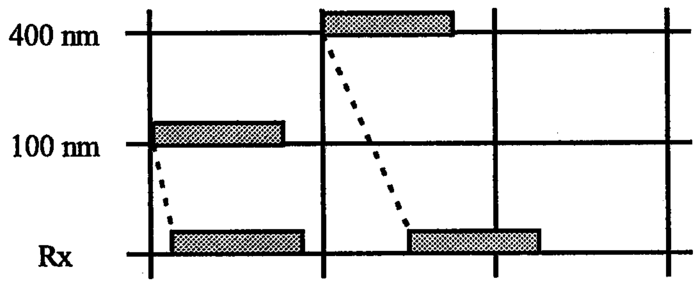

Figure 3. 16 d1/d2 > 2 transmission is at closer range

(d1 / d2) < 2: According the assumption, the following scenario would result in garbling. But it can be clearly seen that the propagation time separates the two transmissions . Thus, garbling due to propagation time only, can never occur in the STDMA system.

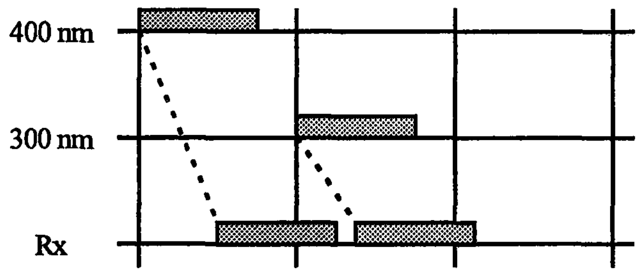

Figure 3. 17 d1/d2 <2

To examine propagation effects a C++ program is created [14]. This program constructs a virtual image of a traffic situation with stations randomly spread within a 400 nm radius of a receiving station. The analysis is studied performed to see if a transmission is in conflict with the previous transmission, based on the distance. The program constructs the virtual image 1000 times and then calculates average values of slots which are okay, slots which are garbled and slots which are discriminated. The result of the test program below:

Table3. 2 The result of test program

% in AB	**slots A**	**slots B**	**Slots C**	**Discr. in C**	**C tp**	**Net tp**
5%	56	169	4275	79	98,15%	98,24%
10%	113	338	4050	150	96,30%	96,67%
15%	169	506	3825	213	94,43%	95,27%
20%	225	675	3600	267	92,58%	94,07%
25%	281	844	3375	313	90,73%	93,04%
30%	338	1013	3150	351	88,86%	92,20%
35%	394	1181	2925	380	87,01%	91,56%
40%	450	1350	2700	400	85,19%	91,11%
45%	506	1519	2475	413	83,31%	90,82%
50%	563	1688	2250	417	81,47%	**90,73%**
55%	619	1856	2025	413	79,60%	90,82%
60%	675	2025	1800	401	77,72%	91,09%
65%	731	2194	1575	379	75,94%	91,58%
70%	788	2363	1350	349	74,15%	92,24%
75%	844	2531	1125	312	72,27%	93,07%
80%	900	2700	900	266	70,44%	94,09%
85%	956	2869	675	213	68,44%	95,27%
90%	1013	3038	450	150	66,67%	96,67%
95%	1069	3206	225	79	64,89%	98,24%

The results are shown in the figure 3.18 below:

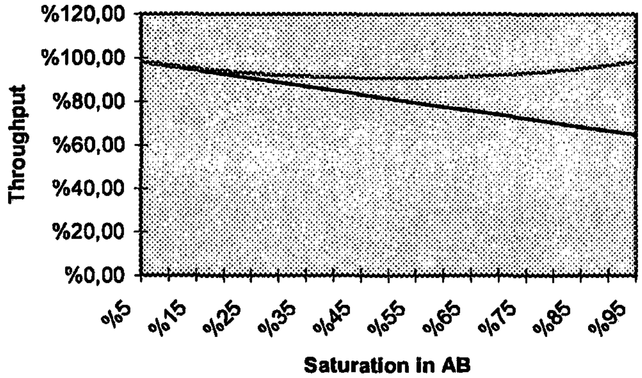

Figure 3. 18 Throughput - Saturation

The curved line shows the overall net throughput from areas A, B and C. The straight line shows the throughput from stations in area C. Now, it can be given throughput equations. They are contain constants which have been derived from the empirically collected data.

TP(net) = 0.37*(Pop(AB)-0,50)+0,907 (3. 13)

- TP(net) = Net throughput of all transmissions
- 0.37 = Derived constant which smoothes out the curve.
- Pop(AB) = Population inside the area covered by the 200 nm radius .
- 0.50 = At 50% the lowest throughput is recorded (90,73%).
- 0.907 = The lowest net throughput.

The throughput of transmissions outside the 200 nm can be expressed as shown below:

TP(C) = 1 - 0,37 * Pop(AB) (3. 14)

- TP(C) = Throughput of transmission outside the area protected by the 200 nm radius
- 0.37 = Derived constant which gives the proper angle of the linear curve.
- Pop(AB) = Population inside the area covered by the 200 nm radius (1%-99%).

At the same time, the test program keeps statistics about discrimination in relation to distance from receiving station . Figure 3.19 is result of this.

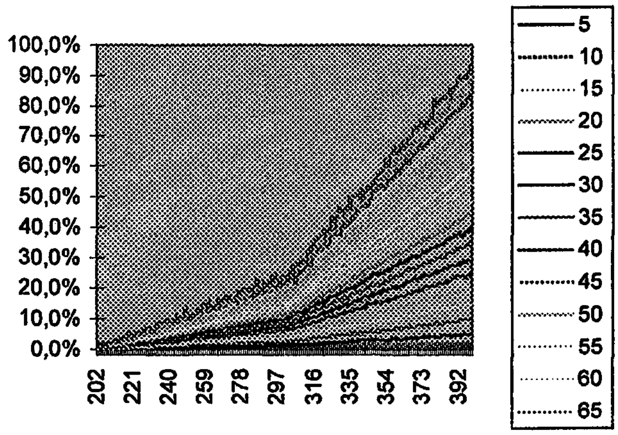

Figure 3. 19 Discrimination - Distance

Each curve in figure 3. 19 represents a certain population within area A and B. The probability of discrimination is increasing with an increase in distance and an increase in population. Based on this, the equation of probability of discrimination can be given as shown below:

Between 201 nm and 300 nm :

$$P(201\text{-}300) = 0{,}0025 * Pop(AB) * (D-200) \quad (3.\ 15)$$

- 0,0025 = The constant, which gives the curve angle in figure 3.19 between 201 and 300 nm.

- D = The distance, between the transmitter and the receiver, where the probability shall be calculated (200 < D < 300) nm.

Between 301 and 400 nm can be expressed as:

$$P(301\text{-}400) = 0{,}0075 * Pop(AB) * (D-300) + 0{,}25 * Pop(AB) \quad (3.\ 16)$$

- 0,0075 = The constant which gives the curve angle in figure 3.19 between 301 and 400 nm.

- D = The distance, between the transmitter and the receiver, where the probability shall be calculated (300 < D < 401 nm).

- 0,25*Pop(AB) = The probability of discrimination at 300 nm.

Finally, the table 3.3 gives acceptable throughput ranging from 50% to 90%.

Table3. 3 Cell radius and saturation in AB

Pop(AB)	R(50%)	R(60%)	R(70%)	R(80%)	R(90%)
0%	400	400	400	400	400
5%	400	400	400	400	400
10%	400	400	400	400	397
15%	400	400	400	400	356
20%	400	400	400	399	333
25%	400	400	400	373	321
30%	400	400	399	356	312
35%	400	400	382	343	306
40%	400	399	366	334	296
45%	400	386	356	327	286
50%	399	374	347	323	279
55%	389	364	342	316	269
60%	380	357	336	313	262
65%	371	350	330	310	261
70%	364	343	325	306	255
75%	358	340	322	304	252
80%	352	335	319	299	248
85%	346	330	315	292	248
90%	343	328	315	282	248
95%	336	323	312	279	243
100%	200	200	200	200	200

The results are shown in the figure 3.20 below:

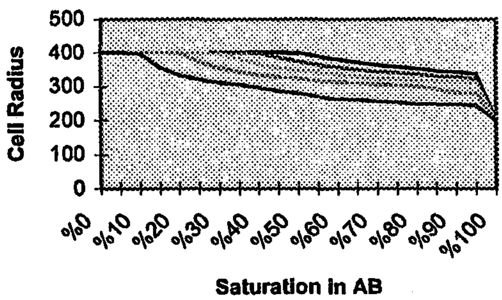

Figure 3. 20 Cell radius – saturation in AB

The scenario assumes that all transmissions are STDMA organized which is quite unlikely in reality. In this scenario, if all transmissions would have been inside 200 nm, the net throughput would have been 100%. Similarly, if all transmissions would have been outside the 200 nm radius, the throughput would have been 100%. This is not realistic. However, this examination denotes some important points:

- Garbling will never occur as a result of propagation time only.
- The net throughput, with respect to propagation, will always be above 90,7%.
- In reality it is the difference in power levels which determines the outcome of conflicting transmissions. Distance between the stations affect the received power but, antenna installation is also an important factor.
- The throughput of transmissions outside the protected distance is gracefully reduced because of increasing the traffic density closer to the receiving station.

3.3.1.3 Synchronization

Time synchronization analyses focus on the different sources of synchronization to the TDMA data link when the primary synchronization source is lost. It determines the effects of an isolated station losing its primary time source due to loss of GNSS receiver. This source can be provided by the 1PPS pulse generated by a GNSS receiver.

It is assumed that a station loses its primary time source. In this case, the receiving station is separated with the transmitting station by the guard distance (200 nm). This eats up the buffer allocated for guard distance. At the same time the transmitting station produces a transmit jitter (G) which is equivalent to the sum of all timing errors. Based on the start jitter (Figure 3.21), transmissions start either prior to, or after nominal slot start.

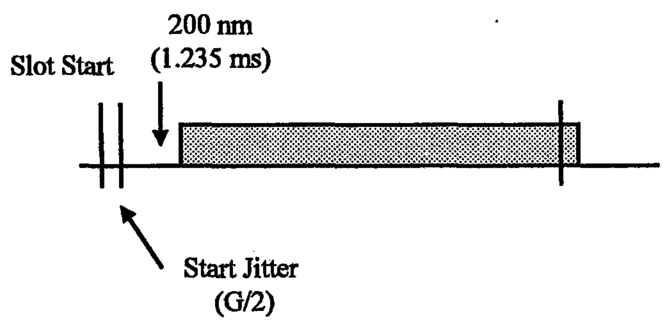

Figure 3. 21 Starting of jitter

According to capability of accesing to the base station or mobile station, different cases occurs.

Synchronization to a Base Station

The base station uses the high position accuracy and will thus gives the smallest error in distance measurement. When a station attempts to synchronize to transmissions from another stations it will try to compensate for the distance between itself and the transmitting station. A timing error is introduced as a result in the inaccuracies in position information. The figure 3.22 illustrates this:

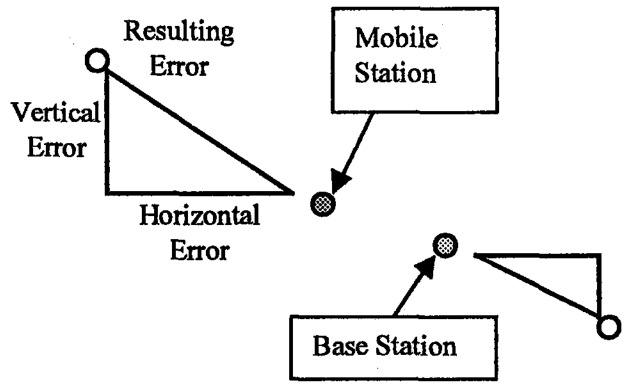

Figure 3. 22 Worst case scenario

If it assumes that:

- The horizontal accuracy in position is 100 m. when differential corrections are unavailable or a back up system is used as a position source.
- The vertical accuracy in position is 200 m. when differential corrections are unavailable or a back up system is used as a position source.
- The horizontal accuracy in position is 2 m. when differential corrections are available or a position is output by a base station.
- The vertical accuracy in position is 5 m. when differential corrections are available or a position is output by a base station.

The worst case distance error between the mobile and a base station can be calculated as shown below:

$$\text{Distance Error} = \sqrt{200^2 + 100^2} + \sqrt{2^2 + 5^2} = 229 \text{ m} \tag{3. 17}$$

The position source is updated once every second. In the worst case scenario, the synchronization calculations are performed just before a new position is derived. The position is then 1 second old . At this time, the station has traveled a distance based on its speed over ground (SOG). The position error can be calculated as shown below:

$$\text{Position Error} = (SOG*1000)/60^2 \quad (3.18)$$

The following example gives an idea about the value of error. Table 3. 4 shows the timig errors common to aviation environment:

Table3. 4 Timing errors common to aircraft environment

Inaccuracy in arrival time measurement	5 us
Transmitter start jitter	5 us
Primary time source stability	1 us
Distance error	229 m / 300 us = 0.76 us
Sum	**11.76 us**

Table 3.5 shows the accumulated timing error for the three different environments:

Table3. 5 Timing error for three environments

Value	Airport	Terminal	En route
Common error	11.76 us	11.76 us	11.76 us
Position error	0.23 us	0.42 us	0.83 us
Sum	**11.99 us**	**12.18 us**	**12.59 us**

This examination shows that the timing error will be less than 13 us for all environments. 13 us equates to 3.9 km. (13*300/1000 km). This error which is called jitter affects the buffer allocated to the guard time. The degradation in performance, due to loss of primary synchronization, only affects the radius protected by guard time. In the martime AIS system, the cell size is always restricted by line-of-sight distances which is approximately 64km. The guard distance is 370 km. The guard distence is reduced 3.9 km. by the effects of error. This error is acceptable in maritime environment.

Synchronization to a Mobile Station

The mobile station uses the low position accuracy (in accordance with assumptions) and will thus give higher error in distance measurement than the base station case. Distance error is derived in the same manner as above section but the equation looks like below:

$$\text{Distance Error} = 2 * \sqrt{200^2 + 100^2} = 447 \text{ m} \qquad (3.19)$$

In the worst case scenario, both stations are moving away from each other with a relative speed of 2*SOG.

$$\text{Position Error} = 2 * (\text{SOG}*1000)/60^2) \qquad (3.20)$$

The table below shows the timing errors common to every aviation environment. The only changing is distance error.

Table3. 6 Timing errors common to aviation environments for mobile synchronization

Inaccuracy in arrival time measurement	5 us
Transmitter start jitter	5 us
Primary time source stability	1 us
Distance error	447 m / 300 us = 1.5 us
Sum	**12.5 us**

Table 3.7 below shows the accumulated timing error for the three different environments:

Table3. 7 Timing error for three environments at the case of mobile synchronization

Value	Airport	Terminal	En route
Common error	12.50 us	12.50 us	12.50 us
Position error	0.46 us	0.84 us	1.66 us
Sum	**12.96 us**	**13.34 us**	**14.16 us**

The calculations show that the timing error is less than 15 us for all environments. This equates to 4.5 km, which still is approximately 1.2 % of the distance allocated to guard time. This only less than when synchronization is derived from base stations. It can be ignored in the maritime environment .

Floating Network

A floating network exists the GNSS system fails and all stations are suddenly without primary time source. The only source left for time synchronization is the transmission from other un-synchronized stations, or possibly base stations with a backup system for time synchronization. The TDMA data link becomes a floating network of stations continuously attempting to synchronize to each other. Usually, base stations are equipped with a backup source for time synchronization. This source is equal to, or better than the timing provided by the GNSS system. If mobile stations synchronize to transmissions from base stations, the scenario is similar to that described in the above section and the timing errors are the same. Now, it is assumed that a population of mobile stations are unable to receive transmissions from base stations all sources of time are lost. This is a true floating network situation and will be examined in the following sections.

Synchronized and then Loosing Timing : If a station has been fully synchronized to the primary time source and then suddenly loses it, it will maintain a very accurate synchronization for quite some time. Some design drifts approximately 3 us per minute is realistic to achieve [15]. If it is assumed that transmissions in adjacent slots drift in opposite directions, the cell radius can be described as shown below:

Cell Radius in nm = (1248 - Time*6) * 300) / 1852 (3. 21)

- 1248 = The guard time in each slot ((1248 us *300/100) equates to 370 km. approximately.)
- Time = The time from loss of primary time source, in minutes.
- 6 = The total drift of two stations drifting opposite directions in time (2*3 us)
- 300 = The speed of light in meters per us
- 1852 = The length of one nautical mile in meters.

If it is acceptable that the cell radius shrinks, the system can be allowed to drift for an extended period of time. The limit to the drift is dependent on the relative speed between mobile stations. Following table (3.8) is obtained by using the equation (3.21). Based on the table, the system can be allowed to remain in the lost sync state for over 3 hours. It is assumed that the TDMA data link traffic is saturated . If the link traffic is low, the transmission jitter will be less since a transmission can be allowed to drift into an adjacent slot which is unused.

Table3. 8 Cell radius and Time

Time (minutes)	Radius (nm)
0	206
10	196
20	186
30	176
40	167
50	157
60	147
70	138
80	128
90	118
100	108
110	99
120	89
130	79
140	69
150	60
160	50
170	40
180	31
190	21
200	11
210	1

Primary Time Source is Unavailable: If it is assumed that the system lacks the very accurate primary time source, the system must rely on some sort of fallback mode. Each station knows its nominal start time. The stations continuously calculate an average start time based on the latest received transmissions. The average time is compared to the nominal start time. If there is a difference between the calculated average value and nominal start time by a certain amount (maybe 21 us), the own timing is readjusted. Following figure 3.23 shows an example where 100 transmission are spread within one slot (0 – 13.33 ms) and shows how an average start time is continuously calculated and used.

The first 100 transmissions are randomly assigned a transmission start between 0 and 13.33 ms. From transmission 101, average transmission start is calculated. Approximately 150 transmissions after starting to calculate average values, the transmissions are again in harmony assuming that all transmissions were received and included in the calculation.

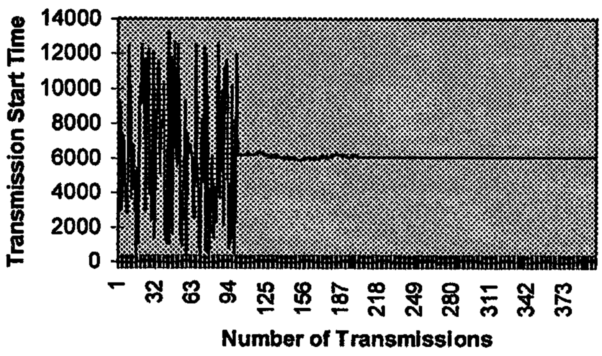

Figure 3. 23 Transmission start time – Number of transmission

Throughput Analaysis

It assumed that two populations have been flowing independently of each other as shown figure 3.24:

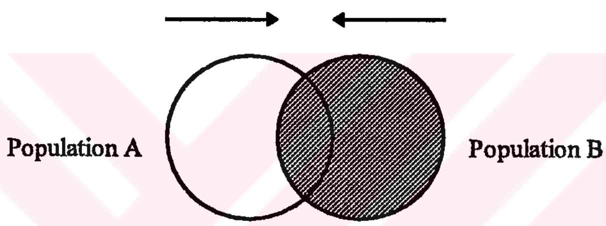

Figure 3. 24 Seperated populations begin to merge

The TDMA data link is saturated. Transmissions from population B are then merged with the original cell and the effects are analyzed. The factors affecting the throughput are:

- Transmission start time. If the transmission start time overlaps the next adjacent slot, a conflict occurs.
- Distance between conflicting stations. Garbling or discrimination occurs as a result of the transmit conflict. If the conflicting transmissions are close to each other they will both be garbled. If they are separated by a factor of 2, the farthest transmission is discriminated.

The transmission from population B are synchronized. The net thoroughput is measured from the center of the cell A. By using a C/ C++ test program, following table is obtained [14].

Table3. 9 Merging time and Throughput

Merging time (min)	Relative speed (km/h)	Time to restore sync (seconds)	Lowest throughput	Average throughput
10	2220	56	78%	95%
20	1110	75	85%	96%
30	740	94	85%	97%
40	555	121	86%	97%
50	444	121	88%	97%
60	370	140	87%	98%
70	317	145	90%	98%
80	278	131	90%	98%
90	247	160	91%	98%
100	222	147	91%	98%

- Merging time = The time it takes before the two populations have merged completely
- Relative speed = The resulting relative speed between the populations
- Time to restore sync = The time it takes to restore synchronization close to 100%
- Lowest throughput = The lowest average throughput calculated over 100 slots during the time to restore sync
- Average throughput = The average throughput calculated on all slots from the first reduction in throughput until the throughput is restored to its original value

3.3.1.4 Organization

This section analaysis the capability of the STDMA algorithm to maintain slot organization on the TDMA data link. Before this some definition is given.

The VHF Cell : Each participating station operates in its own unique VHF cell (Figure 3.25). The cell shape can be approximated as a cylinder. The radius of cylinder extends to the range given by link budget.

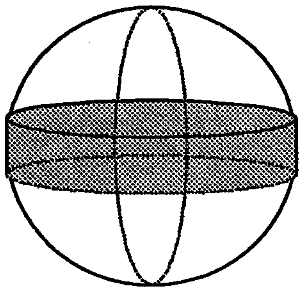

Figure 3. 25 VHF Cell

Automatic Slot Reuse : Two or more station may attempt to use same time slot for transmission. This is called automatic slot reuse. These stations are unaware that the are using the same time slot. They have determined the time slot to be free and available for use.

Intentional Slot Reuse : It is assumed that TDMA link is used to maximum capacity and a station experiences it. If the station attempt to use time slots which are reserved by other station, this case is called Intentional Slot Reuse.

Remote Area Operation

This analysis determines the ability of the STDMA algorithm to resolve transmission conflicts in low traffic situations. It assumed that two stations approaching to each other at a speed of (v). Their cells have equal size (r) and same update rate (u).When they reach the VHF are of one another, they are unorganized. In this case, they use probably the same time slot for transmission which results unable to see each other. Based on the their update rate, it is possible more approaching without seeing each other.

Now remember that the STDMA algorithm attempts to spread transmissions using a Nominal slot Increment (NI). The jump to a new slot is always within an interval which is 0.2*NI (Selection Interval (SI)). When a conflict occurs, SI of each station must overlap in whole or partly. In the worst case scenario they overlap completely. The probability of this:

P(Overlap) = 1 / (SL-SI) (3. 22)

- SL = It denotes how many slots the data link uses per minute.

Additionally, the two stations must have selected the same slot within the SI.

P(Same Slot) = 1/S (3. 23)

The Nominal Increment - NI and the Selection Interval (SI) are given by:

$$NI = SL / u \quad (3.24)$$

$$SI = 0.2NI = 0.2SL / u \quad (3.25)$$

Combining the last two equation:

$$P(\text{Same Slot}) = u / 0.2SL \quad (3.26)$$

The probability of a conflict in the first slot which could be received is:

$$P(\text{Overlap}) * P(\text{SameSlot}) \quad (3.27)$$

The probability of n successive conflicts is:

$$P(\text{n conflicts}) = \frac{1}{(SL\text{-}SI)}\left[\frac{u}{0.2SL}\right]^n \quad (3.28)$$

After further simplification, the probability is:

$$P(\text{n conflicts}) = 1 / [(SL\text{-}SI)(SI)^n] \quad (3.29)$$

Probability of detection within n transmissions is:

$$P(\text{Detection}) = 1 - \text{Eq. } 3.29 \quad (3.30)$$

The following example gives idea about the value of probability of conflicts in n successive slots. In following problem:

- SL = 200 (station) * 10 (update rate) = 2000
- u = 10 (update rate)
- NI = 200
- SI = 40

Table3. 10 Probability of n successive conflicts

n	P(n successive conflicts)
1	$1.275 * 10^{-5}$
2	$3.187 * 10^{-7}$
3	$7.968 * 10^{-9}$
4	$1.992 * 10^{-10}$

It seems clearly that the probability of a transmission conflict is very small. Even if one should occur, it affects only one out of all transmissions during a minute. The conflict is, on average, resolved after 4 minutes.

Even though two stations are within VHF coverage, the actual detection may be delayed. During transmission , it will take an additional 60 / u seconds until next transmission. If the stations travel with speed of v, the relative distance (d) is expressed as shown below:

$$d = 2 * v * (60 / u) * n \quad (3.31)$$

As a result of this, the VHF cell radius is compressed with (d) ahead of the station as shown figure 3.26:

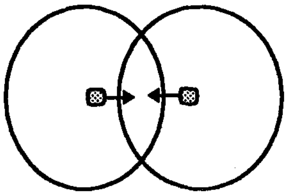

Figure 3.26 At the high speeds, the cell is compressed

High Data Link Load

This analysis determines how the throughput varies with distance between receiving and transmitting station and how TDMA data link saturation affects the througput. It is assumed that A and B are transmitting but unable to receive each other. But the third station (C) receives both stations. A and B are STDMA organized. But it seems to C that they are randomly selecting slots. A scenario was simulated using a C/ C ++ program for this case [14] . At the beginning, the TDMA link was empty and then it is loaded up to maximum capacity. Then it is continued with an overloaded system. The result of this program is shown below:

Table3. 11 Required capacity - Slot reuse

Required Capacity (%)	Slot Reuse (%)
0	0
10	10
20	18
30	26
40	33
50	39
60	45
70	50

80	55
90	59
100	*63*
110	67
120	70
130	73
140	75
150	78
200	86
300	95
400	98
500	99

Garbling and Discrimination

The Aloha Zone: It seems to the station that transmitters in region r to r/2 selects slots randomly. This region is called aloha zone. In this region, garbling occurs as a result of slot reusing. The net througput in Aloha Zone is:

$$TP(r \geq d > r/2) = 1 - \text{Slot Reuse} \qquad (3.32)$$

- Slot Reuse = Table 3. 1

Discrimination Zone: The region which stretches from r/2 to r/3 is called discrimination zone. In this zone, transmissions which are in reused time slots may result in garble or discrimination. Only the garbling area may reduce the througput. The area is derived by approximation of the discrimination area (A_d).

$$A_d / A = (1 - 4k^2)^2 * \arccos(k/2); \quad 0 \leq k \leq 1 \qquad (3.33)$$

The net throuhput in Discrimination Area is:

$$TP(r/2 \geq d > r/3) = ((A_d + (1\text{-E. } 3.32)*(A - A_d)) / A \qquad (3.34)$$

Protected Zone: The region which stretchs from r/3 to 0 is called protected zone. In this area all stations are STDMA organized. In this zone, transmission which are in reused time slots may result in discrimination. Automatic reuse is performed by reusing slots from the aloha zone. The net througput in protected zone is equal (1). Following table 3.12 illustrates the net througput for different distance .

Table 3. 12 Required capacity and Net throughput

	Required Capacity and Net Throughput				
Dist	**10%**	**50%**	**100%**	**150%**	**200%**
0,00	100%	100%	100%	100%	100%
0,05	100%	100%	100%	100%	100%
0,10	100%	100%	100%	100%	100%
0,15	100%	100%	100%	100%	100%
0,20	100%	100%	100%	100%	100%
0,25	100%	100%	100%	100%	100%
0,30	100%	100%	100%	100%	100%
0,35	94%	75%	60%	50%	45%
0,40	92%	68%	48%	36%	29%
0,45	90%	63%	40%	26%	18%
0,50	90%	61%	37%	22%	14%
0,55	90%	61%	37%	22%	14%
0,60	90%	61%	37%	22%	14%
0,65	90%	61%	37%	22%	14%
0,70	90%	61%	37%	22%	14%
0,75	90%	61%	37%	22%	14%
0,80	90%	61%	37%	22%	14%
0,85	90%	61%	37%	22%	14%
0,90	90%	61%	37%	22%	14%
0,95	90%	61%	37%	22%	14%
1,00	90%	61%	37%	22%	14%

Intentional Slot Reuse

All slots, in TDMA link, are marked as free, reserved, or available.

- Free means that the receiving station is detected only noise, with little or no carrier, in it.
- Reserved means that the receiving station has received data indicating that the slot is occupied.
- Available means that a receiving station detected a carrier, an aborted data burst or data with incorrect checksum.

Intentional slot reuse only effects reserved slots. The other types are needed by the automatic slot reuse. Intentional slot reuse is only needed protected zone where garble doesn't occur an overloaded datalink. It is applied only when the required capacity approaches 700% of available. Inreality intentional slot reuse is applied even though the link appears to be less than 100% reserved.

4 DIGITAL SELECTIVE CALLING

This section is divided to three part.

- DSC System
- DSC Transponder
- Test Result of the DSC System

4.1 DSC System

Automated Dependent Surveillance (ADS) is an improvement to the current Vessel Traffic Service (VTS) operations and it is a step towards a 'voiceless (VTS).' At the same time. ADS is a technology which is capable of transferring information in a digital format from vessel . The United States Coast Guard (USCG) Research and Development Center has been studying the technologies available to enable this digital information flow.

The Coast Guard groups and Communications Stations (COMMSTAs) are responsible for maintaining radio distress watches. Presently, most radio contact is established by making a voice call and relying on an aural watch by the called party to hear the call. The COMMSTAs offers a new MF/HF radiotelephone service to mariners as part of the new Global Maritime Distress and Safety System (GMDSS). The new service is called Digital Selective Calling (DSC). Digital Selective Calling (DSC) automatically monitors calling frequencies and signals when a communications link is established between marine radios (ship/shore ship/ship) for distress calls and routine operational communications. It allows mariners to send automatically formatted distress alert to the rescue authority anywhere in the world. The advantages of DSC include faster alerting capabilities and automatic transmission of information such as the nature of distress, situation, and the identity and location of the caller. DSC allows mariners to initiate or receive distress, urgency, safety and routine radiotelephone calls to or from any similarly equipped vessel or shore station, without requiring a radio loudspeaker. Further, in a non-distress situation, DSC minimises the time necessary to establish communications and increases spectrum efficiency. DSC acts like the dial and bell of a telephone, allowing you to "direct dial" and "ring" other radios. Additionally, it allows others to "ring" you, without having to listen to a speaker. New VHF and HF radiotelephones have or soon will have DSC capability.

4.1.1 What is DSC

DSC is a semi-automated method of establishing a radio call. It has been designated by the International Maritime Organization (IMO) as an international standard for establishing maritime MF, HF, and VHF radio calls [20]. DSC will eventually replace aural watches on distress frequencies and will be used to announce routine and urgent maritime safety information broadcasts. To understand DSC, it will be better looking at the term "Digital Selective Calling"

DIGITAL : DSC uses a DIGITAL signal to send a specific set of information.

- The caller's Maritime Mobile Service Identity or MMSI (a number that uniquely identifies the caller, similar to a phone number).
- The caller's location, and time of location. This can be obtain directly from an interface to a GNSS (i.e GPS, Loran, SatNav ...) receiver, or it can be entered manually. Location and time of location are normally only transmitted with a distress alert.
- The requested working frequency & mode. Frequency and mode of emissions will be used to transact business. DSC is only used for call set-up as said before . Once the call is established the two parties change to a working frequency and mode to continue the call.
- The priority of call. DSC can be used for anything from distress calls, to setting up a routine phone patch through a commercial coast station.
- For distress calls, the DSC call can even indicate the type of emergency (fire, taking on water, etc).

SELECTIVE : DSC calls can be addressed to a certain user or set of users. For example, DSC calls can be addressed to:

- A specific vessel or shore station
- Receivers in a specific geographic area
- A specific set of DSC receivers (for example all Coast Guard receivers).

- All receivers in radio range (used, for example, when the individual identity of the ship called is unknown).

When a DSC receiver "hears" a DSC call it looks at the address, geographic information, etc. It alerts an operator only if the call is intended for that unit.

CALLING : When a DSC call is received, the receiving station will use the DSC protocol to acknowledge the call. At this point the two parties will move to a working frequency and a different mode (voice, fax,...) to complete the call. Generally a DSC-equipped radio will "ring" when called, as would a telephone.

4.1.2 What is MMSI

MMSI will be used many times in text part of this study. Because of this, I decide to explain this term. Maritime Mobile Service Identities are formed of a series of nine digits which are transmitted over the radio path . MMSI identify ship stations, ship earth stations, coast stations, coast earth stations, and group calls [21]. There are four kinds of maritime mobile service identities:

- Ship station identities,
- Group ship station identities,
- Coast station identities,
- Group coast station identities.

The First Digit of an MMSI: The first digit or two of an MMSI means something about the identity.

First digit(s)	Meaning
0X	Ship Group identity
00	Coast station, or Group of Coast Stations
1	Not used (the seven digit identity begining with "1" is used by Inmarsat A)
2	These are valid MMSI's used by individual ships
.	"

.	"
7	"
8	Assigned for Regional Use
9	Assigned for National Use

Maritime Identification Digits (MID) : A single MID has been allocated to each country. A second MID can be assigned once the MID first or subsequently allocated is more than 80% exhausted and the rate of assignments is such that 90% exhaustion is foreseen. A MID always starts with a digit from 2 to 7.

4.1.3 Classes of Digital Selective Calling

The DSC protocol is defined by ITU-R (CCIR) Recommendation M.493-9. DSC operation is defined by ITU-R Recommendation M.541-8 [22].

Class A: All DSC options provided. Required on MF/HF radios used by SOLAS (Safety of Life at Sea) -regulated ships. Class A includes polling and vessel tracking, data and telex connection in addition to voice, and optional means for canceling a distress alert.

Class B: Required on VHF and MF radios used by SOLAS-regulated ships. Class B required capabilities include:

- Distress call
- All-ships call
- Individual station call
- Semi-automatic/automatic service call
- Use of distress, urgency, safety and routine priorities
- Nature of distress
- Distress coordinates
- Time for last (distress) position update
- Type of subsequent communications

- Distress relay
- Distress acknowledgment
- Test call (for MF/HF only)
- Radio frequency or channel
- Display
- Receive geographical area calls
- Alarm
- Optional means for canceling a distress alert

Class C: Only capable of transmitting a distress alert. No longer recognized by the ITU. The U.S. Coast Guard does NOT recommend purchase or use of a radio having this class of DSC.

Class D: Minimum DSC capability for VHF marine radios carried by recreational boaters, commercial fishing vessels, and other non-SOLAS regulated vessels. Class D required capabilities include:

- Distress call
- All-ships call
- Individual station call
- Use of distress, urgency, safety and routine priorities
- Nature of distress
- Distress coordinates
- Time for last (distress) position update
- Type of subsequent communications
- Radio VHF channel
- Display
- Receive distress relay and distress acknowledgment calls
- Alarm

Class E: Minimum DSC capability for HF marine radios carried by recreational boaters, commercial fishing vessels, and other non-SOLAS regulated vessels. Class E required capabilities include:

- Distress call
- All-ships call
- Individual station call
- Use of distress, urgency, safety and routine priorities
- Nature of distress
- Distress coordinates
- Time for last (distress) position update
- Type of subsequent communications
- Radio channel or frequency
- Display
- Receive distress relay and distress acknowledgment calls
- Alarm

Class F: VHF. Similar to Class D, but cannot make an individual or routine call, and does not require a display. Voice calls default to channel 16. Acceptable for VHF handhelds; not recommended for use in U.S. on other types of radios. Class F required capabilities include:

- Distress call
- All-ships call
- Use of distress, urgency, and safety priorities
- Distress coordinates
- Time for last (distress) position update
- Receive acknowledgment of its own distress calls

Class G: Similar to Class F, but applies to MF/HF. Voice calls default to 2182 kHz. Not recommended for use in U.S. Class G required capabilities include:

- Distress call
- All-ships call
- Use of distress, urgency, and safety priorities
- Distress coordinates
- Time for last (distress) position update
- Receive acknowledgment of its own distress calls

Recommended Minimum Standard for DSC, Version 1.0, 10 Aug 1995 applies to VHF and to MF/HF. Required capabilities include:

- Distress call
- All-ships call
- Individual station call
- Use of distress and routine priorities
- Use of safety priority (MF/HF only)
- Distress coordinates
- Time for last (distress) position update
- Acknowledgment or unable to comply response
- Receive distress relay and distress acknowledgment calls
- Receive Geographical area calls
- Test call (MF/HF only)
- Alarm

4.1.4 DSC Operational Procedures for Ships

The following procedures were adapted from the International Telecommunications Union, Radiocommunications Study Group Recommendation M.541 [23 - 24]. (Draft revision to Recommendation ITU-R M.541-7, dated 1 November 1996.)

4.1.4.1 Distress Case

Transmission of DSC distress alert: The DSC distress alert is transmitted as follows:

- Tune the transmitter to the DSC distress channel (2 187.5 kHz on MF, channel 70 on VHF)

- If time permits, key in or select on the DSC equipment keyboard, the nature of distress, the ship's last known position (latitude and longitude), the time (in UTC) the position was valid, type of subsequent distress communication (telephony), in accordance with the DSC equipment manufacturer's instructions;

- Transmit the DSC distress alert

- Prepare for the subsequent distress traffic by tuning the transmitter and the radiotelephony receiver to the distress traffic channel in the same band (i.e. 2 182 kHz on MF, channel 16 on VHF) while waiting for the DSC distress acknowledgment.

Reception of a distress alert : Acknowledgment of a DSC distress alert by use of DSC is normally made by coast stations only. Only if no other station seems to have received the DSC distress alert, and the transmission of the DSC distress alert continues, the ship should acknowledge the DSC distress alert by use of DSC to terminate the call. Additionally, the ship should then inform a coast station or a coast earth station . When ships receive a DSC distress alert from another ship they should:

- Watch for the reception of a distress acknowledgment on the distress channel (2187.5 kHz on MF and channel 70 on VHF);

- Prepare for receiving the subsequent distress communication by tuning the radiotelephony receiver to the distress traffic frequency in the same band in which the DSC distress alert was received, i.e. 2182 kHz on MF , channel 16 on VHF;

- Acknowledge the receipt of the distress alert by transmitting the following by radiotelephony on the distress traffic frequency in the same band in which the DSC distress alert was received, i.e. 2182 kHz on MF, channel 16 on VHF:
  - "MAYDAY",
  - the 9-digit identity of the ship (MMSI)in distress, repeated 3 times,
  - "this is",
  - the 9-digit identity (MMSI) or the call sign or other identification of own ship, repeated 3 times,
  - "RECEIVED MAYDAY".

Distress Traffic : When the ship which in distress receives a DSC distress acknowledgment, it should start the distress traffic by radiotelephony on the distress traffic frequency (2182 kHz on MF, channel 16 on VHF) as follows:

- "MAYDAY",
- "this is",
- the 9-digit identity (MMSI) and the call sign or other identification of the ship,
- the ship's position in latitude and longitude or other reference to a known geographical location,
- the nature of distress and assistance wanted,
- any other information which might facilitate the rescue.

Transmission of a DSC distress relay alert : When the ship knows that another ship is in distress, it should transmit a DSC distress relay alert only if the ship in distress is not itself able to transmit the distress alert or the Master of the ship considers that further help is necessary. The DSC distress relay alert is transmitted as follows:

- Tune the transmitter to the DSC distress channel (2187.5 kHz on MF, channel 70 on VHF),
- Select the distress relay call format on the DSC equipment, key in or select on the DSC equipment keyboard:

- all Ships Call or the 9-digit identity of the appropriate coast station,
- the 9-digit identity of the ship in distress, if known,
- the nature of distress,
- the latest position of the ship in distress, if known,
- the time (in UTC) the position was valid (if known),
- type of subsequent distress communication (telephony);
- transmit the DSC distress relay call,

- Prepare for the subsequent distress traffic by tuning the transmitter and the radiotelephony receiver to the distress traffic channel in the same band (2182 kHz on MF and channel 16 on VHF) while waiting for the DSC distress acknowledgment.

Receiption of distress relay alert : After having received DSC distress relay alert by the coast station it should be retransmitted the information received as a DSC distress relay call, addressed to all ships, all ships in a specific geographical area, a group of ships or a specific ship. When the ship receives a distress relay call which transmitted by a coast station, it should acknowledge the receipt of the call by radiotelephony on the distress traffic channel in the same band in which the relay call was received (i.e 2182 kHz on MF, channel 16 on VHF).

Acknowledge the receipt of the distress relay alert :

- "MAYDAY",
- the 9-digit identity or the call sign or other identification of the calling coast station,
- "this is",
- the 9-digit identity or call sign or other identification of own ship,
- "RECEIVED MAYDAY".

4.1.4.2 Urgency Case

Transmission of urgency message shall be carried out in two steps. One of them is announcement and the other is transmission.

Announcement :

- Tune the transmitter to the DSC distress calling channel (2 187.5 kHz on MF, channel 70 on VHF);
- Key in or select on the DSC equipment keyboard:
- All Ships Call or the 9-digit identity (MMSI) of the specific station,
- the category of the call (urgency),
- the frequency or channel on which the urgency message will be transmitted,
- the type of communication in which the urgency message will be given, in accordance with the DSC equipment manufacturer's instructions;
- Transmit the DSC urgency call.

Transmission :

- Tune the transmitter to the frequency or channel indicated in the DSC urgency call;
- Transmit the urgency message as follows:
  - "PAN PAN", repeated 3 times,
  - "ALL STATIONS" or called station, repeated 3 times,
  - "this is",
  - the 9-digit identity (MMSI) and the call sign or other identification of own ship,
  - the text of the urgency message

Reception of an urgency message : When the ship receives a DSC urgency call it should NOT acknowledge the receipt of the DSC call. But it should tune the radiotelephony receiver to the frequency indicated in the call and listen to the urgency message.

- the frequency or channel on which the safety message will be transmitted,
- the type of communication in which the safety message will be given

- Transmit the DSC safety call.

Transmission :

- Tune the transmitter to the frequency or channel indicated in the DSC safety call;
- Transmit the safety message as follows:
    - "SECURITE", repeated 3 times,
    - "ALL STATIONS" or called station, repeated 3 times,
    - "this is",
    - the 9-digit identity (MMSI) and the call sign or other identification of own ship,
    - the text of the safety message.

Reception of a safety message : When the ship receives a DSC urgency call it should NOT acknowledge the receipt of the DSC call. But it should tune the radiotelephony receiver to the frequency indicated in the call and listen to the urgency .

4.1.4.4 Public Correspondence Case

Transmission of a DSC call for public correspondence :

- Tune the transmitter to the relevant DSC channel;
- Select the format for calling a specific station on the DSC equipment;
- Key in or select on the DSC equipment keyboard:
  - the 9-digit identity of the station to be called,
  - the category of the call (routine),
  - the type of the subsequent communication (normally radiotelephony),
  - a proposed working channel if calling another ship.
- Transmit the DSC call.

If no acknowledgment is received within 5 min., the call may be repeated on the same or another DSC channel. If acknowledgment is still not received, further call attempts should be delayed at least 15 min.

Reception of call for public correspondence:

- Tune the transmitter to the transmit frequency of the DSC channel on which the call was received,
- Select the acknowledgment format on the DSC equipment,
- Transmit an acknowledgment indicating whether the ship is able to communicate as proposed in the call (type of. communication and working frequency),
- If able to communicate as indicated, tune the transmitter and the radiotelephony receiver to the indicated working channel and prepare to receive the traffic.

Reception of acknowledgment:

- Tune the transmitter and receiver to the indicated working channel;
- Commence the communication on the working channel by:
- The 9-digit identity or call sign or other identification of the called station,
- "this is",
- The 9-digit identity or call sign or other identification of own ship

4.1.5 Frequencies used for DSC

The frequencies used for distress and safety purposes using DSC are follows (Table 4.1) . [24]

Table4. 1 The frequencies used for distress and safety purposes

2187.5	kHz
4207.5	kHz
6312	kHz
8414.5	kHz
12577	kHz
16804.5	kHz
156525	kHz

Note 1: The frequency 156.525 MHz may also be used for DSC purposes other than distress and safety.

The frequencies used for purposes other than distress and safety purposes using DSC are follows (Table 4.2 and 4.3).

Table4. 2 Ship stations frequencies used for purpose other than distress and safety

458.5			kHz
2177	22189.5		kHz
4208	4208.5	4209	kHz
6312.5	6313	6315	kHz
8415	8415.5	8416	kHz
12577.5	12578	12578.5	kHz
16805	16805.5	16806	kHz
18898.5	18899	18899.5	kHz
22374.5	22375	22375.5	kHz
25208.5	25209	25209.5	kHz
		156525	kHz

Table4. 3 Coast stations frequencies used for purpose other than distress and safety

455.5			kHz
2177			kHz
4219.5	4220	4220.5	kHz
6331	6331.5	6332	kHz
8436.5	8437	8437.5	kHz
12657	12657.5	12658	kHz
16903	16903.5	16904	kHz
19703.5	19704	19704.5	kHz
22444	22444.5	22445	kHz
26121	26121.5	26122	kHz
		156525	kHz

4.1.6 Why DSC Background

On February 1, 1992, changes to the Safety of Life at Sea (SOLAS) Convention affecting distress and safety telecommunications came into effect. The SOLAS Convention is a treaty document which affects cargo, passenger and other ships on international voyages. The SOLAS Convention is both a national and international standard for maritime distress and safety telecommunications for all of the maritime community. According to these changes, ships will begin carrying VHF and MF/HF radios with digital selective calling (DSC) capable of initiating radiotelephone calls. DSC will be mandatory on board all ships of this type in 1999 [25].

This system will provides discontinue watchkeeping on VHF channel 16 and on 2182 kHz . When this occurs, non-SOLAS without DSC will be unable to contact a SOLAS vessel in a closing situation or other emergency in international waters. The Coast Guard currently responds to an average of 360 collision incidents between vessels each year. Average loss in a year is 12 lives and over $5 million [25]. Once existing radio watchkeeping rules are suspended in 1999, it is believed these collisions will likely increase unless DSC.

DSC also provides the opportunity for reducing or eliminating the congestion problem on VHF channel 16, alleviating hoax problems, more rapid receipt of a distress alert, and improved distress radio watchkeeping on VHF and MF/HF by Coast Guard stations. Further Reasons for DSC Requirement is for reasons of safety, to ensure maritime distress and safety communications remain interoperable among all vessels, as discussed earlier. As one form of Automatic Identification System (AIS), the FCC and Coast Guard have been developing a digital selective calling (DSC) system for marine frequencies for use in the Global Maritime Distress & Safety System. DSC could perform effectively either to enable identification of hoaxers or help establish legitimate distress calls.The identifying code of the transmitter used in a hoax call would be an extremely powerful piece of evidence in identifying and prosecuting violators.

DSC provides rapid receipt of distress alert. Additionally, it provides a preformatted distress alert which includes vessel identification, location and other vital information. Vessel location can be obtained automatically from GNSS system (i.e LORAN C, GPS…) or entered manually. This capability provides to send a complete MAYDAY message over radio immediately.

DSC significantly increases the probability that a call to the Coast Guard will be received. The FCC noted in their report on use of VHF Maritime Radio in Boston Harbor that "It was quite common to observe 400 calls being made per hour on Channel 16 in Boston Harbor during prime time on weekends" and stated calls were more than double that on some occasions. The Coast Guard providers watchkeeping over channel 16 twenty four hours/day through the U.S. National Distress System which is a network of over 300 transceivers with antennas located at high levels to ensure wide coverage, and remoted to one of 53 Coast Guard Group operations centers. The Coast Guard responds to over 26,000 such distress calls each year. The continued growth in the amount of traffic on channel 16 and the constantly increasing duties required of the Coast Guard Group watchstanders, makes their ability to acknowledge a distress call increasingly difficult. The same Coast Guard Group watchstanders who guard VHF channel 16 also guard the radiotelephone distress frequency 2182 kHz. Watchstanders at Coast Guard Communications Stations also guard several high frequency single sideband frequencies. These channels are noisy and difficult to guard, particularly if traffic on these channels are light. As a result, the quality of watchkeeping on these channels is not high. Unless a solution is found to each of these problems, an increasing number of distress calls will go unanswered, an intolerable situation.

Digital selective calling is capable to solve these problems. DSC can ensure nearby ships capable of assisting a distressed vessel receive the distress alert. The current maritime distress system consisting of ship and shore watchkeeping on the Morse code frequency 500 kHz and the voice frequencies of 2182 kHz and VHF channel 16 ensured that ships in the vicinity of a vessel in distress could receive the distress alert. In many cases these nearby vessels can arrive on scene to assist the vessel in distress much more quickly than can the Coast Guard. Cellular telephones and satellite communications do not have this capability. DSC improves the ability of the Coast Guard to contact ships in an emergency.

DSC technology is established in treaty and is recognized internationally. While other technology could conceivably be developed to resolve many of these same problems, both the International Telecommunications Union and International Maritime Organization, United nations organizations, selected DSC as the technology for this purpose after ten years of study.

4.2 DSC Transponder

Digital Selective Calling is a one form of automatic identification system (AIS). AIS is for use as navigation safety system. The new AIS is more of an information network. Its prime purpose is to provide those professional mariners with a tool to anticipate problems and take action before they become and. You see the AIS participants, know who they are, what is their cargo, width, draft, and other information important in keeping vessels apart. Shore users may have access to this information for many reasons, such as scheduling, messaging and other company business. Communications with other vessels and even calls placed through the phone system can be achieved. And the coast guard can still watch what is happening in the hands of the master or pilot in charge of the vessel's safe operation.

4.2.1 How does AIS System Operates

AIS is a system whereby mobile vessels are fitted with a "transponder" unit (automatic identification system shipboard equipment) which may be fixed or transportable (Figure 4.1). On a time schedule that is adjustable by the control station operator, the base station sends an electronic all ships call on channel 70. This call can be a general or geographic call. The base station requests automatic information from the mobile(s). The AIS computer will decide to enter the vessel into the system on a working channel or monitor the vessel on channel 70. Monitoring on channel 70 conforms to the current ITU-R recommendations and is only done if the mobile does not have the capability to work on an AIS channel or if the AIS channel is in operable.

The AIS base will assign a group number, sequence number and channel to the mobile. The mobile will switch to the AIS channel. At the appropriate time the AIS base will inform the mobile of data pertaining to all other mobiles in the system. Upon entry into the system, all mobiles are given information pertaining to the new vessels. As vessels move through locations near to or far from the transmitting tower, they can be automatically or manually shifted to or from low / high power. Up to 120 groups of up to 120 vessels in each group can be controlled by the AIS base [26]. The AIS operator can move vessels from one group to another, or change the group timing interval.

The AIS computer keeps track of the timing for all groups and the timing of vessels tracked on channel 70. At the appropriate time, the AIS base will initiate the sequence for vessels to report. The base is in repeater mode and rebroadcasts location, course and speed as the vessel is sending. In this way all vessels which are on the working channel can receive the pertinent information of all other vessels in the control area. If the AIS unit is interfaced with a computer with mapping, it will see also position of all other vessels. By this function, the system act as a collision avoidance tool.

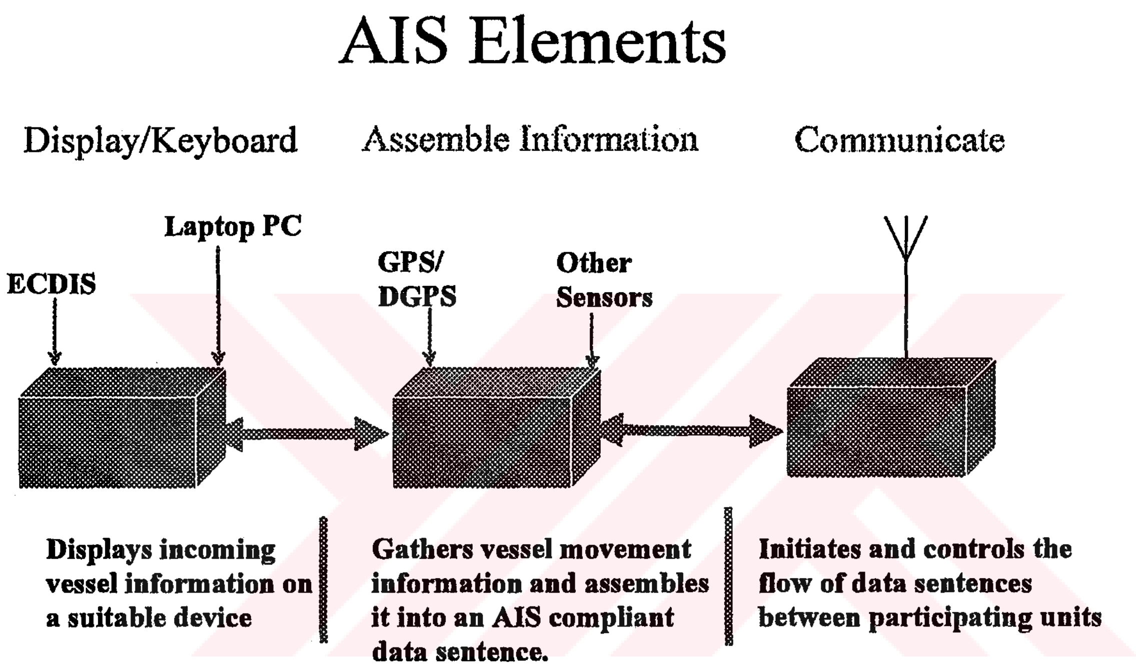

Figure 4. 1 AIS elements

Ship to shore, ship to ship and shore to ship messaging is accomplished by this system. An operator enters a free form text message. The AIS computer recognizes a request to send from its own operator or a mobile and handles the transmission in appropriate packet sizes and times. In this way, there is a minimal time burden to the location reporting process. All messages use the AIS tower. In this way if vessels are in the control area, they can receive and transmit messages to each other.

The AIS control site authorizes shore side users to view any part or all of the control area. But, this authorizing is not to control. Authorized users can see what the control operator is seeing. It can be provided by the "mirror" option. Additionally, they can zoom in or out on any part of the control area. From the shipboard side the computer screen has available electronic mapping information and the icons representing all participating traffic.

By loading route information to the AIS, the system shows the users position based on range line navigation and constant radius turns. In this way, important steering data for the pilot or master is obtained .

If a DSC distress is received from any vessel an audible and visual alarm is made. If the vessel is not in the system, it is automatically logged in and tracked on channel 70. An acknowledgment of the distress may be sent according to the ITU-R recommendation.

If no position report is received after 10 reporting cycles (means vessels not reporting to the AIS) from the vessel, it will be shown in black [26]. The color returns to normal case after resuming position report. When the vessels go out of range (beyond the control area), their icon will be removed from the screen and their data from the data displays. When the vessels which are out of range come in the control area, they will be logged back in on the next automatic all ships call.

The AIS center software is written to be able to control older versions of AIS. The AIS base station maintains a log of several weeks of operations depending on traffic loading and the operational needs of the traffic center. This log can be offloaded to other mediums and saved or replayed as needed. The system data can be made available for interface with other systems.

There are numerous options available to the AIS control station. "Ports" data may be added where is available. In this way, it is provided periodic updates of wind, tide, current and other valuable information for display on the AIS. Weather radar pictures may be added for periodic viewing on the AIS. Some stations are operated with their own DGPS reference station. This provides an all satellites in view update through the AIS working channel.

4.3 Test Results of DSC System

In 1991 the U.S. Coast Guard Research and Development was assigned the task of developing a satellite based surveillance system. The main aim of this system was to improve oil pollution prevention and the safety of vessel movement in coastal and inland waterway. The task was developed as a provision of the "Oil Pollution Research and Technology Plan" authored in 1990 by the U.S. Interagency Coordinating Committee on oil pollution research. The efforts by the R & D Center have focused on the use of state-of-the-art Global

Positioning System satellite technology commonly referred to as GPS, particularly on the use of the R & D Center developed differential GPS system or DGPS. DGPS allows a vessel's position to be fixed to within 10 m or less and also provides a very precise course and speed determination [27]. The use of DGPS has led to the development of a VTS technology known as ADS (Automated Dependent Surveillance) . The R&D Center has been studying the communications technologies necessary and commercially available to enable the flow of digital information from vessels underway to the shoreside VTC . The center examine and evaluate the similar technologies. End of this working it is decided to test three communication system [28].

- Advanced Mobile Phone Service (AMPS) Cellular
- VHF – FM Digital Selective Calling (DSC)
- Newcomb L-band satellite

In our study, we interest on Digital Selective Calling System. Because of this, only the test result of DSC sytem will be stated.

4.3.1 DSC Test Configuration

In order to test DSC, equipment needed to be installed both onboard vessels and at a shore location in the Narragansett Bay area [29]. The shore installation consisted of a computer with DSC card to control operations, a VHF-FM radio, an RF power amplifier (Figure 4.2). Additionally a Yagi antenna mounted on an existing tower. The shipboard equipment consisted of a DSC radio connected to a standard marine VHF-FM whip antenna (3 dB gain, omnidirectional). The same differential GPS system described above was used to provide Automated Dependent Surveillance (ADS) data to this communications system as well. VHF DSC radio communication subsytem :

- provides the requirement of draft recommendation ITU-R M.1084-2 .
- provides transceivers that are tunable over the VHF maritime radio frequency band (156 – 174 MHz) .
- provides continuous channel 70 monitoring.
- provides the capability for operator input of self identification data which is stored in the radio communication subsystem

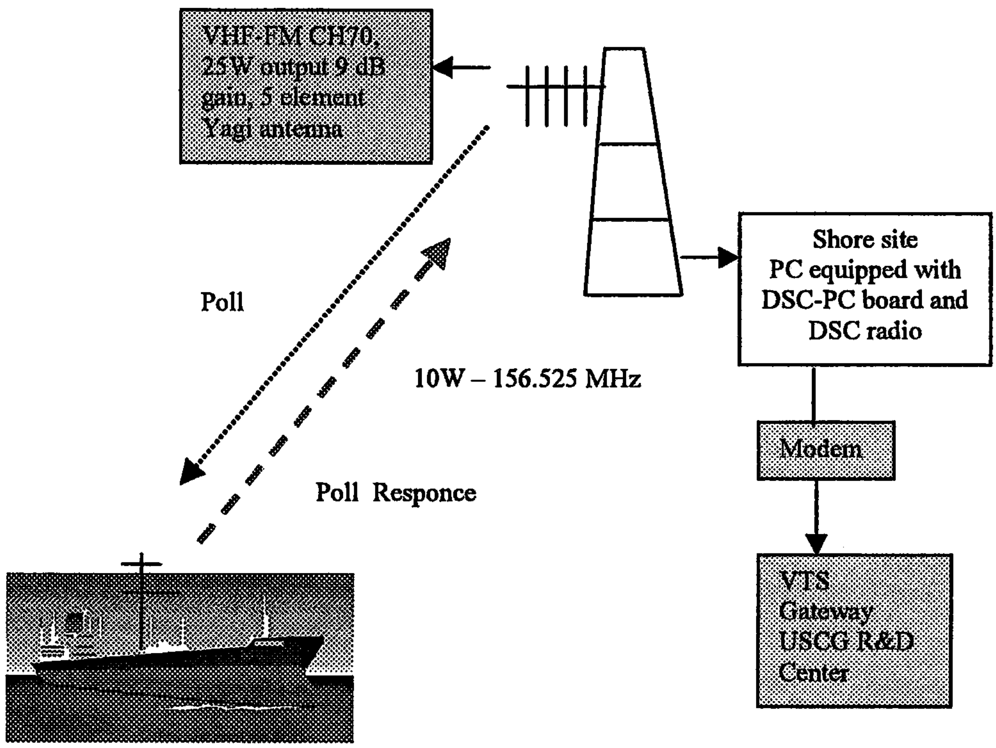

Figure 4. 2 DSC test configuration

4.3.2 Results of Testing

This part of our studying describes the results obtained with the shore facility installed in Newport, Rhode Island. Similiarly shore facilities were also installed in Groton, New York, Governos and Connecticut. The test were performed with the vessel Vista Jubilee and the USCG Cutter Towline. The test were scheduled around the standard operations of the Vista Jubilee. Additional experimentation was done by using the CGC Towline when operations of that vessel coincided with the Vista Jubilee schedule. The following tables (4.4 and 4.5) summarize the collected DSC data

Table 4. 4 Results from CGC Towline [29]

Date	Hours of Data	Total of Reports	Reports rcvd w/no Cse/Spd	Percent Incomplete Reports	# of Reports Missed	Percent Success	RSS MIN	RSS MAX
25-Aug	1.96	117	4	3.31 %	4	96.69 %	22	27
26-Aug	3.11	524	0	0.00 %	15	97.22 %	19	27
30-Aug	0.07	8	0	0.00 %	0	100 %	23	24
31-Aug	0.42	36	0	0.00 %	13	74.51 %	8	19
1-Sep	3.55	373	0	0.00 %	55	87.15 %	8	29
27-Sep	5.64	626	0	0.00 %	49	92.76 %	10	32
13-Oct	4.75	552	2	0.36 %	17	97.01 %	20	26
13-Dec	0.42	39	2	4.88 %	12	76.47 %	11	20
Overall	**19.92**	**2279**	**8**	**0.35 %**	**165**	**93.25 %**	**8**	**32**

Table 4. 5 Results from Vista Jubilee [29]

Date	Hours of Data	Total of Reports	Reports rcvd w/no Cse/Spd	Percent Incomplete Reports	# of Reports Missed	Percent Success	RSS MIN	RSS MAX
25-Aug	4.09	351	0	0.00 %	116	75.16 %	8	46
26-Aug	4.49	510	3	0.58 %	56	90.11 %	18	47
29-Aug	4.09	429	0	0.00 %	55	88.64 %	21	47
30-Aug	5.87	641	1	0.16 %	66	90.66 %	20	47
31-Aug	3.85	429	2	0.46 %	35	92.46 %	22	47
1-Sep	10.84	1203	0	0.00 %	55	95.63 %	20	47
2-Sep	3.70	404	0	0.00 %	40	90.99 %	23	47
7-Sep	4.05	429	3	0.69 %	58	88.09 %	16	47
11-Sep	2.04	241	37	13.31 %	4	98.37 %	20	46
15-Sep	3.01	333	35	19.51 %	29	91.99 %	19	23
16-Sep	8.71	845	102	10.77 %	78	91.55 %	15	47
20-Sep	6.38	661	80	10.80 %	91	87.90 %	21	47
27-Sep	5.68	649	63	8.85 %	32	95.30 %	19	23
28-Sep	3.58	413	43	9.43 %	17	96.05 %	18	47
29-Sep	5.66	741	132	15.12 %	65	91.94 %	17	47
7-Oct	4.01	452	61	15.20 %	31	93.58 %	15	47
8-Oct	3.95	450	63	12.28 %	25	94.74 %	15	47
12-Oct	4.28	469	52	9.98 %	44	91.42 %	15	47
13-Oct	5.28	619	97	13.55 %	12	98.10 %	17	47
13-dec	5.52	565	76	11.66 %	65	89.68 %	13	25
Overall	**99.06**	**10834**	**870**	**7.43 %**	**974**	**91.75 %**	**8**	**47**

a) Coverage Area:

A DSC coast station was established at the Castle Hill Coast Guard Station. A Yagi antenna which was used to transmit and also receive was mounted on an existing tower. The hight of the tower is about 110 feet above sea level. The Yagi antenna had a 60° horizontal beamwidth and 9 dB of gain. The direction of antenna was towards North. This setting provided good coverage of the area traversed by the Vista Jubilee. The DSC receiver at the coast station provided Relative Signal Strength (RSS) measurements. These measurements were included in the ADS report passed to the VTS Gateway.

All the DSC ADS reports received from the Vista Jubilee and the CGC Towline . For a given location, the RSS values from the CGC Towline were different from the Vista Jubilee based on the differences in the shipboard installation. This constant offset was calculated and used to adjust the CGC Towline values to match those of the Vista Jubilee. According the receiving values the RSS decreased when the vessels moved away from the Castle Hill station or when they moved outside the primary beamwidth of the antenna. The only place where the vessels could not be reliably tracked was in Providence harbor.

b) Reliability / Integrity:

It is clearly seen that the DSC system as a whole was very reliable according to the tables (4.4 and 4.5). The results in Tables (4.4) and (4.5) show that almost 92% of the reports were received from the Vista Jubilee and 93% were received from the CGC Towline. The missing reports were not result from DSC failure. On the contrary, missed report were primarily due to a problem with the coast station transmitter. It is founded that occasionally the coast station DSC board would "lock up." There was only way to determine that this "lock up" had occurred. It was that any reports can't be received from a local DSC transceiver. A process to monitor and correct this problem was automated. However, a complete polling cycle was lost each time a "lock up" occurred.

On 25 August, the poor performance was observed. The poor performance was due to a faulty antenna installation at Castle Hill. By replacing the antenna on the twenty-sixth, signals from the same geographic locations improved by 16 dB over their 25 August signals.

The result of observing poor performance of the Vista Jubilee on 13 December and CGC Towline on 31 August was that the vessels was operating for part of the time in fringe coverage areas (low RSS).

A more troubling problem is the lack of complete data reports. This was more evident in reports from the Vista Jubilee than from the CGC Towline. It is believed that this problem was with the specific DSC radio or installation onboard the Vista Jubilee. In fact, no correlation of incomplete reports to RSS or geographic position couldn't be found in the data. Why certain DSC radios sometimes fail to report complete data is still under investigation.

c) Reporting Interval / Latency:

The coast station software used for the Narragansett Bay testing polled all vessels under test at identical intervals. The reporting interval was choosed thirty second. The reason of this was to limit radio activity on GMDSS channel 70. The thirty second interval was judged to be long enough so as not to tie up the channel and short enough to allow adequate vessel tracking. This report interval was more appropriate to keep an accurate track of the vessels when it is combined with dead reckoning (DR) positions generated by the display system. It is observed that the DR positions were highly accurate when the position dynamics of the vessel changed slowly and DGPS provided very accurate course and speed over ground.

The latency of a DSC report was found to be about four seconds. This was due in large part to operating the DSC equipment in a poll-response mode. The times required for the coast station to transmit a poll and for the shipboard radio to transmit a response are shown in Table (4.6). All of the values were also measured experimentally using an oscilloscope. It can be clearly seen that measured values are quite close to calculated values.

The biggest single factor contributing to the time required for a complete poll-response cycle is a provision of the DSC protocol. DSC protocol requires a random 0–2 second delay prior to a poll response. This delay time was measured experimentally. The average value of this delay time was observed around of 1.55 seconds. On average, it is required 3.36 seconds plus processing overhead for a complete poll-response cycle. This limits a DSC coast station to about fifteen poll-response cycles per minute when using the channel 70 GMDSS frequency. In reality, it is not achievable because sometimes is required retransmission.

Table 4.6 Timing Calculations

	Individual Poll	**Poll Response**	**Notes**
Data Count to/from DSCPC Board	16 bytes	34 bytes	
Actual Data Bytes	15 bytes	33 bytes	
Header Info	14 bytes	14 bytes	Add in format(2), Orig. add (5), Freq info(6)
Total Msg Length	29 bytes	47 bytes	
10bits per symbol	290 bits	470 bit	
Each info symbol is transmitted twice	580 bits	940 bits	
Phasing Sequence(6DX, 8RX)	140 bits	140 bits	
EOS (3 DX, 1RX) plus cksum	120 bits	120 bits	Using expansion data so double
Dot Pattern	20 bits	20 bits	
Total bits to transmit	860 bits	1220 bits	
Transmit at	120 bps	1220 bits	
Transmit Time **Avg. Transmit Time**	**0.72 sec** **0.77 sec**	**1.02 sec** **1.04 sec**	**Calculated** **Measured**

d) Coast

It is difficult to assess the cost of a DSC ADS system. There is many factor effecting the cost of system. On the surface, it appears to be free. There is no cost for each transmission. On the other hand, the entire cost of installing and maintaining the system equipment must be recognized. The cost of items such as power, facilities, and spare equipment must be considered. Many of these costs would be dependent upon the geographic area being serviced. DSC capability could be added for minimal additional cost, if there was an existing VHF-FM network.

4.3.3 New York DSC Testing

During the Fall of 1995, additional DSC ADS testing was conducted in New York City. For DSC testing, two high-speed water taxis were outfitted with DSC ADS equipment. They made regular trips between New Jersey, Sandy Hook and lower Manhattan. A DSC coast station was established at the USCG VTS located on Governor's Island. In this station, an existing omni-directional antenna is used. The height of antenna is about 100 feet above sea level. Coverage from this antenna was adequate for the New York harbor area, but it did not reach Sandy Hook, New Jersey.

Using the additional VHF-FM channels increases DSC capacity. During the New York tests, a working channel of 157.175 MHz (channel 83A) was used. Initial DSC contact was made on channel 70 . Then the vessel's VHF radio was directed to shift to the working channel, 83A. Periodically, an "all-ships" DSC call would be made on channel 70 in order to pick up any new vessels. Using the working channel provides faster "poll-response cycle." Because a working channel is not used for distress calls, there is no requirement for a delay prior to a polled response being transmitted.

The radios used in these tests had the feature of no delay when it transmitted on a working channel. The delay between a poll being received and a response transmitted was measured experimentally using an oscilloscope. The average delay was approximately 0.2 seconds. Therefore a poll-response cycle would take approximately 2 seconds (on average). This value was approximately 4 seconds for channel 70 polling. It is clearly seen that using working channel increased channel capacity two hundred percent.

5. CONCLUSION

In this work data link technologies known as Automatic Identification Systems (AIS) that is used in aviation, maritime and land mobile application is introduced. It is clear that navigation information is the cornerstone of the surveillance or tracking. For this reason, navigation system is also included in this study. All of the navigation system is investigated based on the GPS (Global Positioning Service). There is no more difference already between GPS and the other navigation systems.

First part of this thesis is GPS. GPS provides two service: Standart Positioning Service (SPS) and the Precise Positioning Service (PPS). PPS is designated for U.S. authorized military and select government agency users. It provides an accuracy of at least 22 m in the horizontal plane and 27.7 m in the vertical plane. It also provides a UTC time transfer accuracy within 200 nsec. SPS is designated for all users wolrwide. SPS provides an accuracy of at least 100 m in the horizontal plane and 156 m in the vertical plane. It also provides UTC time transfer accuracy within 340 nsec. The similar system GLONASS is also provides civil and military service. For the civil application, positioning accuracy is 100 m in the horizontal plane, 150 m in the vertical plane. For the military application, positioning accuracy is 26 m in the horizontal plane and 45 m in the vertical plane. It can be clearly seen that this system can't be used effectively for the civil application because of the restriction. Altough, for many applications it's plenty accurate. But it's human nature to want more.

Some intelligence scientist developed the differential GPS (DGPS) which corrects the various inaccuracies in the GPS system, pushing its accuracy even further. Differential GPS can yield measurements good to a couple of meters in moving applications and even better in stationary situations. But it is not enough also for human. Now it is mentioned to a couple of centimeter. The new system is called 'carrier-phase GPS'. Now we remember that a GPS receiver determines the travel time of a signal from a satellite by comparing the "pseudo random code" it's generating with an identical code in the signal from the satellite. The receiver slides its code later and later in time until it syncs up with the satellite's code. The amount it has to slide the code is equal to the signal's travel time. The problem is that the bits (or cycles) of the pseudo random code are so wide that even if you do get synced up there's still plenty of slop. Using the GPS carrier frequency can significantly improve the accuracy of GPS. Survey receivers beat the system by starting with the pseudo random code and then move on to measurements based on the carrier frequency for that code. This carrier frequency is much higher so its pulses are much closer together and therefore more accurate.

And the other project is 'Augmented GPS'. The main goal of this system accrossing of DGPS accuracy to the whole USA country. May be to the whole world. In this system, additional satellite is used to relay differential corrections . It ensures that plenty of satellites are always visible around the country. This satellite could gather pretty good correction data for most of the country and transmit it to whole world. It might be possible in future using self-guided cars which could take us across town while we quietly slept in the back seat. It might reduce rate of accident on the road or motorway. We can send also our children to the school by this car. Or to shop, it would be enough to send this car to the shop. Who knows...

The second part of this work is surveillance system. Firstly, we studied Digital Selective Calling (DSC) system.We utilized the test results of the United States Coast Guard (USCG) Research and Development Department for the capability of DSC. USGC R&D department selected for test three communication system: Advanced Mobile Phone Service (AMPS) , DSC and Newcomb L-band Satellite system. I want to introduce the results of the three communication system.

According the test results DSC is a viable alternative for Automated Dependent Surveillance (ADS). The system reliability and integrity are very good. And the latency on the working channel is also good. Coverage area depends on geographic area. It might be needed more DSC sites in the complex area. And it increases cost of the system. DSC has a capacity problem. 15 DSC polls can be made and responded to per minute based on the DSC protocol. Capacity might be increased by using additional channels for DSC. One more advantage of this system is that there are no monthly or per charge for use regardless of traffic volume. And the shipboard equipment is small and inexpensive.

The other system, Newcomb L-band Satellite, is good candidate for ADS. The coverage and reliability is very good. And also integrity and latency is very good. It is easy to install Newcomb transponders on vessel. The system capacity is quite high. The reports can be received quickly and reporting interval is shorter due to high capacity of the system. But the cost of the shipboard equipment is still fairly expensive.

The last of three is Advanced Mobile Phone Service (AMPS). It is not an economic ADS system. And maintaining the connection continuously is more complex. On the positive side, the cellular connection is the most reliable. The analog service of AMPS has been updated with Digital-AMPS. D-AMPS adds time division multiple access (TDMA) to AMPS to get three channels for each AMPS channel, tripling the number of calls that can be handled on a channel. D-AMPS uses frequency ranges within the 800 and 900 MHz spectrum like AMPS. Although AMPS and D-AMPS originated for the North American cellular telephone market, they are now used worldwide with over 74 million subscribers, according to Ericsson.

The other surveillance system is Self Organized Time Division Multiple Access (STDMA) which is studied in this work. In STDMA, transmissions are normally in broadcast and autonomous mode. That means transmission can be monitored by the all the ships or shore stations within the VHF radio range. The capacity of STDMA is very high. More than 2000 position reports in minute can be transmitted on a single radio channel which is 25 kHz. Each reports obtains identity, position, altitude, speed… In STDMA, the data link can be shared among a large number of stations. The system provides minimizing of the transmission conflicts. And also, there is no need master or control station. STDMA system is capable handling overload case and constantly changing population of participating stations. The VHF cell are primarily restricted by line-of-sight. But the effective limitation for radius of each station is traffic density. The cell radius will gracefully reduce with an increasing traffic. For this reason, when creating a ground infrastructure, the traffic density and geography should be considered. The STDMA algorithm cooperates with strong discrimination to provide a protected zone, ensuring slot integrity and safe delivery of time critical informaton, close to each individual station. The U.S. Air Force already is using this system on its giant Lockheed C-5 Galaxy transport aircraft flying close formation day, night or in adverse weather to provide highly accurate aerial cargo delivery. It observed that the system's real-time navigation accuracy is down to 1 meter with the location of each aircraft using GP&C displayed in the cockpit of every user via data link. It seems that STDMA is more useful system for surveillance and tracking purpose with its these feature.

Finally, Iridum ,the favourite system of last years, comes. Iridium is a global wireless telephone service. The Iridium system is the first low-Earth-orbiting system for wireless telephone service with its 66 satellites forming a cross-linked grid above the earth. All of the satellite is on the 780 km above Earth. It provides two major advantage. One of them is that they can easily receive the signals of handled device, and the other that they act like cellular towers in the sky. Iridium aeronautical service provide essential voice, facsimile and data service. The Iridium system employs a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA) signals multiplexing to make the most efficient use of limited spectrum. The L-Band (1616-1626.5 MHz)is used for the link between the satellite and Iridium subscriber equipment. The Ka-Band (19.4-19.6 GHz for downlinks; 29.1-29.3 GHz for uplinks) is used for the link between the satellite and the gateways and earth terminals.

System Control, in northern Virginia, USA, serves as the central management component for the Iridium system. Additionally, three Telemetry, Tracking, and Control Centers (TTACs) are linked directly with the Satellite and Network Operations Center. TTAC facilities communicate with the satellite network to regulate the positioning of satellites during launch placement and subsequent orbit. These centers is located in Hawaii and Canada. Iridium gateways interconnect the Iridium constellation with public switched telephone networks. It makes communication possible between Iridium phones and any other telephone in the world. Gateways are owned and operated by Iridium LLC investors.

Iridium means that your calls is directly routed to Iridium satellite and is relayed from one satellite to another satellite until it reach to the required area and then it will be relayed back to the earth. It sounds nice. It is not matter if there is a facility closed to you or you have been in complex area where includes lots of geographical obstacle. Because we know that satellites always see us and we can reach them as soon as possible and send the information to the anywhere in the world. It seems that it can be most useful surveillance system and it will be. Iridium, Motorola-led satellite phone consortium has announced the first commercial call on its network has been completed at 28 may 1998 and the potential competitors of Motorola such as Globalstar and ICO will start similar service. When the competing services began, Iridium second generation project will be ready for deployment.I think we will have more and more satellite.

REFERENCES

[1] **Kaplan, Elliot D.,** "Understanding GPS Principles and Applications" , Artech House Publishers, Boston, 1996

[2] **Parkinson, B.,** " A History of satellite Navigation," NAVIGATION : Journal of navigation, Vol. 42, No. 1, Spring 1995, pp. 109 – 164.

[3] **GPS Joint Program Office,** NAVSTAR GPS User Equipment Introduction, Public Release Version, Feb. 1991.

[4] **Department of Defense/Department of Transportation,** 1994 Federal Radionavigation Plan, Springfield, VA, National Technical Information Service, May 1995

[5] **Doucet, K., and Y. Georgiadou,** "The Issue of Selective Availability," GPS World Magazine, Sept. / Oct. 1990 pp. 53-56

[6] **Navstar GPS Joint Program Office (JPO),** GPS Navstar User's overview, YEE-82-009D, GPS JPO, March 1991.

[7] **ANSER,** Russia's Global Navigation Sateiilte System, Contract Number F33657-90-D-0096, Arlington, Virginia, May 1994.

[8] **Bates, R.,** et al., Fundamentals of Astrodynsmics, Newyork, NY: Dover Publications, Inc., 1971.

[9] **Scadera, M. P.,** "The Navstar GPS Master Control Station's Kalman Filter Experience," Flight Mechanics Estimation Theory Symposium 1990, NASA Conference Proceedings CP3102, 1991.

[10] **Braasch, M. S.,** "Optimum Antenna Design for DGPS Ground Reference Station," Proc. Of ION GPS-94, Seventh International Meeting of the Satellite Division of the Institute of Navigation, Sept. 20-23, 1994, pp. 1291-1297.

[11] **DOD,** NAVSTAR GPS User Equipment Introduction (Public Release Version), GPS Joint Program Office, Feb. 1991.

[12] http://www.utexas.edu/depts/grg/craft/notes/gps

[13] **The Swedish Civil Aviation Administration-LFV. 1995,** Cellular CNS Concept-Discrimination of Weaker Signal using STDMA VHF/GMSK, The Swedish Civil Aviation Administration.

[14] **Kjellberg R.,** "Capacity and Throughput using a STDMA VHF Data link in surveillance application" Master Thesis, Stockholm , Sweden, April 1998.

[15] **Dreier, L.,** GP&C Sweden AB, 1997, Requirement Specification for Transponder R3, GP&C Sweden AB.

[16] **Johnson, L.,** 1996, Comparison of Capacity and Robustness for GMSK and D8PSK Modulation, Aeronautical Mobile Communications Panel – AMCP, Agenda ITEM 3, Jan 15-24 1996

[17] **Maral, G., Bousquet, M.,** 1986, Satellite Communications Systems, John Wiley & Sons Ltd

[18] http://www.ssc.se/ssd/gps/general.html

[19] http://www.gpcsweden.com

[20] http://www.navcen.uscg.mil/marcomms/gmdss/dscworks.htm

[21] http://www.navcen.uscg.mil.marcomms

[22] http://www.navcen.uscg.mil/marcomms/gmdss/dsc.htm

[23] http://www.navcen.uscg.mil/marcomms/gmdss/dscproc.htm

[24] **Draft Revision Of Recommendation ITU-R M.541-7** "Operational Procedures for the use of DSC" , 1Nov 1996.

[25] **Commandant (G-TTM) U.S. Coast Guard,** Washington DC 20593, " Why Digital Selective Calling Background", 4 December 1995

[26] http://www.rossdsc.com/ais.htm "Ross Engineering AIS Operating Review"

[27] **Alsip, D. H., Butler , J. M., and Radice, J.T.,** "Implementation of the U.S. Coast Guard's Differential GPS Navigation Service", U. S. Headquarters Office of Navigation Safety and Waterways Services Report, June 28, 1993

[28] **Gregory, Lt., Johnson, W., Pietraszewski D.,** " Results of ADS Communication Testing", Presented at Oceans 96 MTS/IEEE, Fort Lauderdale Conference Record pp 95-104, 1996.

[29] **Gregory Lt., Johnson, W.,** "Communication Technologies for Automated Dependent Surveillance", Presented at MILCOM 95, Conference Record pp 40-44, San Diego, 6 Nov 1995.

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