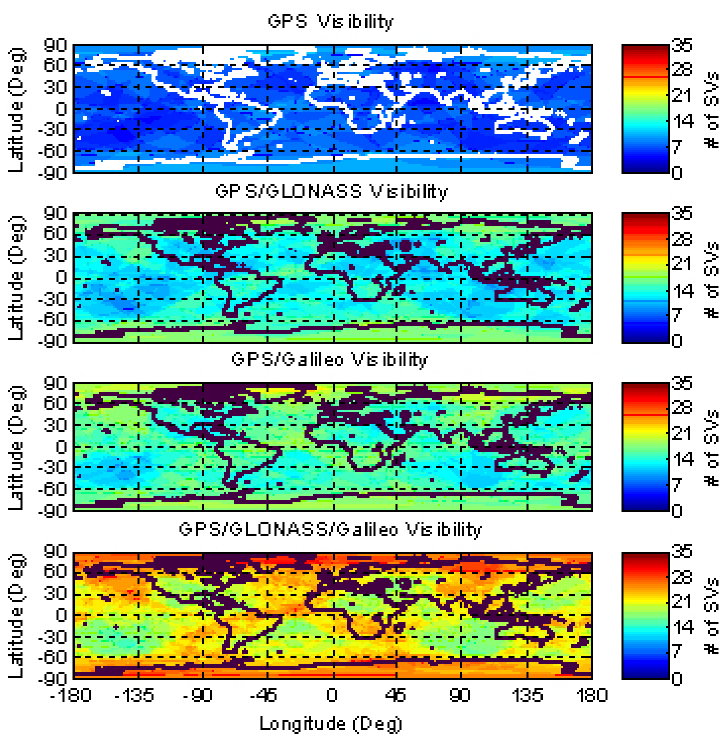
The Future of GNSS

Introduction

GNSS, the Global Navigation Satellite System, is on its way. A European Commission report recently predicted that GNSS and related businesses will account for 140 billion Euros in applications and hardware by 2015.[1] So it is no surprise that there is great anticipation from a business perspective, but from a user's point of view the situation is not unlike the advent of GPS more than 30 years ago. Much is promised but little assured. New capabilities will be available, but exactly what and exactly when is by no means certain. Nevertheless, it is prudent to consider the ramifications of a constellation including QZSS, GLONASS, Beidou, GALILEO and GPS satellites. Within a decade there may be as many as 80 navigational satellites in orbit. What will that mean from the user's point of view?

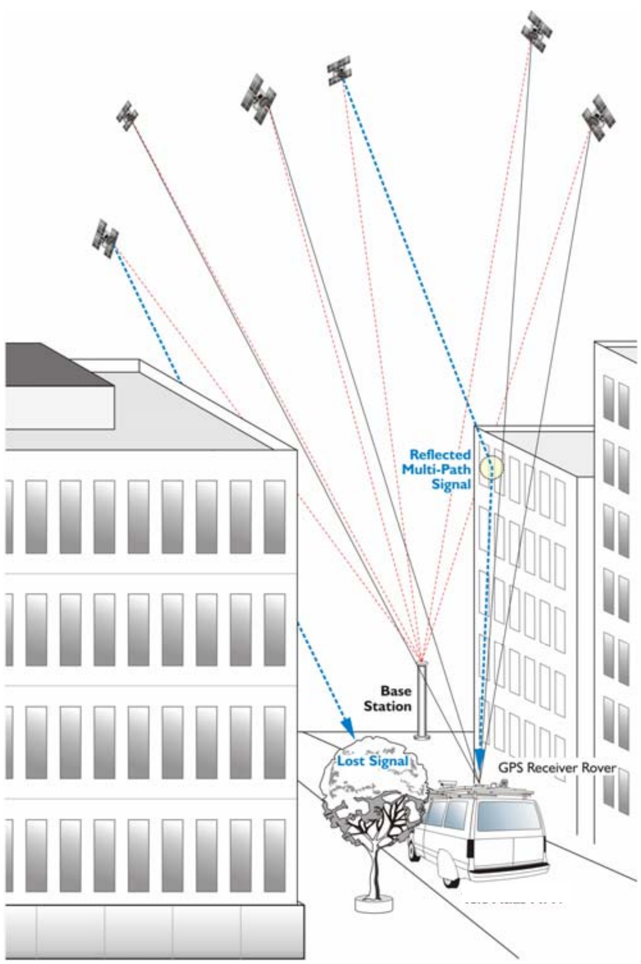
More Satellites



Increased Satellite Availability from GNSS
Figure 1.1[2]

How many more? GPS and GLONASS together provide the user with ~2 times the satellites than does GPS alone. In other words, if one considers that 6 satellites are normally above a user's horizon with GPS alone there will usually be about 12 available with GPS and GLONASS combined. If GPS and GALILEO are considered together there are ~ 2½ times or about 15 satellites typically available to a user. The number increases to 21 or ~3½ times more satellites with all three GPS, GLONASS and GALILEO together and particularly if Beidou and QZSS are included.

Accessibility. In a sense the more satellites the better the performance particularly among trees and in urban canyons, those places where signals bounce, scatter and multipath abounds.



The Urban Canyon
Figure 1.2

Flexibility. When more satellites are overhead the user has more flexibility. For example, since there are six satellites in a window available to the van with the GPS receiver in Figure 1.2, the user may be able to increase the mask angle to decrease the multipath and still have four satellites to observe. Imagine if there were 12, 15 or even 21 satellites in the picture and you can see how more satellites can mean better accessibility in restricted environments.

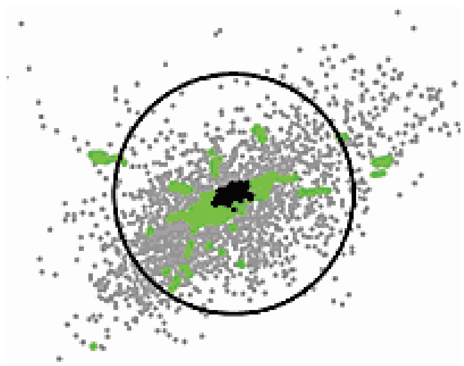
Faster Positioning
Figure 1.3

Reliability. Also, the more diverse the maintenance of the components of GNSS the less chance of overall system failure, the United States, Russia, Japan, the EU and China all have infrastructure in place to support their contribution to GNSS. Under such circumstances simultaneous outages across the entire GNSS constellation are extremely unlikely.

Faster Positioning. More measurements in shorter time means observation periods can be shortened without degrading accuracy and interference can be ameliorated more easily. In short, better accuracy can be achieved in less time.

Faster Initialization. Also, with more satellites available the time to first fix for carrier phase receivers, the period when the receiver is solving for the integers, downloading the almanac and etc, *aka initialization*, will be shortened significantly. And fixed solution accuracy will be achieved more quickly. Today dual-frequency carrier phase solutions are accurate but noisy, but with the new signals available on L2C, L5 and other GNSS signals dual-frequency solutions will be directly enhanced.

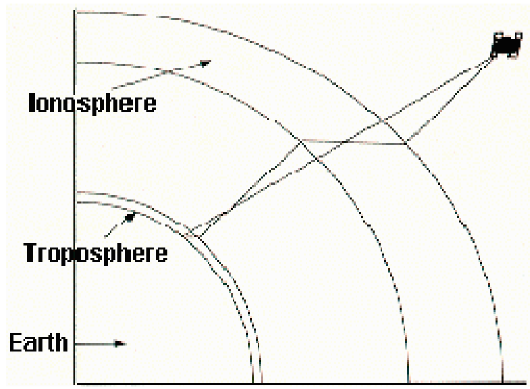
Accuracy



GPS Accuracy
Figure 1.4

GPS Accuracy. As we have discussed, from the beginning it has been, and continues to be, possible to achieve centimeter, even millimeter, positional accuracy with GPS. Using the signals of two carrier frequencies, *L1 and L2,* and two PRN codes, *P and C/A,* on all available satellites the users of GPS can have accuracy commensurate with virtually any requirement. The cost and time required to accomplish this high accuracy has declined steadily, but are still more substantial than many would like.

While a GNSS capable receiver may offer a user improved availability and reliability, it may not necessarily offer higher accuracy than is available from GPS. However, the achievement of high accuracy more conveniently and in more places- that seems to be within reach with GNSS.

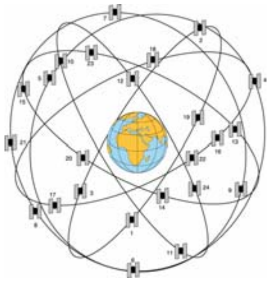


Ionospheric Delay
Figure 1.5

GNSS Accuracy - Faster. When more satellites are available to a real-time GPS solution high accuracy is. The same is true with GNSS, and along with more signals that means better ionospheric correction too. Remember the ionospheric delay is frequency dependent. More signals also means the number of observations available for ambiguity resolution is increases and the integers can be fixed more rapidly. Also consider the utility of dual-frequency measurements in GPS. Three frequencies, i.e. L5, will increase performance even more.

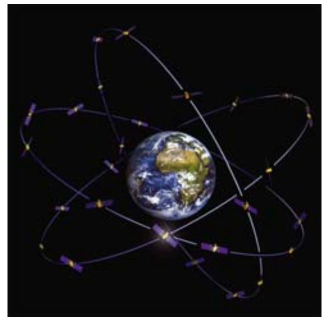
Simplificiation. The algorithms currently necessary for the achievement of high accuracy with carrier phase ranging may be simplified since many of the new GNSS signals will be carrying a civilian code. Generally speaking code correlation is a more straightforward problem than is carrier differencing. This may lead to less complicated receivers. This presents the possibility that they will be less expensive.

Interoperability



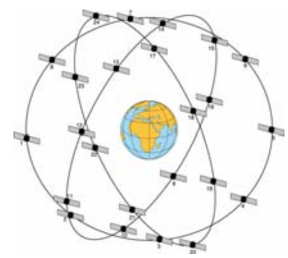
GPS

- 6 orbital planes
- 24 satellites + spare
- 55° inclination angle
- altitude 20200 km



GALILEO

- 3 orbital planes
- 27 satellites + 3 spare
- 56 ° inclination angle
- altitude 23616 km



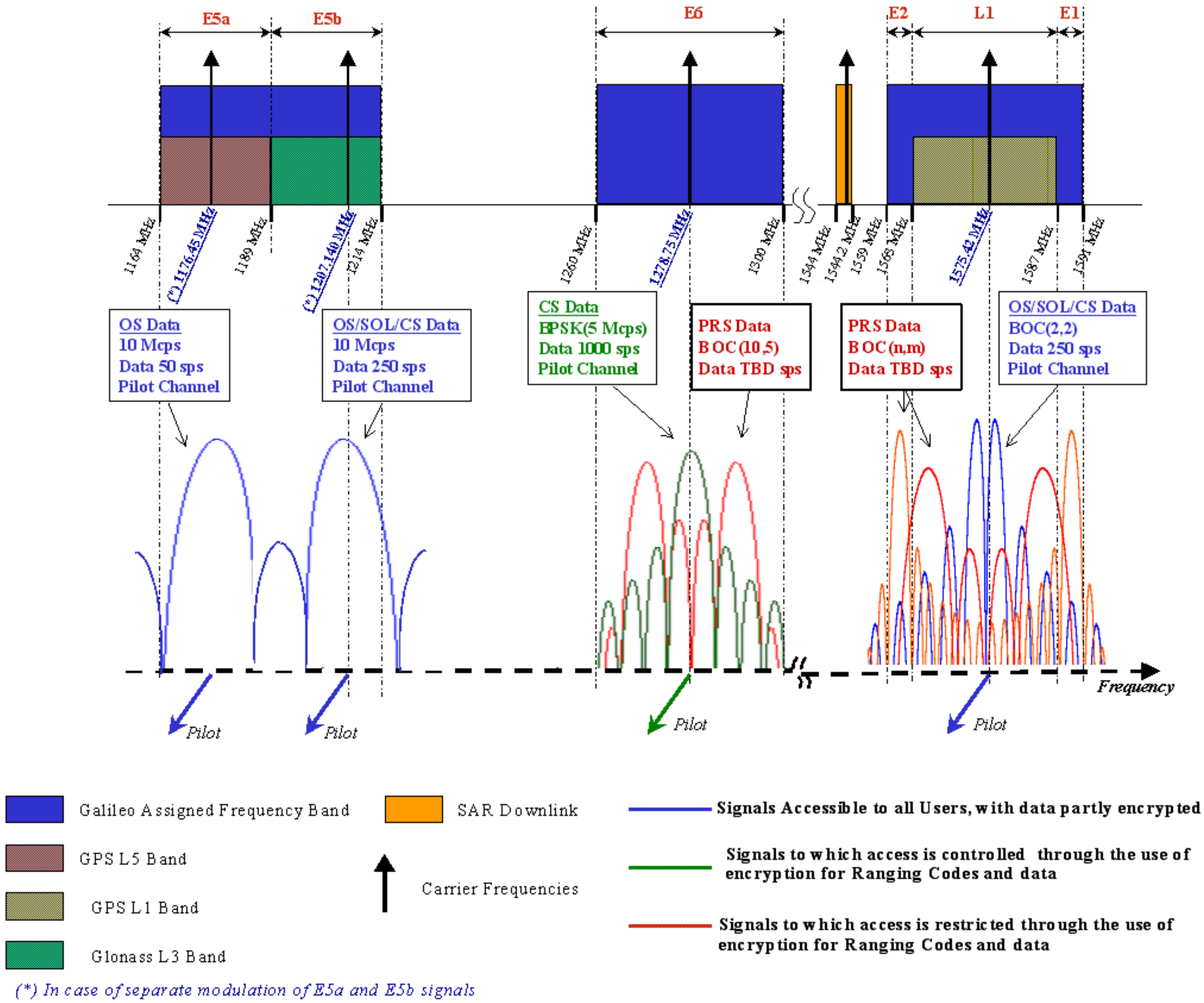
GLONASS

- 3 orbital planes
- 21 satellites + 3 spare
- 64.8° inclination angle
- altitude 19100 km

GPS-GALILEO-GLONASS Constellations
Figure 1.7

Inconsistency. Despite similarities there are some issues in the consistency GNSS issues as you know. For example, in lesson 3 you may recall that the roll-out of the new systems are not coordinated. In other words GPS Modernization, GLONASS replenishment, and QZSS and Galileo deployment have not been synchronized. Despite much cooperation there is no clear agreement among nations that launches and operational capabilities of GLONASS, GALILEO, GPS, QZSS and Beidou will happen in the same time frame. Also as we discussed last time there are differences between GLONASS and GPS regarding CDMA and FDMA. There are also differences in the time standards between the two systems. Not to mention the overlap between the GPS M-code and Beidou. It is important that these inconsistencies are worked out technologically because apart from the less sophisticated applications for GNSS interoperability will be required. For the full potential of the system to realize multiple GNSS frequencies will need to work together. In other words they require as many satellites as possible delivering signals that can be used in conjunction with one another any time, any place.

Consistency. However, there is signal compatibility among subsets of the 80 satellites that will be broadcasting at the same frequencies. As mentioned before interoperability is achieved by partial frequency overlap using different signal structures and/or different code sequences for spectral separation. In Figure 1.8 you can see the overlap of GPS L1 and GALILEO L1. We can also look forward to GPS L5 and GALILEO E5a. It may also be possible for GLONASS L3 to be interoperable with GALILEO E5b. Also please note that the Galileo satellites will make use of code division multiple access *CDMA* techniques which, as you know, are compatible with the GPS approach.



GNSS Interoperability[3]
Figure 1.8

Signals. There are GALILEO signals available to all users; they are known as Open Service or OS. They include three data-less channels or *pilot tones*. Pilot tones are ranging codes not modulated by data.

The signal E5 will be spread from 1164 to1215 MHz. If they are separately modulated, E5a will be centered on 1178.45 MHz this corresponds with the coming GPS L5. And E5b at 1207.14 MHz. will be in the range of GLONASS L3.

From 1260 to1300 MHz the signal designated E6 is part of the Radio Navigation Satellite Service, *RNSS* allocation for GALILEO. The GALILEO signal E2-L1-E1 from1559 to1592 MHz is also part of the Radio Navigation Satellite Service. This signal is often known as simply L1. That is a convenient name since the GPS L1 is right there too. Spectral separation of GPS and GALILEO L1 signals is accomplished by use of different modulation schemes. This strategy allows jamming of civil signals, if that should prove necessary, without affecting GPS M-code or the Galileo PRS service. You can see the modulation method – *BOC or BPSK*, chipping rates, data rates in Figure 1.8. Also please note the places where the carrier frequencies and frequency bands are common between GPS, GLONASS and GALILEO.

There are also two signals on E6 with encrypted ranging codes, including one data-less channel which are only accessible to users who gain access through a given Commercial Service, CS, provider. And lastly there are two signals, one in E6 band and one in E2-L1-E1, with encrypted ranging codes and data that are accessible to authorized users of the Public Regulated Service, *PRS.*

Business

High Costs and High Risks
Figure 1.6

Robust Solutions. In fact, high accuracy and interoperability are not only a matter of convenience - robust, reliable solutions are becoming a business necessity. Consider *safety-of-life* uses for things such as routing of emergency vehicles, or the GPS based automated machine control system now in used in construction. Mining, agriculture, aircraft control, etc are depending more and more on satellite navigation systems. These industries have high costs and high risks and not only require high accuracy but reliability as well.

The Business of GNSS
Figure 1.7

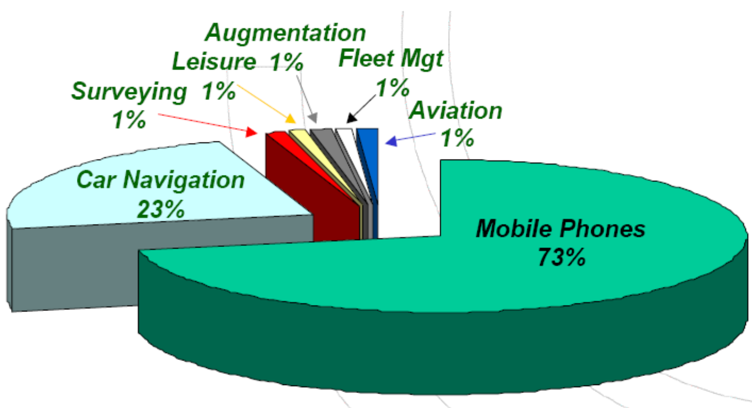
If GNSS can deliver inexpensive receivers tracking the maximum number of satellites broadcasting the maximum number of signals it will live up to the fondest hopes of not only many individuals but also many industries as well.

Commercial Service. Concerning the EU contribution to GNSS Commission Vice-President Jacques Barrot said recently, "GALILEO is perfectly in line with the Lisbon growth strategy. It is the largest industrial project ever organized on a European scale, the first European public-private partnership, the first European public infrastructure. “And there is hardly a better illustration of business interest in GNSS than the upcoming Commercial Service to be offered by GALILEO. It is expected to serve a large market in hardware and applications for the private sector. Specifically GALILEO’s Commercial Service is designed to deliver improved differential solutions directly to users through correction signals available to subscribers via RF. But whereas GALILEO’s Open Service, *OS* will be free for anyone to access the Commercial Service is not. This service will have an encryption managed by the service providers and the future Galileo concessionaire. For a fee those that require higher performance than the Open Service can purchase a key code for their receiver.

The service providers will buy the right to use the commercial signals from the Galileo concessionaire. There will actually be two available. And then they will develop commercial applications either using the commercial signals alone, in combination with other Galileo signals or even perhaps external communications systems. There are obviously many options. For example, differential correction signals could be created, not unlike those available now from OmniSTAR but the global scope would be a clear commercial advantage in this arrangement. Precise timing services and ionospheric delay modeling are two others that come immediately to mind.

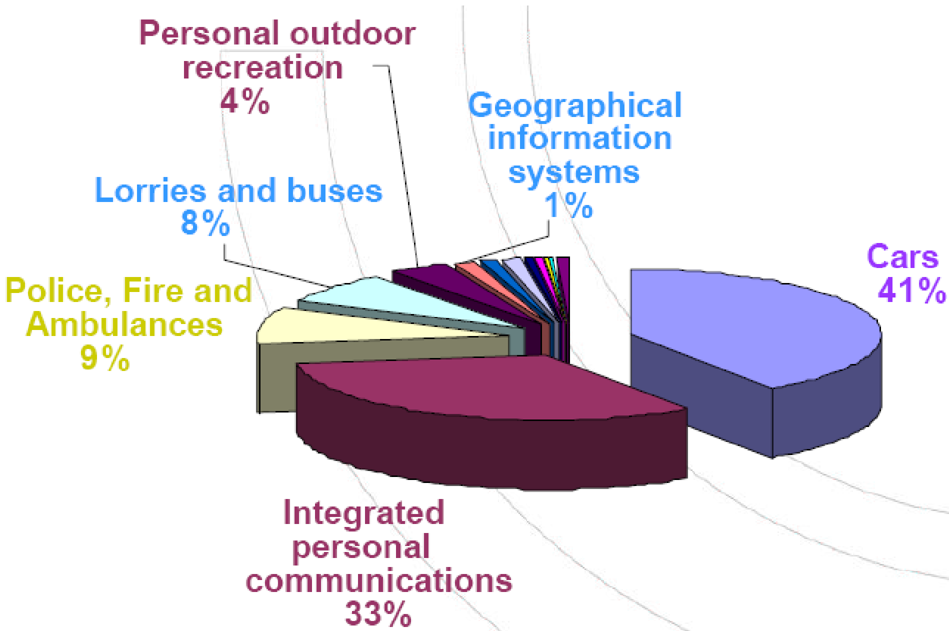
Fee-Based. In other words, the extra satellites and signals of GNSS will make the centimeter accuracy techniques of geodesy more easily and more widely available. However, it is worthwhile to note that this is a harbinger of a change in satellite navigation. The services available through GALILEO’s Commercial Service will not be free. There have been discussions of fee-based services in the past. But up to this time satellite signals have been free, and, excepting those restricted for military use, freely available. It looks as if that will change. You may recall that there is also some discussion of subscription arrangements with the expanded Chinese Beidou system as well. There the Authorized Service will be available to subscribers and will provide more reliable positioning and system integrity information.   In any case, it appears that high accuracy GNSS may be more conveniently available, but may come at a cost, at least for some users.

Agreement. Regarding its development of GALILEO EU has signed agreements with several countries: Ukraine, Israel and India are among them. China has also signed an agreement of cooperation; however, recent events and China's declared intention to expand Beidou call that into question. Talks are underway with Argentina, Norway, South Korea Canada, Malaysia, Australia, Mexico Brazil, Russia, Chile, and Morocco. The international character of GNSS could not be more apparent. The United States as gone so far as to commit to interoperability between GPS and GALILEO. Since users will be able to depend on common operating standards between the systems access to signals from both with one receiver will certainly be possible.



GNSS Markets Today
Figure 1.8[4]
(Jörn Tjaden, Head of Technical Division, GALILEO Joint Undertaking)

Markets. When GNSS is unremarkable, virtually unnoticed that is when it will have become truly integrated into the market. For example, location based services, or *LBS*, are on the rise. These services are apparent in the legal requirement that cell phones making an emergency call must be capable of being positioned to better than 100m accuracy. There has also been an impetus to the development of positioning technologies that can work inside buildings. There are signs that there will be substantial growth in Advanced Driver Assistance or ADAS technologies such as - in-vehicle navigation systems with up-to-date traffic information, adaptive cruise control, lane/road departure detection/warning system, collision warning system, etc. In other words specialized markets such as navigation, surveying and mapping are being joined by a more consumer focused emphasis. GNSS will be available to the general public and position capability is likely to become much more *ubiquitous* during the coming decade.



GNSS Markets 2015
Figure 1.9[5]
(Jörn Tjaden, Head of Technical Division, GALILEO Joint Undertaking)

Predictions

At the end of this decade receivers which track only GPS will be able to utilize carrier phase on L1, be codeless on L2 with L2C and perhaps L5 if the Block IIF satellites are operational. Receivers that track only GALILEO will be able to utilize L1, E5 and E6 from a full, or nearly full, constellation. It is probable that there will be a charge for observation of GALILEO's E6 signals. However, receivers with both GPS and GALILEO capability will have the carrier phase on L1, codeless on L2 with L2C and L5 as well as Galileo L1 and E5 signals. It is possible that such receivers will also have GLONASS and QZSS capability.

About 5 years after the end of this decade the modernized GPS constellation should be in place, including L5 and GALILEO should be fully operational. Just considering GPS and GALILEO there will be 60 or so satellites in orbit and available. Including GLONASS and QZSS there could be as many as 80 satellites available. A typical user will find approximately 10- 20 satellites above the horizon anywhere, any time. L2C should be fully implemented and there ought to be no more necessity to track the L2 with cross-correlation. Receiver technology should be simpler, and receivers less expensive. GLONASS and QZSS signals will be available. And integration with other technologies will mean that indoor positioning will be a reality and it should be possible to integrate a user's position with mobile communications data in the receiver using GALILEO's commercial service. The mass market will have incorporated centimeter level accuracy into day-to-day proceedings and high accuracy will no longer be the exclusive purview of surveyors and geodesists. It will be unremarkable, virtually unnoticed and truly integrated into the market

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[1] Chris Rizos, Matthew B. Higgins and S. Hewitson, New Global Navigation Satellite System Developments and Their Impact on Survey Service Providers and Surveyors, , International Federation of Surveyors Article of the Month, page 2 of 16 October 2005.

[2] Ibid

[3] Jean-Luc Issler, Gunter W. Hein, Jeremie Godet, Jean-Christophe Martin, Philippe Erhard, Rafael Lucas-Rodriguez, Tony Pratt , Galileo Frequency & Signal Design, GPS World , June 2003.

[4] Jörn Tjaden, Head of Technical Division, GALILEO Joint Undertaking, Hessen-IT, Slide 20 of 28

[5] Jörn Tjaden, Head of Technical Division, GALILEO Joint Undertaking, Hessen-IT, Slide 21 of 28