UWB Vs BLE Whitepaper

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Why do we need UWB, can't BLE provide location services?

This is a question we get asked routinely at GS Technology, being an experienced design house for UWB (ultrawide-band) applications, clients will ask why they need to use this new technology. There are two ways to answer that question; first of all, we can explore how UWB ToF (time of flight) differs from BLE (Bluetooth low energy) RSSI (receive signal strength indication) for the purposes of location services.

The second way to understand that UWB is clearly the better choice for performing micro-location is the simple fact that despite Apple promoting their iBeacon BLE location services for several years, they have now switched to UWB with the inclusion of the U1 chip in the iPhone 11. They didn't do that (a huge investment in R&D) unless there was a very good reason for it. It is self-evident that this investment was made to both increase the number of applications (the width) and to increase the quality (the depth) of the applications.

All of which brings us back to the fundamental differences in the technologies and why UWB offers very significant improvements over BLE based systems in terms of location accuracy and data rates.

<u>Bandwidth and Multipath</u>

UWB (Ultra-wideband) has by definition, a very wide spectrum, ie it operates in a very wide frequency range (typically 500 MHz) compared to BLE with a total bandwidth of around 2 MHz. This has a major impact on what is called the multipath performance.

In a typical indoor environment, there are many surfaces for GHz-type radio waves to bounce off. This is analogous to soundwaves echoing in a large room, making the original sound loose intelligibility. With radio waves, these reflected waves can cause *constructive* and *destructive*

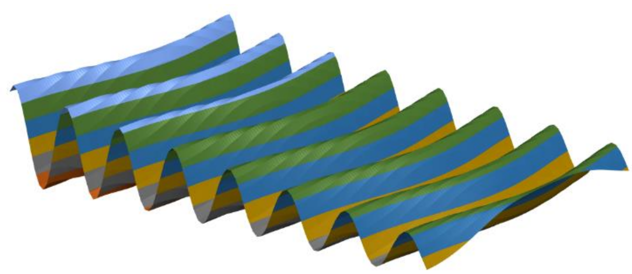

Figure 2: Wave propagation without reflections

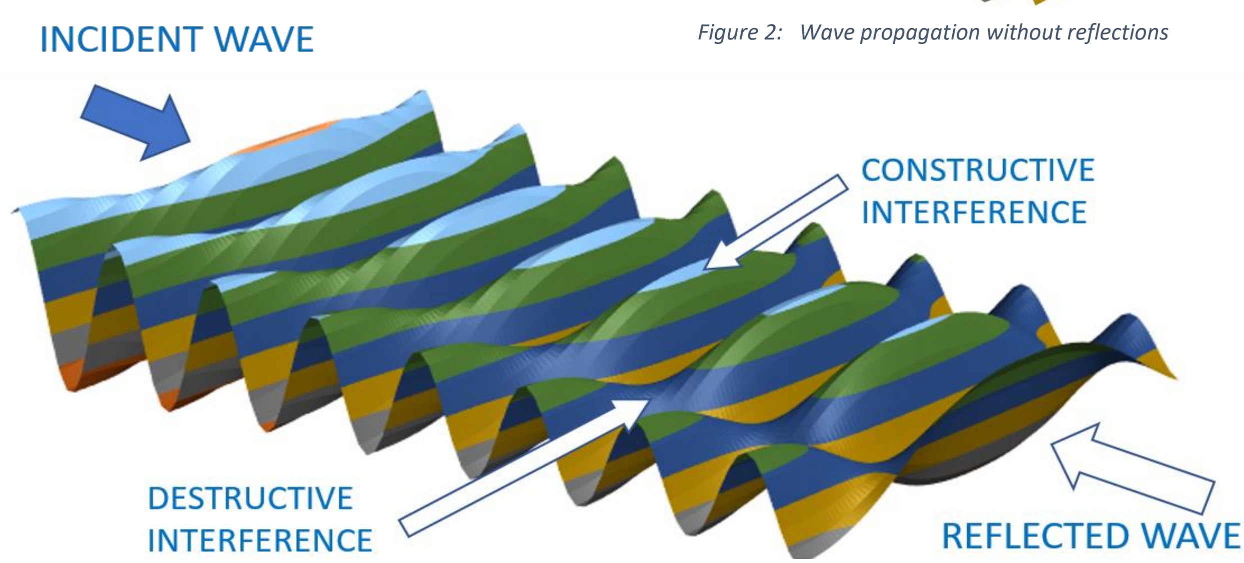

Figure 1: Constructive and destructive interference in waves due to reflections (courtesy of GS Technology)

interference with the original radio signal. This multipath interference means that the signal level as seen by radio receiver can change in the presence of these reflections.

Multipath is a common problem in high frequency radio, often the way to reduce this effect is to use two or more frequencies at the same time, the likelihood of multiple frequencies having a significant multipath fading at the same exact point in both time and space, becomes much lower.

UWB is essentially extending that principle, the extremely wide bandwidth means it is like having 250 separate BLE connections working together but all at *different* frequencies.

The Human Element

One of the major challenges for GHz-type radio links is the signal degradation that the human body can have can on it. The human body can be modelled for RF propagation in a number of different ways and often in great detail, but a "bag of slightly salty water" isn't too far from the truth.

This means that when you hold your handset in your hand or put it in your pocket or in a backpack, your body is causing a lot of signal attenuation. The human body is not just an absorber of this type of RF energy, it is also responsible for scattering, refraction and other propagation effects that degrade the signal.

In the world of Bluetooth headphone design (the same frequency band as BLE), this a major issue that needs to be designed around. At GS Technology, we are well used to designing custom antennas for each headphone type to optimize the signal strength from the handset to each of the earbuds. Modelling the RF characteristics of the human body has become an essential part of headphone design.

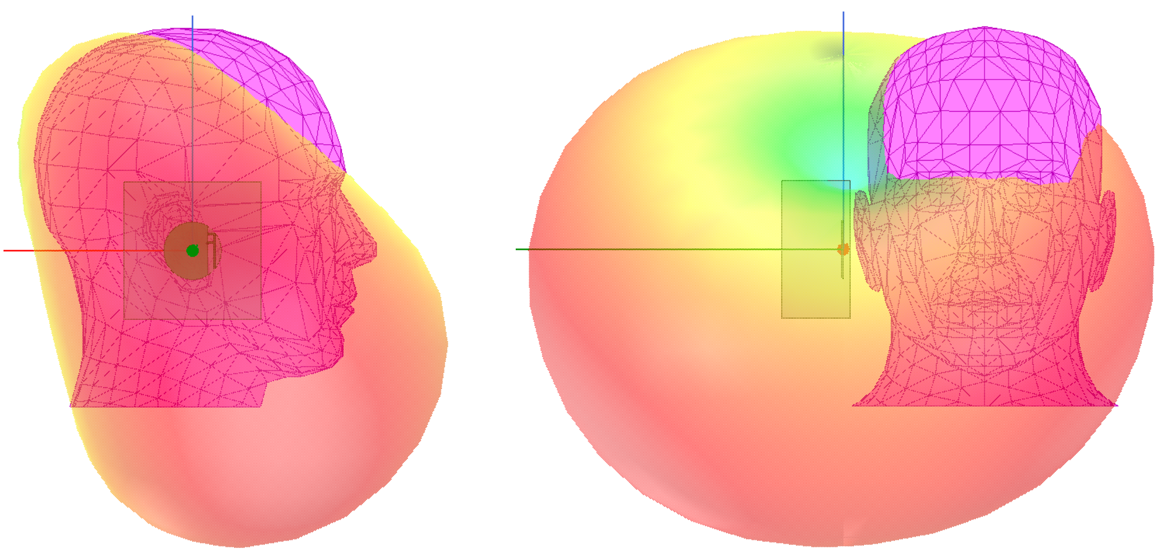

Figure 3: An RF simulation of Bluetooth propagation patterns around a human head for a headphone (courtesy of GS Technology)

BLE and RSSI

BLE location services are principally based on RSSI, measuring the strength of the signal received from a fixed beacon, the further away the receiver and transmitter are from each other, the lower the received signal strength so estimates can be made as to the distance. If there are several beacons at known and fixed locations, then the location of the device of interest can be triangulated by looking at the results over a number of measurements from spatially diverse beacons. There are clearly issues with this approach:

- The multipath issue mentioned above will result in a large errors (noise) being added to the estimated range. Normally, noise can be filtered out by taking a large set of samples and applying statistical techniques, but this only works if the noise is unbiased, in other words has equal probability of giving a range estimate that is more or less than the actual distance. Because of the way nature of multipath, in a fixed location, the results might be biased one way or the other. This means that filtering cannot be assured to settle on the right distance estimate, no matter how intensive the filtering process is.
- The human body will very strongly affect the signal level seen by a receiver so the RSSI, will vary considerably depending upon the location of the BLE device, being handheld, held to the ear, in the pocket, etc. will have a significant impact on RSSI based systems. Again, this interference will be biased and so no matter how much filtering is applied, the distance estimate can converge on an incorrect value.
- RSSI based systems require constant recalibration to work. One way that this can be implemented is a beacon can send two or more BLE data packets with different signal strengths and then ask the device being tracked to report the difference in levels of the packets. The issue with these types of calibration techniques is that the data packets need to be sent at different times (these calibration data packets cannot occur simultaneously) and so any small differences in the location, or body obstruction changes of the item of interest during the calibration process will result in calibration errors from the outset.

In the example below, both a UWB and BLE system are trying to measure a 1-meter distance with a hand placed in-between. In both situations, this will cause a measurement error by each system.

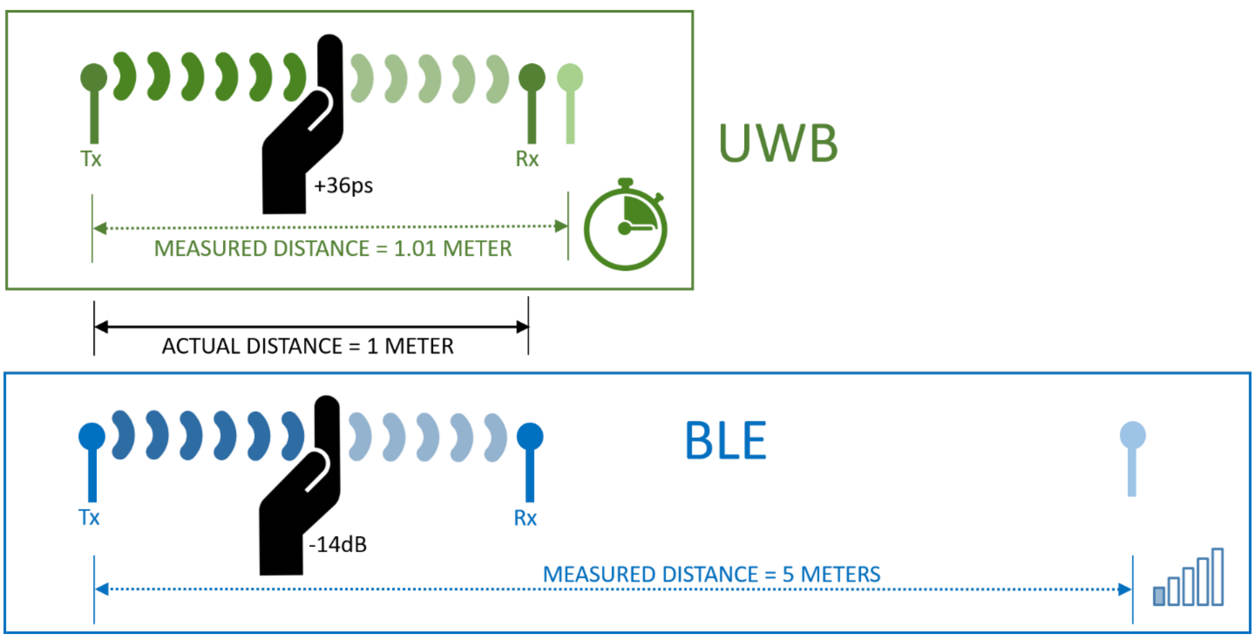

Figure 4: Typical ranging error sources in UWB and BLE

In the case of the BLE system, the error comes from the 14 dB signal attenuation caused by the hand, in the case of the UWB system, the error will come from the reduced speed of light when passing though the hand. In the case of the BLE system, the error will be around 500% but in the UWB the measurement error will only be around 1 centimeter (1%) and that will be fixed, so even if measuring 10 meters, the hand would still only cause a 1 centimeter error.

UWB and ToF

UWB location services work in a totally different way to BLE location services. Instead of measuring the signal level, UWB directly measures the time taken for radio pulses to travel between the transmitter and the receiver. Ordinarily, this is very hard to measure, because of the time-smearing effect of multipath and slow rise times of normal radio pulses. Because UWB is almost immune to multipath issues and uses very fast rise-time impulses, it is inherently able to perform time-of-flight measurements.

Figure 5: Racing Photons (courtesy of GS Technology)

Just to be clear, time-of-flight measurement means that UWB is measuring the speed of light, which by definition, nothing can travel faster than. This has another interesting benefit, when measuring distances, there is no way to intercept the UWB signal, relay it to another UWB transceiver that is closer to the measuring device and then spoof the system into thinking that the device is closer than it really is. Whatever is being used to relay the UWB signal is also fundamentally limited by the speed of light too! This means for security applications, UWB offers the ultimate defeat mechanism against 'relay attacks' that have in the past been used to perform nefarious activities like stealing cars.

This security element makes UWB ideal for secure transactions such as contactless payments and probably another reason why this will become standard in all cell phones going forward.

Sensor Fusion

Because of the many deficiencies of BLE based location services, developers have had to use many creative solutions to improve the accuracy of such systems. One of the smart techniques that has been developed is IMU sensor fusion. In IMU sensor fusion, typically data from a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis magnetometer (compass) is used to iteratively determine the device location between RTLS (real time location system) samples. For short periods, IMU location can be quite accurate but eventually the errors will integrate over time and the location estimate will have too much uncertainty to be of any use.

UWB location services can also use these mature refinement techniques to improve the update rate and accuracy of the location estimate but building upon a far more accurate set of initial location data points. In such a way, UWB location services have demonstrated sub-centimeter accuracies in 3 dimensions. At these levels of accuracy, the applications for RTLS grow significantly. Imagine an object with a location tag at each end, now you can not only determine where it is but also which way it is facing and with high precision. This type of orientation sensing is vital for robotics applications.

Accuracy, UWB Vs BLE

As described above, there are a number of reasons why UWB is a far better choice for implementing RTLS and this also translates into system accuracy. Typical accuracy levels are shown below:

RTLS Technique	Typical Basic Accuracy	Accuracy with IMU sensor fusion added	Data rate
UWB	10 cm	Under 10 mm	Over 20 Mbps
BLE	200 cm	Under 1000 mm	Over 2 Mbps

A further advantage that UWB signals have is that having such a wide bandwidth means that can also carry a lot of data within the pulses that are used for ranging. Current solutions are over 20 Mbps and this will only increase over time. That data capacity will come in very handy for the handset vendors to allow ultra-secure network bonding and other applications that need an OOB (out of band) pairing solution that is highly secure. Part of that large data capacity will no doubt get used to allow all the various UWB infrastructure components to communicate and thus triangulate onto the location of objects that needs to be tracked.

What's Next?

For sure the other major handset brands will be wanting to include this feature into their devices. The real question is will Apple treat this like they did NFC and keep the hardware locked up for only Apple internal development or will they open up the system to 3rd party developers? NFC would appear to be a good example for the business strategy's of Apple and Samsung, both include the hardware but only Samusng has opened the door to 3rd parties.

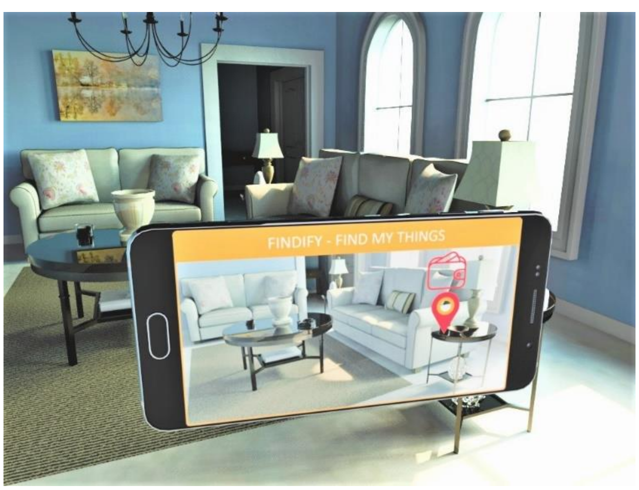

Figure 6: AR tracking application

It will probably depend completely on the main use cases that Apple has for this technology, if they see this as just a replacement for NFC for use with Apple Pay then they will more than likely keep the hardware locked up, if Apple has bigger designs for UWB then we might see the opportunity for whole new classes of products based around UWB.