Combined Use of GLONASS and GPS in Electronic Tolling

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Abstract
We present a new On Board Unit (OBU) hardware platform which is being prepared for tolling applications based on Global Navigation Satellite Systems (GNSS). The new OBU has an integrated chipset which receives both GPS and GLONASS signals simultaneously. Higher position accuracy has been achieved in critical environments in which GPS signals alone are insufficient. Taking advantage of both satellite systems, GNSS-based tolling technology can overcome many of the limitations it has faced until now, such as urban canyons in downtown areas having very tall buildings or very narrow streets. The first results of the deployment of the new GPS/GLONASS platform are presented.

Keywords:
On Board Unit, GLONASS, Global Navigation Satellite System (GNSS), Open Road Tolling, Electronic Tolling, Urban Canyons.

Introduction

The GLONASS satellite positioning system of the Russian Federation is starting to take a prominent place alongside GPS for commercial positioning applications. Since October 2011, the full orbital constellation of 24 GLONASS satellites enables complete global coverage. Some of the newest smartphones are already using chipsets which combine both GPS and GLONASS positioning information, improving both the reliability and the accuracy of the position data, particularly in challenging environments. A GNSS device using both satellite systems has a clear advantage in getting better and / or more reliable positioning data. This principle also applies to Electronic Tolling systems using GNSS technology. An OBU using both GPS and GLONASS signals simultaneously provides remarkably good positioning results in demanding settings, as we will demonstrate. While high expectations are being made on the future introduction of the European GALILEO system, GLONASS already provides many of the advantages that are anticipated once GALILEO is in full operation. Furthermore, the constellation of GLONASS provides some technical advantages which are beneficial to GNSS-based tolling that are not given by GPS or by GALILEO.

Current Growth of GNSS Technology in Electronic Tolling

Since the beginning of 2005, GNSS tolling has been in use for electronic tolling, with the launch of the nationwide truck tolling scheme in Germany. Currently, about 800,000 German OBUs are in use. In the past few years, GNSS technology has advanced to a point where a relatively small and cost-effective plug-and-play OBU can be installed in a matter of minutes by the driver, as is the case with the nationwide truck tolling scheme in Slovakia (Figure 1).

The Slovak tolling system was launched at the beginning of 2010, and more than 200,000 GNSS OBUs have been deployed. In Slovakia, the use of GNNS OBUs for vehicles above 3.5 tons is mandatory – not only on the motorways, but also on all major first-class roads. With a tolled road network of nearly 2500 km, the Slovak tolling scheme the second largest in Europe after Germany. In 2013, France will also introduce an obligatory GNSS-based tolling scheme on approximately 13,000 km of national roads. Currently, tenders in other EU member states are being prepared for nationwide tolling schemes; it is anticipated that these new tolling systems will be based on GNSS technology.

Figure 1 – Windshield-installed GNSS *Sensus Unit* used in Slovakia (and soon also in France)

Growing need of Position Accuracy for GNSS-Based Tolling

Until now, GNSS-based tolling schemes have only been deployed in large nationwide schemes. The German system requires supportive roadside infrastructure to assist the OBUs in achieving greater position accuracy in critical areas. The GPS data derived by the OBU used in Slovakia has proven to be accurate enough without the need for any additional positioning information - thanks to the deployment of algorithms specially developed to improve the accuracy of toll-section recognition.

Parallel Roads

In critical situations, such as a parallel toll-free road running parallel to a tolled motorway, greater position accuracy could become a valuable asset. Figure 2 shows the tracking data of the new GPS / GLONASS OBU placed in a vehicle driving along a parallel road in Bratislava that is separated from the motorway by a single wall. It is clearly visible that the vehicle equipped with this new GNSS OBU was on the parallel road and not on the motorway.

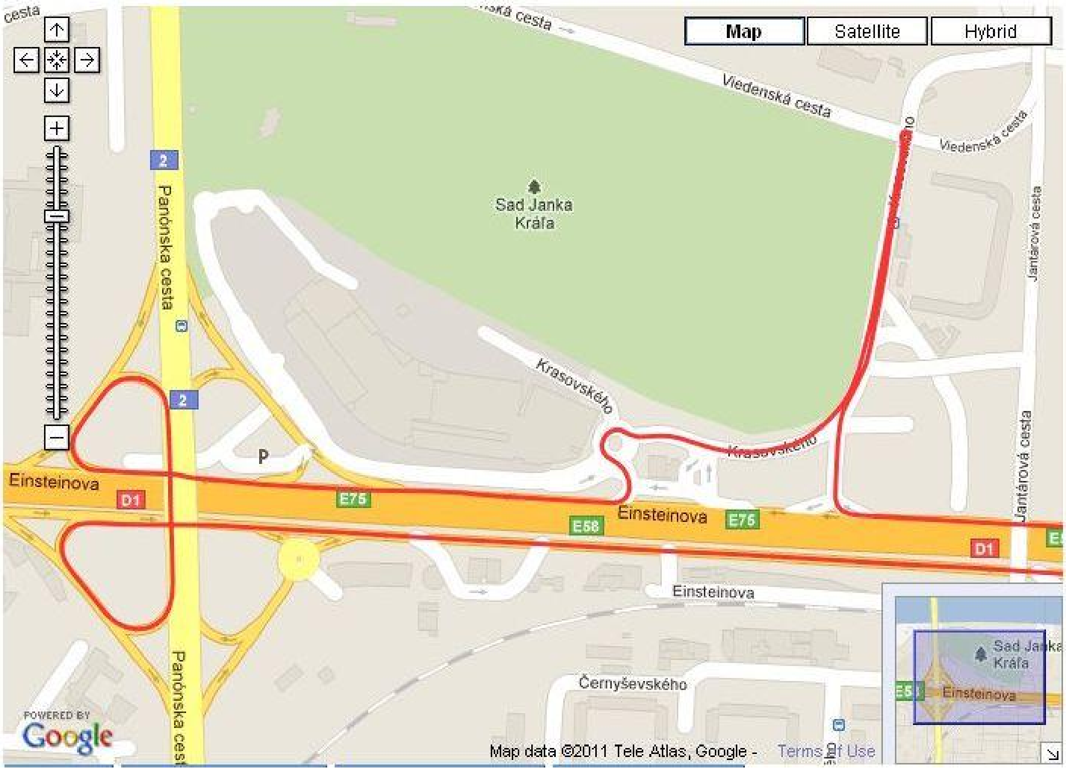

Figure 2 - A trip in Bratislava, on a parallel road to the motorway

Although the current toll system can successfully distinguish all parallel (tolled) roads in Slovakia (with the use of special algorithms), the need for accurate toll segment detection along parallel roads will surely grow as nationwide tolling schemes follow the Slovak example of tolling all major thoroughfares – rather than just the motorways. As GNSS-based tolling systems become more wide-spread, such demanding circumstances will appear more often and there will be an increasing need for higher position accuracy. When the nationwide truck tolling scheme in France is launched in mid-2013, the GNSS solution will need to overcome considerable challenges in order to correctly identify toll sections on parallel roads and in urban centers.

Urban Canyons

One of the major challenges for GNSS-based tolling has been the level of accuracy possible in urban canyons, where the number of reliable satellite signals is reduced significantly (as illustrated in Figure 3). By using both GPS and GLONASS simultaneously, about twice as many satellite signals can be received on average, thus improving position accuracy dramatically.

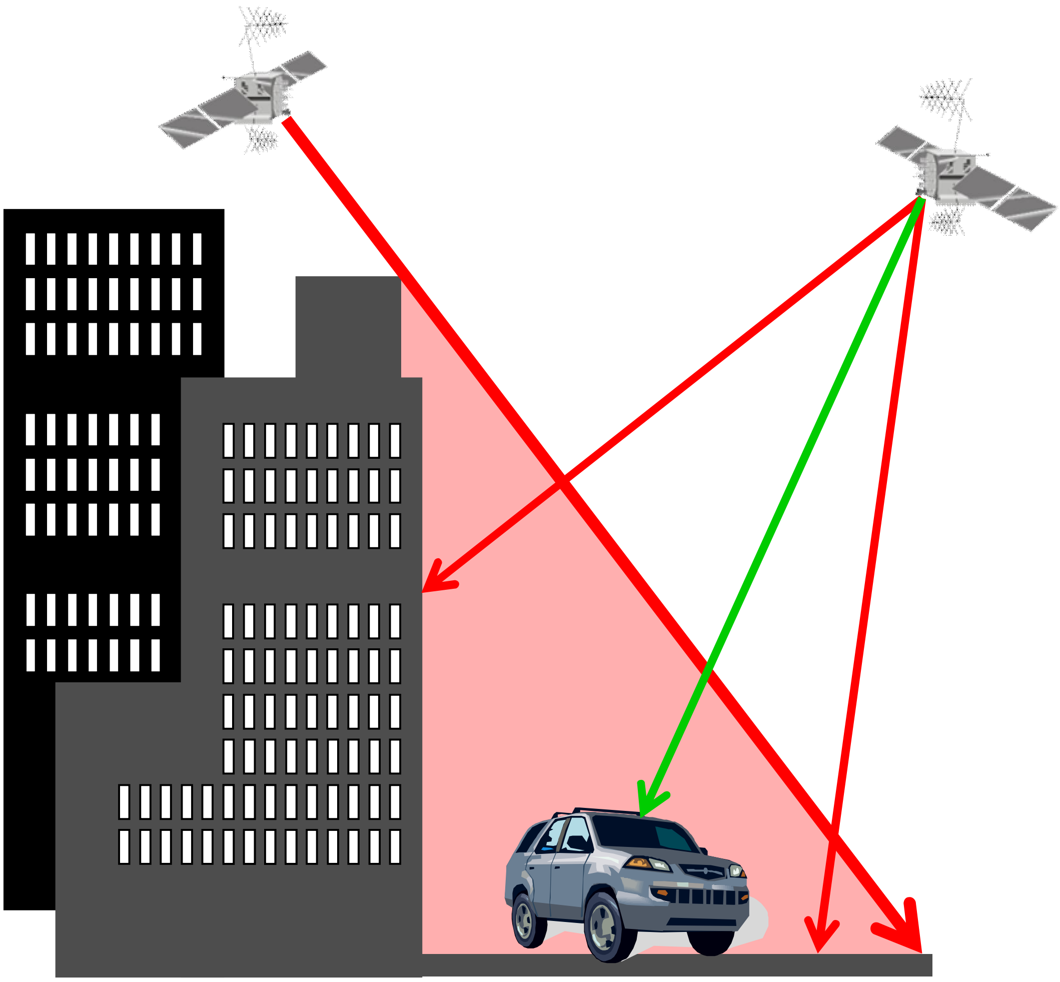

Figure 3 – Severe reduction of satellite reception in Urban Canyons

On an overcast November evening, a trip was taken through the narrowest streets of Vienna's historical old town using both a conventional GPS OBU as well as with an OBU having the combined GPS-GLONASS chipset. Figure 4 illustrates the typical problems of GNSS-based systems passing through urban environments when using only GPS (on the left). Yet, when both GPS and GLONASS are used simultaneously, the OBU has drawn a nearly flawless path through those narrow streets (as is shown on the right). Such accuracy will become necessary when GNSS is used for charging vehicles based on the distance travelled in city centers.

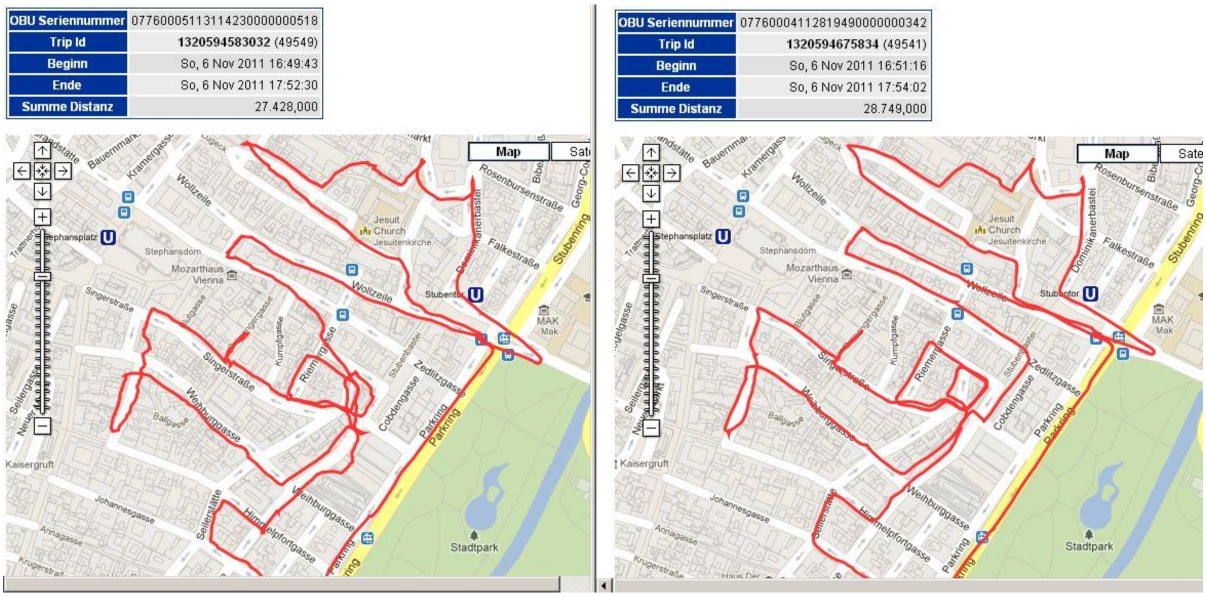

Figure 4 - A trip through the center of Vienna's Historical Center with a GPS-only OBU (left) and a combined GPS/GLONASS OBU (right)

Higher Latitudes

At present, tolling schemes based on GNSS technology have not yet been implemented in regions of higher latitudes. This should change radically by 2014, when the Russian Federation launches the largest tolling system in the world. By then, up to two million vehicles in Russia will be equipped with GNSS-based OBUs for the payment of distance-based fees on the entire federal road network of 50,000 km. For several years, Sweden has also been exploring the development of GNSS-based technology for its own nationwide truck tolling scheme, and Finland has recently begun its own investigations on the subject as well.

At very high latitudes, the level of GPS position accuracy drops significantly – at levels which would most likely compromise the performance of a distance-based tolling scheme. As Figure

5 illustrates, GPS consists of 24 satellites in 6 planes inclined at 55 degrees to the equator – thus providing less coverage at the poles. GLONASS, on the other hand, comprises a constellation of 24 satellites placed on 3 planes, inclined at 63 degrees to the equator.

Figure 5 – The orbits of GLONASS Satellites (left) and of GPS Satellites (right)

Therefore, on high latitudes (north or south), the accuracy of GLONASS is better than that of GPS due to the "steeper" orbital position of the satellites. In fact, a Swedish firm has been using GLONASS for GNSS-based services since 2011.[1] Using GLONASS in combination with GPS will thus make it possible to create distance-based tolling schemes in Russia, Scandinavia and other regions which until now would have faced major obstacles in achieving a satisfactory level of position accuracy.

Other Technical Advantages of GLONASS as compared to GPS

In addition to the advantage of having a unique orbital constellation as compared to GPS, GLONASS has other characteristics that set it apart from GPS. Whereas GPS signals are transmitted on a single frequency, using Code Division Multiple Access (CDMA), GLONASS satellites transmit their signals on multiple frequencies by means of Frequency Division Multiple Access (FDMA). In other words, GLONASS signals have a higher noise immunity which can improve the overall position accuracy. This might prove to be useful with respect to "jamming" of the satellite signals which could compromise the position accuracy to the point where distance-based tolls could no longer be reliably calculated in a GNSS-based system.

A major motivation for the development of the European GALILEO positioning system has been the desire to become less dependent on GPS signals for critical applications, such as

[1] http://www.reuters.com/article/2011/04/11/us-russia-sweden-glonass-idUSTRE73A1S320110411

tolling systems which in larger countries can generate revenues of several billion Euros annually. In 2008, for example, the GPS signal was disabled in the former Soviet Republic of Georgia, making it impossible for civilian GNSS receivers to function. For a nationwide tolling scheme based on GNSS positioning, this would translate into a significant loss of revenue. Whereas the reliance on GLONASS alone could carry similar risks in terms of the system being (temporarily) disabled, GNSS positioning based on two independent satellite positioning systems – GPS and GLONASS – significantly mitigates the risk of total revenue loss of a tolling system requiring reliable position data.

Next steps towards full integration of combined GPS / GLONASS GNSS OBUs

We have created a series of OBUs using one of the first commercially produced GPS / GLONASS chipsets, integrated into the “Sensus Unit” platform. After running a series of field tests with these units under a variety of road environments in several countries, we are currently preparing the complete integration of a new generation of GPS / GLONASS chipsets for mass production.

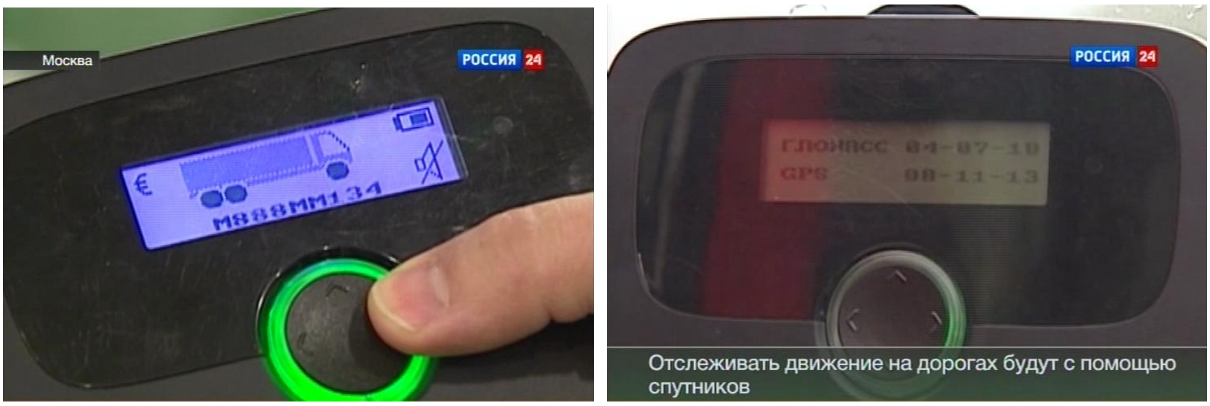

Figure 3 – Demonstration of the GPS / GLONASS OBU Functionality in Moscow, in which also the simultaneous reception of GPS and GLONASS signals can be viewed in real-time (right) [2]

The first series of GPS / GLONASS OBUs demonstrated the added robustness of the GNSS solution as compared to its “traditional” counterpart based on GPS only. These units also successfully passed formal benchmark testing in Russia in 2011, in preparation of the highly ambitious nationwide truck tolling scheme which should be implemented as early as 2013.

Due to the difference of GLONASS signalization described above, it is necessary not only to select and integrate a high-performance GPS / GLONASS chipset into the OBU hardware

[2] Photos provided courtesy of *Rossiya 24* television news channel.

platform, but also an appropriate built-in antenna which can accurately receive the wider frequency range of GLONASS signals in addition to the GPS signals. This integration process should be completed by the end of 2012, after which the adapted *Sensus Unit* platform will be prepared to address the new challenges of GNSS-based tolling environments reviewed above.

Conclusion

As of today, GNSS-based tolling systems are still an exception in the domain of electronic tolling schemes. However, in the coming years several countries will be implementing new – and very large – GNSS-based schemes. The number of installed GNSS-based OBUs will soon multiply from a few hundreds of thousands to several million units. Thus, the demand for higher position accuracy in increasingly demanding tolling environments will continue to grow. Once GNSS-based tolling systems are deployed across Europe (and eventually in other continents), the dependency on a single satellite system – until now GPS – will become a growing commercial risk.

As we have seen, the combination of raw data from both GPS and GLONASS has already yielded excellent positioning accuracy. The use of algorithms for improving toll section recognition, like those that have already been successfully deployed in Slovakia, will surely further improve the tolling accuracy of future GNSS-based schemes which take advantage of the GLONASS satellite positioning system in addition to GPS.

By using both GPS and GLONASS, GNSS-based tolling solutions can overcome many of the limitations that are currently faced in demanding environments. Thanks to the increased position accuracy demonstrated by the combined GPS/GLONASS module described above, we can anticipate a significant reduction in the implementation cost of future GNSS schemes that take advantage of multiple satellite signals; in many circumstances, the need for installing supporting roadside infrastructure to improve position accuracy will become obsolete.