

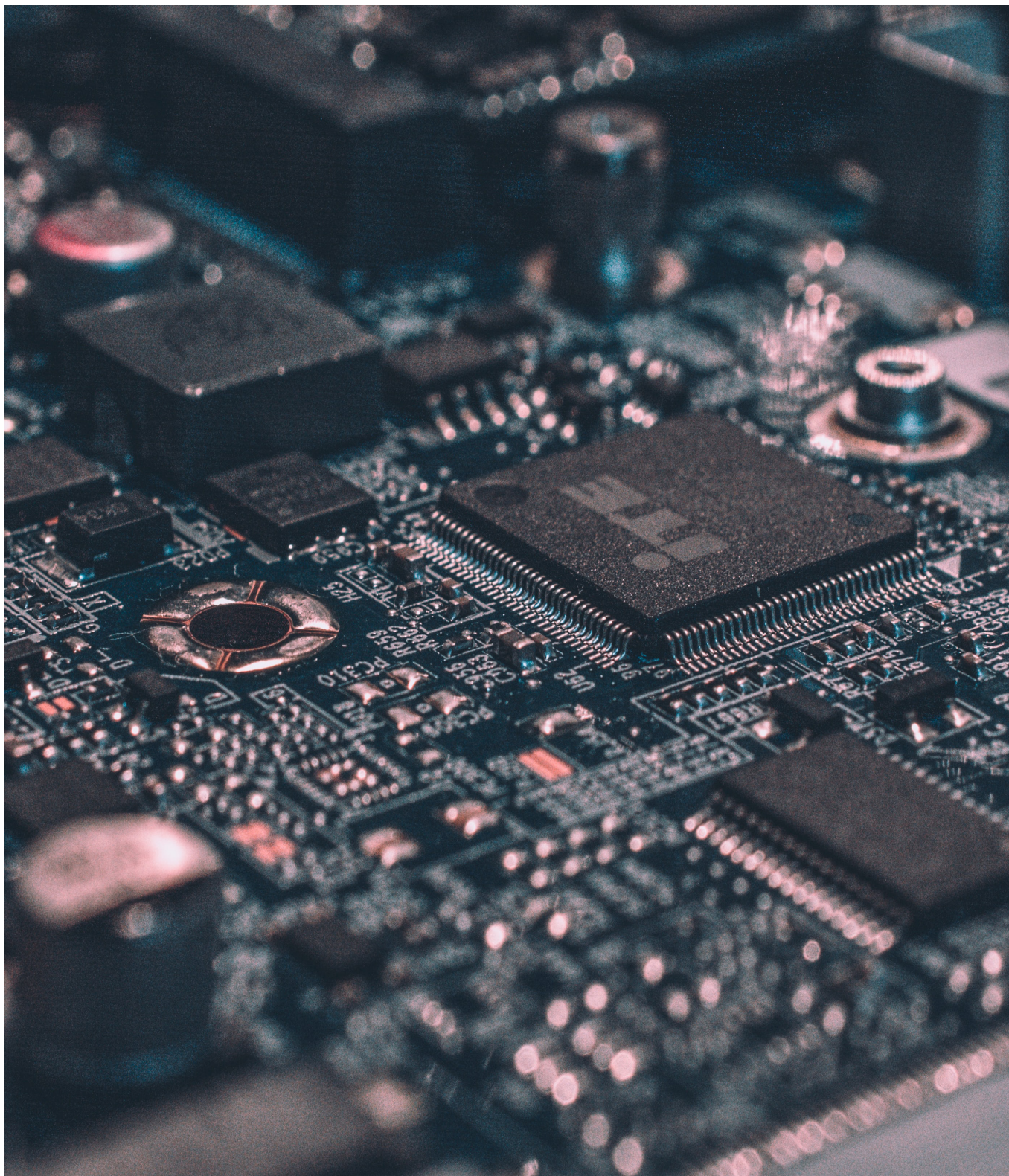
UWB Positioning Technology

Whitepaper

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This whitepaper mainly introduces the principle, scheme selection, and implementation methods of UWB ultra-wideband positioning technology in different application scenarios.

Currently, the mainstream positioning technologies can be divided into four types based on their principles:

Sound, Light, Electromagnetic and UWB

This design document lists the main advantages and disadvantages of each principle after basic analysis. The document mainly explains the system design and implementation method of using UWB ultra-wideband positioning technology for positioning.

Chapter 1

Positioning Principle

In principle, the current positioning methods mainly include sound, light, electricity, and magnetism. There is also inertial navigation, but because the technology is not mature enough and the application scenarios are limited, it will not be discussed here.

1.1 Sound

It mainly measures the distance by collecting the flight time of ultrasonic waves in the air. A typical transmitter is a speaker and the receiver is a microphone (such as a mobile phone). The transmitter sends fixed information, and the receiver calculates the transmission time of the data and converts it into a distance. Then, it performs positioning by using two-point or three-point methods.

Advantage:

It has a very high positioning accuracy, reaching the centimeter level. It also has a relatively simple structure, a certain penetration ability, and a strong anti-interference ability of the ultrasonic wave itself.

Disadvantage:

The air attenuation is high, and it is not suitable for large-scale events, the multipath effect and non-line-of-sight propagation cause significant errors in reflection ranging, causing the need for accurate analysis and calculation of the underlying hardware facilities, and the cost is too high.

Scope of application:

Ultrasonic positioning technology is widely used in digital pens and offshore exploration. This indoor positioning technology is also used for object positioning in unmanned workshops

1.2 Visible Light Positioning

This technology can be developed by LED lights. The lights send out high-frequency flashing signals. After receiving them, the receiver calculates the flight time to measure the distance and then obtains the location information.

Advantage:

Large dynamic range, capable of high-rate communication.

Disadvantage:

Because of the short light wavelength, and the poor diffraction ability, it is easy to be blocked. The other is to use image recognition to compare timely image information with those in the database for positioning. The disadvantage is that the image processing takes a long time, and the power consumption is large.

1.3 Magnetic Field Positioning

The Earth itself is a giant magnet, creating a fundamental magnetic field between the geographic north and south poles. However, this earth's magnetic field can be disturbed by metal objects, especially in buildings with reinforced concrete structures. The building materials (metal structures) interfere with and distort the original magnetic field, making each building have a unique magnetic texture. In other words, a regular indoor magnetic field is formed inside the buildings.

By collecting the magnetic field information in the field in advance, and then comparing it with the information collected by the magnetometer in a tracker (such as a mobile phone), we can obtain precise location information. Theoretically, the magnetic field difference at different locations is microseconds, which is undetectable by ordinary measuring tools. But this indoor magnetic field distorted by the building interference enhances the magnetic signal difference, making the indoor acquisition of magnetic data possible and indirectly improving the positioning accuracy. Since the magnetic field pattern of each small space in the room is unique, the mobile phone can be accurately positioned by matching the magnetic field characteristics of the area with the magnetic field database in the system, usually with an accuracy of about 2 meters. However, if the layout of nearby buildings changes, such as the movement of vehicles, the magnetic field will also change, and the accuracy will be hard to evaluate.

This method requires frequent calibration of the magnetic field and is not recommended.

1.4 Electromagnetic Wave Positioning

1.4.1 Signal Strength

A typical application is a Bluetooth tracker + Bluetooth gateway, which can be located by calculating the signal strength. Our company's B-Fixed system and B-Mobile system both use this scheme. Its main advantages are low cost and easy layout, but the accuracy is only 2~3 meters at most. It is mainly used for regional positioning of assets and personnel.

1.4.2 AoA

It's usually referred to Bluetooth Angle of Arrive technology.

Advantage:

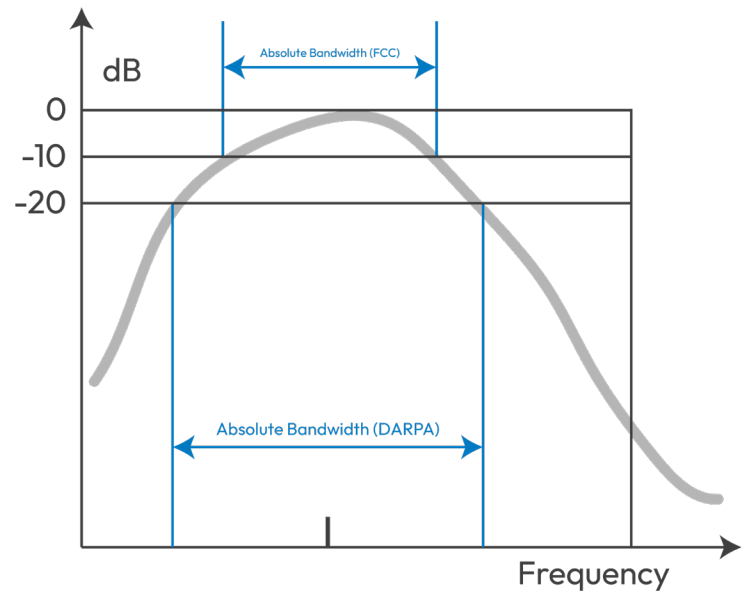
Low cost of the terminal, only need to deploy one gateway and high positioning precision.

Disadvantage:

Limited coverage and the coverage radius is equal to the height of the gateway. The gateway needs to fix its position precisely, and it cannot be shaken during use. Otherwise, it will affect the positioning effect.

1.4.3 UWB

DARPA and the FCC have proposed different definitions for UWB, but only with subtle differences in parameters.



UWB baseband narrow pulse specifications:

IR-UWB (Impulse Radio-UWB):

It transmits directly through the antenna without modulating the sine wave. This kind of system is simple, real-time, low-cost, low-power, anti-multipath, and good at penetration. It was later adopted by the 802.15.4a standard.

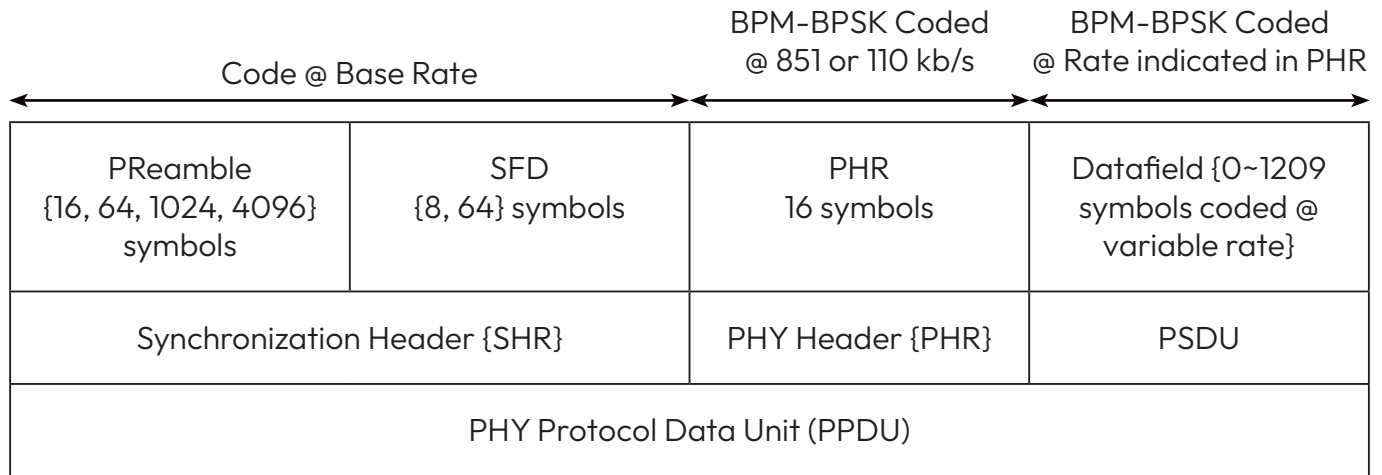
Bandpass carrier modulation:

DS-UWB (Direct Sequence Code Division Multiple Access) and MB-UWB (Multiple Band Orthogonal Frequency Division Multiplexing).

Among them, IR-UWB defines two physical layers in the IEEE 802.15.4a-2007 specification: one is CSS technology (provided by German Nanotron, working at 2.4G, narrowband positioning technology), and the other is IR-UWB technology.

Property	Value	
PHY Option	UWB PHY	CSS PHY
Frequency Bands	250~750 MHZ (sub-gigahertz)	2400-2483.5 MHZ
Channels	16 Channels	14 Channels
Data Rates	110 kb/s; 851 kb/s (nominal); 6.82 Mb/s; 27.24 Mb/s	1 Mb/s (nominal); 250 kb/s
Ranging Support	Yes	No
Range	10~100m	
Channel Access	CSMA/CA or Aloha, as appropriate	

UWB Payload Structure:



Modulation

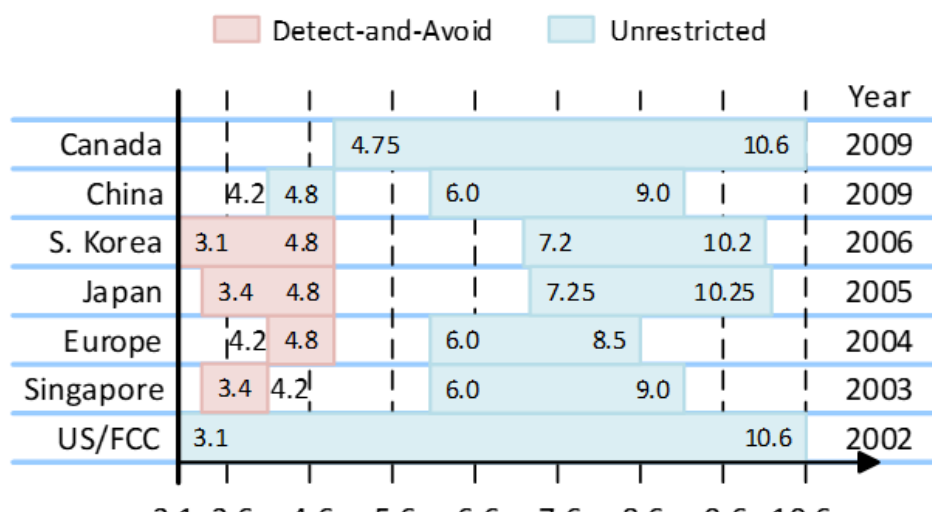
BPM-BPSK:

It combines BPM (burst position modulation) and BPSK (Binary Phase Shift Keying).

Working Frequency Band/Channel:

The global available frequency band distribution table is as follows

Area	Allowing Working Frequency Band
Europe	6.0 to 10.6 GHz
US	3.1 to 10.6 GHz
Japan	7.25 to 10.25 GHz
S.Korea	7.2 to 10.2 GHz
Singapore	3.4 to 10.6 GHz
China	6.0 to 9.0 GHz



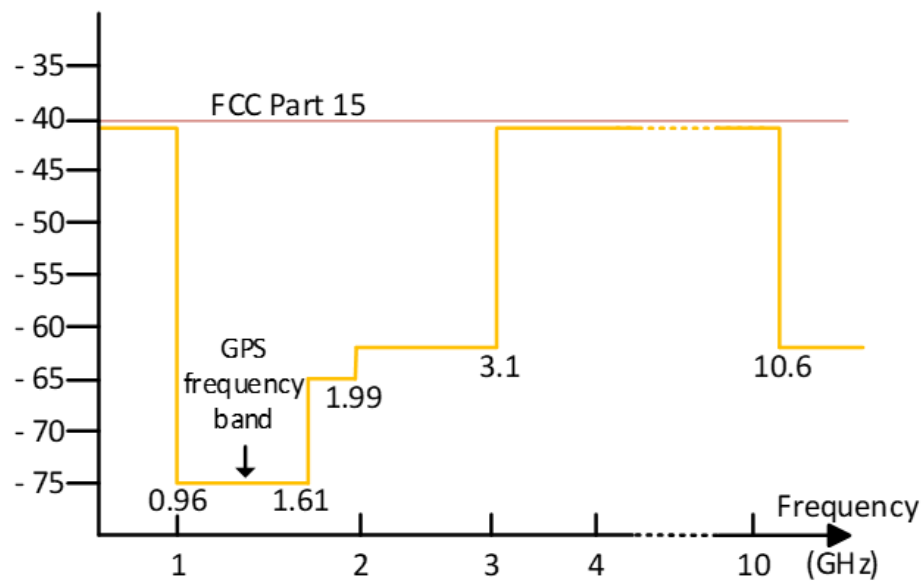
Channel Division

UWB Channel Number	Centre Frequency (MHz)	Band (MHz)	Bandwidth (MHz)
1	3494.4	3244.8 – 3744	499.2
2	3993.6	3774 – 4243.2	499.2
3	4492.8	4243.2 – 4742.4	499.2
4	3993.6	3328 – 4659.2	1331.2*
5	6489.6	6240 – 6739.2	499.2
7	6489.6	5980.3 – 6998.9	1081.6*

The channel division has two kinds of channels: 500MHz and 1GHz. Currently, the 500MHz channels are mainly used, that's channels 1, 2, 3 and 5.

Output Power and Regulations:

According to the FCC regulations, the maximum limit is -41dBm/MHz.



Power Rules in China:

Frequency Range (GHz)	Limit value (dBm/MHz)	Detection Mode
Below 1.6GHz	-90	RMS
1.6 – 3.6GHz	-85	
3.6 – 6.0GHz	-70	
6.0 – 9.0	-41	
9.0 – 10.6	-70	
Above 10.6GHz	-80	

Chapter 2

Positioning Technologies Compared

2.1 Comparison of UWB Positioning & Bluetooth AoA Positioning

	UWB (DS-TWR/TDoA/PDoA)	Bluetooth AoA
Single-Gateway Coverage	Coverage Radius: >20m	Coverage radius: 1~2 times of the installation height (10m or less).
Multipath Interference Resistance	UWB is an ultra-wideband signal, which has stronger resistance to common electromagnetic interference; UWB can identify the direct path arrival more easily and has better positioning accuracy in complex environments with many obstacles.	Bluetooth uses 2.4GHz, which is easily interfered with by other electronic devices (WIFI, Bluetooth headset, smart home, wireless mouse)
Positioning Accuracy	10 - 30cm	10 - 100cm
Product Form	1) DS-TWR: The gateway can be powered by a large-capacity battery and use LoRa for time synchronization and backhaul. 2) TDoA: Wireless synchronization with UWB is possible, an external power supply is required, and wired ETH or WIFI is required for backhaul. The tracker capacity has no theoretical limit. 3) PDoA (AoA): External power supply is required, and wired ETH or WIFI is required for backhaul. The tracker capacity has no theoretical limit. Three-dimensional positioning can be done with ranging. 4) The volume can be relatively small.	1) An external power supply is required, and wired ETH or WIFI is required for backhaul. The tracker capacity has no theoretical limit. 2) The antenna uses an array design, and the volume is relatively large.
Power Consumption	1) DS-TWR: The tracker power consumption is large, and the gateway power consumption is large (can be powered by a battery). 2) TDoA: The tracker power consumption is small, and the gateway is externally powered. 3) PDoA: The tracker power consumption is small, and the gateway is externally powered.	The tracker power consumption is small, and the gateway is externally powered
Cost	The gateway cost per unit area is low. The tracker cost is high.	The gateway cost per unit area is high. The tracker cost is low.

2.2 Comparison of UWB-AoA and Bluetooth AoA Positioning

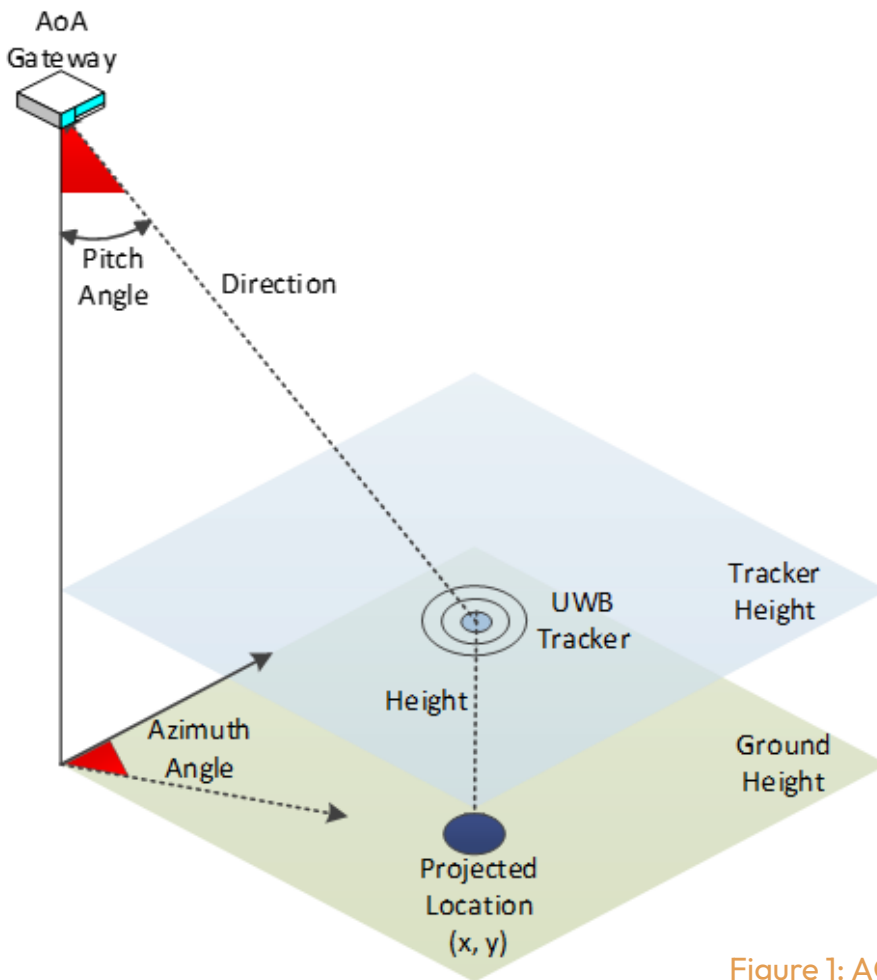


Figure 1: AOA Positioning Schematic Diagram

Principle Comparison:

Bluetooth AoA:

This method only measures the signal angle from a single gateway, not the distance. It also assumes that the tracker's height is fixed and projects its position from the angle-height intersection. Lifting and lowering the tracker can seriously affect positioning accuracy.

UWB-AoA:

This method measures both the angle and the distance with centimeter-level accuracy, which is more precise. It can also locate the tracker in three dimensions.

Antenna Comparison:

Bluetooth AoA:

This method uses an antenna array, usually with 16 or 64 antennas, and RF switches to calculate the signal's angle of arrival and distance from multiple arrival times. The complex antenna array design prevents the Bluetooth AoA gateway from being miniaturized. The gateway also has strict installation requirements and a limited coverage area of about 1-2 times the height radius.

UWB-AoA:

This method usually uses two antennas and the PDoA phase difference method to calculate the optimal angle. PDoA requires that the distance between the two receiving antennas be half of the wavelength, or $\lambda / 2$. For channel 5 (6489.6MHz), the anchor antennas are 2.08cm apart, and for channel 9, they are even closer. This allows PDoA to be miniaturized, which is why it can be used in scenarios such as smartphones, smart door locks, and smart home controllers.

Chapter 3

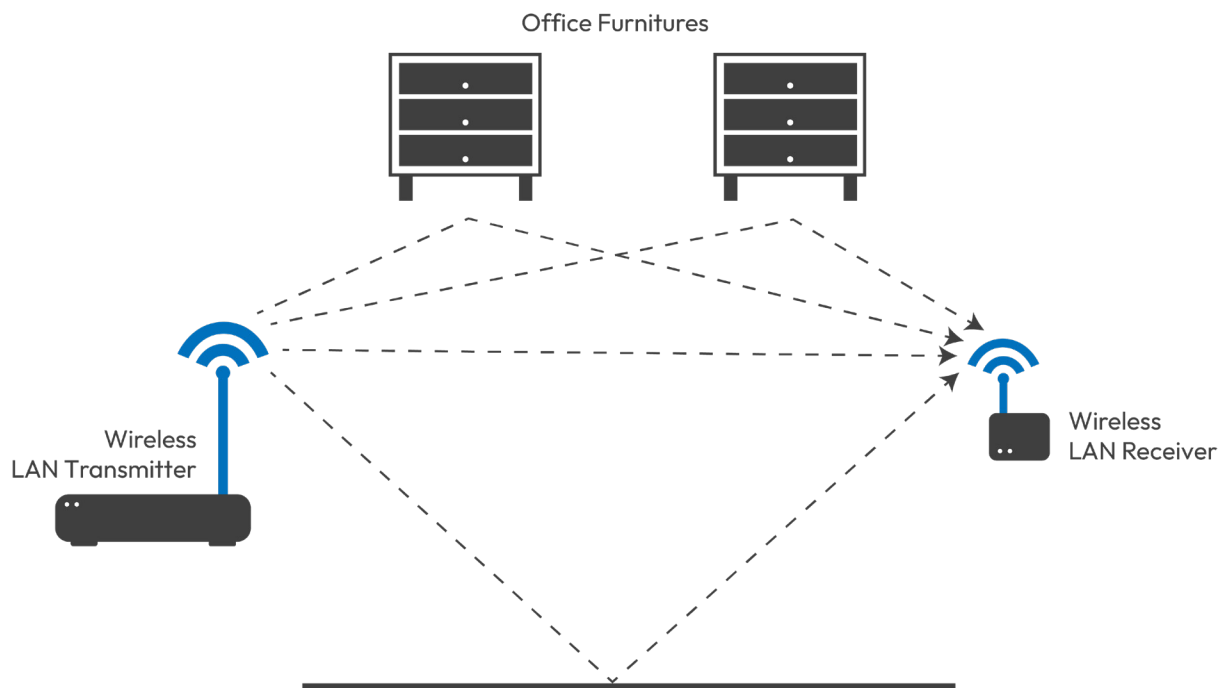
UWB Technology

3.1 UWB Features

1. UWB covers 3G~5G, 6G~10G, a total of 7G frequency bands, and has a single channel bandwidth of more than 500MHz.
2. Low power. According to FCC and other regulations, its output power is limited to -41dBm/MHz. Based on a single channel of 500MHz, its channel power is -14.3dBm.
3. The ultra-short pulse, with a duration of a few tenths of a nanosecond.
4. Penetrating the wall: It can penetrate walls effectively but will cause some signal attenuation. The table below shows the signal attenuation caused by wall penetration when working on channel 2 (with 4GHz as the center frequency).

Material	Attenuation at 4 GHz	Notes
Brick	-15 dB	89 mm thick brick sample
Brick/Concrete combo	-36 dB	90 mm brick backed by 102 mm of plain concrete
Concrete – solid	-23 dB	102 mm thick sample
Concrete – solid	-46 dB	203 mm thick sample
Concrete – solid	-73 dB	306 mm thick sample
Masonry block	-15 dB	203 mm thick sample
Masonry block	-24 dB	406 mm thick sample
Masonry block	-34 dB	610 mm thick sample
Dry Wall	0 dB	16 mm sample
Dry Wall	0 dB	13 mm sample
Dry Wall	-0.1 dB	16 mm sample
Glass	-1.3 dB	6 mm sample
Glass	-0.1 dB	13 mm sample
Glass	-0.8 dB	19 mm sample
Human body	15~30 dB	Depending on the body mass index and incident angle of the incoming signal
Plywood	0 dB	6 mm sample
Plywood	0 dB	13 mm sample
Plywood	-0.3 dB	19 mm sample
Plywood	-1.5 dB	22 mm sample

Multipath identification



Electromagnetic waves can travel directly from the transmitter to the receiver, or they can be reflected to the target. In general narrowband communication, the signal with the strongest strength is usually processed, which may not be the first signal to arrive.

In UWB communication, the first signal to arrive (First Path) can be accurately identified based on the time difference. But when arriving directly or penetratingly, we can only assume that the first multipath signal is the direct signal we need.

Like all other electromagnetic waves, UWB cannot penetrate metal.

3.2 Accuracy

Accuracy mainly involves three aspects: ranging accuracy, time synchronization accuracy, and positioning accuracy. The ranging accuracy is mainly affected by two factors: the ranging algorithm and the clock accuracy used.

1. Ranging Accuracy:

DS-TWR minimizes the error caused by clock deviation.

2. Time Synchronization Accuracy:

In the ranging system, a 0.5PPM clock temperature-compensated crystal oscillator (TCXO) can be used to achieve better accuracy. The ranging accuracy can be controlled within 10 cm. Accuracy can be improved by using TCXO.

In a UWB wireless positioning system, both ranging and TDoA are supported. In TDoA, all positioning gateways need to be synchronized wirelessly. The system has a synchronization accuracy of 0.3ns.

Compared with the wired synchronization method, a wireless system is much simpler and can be expanded without limit, and is not constrained by the wired distance. It also simplifies the difficulty of project implementation.

3. Positioning Accuracy:

It has an accuracy of 30 cm. The system's positioning accuracy is influenced by various environmental factors, not just the distance measurement accuracy of 10 cm. The positioning accuracy of 10 cm can only be achieved in an ideal environment without any interference in the laboratory. Any signal disturbance may cause deviation to the system.

Chapter 4

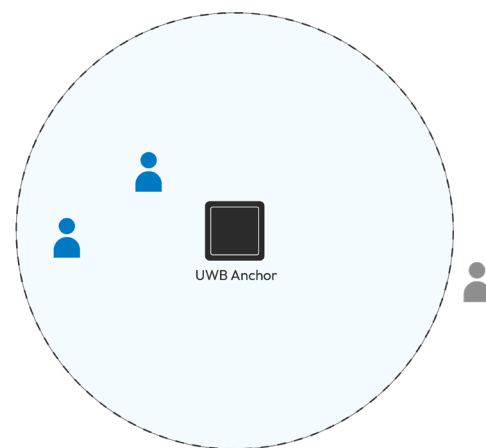
About Positioning

4.1 UWB Features

The positioning dimension is chosen based on the use case and the on-site situation. The zero-dimensional scene is mainly used for entry and exit detection. The one-dimensional scene is mainly a scene with a disproportionate aspect ratio, such as a tunnel scene, and it also works in a factory. In a one-dimensional scene, the positioned target will be aligned to a line. The 2D scene is to locate the XY coordinates without height information, while the 3D scene has height information. Still, it requires that the anchor has a height difference during system installation to ensure a certain accuracy of the Z axis.

4.1.1 Zero-Dimensional

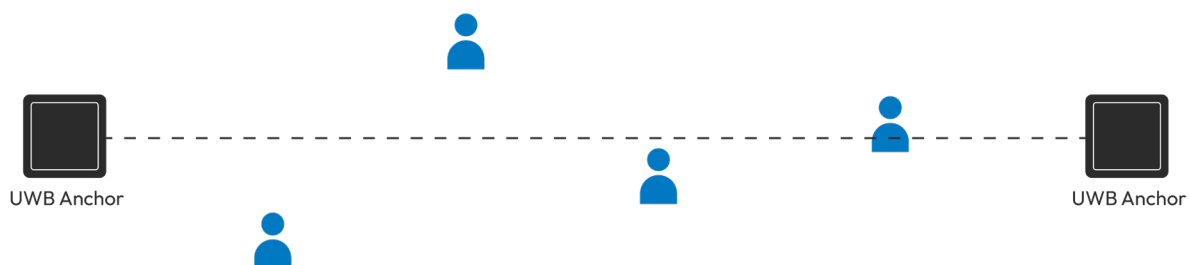
In UWB positioning, to achieve better zero-dimensional positioning is generally achieved through ranging, which is used for distance limitation, such as how far a device is from a anchor. It is considered to have entered the zero-dimensional area.



4.1.2 One-Dimensional

One-dimensional positioning can be achieved by using ToF, TDoA, or combined AoA technology. Even when the UWB tracker is not on the straight line connecting the two anchors, it can be on that straight line.

Actual Location:

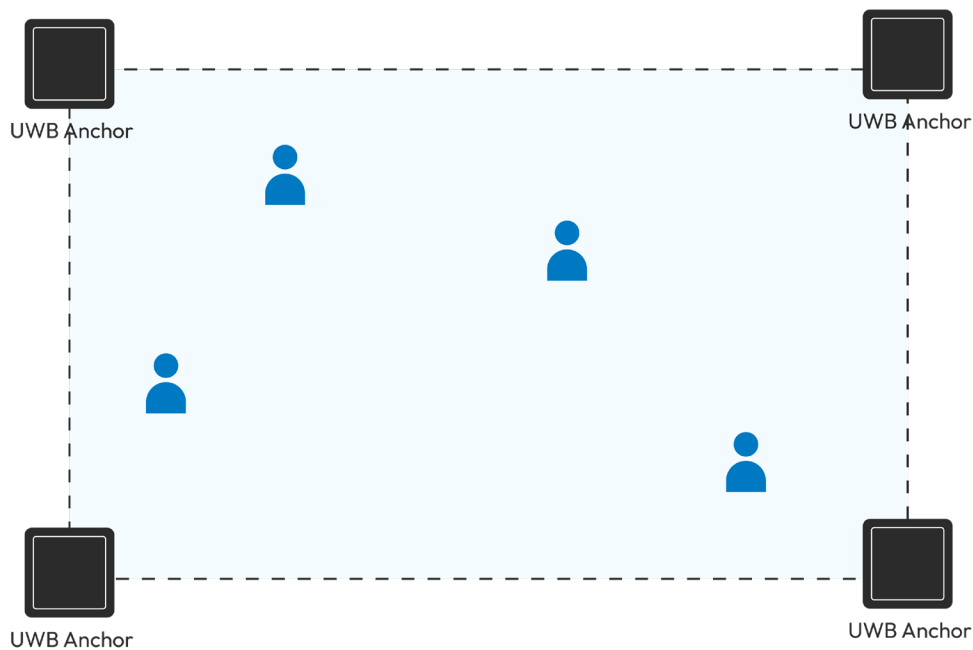


Positioning Result:



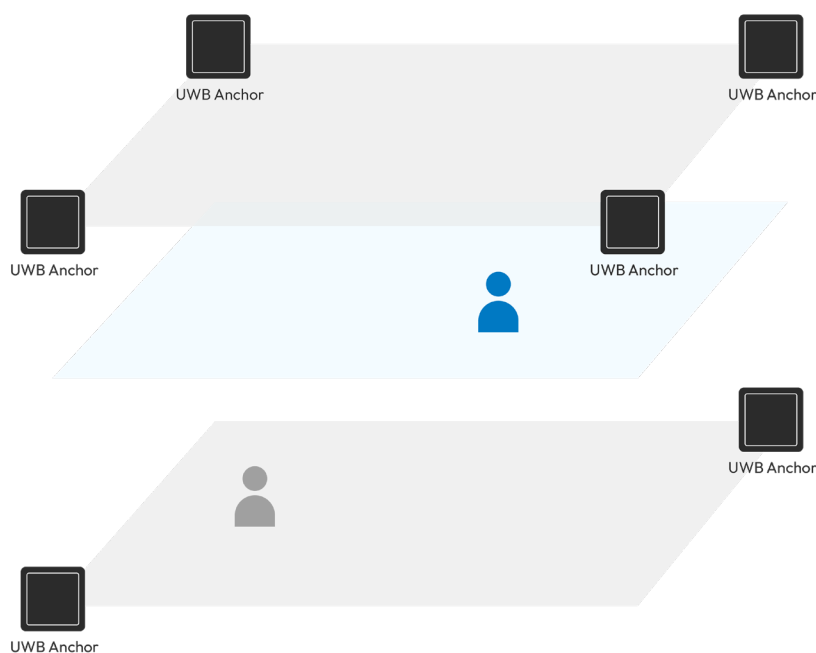
4.1.3 Two-Dimensional

Two-dimensional positioning will show the XY coordinates of the target location. If the anchors are installed at the same height, the positioning results will not be affected by the installation height of the trackers.



4.1.4 Three-dimensional

The result of three-dimensional positioning is the XYZ coordinates of the target. There are two methods to achieve this. One is based on distance measurement, which requires a height difference between the anchors. The other is based on AoA, which requires a high-angle resolution on the Z axis to ensure the accuracy of the Z coordinate.



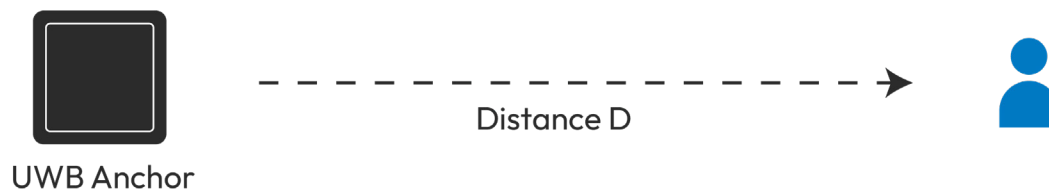
4.2 Positioning Method

Currently, UWB positioning mainly uses TOF ranging, TDoA, and AoA positioning. The first two methods work independently, while the latter AoA method is usually combined with ToF or TDoA.

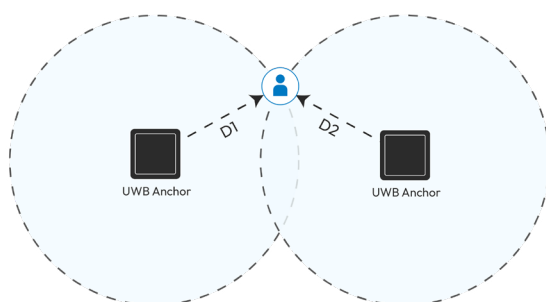
4.2.1 ToF Positioning

ToF positioning is based on range. The UWB tracker initiates ranging with each anchor that needs to be positioned. After the ranging is completed, the position is calculated. For zero-dimensional mode, it only needs to range with one anchor, for one-dimensional mode, It needs to range with at least two anchors, for two-dimensional mode, it generally needs three or more anchors for ranging, but in some special mode, two anchors are enough. For three-dimensional mode, it needs to range with four anchors.

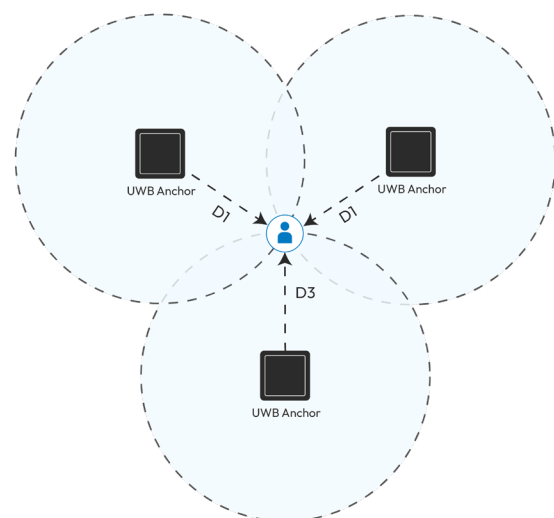
For one-dimensional cases, the anchor is placed at the top, and ranging with only one anchor to achieve one-dimensional positioning.



For one-dimensional cases, you can measure distance with only two anchors:

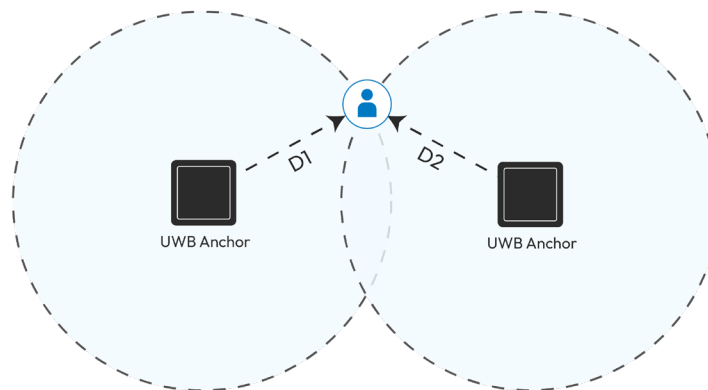


Two-dimensional positioning:



4.2.2 TDoA Positioning

TDoA positioning is to determine the position of the target by detecting the absolute time difference between the arrival of signals at two anchors or different antenna units, instead of the time of flight of arrival. This reduces the time synchronization requirements between the signal source and each monitoring anchor but increases the time synchronization requirements among the anchors. Two TDoAs can be detected by using three different anchors, and the mobile tracker is located at the intersection of the hyperbolas defined by the two TDoAs.



The advantage of TDoA is that the number of communications for one positioning is significantly reduced, and it also has higher accuracy than ToA. However, this kind of positioning depends on the propagation of waves, and the inherent clock error of 1ns can cause a distance error of 30cm. Therefore, the clocks of each anchor must be strictly synchronized. And it is very expensive to build a precise synchronization system with relatively large spacing.

There are two kinds of Time Synchronization:

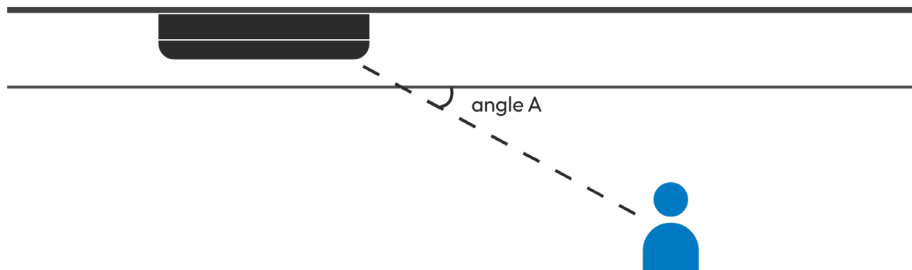
One is to use wired connections, which can achieve a synchronization accuracy of 0.1ns, but it increases the complexity and cost of network maintenance and construction. Moreover, it requires a dedicated cable (ethernet, for example) to synchronize the clock, which is also expensive.

The other is wireless connections, which can achieve a synchronization accuracy of 0.25ns and is slightly lower than wired, but the system is relatively simple. The positioning gateway only needs a power supply, and the data return can use WiFi, LoRa or Ethernet, which effectively reduces the cost.

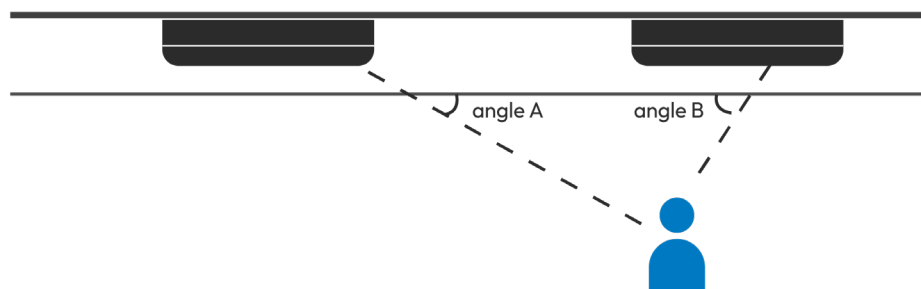
4.2.3 AoA Positioning

Angle of arrival (AoA) positioning is generally based on the phase difference between signals, but it is not often used alone because AoA has a problem with angular resolution, which means that the positioning accuracy gets worse as the distance from the anchor increases.

AoA can work together with the time of flight (ToF) ranging for positioning. In this mode, we can use one anchor for positioning.



It is also possible for two anchors to achieve positioning through AoA



4.3.1 Positioning Mode and Power Consumption

We will mainly compare the power consumption of ToF and TDoA modes.

In the ToF mode, the UWB tracker measures the distance with each anchor separately, and they need multiple rankings. Generally, one range takes more than 5ms.

For TDoA positioning, the UWB tracker only needs to send a message to complete the positioning. Generally, it takes less than 0.5ms from preparation to sending and consumes much less power than the ToF mode.

4.3.2 Environmental Factors

There are many environmental factors, and the most typical ones are intra-area positioning and out-of-area positioning;

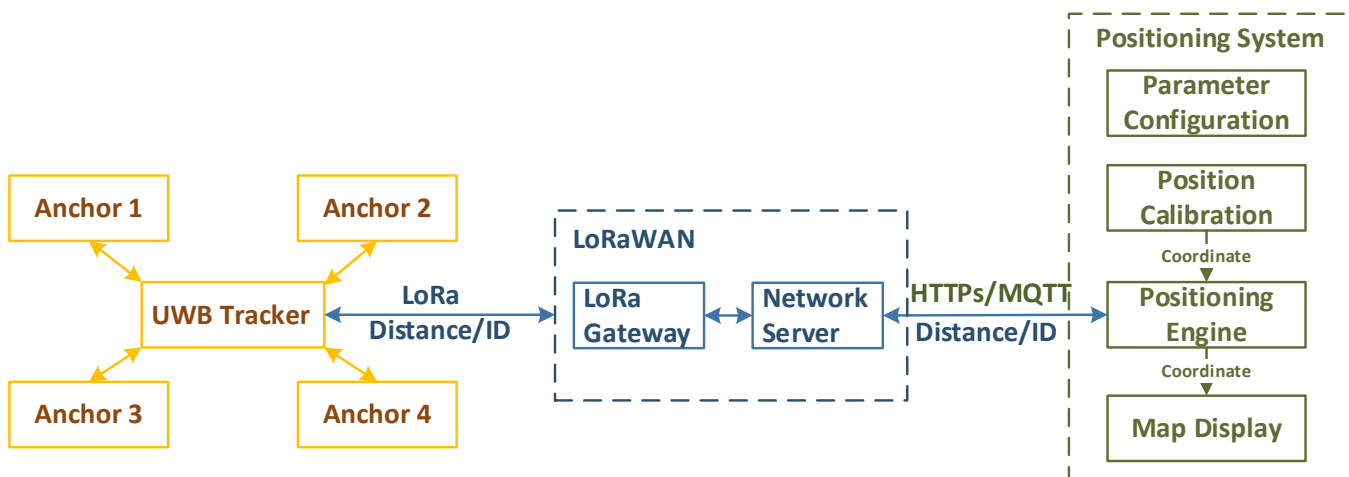
Since TDoA is based on the arrival time difference of signal, it usually uses a hyperbolic algorithm is generally used after converting the time difference of arrival into a distance difference. The limitation of the hyperbolic algorithm determines that the positioning accuracy is high in the area covered by the anchors, and the positioning accuracy is relatively poor outside the area. In complex environments such as power plants, the system faces great difficulty in deployment, and it is hard to use TDoA positioning to meet the application needs. In this mode, we can use ToF, or TDoA combined with AoA.

Chapter 5

LoRaWAN based UWB Positioning Solution

This chapter introduces the related device and theory on how the system works.

- **UWB Anchor:**
It advertises beacon messages for ranging with trackers. Battery powered, 5-year battery life.
- **UWB Tracker:**
It receive beacon messages and ranging with the anchor periodically. Battery powered.
- **LoRaWAN Gateway:**
It sends beacons messages to all anchor and trackers to sync the clock and receive distance messages from trackers.
- **Server:**
Use the distance information and anchor's coordinates to calculate trackers' position as explained in [Section 4.1](#) . The server is also used to configure the anchor and tracker, calibrate anchor's position and act as a positioning engine.



Chapter 6

About Ranging

6.1 Ranging Method

In the ranging system, there are two ranging methods: Single-sided Two-way Ranging (SS-TWR) and Double-sided Two-way Ranging (SD-TWR).

6.1.1 SS-TWR

The basic principle of Single-sided Two-way Ranging is shown in Figure 2 Schematic diagram of SS-TWR principle. Device A sends a pulse to device B. After a period of T_{round1} , it receives the pulse returned by device B. Assume the flight time is T_{prop} , then can be roughly calculated as:

$$T_{prop} = \frac{1}{2} (T_{round} - T_{reply})$$

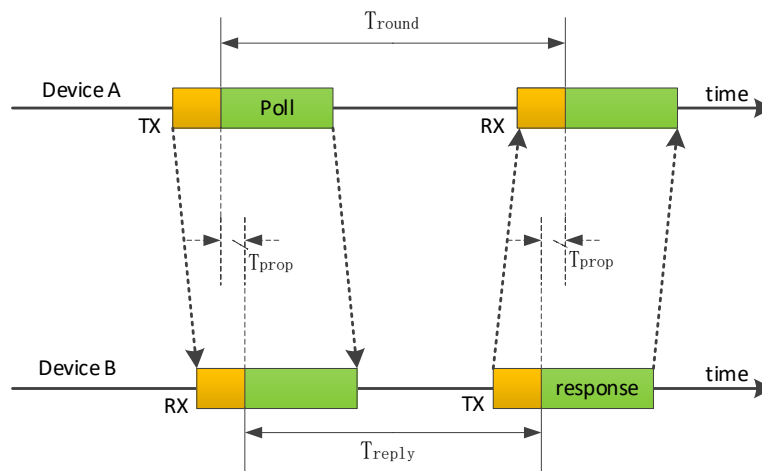


Figure 2: Schematic diagram of SS-TWR principle

Because device A and device B use independent clock sources, the clocks will have a certain deviation, which is also unacceptable for the speed of light.

6.1.2 SD-TWR

Double-sided Two-way Ranging is an extended ranging method of signal-sided two-way ranging. It records two round-trip timestamps and finally gets the flight time. Although it increases the response time, it reduces the ranging error. As shown in Figure 3 Schematic diagram of DS-TWR principle, the basic principles are as follows:

1. Device A sends a pulse to device B;
2. After device B receives the pulse, it delays for T_{reply1} and send back a pulse;
3. After T_{round1} , device A receives the reply pulse sent by device B;
4. Device A delays for T_{reply2} and then sends another pulse to device B;
5. Device B receives the final pulse from A after T_{round2} .

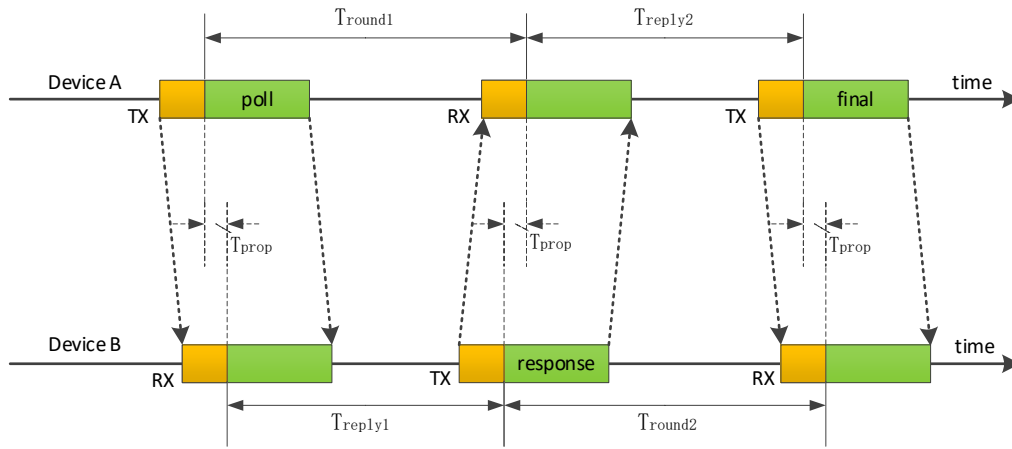


Figure 3: The schematic diagram of DS-TWR principle

Roughly calculated: $T_{prop} = (T_{round1} * T_{round2} - T_{reply1} * T_{reply2}) / (T_{round1} + T_{round2} + T_{reply1} + T_{reply2})$

DS-TWR ranging is an extra communication based on SS-TWR ranging, and the time of the two communications can cancel out the error caused by the clock offset.

The error caused by the clock using the DS ranging method is:

$$\widehat{error} = T_{prop} * \left(1 - \frac{K_a + K_b}{2}\right)$$

The error of this ranging method mainly depends on the following factors:

1. The clock error of devices A and B;
2. The average delay time of device processing.

Assuming that the clock accuracy of devices A and B is 20ppm (poor), and 1ppm is one millionth, then K_a and K_b are either 0.99998 or 1.00002, and k_a and k_b are the ratios of the actual frequency and expected frequency of devices A and B clock respectively. Devices A and B are 100m apart, and the flight time of electromagnetic waves is 333ns. Then, the error caused by the clock is $20 * 333 * 10^{-9}$ seconds and the ranging error is 2.2mm, which can be ignored.

6.2 Ranging Error Analysis

The factors that lead to ranging errors are environmental disturbance, human body occlusion, metal object occlusion, time accuracy, and minimum time granularity.

6.3 Typical Ranging Scenarios

To meet the requirements of different wireless precise ranging use cases, there are mainly three modes: point-to-point ranging, point-to-multipoint ranging, and free-space ranging. The following mainly introduces the two modes of point-to-multipoint ranging and free-space ranging.

6.3.1 Point-to-Multipoint Ranging

It is mainly used for distance measurement between two devices. This type of distance measurement is the simplest, with better accuracy and strong convenience. Because distance measurement is the most basic function, it can be integrated with other methods.

Some typical applications are:

- When a vehicle is running, it needs to know its precise location, which can be done through distance measurement;
- When a prisoner is on parole for medical treatment, prison guards can control the prisoner within a safe distance through accurate distance measurement, and administrators can also use the platform to prevent favoritism;
- Precise distance measurement between drones and people;
- Tour groups can control the distance between each person and the tour guide through UWB to ensure that no one gets lost.

6.3.2 Free-Space Ranging

Free-space ranging is a relatively special ranging mode. The main reason is that all targets are moving in space. Before each ranging, the device needs to know the surrounding conditions; when there are many ranging targets, it is necessary to allocate them well to avoid mutual interference between them and prevent them from ranging.

Free-space ranging is mainly used for the following two purposes:

A Spatial Relationship Network:

For example, drone formations can form a self-organizing network based on the spatial distance between all targets. When there is no GNSS system, UWB can be used to form a spatial formation position relationship network;

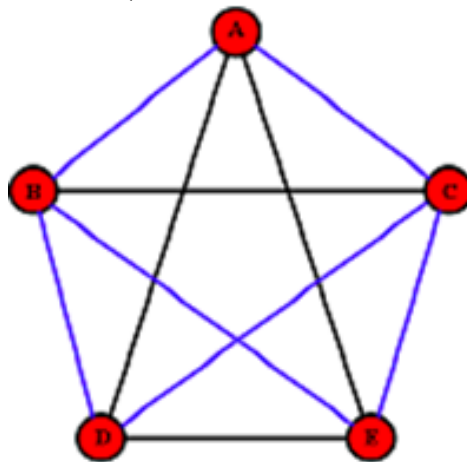


Figure 4 Schematic diagram of spatial relationship network

If this system is applied in the Mesh network of wireless communication, it can also provide distance parameters for Mesh to make decisions.

Anti-Collision:

For example, a maintenance locomotive running on a train track can have another guarantee based on this dynamic distance measurement.

Chapter 7

Scheme Design

Anti-Collision System and Positioning System:

The device installed on the anti-collision system is defined as a UWB gateway, which can be powered with external power.

The device that people wear is a UWB tracker, which is powered by a rechargeable battery.

Positioning Engine:

This is for calculating the position of positioning devices. The positioning engine uses the relative location of the gateway on the map, and the distance between the UWB tracker and the gateway, to determine the UWB tracker's position and output position coordinates.

Position Calibration:

Indicate the position of the gateway on the map such as marking the origin and gateways' position. The gateway needs to be fixed and not moved arbitrarily.

Map display:

Customers can upload their own map files and provide the corresponding origin information in position calibration, and display the real-time position of the positioning device on the flat map.

7.1 Anti-collision System Scheme Design

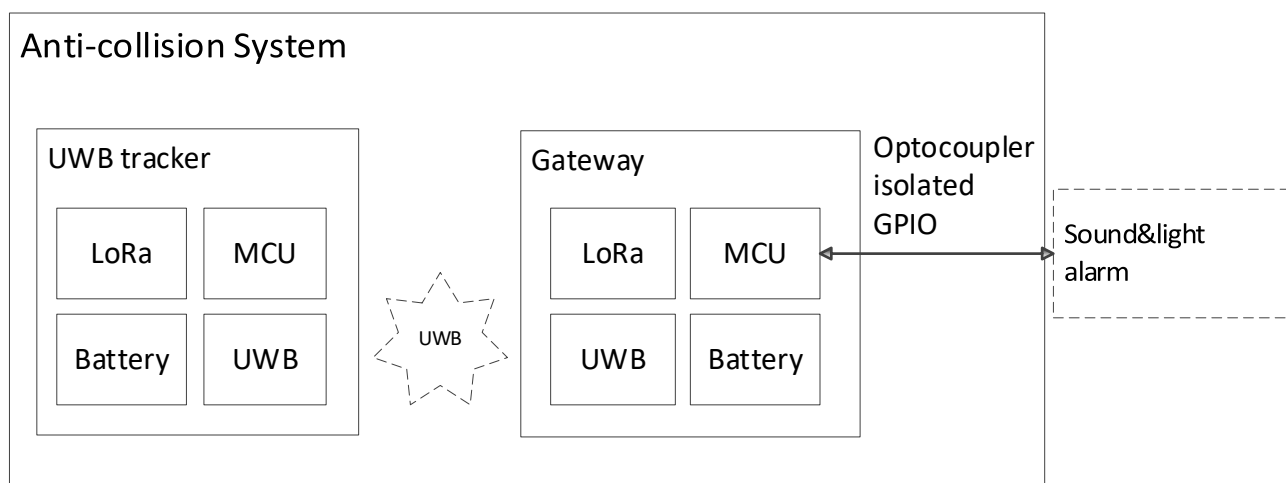


Figure 5: Anti-collision system block diagram

The gateway is powered by the device and constantly receives UWB, waiting for the ranging information of the UWB tracker. The UWB tracker ranges every 4 seconds. When approaching the gateway, the tracker measures the distance every 1 second to save power and extend the standby time.

The gateway has an IO interface with optocoupler isolation. When the distance between the UWB tracker and the gateway is less than 3 meters, the gateway outputs a high level output power. The isolated IO can be connected to an external sound and light alarm.

The area division is shown in **Figure 6: Anti-collision system area division. (next page)**

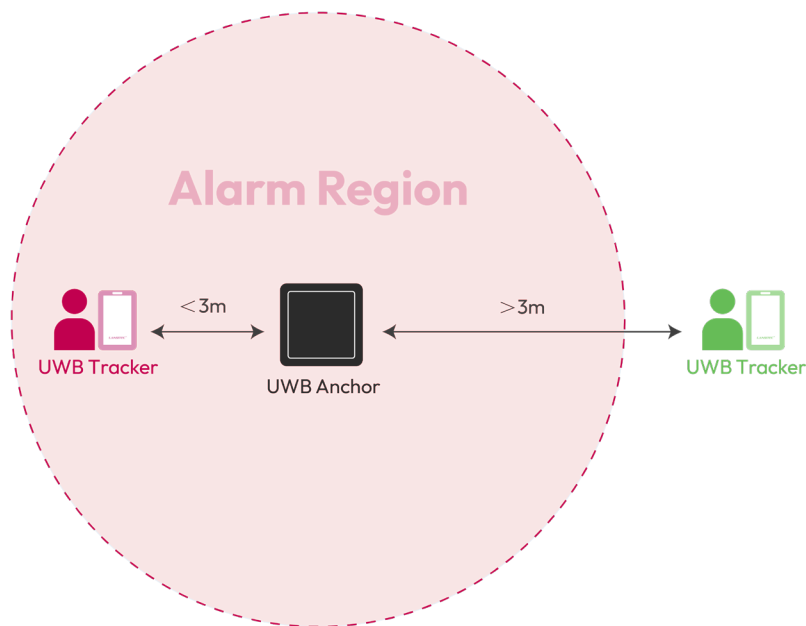


Figure 6: Anti-collision system area division

7.2 Positioning System Scheme Design

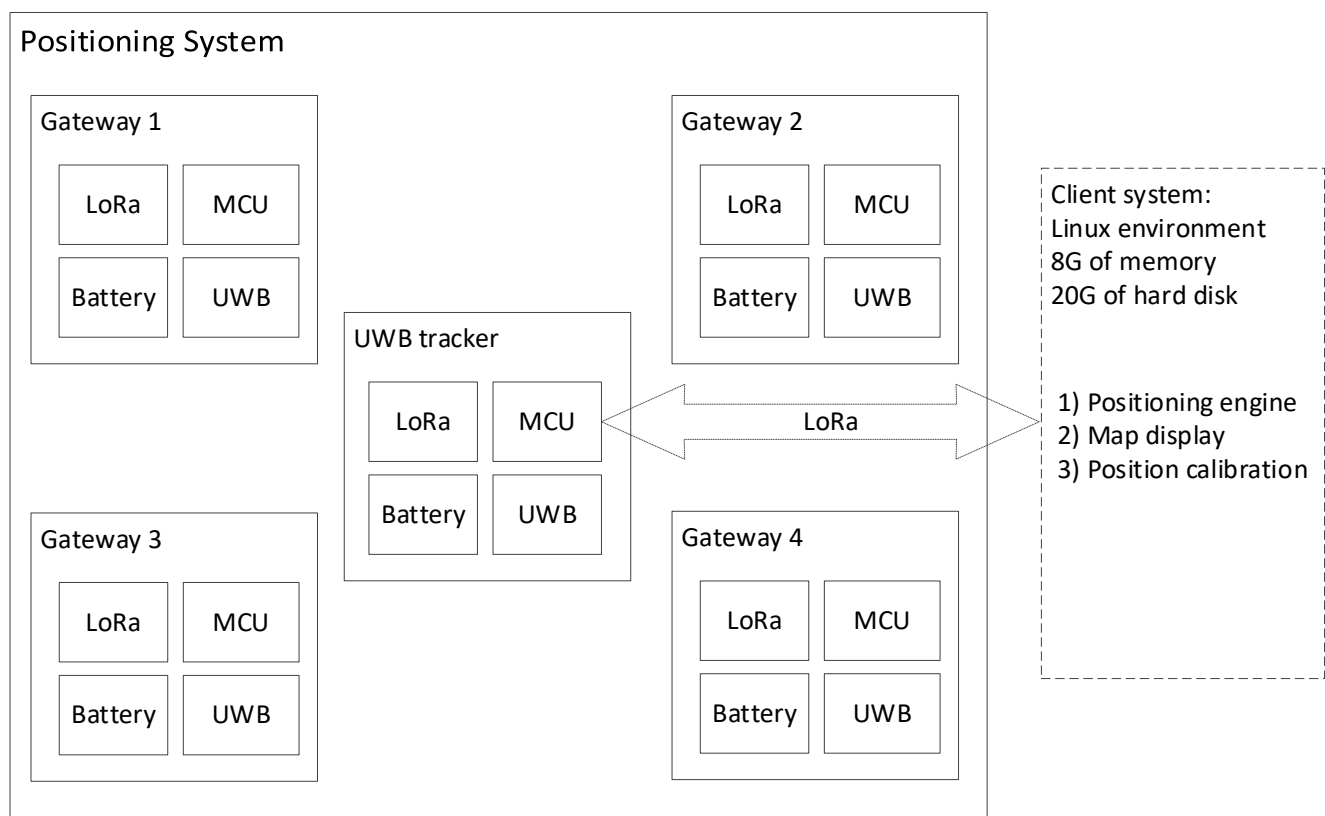


Figure: 7 Positioning system block diagram

Both the gateway and UWB tracker have UWB modules and LoRa modules. The UWB module is for distance measurement and positioning. The LoRa module is . The UWB tracker transmits the distance between the UWB tracker and gateway, the ID, and other parameters to the application system through LoRa. The application system has three software modules: positioning engine, map display and position calibration. These software modules need to run in a Linux environment, or a Linux virtual

machine can also be installed in a window system. The Linux environment requires at least 8GB of memory and 20GB of harddisk.

7.3 System Workflow

Anti-Collision System Workflow:

1. The gateway uses an external power supply, so it is always ready to test data.
2. The gateway and the UWB tracker use DS-TWR for distance measurement.
3. The UWB tracker periodically (4s) measures the distance with the gateway.
4. The UWB tracker detects a nearby gateway and measures the distance with it, and then changes its own distance measurement cycle to 1s.
5. The gateway outputs an alarm signal (sound and light alarm) based on the distance from the UWB tracker.

Positioning System Workflow:

1. Run the position calibration software to calibrate the actual installation position of the gateway.
2. Run the positioning engine software to calculate the location information of the UWB tracker based on the distance between the UWB tracker and gateway.
3. The gateway and the UWB tracker use DS-TWR for distance measurement.
4. The UWB tracker periodically measures the distance with multiple nearby gateways.
5. The UWB tracker sends the distance from multiple gateways to the positioning engine in the form of LoRa.
6. The location information calculated by the positioning engine is sent to the map display software for display.

7.4 Positioning Calculation

The positioning engine can calculate the position information of the UWB tracker based on the distance between the gateway and the UWB tracker and the position coordinates of the gateway with triangulation, as shown in **Position Calculation-Triangulation**.

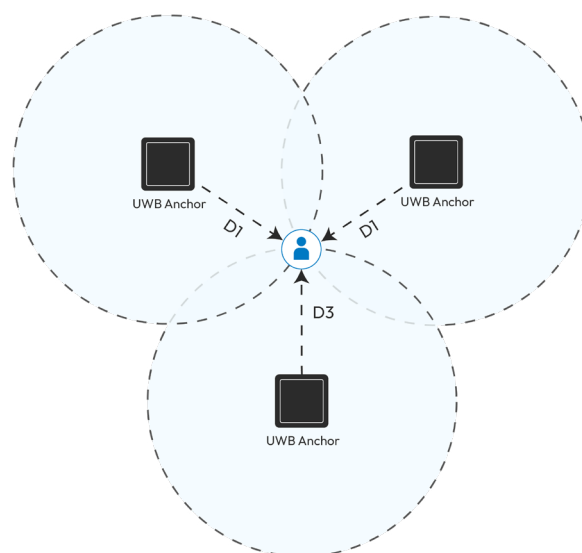


Figure 8: Position Calculation-Triangulation