Master of Science in Internetworking

Capstone Project Proposal

On

An Analysis of the Security of the Global Positioning System (GPS) and Proposed Solutions

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1 Abstract

The Global Position System (GPS) does ensure that we get different services, including weather, time, and location. The global position System is widely used as it provides services to consumer applications and the commercial military. As GPS users, we are privileged to understand and know our current location, precise time, and velocity. The global position system has proved more effective and practical than traditional positionings such as radio-based devices, clocks, and magnetic compasses. In the world, it is estimated that the Global position system does comprise 24 satellites in total.

We have three satellites used as spares, ensuring 21 satellites are active in practice. The three reserves are about ten thousand six miles above the earth's surface. Ground-based GPS receivers are equipped with computers that can triangulate their sense after receiving bearings from the other three of the four GPS satellites on the same horizon. Space, control, and user segments are the categories under which GPS segments are divided.

The global position has specific functions that it provides to users worldwide. The GPS provides a collection of purposes at sea, on land, and even in the air. The GPS's different characteristics that make it effective and efficient include ensuring a supply of high positioning accuracies. Secondly, GPS allows users to determine accurate velocity and time at any moment of need (Lombardi, 2021).

GPS has been signaled in all parts of the world, ensuring that all users can easily connect and have adequate services. Moreover, the services offered are free of charge, and to make it resourceful enough, they are of all-weather service providence. However, we have some challenges in that users need help to work with GPS despite its many advantages. Most of the difficulties include errors, for instance, inaccuracies related to the conveyed location of satellites. We refer to the errors as orbital errors. Other mistakes have signal multipath, quite a percentage of visible satellites, and receiver clock errors.

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1 Introduction

1.1 The Global Positioning System

The Global Positioning System (GPS) may be divided into three categories: the user, the space, and the control. Many distinct satellites—24 in total—carry atomic clocks as their primary payload in this space section. The satellites are the spare timepieces and satellites in the space sector. Four or more satellites are virtually always visible from every position on Earth because of the dispersion of the six orbital planes' worth of satellites; each inclined at 55 degrees relative to the equatorial plane.

Each satellite has a clock that it uses to send out timing signals. These may be thought of as locations and transmission times in spacetime sequences. Below, I will go through the frame of reference for the spacetime coordinates supplied in messages related to transmission events. The communications include an almanac for the whole satellite constellation, information on the status of satellite vehicles, and data that may be used to determine UTC(USNO) (Universal Coordinated Time, as recorded by the United States Naval Observatory) (Larson, 2019).

Ground-based monitoring systems are included in another section called "Control." To process information received from satellites, stations are put in place. As soon as data is collected, it is sent to a Master station in Colorado Springs. For this reason, the analysis is performed, forecasting the clock and satellite ephemerides' behavior.

The data is projected, analyzed, and sent to the satellites for storage and rebroadcast. More importantly, The User Segment includes everyone who can utilize satellite signals to determine their location, speed, and local time. As the United States Department of Defense (DoD) administers the GPS navigation and timing system, it contains sensitive information in several places. To keep an eye on GPS transmissions, many government agencies are responsible.

On top of that, they keep an eye on the GPS signals to ensure accurate timekeeping and satellite ephemerides are always available. The two groups are entirely separate from one another. Typically, the accuracy will fall anywhere between 5 and 10 cm. Typically, measurements of transmitted signals' carrier phase are accurate to within a millimeter.

Two carrier frequencies, L1 (154.1023 MHz) and L2 (1575.52 MHz) are used by GPS signals to locate satellites in space (120 10.23 MHz). The L1 carrier is modulated using two pseudorandom noise codes: the course/acquisition or C/A-code at 1.023 MHz and the encrypted P-code at 10.23 MHz.

While civilian users are limited to the C/A code, military users can access the more advanced P-code receivers with automatic ionospheric delay correction and access to both L1 and L2 frequencies. Therefore, there are two tiers of real-time positioning services: the Precise Positioning Service (using P-code) and the Standard Positioning Service (only using C/A-code).

Due to the Department of Defense's ability to dither the broadcast signal frequencies and other signal properties, the placement accuracy of C/A-code users would be restricted to roughly 100 meters. SA, or Selective Availability, describes this circumstance. In May of 2000, President Clinton signed an executive order to terminate SA.

The technology foundation of GPS is atomic clocks, which are very accurate and trustworthy. As shown in Figure 1, the Allan deviation of a high-performance Cesium clock is plotted against sample time. The Allan deviation is the root-mean-square fractional frequency difference between clocks in a synchronized ensemble due to the clocks' internal noise processes. Frequency offsets and drifts are two additional systematic effects that must be accounted for separately.

Figure 1 also depicts an Allan deviation plot for a Quartz oscillator, which may be found in GPS receivers. Short-term stability performance qualities are usually better for quartz oscillators, but cesium clocks have a performance advantage in the first 100 seconds. There is much variation around the nominal values shown in the actual watches in Figure 1.

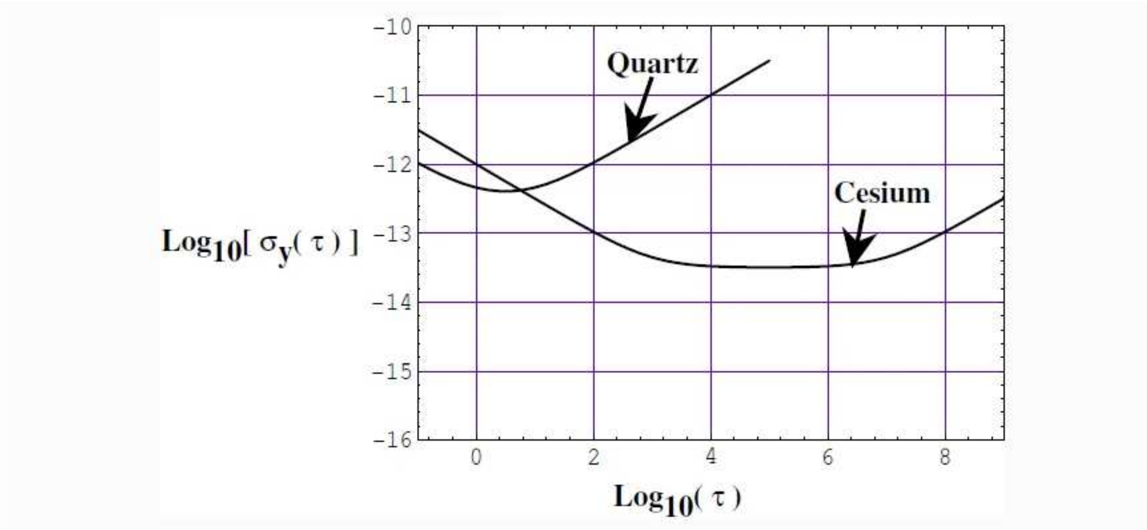

Figure 1: Cesium clock and quartz oscillator typical Allan deviations plotted.

Source:www.researchgate.net/figure/Typical-Allan-deviations-of-Cesium-clocks-and-quartz-oscillators-plotted-as-a-function_fig1_348735509

Furthermore, the Cesium figure indicates the most accurate GPS orbiting clocks. After being set and left alone for a day, a Cesium clock's accuracy should be within around five parts in 1014 or four nanoseconds. Impacts caused by the relativity are substantial in comparison. The primary goal of this work is to explain the relativistic implications of GPS and how such effects may be controlled and accounted for.

In addition, we need to learn about the difficulties people have while using GPS. Numerous applications of relativity's fundamental concepts may be seen in the Global Positioning System. These should be investigated thoroughly. Experimental tests of relativity using GPS are possible, albeit they are only sometimes more exact than prior experiments.

1.2 Development

The military created the global positioning system in the United States of America. In the 1960s, the first development began, and we experienced the innovation of our first satellite in February 1978. In 1989 we had our first hand-held receiver in the United States, which Magellan Corp incorporated. The American government, headed by president Ronald Reagan, allowed American citizens to use the GPS for free.

The president's contribution showed that the federal government is to enable citizens to use GPS technology free of charge all around the globe for peaceful purposes. There have been several developments to the GPS since its deployment stage, which have led to its improvement and performance.

The different improved activities include new signals for civil usage and sufficient accuracy when using the technology. For years, the US Department of Defense has been working on the modernization of the satellite system to meet the demands of the military, the market, and people around the globe.

We have experienced tremendous growth in GPS technology from the year 2015. We have observed that the High-quality Standard Positioning Service (SPS) GPS receivers with FAA certification offer horizontal accuracy of greater than 3.5 meters as of early 2015 (GPS Precision, 2015), while several variables, including receiver quality and atmospheric conditions, can alter this accuracy. The global position system is operated and owned by the government of the United States as a national resource.

Figure 2: Maps Produced from a GPS Receiver

Source: www.expertgps.com/screenshots.asp

Over the past several decades, the GPS has continued to evolve and improve. The system has undergone significant upgrades, including new satellites and improved ground-based control systems.

One significant upgrade to the GPS was developing the Selective Availability (SA) system in the 1990s. The SA system intentionally degraded the accuracy of the GPS signals available to civilian users to prevent the system from being used for military purposes. In 2000, the US government discontinued the SA system, allowing civilian users to access the complete accuracy of the GPS signals.

Another significant upgrade to the GPS was the Wide Area Augmentation System (WAAS) development in the early 2000s. The WAAS system uses a network of ground-based reference stations and geostationary satellites to improve accuracy and reliability for GPS users in North America.

GPS has continued to evolve in recent years with the development of new technologies and applications. This includes the development of new satellite constellations, such as the European Galileo system and the Chinese BeiDou system, which provide additional global navigation options for users.

1.3 System Description

The Global Positioning System (GPS) is a space-based global navigational system that provides location and time information in all weather conditions, anywhere on or near the Earth, with an unobstructed line of sight to four or more GPS satellites. GPS is a network of satellites and receivers designed to provide accurate global positioning, navigation, and timing information.

GPS is used in various applications, including transportation, recreation, land surveys, emergency services, and military operations. GPS satellites are placed in six orbital planes around the Earth at an altitude of 20,200 km, each containing four satellites. The satellites are in continuous motion, orbiting the Earth every 12 hours. The GPS constellation is managed by the US Air Force and is monitored and maintained 24 hours a day.

GPS satellites broadcast signals picked up by GPS receivers, which use the signals to calculate their exact position on the Earth's surface. The GPS receiver uses trilateration to calculate its position by measuring the distance to three or more satellites. The space is calculated by measuring the time the signal travels from the satellite to the receiver. GPS receivers come in various sizes and shapes, from hand-held devices to car navigation systems.

GPS receivers can be used in various ways, such as tracking the movements of people, vehicles, or animals or determining the location of a remote object or person. GPS receivers can also choose an aircraft's altitude or a vehicle's speed. GPS receivers are also used in many scientific and engineering applications, such as surveying, navigation, and oceanography.

GPS receivers can also be used in military operations, such as air and ground navigation, to identify targets and to provide precise timing signals. GPS receivers, such as the Global Maritime Distress and Safety System (GMDSS), are essential to many navigation systems. The GMDSS is a worldwide emergency communications system that is used in the event of an emergency.

GPS receivers are also used in air traffic control systems to assist in air traffic control decisions. It has been asserted by Collins, Lichtenegger, and Hoffman-Wellenhof (2001). GPS comprises three "segments," or components: Now, 28 satellites circle the planet at an average distance of 11,000 nautical miles. Receivers for vehicle use and personal usage are available in the user area. To keep tabs on the health of the satellites, a control section made up of five locations on the ground worldwide is in place.

The GPS consists of three main components: the space segment, the control segment, and the user segment.

1.3.1 Space Segment

The space segment consists of a constellation of 24 GPS satellites orbiting the Earth at an altitude of about 20,000 km. The GPS satellites are arranged in six orbital planes, with four satellites in each. The satellites orbit the Earth twice daily, providing continuous coverage of the Earth's surface.

Each GPS satellite transmits two signals: the L1 signal at a frequency of 1575.42 MHz and the L2 signal at 1227.60 MHz. The L1 signal is used for civilian applications, while the L2 is used for military applications.

1.3.2 Control Segment

The control segment consists of a network of ground-based monitoring stations and a Master Control Station (MCS) located at Schriever Air Force Base in Colorado. The ground-based monitoring stations track the GPS satellites and collect data on their orbits, clock errors, and signal quality.

The data collected by the ground-based monitoring stations is transmitted to the MCS, which uses it to calculate corrections that are sent back to the GPS satellites. The corrections adjust the satellite orbits and clock errors, ensuring the GPS remains accurate and reliable.

1.3.3 User Segment

The user segment consists of GPS receivers that individuals, organizations, and governments use to determine their location and time. GPS receivers work by receiving signals from multiple GPS satellites and using the signals to calculate their position on the Earth's surface.

GPS receivers use a process called trilateration to determine their position. Trilateration involves measuring the distance between the GPS receiver and at least three GPS satellites. By knowing the length of three or more GPS satellites and their exact positions in space, the GPS receiver can calculate its position on the Earth's surface.

GPS receivers can provide accurate positioning information anywhere on or near the Earth if they have an unobstructed view of the sky and can receive signals from at least four GPS satellites.

In conclusion, The GPS is a complex network of satellites, ground-based monitoring stations, and receivers that work together to provide accurate and reliable location and timing information anywhere on or near the Earth. The GPS system is valuable in many areas, including navigation, surveying, tracking, and logistics.

2 Types of GPS

We have different receivers that various organizations in the United States produce. The receivers have other functions according to the available software installed unto them. In most cases, the software can be purchased online or downloaded online. When the proper software is used, one type of receiver can scan maps (Fig. 1.3), and if a GPS is connected, it can directly create trails on the map and send them to the GPS (Zheng & Yangjun 2019). The Global Positioning System (GPS) is a satellite-based navigation system for locating objects and measuring distances.

It is a satellite network that sends signals to receivers on the ground. The receivers use these signals to calculate their exact locations. GPS is used in many military, aviation, marine, and consumer applications. GPS technology has changed the way people interact with the world. It has enabled people to navigate more accurately and efficiently and to access location-based services such as maps, directions, and traffic information.

GPS is available in several different types of devices. The handheld device is the most common type of GPS, typically used for consumer applications. Handheld GPS devices are small, portable, and easy to use. They can be used for navigation, tracking, and location-based services. Other types of GPS technology include vehicle tracking systems, fleet management systems, and marine navigation systems. GPS is also available in wearable devices like fitness trackers and smartwatches. Wearable GPS devices are small and unobtrusive and can track activity levels; distances traveled, and other health-related data.

GPS is also used in a variety of commercial applications. Businesses use GPS to track fleets of vehicles and manage their employees' time and attendance. GPS is also used in asset tracking to track the location and movement of expensive equipment. In agriculture, GPS is used to improve crop yield and reduce the need for manual labor. GPS can be used for geospatial analysis, analyzing, and interpreting data about the Earth's surface. Geospatial analysis is used in many fields, including urban planning, public safety, and natural resource management. GPS is also used in scientific research to study the movement of wildlife and the effects of climate change.

2.1 Overview of the different types of GPS systems

2.1.1 Automotive GPS

Automotive GPS systems are devices designed for use in cars and other vehicles. These systems provide drivers with real-time directions, traffic updates, and other features that help make driving more efficient and safe.

Automotive GPS systems typically come with pre-installed maps that can be updated periodically. They use GPS signals to determine the vehicle's location and provide turn-by-turn directions to the destination. These systems also provide information on estimated arrival time, distance to the goal, and upcoming points of interest (POIs) such as gas stations and restaurants.

One of the key features of automotive GPS systems is real-time traffic updates. These systems can access traffic data and provide alternate routes to avoid congestion and reduce travel time. They can also provide alerts for road closures, accidents, and other hazards affecting the route.

Another essential feature of automotive GPS systems is voice guidance. These systems provide spoken directions to the driver, allowing them to keep their eyes on the road. Some systems also provide visual cues on the dashboard display or windshield, using augmented reality (AR) technology.

Automotive GPS systems can also provide information on nearby POIs, such as gas stations, restaurants, and hotels. They can also provide information on points of interest along the route, such as scenic vistas and historical landmarks.

Examples of popular automotive GPS systems include Garmin, TomTom, and Magellan.

2.1.2 Outdoor GPS

Outdoor GPS systems are designed for outdoor activities such as hiking, camping, and hunting. These systems provide features such as topographic maps, trail routing, and waypoints to help users navigate through wilderness areas. Outdoor GPS systems are typically rugged and waterproof, designed to withstand harsh weather conditions and rough handling. They use GPS signals to determine the user's location and provide real-time information on their position, altitude, and heading. Some systems also provide barometric altimeters and compass sensors for improved accuracy and reliability.

One of the critical features of outdoor GPS systems is topographic mapping. These systems provide detailed terrain maps, including contours, elevation, and vegetation. They can also provide information on trails, campgrounds, and other areas of interest (POIs). Some systems allow users to download additional maps and data, including satellite imagery and aerial photographs.

Another important feature of outdoor GPS systems is trail routing. These systems can help users plan and follow a route through the wilderness, including waypoints and landmarks. They can also provide information on each route segment's distance, elevation gain, and estimated arrival time.

Outdoor GPS systems can also provide information on weather conditions and other hazards. They can access real-time weather data and provide alerts for thunderstorms, high winds, and other threats affecting the user's safety. Some systems also provide information on wildlife activity, avalanche risk, and other environmental factors that may impact the trip. Examples of popular outdoor GPS systems include Garmin GPSMAP and Magellan eXplorist.

2.1.3 Wearable GPS

Wearable GPS devices are compact, lightweight devices that track users' location, speed, and other fitness-related data during physical activity. They are commonly used by athletes, hikers, and other outdoor enthusiasts who want to monitor their progress and track their performance.

Wearable devices use GPS technology to provide accurate and real-time information on the user's location, speed, and other fitness-related data. They can be worn on the wrist, attached to clothing, or carried in a pocket. These devices can track various metrics, including distance, speed, elevation, heart rate, and calories burned.

One of the critical features of wearable GPS devices is the ability to sync with mobile devices and other fitness apps. This allows users to track their progress and set goals for themselves. Many wearable GPS devices also offer social features enabling users to connect with other athletes and share their progress.

Another essential feature of wearable GPS devices is the ability to provide audible and visual feedback to the user. This feedback can help users stay motivated and on track during their workouts. Some devices even offer coaching features that provide personalized training plans and recommendations based on the user's performance.

Wearable GPS devices are also designed to be durable and weather-resistant. They are often waterproof and can withstand rain, sweat, and other moisture exposure. This makes them ideal for outdoor activities, including running, hiking, and cycling.

In summary, wearable GPS devices are potent tools for athletes and outdoor enthusiasts, providing accurate and real-time information on location, speed, and other fitness-related data. They offer a variety of features designed to help users track their progress, stay motivated, and achieve their fitness goals.

Examples of popular wearable GPS systems include Garmin Forerunner and Apple Watch.

2.1.4 Aviation GPS

Aviation GPS (Global Positioning System) is a sophisticated navigation system used in aircraft for accurate and precise navigation, guidance, and communication. Aviation GPS systems are designed to meet the unique needs of aviation, including the high-speed and high-altitude requirements of aircraft.

Aviation GPS systems use the same GPS technology as automotive and outdoor GPS systems but with additional features designed specifically for aviation. These systems provide accurate and real-time information on the aircraft's position, altitude, speed, and heading. They also provide information on other nearby planes, weather conditions, and airspace restrictions.

One of the critical features of aviation GPS systems is the ability to display navigational charts and maps. These systems provide pilots detailed information on airports, runways, and other points of interest (POIs). They can also show air traffic control (ATC) clearances, including route instructions, altitude restrictions, and approach procedures.

Another essential feature of aviation GPS systems is the ability to provide real-time weather data. These systems can access weather information from sources such as the National Oceanic and Atmospheric Administration (NOAA) and give the pilots current and forecasted weather conditions for their route. This information can help pilots make informed decisions regarding flight planning, routing, and safety.

Aviation GPS systems also provide features such as terrain mapping and obstacle avoidance. These systems can display terrain elevations, obstructions, and other hazards that may pose a risk to the aircraft. They can also provide audible and visual alerts to warn pilots of potential hazards and help them avoid collisions.

GPS systems are essential for modern aviation, providing accurate and reliable navigation assistance in all weather conditions and environments. They can help pilots plan and execute safe and efficient flights while enhancing the aviation system's safety and reliability.

Examples of popular aviation GPS systems include Garmin GNS and BendixKing KLN.

2.1.5 Marine GPS

Marine GPS (Global Positioning System) is a navigation system designed for use on boats and other watercraft. Marine GPS systems are designed to provide accurate and reliable navigation assistance in the challenging and ever-changing marine environment. This report will provide more detail about marine GPS systems and their features.

Marine GPS systems use the same GPS technology as other GPS systems but with additional features designed for the marine environment. These systems provide accurate and real-time information on the boat's position, speed, heading, and course. They also provide information on other vessels in the area, weather conditions, and marine hazards such as rocks, shoals, and buoys.

One of the critical features of marine GPS systems is the ability to display nautical charts and maps. These systems provide boaters with detailed information on water depths, channel markers, and other points of interest (POIs). They can also display information on tide levels, currents, and other environmental factors that may impact the boat's course.

Another essential feature of marine GPS systems is the ability to provide real-time weather data. These systems can access weather information from sources such as the National Oceanic and Atmospheric Administration (NOAA) and give the boaters current and forecasted weather conditions for their route. This information can help boaters make informed course, speed, and safety decisions.

Marine GPS systems also provide features such as waypoint marking and route planning. These systems allow boaters to mark their favorite fishing spots, anchorages, and POIs and create custom trip routes. They can also provide audible and visual alerts to warn boaters of potential hazards and help them avoid collisions.

Marine GPS systems are essential for boaters, providing accurate and reliable navigation assistance in all weather conditions and environments. They can help boaters plan and execute safe and efficient trips while enhancing the marine system's overall safety and reliability.

Examples of popular marine GPS systems include Garmin GPSMAP and Raymarine Dragonfly.

Finally, GPS is available in a variety of military applications. Military personnel uses GPS to navigate, track targets, and coordinate military operations. GPS can also be used in weapons systems to guide missiles and other weapons to their targets. GPS is an invaluable tool for navigation and location-based services. It has revolutionized how people interact with the world and continues to be used in various applications. Whether you are using it for personal navigation or military operations, GPS is an essential technology that is here to stay.

Figure 3:Types of GPS

Source: www.garmin.com/en-US/p/87768

3 Accuracy

According to information from GPS.Gov, commercial GPS service (SPS) and military GPS signal accuracy are the same in space (2015). (PPS). One frequency is used for SPS transmissions, whereas PPS uses two. Military users will now be able to undertake ionospheric correction to lessen radio degradation brought on by the Earth's atmosphere. PPS offers better precision than the fundamental SPS and suffers from less deterioration (Zheng & Yangjun 2019).

The accuracy of a GPS unit depends on various factors, including the quality of the receiver, the number of satellites in view, the environment in which it is used, and the signal strength. GPS accuracy is reported in meters, typically between 5 and 10 meters. For most applications, this level of accuracy is more than adequate. However, higher accuracy levels may be required in specialized applications such as surveying. In these cases, the accuracy of the GPS unit can be improved by using different techniques or augmentation systems such as WAAS or the European EGNOS.

Differential GPS can improve accuracy by comparing the readings of two receivers at different points. The difference between the two readings is then used to correct the readings of both receivers. This technique can improve accuracy to as little as 1-2 meters. Another way to enhance a GPS unit's accuracy is through augmentation systems such as WAAS or the European EGNOS.

These systems use ground-based stations to monitor and improve the accuracy of the GPS signal. By combining their data with the data from the satellites, the accuracy of the GPS unit can be enhanced to as little as 3 meters. In short, the accuracy of a GPS unit is dependent on a variety of factors. The accuracy is between 5 and 10 meters, but this can be improved through differential techniques or augmentation systems.

3.1 Factors Affecting GPS Accuracy:

3.1.1 Satellite Geometry:

GPS positioning accuracy is affected by the geometry of the satellites in the sky. The ideal situation for GPS accuracy is when the satellites are evenly distributed throughout the sky. This situation is known as Dilution of Precision (DOP). DOP values range from 1 to infinity, where lower values indicate better GPS accuracy. The satellites are positioned directly overhead with a DOP value of

1, and the GPS accuracy is excellent. However, the satellites are placed on the horizon in a DOP value of infinity, and the GPS accuracy is poor (Kaplan & Hegarty, 2006).

3.1.2 Atmospheric Conditions:

The accuracy of GPS positioning is also affected by atmospheric conditions such as ionospheric and tropospheric delays. The ionosphere is the upper layer of the earth's atmosphere that affects GPS signals by causing them to bend. The troposphere is the lower layer of the atmosphere that affects GPS signals by slowing them down. Atmospheric delays can cause errors in GPS positioning, leading to inaccuracies (Rizos & Willis, 2013).

3.1.3 Receiver Errors:

GPS receiver errors are another factor that affects the accuracy of GPS positioning. Receiver errors are caused by multipath, noise, and clock drift. Multipath occurs when GPS signals reflect off surfaces such as buildings, leading to signal interference. Noise is caused by interference from other electronic devices, and clock drift is caused by the slightly off GPS receiver's internal clock (Dawson, 2014).

3.1.4 Impact of Factors on GPS Accuracy:

Satellite geometry, atmospheric conditions, and receiver errors can all have a significant impact on GPS accuracy. GPS accuracy can be as precise as a few centimeters in ideal conditions. However, GPS accuracy can be off in poor conditions by tens of meters or more (El-Rabbany, 2013).

Satellite geometry can affect GPS accuracy by reducing the number of satellites visible to the receiver or by causing satellites to be located in areas of the sky where their signals are weaker. Atmospheric conditions can affect GPS accuracy by slowing down or bending GPS signals, leading to errors in positioning. Receiver errors can affect GPS accuracy by introducing noise or interference into the GPS signal or causing the receiver to have an inaccurate clock (Parkinson & Spilker, 1996).

3.2 GPS Accuracy Improvement Techniques:

3.2.1 Differential GPS (DGPS):

DGPS is a technique that improves GPS accuracy by correcting for errors in the GPS signal. DGPS uses a reference station with a known position to compare its GPS signal with the receiver's. Any differences between the two signals are used to calculate corrections applied to the GPS signal. DGPS can improve GPS accuracy within a few centimeters (Rizos & Willis, 2013).

3.2.2 Real-Time Kinematic (RTK):

RTK is a technique that uses a similar principle to DGPS but provides real-time corrections to the GPS signal. RTK uses a base station with a known position to transmit corrections to the GPS receiver. The GPS receiver then applies these corrections to its real-time GPS signal, providing accurate and reliable positioning information. RTK can improve GPS accuracy within a few millimeters (Teunissen & Montenbruck, 2017).

3.2.3 Assisted GPS (A-GPS):

A-GPS is a technique that improves GPS accuracy by using additional data sources to assist the GPS receiver. A-GPS uses data from cellular networks, Wi-Fi, or other positioning technologies to supplement the GPS signal. This extra data can help to improve GPS accuracy in areas with poor GPS signal quality, such as urban environments or indoors. A-GPS can improve GPS accuracy within a few meters (El-Rabbany, 2013).

3.2.4 Multi-constellation GPS:

Multi-constellation GPS is a technique that improves GPS accuracy by using multiple satellite constellations to provide positioning information. In addition to the GPS constellation, multi-constellation GPS can use other satellite constellations such as GLONASS, Galileo, and BeiDou. Using multiple constellations, multi-constellation GPS can provide more accurate and reliable positioning information in areas with poor GPS signal quality (Teunissen & Montenbruck, 2017).

In conclusion, GPS accuracies improvement techniques such as DGPS, RTK, A-GPS, and multi-constellation GPS have revolutionized GPS technology, providing accurate and reliable location and timing information. These techniques have been developed to mitigate the effects of factors that affect GPS accuracy, such as satellite geometry, atmospheric conditions, and receiver errors. Using these techniques, GPS accuracy can be improved to within a few centimeters or even millimeters, making it a valuable tool in many areas, including navigation, surveying, tracking, and logistics.

4 Applications

GPS has become a widely used tool worldwide, and its functions are deployed in different places, such as surveillance, tracking, and business and scientific uses. GPS simplifies daily activities such as banking, the operation of mobile phones, and power grid control by ensuring synchronization and hand-off switching. We have seen GPS technology work better in studying the movements and feeding of animals. In addition, setting land property disputes among neighbors or landowners helps marine archaeologists do their research effectively to obtain vital information.

For instance, according to GPS experts, we discovered that Mt. Everest is getting taller (Firouraghi, 2022). GPS has several applications, both in the military and in civilian life. As well as its many civilian uses (in areas such as navigation, astronomy, cartography, mapping, cellular telephony, emergency response, radio occultation, clock synchronization, geotagging, geofencing, fleet tracking, air tracking, mining, tours, recreation, robotics, surveying, sports, tectonics, and telematics), GPS has also proven helpful in the military (Gray, 2018).

4.1 Agriculture:

GPS equipment is now essential to farmers as the developed tools help users do agribusiness efficiently and make it more productive in their exact farming. The advantages of using GPS tools include the following.

4.1.1 Precision Farming:

GPS technology is used in precision farming to map fields, measure boundaries, calculate area, and help farmers identify and monitor field conditions, such as soil fertility and moisture levels. GPS also allows farmers to accurately measure and record the number of fertilizers, pesticides, and herbicides applied to each field, which reduces waste and improves crop yields.

4.1.2 Crop Scouting:

GPS technology helps farmers quickly and accurately locate areas of their fields that may need additional attention, such as areas with weeds, pest infestations, low soil fertility, etc. GPS can help farmers more efficiently manage their crops and maximize crop yields by providing this information.

4.1.3 Variable Rate Application:

GPS technology can accurately apply fertilizers, pesticides, and other agricultural inputs efficiently and cost-effectively. By precisely measuring the number of information to be involved and accurately using them in the right areas, farmers can reduce their costs and improve crop yields.

4.1.4 Livestock Tracking:

GPS technology can track the location of livestock, allowing farmers to monitor their animals better and respond quickly to any health or safety issues. GPS tracking systems can also monitor livestock movement, helping farmers ensure their animals are where they should be and not straying onto neighboring properties.

4.1.5 Crop Yield Monitoring:

GPS technology can accurately measure and record crop yields from each field, allowing farmers to compare different fields and identify areas that need improvement. Farmers can create a more efficient and cost-effective farming operation by tracking crop yields over time.

4.1.6 Automated Irrigation:

GPS technology can be used to automate the irrigation of crops, allowing farmers to save time and energy while still maintaining a healthy crop. Automated irrigation systems can also reduce water waste, as they can be programmed to apply water only when needed.

4.1.7 Autonomous Vehicles:

GPS technology can guide autonomous vehicles, such as tractors, to perform various tasks accurately and efficiently, such as tilling, planting, and harvesting. Autonomous cars can help farmers reduce labor costs and improve efficiency.

4.1.8 Livestock Management:

GPS technology can help farmers better manage their livestock by providing real-time information on their animals' location, health, and welfare. GPS tracking can monitor livestock movement, assisting farmers in ensuring their animals are not straying onto neighboring properties.

4.1.9 Guidance Systems:

GPS technology can provide farmers with vehicle guidance systems, helping them drive more accurately and efficiently. Guidance systems can also help farmers accurately perform various tasks, such as planting and harvesting, which can help them save time and improve efficiency.

4.1.10 Weather Monitoring:

GPS technology can provide farmers real-time weather information, such as rainfall data, wind speed, and more. This information can help farmers make more informed decisions about when and how to manage their crops, which can help them maximize crop yields.

These are just a few ways GPS technology can be used in agriculture. As technology continues to develop, there will be even more applications.

4.2 Aviation

GPS has many advantages, and assistance in aviation is also an activity that GPS controls to ensure increased flight safety. GPS provides accurate readings worldwide that help with seamless satellite navigation services, which is vital for the aviation industry. GPS's advantages to the aviation industry include allowing all parties access to global, continuous, and accurate positioning data for all flight phases.

Secondly, secure, versatile, and fuel-efficient routes for both customers and providers of airspace services. Moreover, possible reduction and decommissioning of high-priced ground-based navigation services and systems. Also, situational awareness enables increased safety for surface mobility operations. Besides, fewer aircraft delays result from additional capacity, which is made feasible by lowering separation requirements and improving air traffic control, particularly in lousy weather, and enhanced life-saving capabilities like EGPWS.

4.3 Environment

GPS provides several functions to the environment, making it efficient for users. The advantages of GPS to the environment include A way to conduct a thorough investigation of environmental issues provided by GPS data collection systems combined with GIS software. GPS/GIS data collecting technologies allow for the quick and simple creation of thematic maps and efficient identification of environmental patterns and trends. Without the need to first transcribe field data into a digital format, GPS data may be evaluated immediately. Moreover, oil spills and other environmental calamities can be accurately tracked more effectively. Also, crustal and seismic monitoring scientists can benefit from precise positioning data from GPS. In addition, using GPS tracking and mapping can make it easier to monitor and protect endangered species (Carlevaro-Fita, J., & Johnson, R. (2019).

4.4 Marine

The maritime port infrastructure administration is becoming increasingly dependent on GPS. GPS provides different advantages to Marines and enables quick and precise position, course, and speed information access, reducing the time, and fuel navigators must spend navigating through traffic. Also, it provides mariners with accurate navigational information. Moreover, it enhances the accuracy and effectiveness of dredging, sweeping, and buoy positioning operations. In addition, it improves the economics and efficiency of container management in port facilities. Increases the security and safety of AIS-equipped ships.

4.5 Public safety and Disaster Relief

Another significant area where GPS is helpful is in this one. It helps save lives and restore vital infrastructure while providing disaster help to affected communities more quickly and accurately (Boukhechba, 2018). It also supplies position data for mapping catastrophe areas without scant or no mapping data. Besides, there is improving the capacity for flood forecasting, keeping track of seismic activity, and supplying emergency services with location data about people using mobile phones and inside cars (Saha, 2018).

4.6 Rail

Rail operations are more efficient and secure thanks to GPS. The system boosts track capacity, customer happiness, and cost-effectiveness while lowering accidents, delays, and operational costs. Further, it: enhanced situational awareness for the benefit of train and maintenance personnel safety. avoiding entering work zones, derailments, crashes, and faulty rail switches. Also, For all rail users, increased capacity and effectiveness. Furthermore, being informed of the location of the equipment and a reliable schedule. Also, automated inspections and surveys of tracks. In addition, Systems for a synchronizing time in communications.

4.7 Recreation

Outdoor enthusiasts can explore the world more safely thanks to highly accurate all-weather positioning data provided by GPS devices. Despite shifting terrain conditions, the capacity to precisely return to unique fishing places, paths, campgrounds, or other destinations year after year. Every day, outdoor enthusiasts create and share new and fascinating activities based entirely on the capabilities of GPS (Beato, 2018). Various recreational activities can be carried out using compact, portable, and economical handsets.

4.8 Roads and Highways

All surface transportation system users will experience excellent safety and mobility levels. Precise position determination must provide more fantastic passenger information (Khadhir, 2021). An improved monitoring system to ensure schedule adherence will result in a transit system that is more responsive to the needs of transportation customers. For commercial and individual customers, electronic maps for in-vehicle navigation systems can provide better location data, improving road surveying efficiency and cost reduction.

4.9 Space

We are allowing for minimal ground control while providing high-accuracy positioning. It is replacing onboard sensors that are expensive and heavy.

4.10 Surveying and Mapping

Time, resources, and labor requirements significantly increased productivity and fewer operational constraints than traditional approaches—placement of physical elements that may be used in models and maps with accuracy. Decision makers require a quicker supply of spatial data—results of real-time centimeter-level surveying.

5 The National Marine Electronics Association and Proprietary (NMEA)

A common language for marine electronics, including GPS receivers and autopilot systems, is the NMEA protocol developed by the National Marine Electronics Association (NMEA). In this way, it serves as a language that facilitates communication between and cooperation among the many devices involved (Marcus, 2016). Members of the National Marine Electronics Association (NMEA) created the standard in the late 1980s, and it is now universally utilized in marine electronics systems across the globe.

The NMEA protocol is a method of exchanging data between electronic gadgets via a string of messages. Tasks- or information-specific data, such as location coordinates or navigational instructions, is included inside each letter. Various channels, including serial connections and digital radio transmissions, may send messages of this kind.

The NMEA protocol allows devices to talk to one another and has several other characteristics that improve boat navigation. By using checksums, for instance, data transmission problems may be detected and fixed before they reach the target device. Also, it specifies many communication standards so that all interoperable gadgets may communicate with one another.

The NMEA protocol is widely used in maritime navigation systems because it provides precise and dependable information regarding the boat's location, course, speed, and wind direction. It is also helpful in exchanging nautical data between ships or computers on board a single vessel. Because of this, it is ideal for boats that must stay in touch across great distances.

Devices must be correctly set up and have suitable hardware and software to use the NMEA protocol well. This entails ensuring all your gadgets are set up to use the same message formats for sending and receiving (e.g., GPS coordinates). If filters are required, they should be put up during setup so that only relevant data is sent.

Compared to alternative navigation systems, the NMEA protocol's many benefits include its scalability (it can connect with several devices simultaneously) and uniformity (it uses the same format for transmitting data regardless of the hardware or software used). Because of this, it is suitable for installation in any boat, whether it is a commercial fishing vessel or a pleasure craft. In addition, NMEA messages are complete in themselves, allowing them to be delivered successfully across great distances without being corrupted by other factors.

Ascii strings with an 8-character header followed by message-type-specific parameters are the standard format for NMEA messages (e.g., position coordinates). When receiving data, it is simpler to understand the context if the first two letters consistently identify the message type. NMEA messages also have elaborate error-checking and repair processes to guarantee precision and dependability across various devices.

Also, NMEA is a manufacturer-agnostic global language. Thus, it may be used to exchange data across devices from various companies. This allows data to be transferred across gadgets of different makes and models. NMEA is thus an excellent option for projects that need interoperability across additional software and hardware vendors. Because of its widespread applicability, many contemporary navigation systems use NMEA as the principal communication protocol.

The NMEA protocol's versatility in transmitting a wide variety of messages is another one of its strengths (Marcus, 2016). Over fifty distinct message kinds exist, and further messages may be easily added to the protocol. Complex data like navigation algorithms and instrument readings may be sent through NMEA messages with the usual location, speed, and course information. For this reason, it is well-suited for use cases in which an extensive range of data must be sent.

When other communication protocols fail under harsh conditions, NMEA will continue to function dependably (Mertens, 2019). It has been developed to work over long distances (up to 2000 km) with slight signal deterioration and interference from ambient conditions. It can operate in environments with high levels of electrical noise, like busy factories or ships traversing stormy seas.

NMEA is a dependable and easy-to-understand system for transmitting data. It employs machine- and human-readable strings that include standard data fields. This makes it a good choice for use cases that need fast data interpretation without elaborate decoding procedures.

In addition to its use in the maritime and aviation sectors, NMEA is also popular in government and academia. Since NMEA is the language many GPS receivers use, deciphering its signals may aid in creating more accurate positioning systems. In addition, NMEA is operated by various scientific devices, including depth sounders, to communicate environmental data.

Position, altitude, speed, and direction are only a few of the data types included in NMEA signals. We can learn more about the present situation by deciphering these data fields. This data is crucial for navigation, including route planning and obstacle avoidance. NMEA also facilitates networked device coordination, also known as Automatic Identification System, which may be used to exchange location information between moving vehicles (AIS).

NMEA offers various benefits over other protocols, including its ease of implementation, lack of complexity in decoding algorithms, and adaptability to future needs (Zheng & Yangjun, 2019). Most GPS receivers also have built-in NMEA capability, so you will not need extra equipment.

Because of this, it is perfect for uses like maritime navigation, where low prices and mobility are of utmost importance. NMEA is also commonly used in aviation, providing pilots with up-to-the-moment data like position, velocity, wind direction, altitude, and more.

Supplemental data, such as speed over ground (SOG), course over ground (COG), magnetic variation (MAGVAR), and time since the last fix (TIMELFIX), may be provided by NMEA in addition to its essential navigational function. This further information improves accuracy beyond that of simple GPS coordinates. This is crucial for uses like surveying and military operations that depend on pinpoint accuracy in placement.

Figure 4:Marine GPS receiver

Source:www.topgnss.store/en-ca/products/marine-ship-gps-receiver-antenna-module-nmea-0183-baud-rate-4800-diy-connector-voltage-12v-rs232-protocol-2

5.1 NMEA Standards

NMEA develops and maintains a series of standards for marine electronics. These standards help ensure that products from different manufacturers are compatible with one another, enabling them to communicate and share data. The most widely used NMEA standards are:

NMEA 0183: This standard defines the electrical, mechanical, and functional requirements for a serial data bus for marine electronics. It is the most widely used standard for communication between navigational devices and is used for both power and sailboats.

NMEA 2000: This standard defines the electrical, mechanical, and functional requirements for a universal data bus for marine electronics. It is commonly used for powerboats but is also applicable to sailboats.

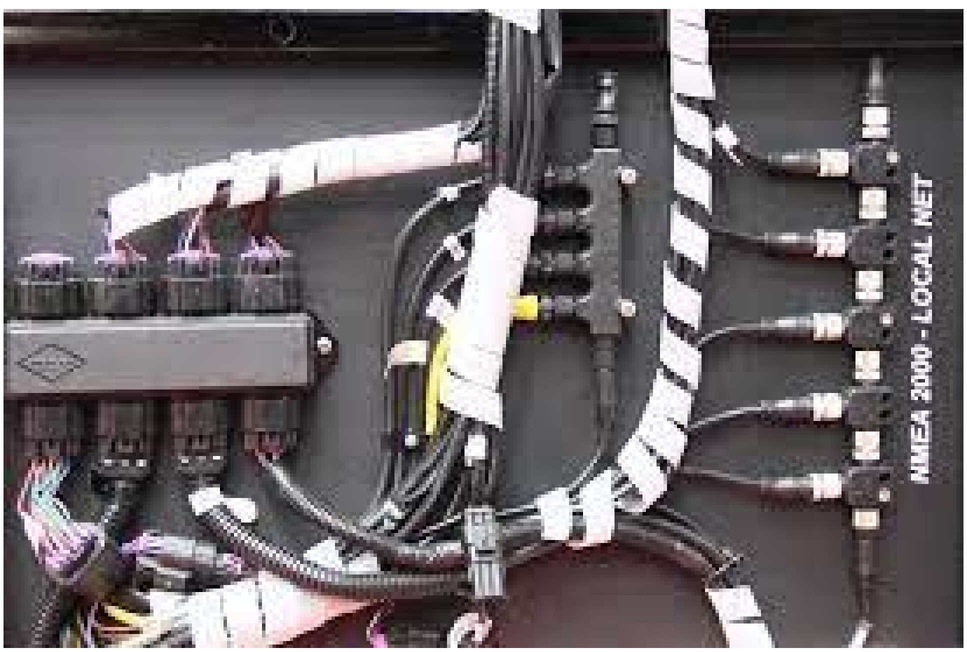

Figure 5: NMEA 2000 for mercury outboard engine

Source: www.shutterstock.com/image-photo/moscow-russia-03-08-2018-close-1215800209

NMEA 0183-HS: This standard extends the NMEA 0183 standard and provides a higher-speed data link with improved error checking and data integrity. It is used for both power and sailboats.

Figure 6: NMEA 0183

https://www.topgnss.store/products/marine-ship-gps-receiver-antenna-module-nmea-0183-baud-rate-4800-diy-connector-voltage-12v-rs232-protocol-2

NMEA Wi-Fi: This standard defines the electrical, mechanical, and functional requirements for a wireless data bus for marine electronics. It is used for both power and sailboats.

5.2 Proprietary Protocol

Proprietary protocols are communication protocols developed by companies for use in their products. These protocols are private and are usually incompatible with products from other companies (Mertens, 2019). Companies use proprietary protocols to protect their intellectual property and ensure that their products will only be used with their products.

This allows them to maintain a competitive advantage and prevent competitors from copying their designs. Proprietary protocols are often used for communications between marine electronics devices, such as GPS receivers and chart plotters, as shown in figure 1.5.

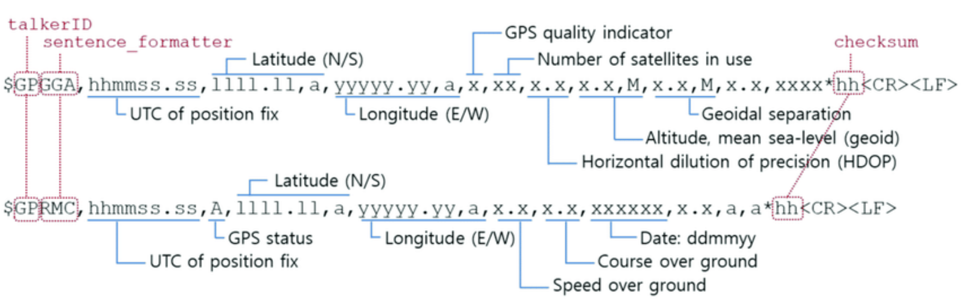

Figure 7: NMEA Protocols and format of GPS fix

Source: www.researchgate.net/figure/The-National-Marine-Electronics-Association-NMEA-format-of-GPS-fix-data-GPGGA-and_fig1_340347817

5.3 Decoding in NMEA sentences

NMEA decoding is a process used to read the information in NMEA sentences. NMEA sentences are data strings that contain information about a device's location, speed, direction, and other data. The NMEA decoder translates these data strings into human-readable information. The decoder can also convert NMEA sentences to other formats, such as GPS coordinates, bearing, and speed.

NMEA decoding is an essential part of navigation systems because it allows devices to understand the data contained in NMEA sentences (Zheng & Yangjun, 2019). By understanding this data, navigation systems can calculate the most efficient route to a destination and use it to update the user's position in real time. NMEA decoding is also used to diagnose communication problems between devices and provide accurate data for display and analysis.

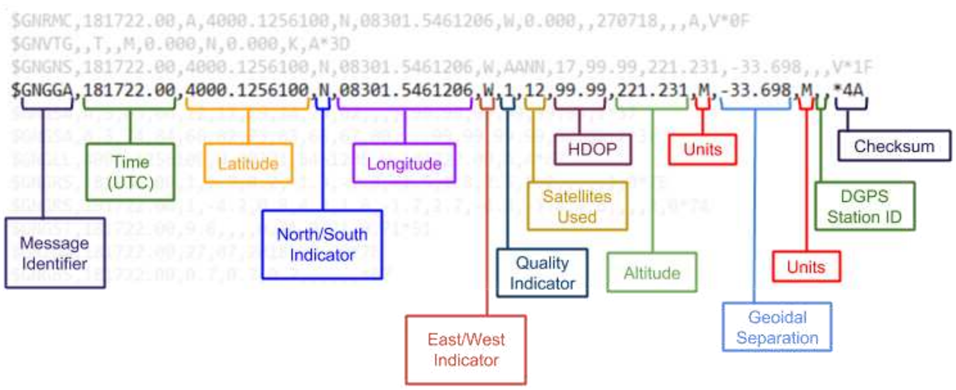

Figure 8: Decoding in NMEA sentence.

Source: https://brandidowns.com/?p=77

NMEA is the standard they employ when two devices need to talk to one another through a serial cable. For example, NMEA may interface an internal GPS with other electronics like an autopilot or radar. As a result, a ship or plane's different parts are more likely to receive and transmit data correctly. The five building blocks of an NMEA phrase are the start character, talker ID, data type code, data values, and checksum.

A '$' is always used as the first character in a sentence. The talker ID then follows to reveal the source of the statement (i.e., GPS receiver). Following this is the data type code, which denotes the information's format (location, speed, etc.). The data contents come next, and then there is a checksum to ensure everything goes well during transmission.

Data from any nautical instrument, including position (latitude/longitude), time (UTC & date), ground speed, course, magnetic deviation from true north, and more, may be sent through NMEA phrases from a GPS receiver. Consequently, the GPS receiver may be used to update various onboard devices. Equipment like an autopilot or radar unit may also relay instructions to the ship's control center using NMEA phrases.

All NMEA phrases have a checksum, as was previously established. This is only a quick mathematical procedure to check the validity of the words. If the checksum computed does not match the checksum transmitted with the sentence, then the sentence has been corrupted and should be thrown away. All characters following the "$" and before the "*." are used in an 8-bit exclusive OR computation to get the checksum.

Due to their adaptability and precision, NMEA phrases have found widespread application in various fields, including maritime navigation, aviation, automobile, etc. IEC 61162-1, Digital interfaces for marine navigation and radiocommunication equipment and systems, Part 1: Single talker and multiple listeners, is only one example of a standard that uses them. Although older protocol versions only supported transmission via RS-232 and Bluetooth, recent versions enabled transmission over USB and Ethernet.

NMEA words are widely used in various contexts, such as GPS navigation, autopilot control systems, fishfinders/depth sounders, echo sounders, and weather stations. Time, velocity, location (latitude/longitude), altitude, direction, and other navigational data may all be sent using NMEA words. The information presented may change from one sentence to the next (e.g., GGA) depending on the kind of sentence being sent and received. A typical NMEA sentence has at least five fields, including a talker ID, sentence type, data, and checksum.

Dated back to 1983, the NMEA 0183 protocol has seen extensive usage in the realm of maritime navigation ever since its inception. Most GPS makers use this protocol as the de facto standard for sharing navigational data. Several boat instrumentation systems, including those made by Simrad, Lowrance, and Furuno, are based on this protocol. NMEA is compatible with several types of networks and cables, such as serial (RS-232/RS-422), Bluetooth, WIFI, USB, and Ethernet. The standard logic levels at which it functions are 5V or 3, and its transmission rates are between 4800 and 38400 bauds (Mertens, 2019).

The protocol is broken down into messages, each including a set amount of data fields that may include any combination of ASCII letters between 0 and 9, A and Z, and the unique characters '$' (start) and '*.' (end). Standardized message formats include GGA (Global Positioning System Fix Data), RMC (Recommended Minimum Navigation Information), GSA (Global Positioning System Depth of Packet and Active Satellites), GSV (Global Positioning System Satellites in View), and HDT (High-Density Text) (Heading True).

These send data like location, velocity, course, altitude, and time. In addition to the essential phrases, NMEA allows for using specialized sentences to describe phenomena like depth sensing, wind direction/speed, etc. Fix global positioning system (GPS) data is sent in GGA messages. GPS coordinates, timestamps, the number of satellites being followed, and high-definition orbital parameters (HDOP) (Horizontal Dilution of Precision) are included. Here is an example of a GGA message:

To convert meters to kilometers, enter:
*$GPGGA,time>,lat>,NS>,long>,EW>,qual>,numsats>,HDOP>,altitude>unit of measurement>*CS*

5.4 The Recommended Minimum Specific GNSS Data (RMC) in NMEA

The Recommended Minimum Specific GNSS Data (RMC) in NMEA is a navigation sentence that provides important navigational information to a receiver, such as:

- Time
- Date
- Position
- Ground speed
- Course over ground
- Magnetic variation
- Mode of operation

A GPS receiver may transmit many data messages, including the RMC message. The GGA (Global Positioning System fixed data), VTG (Track made good and ground speed) (Zheng & Yangjun, 2019), GLL (Latitude and Longitude), and GSA (Global Signal Availability) are other frequently used messages (GNSS DOP and Active satellites). These signals are a standard that the National Marine Electronics Association (NMEA) developed so that GPS receivers can communicate.

Positional data in the form of latitude and longitude is only one of 11 pieces of information included in the RMC message. If you need to know your precise position for navigation reasons, this will help. The remaining components are UTC, ground speed, ground course, and magnetic variation direction. The checksum is the last piece of information used to verify the integrity of the data during transmission.

The NMEA protocol supports different measuring methods, including metric and US customary units, such as knots for ground speed. This allows for adaptability to a wide variety of navigational needs. In addition to the position data supplied by the NMEA, GGA messages also include the time and global positioning system fix data. A device's height may be determined, and its location in visible satellites can be pinpointed with greater precision using this method.

NMEA gives you your coordinates and things like wind speed, direction, and temperature (via the MWV message). Drift, leeway angle, and proper heading computations are just some of the many navigational metrics that may be accounted for in this fashion. It is also possible to utilize these numbers in conjunction with autopilot navigation systems to plot a path to a predetermined destination.

Regarding maritime electronics like radios and navigation systems, NMEA is the de facto standard for interoperability. In addition to facilitating location-based services, the protocol facilitates inter-device communication, which enables the seamless incorporation of new hardware into an existing vessel infrastructure.

If a boat already has a GPS receiver and radio installed, an autopilot may be added by simply connecting the three devices using NMEA-compatible connections. Because of its extensive capabilities, which include precise navigation computations, location monitoring, relative velocity readings, and more, NMEA is extensively utilized by commercial boats and recreational sailors alike (Zheng & Yangjun, 2019).

Additionally, it allows for simultaneous data transfers between different boats or even inside a single vessel, thanks to its NMEA 2000 compatibility. NMEA provides a complete navigation suite to be installed on a ship, including high-tech tools like an Automatic Identification System (AIS) and sophisticated chart plotting software.

Five components make up NMEA data strings in the NMEA 0183 standard. These five components include a two-character manufacturer prefix, a two-character talker identity, a three-character sentence format code, a comma to separate data fields, and a comma for a sentence check total. Since each string is distinct in its content and format, devices and components may exchange information with pinpoint accuracy. The NMEA protocol relies on two essential words to relay information about a ship's location, course, and ground speed field (Marcus, 2016).

The RMC sentences and the RMA navigational details are the minimums that are recommended. There is a significant distinction between the two. A relative bearing from the ship's present heading is used in the RMC sentence, whereas an actual path from the north is used in the RMA phrase.

These two phrases may convey a wealth of information, including coordinates (latitude and longitude), speed (SOG), direction (COG), and time (date). Typically, this data is utilized by navigation systems to provide ships with an exact location and an idea of where they are about other watercraft and land-based landmarks like buoys and shorelines.

In addition to the standard NMEA data strings, the NMEA protocol also recognizes several alternative string types that may be used to give supplementary navigational and safety data. The AtoN Report (ATR) phrase indicates the presence of any Automatic Identification System (AIS)-enabled buoys or other vessels, and the Dynamic Location Update (DLU) sentence offers a position report that is updated at regular intervals.

The NMEA protocol is not only for pinpointing your exact location; it can also gather environmental details like the water's temperature and the air's pressure field (Zheng & Yangjun, 2019). The Temperature/Pressure/Humidity Sensor (TPH) phase can reliably record values from a connected sensor, offering information on environmental factors that may impact navigation. Last but not least, the NMEA protocol allows people to get crucial navigational information and alerts from government agencies.

To do so, the Safety Related Message (SRM) phrase is used, which notifies mariners of any changes to the maritime environment (such as new speed restrictions or off-limits regions) that they should be aware of and prepare for.

Awange, 2000; Park, et al., 2013 and Amin, et al., 2014.

Field	Name	Explanation
hhmmss.ss	UTC Time	UTC time in hhmmss.sss format
X	Situation	Situation 'A' = Data Suitable 'V' = Navigation receiver caution
llll.lll	Latitude	Latitude in dddmm.mmmm format.
A	N/S Indicator	North='N', South='S'
yyyyy.yyy	Longitude	Longitude in dddmm.mmmm arrangement
A	E/W Indicator	East='E', West='W'
x.x	Speed above ground	Speed above ground in knots (000.0 ~ 999.9)
u.u	Track above ground	Track above ground in degrees (000.0 ~ 359.9)
Xxxxxx	UTC Epoch	UTC epoch of position solution, ddmmyy
V	Style index	Style index 'N' = Files not adequate, 'A' = at large style

Figure 9: RMC in NMEA

Source: https://www.researchgate.net/publication/323428864_Improving_the_Accuracy_of_Handheld_GPS_Receivers_Based_on_NMEA_File_Generating_and_Least_Squares_Adjustment

The NMEA protocol generally delivers a full spectrum of services for boaters of all stripes. In addition to current location data, it may also give helpful environmental readings and instant alerts about any local threats that may be faced at sea. Consequently, since its introduction, it has become one of the most widely utilized protocols for modern maritime navigation applications.

6 Different types of Cybersecurity threats & Potential Solutions

The United States government created and managed the Global Positioning System (GPS) satellite navigation network. Users across the globe rely on it for their navigational needs. Navigation, surveying, tracking, and even military activities are just some of the many uses for the global positioning system technology field (Zheng & Yangjun, 2019). Increased reliance on GPS has prompted further scrutiny of the system's safety.

GPS is vulnerable to security threats, such as spoofing, jamming, replay attacks, and man-in-the-middle attacks. Jamming is the intentional disruption of GPS signals by using a jamming device. Spoofing is the malicious manipulation of GPS signals to make it appear that the user is somewhere they are not. Hijacking is the unauthorized access of a GPS device or system.

Several safeguards have been implemented to prevent these dangers from compromising GPS. Two types of precautions may be taken: physical and the second being technological (Zheng & Yangjun, 2019). Protecting the satellites, receivers, and other hardware that makeup GPS requires using physical security measures.

Technical security measures involve encryption and authentication protocols to protect the data transmitted over the GPS network. Although GPS systems are vulnerable to security threats, several potential solutions can be implemented to mitigate these threats. These solutions include authentication protocols, encryption techniques, anti-spoofing techniques, and jamming detection systems.

Although GPS systems are susceptible to security threats, several potential solutions can be implemented to mitigate these threats (Mertens, 2019). These solutions include authentication protocols, encryption techniques, anti-spoofing techniques, and jamming detection systems. Implementing these solutions makes it possible to protect GPS systems from malicious attacks and ensure that they provide accurate and reliable location data.

6.1 GPS Spoofing

GPS spoofing is a cyber-attack that uses malicious software to falsify the data transmitted by a GPS receiver. It involves sending false GPS signals to a receiver to deceive it into believing it is in a different location. GPS spoofing can cause a receiver to display inaccurate information or cause a receiver to lose its ability to receive signals altogether.

6.1.1 Case study

A recent example of GPS spoofing happened in June 2019 when a Russian-flagged vessel, the Nadezhda, was tracked off the coast of Syria. According to the vessel's Automatic Identification System (AIS) data, the ship was located in the port of Tartus, Syria, in the Black Sea.

Further investigation revealed that the vessel had been spoofed by a GPS jammer, which was detected two hundred kilometers away from the vessel's actual location (Zheng & Yangjun, 2019). In this case, the Nadezhda had been broadcasting false GPS signals to appear in a different location than it was.

The vessel was located off the coast of Syria but was broadcasting false signals that indicated it was in the Mediterranean Sea near Cyprus. This allowed the Nadezhda to travel undetected for some time. The incident was only discovered when researchers from the University of Texas at Austin noticed anomalies in the vessel's GPS signals. They found that the signals were not from the boat but from a separate source. Further investigations revealed the start of the false alerts in Russia.

This incident is a clear example of how GPS spoofing can be used to cover up the movements of a vessel. It is a severe threat to the security of GPS systems, as it can be used to mask a vessel's signs and manipulate its location. Furthermore, GPS spoofing can disrupt navigation systems and cause significant disruption to any dish or device that relies on GPS.

In response to this incident, the US government has increased GPS security. This includes the use of encryption and authentication protocols to prevent spoofing attacks. Additionally, the US has increased its GPS monitoring to detect anomalous activity.

Overall, the incident involving the Nadezhda is a clear example of the dangers of GPS spoofing. It is a severe threat to GPS systems and can be used to mask a vessel's movements and manipulate its location. As such, governments and organizations need to increase the security of their GPS systems to protect against such attacks.

Figure 10: Russian Navy Vessels in Syria

Source: https://news.usni.org/2020/10/21/russian-navy-seen-escorting-iranian-tankers-bound-for-syria

6.1.2 Procedure

Malicious actors with access to powerful computer equipment and sophisticated software typically carry out this attack. The attacker will begin by broadcasting a false GPS signal that is strong enough to override the signal from the legitimate GPS satellites. The attacker will then use the wrong password to control the receiver's position and make it appear in a different location than it is.

6.1.3 Solution

A few steps can be taken to protect against GPS spoofing attacks. The first is to use GPS receivers with built-in anti-jamming technology. These receivers are designed to detect when an unauthorized signal is being broadcast and will automatically switch to a different frequency or switch off altogether.

Secondly, users should ensure that their GPS receivers are running the latest software and firmware updates, as these can help to protect against newly discovered vulnerabilities. Finally, users should use encrypted GPS signals whenever possible, as these are much more difficult for attackers to intercept and manipulate.

6.2 Jamming

Jamming is a type of cyber-attack that occurs when a malicious attacker attempts to interfere with the regular operation of a GPS by flooding it with false signals. This attack can disrupt navigation systems, cause errors, and even disable the system entirely. Jamming can occur through various methods, such as broadcasting a signal at the same frequency as the GPS or through signal amplifiers.

6.2.1 Procedure:

The procedure for jamming a GPS is relatively simple. An attacker must first identify the frequency of the GPS signal they wish to disrupt. This can be done using a specialized receiver capable of detecting GPS signals. Once the frequency is identified, the attacker will use a transmitter to broadcast a call at the same frequency. This signal will disrupt the regular GPS operation, causing navigation errors or disabling the system entirely.

6.2.2 Case Study

In June 2020, the US Department of Defense reported a GPS jamming incident in the Middle East (Mertens, 2019). According to the report, the jamming was conducted by a hostile nation-state and was likely intended to disrupt the operation of US military aircraft in the region. The jamming was born in the VHF frequency band, which overlaps with the GPS signal.

The jamming successfully disrupted the GPS signal, causing issues with the navigation and timing of military aircraft operating in the area. The incident highlights the need for increased vigilance and awareness of GPS jamming threats in the future. According to DoD officials, the jamming came from a single source in the Middle East. The jamming caused the GPS signals used by the US military to be blocked, preventing GPS-guided weapons from being used and disrupting communication links.

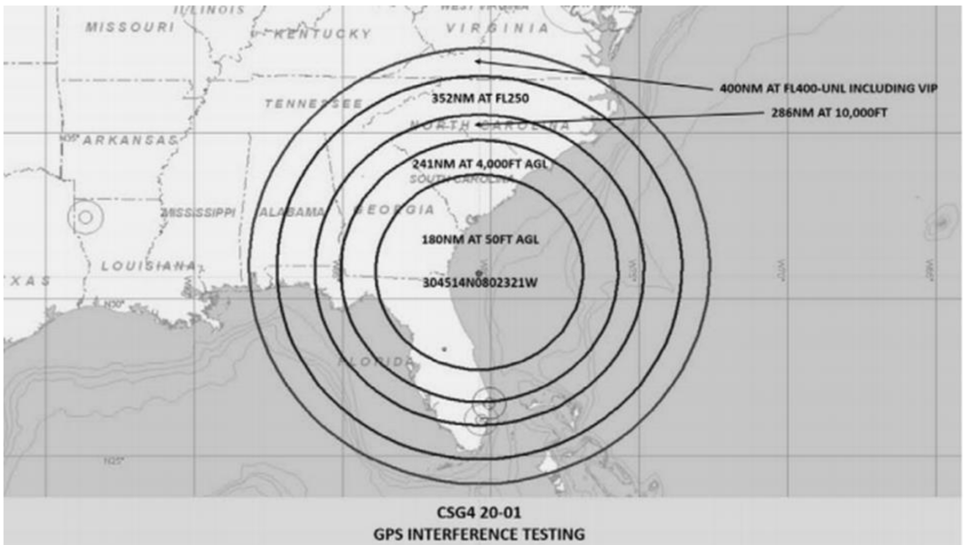

Figure 11: GPS Interface Testing

Source: https://blog.foreflight.com/2016/06/08/faa-advisory-gps-interference-testing/

The incident was reported to have started on June 20th and lasted for about two weeks. It was unknown who was behind the jamming or their motives. The US military also stated that it was unclear if the jamming was intentional or accidental (Mertens, 2019). GPS jamming is a cyber security threat that can have serious consequences.

Jamming is a form of electronic warfare that disrupts or blocks the reception of GPS signals. This can interfere with navigation and communication systems and disrupt the operation of weapons systems that rely on GPS. In the case of the US military, the jamming incident prevented them from using their GPS-guided weapons and disrupted communication links.

While the source of the jamming incident in the Middle East remains unknown, it serves as a reminder of the importance of cyber security measures. GPS jamming is a severe threat and can have serious consequences. By implementing strong security measures and vigilance, the US military can help protect itself against future jamming incidents.

Figure 12: Vessel affected by GPS Jamming

https://maritime-executive.com/editorials/the-rising-threat-to-the-integrity-of-maritime-navigation-data

6.2.3 Solution:

A secure GPS is the best way to protect against jamming attacks. Secure GPS systems use encryption techniques to ensure that the signals transmitted and received by the system are secure (Marcus, 2016). Additionally, using GPS spoofing detectors can help detect and prevent the transmission of false signals. Finally, ensuring the GPS is regularly updated with the latest security patches is essential to protect against new and emerging threats.

6.3 Man-in-the-Middle Attack

A man-in-the-middle (MITM) attack is a cyber-attack where a malicious actor secretly intercepts and relays communication between two unsuspecting parties. In a GPS context, a hacker could intercept the communication between the user and the navigation system, allowing them to modify, manipulate, or eavesdrop on the transmitted data. This attack can be used to gain access to sensitive information or disrupt navigation systems.

6.3.1 Procedure

The attacker must first access the communication between the user and the navigation system. This can be done using techniques such as spoofing, which involves the attacker pretending to be an authorized user or device. They can then intercept the communication using a malicious program or device as an intermediary between the two parties.

6.3.2 Case study

On December 5, 2019, researchers at the University of Texas at Austin reported discovering a man-in-the-middle attack against the Global Positioning System (GPS). The attack targeted a single GPS receiver in a controlled environment near a GPS signal generator. The researchers used a low-cost and low-power device to spoof the GPS signal and redirect the receiver to a false location (Mertens, 2019). The attack turned the receiver up to 200 meters off its proper location. The attack could be conducted without the attacker ever leaving their location, making it difficult to detect.

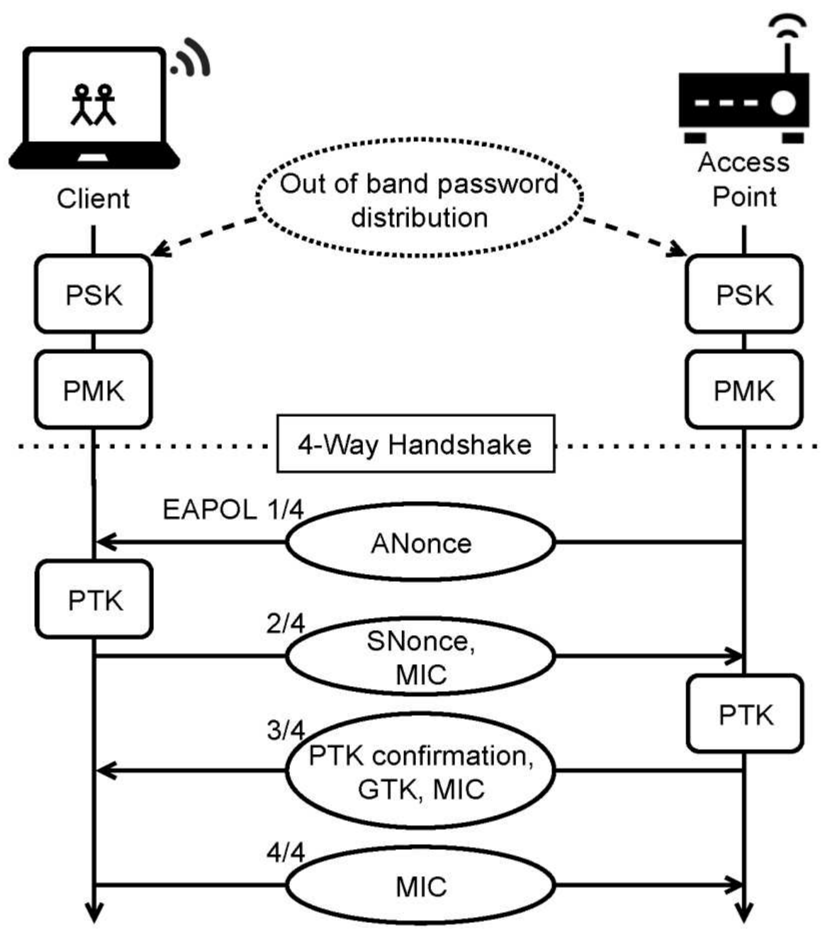

Figure 13: Man-in-the-Middle Attack

Source: https://www.mdpi.com/1424-8220/23/2/733

The attack was conducted using techniques commonly called “signal injection” and “jamming.” The signal injection was used to send false signals to the GPS receiver while jamming blocked the actual GPS signal. The attacker then controlled the GPS receiver, allowing them to send it to the wrong location.

The attack was conducted using an SDR (Software Defined Radio), a low-cost, low-power device. This device allowed the researchers to inject false signals into the GPS signal and block out the actual movement. The researchers were able to successfully spoof the receiver’s location by up to 200 meters.

The attack was conducted in a controlled environment, and the researchers carefully ensured that the attack did not interfere with other GPS receivers or services. However, the episode highlights the potential vulnerabilities of the GPS. Malicious attackers can use similar techniques to spoof the location of a GPS receiver, which could have severe implications for navigation and other location-based services (Zheng & Yangjun, 2019).

As such, GPS users need to be aware of the potential risks and take steps to protect their devices. The researchers also noted that the attack was conducted in a controlled environment and may not be feasible in a real-world scenario. The power and cost of the attack would likely be prohibitively expensive and challenging to pull off in the real world. Nevertheless, it is essential to know that GPS receivers are vulnerable to attack and can be spoofed. It is necessary to protect GPS receivers and take steps to mitigate the risks involved in using them.

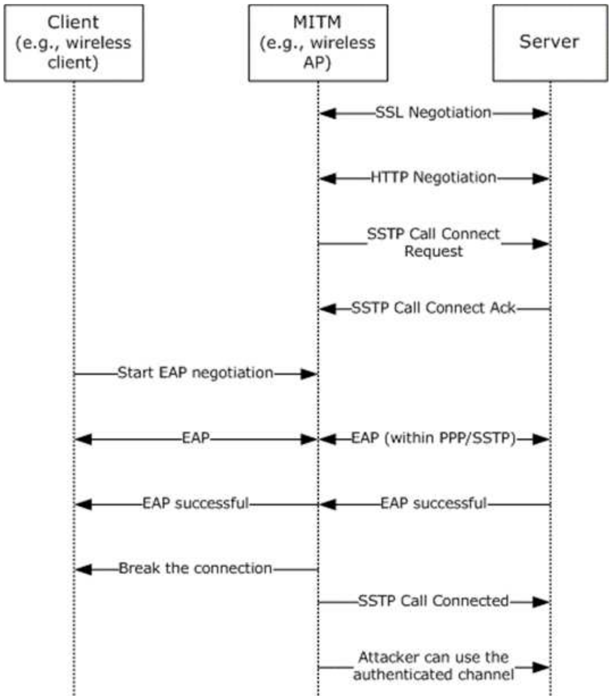

Figure 14: MITM scenario without the SSTP crypto binding solution

Source: https://learn.microsoft.com/en-us/openspecs/windows_protocols/ms-sstp/4a6778bc-a4a9-46c6-9120-7493c61f95e5

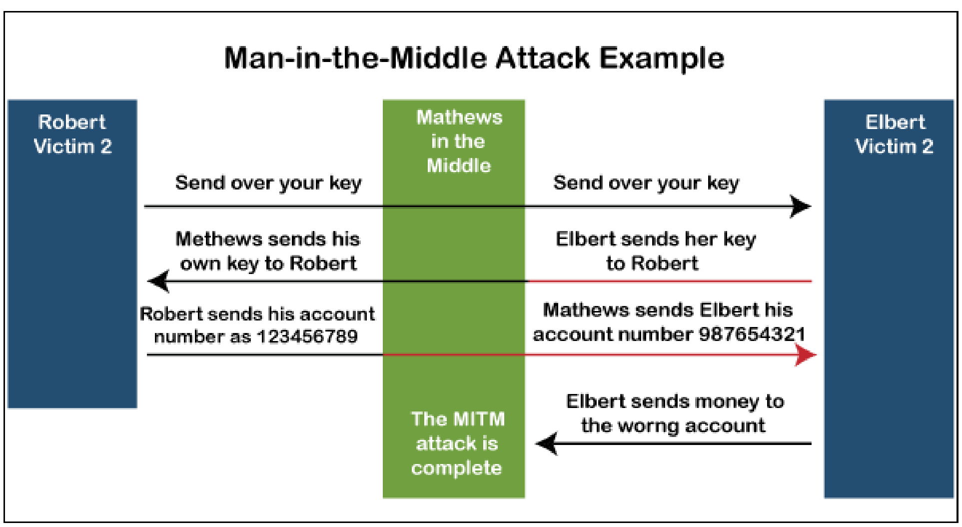

Figure 15: Instance of MITM

Source: www.javatpoint.com/cyber-security-mitm-attacks

6.3.3 Solution

GPS systems should use encryption to secure the sent and received data to prevent MITM attacks. GPS systems should also employ authentication protocols to ensure only authorized users and devices can access the system. GPS systems should use regular patching and security updates to address new vulnerabilities.

6.4 Location Data Leaks

Location data leaks are among GPS systems' most common cyber security threats. This attack occurs when attackers access location data stored on a GPS or its associated servers, allowing them to track users' locations and movements. Furthermore, attackers can use this data to access other sensitive information, such as passwords and credit card numbers.

6.4.1 Procedure

Location data leaks can occur through various methods, including malware, phishing attacks, and social engineering. In the case of a GPS, attackers may use malicious software, such as a Trojan horse, to access the system. Once inside the system, they may access location data stored on it or its associated servers. Another standard method to gain access to location data is phishing (Zheng & Yangjun, 2019). This technique involves sending out emails or links to malicious websites that appear to be legitimate.

Once clicked, these links can install malware on a user's device, allowing attackers to access their GPS and location data. Lastly, attackers may use social engineering to access a user's GPS. This involves manipulating users to access the system or its associated servers. Attackers may use various methods, such as fake emails or phone calls.

6.4.2 Example

In 2020, a Location Data Leaks cybersecurity attack hit the popular restaurant chain Chipotle. Attackers could gain access to the Chipotle mobile app, which allowed them to access the GPS coordinates of customers who had enabled the location services feature while using the mobile app. The attackers were then able to track the location of the customers in real time and target them with targeted phishing and malware attacks (Zheng & Yangjun, 2019). The attack was only discovered after customers reported suspicious activity to the company, and their security team investigated it.

The company was able to quickly address the issue and update the security of its mobile app. The attack was discovered when a security researcher noticed Chipotle's website exposed customers' geolocation information when ordering food online. This meant that anyone looking at the Chipotle website could see the location of anyone who had ordered food, including their exact GPS coordinates.

Figure 16: Chipotle website breach day

Source: www.bankinfosecurity.com/chipotle-hackers-dined-out-on-most-restaurants-a-9951

The security researcher notified Chipotle of the issue. The company quickly took steps to fix the problem, including ensuring that all customer data was encrypted and removing the exposed location data (Marcus, 2016). Chipotle also issued an apology and updated its privacy policy to ensure that similar issues do not occur in the future.

The incident highlights the importance of keeping customer data secure, especially regarding location data. Companies must regularly monitor their website and data security practices to avoid exposing customers' sensitive information. Additionally, companies should educate their customers on the importance of data security and best practices to protect their personal information.

Fortunately, no customer data was compromised during this attack. However, the episode showcased the potential risk of location data leakage and the need for companies to ensure their mobile apps are secure. In response to this attack, Chipotle updated its mobile app and implemented additional security measures, such as two-factor authentication, to protect customer data.

The company also committed to continually reviewing its security practices and updating its mobile app with the latest security features. This attack is an important reminder that Location Data Leaks can be a significant security risk for businesses and customers. Companies must remain vigilant and secure their mobile apps to protect customer data.

6.4.3 Solution

The best way to protect against location data leaks is to ensure that GPS systems are kept up to date with the latest security patches and updates (Yangjun, 2019). Additionally, users should be aware of the potential risks associated with using GPS systems and take steps to protect their data. This includes using strong passwords, avoiding clicking suspicious links, and being cautious when providing personal information. Finally, organizations should ensure their GPS systems are adequately secured and monitored regularly.

6.5 Malware

Malware is malicious software that is designed to cause damage to a computer system or network. GPS systems are vulnerable to malware attacks since they are connected to the internet and can be accessed by attackers. Malware can be used to gain access to GPS systems and steal data, alter or delete information, or disrupt service.

6.5.1 Procedure

Malware attacks typically begin with phishing emails that contain malicious links or attachments. Once a user clicks the link or downloads the attachment, the malware is installed and spreads throughout the system.

6.5.2 Example

In August 2020, researchers at Kaspersky revealed a new form of malware called PowerGhost. This malware is designed to infect computers and use them to create a large-scale cryptocurrency mining operation (Mertens, 2019). PowerGhost uses various malicious techniques to spread, such as exploiting weakly secured remote desktop protocol (RDP) connections, using malicious macros in documents, and exploiting vulnerabilities in Windows and other systems.

Once a computer is infected, PowerGhost downloads a file that contains a CryptoNight mining module and a backdoor. The backdoor allows attackers to access the compromised system and then spread the malware to other computers. It also allows attackers to control the infected system remotely, including exfiltrating data and downloading additional malicious files.

PowerGhost can run on both 32- and 64-bit versions of Windows, including Windows Server 2008 or later. In addition to mining cryptocurrency, PowerGhost can also be used to launch distributed denial-of-service (DDoS) attacks, steal passwords, and download additional malware. The malware can also evade detection by traditional antivirus programs and even bypass Windows Defender (Zheng & Yangjun, 2019).

It is a fileless malware that infects systems by using the Windows Management Instrumentation (WMI) and Windows Remote Management (WinRM) services to infect and spread. PowerGhost is capable of stealing credentials, cryptocurrency mining, and data exfiltration. It has been found in over 85 countries and has infected many corporate networks. It can also spread to other computers on the same local network and can even be used to create a botnet.

PowerGhost can be used for various malicious activities, including remote code execution and data theft. To detect and defend against PowerGhost, organizations should enable network segmentation, monitor WMI and WinRM services, and deploy endpoint security solutions.

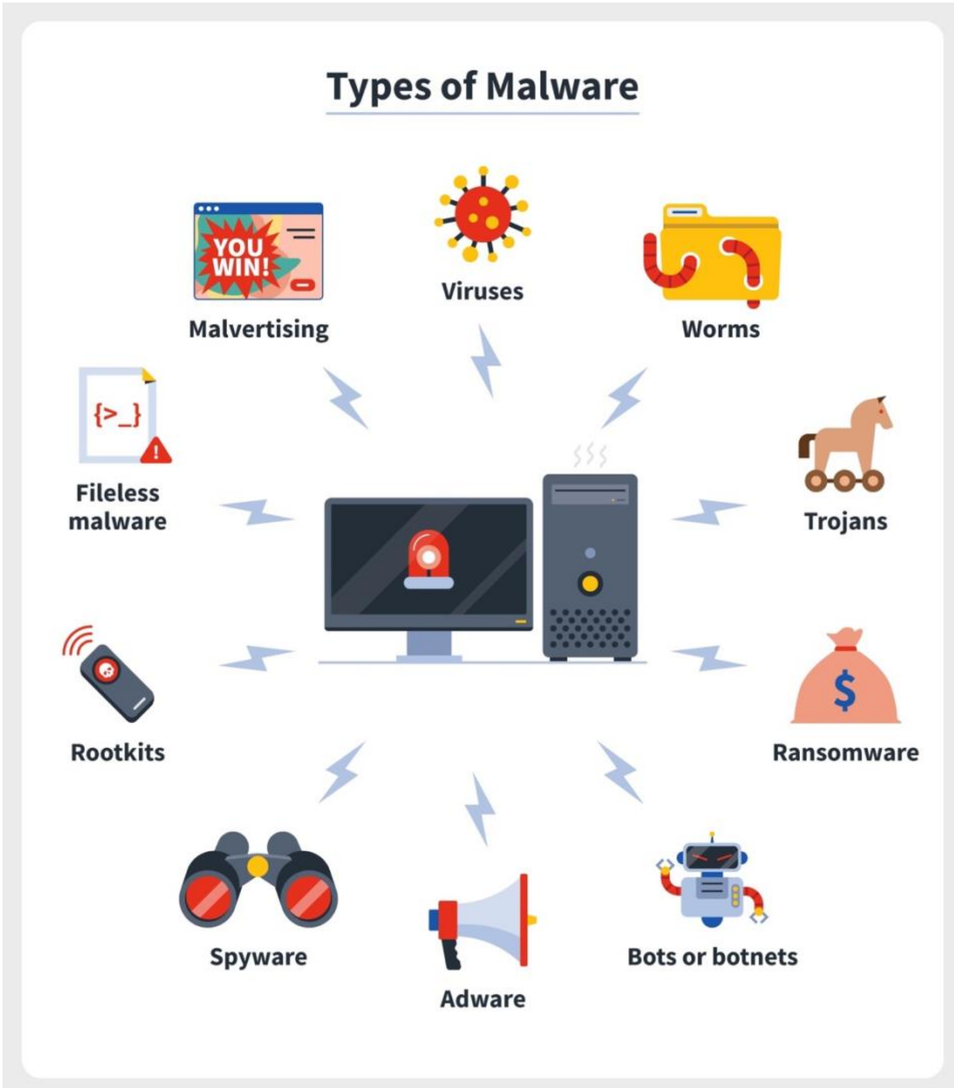

Figure 17: Malware types

Source: https://us.norton.com/blog/malware/types-of-malware

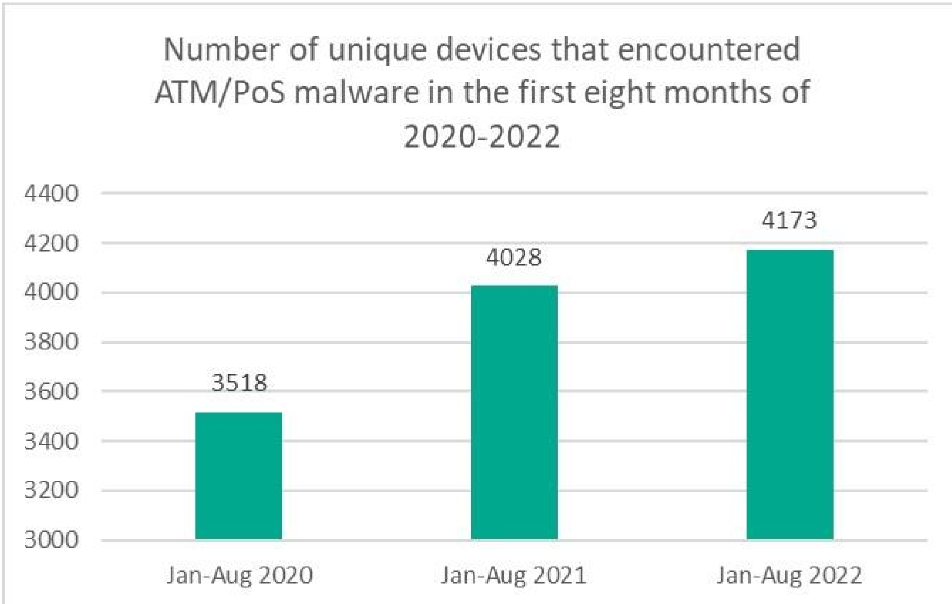

Figure 18: Unique devices that encountered ATM/PoS malware in 2020-2022

Source: www.kaspersky.com/about/press-releases/2022_atmpos-malware-recovers-from-covid-19-with-the-number-of-attacks-continuing-to-grow-in-2022

To protect against this attack, users should keep their systems current, use strong passwords, and always use caution when opening emails or attachments from unknown sources. Additionally, organizations should consider using endpoint detection and response (EDR) solutions to detect and respond to potentially malicious activity.

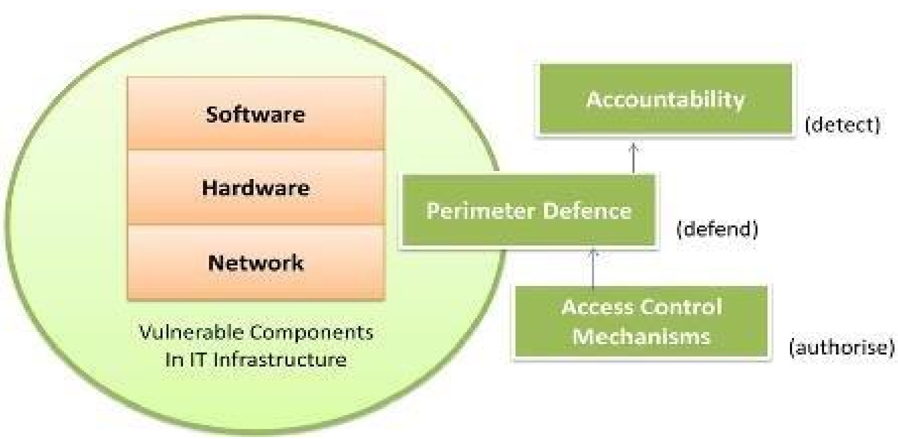

Figure 19: Vulnerabilities and Defense Strategies

Source:www.researchgate.net/figure/Vulnerabilities-and-Defense-Strategies-in-existing-systems-Many-cyber-security-experts_fig1_347373943

6.5.3 Solution

To prevent malware attacks, users should never click on links or open attachments from unknown sources. Additionally, all GPS systems should be regularly updated with the latest security patches and anti-virus software to help prevent and detect malware.

6.6 DDoS Attack

A distributed denial-of-service (DDoS) attack is a cyberattack that seeks to disrupt a system by overwhelming it with traffic from multiple sources. GPS systems are vulnerable to DDoS attacks as they are connected to the internet and can be targeted by attackers.

6.6.1 Procedure

A DDoS attack typically begins with the attacker sending significant traffic to the target system. Bots, compromised devices, or multiple systems can generate this traffic. This flood of traffic overwhelms the system and disrupts its regular operation.

6.6.2 Example

On April 15th, 2020, a distributed denial of service (DDoS) attack was launched against a GPS provider called Global Positioning System (GPS) (Mertens, 2019). The attack was launched from a botnet of over 100,000 vulnerable IoT devices, such as routers and CCTV cameras, located worldwide. The attack flooded the GPS's servers with more than 4 million requests per second, ultimately causing an outage of the entire system.

The attack was detected and blocked within minutes, but the system was offline for over two hours. By the time the attack was blocked, the GPS had already suffered more than $800,000 in damages. After investigating the attack, researchers identified a botnet responsible for launching the DDoS attack. The botnet comprised over 100,000 IoT devices infected with a nasty piece of malware that allowed the attackers to control the devices and launch the attack.

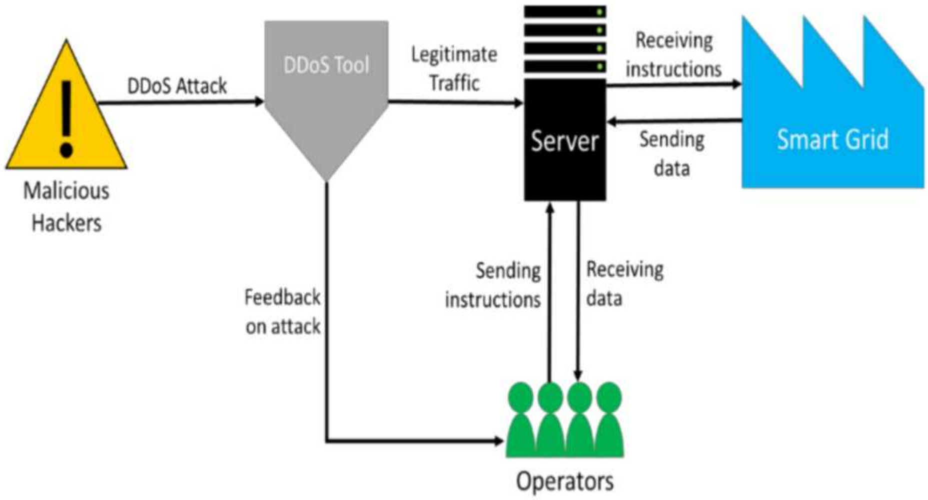

Figure 20: System model of the intelligent grid

Source: www.mdpi.com/2071-1050/14/5/2730

The attackers used the compromised devices to launch attacks against other targets, including GPS providers, government organizations, and financial institutions. The attack was eventually stopped by a coordinated effort between law enforcement, security researchers, and the GPS provider. The attackers were identified and held responsible for the attack. The attack serves as a reminder of the importance of securing IoT devices. In this case, the attackers exploited vulnerable devices to launch a massive DDoS attack, resulting in significant financial losses.

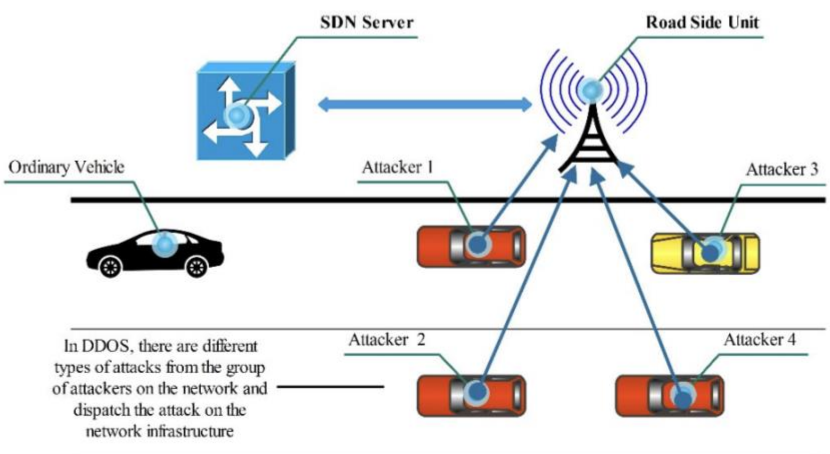

Figure 21: Sybil attack in vanet

Source: www.researchgate.net/publication/341210309_SDNbased_VANETs_security_attacks_applications_and_challenges#pf24

Organizations must ensure that all their IoT devices are adequately secured, as these devices can easily be exploited to launch large-scale attacks. Additionally, organizations should have a sound security monitoring system to quickly detect and respond to potential threats (Zheng & Yangjun, 2019). This attack highlights the need for organizations to be aware of the potential risks posed by unsecured IoT devices and has the necessary security measures to protect their systems from attacks.

This attack also highlights the importance of international collaboration to combat cyber-attacks effectively. The coordinated effort between law enforcement, security researchers, and the GPS provider was crucial in identifying and arresting the attackers and preventing further damage. Finally, this attack serves as a reminder of why organizations must keep their systems updated with the latest security patches and updates.

Many of the IoT devices exploited in this attack had not been updated with the latest security patches, leaving them vulnerable to exploitation. Organizations should ensure that their systems are appropriately patched and updated to protect them from potential cyber-attacks.

6.6.3 Solution

To prevent DDoS attacks, GPS systems should be monitored for suspicious activity and have access restrictions implemented, such as rate limiting or IP address allow listing. Additionally, the system should be segmented from the internet, and an intrusion detection system should be deployed to detect and respond to any attempted attacks.

6.7 Weak Encryption

Weak encryption is a type of cybersecurity threat that occurs when an attacker can gain access to data that has been encrypted with an insecure encryption algorithm (Marcus, 2016). This attack is hazardous because the attacker can use weak encryption to access sensitive information such as passwords, financial data, or personal information.

6.7.1 Procedure

The attacker will first try to identify vulnerable encryption algorithms used to protect the data. Once the algorithm is specified, the attacker will attempt to access the encrypted data by using a brute force attack or exploiting any weaknesses or flaws in the encryption algorithm. If the attacker is successful, they can access the confidential data stored in the GPS.

6.7.2 Example

In April 2019, a cybersecurity firm called Kryptowire uncovered a Weak Encryption vulnerability in a fleet management company's Global Positioning System (GPS). The vulnerability allowed hackers to access the GPS data of the fleet management company's customers, including the locations of their vehicles.

To exploit the vulnerability, hackers needed only the phone number associated with the customer's account. Once they had that, they could send a specially crafted SMS message to the customer's phone, granting them access to the GPS data (Mertens, 2019).

The hackers could then track the customer's vehicles in real time and possibly even manipulate the data to make it appear like the cars were in a different location. The Weak vulnerability allowed an attacker to access the GPS data of vehicles without authentication. This would allow them to track the movements of the cars, which could be used for malicious purposes.

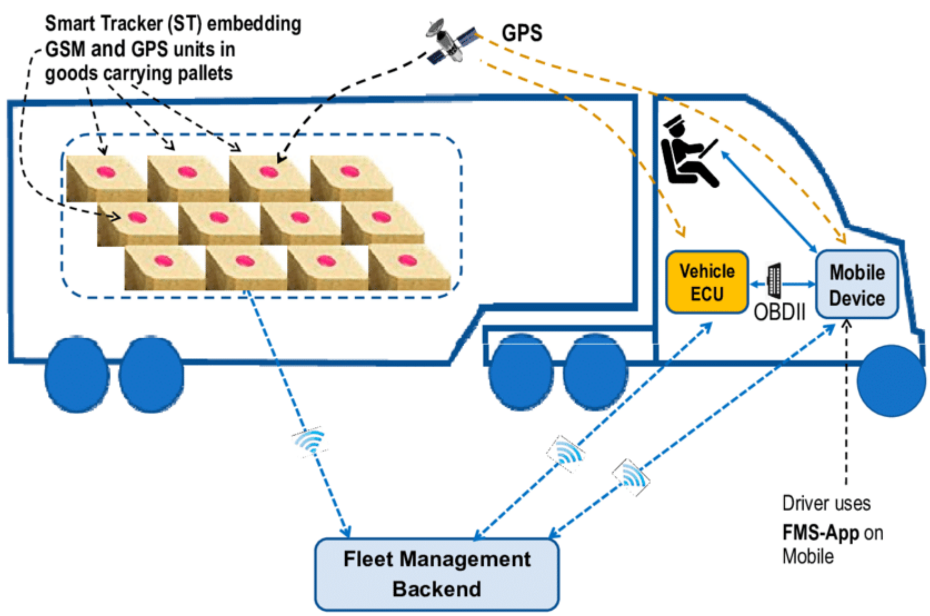

Figure 22: Weak Encryption

Source: www.researchgate.net/figure/Sample-typical-modern-fleet-management-system-architecture_fig1_338457999

Kryptowire alerted the fleet management company of the flaw and worked with them to patch the GPS. This involved updating the fleet management software to use more robust encryption algorithms to protect the GPS data. Kryptowire also released a statement to the public, alerting them to the vulnerability and urging other fleet management companies to check for similar weaknesses in their systems (Zheng & Yangjun, 2019). This was done to protect the data of different fleet management companies from potential attackers.

The fleet management company eventually patched the vulnerability, but the incident highlights the importance of robust encryption protocols regarding GPS data. Weak encryption protocols can leave GPS data vulnerable to malicious actors. As such, companies that rely on GPS data should ensure they are using robust encryption protocols to protect their customers' data.

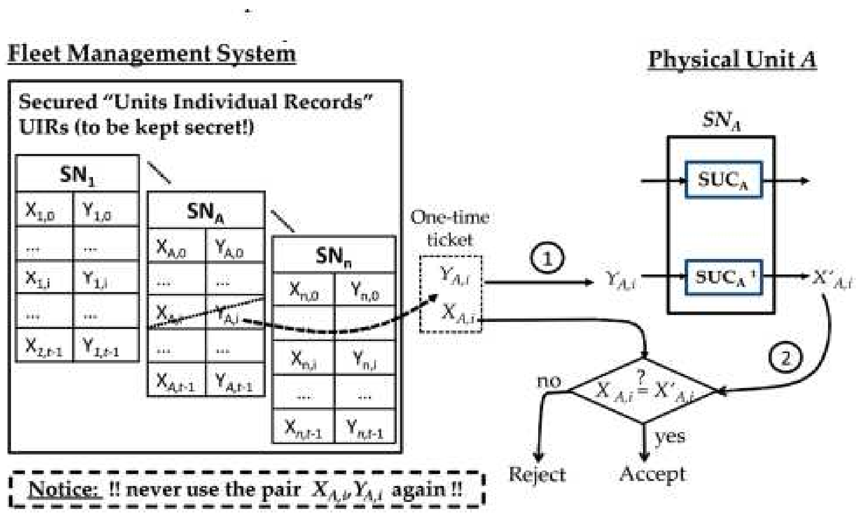

Figure 23: Fleet management system

Source: https://mdpi-res.com/d_attachment/cryptography/cryptography-04-00001/article_deploy/cryptography-04-00001-v5.pdf?version=1583415599

6.7.3 Solution

The best way to prevent weak encryption attacks is to use secure encryption algorithms such as AES or RSA (Mertens, 2019). Additionally, it is essential to ensure that the encryption keys are regularly changed and that all passwords are strong and regularly updated. Additionally, using two-factor authentication wherever possible is vital to protect sensitive data further. It is essential to periodically monitor the system for suspicious activity or unauthorized access attempts.

6.8 Social Engineering

Social engineering is a cyber attack that relies on human interaction to acquire confidential information.

6.8.1 Procedure

This attack typically occurs when a hacker attempts to manipulate a user into providing sensitive information by posing as a legitimate source or using deceptive tactics. For example, a hacker may email a user pretending to be from the user's bank, asking the user to provide their account information.

6.8.2 Example

On April 15, 2020, a social engineering attack was launched against the GPS navigation system for a fleet of cars in the United Kingdom. The hacker attacked using a malicious USB drive to break into the car's onboard computers. The hacker uploaded a malicious program to the cars' computers, allowing them to track the vehicles and gain access to the GPS navigation system. The hacker could also access the car's performance data, such as fuel consumption, speed, and acceleration.

The hacker-controlled the GPS navigation system, allowing them to direct the cars to take unwanted routes. The hacker could access the cars' emergency response system and even the command-and-control systems for the vehicles. The attack occurred at approximately 6:30 am and involved two individuals, one a hacker and the other a driver for the company.

The hacker created a fake GPS signal sent to the cars in the fleet, causing them to follow a predetermined route (Mertens, 2019). The hacker then used a fake email address to contact the driver and falsely inform him that the company had changed its route. The driver followed false instructions and ended up over 40 miles from the destination.

The hacker then used the distraction of the false route to access the car's GPS and inject malicious code, allowing them to control the vehicle remotely. Fortunately, the driver realized that something was amiss and contacted the company. The company investigated the attack and closed the vulnerability, preventing further damage.

The attack was eventually stopped, but not before the hacker was able to cause some disruption to the fleet's operations. This attack demonstrates the importance of security measures for GPS navigation systems and how hackers can exploit them. As such, companies should invest in robust security measures for their GPS navigation systems, such as encryption and authentication methods. Additionally, companies should consider training their employees to spot and respond to potential social engineering attacks.

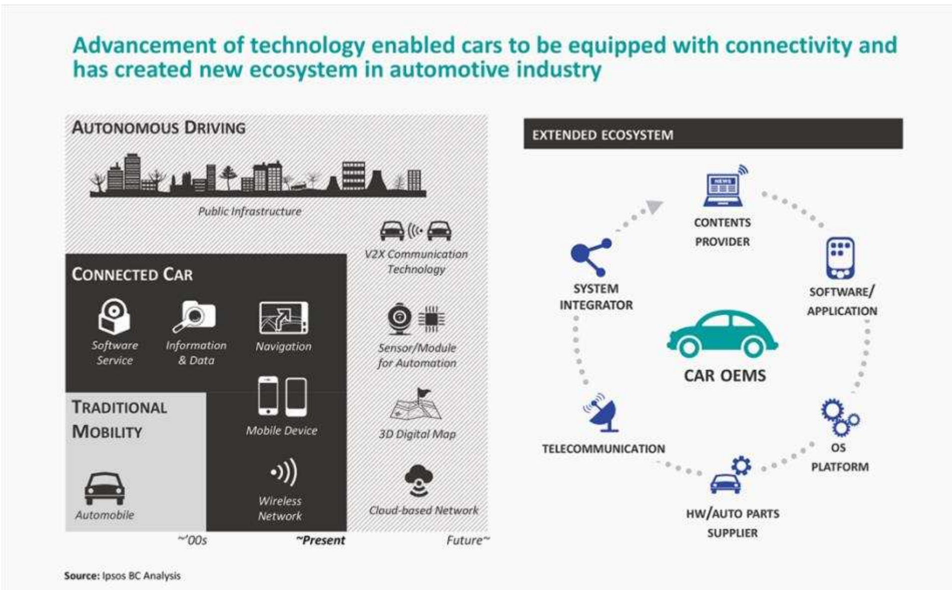

Figure 24: Vision for GPS in cars

Source: https://www.tyrepress.com/2016/06/five-ways-connected-cars-will-change-lives-ipsos-report/

6.8.3 Solution

To prevent social engineering attacks, users should be cautious when responding to emails and other online communications that ask for personal information or require them to click on a link. They should also be aware of phishing scams and ensure that any emails received from unknown sources are legitimate. Additionally, organizations should consider implementing security awareness training programs for their employees to help them identify and respond to these threats.

These are the different types of cybersecurity threats in the GPS. It is essential to be aware of these threats and protect yourself and your GPS from them (Mertens, 2019). By implementing strong cybersecurity measures, such as encryption, access control, and monitoring, you can help to protect your system from these threats. Understanding the different types of GPS cybersecurity threats and taking steps to protect against them is essential to keeping your GPS data safe and secure.

7 Are there backups when GPS fails

Yes, there are several backup options when GPS fails. These include dead reckoning, which uses a combination of a vehicle's speed and direction to estimate its position; an inertial navigation system, which uses accelerometers, gyroscopes, and other sensors to determine the vehicle's position; and a combination of both. Additionally, some vehicles may be equipped with a backup navigation system, such as a cellular or satellite system, which can provide navigation information even if GPS signals are unavailable.

Other navigation systems, like LIDAR, radar, and vision-based systems, may be used as a backup if necessary. If your GPS fails, these solutions may help you find your way. Some automobiles may also include map-based navigation systems as a fallback in case the GPS stops working. (Mertens, 2019)

Finally, some vehicles may also be equipped with a manual override system, which allows the driver to enter a destination or route and override the GPS manually. This may be used as a backup in a GPS failure. Several backup options exist when GPS fails, including dead reckoning, inertial navigation, cellular/satellite navigation, other navigation systems, and manual override systems.

7.1 Inertial Navigation

Inertial navigation is a self-contained navigation system that uses accelerometers, gyroscopes, and sometimes magnetometers to track a vehicle's or person's movement. The accelerometers measure the linear acceleration of the vehicle or person, while the gyroscopes measure the angular velocity or rotation.

By integrating acceleration and process, the navigation system can calculate the vehicle's or person's position and velocity in three-dimensional space. Inertial navigation systems measure the acceleration of an object and use it to calculate its position. These systems are accurate for short periods and can provide a backup to GPS if it fails.

In addition to these backup systems, data fusion algorithms can combine multiple data types to determine a more accurate location. This means that data from various sources, such as GPS, inertial navigation systems, and radio beacons, can be used to build a more reliable location system.

7.2 Dead Reckoning

Dead reckoning is an ancient navigation technique that involves estimating one's current position based on a previously determined place or fixing and advancing that position based on known or estimated speeds over time and course. This technique has been used for centuries by sailors and is still used in specific applications today. The key to successful dead reckoning is accurately measuring the speed and course of a moving object and determining the elapsed time.

7.3 Cellular/Satellite Navigation

GPS is a satellite-based navigation system that uses a constellation of 24 satellites and corresponding ground-based sensors to give users pinpoint location, route guidance, and accurate timekeeping. Receivers on the ground pick up signals broadcast by the satellites and utilize that information to identify the user's precise position and time. The Global Positioning System (GPS) has several uses, including navigation, surveying, and mapping.

Cellular and satellite navigation operate very differently when communicating with GPS devices. GPS receivers for satellite navigation systems rely on satellites in Earth's orbit, whereas cellular navigation systems rely on cellular towers. As satellites are in a higher orbit, they can deliver more accurate location information than cellular towers.

Although the satellite navigation system is more reliable, the cellular navigation system is more cost-effective since it uses fewer satellites. Cellular towers are necessary for sending and receiving navigation signals in a cellular environment. The position and time of a user are determined by the GPS receiver using signals from nearby cell towers. The GPS receiver contacts the cellular network via which the buildings are linked to getting its location.

As an alternative, satellite navigation systems rely on a constellation of satellites to relay location data to a GPS receiver. The satellites are stationed in a higher orbit than the cell towers to deliver more accurate location data. The GPS receiver deduces an individual's position and time from signals satellites receive.

In sum, there are benefits and drawbacks to both cellular and satellite navigation systems. Cellular navigation is more affordable than satellite navigation but needs more precision. The cost-effectiveness trade-off for satellite navigation is higher accuracy. You can trust your GPS receiver to provide accurate and reliable positional data regardless of the kind of navigation system you use.

7.4 Manual Override Systems

Manual override systems override the automated navigation system in case of a system failure. In these systems, the user takes control of the navigation system and manually enters the position, speed, and course of the vehicle or person. This type of system is generally used in cases where the navigation system is not functioning correctly or is not accurate enough for the desired application.

8 Future of GPS

The future of GPS is bright and appealing; modernization is one of the programs still taking shape as developers work to ensure they can upgrade the control segments and GPS space. The upgrade will have improved performances for market and user satisfaction.

Figure 25: GPS modernization

Source: https://egnos-user-support.essp-sas.eu/sites/default/files/training_material/LPV%20Training_package.pdf

The space and control departments are using cutting-edge technology to boost efficiency. As a result, traditional computer and communications systems are being phased out. A network-centric design is implemented to facilitate the transmission of satellite orders with greater frequency and precision. To finish the GPS modernization program, satellites like GPS IIR(M), GPS IIF, and GPS III must be obtained one after another.

The Next Generation Operational Control System (NGOCS) and the Architecture Evolution Plan (AEP) are also a part of the effort to upgrade the GPS control subsystem (OCX). This timetable details the maintenance schedule for the parallel space and control section. Also, the lost ones will be located using a GPS device in the future. Every automobile will have a GPS gadget to measure how many miles are traveled, and when someone fills up their gas tank, they can be taxed according to how many miles they have driven.

Advances in technology will enable GPS to become even more precise and reliable. One of the most significant advances in GPS technology has been the advent of autonomous vehicles. Autonomous vehicles use GPS to find their way around a designated area. The accuracy of GPS has enabled these vehicles to do things such as detect obstacles, avoid traffic, and find the most efficient route to a destination.

Another advancement in GPS technology is the development of tiny, low-cost receivers. These receivers are much smaller than those used in the past and can be used in various devices, including smartphones and tablets. This has enabled GPS to become more accessible to the public and has made it easier to use and more affordable.

One of the major advancements in the future of GPS is the development of more precise and accurate positioning. This will be achieved through the use of new satellite constellations, such as the European Galileo and the Chinese Beidou systems, which will provide more signals and coverage areas. Additionally, new receiver technologies, such as multi-frequency and multi-constellation receivers, will enhance the accuracy and reliability of GPS positioning (Kaplan & Hegarty, 2018).

Another significant development in the future of GPS is the integration of GPS with other positioning and navigation systems. This includes the use of complementary technologies such as INS (Inertial Navigation System), LiDAR (Light Detection and Ranging), and V2X (Vehicle-to-Everything) communication. These technologies can work together to provide more robust and accurate positioning, particularly in challenging environments such as urban canyons and indoor areas.

The future of GPS also includes improvements in the user interface and user experience. This includes the development of new apps and services that leverage GPS data, such as location-based advertising, social media, and fitness tracking.

Additionally, the integration of augmented reality (AR) and virtual reality (VR) technologies can enhance the user experience and enable new applications, such as indoor navigation and location-based gaming (Kaplan & Hegarty, 2018).

Augmented reality uses GPS to overlay virtual images, text, and audio onto the real world. This allows users to experience a more immersive experience when using GPS. For example, augmented reality can create interactive maps that give users more detailed information about their location, such as nearby restaurants, shops, and attractions.

Finally, in the future, GPS technology will be used in various ways. For example, it could provide more accurate weather predictions and better environmental monitoring. It could also be used to locate lost or stolen items and to provide real-time location data for emergency services. Overall, the future of GPS looks very promising. With advances in technology, GPS will become even more accurate and reliable. It will also become more accessible to the public and be used in various ways. The possibilities for GPS are genuinely endless.

9 Conclusion

The Global Positioning System, sometimes known as GPS, is a navigational system based on satellites and has fundamentally altered how we engage with the world around us. It helps us navigate and find our way around, gives us access to information, and puts us in touch with others. This innovation has revolutionized our day-to-day life. The development of GPS technology has made it possible for us to chart our routes and keep track of our travels, locate the establishments and shops that are geographically nearest to us, and even monitor our health and fitness.

GPS technology research and development have been ongoing for decades, and the technology has seen significant growth and refinement. The Global Positioning System (GPS) is an exact technology that may be utilized today in various applications, ranging from surveying and mapping to navigation and tracking. Research on GPS is constantly pushing the limits of what is now achievable with the technology, which is why it is such an essential part of a wide variety of businesses and applications.

Research on GPS has looked at various issues, ranging from the fundamentals of the system's architecture to the implications of GPS technology for our everyday life. Researchers have investigated the precision and dependability of GPS systems and how GPS data may enhance navigation, tracking, and mapping. The development of technology for global positioning systems (GPS) has also been a critical focus of study, as scientists have endeavored to produce more precise, efficient, and dependable systems.

This has included the creation of more sophisticated algorithms for satellite navigation, the implementation of enhanced hardware and software, and the development of novel techniques for the transmission and receiving of data. In addition to the advancement of GPS technology, a study has been conducted on the effects of GPS on our communities and the environment. Research has shown that global positioning satellites (GPS) can enhance public safety, reduce traffic congestion, and make communication easier.

In addition, research has investigated the possibility that using GPS might interfere with other systems, such as radio and television transmissions, and could endanger our privacy and security.

Over many decades, GPS has been one of the most important focuses of research and development. As technology has improved in accuracy and dependability, more and more researchers are turning to using GPS in their work. Researchers have used GPS technology to monitor the migration patterns of animals, investigate the planet's geology, and assess the impact of human activities on the natural world. In addition, GPS has been used in mapping the ocean bottom, monitoring agricultural production, and evaluating the effects of natural catastrophes.

One of the most powerful and forward-thinking applications of GPS research may be found in robotics. Researchers have successfully developed autonomous robots capable of exploring their surroundings and carrying out various duties thanks to GPS data.

There are various services for autonomous robots, including search and rescue, military operations, and scientific study. In the sector of agriculture, autonomous robots are also finding applications. These robots monitor crops, identify pests, and boost agricultural production.

Research-based on GPS technology has also been used in medicine. A patient's heart rate and breathing may be adequately measured using GPS, and doctors can utilize the technology to monitor their overall health while operating on them. In addition, GPS may be used to assess the efficacy of medical treatments and locate regions with an elevated risk of injury. Research on GPS has also been used to study the consequences of a changing climate on a global scale.

Researchers have gained a deeper comprehension of the effects of climate change on the natural world as a direct result of their work in monitoring variables such as sea level, air temperature, and others. Moreover, GPS has been used in the monitoring of the impacts that human activities have had on the natural environment. These activities include things like urbanization and deforestation.

The global community has been profoundly influenced by GPS research. Researchers have been able to comprehend the environment better and better safeguard it as a result of the data that GPS has provided, which is accurate and dependable. The Global Positioning System (GPS) has also been used to improve the effectiveness of various operations, including navigation, search and rescue, and more.

In conclusion, global positioning system technology has been used for the improvement of medical treatments as well as research on the consequences of global climate change. Research on GPS is an essential component of the scientific community. It will continue to play a vital role in advancing the overall comprehension of our world for years to come.

Research on GPS has, in general, had a considerable effect on our lives, and the technology itself continues to be a primary subject of a significant amount of academic investigation. GPS has wholly altered how we engage with the environment around us, making it more straightforward to get information and connect with others. Global Positioning System (GPS) technology is essential to our everyday lives.

Its continued development is anticipated to improve the system's accuracy and dependability; the Global Positioning System (GPS) has revolutionized how many people live and do business. GPS has enabled people to navigate from one place to another with great accuracy, and it has allowed for the development of a wide range of applications that can be used for various purposes.

GPS has been used in various military, commercial, and recreational activities, and the technology is continually evolving to meet the needs of its users. GPS is an invaluable tool that can help people find their way, save time, and increase safety, and it will continue to be an essential part of our lives for many years to come.

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