

Bluetooth 5.1 Direction Finding

Theory and Practice

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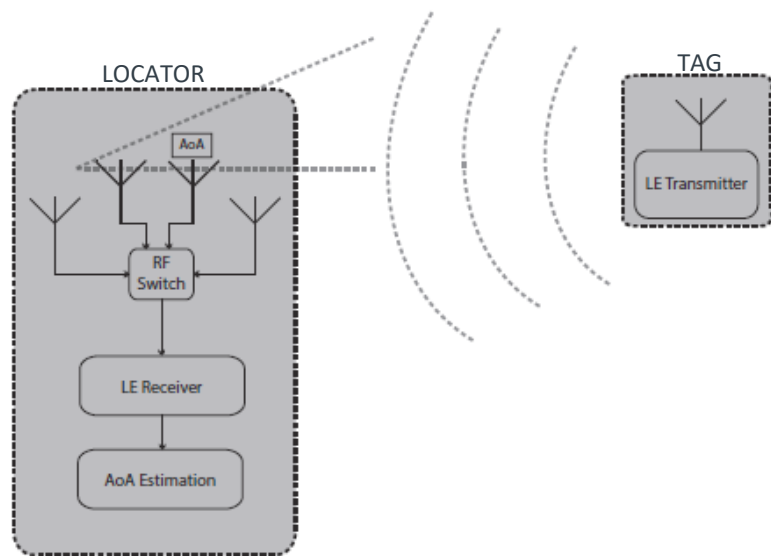
Agenda

- Direction Finding – The theory
- Direction Finding supported on Bluetooth 5.1
- Bluetooth 5.1 Direction Finding and the myths
- From Direction to Positioning – the important factors
 - Antenna constellation
 - Locators
 - Algorithm
 - Adaptation to operating environment

Direction Finding

The Theory

Angle of Arrival (AoA)



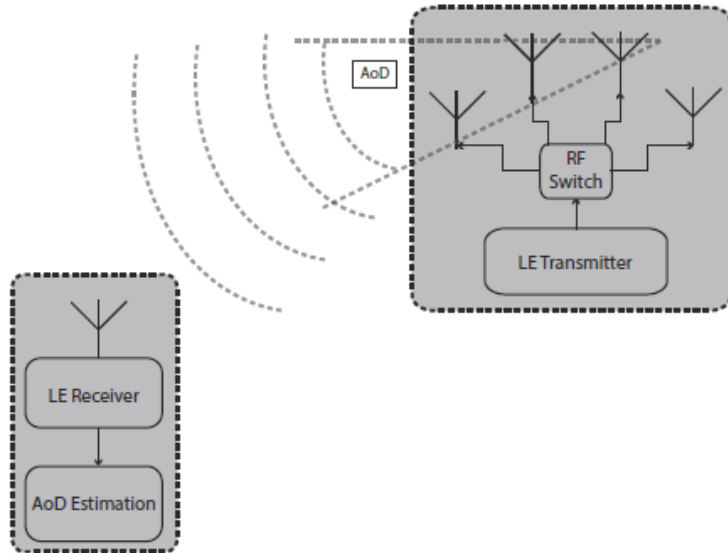
Transmitter or TAG

- Simple “Beacon” like
- Single Antenna
- No I/Q data needed

Receiver or LOCATOR

- Advanced
- Multiple antennas in Antenna Array
- I/Q data needed for angle estimation

Angle of Departure (AoD)



Transmitter

- Beacon like
- Multiple antennas in a array
- No I/Q data needed

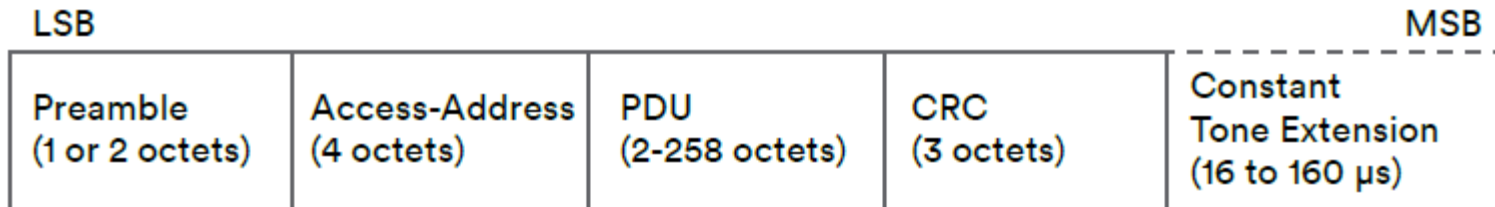
Receiver

- Scanner / Observer
- Single antenna
- I/Q data needed for angle estimation

Direction Finding

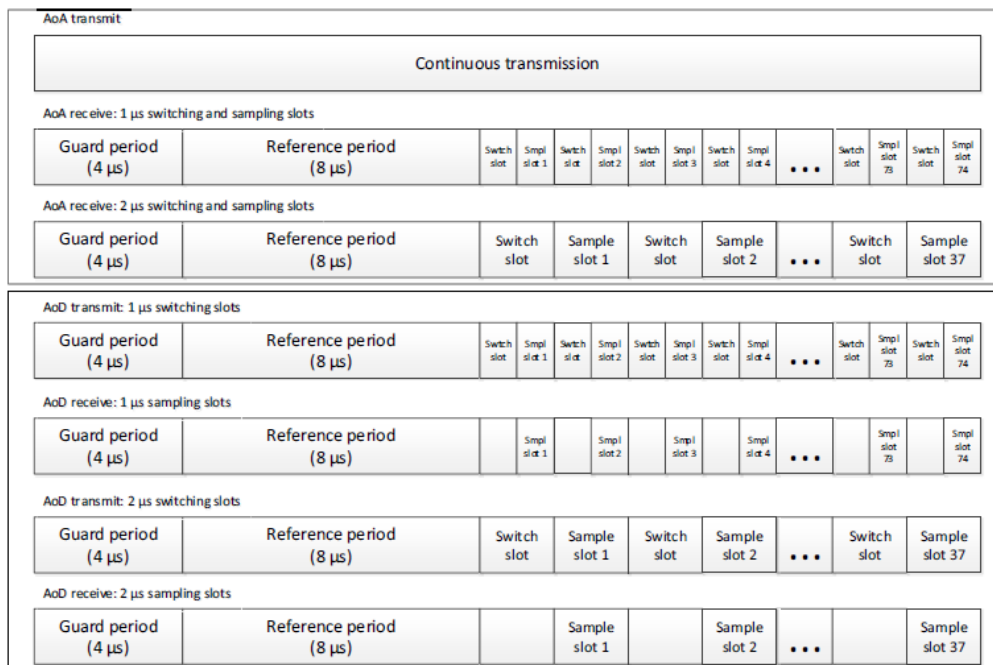
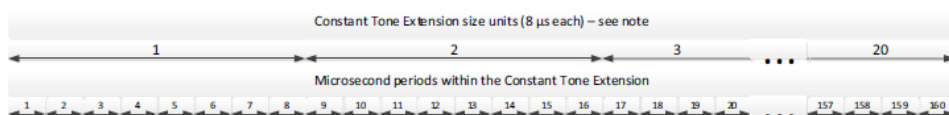
With Bluetooth 5.1

Constant Tone Extension (CTE)



- Purpose of CTE is to provide constant frequency and wavelength signal against which IQ sampling can be performed
- The field contains an unwhitened sequence of 1s (Tone) and is appended after CRC
- CTE is supported in connection-less and connection-oriented scenarios
- In connection-less, **periodic advertising** is required (deterministic timing)
- Supported for 1Mbit and 2Mbit PHYs

Constant Tone Extension (CTE) Part II



- CTE is minimum 16 μ s and maximum 160 μ s
- CTE supports **minimum 2 antennas** and **maximum 38/75 antennas** (depending on switch and slot length)
- Guard Period – antenna may switch
- Reference Period – 8 reference IQ samples
- Switch Slot – Time for switching antenna
- Sample Slot – Time for getting IQ samples
- Switch / Sample slots needs to be 2 μ s or optionally 1 μ s

“Sampled data is passed up the stack via the Host Controller Interface (HCI) where it will then be possible to apply a suitable algorithm to the sampled data to calculate the direction of one device from the other. **Algorithms for calculating angles from IQ samples are not defined in this core specification release.** Once associated profiles are available, application developers will have the opportunity to implement algorithms suitable for the intended use case.”

The above is from BT SIG,
BT5.1 only specifies how IQ data are collected, not how angles are
calculated which is up to the application.

There are currently no profiles on top of Direction Finding

Direction Finding

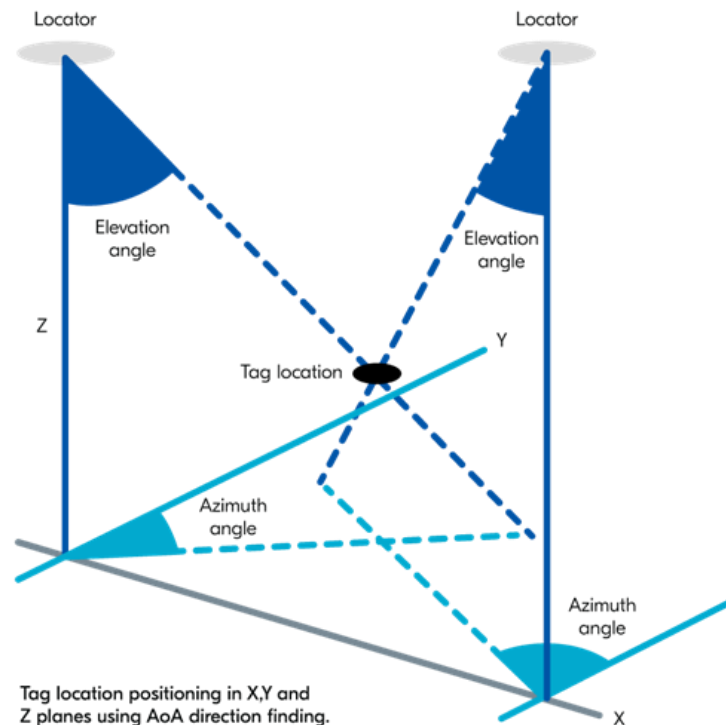
And the myths

Direction Finding is distance finding ...

- Direction finding is NOT distance finding
- You cannot work out the distance between the a transmitter and a receiver with direction finding
- Distance can be found by other means
 - RSSI for very coarse distance finding, e.g. beacon based systems
 - Time-of-Flight for more accurate distance finding but it is NOT in the scope of Bluetooth 5.1

Direction Finding means positioning

- With one receiver and one transmitter, both AoA and AoD can only figure out a relative direction to each other
- Direction finding can be a building block for positioning systems
- With multiple locators (RX) receiving signal from a tag (TX), the location of tag relative to the locators can be figured out by triangulation

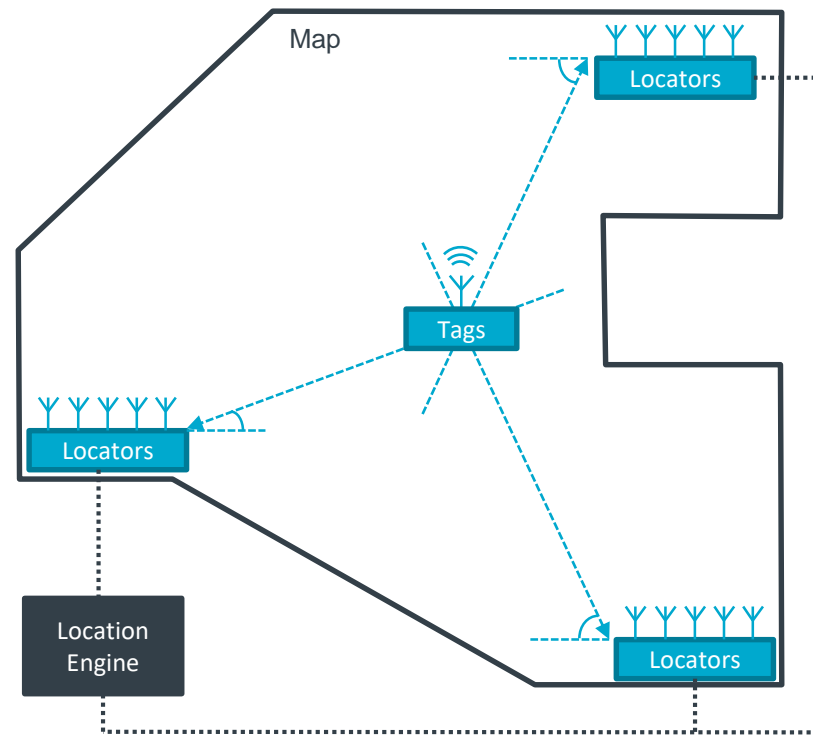


Direction Finding

To Positioning and RTLS

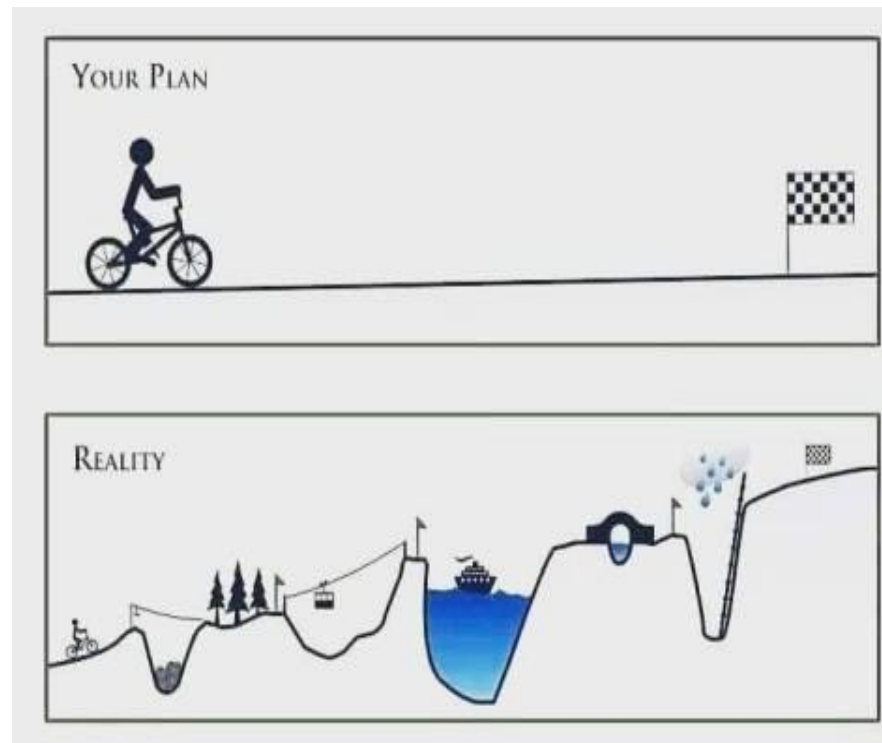
From Direction Finding to Positioning

- Positioning as a starting point for RTLS
- Triangulation is the keyword
- Typically based on AoA
 - Locators receive CTE from Tags
 - With multiple antennas, Locators can figure out direction of Tags
 - With multiple locators, Tags location can be figured out by Triangulation and mapped with a location engine
- Pros
 - Simple single antenna tags which allows scaling up in volume
 - Complexity in locators which a large number of units is typically not needed
- Cons
 - Distributed locators adds complexity to location engine implementation



Reality Check

- The ideal ...
 - Accuracy in centimeters can be achieved!!
 - Location can be tracked in real time!!
 - RF signal received from single paths!!
- The reality ...
 - Positioning with direction finding is a **system**
 - Antenna constellation
 - Locators
 - Positioning Algorithm
 - Adaptation to operating environment



Positioning with Direction Finding

- The primary questions

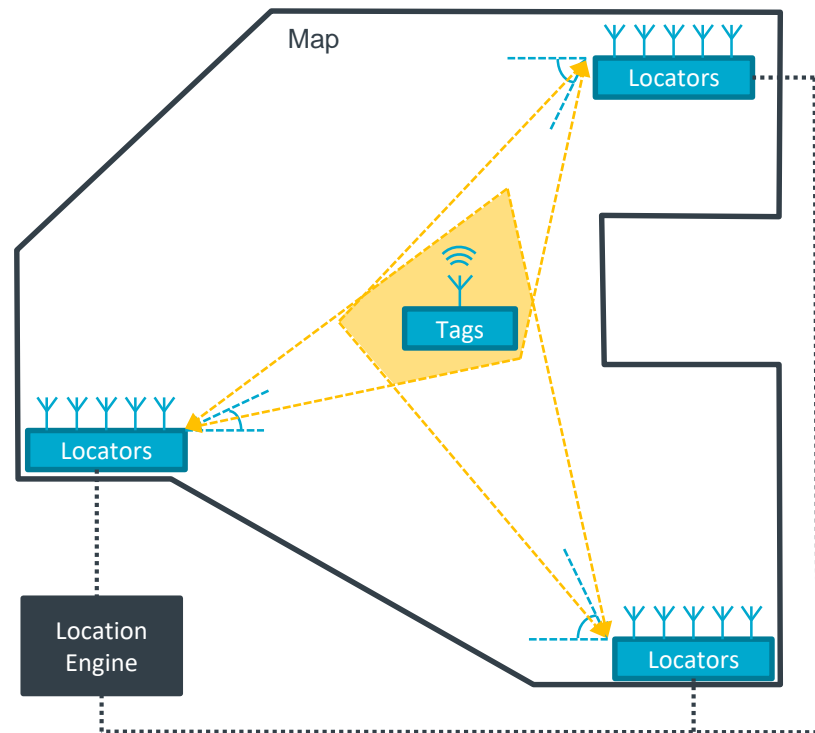
How many locators are needed for a RTLS?

How should the locators be spatially distributed?

- Ideally, a minimum of 2 locators is sufficient for triangulation

- In reality, it depends ...

- Shape of your premise with columns, walls, etc.
- Angular accuracy achievable by locators
- Distance between tags and locators



Antenna constellation

- The primary questions are

How many antennas are needed?

How the antennas should be arranged?

How should the antennas be oriented to achieve the best polarization for your scenario?

- The diversity of data is directly proportional to number of antenna
- The polarity of antenna is directly related to the configuration of antenna
- The configuration of antenna is related to the relative orientation between transmitter and receivers

Positioning Algorithm

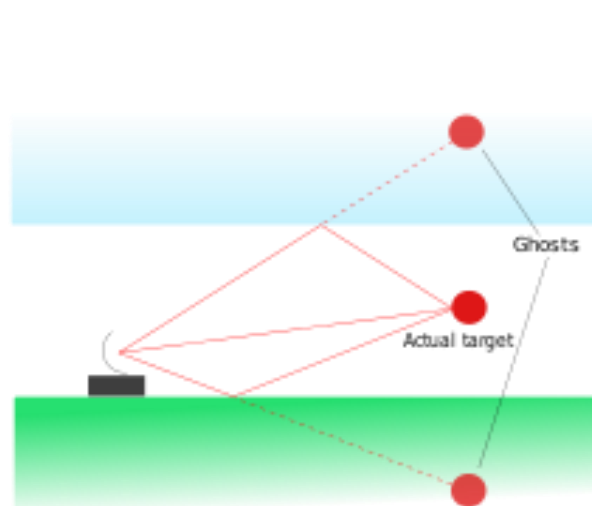
- The primary question

What are the primary factors affecting the output of the algorithm?

- Input diversity
 - Number of Antenna
 - Antenna Constellation
- Adapting the algorithm to its operating environment
 - Absorbers, e.g. human body, water, etc.
 - Reflectors, e.g. metallic cranes, surfaces, etc.

Adaptation to operating environment

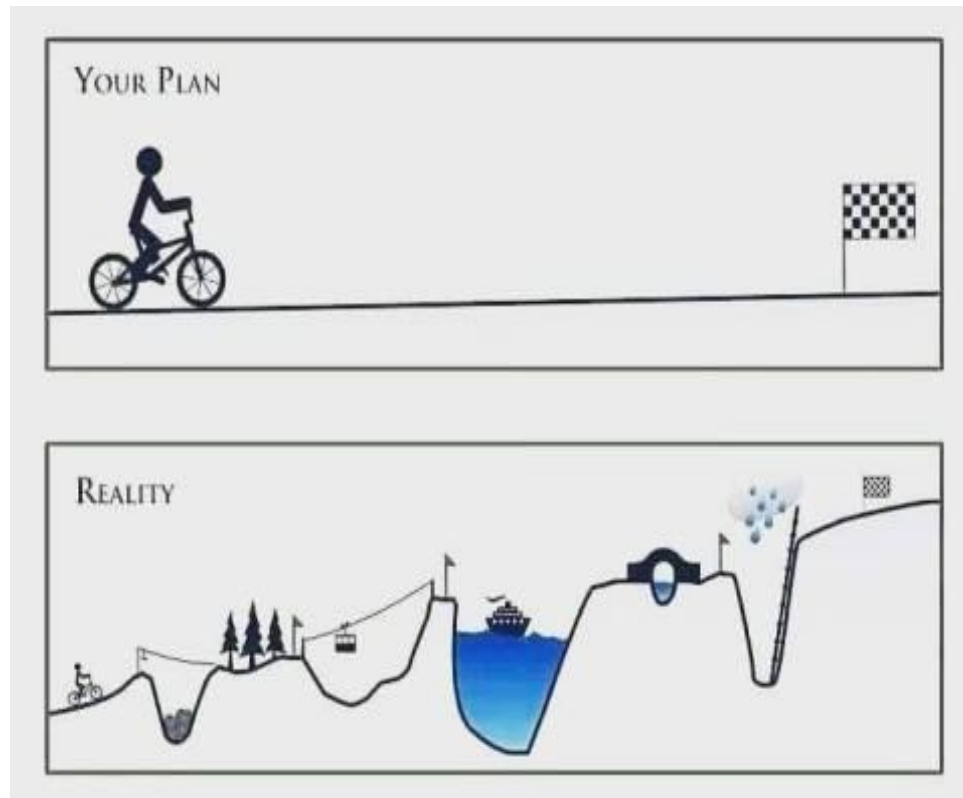
- Absorbers and Reflectors
 - Metallic objects are blockers and reflectors
 - Human bodies are absorbers
- Multi-path interference and Image rejection
 - In the real world, signal rebound from obstacles, walls, etc. Signal coming from multiple path:
 - › interfere with each other, constructive and destructive
 - › multiple 'ghosts' formed for one signal source



The other error sources ...

- Jitter
- Propagation delays
- Antenna switching timings

And more ...



Direction Finding

Key Takeaways

Key Takeaways

- Bluetooth 5.1 defines the support for extracting phase information, i.e. IQ-data, for direction finding algorithms
- Bluetooth 5.1 does not based its assumptions on any specific direction finding algorithm
- Bluetooth 5.1 does not specify any distance finding or positioning
- Positioning based on Bluetooth 5.1 direction finding is a 'system' but not a single 'device'
- To achieve a certain positioning quality, these are the questions to ask
 - Antenna Constellation design in locators
 - Number of Locators in the system; Spatial configuration of the locators
 - Positioning algorithm
 - Adaptation to the operating environment, manually or automatically?

Bluetooth 5.1 on nRF52811

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