DIFFERENTIAL SATELLITE POSITIONING OVER INTERNET

Ying. GAO and Zhi. LIU
Department of Geomatics Engineering
The University of Calgary
2500 University Drive N.W.
Calgary, Alberta, Canada T2N 1N4
Tel: 403-220-6174   Fax: 403-284-1980
Email: gao@geomatics.ucalgary.ca

ABSTRACT

A differential GPS positioning system is able to provide more precise position solutions than a stand-alone system through the application of corrections calculated at a reference station or a network of reference stations with known surveyed coordinates. Differential corrections are usually transmitted to the users via radio, beacon or communication satellite. In this paper, the concept of differential GPS positioning based on wireless Internet has been described. To assess the feasibility of the proposed method, a prototype system has been developed and tested in the field using CDPD-based wireless Internet access. The field results have shown satisfactory positioning accuracy and differential data latency over the Internet. In addition to Internet advantages for wireless communication, the use of the Internet to develop new positioning methods has also been discussed.

1. INTRODUCTION

Measurements made from Global Positioning System (GPS) are affected by a number of error sources including satellite orbit error, satellite clock error and atmospheric effects. Autonomous GPS positioning is therefore subject to the effects of all the above error sources and can provide positioning accuracy only in the neighborhood of about 10 meters. Therefore, in order to achieve higher positioning accuracy such as in the order of meter to centimeter level, differential GPS (DGPS) techniques must be employed.

The objective for DGPS is to reduce the error sources within the GPS satellite clock and orbit data, atmosphere effects as well as other errors due to GPS receivers. Using DGPS method, at least two GPS receivers must be used with one serving as a reference receiver station with precise known coordinates, and the other as the rover station for which positioning is required. The reference station is used to generate differential corrections be applied by the rover station to reduce the above mentioned error sources and subsequently to derive an improved position solution. Due to the use of a reference station, the method is effective only for short reference-rover separations because the spatial correlation of the error sources between the reference and rover stations reduces as the increase of the reference-rover separation. DGPS positioning using a single reference station is often referred as Local Area DGPS (LADGPS).

To increase the effective area of the generated differential corrections, multiple reference receiver stations are often employed to form a reference network. Dependent on the size of the network, there are two different types of reference networks, namely,

a) Wide Area DGPS (WADGPS) network and

b) Regional Area DGPS (RADGPS) network.

A WADGPS network focus on providing differential correction service continental-wide even worldwide while a RADGPS network focus on a region of hundred kilometers in dimension (Gao et al., 1997). A number of different WADGPS and RADGPS networks have been implemented to date and many others are currently under development. The US Wide Area Augmentation System (WAAS) is a typical example of WADGPS networks whose reference station separations are typically a few thousand kilometers apart (Loh, 1995). WAAS differential corrections are currently available with obtainable position accuracy at the meter-level although the network is not yet fully operational. On the other hand, a RADGPS network consist of multiple reference stations separated in the range of several hundred kilometers and the Swedish SWEPOS network is a typical example of such networks (Hedling, et al., 1996).

For real-time applications, no matter what type of DGPS systems you may implement, a continuous data link must be established between the reference network and the remote users in order for the DGPS users to receive the network generated differential corrections. For local and regional area differential positioning, radios and local communication systems are typically used while for wide area differential positioning satellite communication is appropriate although it is much more expensive to use. As the advance of Internet technology and its fast expansion of the coverage and mobile accessibility, it has been widely demonstrated that the Internet could become a cost-effective and efficient alternative for a wide range of applications including differential positioning that we will discuss in this paper.

This paper describes recent research results in the use of Internet as the communication link for differential positioning and navigation applications. The paper will show that Internet-based differential positioning systems are advantageous when compared to current DGPS systems. The technology will not only improve the efficiency of implementing DGPS technologies but also potentially expand significantly the application spectrum of DGPS technology with new differential positioning methods.

The paper is organized as follows. The paper will first provide a brief description of the Internet and its characteristics as a communication tool. Differential satellite positioning using Internet and a prototype system are then described followed with the introduction of a new Internet-based mobile-to-mobile solution to multiple moving platform applications. Field test results are finally provided to assess the obtainable differential positioning accuracy of an Internet-based system and its feasibility to be used in operational environments.

2. WIRELESS INTERNET ADVANTAGES

Internet is characterized by its low cost, easy accessibility, availability, flexibility, and expandability. Currently the expense

of connecting to Internet is very reasonable and will be much cheaper in the future. In the past several years, Internet has been evolved into one of the most important communication methods. Many applications are also increasingly required to be Internet-based due to its fast and worldwide accessibility. Internet is able to provide many advantages over the conventional radio data transmission method if used for differential positioning applications. Some of them are described in the following.

First, Internet is not limited by an effective data transmission range limitation, which implies the rover station can be away from the base station as far as the user needs. In fact, Internet theoretically can reach any corner of the world and its communication range is not constrained by factors such as the horizon requirement.

Secondly, Internet can be accessed in any place where there is an Internet access either in the office or field. This also makes it affordable to operate many additional reference sites for large WADGPS network beyond those critically needed sites to provide improved network redundancy. Subsequently, improved redundancy guarantees continuous service even if some reference stations go down unexpectedly. Since the Internet keeps expansion daily now, its accessibility will be further enhanced in the future while with reduced cost.

In addition to the above, the Internet has also overcome the narrow frequency bandwidth associated with the conventional radio communication method. As the result, a reference station if based on Internet can serve as a virtual reference station and the only requirement is that the user should have access to the Internet. If using radio communication instead, the rover users then have to use the same type of radio and frequency used at the reference station in order to receive the differential data from the base station for DGPS positioning.

An Internet-based differential positioning approach is particularly advantageous for differential positioning in regions with severe signal interference or for applications with large number of rover users such as fleet and mobile assets. A convergence of technologies, particularly the integration of location, information management, wireless communication systems, regulations and business opportunities is creating a rapidly emerging market known as location-based service, wireless location or location commerce, a multi-billion dollar market in the next five years. In fact, Internet is now being considered the communication standard for the development of future location-sensitive information services such as location-aware billing and advertising. It is expected that Internet will be increasingly used in the future as an efficient communication alternative to conventional methods.

3. AN INTERNET-BASED DIFFERENTIAL POSITIONING PROTOTYPE

An Internet-based WADGPS network implementation has been described in Muellerschon et al (2001) where the focus was placed on the network development using Internet to transmit reference site data to the processing center. In this section, we focus on the development of an Internet-based differential positioning prototype for the DGPS user to access the network differential correction data via Internet.

The prototype system consists of a reference station and multiple rover stations. The system configuration of the developed Internet-based system is depicted in Figure 1. The reference station consists of a navigation receiver capable of generating RTCM differential correction data and a server computer. The server computer at the reference station can be either directly connected to the Internet via a local area network or wirelessly connected to the Internet via a wireless modem. On the other hand, each rover station consists of a rover navigation receiver, a client PC computer and a wireless

modem. The client PC computer wirelessly links to the Internet using the installed wireless modem via a communication network to receive differential data from the reference station.
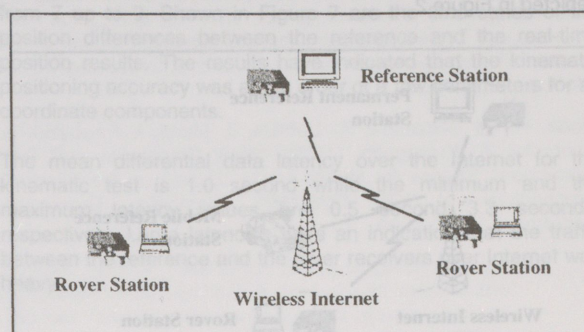

Figure 1: Internet-based DGPS Positioning

The transmission time taken for the user to retrieve the differential correction data from the reference receiver station determines the differential data latency for the positioning. Less than a few seconds of data latency is typically required for most DGPS applications. To minimize the data transmission latency and its subsequent influence on the DGPS positioning accuracy, the Internet protocols should be carefully selected which defines how the data are transmitted through the Internet. Internet currently uses a Transmission Control Protocol/Internet Protocol (TCP/IP) suite to connect all the networks, organizations and users across the world. Transmission Control Protocol (TCP) and the User Datagram Protocol (UDP) are two important transport protocols that have been widely used for Internet applications.

TCP provides a stream delivery and virtual connection service to applications through the use of sequenced acknowledgment with retransmission of packets when necessary while UDP provides a simple message delivery for transaction-oriented services. TCP is able to provide highly reliable data transmission since it takes extra time to ensure reliability, flow control, and connection maintenance. As a price for the superior reliability, the TCP protocol may not suitable for high precision real-time applications such as Real-Time-Kinematic (RTK) positioning because it requires an acknowledgement of data arrival and any lost data must be sent again [Hada et al., 1999]. Compared to TCP, UDP is able to provide faster data transmission although the reliability is not as high as TCP with a possibility of data losses. Since fast differential data transmission is essential for the success of a real-time positioning system to derive accurate positions, UDP protocol has been utilized in this research to test the performance of the developed Internet-based DGPS system.

4. INTERNET BEYOND COMMUNICATION

Although the previous focus has been on the use of the Internet as a communication tool for differential positioning applications. The Internet advantages, however, could help create new methods to the use of satellite navigation systems. It is expected that high precision location information will be no longer a luxury but basic commodity of daily lives. In the following, the concept of mobile-to-mobile differential positioning is described as an example. We definitely will see more new developments in the near future.

Although the establishment of a reference network of multiple reference stations is able to extend the differential correction coverage to large area, the distance between the users to any of the reference stations is often still too long for high precision positioning. This is particularly true for RTK applications. Deployment of highly dense reference stations on a permanent basis seems too costly and difficult to implement. To tackle the

problem without adding new permanent reference station, a mobile reference station can be used as a bridge to tie the rover users to the permanent reference stations. The concept is depicted in Figure 2.
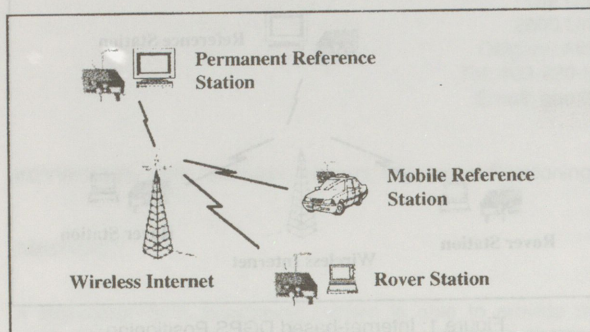

Figure 2: Concept of Mobile Reference Station

From Figure 2, we see that the proposed mobile-to-mobile solution employs a mobile reference station whose separation to either the permanent station or the rover user is less than the separation between the rover user and the permanent reference station. Because the shorter baseline length between the permanent reference station and the mobile reference station, the latter's position can be precisely determined using RTK technology where integer ambiguity resolution becomes feasible. The difference between the mobile reference station and the permanent reference station is that the mobile reference station is usually mounted in a vehicle so the mobile reference station must wirelessly access the Internet. Once the precise position of the mobile reference station is known in real-time, it can be applied to serve as a reference station for the rover users. Since the baseline length between the mobile reference station and the rover user is shorter than before when the rover user is directly differencing with respect to the permanent reference station, it allows the rover user to conduct high precision RTK positioning because integer ambiguity resolution becomes feasible now.

The above concept can be extended to more general multiple moving platform situations where precise RTK positioning is conducted with respect to multiple moving or mobile reference stations (Luo, 2001). Since each mobile user need to access differential corrections from all mobile reference stations, communication bandwidth is a concern if using conventional radios. In this regard, the Internet provides an excellent alternative with no bandwidth barriers. The concept is described in Figure 3.
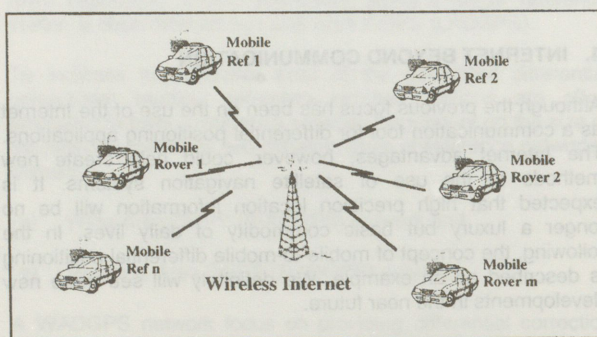

Figure 3: Concept of Mobile-to-Mobile RTK System

5. FIELD TESTS AND DATA ANALYSIS

The Internet-based prototype system described in Section 3 has been tested in the field to assess its positioning performance and feasibility under operational environments. The performance analysis is conducted in a kinematic mode using phase-based Real-Time-Kinematic (RTK) technology.

The wireless equipment used in the test includes an Ethernet NIC linking the reference station to the Internet and a Merlin Wireless PC Card from NovAtel Wireless Inc to allow the rover user to wirelessly access Internet via a Cellular Digital Packet Data (CDPD) network. In the city of Calgary, the CDPD service is provided by Telus™ Corporation with an operational speed of 19.2 Kbps which is sufficiently high for the RTCM message transmission in RTK positioning.

A kinematic field test was conducted in Calgary on February 11, 2001. Two Ashtech GPS+GLONASS single frequency receivers were used as the reference and rover receivers, respectively. The antenna for the reference receiver was setup on the roof of the Engineering Building at the University of Calgary with precisely known coordinates (Figure 4). During the test period, the reference receiver was connected to the server PC from which the differential data was made on-line over the Internet. The rover receiver was installed in a vehicle and the receiver antenna was set up on the roof of the vehicle (Figure 5). Connected to a laptop computer, the rover receiver retrieves the reference differential data from the CDPD modem installed on the laptop.

Figure 4: Reference Receiver Station

Figure 5: Rover Vehicle Station

During the field test, the vehicle was driven away from the campus and the maximum baseline length between the reference receiver and the rover receiver was up to about 12

kilometers. A data rate of 1 Hz was used for the kinematic test. In addition to the real-time RTK position outputs, the raw measurements from both the reference and the rover receivers were also saved for post-processing.

To assess the kinematic positioning accuracy, a high precision reference trajectory of the vehicle must be established. In this investigation, the raw measurements collected during the kinematic test were post-processed using a commercial software package and the position results were then used as the reference. Compared to the reference position results, the accuracy of the real-time RTK position outputs could then be assessed.

Shown in Figure 6 are the PDOP values and the number of visible satellites for the kinematic test during which the PDOP value was around 2.0 while the number of visible satellites was from 7 up to 9. Shown in Figure 7 are the time series of the position differences between the reference and the real-time position results. The results have indicated that the kinematic positioning accuracy was at the order of a few centimeters for all coordinate components.

The mean differential data latency over the Internet for the kinematic test is 1.0 second while the minimum and the maximum latency values are 0.5 second 3.3 seconds, respectively. Large latencies were an indication that the traffic between the reference and the rover receivers over Internet was heavy.
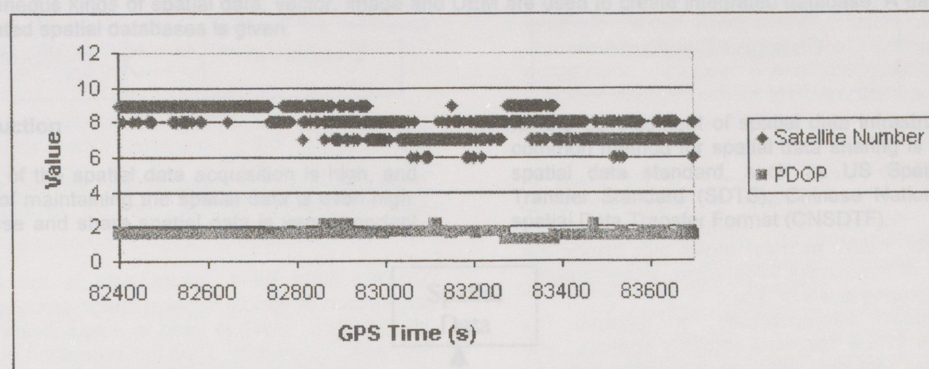

Figure 6: PDOP and Number of Visible Satellites in Kinematic Test
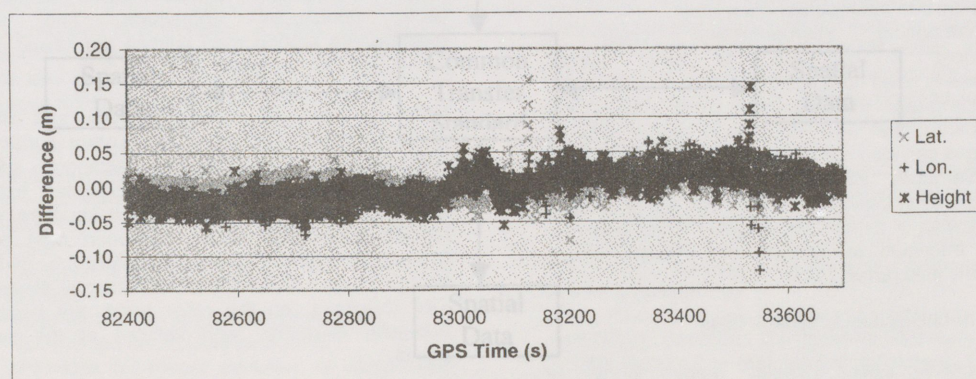

Figure 7: Kinematic Internet-based RTK Positioning Accuracy

6. CONCLUSION

The concept of conducting differential satellite positioning over Internet has been described in this paper. In addition to the Internet advantages for wireless communication, the use of Internet to develop innovative applications using satellite navigation systems has also be explored including the introduction of a new mobile-to-mobile solution for multiple moving platform application.

To validate the concept, a prototype system has been developed and tested in the field. The test results have demonstrated that the data transmission latency over the Internet is typically at the level of one second while the obtainable positioning accuracy is at the centimeter level when using Real-Time-Kinematic (RTK) technology. As the fast advances of the Internet technology and its increased

accessibility in the near future, Internet will help the development of new location system and device, not only cost-effective but also available anywhere at anytime, to support a wide range of applications including the emerging location-based services (LBS).
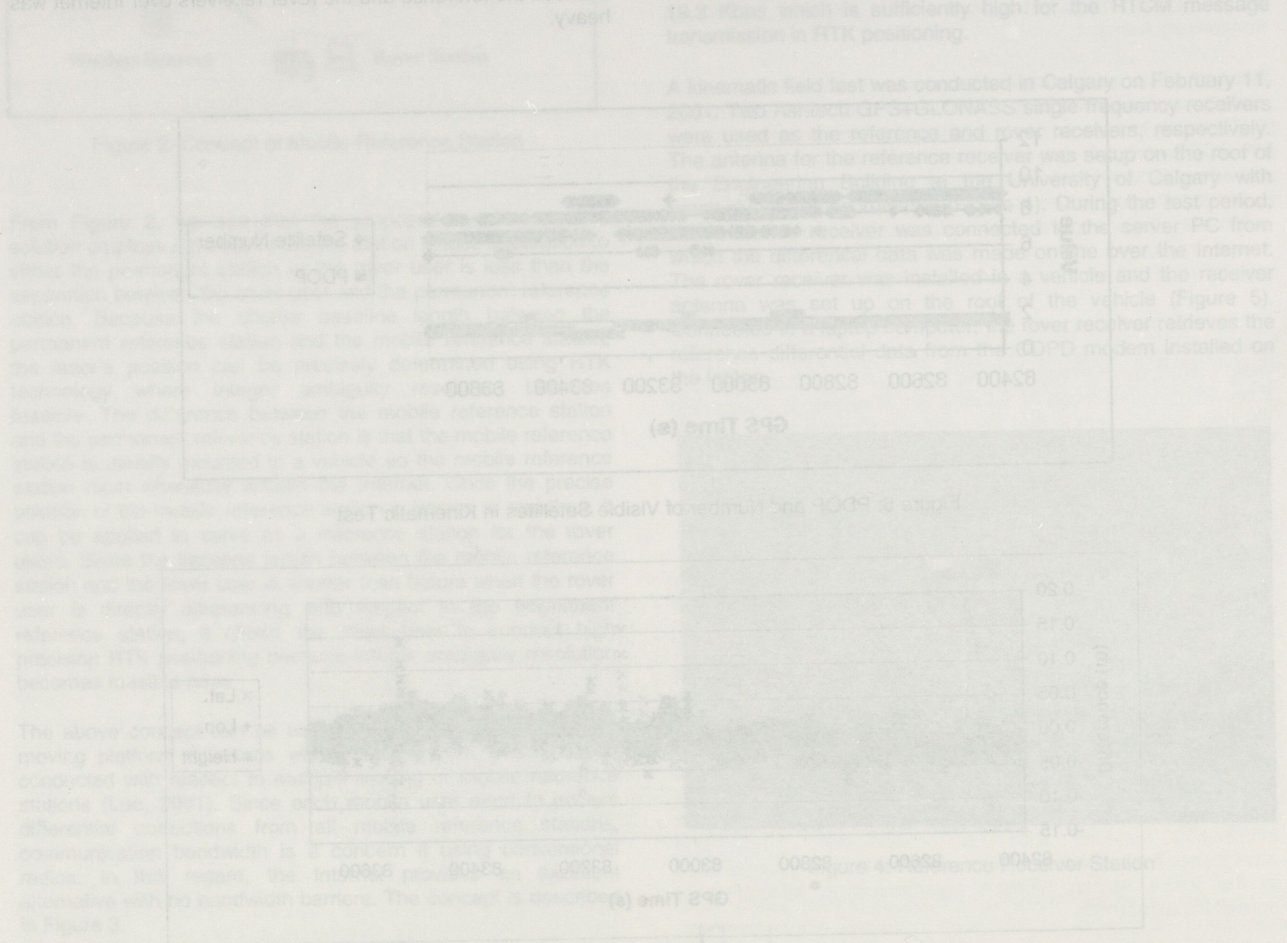
REFERENCES

Gao, Y., Z.F. Li, and J.F. McLellan (1997). "Carrier phase Based Regional Area Differential GPS for Decimetre-Level Positioning and Navigation", Proceedings of ION GPS-97, The 10th International Technical Meeting of the Satellite Division of the Institute of Navigation, Kansas City, Missouri, September 16-19, 1997, pp. 1305-1313.

Hada, H., H. Sunahara, K. Uehara, J. Murai, I. Petrovski, H. Torimoto, S. Kawaguchi (1999). "New Differential and RTK Corrections Service for Mobile Users, Based on the Internet", Proceedings of ION GPS'1999, Nashville, Tennessee, September 14-17, 1999.

Hedling, G. and B. Jonsson, (1996). "New Developments in the SWEPOS Network", Proceedings of ION GPS-96, Kansas city, Missouri, September 17-20, 1996, pp. 1803-1808.

Loh, R. (1995). "Seamless Aviation: FAA's Wide Area Augmentation Systems", GPS World Magazine, Vol. 6, No. 4, pp. 20-30.

Luo, N. (2001). "Precise Relative Positioning of Multiple Moving Platforms Using GPS Carrier Phase Observables", UCGE Report No. 20147, Department of Geomatics Engineering, The University of Calgary.

Muellerschoen, R., Y. Bar-Sever, W. Bertiger and D. Stowers (2001). NASA's Global DGPS for High-Precision Users". GPS World Magazine, Vol. 12, No. 1, pp. 14-20.