## 6.1 Approximate and Cell ID

Among the positioning techniques, this is the simplest one to implement. “Approximate” and “Cell ID” are very similar concepts. In the case of the former this typically implies that the base station (BS) services a very small coverage area, such as RFID scanner, and only when the mobile station (MS) is very close to the BS can the MS’s location be determined. It is assumed that the BS’s location is known, and the MS’s location is taken to be identical to that of the BS. Due to the short range of the BS, the positioning accuracy can be very good (say few cm), adequate for many applications. However, the disadvantages are significant: the availability is limited due to the small coverage area, and a possible limitation on the number and distribution of BSs. Hence the location of a MS may not be able to be determined at all times. Apple’s ibeacon is an example of a technological implementation of the approximate positioning principle.

In contrast, Cell ID implies the coverage of a BS is relatively large. Each BS broadcasts messages including Cell ID across its “cell”. An MS is receiving these broadcast messages, and thus it always knows its Cell ID. Same as in “Approximate” concept, an MS can have its actual location simply by using the geographical coordinates of the serving BS. However, as the coverage of a BS is large, Cell ID suffers from a loss of positioning accuracy. A typical Cell ID system is the cellular network. It is also widely used in WiFi, BLE positioning systems. The advantages are simplicity and excellent availability. There are extensions of Cell ID which can narrow down the Cell (such as using received signal strength to estimate the distance from the BS) or divide the Cell to smaller cells (such as using sector antennas). In this way, the positioning accuracy can be improved.



6.2.1 TOA

The time-of-arrival (TOA) approach determines the MS’s position, in a geometric sense, based on the intersection of the distance (or range) circles centred on several BSs. This is known as trilateration. In the case of RF signals multiplying the propagation time by the speed of electromagnetic radiation (EMR) allows the range from the MS to the BS to be computed. For one-way ranging, two clocks located at the BS and MS respectively, are needed. One to note the signal transmission time, and the second to record the signal arrival time. Ideally, the MS and BS should be synchronised. However, it is a difficult task.

Unsynchronised clocks between the MS and the BS will cause a bias in the range measurement, which will in turn systematically bias the position solution derived from the range measurements. For high positioning accuracy (metres to decametres level) the MS and BS clocks have to be synchronised to the few nanoseconds level, or even better. In principle using TOA measurements is a good approach, however in practical underground positioning systems the synchronisation difficulties may be insurmountable.

To overcome the synchronisation problem, measuring the round trip of the signal is an alternative approach that is widely used (such as UWB two way ranging). The initial signal can be generated either in the MS or BS. Measuring the round trip of the signal has significant advantages, nevertheless there are some disadvantages:

* the processing time has to be estimated accurately, otherwise it can be a major source of error.
* the MS design is more complex.
* the system often has a capacity issue, as it may only support a limited number of
* MSs at the same time.



6.2.2 TDOA

An alternative technique of TOA is to measure time difference of arrival (TDOA) of signals. This approach uses time difference measurements rather than absolute time measurements as TOA does, and has the major advantage that the error due to unsynchronised MS time is eliminated (note the synchronisation of BS is still required while synchronisation of MS is not needed). The TDOA measurement removes the MS’ time stamp, the MS’ clock error can be ignored. The TDOA technique of positioning is often referred to as a “hyperbolic” system because the time difference is converted to a constant distance difference to two BSs (as foci) that define a hyperbolic curve. The intersection of two hyperbolas determines the position in 2D. The accuracy of the system is a function of, among other factors, the relative BS locations.



## 6.3 Angle-based

Using angle-of-arrival (AOA) observations is one of the oldest positioning methods. It was widely used by surveyors when the long range measurement technologies were not available. Once the absolute angle is obtained, the angle from the mobile station to the base station can be modelled as:

With the knowledge of at least two AOA measurements with respect to different BSs, the MS location can be found at the intersection of apparent arrival directions (in the 2D case).

The accuracy of AOA methods can be high, however in real-world applications using RF signals it is limited by signal interference, multipath, and non-line-of-sight (NLOS) propagation, especially in indoor and underground environments. To make the AOA measurement an antenna array is necessary at the stations, which is an extra cost. The new BLE5.1 standard provides AOA and AOD (angle of departure) measurement. Our tests have shown that in an ideal environment, accuracy of 1-2 degrees angle measurements can be achieved; In a typical underground mine, the angle measurement accuracy is between 10 degrees to several 10s degrees {test report}.

AOA is important for vision-based systems. These systems measure image coordinates that represent angular information, AOA is actually used by some optical positioning systems.

## 6.4 Feature-matching

Feature-matching is a large category of techniques, which include vision-based positioning as well as the popular RSS “fingerprinting” technique. One distinguishing characteristic of such techniques is the need to have a pre-created database of “features”. The positioning techniques then take advantage of such pre-created data by using an algorithm that finds the best “match” to the observed “feature”.

For instance, the key requirement of the RSS fingerprinting technique is to map location-sensitive parameters of measured signals across the areas of interest. The fingerprinting technique has been applied for positioning to a variety of wireless communications technologies, including WiFi, BLE (Bluetooth Low Energy), RFID, FM and AM radios. This positioning technique therefore consists of two phases: the training phase and the positioning phase. The objective of the training phase is to construct a fingerprint database. This is done by identifying (and positioning) a set of reference points (RPs). At each RP, RF parameters such as RSS are measured and the characteristic RF features of that RP are determined. These are then recorded in a database. This process is repeated at all RPs. During the positioning phase the MS measures the RF parameter at a location where it requires its position. The measurements are compared with the parameter values in the database using an appropriate search/matching algorithm. The outcome is the likeliest position of the MS, in the coordinate or positioning system used for mapping the RPs.

B

A

RSS1, RSS2, …

(?,?)

MU

(x,y)

MU location

meas

meas

meas

(x,y)1

RSS1, RSS2, …

(x,y)2

RSS1, RSS2, …

(x,y)n

RSS1, RSS2, …

…

database

AP(1)

AP(2)

AP(3)

AP(L)

…

at RP(3)

store

meas