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A-GPS for Firefighting

ABSTRACT

Fighting fires in vast areas of bush can be a challenge for control centres to establish the location of fire units; however, determining the position of a GPS receiver under foliage is a difficult task, since the GPS signal is greatly attenuated by any object it passes through. Assisted GPS (A-GPS) is a relatively new technology that uses a network to transmit assistance data to the mobile receiver, where the network is usually a mobile phone network such as GSM. Emergency services in NSW have access to a wireless data network that has coverage in areas that these services normally access (such as bushland). GPS testing at the University of New South Wales showed that the attenuation through various types of foliage was no more than approximately 20dB, with acquisition time increases of no more than approximately 30 seconds. Through further investigation and field tests of attenuation of GPS signals through eucalypt foliage, it was found that the A-GPS system could circumvent this attenuation through its increased sensitivity. An A-GPS system was designed for this data network, using an existing standardised protocol that is used for the equivalent system designed for the GSM network. Performance testing showed the initial assistance data would take less than a second to transmit to the receiver, thus making the proposed system viable.

KEYWORDS: Assisted GPS, Attenuation, Emergency Services, Foliage, Sensitivity.

1. INTRODUCTION

Bushland is an area that lacks clearly identifiable features that would facilitate location

services. Determining the position of fire fighting units and personnel in bushland would increase the effectiveness and safety of their work, and provide valuable information for fire fighting control centres. The Global Positioning System (GPS) is an existing technology that can calculate the position of a receiver, nominally anywhere on Earth. GPS signals are weak under foliage; however Assisted GPS (A-GPS) provides help in these conditions when there is a base station that can assist. This is usually provided by a mobile phone network, which could also be used by communicating with the radio used by fire fighting personnel. Limited work has been performed on A-GPS as it is an emerging technology introduced in the past 5-6 years.

Emergency services all over the world are increasingly looking for data solutions to enhance the efficiency of dealing with emergency situations that require incident data. In the UK, many mobile data networks are being built specifically for emergency services including a tetra-based digital radio service, which is already being utilised by their Police and Ambulance services (Edwards, 2006).

Accurate positioning is one type of information that is required by many services that operate outside metropolitan areas, where identifiable landmarks such as buildings and streets are scarce. Bushland is one such area which lack readily identifiable features, and is an area commonly accessed by fire fighting personnel.

This paper describes the problems that GPS has, and proposes the use of a relatively new system called Assisted GPS (A-GPS), which will be designed to solve the problem for this particular situation.

The objectives for this paper are as follows:

- Research existing A-GPS systems and protocols for information on how different products operate.
- Investigate the effect of foliage on GPS signals, primarily the attenuation.
- Design an A-GPS system using the data network available to emergency services in NSW.

After fulfilling the above goals investigated in the following sections, the results suggest that the proposed system is feasible in terms of overcoming the attenuation of GPS signals through foliage, and also with respect to the limitations of the data network utilised.

2. SIGNAL PROPAGATION THROUGH FOLIAGE

2.1 Introduction

Typically, a GPS receiver would register SNR values of 45-50dB (Person, 2004) in open sky, usually tracking 6-9 satellites at any single time. Studies conducted by Babu et al (2004), at UNSW found that attenuation through foliage ranged from 6-11dB, which is significant enough to affect the performance of the receiver, especially during acquisition.

Attenuation during the tracking phase, however, does not tend to affect the receiver to the same degree that it does during acquisition. This is because it has already calculated the necessary parameters to track the satellites, and thus, a slightly reduced signal strength is still

adequate for the purpose. Significant attenuation, however, will degrade the performance of the receiver to the point where it regresses into acquisition phase once again, i.e. it “loses” the satellites.

A-GPS has been reported to provide sensitivity improvements of 20-25dB (Syrjärinne, 2001). Incorporating the figures obtained above for attenuation through foliage, an initial assessment would declare that A-GPS is sufficient to overcome any attenuation through foliage, hence making it a viable solution to the problem.

2.2 Field Tests

Prior research has found that the attenuation of GPS signals through foliage is not consistent for different types of foliage. The main field of interest was of course the SNR. As Australia is densely populated by eucalyptus trees, this type of foliage will be of focus for this paper.

Field tests were conducted using a GPS receiver and a laptop under various types of foliage to determine important parameters such as acquisition time and attenuation. The Signav 5001 GPS receiver took 1 measurement per second. Measurements were firstly taken in an open environment, with no foliage or buildings blocking the signal above the horizon. Another test was then done in nearby bushland or patches of foliage for each type of tree.

2.3 Field Test Results

TABLE 1 below shows the various types of foliage tested, and the effect they had on GPS signals after comparing the open air data to the measurements taken under foliage. The experiments were performed on the UNSW campus and calculations were performed thereafter.

From these results we can see that for Eucalyptus trees, the average attenuation is small enough for A-GPS to overcome, so this system is viable from this perspective.

Tree	Increase in acquisition time (s)	Avg Foliage Depth (m)	Avg canopy width (m)	Avg Attenuation (dBHz)
Ficus Columnaris	29.65	7.5	29	17.82
Ficus Macrophylla	32.8	3.69	19	11.57
Ornamental Pear Tree	29.4	3.22	7	4.35
Broad-Leaved Paper Bark	7.6	5.61	9	9.63
Hills Fig	15.4	9.42	17	14.33
Magnolia Grandiflora	4.8	5.8	9	12.01
Eucalyptus	8.3	7.1	10	6.32

Table 1. Results of field tests

3. ASSISTED GPS

3.1 Background

This paper is based upon a system called Assisted GPS (A-GPS). This system increases the sensitivity of the receiver by reducing its computational load and reducing the amount of data that it needs to receive from GPS satellites (Djuknic and Richton, 2001), which is only received at 50bps. The assistance data is transmitted to the receiver from an A-GPS server, utilising a radio or mobile network between the handset and the server.

Another advantage of A-GPS is the decreased Time-To-First-Fix (TTFF), since the receiver does not need to decode the satellite navigation message that would normally provide the handset with the required data. The handset usually has to search for satellite signals and decode the navigation message, but in A-GPS the network provides an initial position of the MS and decoded satellite ephemeris and clock information (Wikipedia, 2005) to reduce the TTFF.

There are two different modes of A-GPS that have emerged – MS (Mobile Station) Based and MS Assisted. In MS Based mode, the MS calculates the position, whereas MS Assisted mode requires the network to calculate the position and transmit it back to the MS.

3.2 Current A-GPS Systems

The past 5 years has seen the emergence of mobile phones embedded with GPS engines, the development of which has partly been fuelled by the US Federal Communications Commission's E-911 mandate, and the European E-112, which requires the location of a mobile user to be known to the emergency dispatch centre if an emergency call is made from that mobile. The location of a landline telephone can already be determined, since the phone itself cannot relocate, something a mobile phone was designed to do. In the past, various methods such as angle of arrival (AOA), time of arrival (TOA) and time difference of arrival (TDOA) using 3 mobile base stations were available method of determining a user's position. However, its accuracy has a large variability as it is heavily dependent on the cell configuration (Verbil, 2002). GSM cells can have different ranges, usually from 2km up to 20km, although theoretically, they have a maximum range of 36km. This variability means that the error in measurements taken by a base station will usually increase as the cell size increases. As a result, this system only averages an accuracy between 150m-500m, which is insufficient in an emergency. GPS can also determine the altitude of a receiver; therefore any emergency calls from a high-rise building can be located to a specific level.

This current system has been developed in conjunction with 3GPP, a standards body who has defined several protocols for use in A-GPS systems in mobile phone networks.

3.3 A-GPS Messaging Protocol

Radio Resource LCS Protocol (RRLP) is a protocol designed for GSM networks for A-GPS data. It defines the format for assistance data and positioning information to be transmitted between a mobile phone handset and the Serving Mobile Location Centre (SMLC) of a base station (3GPP, 1999).

There are five basic message components in RRLP:

- Measure position request
- Measure position response
- Assistance data
- Assistance data acknowledgement
- Protocol error

3.4 A-GPS Chipsets & Modules

With the recent development of location based services (LBS) using A-GPS systems in mobile phone networks, many manufacturers of GPS modules are now adding A-GPS functionality to their existing devices. Whilst there aren't many A-GPS modules available at this time, several appear to allow similar assistance data. These more common attributes are:

- Almanac or Ephemeris
- Time
- Initial (estimated) position
- Satellite clock corrections

These attributes belong to one mode of assistance known as MS Based A-GPS, where the receiver calculates the position. This method requires a full GPS module. Another method is called MS Assisted A-GPS, where the following assistance data is used instead of the above fields:

- Satellites in view
- Doppler
- Code phase offset
- Time

This method does not require a full GPS module, since it only performs some of the functions needed by a standard GPS receiver. In MS Assisted mode, a receiver will use the assistance data to locate the Satellite Vehicles (SV) in view and perform the pseudorange measurements, which is then sent back to the network for position calculation. Other variables that can be used to reduce error include the following:

- Ionosphere parameters
- UTC model
- Health bit mask

Some of these parameters can be transmitted to the receiver depending on the mode of operation (MS Based or Assisted), whilst others can simply be stored by the A-GPS server on the network side. This is advantageous for when the position calculation is performed on the network side rather than the receiver.

So the main question to be asked is – which mode is better for the fire-fighting application? An in-depth comparison between the two different modes is given in Chapter 4, where the two systems are proposed for implementation.

One advantage of A-GPS that has been outlined is the need for only a partial GPS receiver to perform the required functions. However existing handsets cannot be used and new handsets would be required. As a result, most likely to save development costs, most manufacturers have decided not to design a partial GPS receiver from scratch, instead using existing GPS chipsets that are incorporated into the new handset with the added functionalities required. It would appear that these manufacturers have decided that it would be cheaper to continue producing fully functional GPS receivers and just add A-GPS functionality on top of the existing structure. Analysis of the different A-GPS modes of operation in Chapter 4 will reveal whether this decision will either harm or help this system.

Upon further more recent analysis, there has been the release of modules and chipsets that not only support both modes of A-GPS, but are also fully functional GPS receivers as well, thus allowing autonomous mode in addition to the assisted modes. This would make the chipset an all-in-one item, which is able to work in all conditions.

Caution must be exercised however, since whilst most A-GPS modules support both MS Based and Assisted modes, the assistance data that they accept vary between modules. The Satellite Navigation and Positioning Group (SNAP) at the University of New South Wales (UNSW) has conducted research investigating the different types of A-GPS receivers on the market today, and the various types of assistance data that they accept (unpublished consultancy work). Some products that claim to support MS Assisted mode don't accept Doppler information, which is essential in that mode of operation.

3.5 Wireless Network

A dedicated data-only mobile network is available to all emergency services in NSW. Details of this network remain confidential for security purposes and were not released to the author: however it is known to currently have a capacity of 8kbps, and there are also options that can increase this rate if the number of users, or the load, increases beyond this capacity. The spectrum allocated to the network is in the bottom of the UHF range, which is widely used for 2-way radio, mobile phones and television.

Since little is known about the network, several assumptions must be made to determine some aspects of its operation. These assumptions will be based on characteristics of existing similar networks and what characteristics and are as follows:

- The advertised speed of 8kbps is actually 8kbps. This speed only refers to the radio link between the base station and the handset. This is the speed that is accessible to the users, hence, any overhead due to error checking and correction techniques (e.g. CRC) are transparent to the user in terms of data capacity. Thus the full 8kbps is allocated for information transmitted and received by any handset. Therefore, any tests that are conducted for performance shall use this figure and disregard error-checking overhead.
- Precise locations of all base stations are known. This is essential for the operation of the system, as all reference locations for handsets will be the location of the base station. Even if the base stations themselves are in the field (i.e. mobile) their positions can be determined simply by using a GPS receiver at each location, possibly using Differential or RTK GPS for greater accuracy, if required. The server will also be able

to find out which SVs are visible for each base station, since the server has access to almanac data that is otherwise unused for the rest of the system.

- The base stations are interconnected using wireline or wireless technologies, ensuring extremely fast transmissions between the base stations and the server.
- There are multiple channels for each base station, similar to a phone network, where multiple users can connect to the base station. Each of these channels will have a capacity of 8kbps allocated to it.

4. SYSTEM DESIGN

Two possible configurations will be presented – MS Based and MS Assisted.

4.1 MS Based

The main characteristic of MS Based A-GPS is that the position is calculated in the MS itself. FIGURE 1 below is the block diagram of such a system, and shows the functions of the receiver and the assistance data it uses at a specific point in the cycle. FIGURE 2 shows the transfer of information between the receiver and the server.

A description of the components is given below FIGURE 2.

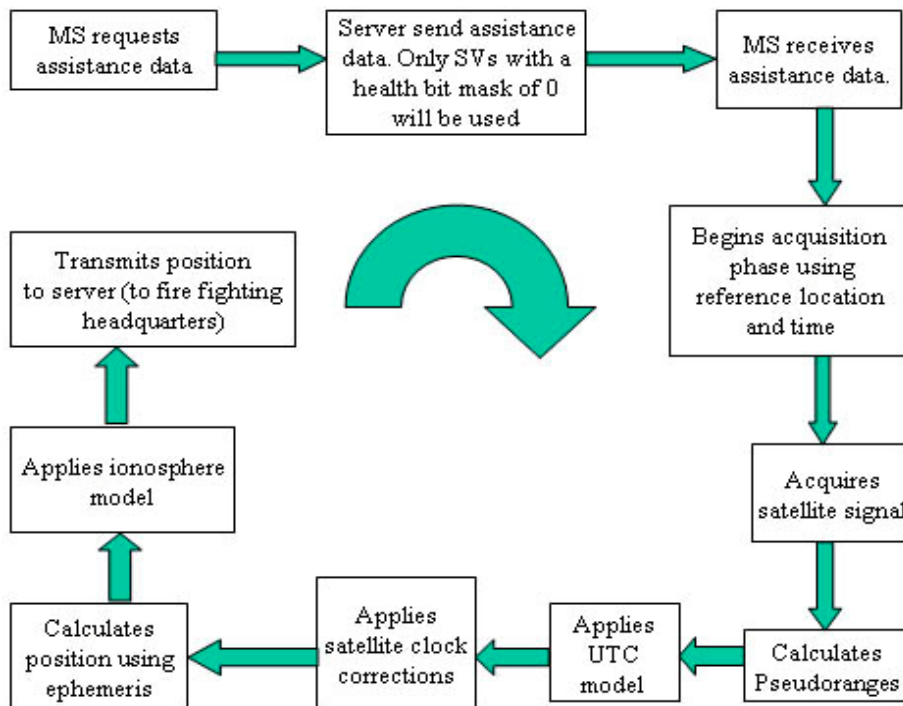


Figure 1. Block Diagram of MS Based A-GPS

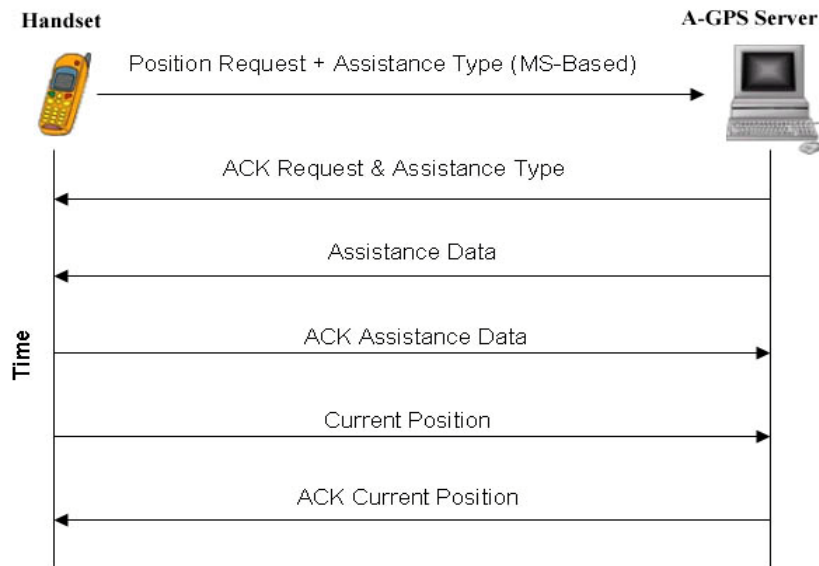


Figure 2. Transfer of information in MS Based A-GPS

4.1.1 Server tasks

The main role of the server in this mode of operation is to supply the MS with the relevant assistance data. The assistance data consists of the following fields:

1. Ephemeris
2. Reference Time
3. Reference Location
4. Satellite Clock Corrections
5. UTC Model
6. Ionospheric Model

1. Ephemeris

The server will know which satellite ephemeris data to send, as it will either see the same satellites itself, or if it is remote, then it will have an approximate idea of the MS position.

2. Reference Time

This refers to the difference in time between GPS time and the time-stamp that is applied by the server which then transmits the data to the base station of the transmitting tower of the network.

3. Reference Location

This is an estimated position that is calculated by the server, taking into consideration the area that the base station covers, and the time taken for the signal to travel between the base station and the receiver (since the packets travelling between them are time-stamped). The simplest location is that of the base station itself.

4. Satellite Clock Corrections

Clock corrections are usually transmitted by each satellite and include data such as clock offset and clock drift, which accurately model the actual difference and the rate of change between the satellite's time-stamp and GPS time (Dana, 2000).

5. UTC Model

This set of parameters describes the differences between GPS time and UTC, and is usually transmitted by each satellite.

6. Ionospheric Model

These are a set of parameters that model the propagation of GPS signals through the ionosphere (TIA, 2002). A "two frequency" user (receiving frequencies L1 and L2) is able to correct the time delay attributed to ionospheric delay by utilising the time delay between L1 and L2 (ICD-GPS-200C, 2003). However, this requires a more sophisticated receiver that is capable of receiving the L2 frequency, which was designed and is dedicated for military use. Hence, for single frequency users, this model presents a more cost-practical method of reducing the error introduced due to ionospheric delay.

The server can get these assistance fields from several sources. The server itself can be positioned anywhere, but linked to a GPS receiver that has full view of the sky. For example, many existing A-GPS systems involving CDMA networks utilise the GPS receivers that are already in each Base Transceiver Station to provide network synchronisation. These are in open areas that suit the receipt of GPS signals. Thus, their locations are already known, and are used as a reference location for handsets that are connected to it. The servers for these systems, however, might be located elsewhere, where technicians can routinely perform maintenance and other necessary duties. Of course, multiple servers will exist for redundancy and to handle the load during busy times.

The server will also be required to update the assistance fields, as required to ensure that any position fixes are accurate. This is crucial for emergency services, especially fire services, where fires can move at an alarming speed, and the personnel that follow them don't necessarily know where they're going. Errors in such conditions can easily result in injury or even death.

The server will update the fields regardless whether there is a request for assistance or not. Since the server cannot determine or predict when a request may occur, constant updates must take place to ensure that the data is kept new. Given that the server will be connected to a full GPS receiver in full view of the sky, it will be able to receive all navigation signals from GPS satellites, and this will be transparent to the end-user (handset).

Data received by the server for each satellite will only be transmitted to the receiver if the health bit mask of that satellite is zero. The health bit indicates whether the satellite is working well and is fully operational, which is usually indicated by a zero, or several zero bits. Anything other than that may indicate either problems with the satellite or maintenance being performed. Server-side filtering of the satellites that shouldn't be used will reduce the amount of data transmitted to the receiver, as well as reducing the number of tasks required by the receiver. This is also something critical, as reducing the load on the receiver will lead to better TTFF results, and more accurate position fixes.

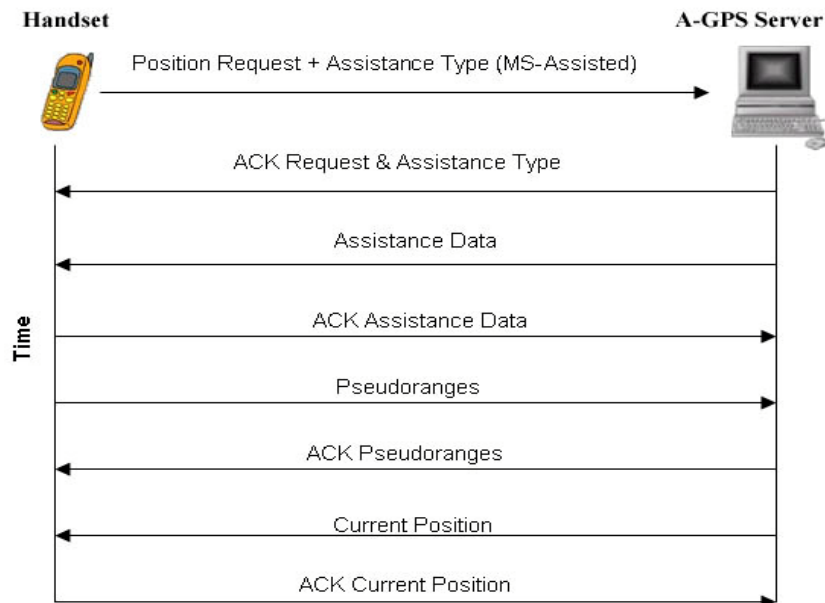


Figure 4. Transfer of information for MS Assisted A-GPS

4.2.1 Server tasks

The server has the main roles of providing the MS with assistance data, as well as calculating the position. The assistance data used in this mode differs greatly from the MS Based mode. The purpose of the assistance fields in this mode of operation is to help the MS locate the satellites by reducing the search space required. The assistance data sent to the MS consists of the following fields:

1. SV in view
2. Doppler
3. Code Phase offset
4. Reference Time

1. SV in view

Rather than the MS trying to figure out which satellites it can view, this job is given to the server, the same way the server does it for MS Based mode. In this case however, the server only transmits the PRN identifiers of each satellite to the MS, rather than the corresponding ephemeris and clock correction parameters for each of those satellites. It is then up to the MS to locate those satellites using the other assistance data provided by the server.

2. Doppler

A Doppler shift is the relative change in frequency of a signal which is caused by the relative movement of the transmitter and receiver. Transmitting Doppler information to the MS allows the receiver to gain help when acquiring the GPS signal, reducing the size of the Doppler search. Doppler can also be calculated from position, time and almanac.

3. Code Phase offset

These are the GPS measurements which are based on the C/A code. This set of data helps the

MS acquire the satellite signal, reducing the size of the delay search. By reducing the Doppler and code delay range in the searches, longer searches can be used in a given total time, resulting in acquisition of weaker signals.

4. Reference Time

The reference time transmitted by the server is the same as in MS Based mode, and also has the same purposes. As in MS Based mode, the server also checks the health bit mask first before transmitting any data for any satellite.

The other main role the server has is to calculate the position of the MS, which it will do based on the pseudoranges transmitted to the server by the MS. Once the MS has calculated the pseudoranges, it transmits a message to the server containing this information, and the server uses this to calculate the handset's position. It does this by using ephemeris data for each satellite that the MS can view, and also applies correction data to reduce any errors. Ionospheric parameters and the UTC model can be applied as per the situation in MS Based mode. The server can then transmit the position back to the MS if required.

4.2.2 Receiver tasks

The main roles of the receiver are to locate the satellites using the supplied assistance data, and continually track the signal from them. The receiver can then calculate the pseudoranges using code phase measurements and transmit this data to the server for position calculation.

The first task of the receiver however, is to initiate communication with the server by requesting assistance data from the server and specifying which assistance mode is required (MS Based or Assisted).

There is less computational load on the receiver in this mode as it does not have to calculate its position or receive large amounts of assistance data from the server.

4.3 Preferred Solution

MS Assisted has the following advantages compared to MS Based mode, with respect to the environment considered for this paper:

- Less assistance data transmitted to the MS.
- Less data sent over the network.
- Position calculation is centralised so any software problems can be fixed at one location rather than fixing many handsets.
- A particular application may not even require the handset to know its location, thus saving transmission of the position across the network, saving the limited bandwidth.
- Less computational load on the handset.
- Only a partial GPS receiver is required.
- Shorter TTFF.

On the other side of the coin, MS Based has the following advantages over MS Assisted mode:

- Distributed processing – no single point of failure.

- Better position accuracy.
- Larger range of assistance data to help perform faster accurate position fixes.
- High sensitivity in receivers and good assistance data can perform fast and accurate position fixes.
- Better tracking capacity – once the receiver is tracking it doesn't need to keep asking the network where it is if a sequence of positions is required.

Most A-GPS manufacturers are using full GPS receivers, hence it is more likely that these receivers will be used for any implementation, especially for it to be cost effective. A-GPS using MS Based mode utilises a full GPS receiver. Hence, research has been conducted to determine if there is a way to increase the sensitivity of the receiver such that A-GPS in MS Based mode can perform just as well as A-GPS in MS Assisted mode, in terms of TTFF. Several commercial A-GPS products employ weak signal tracking techniques, which increases the sensitivity of the receiver to allow acquisition of the GPS signal much faster, and in environments with a lower SNR.

Testing by various companies (such as Ublox, Motorola, Infortech and Navman) has shown that using weak signal techniques in an A-GPS product can increase the sensitivity by approximately 10dB, thus providing a viable alternative to using MS Assisted mode, which only requires part of a GPS receiver, which are rarely produced for mass production economic reasons.

Hence, MS Based has been deemed to be more suitable for this application. Some of the defining characteristics for this decision include the lack of A-GPS chipsets and modules that fully support MS Assisted mode. Another key criterion involves weak signal tracking techniques, whereby the sensitivity of the receiver is higher than other more general A-GPS chipsets. There will also be less computational load on the server, as it will not have to calculate the position for every handset that requests assistance data for location services. This will become very important during times of high load, where literally hundreds of bushfires may take place and the TTFF becomes extremely important.

Another important reason for this decision is that MS Assisted will require more bandwidth, even though it requires fewer bits for its assistance data. The assistance data required for MS Based is not updated as often as the assistance data required for MS Assisted mode.

5. PERFORMANCE EVALUATION

5.1 Protocol Data

As discussed earlier, a modified RRLP is the protocol to be used in this system. The modification does not really change a lot in the existing protocol, but instead reduces the data that is required, to the extent that it does not overload the network but still maintains full operability with respect to this system. The exact details of these bits will not be included here for brevity.

TABLE 2 and TABLE 3 below show the total number of bits that would need to be transmitted to the receiver in different GPS environments, i.e. a different number of satellites may be visible at any time. Four satellites is the minimum for any receiver to attain its position, eleven is usually the maximum number of satellites visible to any receiver (clear sky), and seven is perhaps what this system will be experiencing. The “once-only bits” are

bits that either have no relation to the satellites, therefore occurring only once, or they are only required once and are not updated regularly.

TABLE 3 shows the total number of bits required for each scenario of visible satellites, including the number of once-only bits as well.

Field	bits/satellite	per 4 satellites	per 7 satellites	per 11 satellites	once-only bits
Navigation Model	459	1836	3213	5049	4
Ionospheric Model	0	0	0	0	64
UTC Model	0	0	0	0	104
Reference Time	24	96	168	264	41
Reference Location	0	0	0	0	72
TOTAL	483	1932	3381	5313	285

Table 2. Number of bits required per satellite and once-only bits (Server to MS)

Field	total bits - 4	total bits - 7	total bits - 11
Navigation Model	1840	3217	5053
Ionospheric Model	64	64	64
UTC Model	104	104	104
Reference Time	137	209	305
Reference Location	72	72	72
TOTAL	2217	3666	5598

Table 3. Total number of bits for each scenario.

We can see that even if the receiver tries to determine its position in clear sky, at 8kbps, it will take the server approximately $0.7s \left(\frac{5598bits}{8000bits/sec} \right)$ to transmit the assistance data. This is quite a good figure and makes this system viable.

6. CONCLUSIONS

Various field tests showed that the attenuation of GPS through foliage is low enough such that A-GPS can operate successfully. Manufacturer testing of their commercial products show that this assumption does not lack foundation in a practical sense. Basic performance testing of the designed system shows that the transmission of the navigation data will take less than 1 second, which is fast enough to satisfy the probable requirements for navigation for fire fighting services.

Implementing this system in real life will obviously introduce inconsistencies and errors that generally occur for any communications system. However, this paper does not aim to determine the practical implications but merely to outline how A-GPS can be applied to different applications – the focus here is obtaining the position of a mobile receiver using a radio network that has limitations not usually seen in commercial and publicly accessible communication systems.

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