5.4 GPS ERROR SOURCES

If the world was like a laboratory with perfect laboratory conditions, basic GPS would be a lot more accurate. Unfortunately, it is not so, and has plenty of opportunities for a radio-based system that spans the entire planet to get fouled up. Inaccuracies in GPS signals come from the variety of sources (Fig9.7), like satellite clocks, imperfect orbits and especially from the signal's trip through the earth's atmosphere. Since these inaccuracies are variable, it is hard to predict what they will be in order to correct for them. Although, these errors are small, but to get the kind of accuracies some critical positioning jobs require, all the errors, no matter how minor, are to be minimized. What is needed is a way to measure the actual errors as they happen. The error sources can be classified into three groups, namely satellite-related errors, propagation-medium related errors, and receiver-related errors. These are known as systematic errors. However, sometimes errors are introduced intentionally known as selective availability

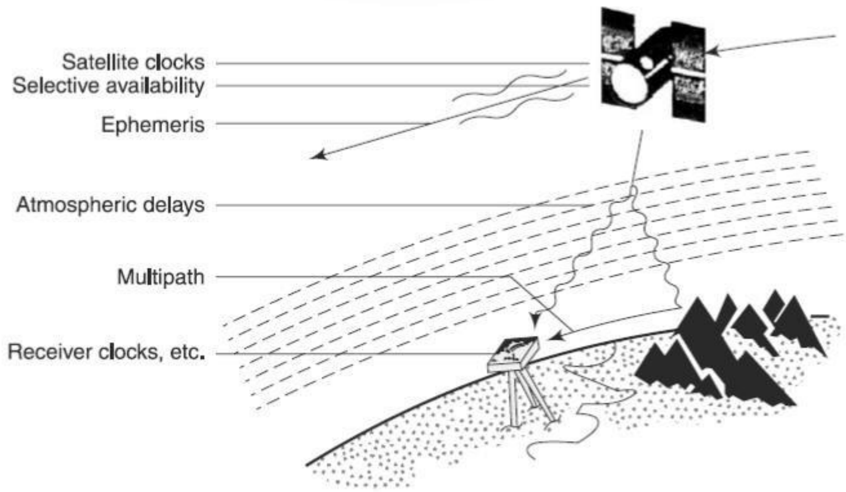

Fig. 9.7 *Error sources*

Systematic Errors

Satellite Error:

GPS satellites are equipped with very accurate atomic clocks. But as good as these clocks are, they are not perfect. Slight inaccuracies in their timekeeping ultimately lead to inaccuracies in our position measurements. The satellite's position in space is also

important equally because it is the starting point for all of the GPS calculations. GPS satellites are placed into very high orbits and so are relatively free from the perturbing effects of the earth's upper atmosphere,
but even so they still drift slightly from their predicted orbits contributing to the errors.

1. ***Signal propagation errors:*** GPS satellites transmit their timing information by radio, and that is another source of error because radio signals in the earth's atmosphere (ionosphere and troposphere) do not behave as predictably desired. It is assumed that radio signals travel at the speed of light, which is presumably a constant. However, the speed of light is not constant. It is only constant in vacuum. In the real world, light (or radio) slows down depending on what it is travelling through. As a GPS signal comes down through the charged particles in the ionosphere and then through the water vapor in the troposphere, it gets delayed a little. Since calculation of distance assumes a constant speed of light, this delay results into a miscalculation of the satellite's distance, which in turn translates into an error in position. Good receivers add in a correction factor for a typical trip through the earth's atmosphere, which helps, but since the atmosphere varies from point to point and moment to moment, no correction factor or atmospheric model can accurately compensate for the delays that actually occur.

2. ***Receiver errors:*** The receivers are also not perfect. They can introduce their own errors which usually stem from their clocks or internal noise, multipath and antenna face centre variation.

(a) Multipath: As the GPS signal arrives at the surface of the earth it may get reflected by local obstructions and gets to the receiver's antenna via more than one path. This form of error is called multipath error because, in a sense, the signal is getting to the antenna by multiple paths. First, the antenna receives the direct signal it being the fastest, and then the reflected signals arrive a little later (Fig. 9.8). These delayed signals can interfere with the direct signal giving noisy results. Secondary effects are reflections at the satellite during signal transmission.

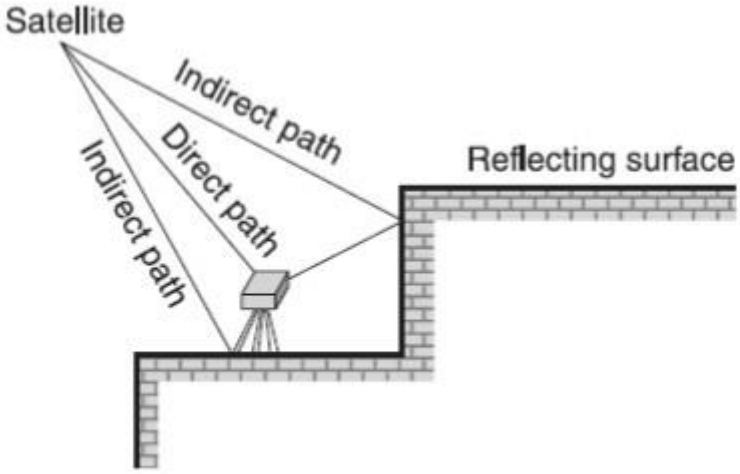

Fig. 9.8 *Multipath effect*

The influence of the multipath, however, can be estimated by using a combination of L1 and L2 codes, and carrier-phase measurement. The principle is based on the fact that troposphere, clock errors, and relativistic effects influence code and carrier phases by the same amount. This is not true for ionospheric refraction and multipath which are frequency dependent. Taking ionospheric-free code ranges and carrier phases, and forming corresponding differences, all aforementioned effects, except for multipath, cancel out. The most effective counter measure to multipath is to avoid sites where it could be a problem.

The elimination of multipath signals is also possible by selecting an antenna that takes advantage of the signal polarisation. GPS signals are right-handed circularly polarised, whereas the reflected signals are left-handed polarised. A reduction of multipath effect may also be achieved by digital filtering, wideband antennas, and radio frequency absorbent antenna ground planes. The absorbent antenna ground plane reduces the interference of satellite signals with low or even negative elevation angles which occur in case of multipath.

(b) Antenna phase: centre offset and variation: The phase centre of the antenna is the point to which the radio signal measurement is referred and generally is not identical with the geometric antenna centre. The offset depends on the elevation, the azimuth, and the intensity of the satellite signal and is different for L1 and L2 codes. Also, the true

antenna phase centre may be different from the manufacturer indicated centre. This antenna offset may simply arise from inaccurate production series. Further, the antenna phase centre can vary with respect to the incoming satellite signals. The variation is systematic and may be investigated by test series.

Systematic effects can be eliminated by appropriate combinations of the observables. Differencing between receivers eliminates satellite-specific biases, and differencing between satellites eliminates receiver-specific biases. Thus, double differenced pseudoranges are, to a high degree, free of systematic errors originating from the satellites and from the receivers. With respect to refraction, this is only true for short baseline where the measured ranges at both end points are affected equally. In addition, ionoshperic refraction can be virtually eliminated by an adequate combination of dual frequency data.

Multipath is caused by multiple reflection of the signal. The interference between the direct and the reflected signal is largely not random; however, it may also appear as a noise. A similar effect is called ***imaging,*** where a reflecting obstacle generates an image of the real antenna which distorts the antenna pattern. Both effects, multipath and imaging, can be considerably reduced by selecting sites protected from reflections (buildings, vehicles, trees, etc.) and by appropriate antenna design. It should be noted that multipath is frequency dependent. Therefore, carrier phases are less affected than code ranges where multipath can amount to the meter level. The random noise mainly contains the actual observation noise plus random constituents of multipath (especially for kinematic applications).

The measurement noise, an estimation of the satellite biases, and the contributions from the wave propagation are combined in the User Equivalent Range Error (UERE). This UERE is transmitted via the navigation message. In combination with DOP factor, UERE allows for an estimation of the achievable point positioningprecision.