Making the Slovak Tolling Network the Largest in the EU

With the Use of GNSS Technology

Norbert Schindler
Global Sales Manager, Siemens Electronic Tolling
Siemensstrasse 90, 1210 Vienna, Austria
norbert.m.schindler@siemens.com

Abstract
Within three months, the expansion of the Slovak National Truck Tolling scheme from 2,447 kilometres to 17,762 kilometres has been implemented, making the Slovak system the largest in the European Union. We demonstrate how the use of Global Navigation Satellite System (GNSS) technology enables the rapid and cost-effective deployment of a significant extension of the tolled road network, without requiring the construction of road-side infrastructure. A total of 3,162 new road segments have been added to the geographic model that is stored in more than 200,000 On Board Units (OBUs). The update of the geographic data to the OBU happens automatically over the air, without any interruption to the underlying tolling application, securing all toll revenue income. The objective of this paper is to provide a clear picture of the flexibility of GNSS technology for road user charging by the example of the real conditions on the Slovak road network. Due to the advantages of this technology, changes were implemented in a very short time, with low costs, thus supporting high toll collection efficiency.

Keywords:
Global Navigation Satellite System, Electronic Toll Collection, Nationwide Truck Tolling.

Introduction

Slovakia introduced its Nationwide Truck Tolling Scheme on 1st January, 2010, after an implementation period of only 11 months. From the beginning, the system was operated for all vehicles over 3.5 tons – on motorways, expressways and first-class roads. The total length of the original tolled road network was 2,401 kilometers, making it the second largest tolling system in the European Union under the management of one operator, after Germany [1]. In Slovakia, for the first time the majority of the tolled roads were first class roads, as opposed to tolling only motorways and highways. Thus, the problems experienced in other countries with similar tolling schemes, where large numbers of trucks leave the major road network in order to avoid paying the road usage fees, were averted. When such traffic diversion occurs, the

secondary road network suffers significant damage, causing an increase of maintenance overhead, traffic congestion, and resulting in a significant loss of toll revenue. In Slovakia, one third of the overall toll revenue was generated on the tolled first class roads in the first three years of operation. The Slovak road authority decided to extend the tolled road network to a majority of public roads, thus eliminating the potential for any traffic diversion that could be motivated by toll evasion. As a result, the use of the road network has been optimized and higher toll revenues are expected. This has been made possible by the deployment of advanced GNSS technology which enables an optimal approach to accurately toll a wider variety of road networks [2]. A map of the initial tolled road network, which was valid until the end of 2013, is provided in Figure 1. Along the major motorways (red), the parallel first class roads (orange) are clearly visible.

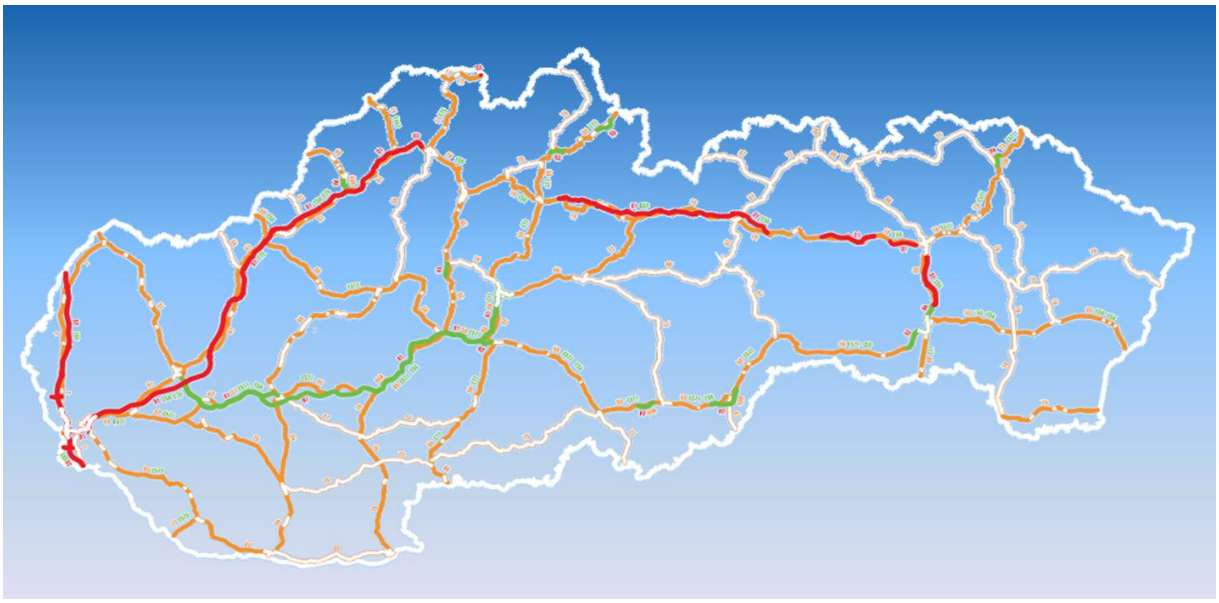

Figure 1 – Tolled Road Network until end of 2013

Extension of the Tolled Road Network in Slovakia

Starting with 1st January 2014, the Slovak Electronic Toll Collection (ETC) has undergone its most significant change since the original implementation. The charged road network was extended from 2,447 km, until the end of 2013, to a total 17,762 km. The most significant addition has been the inclusion of second-class and third-class roads, with a total of 13,479 km. The Slovak republic has therefore become the country with the longest road network in a road user charging scheme within the EU – and the only one covering the complete network of existing first, second, and third class roads. The dramatic extension of the tolled road network is illustrated in Figure 2, in which all the new tolled roads are shown (in light colors).

The legislation containing these changes was approved by the Parliament on 27th November 2013, yet the implementation of these changes already commenced in October 2013. It was

possible to effectively realize such significant changes in the ETC in such a short time – in only three months – thanks to the flexibility of the GNNS-based technology which was deployed in Slovakia from the very beginning.

Figure 2 - Tolled Road Network from beginning of 2014

GNSS Technology Deployed in Slovakia

Slovakia was the first country to deploy a "plug and play" GNSS-based On Board Unit, which can be installed by the driver in a matter of minutes [3]. A photo of the second generation OBU is shown in Figure 3. Much like the microwave-based systems installed in the neighboring countries of Austria, Poland, and the Czech Republic, the Slovak OBU makes a tone each time a tolled road segment has been passed. This informs the driver that a "virtual toll gantry" has been passed and that the user has been charged for the road segment via electronic payment. According to the tolling laws, truck drivers in Slovakia (as in other neighboring countries) are required to report potential technical errors when the OBU does not properly acknowledge the passage of tolled road segments.

The Slovak solution uses the existing infrastructure of GSM networks to enable the data communication between all OBUs and the back office (where registration, billing, and other central services are performed). In other words, the OBUs are basically "online" and can receive updates at any time, thus enabling updates of the geographic data to the OBU. Furthermore, virtually all required modifications to the OBU software or to the firmware of hardware components such as the GSM module, the GPS receiver, or the DSRC module, can be performed over the air without disturbing the underlying tolling application, thus securing the toll revenue income.

Figure 3 – The second generation "plug and play" GNSS OBU used in Slovakia

Technical Implementation of the Extension in Slovakia

In order to implement the expansion of the tolled road network, thousands of "virtual gantries" have been added to the existing geographic model originally consisting of 1,132 road segments. From the beginning of 2014, a total of 4,294 road segments are tolled. For this deployment, engineers defined geographic locations on a digital map that identify the passing of a vehicle's OBU through the toll segment – in some cases even less than 100 meters in length. Standard raster maps with scaling factors from 1:2,000,000 to 1:2,500 are imported to a specially-developed geographic tool in which intersections of the tolled road network can be identified. With each tolled road segment, the most ideal positions for the virtual gantries are found and then "drawn" in place on the graphic interface, as illustrated in Figure 4.

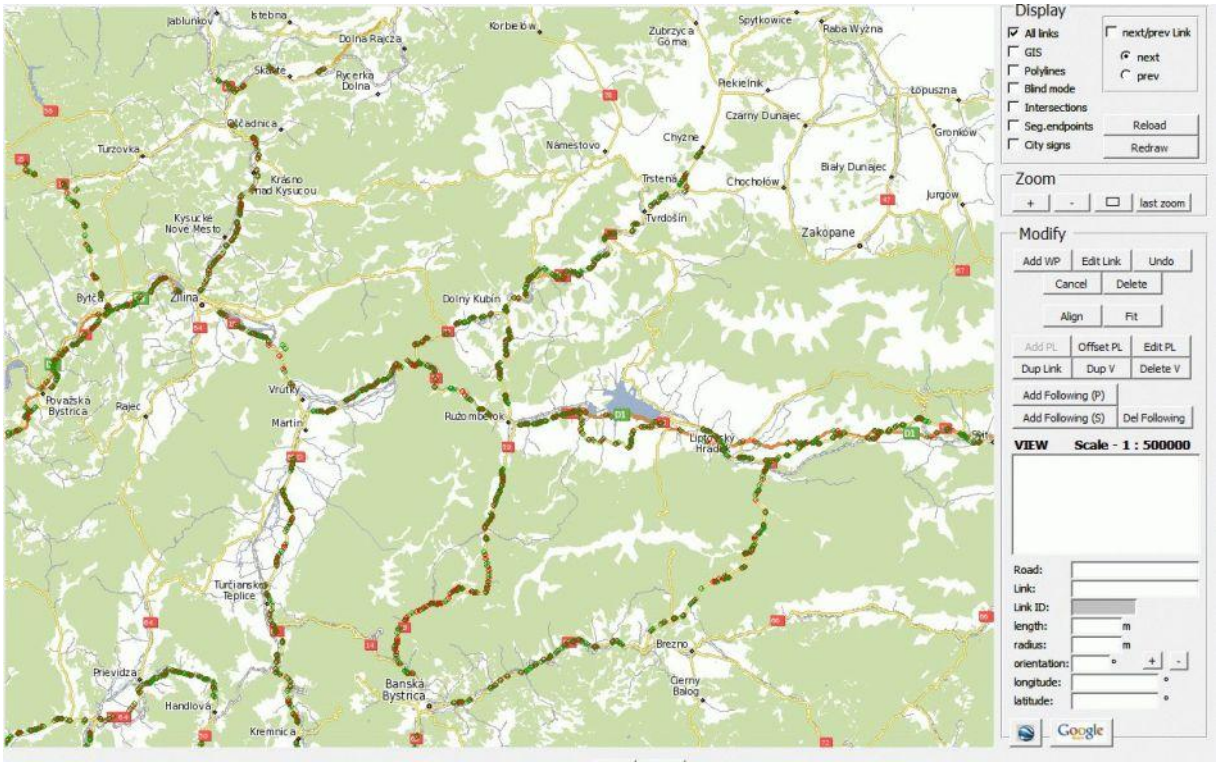

Figure 4 – The graphic environment used for geographic modelling of toll roads

The so-called "waypoint algorithm" was developed to optimize the correct recognition of tolled road segments. With this patented algorithm, the tolling system in Slovakia has achieved an effective toll segment recognition rate well above 99% from the first day of operation. For each direction of travel on a single road segment between two intersections, two points are positioned on the map, using the geographic interface: an initial "entry point" and a second "confirmation point." These direction-specific points are defined in the geographic model to insure that the correct tolled road segment is identified; if a vehicle were to pass the virtual gantry in a different direction (i.e. at an intersection or over a bridge), the segment would not be recognized. The use of two recognition points also assures that the correct toll segment is identified in cases where a parallel road is nearby. Thanks to this algorithm, no supporting infrastructure is needed at the roadside for correct segment recognition – even in environments where the positioning data provided by GPS signals would be insufficiently accurate for other navigation applications, such as map-matching.

A section of the detailed geographic model is shown in Figure 5: the small red circles on the map are the entry points, the green circles are the defined confirmation points. The direction for each point is also seen within the circle. In some cases, the confirmation points are shared in both directions when the toll segments are especially short, as illustrated in the bridge crossing over the river in the center of the map.

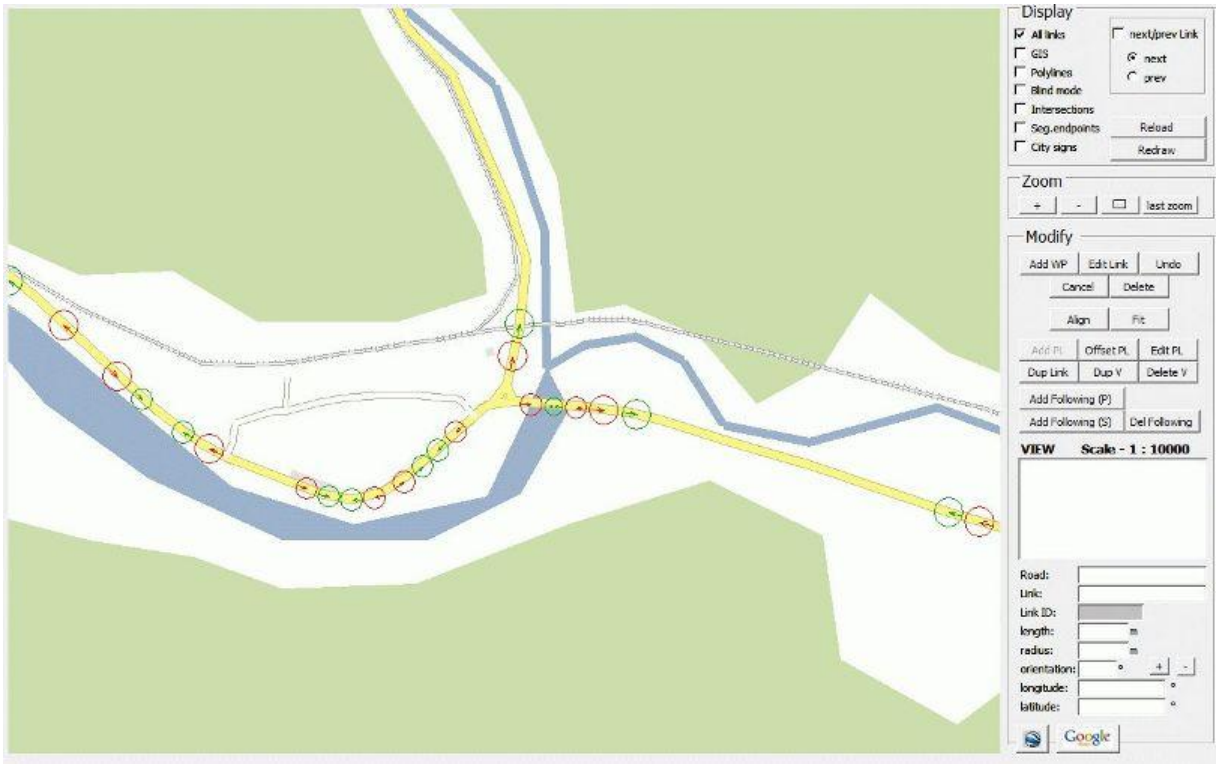

Figure 5 – A close-up of the geographic model with entry points (red) and confirmation points (green) for accurate toll segment recognition

Once the new geographic model has been defined over the entire road network, the new data is transmitted from the back-office system to the OBUs using the data service of the GSM networks. From 1st January 2014, each OBU has received the update automatically from the moment it was activated in the New Year (i.e. when the engine of the tolled vehicle was turned on). For vehicles entering the country from abroad, the OBUs are updated from the moment they enter the tolled road network of Slovakia.

Advantages of GNSS Technology as Compared to Microwave Technology

Seven European states have now introduced nationwide truck tolling schemes: Switzerland, Austria, Germany, the Czech Republic, Slovakia, Poland, and Hungary. These systems use either Dedicated Short Range Communication (DSRC) microwave technology or GNSS for a multi-lane free flow approach. Switzerland uses both technologies, but the fee is based on the total number of kilometers travelled on all roads as measured by the vehicles' tachograph. Austria, the Czech Republic and Poland implemented a DSRC-based system, requiring the erection and maintenance of microwave infrastructure at each and every tolled road segment. An investment in roadside infrastructure makes sense when the tolled road network is relatively small and the number of vehicles being tolled is relatively high, since large numbers of microwave tags installed in the vehicles can be produced inexpensively. Conversely, if initial investments are made in satellite-based On Board technology – rather than in microwave infrastructure – the higher cost of GNSS OBUs becomes negligible for large and

complex tolled road networks which would otherwise require enormous investments in roadside equipment for thousands of road segments.

The limitations of DSRC technology become particularly evident when a tolled road network should be expanded. For example, if the extension of the additional 3,162 road segments in Slovakia would have required the installation of microwave-based infrastructure, an additional investment of more than €100 million would have been needed for the roadside equipment alone. Furthermore, land would need to be purchased along many of the roads, thousands of building permits would be required, and new power lines would need to be installed. The operational costs of thousands of microwave installations along the tolled roads would multiply these capital investment costs over the years. With the GNSS approach, the cost of the extension of more than 15,000 km of tolled roads in Slovakia was marginal – a small fraction of the initial investment costs of the tolling system. After the first three months of operating the extended road network in 2014, the additional revenue generated by the tolling system in this short period has nearly paid back all of the financial investments needed for this extension in Slovakia [4].

By comparison, the Czech Republic launched its tolling system on 970 km of motorways and highways in 2007, using DSRC technology. The original Czech tender and subsequent contract to the General Contractor of the toll system required an extension of the tolled network with an additional 1,300 km of first-class roads after one year, for a total of 2,270 km. However, due to the high costs required for the installation of DSRC infrastructure on these roads, only 170 km of these additional first class roads were actually tolled by 2008 [5]; in 2013 the total length of the Czech tolled road network was still less than 1,400 km [6]. The Czech Ministry of Transportation thus established an “Expert Group” already in 2007 to investigate the how to extend the tolled road network to first, second and third class roads by using GNSS technology.

In Poland, the DSRC-based tolling system was launched in 2011 on 1,543 km of roads, mostly motorways and expressways. Since then, in increments of six to twelve months, a monthly average of 37 km of roads have been added to the tolled network. By the end of 2013, a total of 2,634 km of roads have been tolled in Poland after the stepwise construction of DSRC-based roadside infrastructure throughout the country [7]. Of course, with each added kilometer of tolled roads, additional revenue is generated. One can imagine that the level of toll revenues in Poland could have been much higher from the very beginning, if the initial network already included all the roads that were foreseen for tolling. With a GNSS-based approach, this would have been easily possible [8].

Extensions of Tolled Roads in Other Countries using GNSS

Also in Austria, the political debate has recently intensified with regard to the nationwide truck tolling scheme being extended from the motorways to all of the first class roads, or „Bundesstrassen." It is argued that many trucks avoid the tolling fees and drive for free on these other roads, causing significant damage to the road surface for which regional authorities do not have sufficient financial means to repair. As was the case in the Czech Republic, an Expert Group is being formed in Austria in order to investigate the extension of the existing DSRC-based tolling system to regional roads through the deployment of GNSS technology [9].

The flexibility of GNSS-based tolling technology is also being demonstrated in other countries. In Germany, in August of 2012, the tolled road network of nearly 13,000 km of motorways was extended by 1,136 kilometers of federal roads, with an additional 1,103 toll segments [10]. In France, the existing network of concession-based tolled motorways of approximately 8,000 km is being extended by an additional 15,000 km for trucks above 3.5 tons with the new *écotaxe* [11]. For this major extension, GNSS technology was chosen since microwave technology would have required the prohibitively expensive construction of roadside infrastructure along the new tolled network. A similar approach can be witnessed in Russia as well – albeit to a much greater extent – where 50,000 km of roads will be subject to tolls for trucks above 12 tons through the use of GNSS technology by 2015, even though tolled motorways are already in operation that have deployed microwave technology [12].

Conclusion

GNSS-based tolling technology does not require the construction of roadside infrastructure. Instead, investments are made in On Board Units that are installed in all of the tolled vehicles, having far more complexity than microwave tags. An investment in GNSS technology allows for a cost-effective implementation of a tolling scheme on a comprehensive and complex road network, in which thousands of road segments can be tolled – as opposed to a few hundred toll segments of an infrastructure-based system. In Slovakia, it has been shown that GNSS was the logical choice for the implementation of the nationwide truck tolling scheme in which, for the first time in the European Union, the majority of the tolled roads were first class roads, rather than motorways and expressways.

The innate flexibility of GNSS technology has made it possible for Slovakia to multiply the length of the tolled road network more than seven times – from 2,447 km to 17,762 km – within a few months. The cost of this extension was marginal since the geographic modelling of these new roads is supported by a powerful graphic modelling tool, as we have shown. The ability to update all of the GNSS OBUs with the new geographic data over the air allows for a particularly cost-effective implementation.

Due to the advancement of satellite-based electronic tolling technologies, the prompt deployment of toll policy adaptations can be realized with minimal technical and financial overhead. Public policy goals that are established for reaching a fair distribution of costs for the creation and maintenance of road infrastructure can be achieved by optimally deploying the most advanced technologies. The innovative tolling solution in Slovakia has clearly proven itself as being an ideal platform in providing fairness and flexibility to the road users, road operator and policy makers.

References

1. Bobošík, M. (2013). Hidden benefits, *Tolltrans 2013, Traffic Technology International*, pp. 78-79. UKIP Media.
2. Renner, A., N. Schinder (2010). Finding Fairness in Tolling Schemes. In Proceedings *17th World ITS Congress*, Busan. ITS Korea.
3. Schindler, N. (2009). Fourth Generation On Board Unit for Cost-Effective Automated Electronic Tolling. In Proceedings *16th World ITS Congress*, Stockholm. ERTICO (ITS Europe).
4. SME. (2014). *Príjmy z mýta v prvom kvartáli vzrástli o tretinu*, 17th April, 2014. Petit Press. (http://ekonomika.sme.sk/c/7174363/prijmy-z-myta-v-prvom-kvartali-vzrastli-o-tretinu.html?utm_source=link&utm_medium=rss&utm_campaign=rss).
5. Bína, L., V. Černý, H. Novakova (2012). Road Charging in the Czech Republic and EU and External Costs of Transport, *Journal of Civil Engineering and Architecture*, Dec. 2012, vol. 6, no. 12, pp. 1672–1678.
6. Ředitelství silnic a dálnic ČR (2013). *Road and motorways in the Czech Republic 2013*, Brochure of the Road and Motorway Directorate of the Czech Republic, p. 16. (http://www.rsd.cz/rsd/rsd.nsf/0/00712811179E3270C1257C08005CD18B/$file/RSD2013en.pdf).
7. Kijoch, J. (2014). Polish ETC Heavy Vehicle Levy Objective and Achievements. Presentation in *11th Annual Road User Charging Conference,* Brussels, p. 10. Akabo Media. (roaduserchargingconference.co.uk).
8. Nowacki, G., I. Mitraszewska, T. Kamiński (2008). The National Automatic Toll Collection System for the Republic of Poland. In *Transport and Telecommunication*, 2008, Volume 9, No 2, pp. 24–38. Transport and Telecommunication Institute, Riga, Latvia.
9. Die Presse. (2014). *Länder wollen Lkw-Maut kassieren*, 5th April, 2014. (http://diepresse.com/ home/wirtschaft/economist/1586853/Laender-wollen-LkwMaut-kassieren).

10. Rottinger, F., M. Blum, T. Jestädt (2013). Quick and Clean – Expanding Toll Operations to Include 1,100 Additional km of Roads. Special Interest Session 18, 8th June, 2013, *9th ITS European Congress*, Dublin.

11. Schindler, N. (2013). On Board Unit for the European Electronic Tolling Service. In Proceedings *9th ITS European Congress*, Dublin. ERTICO (ITS Europe).

12. Schindler, N. (2012). Combined Use of GLONASS and GPS in Electronic Tolling. In Proceedings *19th World ITS Congress*, Vienna. ERTICO (ITS Europe).