4ICT9 Lecture Notes – GPS

1 GPS

Here's how GPS works in five simple steps:

1. The basis of GPS is"triangulation" from satellites.

2. To "triangulate," a GPS receiver measures distance using the travel time of radio signals.

3. To measure travel time, GPS needs very accurate timing which it achieves with some tricks.

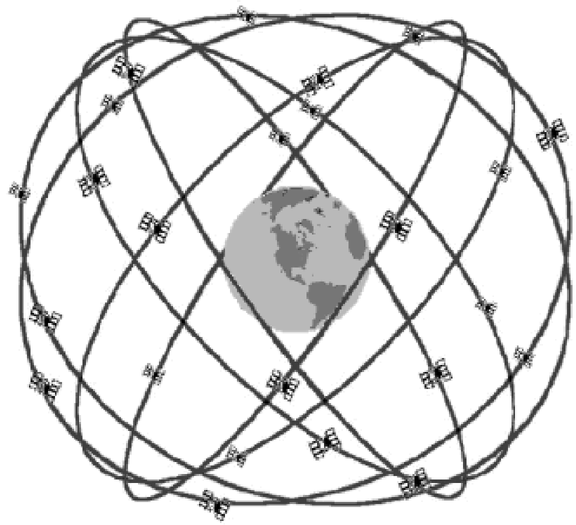
4. Along with distance, you need to know exactly where the satellites are in space. High orbits and careful monitoring are the secret.

5. Finally you must correct for any delays the signal experiences as it travels through the atmosphere.

Improbable as it may seem, the whole idea behind GPS is to use satellites in space as reference points for locations here on earth. By very, very accurately measuring our distance from three satellites we can " triangulate " our position anywhere on earth. Forget for a moment how our receiver measures this distance. We'll get to that later. First consider how distance measurements from three satellites can pinpoint you in space.

1.1 The Big Idea Geometrically

Suppose we measure our distance from a satellite and find it to be 11,000 miles. Knowing that we're 11,000 miles from a particular satellite narrows down all the possible locations we could be in the whole universe to the surface of a sphere that is centered on this satellite and has a radius of 11,000 miles. Next, say we measure our distance to a second satellite and find out that it's 12,000 miles away. That tells us that we're not only on the first sphere but we're also on a sphere that's 12,000 miles from the second satellite. Or in other words, we're somewhere on the circle where these two spheres intersect. If we then make a measurement from a third satellite and find that we're 13,000 miles from that one, that narrows our position down even further, to the two points where the 13,000 mile sphere cuts through the circle that's the intersection of the first two spheres. So by ranging from three satellites we can narrow our position to just two points in space. To decide which one is our true location we could make a fourth measurement. But usually one of the two points is a ridiculous answer (either too far from Earth or moving at an impossible velocity) and can be rejected without a measurement. A fourth measurement does come in very handy for another reason however, but we'll look at that later. Next we'll see how the system measures distances to satellites. We saw that a position is calculated from distance measurements to at least three satellites. But how can you measure the distance to something that's floating around in space? We do it by timing how long it takes for a signal sent from the satellite to arrive at our receiver.



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

1.2 The Big Idea Mathematically

In a sense, the whole thing boils down to those velocity times travel time math problems we did in high school. Remember the old:"If a car goes 60 miles per hour for two hours, how far does it travel?" Velocity (60 mph) x Time (2 hours) = Distance (120 miles) In the case of GPS we're measuring a radio signal so the velocity is going to be the speed of light or roughly 186,000 miles per second. The problem is measuring the travel time. The timing problem is tricky. First, the times are going to be awfully short. If a satellite were right overhead the travel time would be something like 0.06 seconds. So we're going to need some really precise clocks. We'll talk about those soon. But assuming we have precise clocks, how do we measure travel time? To explain it let's use a goofy analogy: Suppose there was a way to get both the satellite and the receiver to start playing "Agadoo" at precisely 12 noon. If sound could reach us from space (which, of course, is ridiculous) then standing at the receiver we'd hear two versions of Agadoo, one from our receiver and one from the satellite. These two versions would be out of sync. The version coming from the satellite would be a little delayed because it had to travel more than 11,000 miles. If we wanted to see just how delayed the satellite's version was, we could start delaying the receiver's version until they fell into perfect sync. The amount we have to shift back the receiver's version is equal to the travel time of the satellite's version. So we just multiply that time times the speed of light and BINGO! we've got our distance to the satellite. That's basically how GPS works - only instead of Agadoo the satellites and receivers use something called a "Pseudo Random Code"

1.3 Carriers

The GPS satellites transmit signals on two carrier frequencies. The L1 carrier is 1575.42 MHz and carries both the status message and a pseudo-random code for timing. The L2 carrier is 1227.60 MHz and is used for the more precise military pseudo-random code. A Random Code? The Pseudo Random Code (PRC) is a fundamental part of GPS. Physically it's just a very complicated digital code, or in other words, a complicated sequence of "on" and "off" pulses as shown. The signal is so complicated that it almost looks like random electrical noise. Hence the name "Pseudo-Random." There are two types of pseudo-random code . The first pseudo-random code is called the C/A (Coarse Acquisition) code. It modulates the L1 carrier. It repeats every 1023 bits and modulates at a 1MHz rate. Each satellite has a unique pseudo-random code. The C/A code is the basis for civilian GPS use. The second pseudo-random code is called the P (Precise) code. It repeats on a seven day cycle and modulates both the L1 and L2 carriers at a 10MHz rate. This code is intended for military users and can be encrypted. When it's encrypted it's called "Y" code. Since P code is more complicated than C/A it's more difficult for receivers to acquire. That's why many military receivers start by acquiring the C/A code first and then move on to P code.

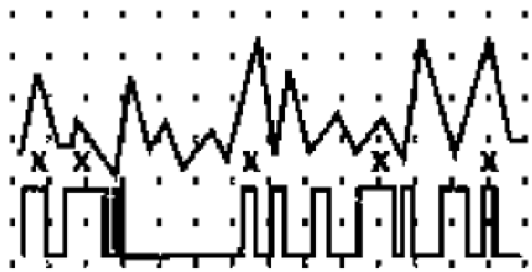
1.4 Navigation Message

There is a low frequency signal added to the L1 codes that gives information about the satellite's orbits, their clock corrections and other system status. There are several good reasons for the complexity of the pseudo-random codes: First, the complex pattern helps make sure that the receiver doesn't accidentally sync up to some other signal. The patterns are so complex that it's highly unlikely that a stray signal will have exactly the same shape. Since each satellite has its own unique Pseudo-Random Code this complexity also guarantees that the receiver won't accidentally pick up another satellite's signal. So all the satellites can use the same frequency without jamming each other. And it makes it more difficult for a hostile force to jam the system. In fact the Pseudo Random Code gives the DoD a way to control access to the system. GPS was developed by the Defense Department primarily for military purposes and even though it's been estimated that there are ten times as many civilian receivers as military ones the system still has considerable military significance. To that end the military maintains exclusive access to the more accurate "P-code" pseudo random code. It's ten times the frequency of the civilian C/A code (and so potentially much more accurate) and much harder to jam. When it's encrypted it's called "Y-code" and only military receivers with the encryption key can receive it. Because this code is modulated on two carriers, sophisticated games can be played with the frequencies to help eliminate errors caused by the atmosphere. But there's another reason for the complexity of the Pseudo Random Code, a reason that's crucial to making GPS economical. The codes make it possible to use "information theory" to "amplify" the GPS signal. And that's why GPS receivers don't need big satellite dishes to receive the GPS signals.

1.5 Using the Pseudo Random Code as an amplifier.

The pseudo random code is one of the clever ideas behind GPS. It not only acts as a great timing signal but it also gives us a way to "amplify" the very weak satellite signals. Here's how that amplification process works: The world is awash in random electrical noise. If we tuned our receivers to the GPS frequency and graphed what we picked up, we'd just see a randomly varying line — the earth's background noise. The GPS signal would be buried in that noise.

The pseudo random code looks a lot like the background noise but with one important difference: we know the pattern of its fluctuations. What if we compare a section of our PRC with the background noise and look for areas where they're both doing the same thing? We can divide the signal up into time periods (called "chipping the signal") and then mark all the periods where they match (i.e. where the background is high when the PRC is high). Since both signals are basically random patterns, probability says that about half the time they'll match and half the time they won't.



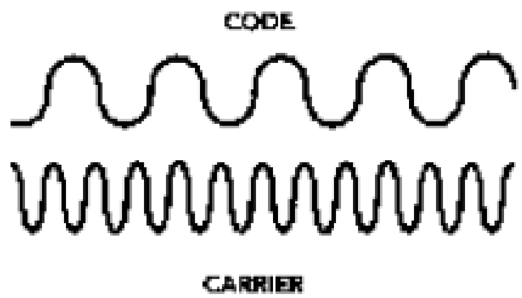
If we set up a scoring system and give ourselves a point when they match and take away a point when they don't, over the long run we'll end up with a score of zero because the -1's will cancel out the 1's. But now if a GPS satellite starts transmitting pulses in the same pattern as our pseudo random code, those signals, even though they're weak, will tend to boost the random background noise in the same pattern we're using for our comparison. Background signals that were right on the border of being a "1" will get boosted over the border and we'll start to see more matches. And our "score will start to go up. Even if that tiny boost only puts one in a hundred background pulses over the line, we can make our score as high as we want by comparing over a longer time. If we use the 1 in 100 figure, we could run our score up to ten by comparing over a thousand time periods. If we compared the PRC to pure random noise over a thousand time periods our score would still be zero, so this represents a ten times amplification. This explanation is a greatly simplified but the basic concept is significant. It means that the system can get away with less powerful satellites and our receivers don't need big antennas like satellite TV. You may wonder why satellite TV doesn't use the same concept and eliminate those big dishes. The reason is speed. The GPS signal has very little information in it. It's basically just a timing pulse, so we can afford to compare the signal over many time periods. A TV signal carries a lot of information and changes rapidly. The comparison system would be too slow and cumbersome.

We glossed over one point in our earlier Agadoo analogy. It assumes that we can guarantee that both the satellite and the receiver start generating their codes at exactly the same time. But how do we make sure everybody is perfectly synced?

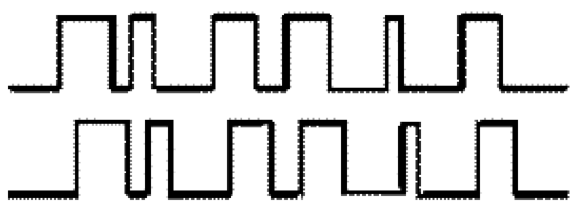
If measuring the travel time of a radio signal is the key to GPS, then our measuring needs to be accurate because if our timing is off by just a thousandth of a second, at the speed of light, that translates into almost 200 miles of error! On the satellite side, timing is almost perfect because they have incredibly precise atomic clocks on board. But what about our receivers here on the ground? Remember that both the satellite and the receiver need to be able to precisely synchronize their pseudo-random codes to make the system work. If our receivers needed atomic clocks (which can cost upwards of 50Kto100K) GPS would be unworkable. Nobody could afford it. The designers of GPS use a work-around that lets us get by with much less accurate clocks in our receivers. This trick is one of the key elements of GPS and as an added side benefit it means that every GPS receiver is essentially an atomic-accuracy clock. Indeed GPS is being used to synchronize computer networks, calibrate other navigation systems, synchronize motion picture equipment and much more. The secret to highly accurate timing is to make an extra satellite measurement. In other words, if three perfect measurements can locate a point in 3-dimensional space, then four imperfect measurements can do the same thing. By using an extra satellite range measurement and a little algebra a GPS receiver can eliminate any clock inaccuracies it might have. Lets graphically illustrate the principle. These drawings will be a lot easier to understand if we keep them two-dimensional. Of course, GPS is a 3-dimensional system but the principles will work just fine in two dimensions. Just remember that in the real 3-dimensional system we need to add one more measurement. Also we've been talking about satellite ranges in terms of distance but since these ranges are just calculated from time let's simplify things by talking about ranges as times. OK, the object here is to see how an extra satellite range can be used to determine if our receivers clocks are out of sync with universal time. Let's say that in reality our position is four seconds from satellite A and six seconds from satellite B. Those two ranges cross and the intersection is our position (remember we're only working in 2D for this example). If our receiver's clocks were perfect, then all our satellite ranges would intersect at a single point (which is our position). But with imperfect clocks, a fourth measurement, done as a cross-check, will NOT intersect with the first three. So the receiver's computer says "Uh-oh! there is a discrepancy in my measurements. I must not be perfectly synced with universal time. Since any offset from universal time will affect all of our measurements, the receiver looks for a single correction factor that it can subtract from all its timing measurements that would cause them all to intersect at a single point. That correction brings the receiver's clock back into sync with universal time. Once it has that correction it applies to all the rest of its measurements and now we've got precise positioning. One consequence of this principle is that any decent GPS receiver will need to have at least four channels so that it can make the four measurements simultaneously. With the pseudo-random code as a rock solid timing sync pulse, and this extra measurement trick to get us perfectly synced to universal time, we have got everything we need to measure our distance to a satellite in space. But for the triangulation to work we not only need to know distance, we also need to know exactly where the satellites are.

1.6 Code-Phase GPS vs. Carrier-Phase GPS

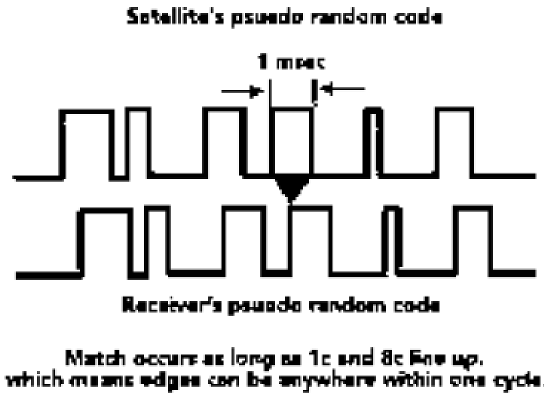
The words "Code-Phase" and "Carrier-Phase" may sound like electronic mumbo-jumbo but, in fact, they just refer to the particular signal that we use for timing measurements. Using the



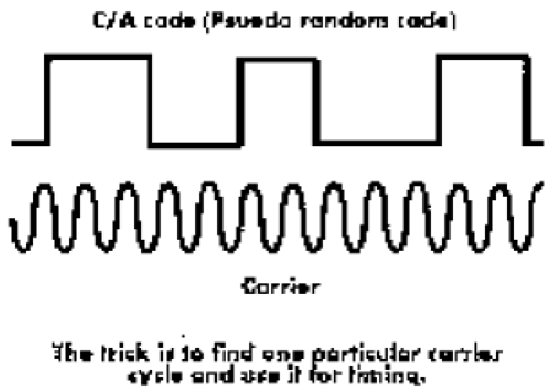
GPS carrier frequency can significantly improve the accuracy of GPS. The concept is simple but to understand it let's review a few basic principles of GPS. Remember that a GPS receiver determines the travel time of a signal from a satellite by comparing the "pseudo random code" it's generating, with an identical code in the signal from the satellite. The receiver slides its code



later and later in time(ie delays it) until it syncs up with the satellite's code. The amount it has to slide the code is equal to the signal's travel time. The problem is that the bits (or cycles) of the pseudo random code are so wide that even if you do get synced up there's still plenty of room for inaccuracy. Consider these two signals: If you compared them logically you'd say they matched. When signal A is a one, signal B is a one. When signal A is a zero, signal B is a zero. But you can see that while they match they're a little out of phase. Notice that signal A is a little ahead of signal B. In fact you could slide signal A almost a half a cycle ahead and the signals would still match logically. That's the problem with code-phase GPS. It's comparing pseudo random codes that have a cycle width of almost a microsecond. And at the speed of light a microsecond is almost 300 meters of error! Code-phase GPS isn't really that bad because receiver designers have come up with ways to make sure that the signals are almost perfectly in phase. Good machines get with in a percent or two. But that's still at least 3-6 meters of error. Survey receivers beat the system by starting with the pseudo random code and then move on to measurements based on the carrier frequency for that code. This carrier frequency is much higher so its pulses are much closer together and therefore more accurate. The pseudo random code has a bit rate of about 1MHz but its carrier frequency has a cycle rate of over a GHz (which



is 1000 times faster!) At the speed of light the 1.57 GHz GPS signal has a wavelength of roughly twenty centimetres, so the carrier signal can act as a much more accurate reference than the pseudo random code by itself. And if we can get to within one percent of perfect phase like we do with code-phase receivers we'd have 3 or 4 millimetre accuracy!



In essence this method is counting the exact number of carrier cycles between the satellite and the receiver. The problem is that the carrier frequency is hard to count because it's so uniform. Every cycle looks like every other. The pseudo random code on the other hand is intentionally complex to make it easier to know which cycle you're looking at. So the trick with "carrier-phase GPS" is to use code-phase techniques to get close. If the code measurement can be made accurate to say, a meter, then we only have a few wavelengths of carrier to consider as we try to determine which cycle really marks the edge of our timing pulse. Resolving this "carrier phase ambiguity" for just a few cycles is a much more tractable problem and as the computers inside the receivers get smarter and smarter it's becoming possible to make this kind of measurement without all the ritual that surveyors go through.

Now back to the mainstream notes and figuring out the satellite position. As already noted the satellites are in orbit around 11,000 miles above the earth. The basic orbits are quite exact but just to make things perfect the GPS satellites are constantly monitored by the US Department of Defense. They use very precise radar to check each satellite's exact altitude, position and speed. The errors they're checking for are called "ephemeris errors" because they affect the satellite's orbit or "ephemeris." These errors are caused by gravitational pulls from the moon and sun and by the pressure of solar radiation on the satellites. The errors are usually very slight but if you want great accuracy they must be taken into account. Once the DoD has measured a satellite's exact position, they relay that information back up to the satellite itself. The satellite then includes this new corrected position information in the timing signals it's broadcasting. So a GPS signal is more than just pseudo-random code for timing purposes. It also contains a navigation message with ephemeris information as well. With perfect timing and the satellite's exact position you'd think we'd be almost ready to make perfect position calculations. But even though the satellites positions are constantly monitored, they can't be watched every second. So slight position or " ephemeris " errors can sneak in between monitoring times. Typically, ephemeris data is updated hourly. Basic geometry itself can magnify these other errors with a principle called "Geometric Dilution of Precision" or GDOP. It sounds complicated but the principle is quite simple. There are usually more satellites available than a receiver needs to fix a position, so the receiver picks a few and ignores the rest. If it picks satellites that are close together in the sky the intersecting circles that define a position will cross at very shallow angles. That increases the gray area or error margin around a position. If it picks satellites that are widely separated the circles intersect at almost right angles and that minimizes the error region. Good receivers determine which satellites will give the lowest GDOP. But there's further complications! Up to now we've been treating the calculations that go into GPS very abstractly, as if the whole thing were happening in a vacuum. But in the real world there are lots of things that can happen to a GPS signal that will make its life less than mathematically perfect. To get the most out of the system, a good GPS receiver needs to take a wide variety of possible errors into account. First, one of the basic assumptions we've been using throughout this tutorial is not exactly true. We've been saying that you calculate distance to a satellite by multiplying a signal's travel time by the speed of light. But the speed of light is only constant in a vacuum. As a GPS signal passes through the charged particles of the ionosphere (The ionosphere is the layer of the atmosphere ranging in altitude from 50 to 500 km. It consists largely of ionized particles which can exert a perturbing effect on GPS signals. While much of the error induced by the ionosphere can be removed through mathematical modelling, it is still one of the most significant error sources.) and then through the water vapour in the troposphere(the troposphere is the lower part of the earth's atmosphere that encompasses our weather. It's full of water vapour and varies in temperature and pressure but it causes relatively little error.) it gets slowed down a bit, and this creates the same kind of error as bad clocks. There are a couple of ways to minimize this kind of error. For one thing we can predict what a typical delay might be on a typical day. This is called modelling(Much of the delay caused by a signal's trip through our atmosphere can be predicted. Mathematical models of the atmosphere take into account the charged particles in the ionosphere and the varying gaseous content of the troposphere. On top of that, the satellites constantly transmit updates to the basic ionospheric model. A GPS receiver must factor in the angle each signal is taking as it enters the atmosphere because that angle determines the length of the trip through the perturbing medium.) and it helps but, of course, atmospheric conditions are rarely exactly typical. Another way to get a handle on these atmosphere-induced errors is to compare the relative speeds of two different signals. This dual frequency measurement is very sophisticated and is only possible with advanced receivers. Physics says that as light moves through a given medium, low-frequency signals get "refracted" or slowed more than high-frequency signals. By comparing the delays of the two different carrier frequencies of the GPS signal, L1 and L2, we can deduce what the medium (i.e. atmosphere) is, and we can correct for it. Unfortunately this requires a very sophisticated receiver since only the military has access to the signals on the L2 carrier. Civilian companies have worked around this problem with some complicated strategies. The difficulties for the GPS signal don't end when it gets down to the ground. The signal may bounce off various local obstructions before it gets to our receiver. This is called multipath error and is similar to the ghosting you might see on a TV. The whole concept of GPS relies on the idea that a GPS signal flies straight from the satellite to the receiver. Unfortunately, in the real world the signal will also bounce around on just about everything in the local environment and get to the receiver that way too. The result is a barrage of signals arriving at the receiver: first the direct one, then a bunch of delayed reflected ones. This creates a messy signal. If the bounced signals are strong enough they can confuse the receiver and cause erroneous measurements. Sophisticated receivers use a variety of signal processing tricks to make sure that they only consider the earliest arriving signals (which are the direct ones). A more invidious set of errors are those that are deliberately introduced. Until 2000/2001, the same government that spent 12 billion dollars to develop the most accurate navigation system in the world intentionally degraded its accuracy. The policy is called Selective Availability or SA and the idea behind it was to make sure that no hostile force or terrorist group can use GPS to make accurate weapons. Basically with SA the DoD introduces some "noise" into the satellite's clock data which, in turn, adds noise (or inaccuracy) into position calculations. The DoD may also be sending slightly erroneous orbital data to the satellites which they transmit back to receivers on the ground as part of a status message. Together these factors used to make SA the biggest single source of inaccuracy in the system. Military receivers use a decryption key to remove the SA errors and so they're much more accurate. Fortunately all of these inaccuracies still don't add up to much of an error. And a form of GPS called "Differential GPS" can significantly reduce these problems.

1.7 Differential GPS

Differential GPS involves the cooperation of two receivers, one that's stationary and another that's roving around making position measurements. The stationary receiver is the key. It ties all the satellite measurements into a solid local reference. Here's how it works: Remember that GPS receivers use timing signals from at least four satellites to establish a position. Each of those timing signals is going to have some error or delay depending on what sort of perils have befallen it on its trip down to us. Since each of the timing signals that go into a position calculation has some error, that calculation is going to be a compounding of those errors. Luckily the sheer scale of the GPS system comes to our rescue. The satellites are so far out in space that the little distances we travel here on earth are insignificant. So if two receivers are fairly close to each other, say within a few hundred kilometers, the signals that reach both of them will have travelled through virtually the same slice of atmosphere, and so will have virtually the same errors. Differential GPS can eliminate all errors that are common to both the reference receiver and the roving receiver. These include everything except multipath errors (because they occur right around the receiver) and any receiver errors (because they're unique to the receiver).

Summary of GPS Error Sources

Typical Error in Meters	(per satellite) Standard GPS	Differential
GPS		
Satellite Clocks	1.5	0
Orbit Errors	2.5	0
Ionosphere	5.0	0.4
Troposphere	0.5	0.2
Receiver Noise	0.3	0.3
Multipath	0.6	0.6
SA	30	0
Typical Position Accuracy		
Horizontal	50	1.3
Vertical	78	2.0
3-D	93	2.8

That's the idea behind differential GPS: We have one receiver measure the timing errors and then provide correction information to the other receivers that are roving around. That way virtually all errors can be eliminated from the system, even the Selective Availability error that the DoD used to put in on purpose. The reference receiver is located on a point that's been very accurately surveyed. This reference station receives the same GPS signals as the roving receiver but instead of working like a normal GPS receiver it attacks the equations backwards. Instead of using timing signals to calculate its position, it uses its known position to calculate timing. It figures out what the travel time of the GPS signals should be, and compares it with what they actually are. The difference is an "error correction" factor. The receiver then transmits this error information to the roving receiver so it can use it to correct its measurements. Since the reference receiver has no way of knowing which of the many available satellites a roving receiver might be using to calculate its position, the reference receiver quickly runs through all the visible satellites and computes each of their errors. Then it encodes this information into a standard format and transmits it to the roving receivers. GPS receivers don't actually transmit corrections by themselves. They are linked to separate radio transmitters. It's as if the reference receiver is saying: "OK everybody, right now the signal from satellite 1 is ten nanoseconds delayed, satellite 2 is three nanoseconds delayed, satellite 3 is sixteen nanoseconds delayed...." and so on. The roving receivers get the complete list of errors and apply the corrections for the particular satellites they're using. Error transmissions not only include the timing error for each satellite, they also include the rate of change of that error as well. That way the roving receiver can interpolate its position between updates. These reference stations often transmit on the radio beacons that are already in place for radio direction finding (usually in the 300kHz range).

1.8 Post Processing DGPS

Not all DGPS applications are created equal. Some don't need the radio link because they don't need precise positioning immediately. It's one thing if you're trying to position a drill bit over a particular spot on the ocean floor from a pitching boat, but quite another if you just want to record the track of a new road for inclusion on a map. For applications like the later, the roving receiver just needs to record all of its measured positions and the exact time it made each measurement. Then later, this data can be merged with corrections recorded at a reference receiver for a final clean-up of the data. So you don't need the radio link that you have to have in real-time systems. There's another permutation of DGPS, called "inverted DGPS," that can save money in certain tracking applications. Let's say you've got a fleet of buses and you'd like to pinpoint them on street maps with very high accuracy (maybe so you can see which side of an intersection they're parked on or whatever). Anyway, you'd like this accuracy but you don't want to buy expensive "differential-ready" receivers for every bus. With an inverted DGPS system the buses would be equipped with standard GPS receivers and a transmitter and would transmit their standard GPS positions back to the tracking office. Then at the tracking office the corrections would be applied to the received positions. It requires a computer to do the calculations, a transmitter to transmit the data but it gives you a fleet of very accurate positions for the cost of one reference station, a computer and a lot of standard GPS receivers. DGPS may soon be able to resolve positions that are no farther apart than the width of your little finger. To understand how this kind of GPS is being developed you need to understand a little about GPS signals. If two receivers are fairly close to each other, say within a few hundred kilometres, the signals that reach both of them will have travelled through virtually the same slice of atmosphere, and so will have virtually the same line. You might be aware that surveyors have been using GPS to do extremely precise surveys for years, fixing points with relative accuracy on the order of millimeters. They get this accuracy by using GPS in a very specialized way. In fact it's really a form of interferometry. Interferometry is a measurement technique based on the fact that two waveforms will constructively or destructively interfere with each other if they arrive slightly out of phase. The large effect of the interference is easier to measure than the signals themselves and so provides a very sensitive way to compare two signals. They use multiple receivers like the differential systems we've been discussing but the technique is much more involved - so involved that only trained geodesists with expensive machines and lots of time can do it. But even though the system surveyors use is too finicky for most users of GPS, one of its underlying principles is starting to find its way into general receivers. It's called "carrier-phase GPS," and it can be orders of magnitude more accurate than the "code-phase GPS" that most mortals use. Differential GPS techniques are also finding applications for aeronautical purposes. The FAA realized the great benefits GPS could bring to aviation, but they wanted more. They wanted the accuracy of Differential GPS and they wanted it across the whole continent. Maybe the whole world. Their plan is called the "Wide Area Augmentation System" or "WAAS," and it's basically a continental DGPS system. The idea grew out of some very specific requirements that basic GPS just couldn't handle by itself. It began with "system integrity." GPS is very reliable but every once in a while a GPS satellite malfunctions and gives inaccurate data. The GPS monitoring stations detect this sort of thing and transmit a system status message that tells receivers to disregard the broken satellite until further notice. Unfortunately this process can take many minutes which could be too late for an airplane in the middle of a landing. So the FAA got the idea that they could set up their own monitoring system that would respond much quicker. In fact, they figured they could park a geosynchronous satellite somewhere over the U.S. that would instantly alert aircraft when there was a problem. Then they reasoned that they could transmit this information right on a GPS channel so aircraft could receive it on their GPS receivers and wouldn't need any additional radios. But if we've got the geosynchronous satellite already transmitting on the GPS frequency, why not use it for positioning purposes too? Adding another satellite helps with positioning accuracy and it ensures that plenty of satellites are always visible around the country.So why not use that satellite to relay differential corrections too? The FAA figured that with about 24 reference receivers scattered across the U.S. they could gather pretty good correction data for most of the country. That data would make GPS accurate enough for "Category 1" landings (i.e. very close to the runway but not zero visibility) The ramifications of this go well beyond aviation, because the system guarantees that DGPS corrections will be raining out of the skies over the US for everyone to use. Europes version of WAAS is known as EGNOS and the Russian version as GLOMASS. In the US the FAA has established the "Local Area Augmentation Systems" (LAAS) near runways. These work like the WAAS but on a smaller scale. The reference receivers would be near the runways and so would be able to give much more accurate correction data to the incoming planes. With a LAAS system aircraft can use GPS to make Category 3 landings (zero visibility). GPS used in conjunction with communication links and computers can provide the backbone for systems tailored to applications in agriculture, mass transit, urban delivery, public safety, and vessel and vehicle tracking. One particularly compelling use of GPS and other location technologies is in the E-911 requirement of the US FCC. E-911 services will help emergency personnel locate a wireless phone user in the event of an accident. There are two basic approaches to satisfying E-911 requirements : using handset-based technology, or a positioning system inside the wireless network. The FCC has adopted a position of technological neutrality in the debate between handset and network based E-911 services. Basic 911 is the delivery of emergency 911 calls to a Public Safety Answering Point (PSAP). E911 provides for additional features, including automatically reporting the caller's location and telephone number. The 911 debate and, indeed, the future of GPS was significantly influenced by the announcement by the Clinton administration on the discontinuation of Selective Availabilty within the GPS network. The Clinton Administration said the decision to discontinue the "selective availability" of GPS would have immediate implications on E-911. "Removing SA will boost the accuracy of implementing the 911 requirements," the White House says. "A GPS-based solution might be simpler and more economical than alternative techniques such as radio tower triangulation, leading to lower consumer costs. When it comes to carriers' enhanced 911 plans, the US industry's response is by no means definitive, because carriers can choose one solution and then change their plans if they later find a better technology. Still, faced with the FCC's mandate which says 67 percent of handsets must be able to be traced within 50 meters, carriers are identifying a variety of handset- and network-based solutions. Sprint PCS chose a handset solution from Qualcomm, while Verizon Wireless opted for a network solution. Cingular Wireless plans to deploy both. Many operators were examining Network Positioning or Location Based Services to satisfy FCC requirements. The variety of Network based positioning technologies are largely incompatible. To this end, Ericsson, Nokia and Motorola have formed the Location Interoperability Forum (LIF) dedicated to developing global interoperability between mobile positioning systems. They propose a family of standards based location determination methods based on Cell-ID and timing advance, E-OTD(GSM) (Enhanced Observed Time Differential), AFLT(IS-95)(Advanced Forward Link Trilateration)) and MS Based Assisted GPS.

We will now look at Network Positioning Technologies in more detail.