CHAPTER EIGHT

GPS Modernization and GNSS

Part II

GLOBAL NAVIGATION SATELLITE SYSTEM

(GNSS)

As I mentioned at the top it may be a bit unexpected but many of the plans that will change GPS as a practical utility will be implemented entirely outside of the GPS system itself.

The GPS system is one component of the worldwide effort now known as the *Global Navigation Satellite System, GNSS*. Another component of GNSS is the GLONASS system of the Russian Federation and a third is the GALILEO system administered by the EU. And it is likely that more constellations will eventually be included in GNSS.

The concept is nothing less than this; these networks of satellites and others will begin to work together. Further they will be augmented by both *ground-based augmentation systems, GBAS* and *space-based augmentation systems, SBAS* to provide positioning, navigation and timing solutions to users around the world.

One goal of this cooperation is interoperability. Interoperability is the idea that properly equipped receivers will be able to obtain useful signals from all available the satellites in all the constellations and have their solutions improved rather than impeded by the various configurations of the different satellite broadcasts.

One example of the scope of this increased horizon in global positioning is illustrated by the name change of the *International GPS Service* to the *International GNSS service, IGS*. It is a federation of 200 worldwide agencies that generate information on the GPS & GLONASS systems, http://igscb.jpl.nasa.gov.

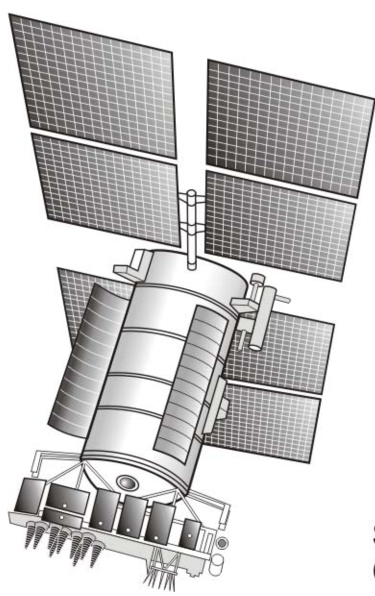
As mentioned above GNSS includes GPS, GLONASS and GALILEO, it will also incorporate the Japanese *Quasi-Zenith Satellite System, QZSS* and the *Chinese Beidou/Compass Satellite Navigation and Positioning System* as well as augmentation systems deployed by the US, Europe, Japan, China and Australia.

One immediate effect of GNSS is the substantial growth of the available constellation of satellites. The more signals that are available for positioning and navigation, the better. The two systems that are currently online and available are GPS and GLONASS.

GLONASS

Russia's *Globalnaya Navigationnaya Sputnikovaya Sistema - Global Orbiting Navigation Satellite System,* known as *GLONASS,* did not reach full operational status before the collapse of the Soviet Union. Its first satellites reached orbit in October of 1982 a bit more than 4 years after the GPS constellation was begun. A nearly full constellation of 24 or so GLONASS satellites was achieved in 1996 but by 2001 only about 7 healthy satellites remained on orbit about 1000 km lower than the orbit of GPS satellites. And the remaining 7 were only expected to have a design life of three years. The situation was not helped by the independence of Kazakhstan, subsequent difficulties over the Baikonur Cosmodrome launch facility and lack of funds. The system was in poor health.

Today there are signs of renewal. Since a decision in August of 2001 that outlined a program to rebuild and modernize GLONASS. The constellation has increased dramatically. Full worldwide 24 hour coverage is expected between 2010 and 2020. For example, there are improvements in the satellites themselves. The original GLONASS satellite was the Uragan. It was first launched in 1982 and had an intended life-span of 4 years.

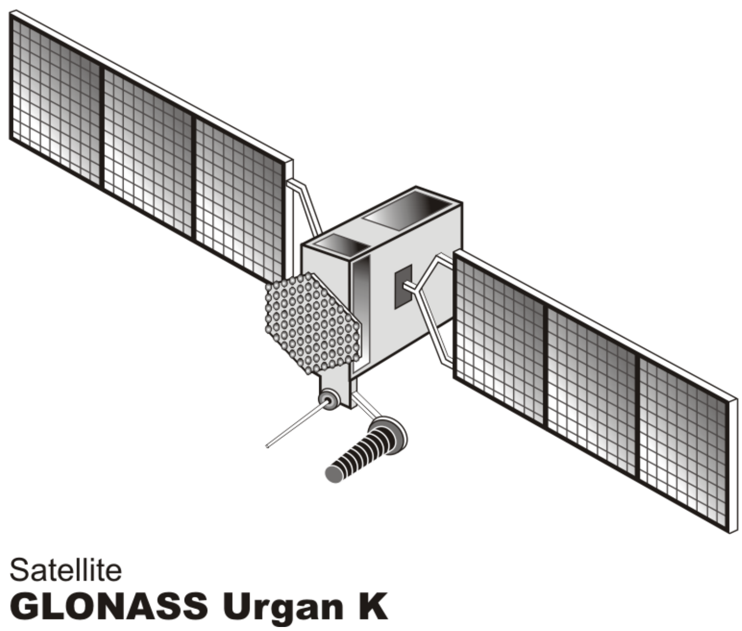


Satellite
GLONASS Urgan M

GLONASS Uragan M

Figure 8.9

The M version of the GLONASS Uragan has improved antennas over the earlier spacecraft. They are also expected to have extended lifetimes of 7 years and carry separate transmission frequencies which are dedicated to civilian users. The first of these were launched in 2003



GLONASS Uragan K

Figure 8.10

The K version of the GLONASS Uragan has a third L-band transmitter for civilian users, an extended service life of 12-15 years and costs less to produce. The first launch of these satellites is expected in 2009.

GLONASS Constellation. In other words, the GLONASS constellation has increased. A complete GLONASS system would contain 21 active and three spare satellites spread over three orbital planes at the altitude of 19,100 km inclined 64.8 degrees toward the Equator.

The day after Christmas in 2004 three GLONASS satellites were launched. The mission included two Uragan, *796 and 797* and a follow-on Uragan-M satellite, *712. Please note that the addition of a 7 to the satellite numbers converts them to their GLONASS numbers, i.e. No. 98 – GLONASS Number 798.* The next year, on Christmas day three more GLONASS satellites a regular Uragan spacecraft *798* and a pair of upgraded Uragan-M satellites, *713 and 714*, achieved orbit. While this brought the number of active satellites to 17 these two Uragan-M spacecraft did not enter service until August 2006.

While the GPS system has six orbital planes, as mentioned GLONASS has three. In September of 2006, 3 out of the 8 satellites in the 3rd plane were deactivated, apparently in anticipation of the re-configuration of the constellation for the launch on Christmas Day in 2006. On that day again three more GLONASS satellites, *715, 716 and 717,* all Uragan M satellites were launched. The goal is to achieve full worldwide 24 hour coverage by the first part of the second decade of the 21st century with 21 Uragan-M satellites in 3 orbital planes, with 3 on-orbit spares in place.

There has also been a recent approval of plans to substantially increase the funding and accelerated the restoration of a complete constellation including upgrading its ground sector. It appears it will be possible to remove the legal barriers to civil use of the GNSS receivers and develop a civilian mass market in GNSS in Russia including digital mapping and equipment.

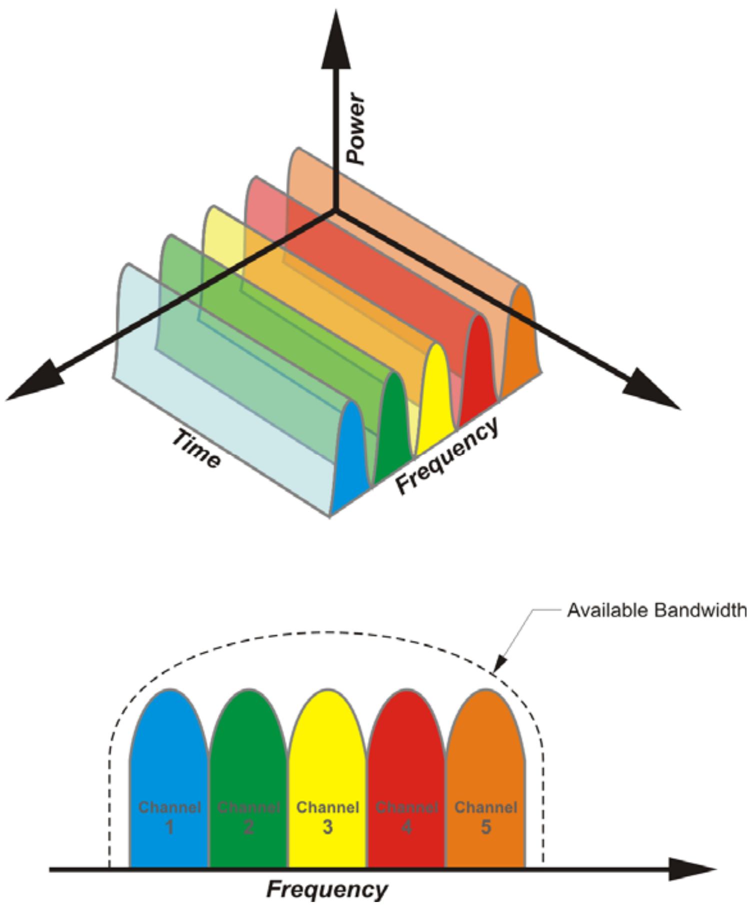
GLONASS Signals

Regarding the signals broadcast by these satellites the original objective was similar to the plan embraced by GPS a system that would provide 100 meters accuracy with a deliberately degraded standard C/A signal and 10-20 meter accuracy with its P signals available exclusively to the military. However, that changed at the end of 2004, the *Federal Space Agency, FKA*, announced a plan to provide access to the high-precision navigation data to all users. This is, of course, based on the code solution.

CDMA and FDMA. Since the revitalization of GLONASS is underway interoperability between it and other systems is enticing. However, as you know a receiver collecting signals from GPS, or GALILEO for that matter, gets a different segment of the P code and the C/A code from each satellite. In other words, as mentioned in Chapter One, a particular segment of the 37 week long P code is assigned to each satellite. For example, SV14 is so named because it broadcasts the fourteenth week of the P-code. Also, each GPS satellite broadcasts its own completely unique segment of the C/A code that it repeats. However, even though the segments of the P code and the C/A code coming into a receiver on L1 are unique to their satellite or origin they all arrive at the same frequency, 1575.42 MHz. The same is true of the P code arriving from satellites on L2 even though the segments of the P code coming into a receiver on L2 are unique to their satellite or origin they all arrive at the same frequency, 1227.60 MHz

This approach is known as *CDMA, Code Division Multiple Access.* CDMA technology was originally developed by the military during World War II. Researchers were looking for ways of communicating that would be secure in the presence of jamming. CDMA does not use frequency channels or time slots. As in GPS CDMA usually involves a narrow band message multiplied by a large bandwidth PRN, pseudo-random noise, signal. As you have read these PRN codes are attached to the GPS carrier by changes in phase. Then all the users can receive the same frequency bands. And again, just as in GPS with CDMA the transmitted message is recovered by correlating the received signal with the PRN code available at the receiver.

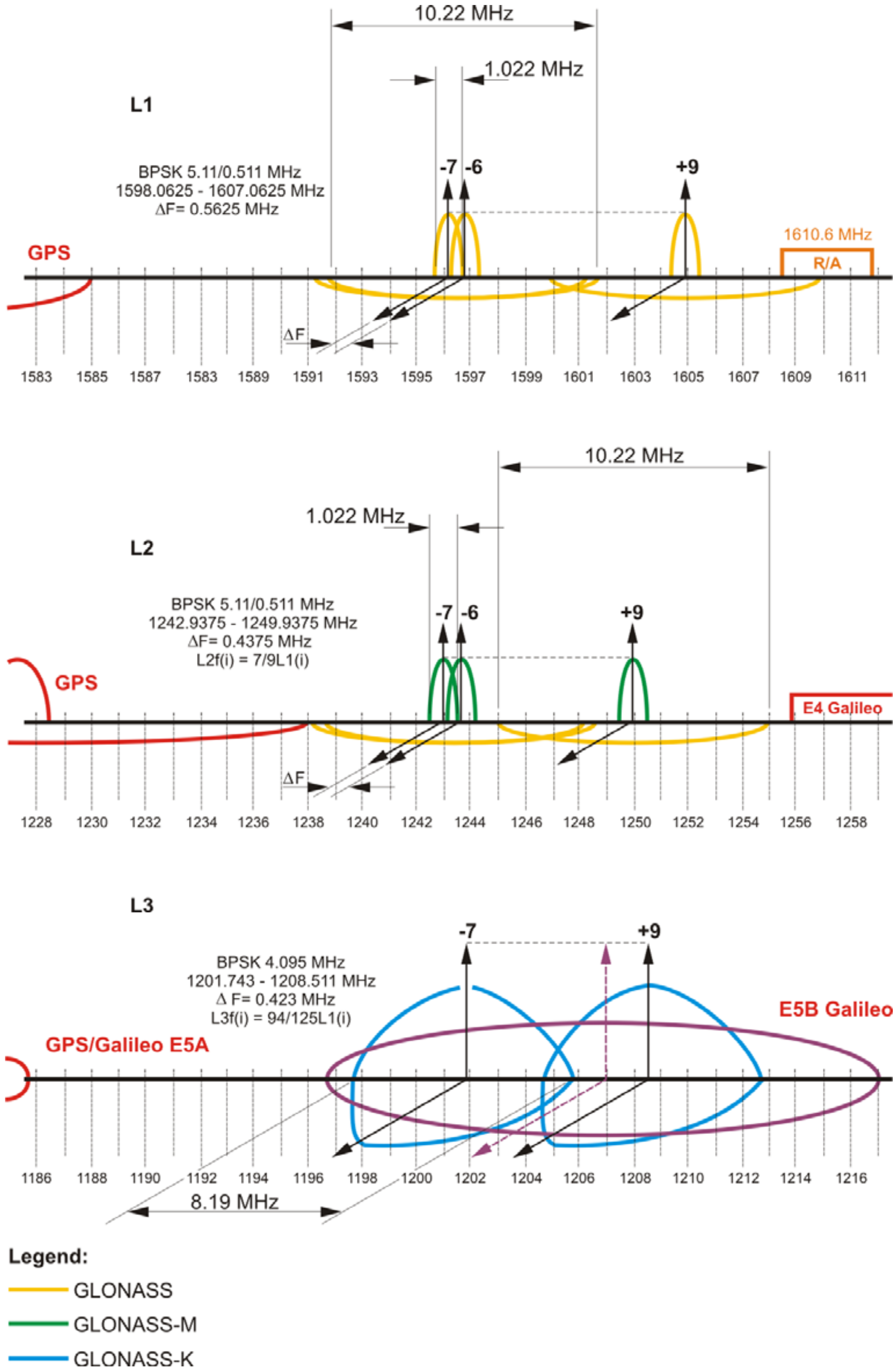
GLONASS uses a different strategy. The satellites transmit L-band signals and unlike GPS each code a GLONASS receiver collects from any one of the GLONASS satellites is exactly the same. Also unlike GPS each GLONASS satellite broadcasts its codes at its own unique assigned frequency. This is known as *FDMA, Frequency Division Multiple Access.*



Frequency Division Multiple Access FDMA

Figure 8.11

(Adapted from Sky DSP, 1.3.1 Frequency Division Multiple Access, http://www.skydsp.com/publications/4thyrthesis/chapter1.htm)



10.22 MHz
1.022 MHz
L1
BPSK 5.11/0.511 MHz
1598.0625 - 1607.0625 MHz
ΔF= 0.5625 MHz
-7
-6
+9
1610.6 MHz
R/A
GPS
ΔF
1583 1585 1587 1583 1589 1591 1593 1595 1597 1599 1601 1603 1605 1607 1609 1611
10.22 MHz
1.022 MHz
L2
BPSK 5.11/0.511 MHz
1242.9375 - 1249.9375 MHz
ΔF= 0.4375 MHz
L2f(i) = 7/9L1(i)
-7
-6
+9
GPS
E4 Galileo
ΔF
1228 1230 1232 1234 1236 1238 1240 1242 1244 1246 1248 1250 1252 1254 1256 1258
L3
-7
+9
BPSK 4.095 MHz
1201.743 - 1208.511 MHz
Δ F= 0.423 MHz
L3f(i) = 94/125L1(i)
E5B Galileo
GPS/Galileo E5A
1186 1188 1190 1192 1194 1196 1198 1200 1202 1204 1206 1208 1210 1212 1214 1216
8.19 MHz
Legend:
GLONASS
GLONASS-M
GLONASS-K

GLONASS Signals

Figure 8.12

(Adapted from V. Dvorkin & S. Karurtin , GLONASS: Current Status and Perspectives, 3rd Allsat Open Conference, Slide 13 of 24, Hannover June 22, 2006)

As shown in Figure 8.12 the two GLONASS L bands have a range of frequencies to assign to satellites. In the future there may be a GLONASS L3. L1 is centered on 1602 MHz with a range between ~1598.0625 to ~1607.0625 MHz and L2 is centered on 1246 MHz with a range between ~1242.9375 to ~1249.9375 MHz. However, within those ranges there can be up to 25 channels of L-band signals; currently there are 16 channels on each to accommodate the available satellites. Please note in the figure the -7 on the left and the +9 on the right for a total range from the center of 16. Each channel is separated from the others by a ΔF which is 0.5625 MHz on L1 and 0.4375MHz on L2. In other words each GLONASS satellite broadcasts the same code, but each satellite gets its own frequencies. The standard code chip lengths on the GLONASS L1 are 0.511MHz – 3135.03 L1 cycles/chip standard and 5.11 MHz precise – 313.503 L1 cycles/chip. On L2 they are 0.511MHz – 2438.36 L2 cycles/chip standard and 5.11 MHz precise – 243.836 L2 cycles/chip.

Also shown on Figure 8.12 is a civil reference signal on the L2 frequency. It is shown here in the dark green to indicate that it will be carried on the Uragan-M satellites. It will substantially increase the accuracy of navigation relaying on civil signals in a similar fashion as L2C will add capability on the GPS L2 signal. Also notice that GLONASS signals do not overlap GPS frequencies, but the third civil reference signal on L3 that will be available on the K satellites will be within a new frequency band that includes 1201.743-1208.511 MHz and will overlap GALILEO's E5B signal. This could be good news.

While there are some differences in the signals available from GPS, the EU's GALILEO system and Russia's GLONASS they are surmountable. And Russia has discussed development and use of GLONASS in parallel with the American GPS and European GALILEO systems.

Changes to FDMA. There may be some changes to the FDMA approach in the future. Recently Russia agreed to alter the architecture a bit. In order to use only half as many bands GLONASS will now assign the same frequency to satellites that are in the same orbital plane but are always on opposite sides of the Earth.

This will not only reduce the amount of the radio spectrum used by GLONASS it may actually improve its broadcast ephemeris information. Utilizing so many frequencies makes it difficult to accommodate the wide variety of propagation rates and keep the ephemeris information sent to the receivers within good limits. There are a number of receiver manufacturers that have GPS/GLONASS receivers available but the differences between FDMA and CDMA signals increases the technical difficulty and costs of such equipment. In the last few months of 2006 it was mentioned that GLONASS probably will be able to implement CDMA signals on the third frequency and at L1. This could make it easier for GPS and GALILEO to be interoperable with GLONASS.

In fact, there are many efforts underway to improve the GLONASS accuracy. The stability of the satellites on-board clocks has improved from $5x10^{-13}$ to $1x10^{-13}$ over 24 hours with precision thermal stabilization. The GLONASS Navigation Message will include the difference between GPS time and GLONASS time, which is significant.

There are also efforts to increase the number of available tracking facilities in the GLONASS Ground Segment from 9 to 12, tie the GLONASS coordinate system to the International Terrestrial Reference System (ITRS), and launch the improved Uragan K spacecraft which may add a third L3 frequency band including differential ephemeris and time corrections that would allow sub-meter real-time positioning accuracy.

GLONASS Time. As you know there are no leap seconds introduced to GPS Time in synch with UTC. However things are different in GLONASS. Leap seconds are incorporated into the time standard of the system. Therefore, there is no integer-second difference between GLONASS Time and UTC as there is with GPS. Still that is not the whole story. The epoch and rate of Russian time, relative to UTC (BIH) is monitored and corrected periodically by the Main Metrological Center of Russian Time and Frequency Service (VNIIFTRI) at Mendeleevo, Moscow. They establish the regional version of UTC which is known as UTC (CIS). There is a constant offset of three hours between

GLONASS Time and UTC (CIS). However, with these differences available in the Navigation Message from GLONASS they can be accommodated. There are also efforts to increase the number of available tracking facilities in the GLONASS Ground Segment from 9 to 12, tie the GLONASS coordinate system to the International Terrestrial Reference System (ITRS), and launch the improved Uragan K spacecraft which may add a third L3 frequency band including differential ephemeris and time corrections that would allow sub-meter real-time positioning accuracy.

Considering interoperability, given the fact that the first GALILEO satellite reached orbit atop a Soyuz-Fregat rocket there is every reason to believe that the GALILEO/GLONASS agreement concerning the signal compatibility and interoperability at the GLONASS L3 and Galileo E5b or E6b bands will be successful.

GALILEO

Just over a dozen years after the idea was first proposed the work on GALILEO culminated in the launch of GIOVE-A (Galileo In Orbit Validation Experiment – A) December 28, 2005. The name GIOVE, Italian for Jupiter, is also a tribute to Galileo Galilei discoverer of Jupiter's moons. In any case, it is intended to be the first of 30 satellites of the constellation. These satellites will orbit in 3 planes, 10 in each plane at approximately 3600 km higher than the GPS constellation. Like the GPS system GALILEO will utilize *CDMA, Code Division Multiple Access*. The full constellation of GALILEO satellites and full operational capability is expected to be in place around 2010-2020.

The Galileo Joint Undertaking *GJU* is the body set up by the European Commission and the European Space Agency *ESA* to oversee Galileo's development phase, this phase may be financed in public-private partnerships, *PPP*. And it is the responsibility of the GJU to help mobilize the public and private sector funds required to complete the various phases of the program. In other words, GALILEO's will be controlled by a civilian agency with a more of a business-operating model than is the case of GPS. The European Commission owns the physical system, the ground stations, and satellites and so on. They are a public asset. Nevertheless the day-to-day operations will be the responsibility of a concessionaire. GALILEO is a civil system and is clearly designed to reduce Europe's dependence on GPS.

GIOVE A and GIOVE B. In fact one of the motivations to launching GIOVE-A was to allow European government authorities to register its Galileo frequencies with international regulators. Registration is necessary to prevent the frequency registration from expiring. It has done its job and continues in orbit and bought time for Europe to build additional satellites without facing a confiscation of its frequency reservations.

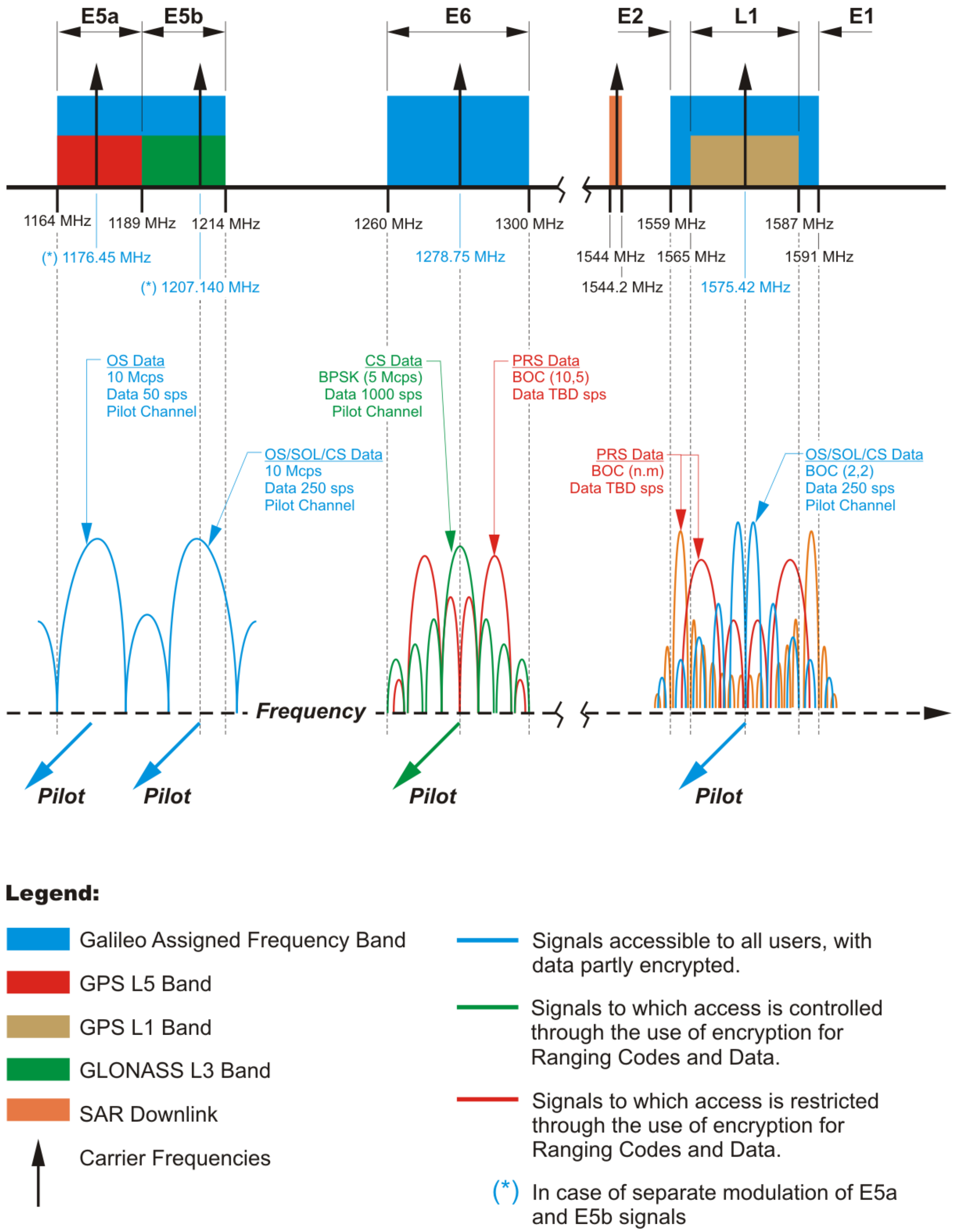
The first follow-on satellite GIOVE-B is more like the satellites that will eventually comprise the GALILEO constellation than is GIOVE-A. As an illustration of the partnerships necessary for the success of GALILEO it is instructive to note that Galileo Industries, the consortium that is building GIOVE-B and the first four operational Galileo satellites, has scheduled their launches aboard Russian Soyuz rockets.

GALILEO Signals and Services. The GALILEO signals are known as L1, E5a and E5b. These signals will be compatible with the existing L1 GPS signal and the coming L5 signal. The system will also broadcast a third frequency band - E6.

GALILEO has defined five levels of service that will be provided by the system. They include - the *Open Service* which uses the basic signals and is quite similar to GPS and GLONASS. The *Safety of Life Service* is along the same line but provides increased guarantees including integrity monitoring, meaning that users are warned if there are signal problems. The *Public Regulated Service, PRS* is encrypted and is meant to assist public security and civil authorities. It provides users with protection against jamming. The *Search and Rescue Service* is intended to enhance space-based services and improve response time to distress beacons and alert messages. Encrypted custom solutions for unique applications are provided in the *Commercial Service*. The business model is still under development, but the GALILEO concessionaire while delivering agreed service for the other four will probably find that the Commercial Service will generate the most profits.

Interoperability. Any discussion of interoperability between GPS and GALILEO must consider the overlapping signals. It is a helpful that the signals center on the same frequency if they are to be used in a combined fashion. For example, please recall that the third GLONASS civil reference signal on L3 that will be available on the K satellites will be within a new frequency band that includes 1201.743-1208.511 MHz and will overlap GALILEO's E5B signal

In Figure 8.13 the GALILEO signals are shown on the top and the GPS signals on the bottom. The GALILEO satellites broadcast signal in several frequency ranges including1176-1207 MHz, near GPS L5.


E5a
E5b
E6
E2
L1
E1
1164 MHz
1189 MHz
1214 MHz
1260 MHz
1300 MHz
1559 MHz
1587 MHz
(*) 1176.45 MHz
1278.75 MHz
1544 MHz
1565 MHz
1591 MHz
(*) 1207.140 MHz
1544.2 MHz
1575.42 MHz
OS Data
10 Mcps
Data 50 sps
Pilot Channel
CS Data
BPSK (5 Mcps)
Data 1000 sps
Pilot Channel
PRS Data
BOC (10,5)
Data TBD sps
OS/SOL/CS Data
10 Mcps
Data 250 sps
Pilot Channel
PRS Data
BOC (n.m)
Data TBD sps
OS/SOL/CS Data
BOC (2,2)
Data 250 sps
Pilot Channel
Frequency
Pilot
Pilot
Pilot
Pilot
Legend:
Galileo Assigned Frequency Band
GPS L5 Band
GPS L1 Band
GLONASS L3 Band
SAR Downlink
Carrier Frequencies
Signals accessible to all users, with data partly encrypted.
Signals to which access is controlled through the use of encryption for Ranging Codes and Data.
Signals to which access is restricted through the use of encryption for Ranging Codes and Data.
(*) In case of separate modulation of E5a and E5b signals

Interoperability GALILEO and GPS

Figure 8.13

(Adapted from Jean-Luc Issler, Gunter W. Hein, Jeremie Godet, Jean-Christophe Martin, Philippe Erhard, Rafael Lucas-Rodriguez, Tony Pratt , Galileo Frequency & Signal Design, GPS World , vol 14, No. 6 June 2003 pp 30-37.)

Please note in Figure 8.13 that GALILEO's E5a signal is centered exactly at 1176 as is L5. The other overlapping signals can be seen at 1575.42 MHz where both GALILEO's L1 and the GPS Ll frequency are both centered. Also, notice that in both cases the GPS signal is based on the binary phase shift key (BPSK) and the GALILEO signal is accomplished with the binary offset carrier (BOC) method. The compatibility of these methods can be seen graphically in Figure 8.13. An important characteristic of BOC modulation is that the codes greatest power density is at the edges that is at the *nulls* which, as it did with the M code on GPS mitigates interference with the existing codes. In this case, not only will there not be interference between the codes on GALILEO and GPS where they overlap they can actually be used together. GALILEO also has a signal E6b at 1278.75 MHz. As you can see this band does not overlap any GPS frequency, however it does happen to coincide with the band that Russia is considering for L3 on GLONASS.

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 8.13. 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.*

Frequency Coincidence. The fortuitous coincidences of frequencies between GPS and GALILEO did not happen without discussion. As negotiations proceeded between the US and the EU one of the most contentious issues arose just as the European Union was moving to get GALILEO off the ground. They announced their intention to overlay GALILEO's Public Regulated Service (PRS) code on the U.S. military's M-code. The possibility that this would make it difficult for the DOD to jam the GALILEO signal in wartime without also jamming the U.S. signal was considered. It became known as the M-code overlay issue. In June of 2004 the US and the EU reached an agreement that ensured the Galileo's signals would not harm the navigation warfare capabilities of the United States and NATO.

So it looks as if some of the hurdles to interoperability between GALILEO and GPS are falling away. If the two systems can be compatible, when GALILEO is fully operational they will provide more than twice the signal-in-space resource available to Global Navigation Satellite System (GNSS) users today.

As mentioned above it looks as if interoperability between its L1 and E5A frequencies and the GPS L1 and L5 frequencies respectively can be accomplished. Therefore, for 1- to 10-meter accuracy the frequencies are already matched at L1 and L5, and the code rates are synchronized around the multiples of 1.023 MHz. However, submeter users may have some issues with time drift between the systems. The problem may require a broadcast correction.

CHINESE BEIDOU/COMPASS

Perhaps it is appropriate to say a word or two about the Chinese System. The fourth GNSS system, joining those undertaken by the United States – *GPS*, Russia – *GLONASS* and Europe – *GALILEO*, will be the Chinese Beidou or *North Dipper* aka *Compass.* The system is already operational but is expected to expand substantially. The Chinese government had launched three Beidou GEO, geostationary Compass Navigation Satellite System *CNSS* satellites, by May of 2003. The Beidou-1 and 1B, launched in 2000 at 140º and 80º E. longitude respectively were followed by 1C in 2003 over 110.5º E. longitude. Since the system only requires two satellites to function 1C is actually an in-orbit spare.

In an announcement made through the government news agency, Xinhua, the People's Republic of China National Space Administration said that two more GEO will be launched in 2007 on the way to an enhanced system of up to 35 satellites will cover all of China and neighboring nations. It is expected to include five GEO and 30 MEO or medium Earth orbit satellites in six orbital planes, the latter operating near the GPS and GALILEO altitude of 20,000 kilometers.

There will be two levels of service. One will be a 10m Open Service and the other will be an Authorized Service. The Open Service will offer an accuracy of 10m, 0.2 mps velocity accuracy and timing accuracy within 50 nanoseconds. The Authorized Service will be available to subscribers and will provide more reliable positioning and system integrity information. This bifurcation will probably resemble GALILEO's publicly regulated service, *PRS*, or the encrypted *P-code* and *M* GPS military signals. However, details are difficult to come by.

This is all actually a bit of a surprise since there had been some expectation that China would pre-empt the expansion of its system in favor of participation in the GALILEO project.

Frequencies. Frequency requests have been made by China for bands for the Beidou signals that may interfere with the Galileo Public Regulated Service (PRS) and the GPS M-code on Ll and L2. The requests are under consideration by the International Telecommuncations Union (ITU), a United Nations affiliate responsible for achieving handling the use of radio spectrum worldwide. The issue will probably be discussed at the World Radiocommunication Conference 2007 set for Geneva, Switzerland, next October/November.

China has said that it is willing to cooperate with other countries in arranging the Beidou so that it will operate with other global satellite positioning systems. However, the proposal to overlay the M-code would prevent the U.S. military from jamming Beidou transmissions without jamming its own signals. This would raise an alarm in the Department of Defense as did the original GALILEO Public Regulated Service design.

The issue is also a concern to the European Union (EU), which has wanted to engage China's support in GALILEO.

In fact, the GJU signed an agreement in October 2003 that included a €200 million Chinese contribution to the Galileo program. However, that participation apparently will not allow the full membership that China wants and GALILEO officials for their part are concerned that expansion of Beidou functionality will undermine the Galileo business case. Even though Beidou has long been planned European industry and governments had expected on it being only used a military system. But recent announcements that Beidou would provide an open level of service with 10-meter accuracy, in addition to its encrypted military service has shown their expectations are not correct. The open service will be free to Chinese citizens and other countries depending on the arrangements they make with China. In any case, European plans to sell receivers and signal subscriptions in China are in jeopardy.

The Quasi-Zenith Satellite System from Japan

The Japanese Quasi-Zenith Satellite System *QZSS* was originally proposed by a private sector consortium, but now the Japanese government plans to launch three geo-synchronous satellites broadcasting GPS-like signals. The configuration is intended to provide satellites at high elevation angles over Japan. This is the origin of the term *quasi-zenith*. It is actually a multi-satellite augmentation system designed to benefit modified GPS receivers operating in areas with significant signal obstructions such as urban canyons. The first demonstration QZSS satellite will be launched in 2008 and the satellites will also pass over parts of the Asia-Pacific region and will effectively increase the number of satellites available to suitably equipped GPS users in that region.

THE FUTURE

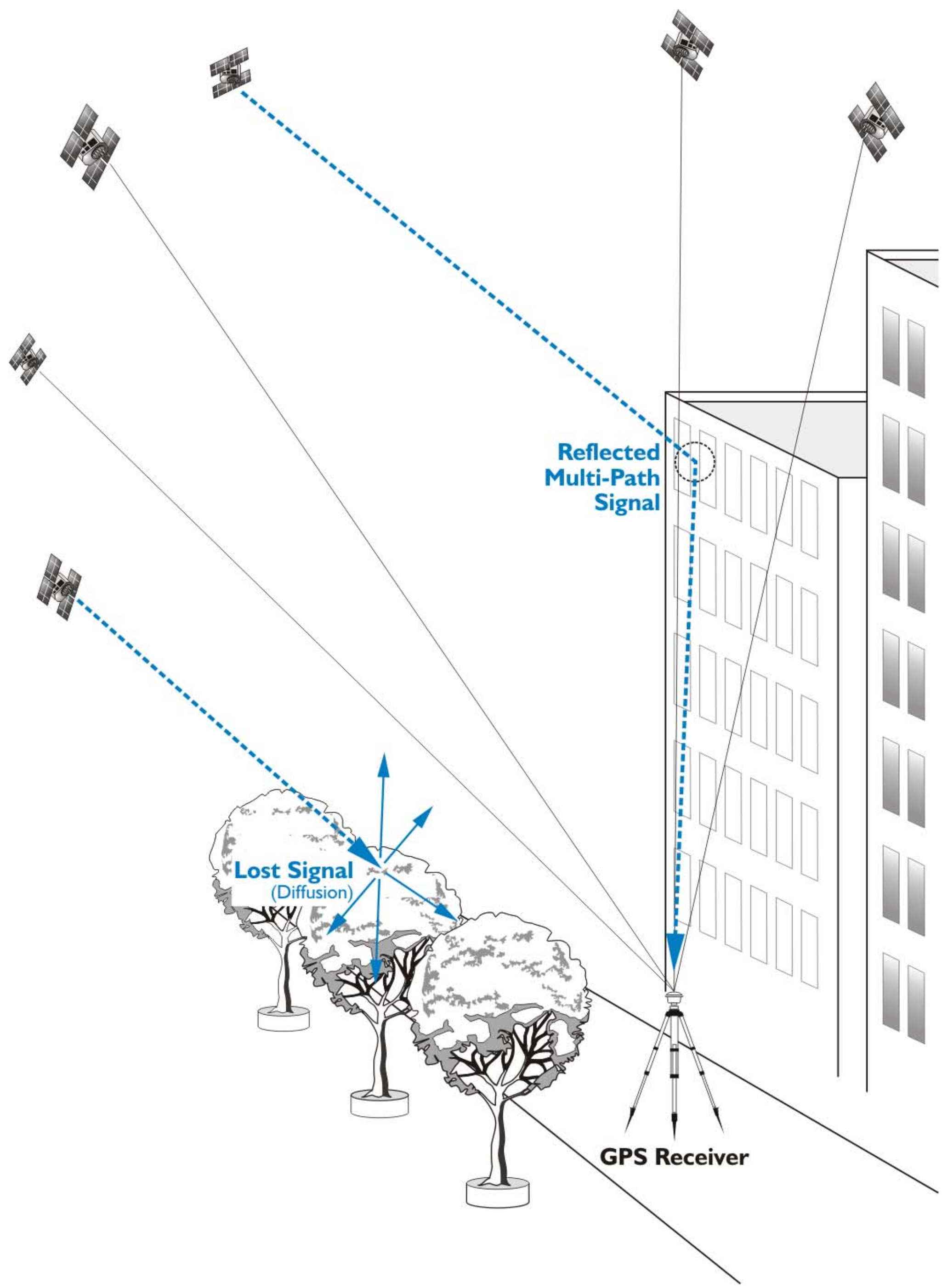
So what is coming? Some day there may be as many as 80 satellites from GPS, GLONASS, Galileo and QZSS. If so the systems will provide users with a variety of signals and codes. The availability of many more satellites will enable new applications in areas where the current lack of satellites has been a hindrance. For civil users, new signals which will provide more protection from interference, ability to compensation for ionospheric delays with pseudoranges and wide-laning or even tri-laning capability. For military users there will be greater anti-jam capability and security. For everybody improvement in accuracy, availability, integrity, and reliability

It looks as if 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. 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.

More Satellites

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.


Reflected
Multi-Path
Signal
Lost Signal
(Diffusion)
GPS Receiver

The Urban Canyon

Figure 8.14

Flexibility. When more satellites are overhead the user has more flexibility. For example, since there are six satellites in a window available to a GPS receiver in Figure 8.14 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.

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.

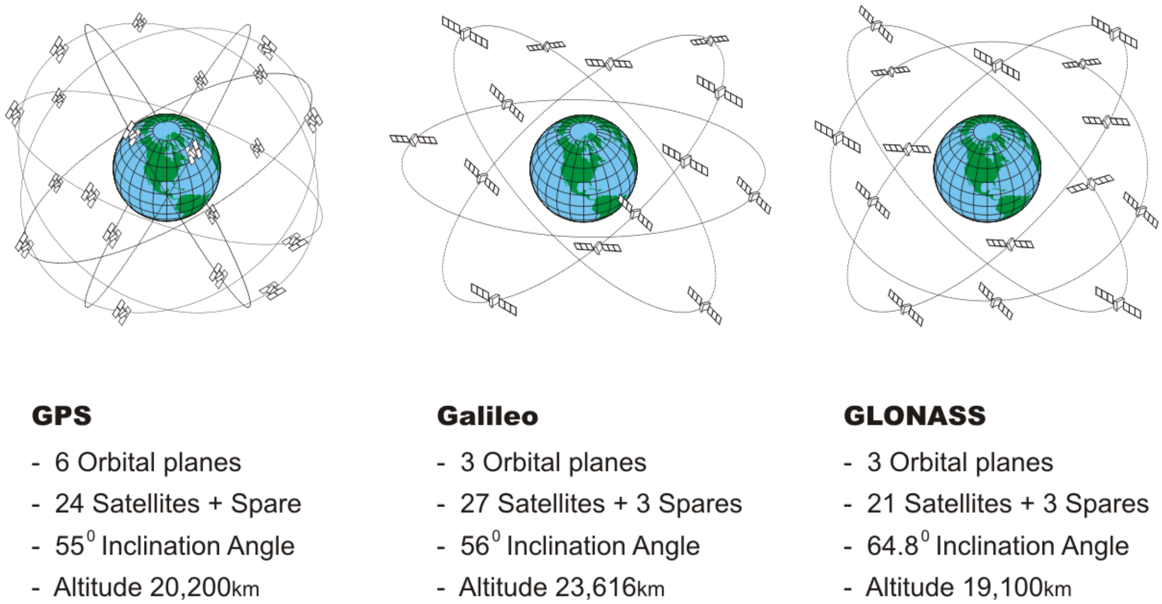
GPS Accuracy. As we have discussed, from the beginning it has been, and continues to be, possible to achieve centimeter, even millimeter, positional accuracy with GPS. Using the signals of two carrier frequencies, *L1 and L2,* and two PRN codes, *P and C/A,* on all available satellites the users of GPS 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.

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-GALILEO-GLONASS Constellations

Figure 8.15

Inconsistency. Despite similarities there are some issues in the consistency GNSS issues as you know. For example, you may recall that the roll-out of the new systems is 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 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 8.13 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.

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. 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.

Summary

Though certainly not assured, it is possible that receivers which track GPS alone will soon be able to utilize carrier phase on L1, be codeless on L2 with L2C and perhaps L5 if the Block IIF satellites are operational.   Further, when it is available, 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 may have the carrier phase on L1, codeless on L2 with L2C and L5 as well as Galileo L1 and E5 signals. It is also possible that some receivers may also be available to track GLONASS and QZSS.

Some years later the modernized GPS constellation may be in place, including L5 and GALILEO. Just considering GPS and GALILEO there could be 60 or so satellites in orbit and available. Including GLONASS and QZSS it is feasible that ~80 satellites could be available. If these constellations become reality a typical user could find 10- 20 satellites above the horizon anywhere, any time.

In fact, the goal of a single receiver that can track all the old and new satellite signals with a significant performance improvement looks possible. But after all, the main attraction of interoperability between these systems is the greatly increased number of satellites and signals, better satellite availability, better dilution of precision, immediate ambiguity resolution on long baselines with three-frequency data, better accuracy in urban settings, and fewer multipath worries those are some of the things we look forward to. It is beginning to look like at least some of those things are achievable.