3301 INTERIM PRESENTATION

Location Intelligence to Create Iconic Audio Experiences

Presented by

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Imagine if your devices were controlled by where you are, instead of what buttons you press...

01

Iconic Audio Experiences

02

Value Proposition

03

Existing Technologies

04

ExUWBisting Technologies

05

Our Solution

06

Adjacent Solutions

07

Prototyping Plan

08

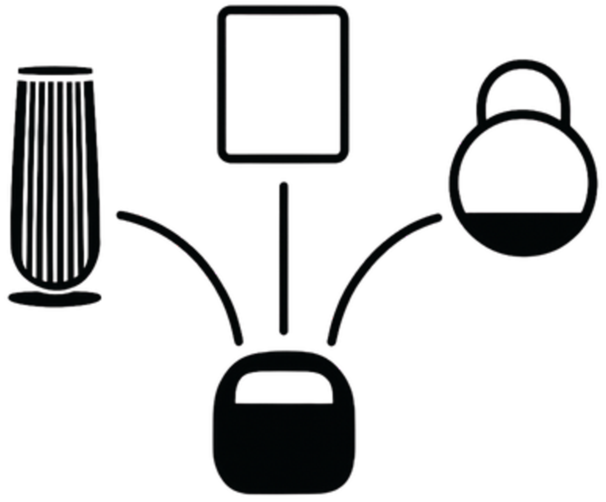
Prototyping Plan

What does a seamless experience mean?

Extending beyond just an App

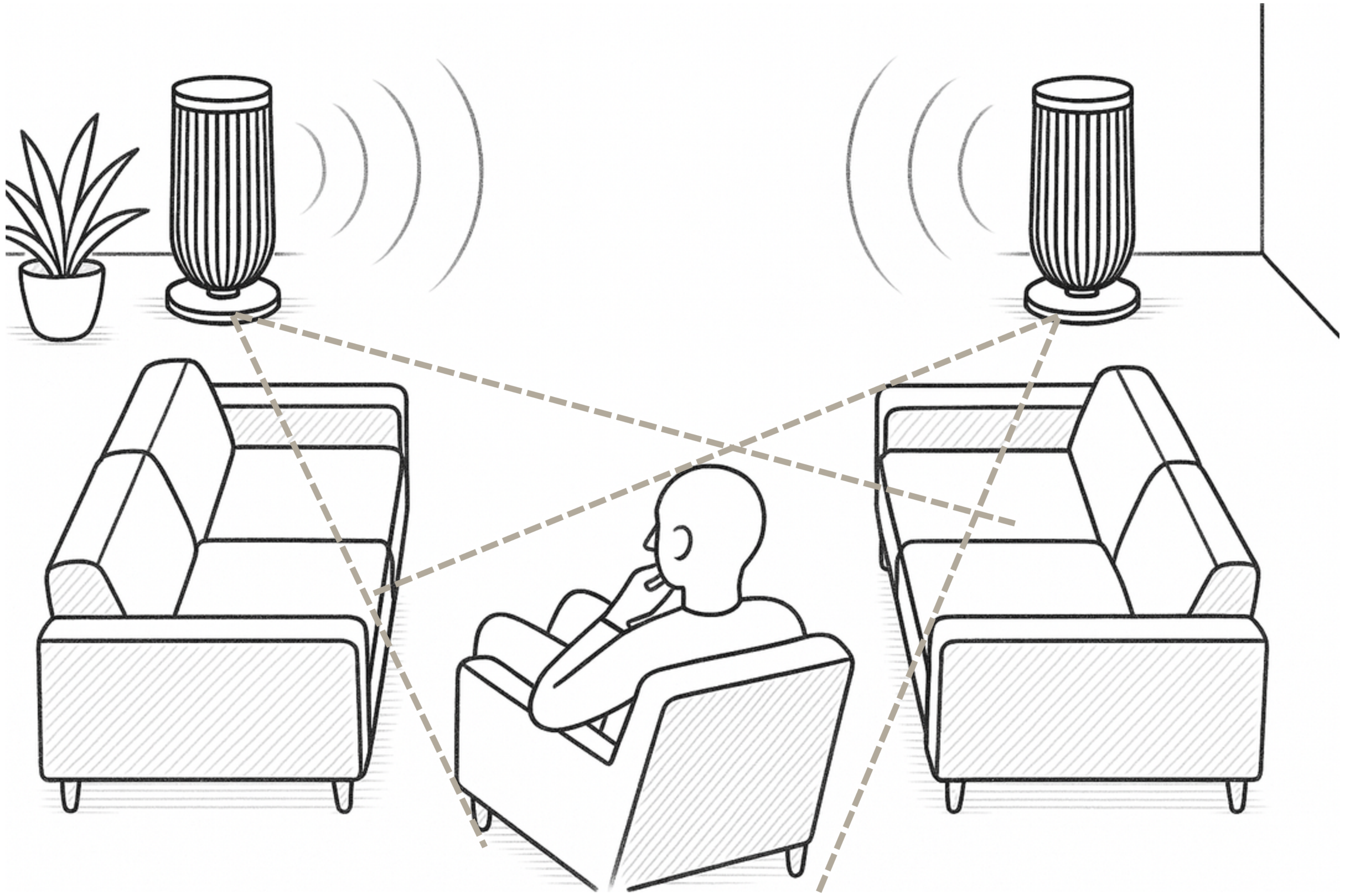
BeoLink

Ecosystems



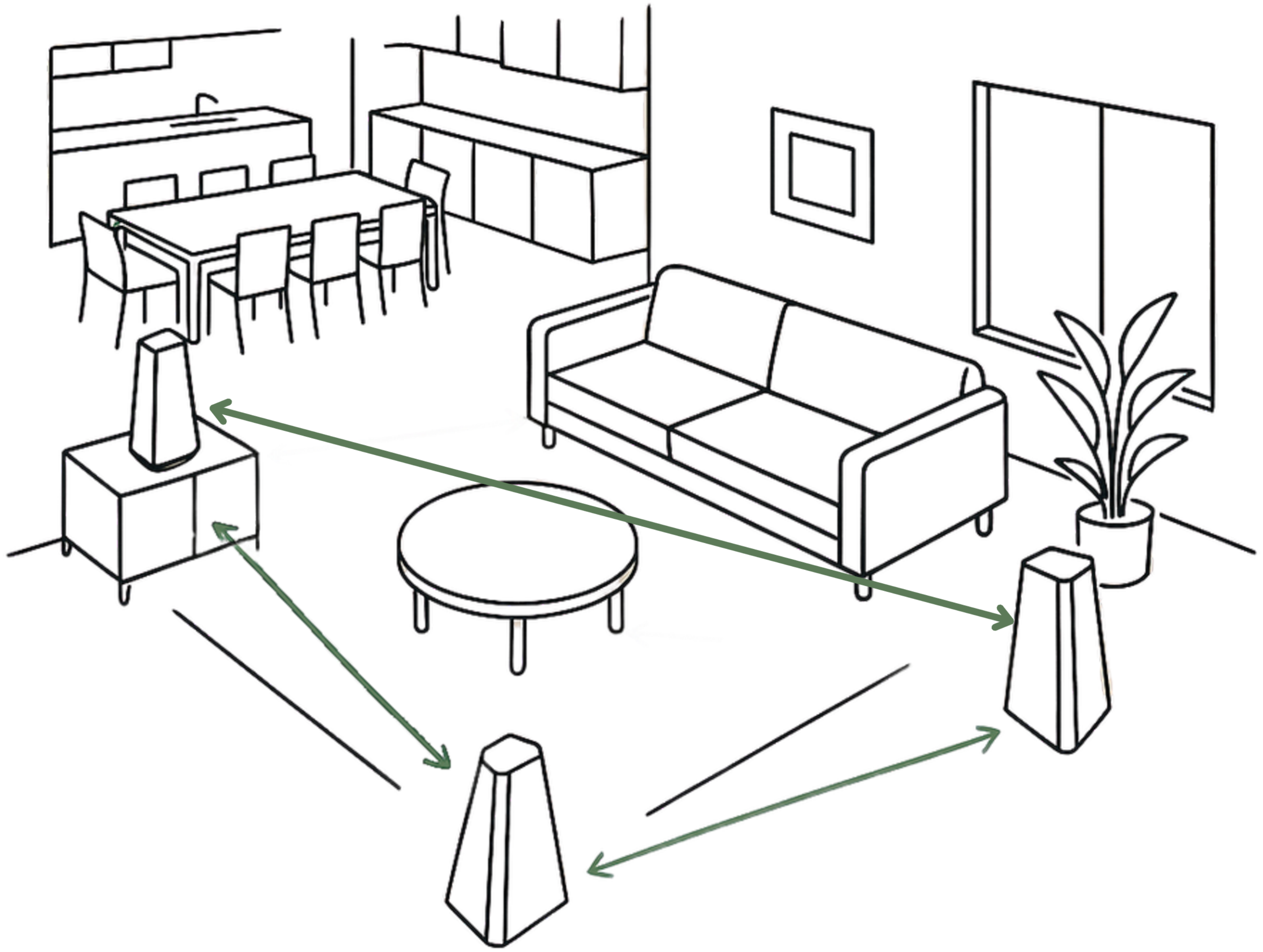
Experiences B&O wants to provide

"Follow me" audio experience



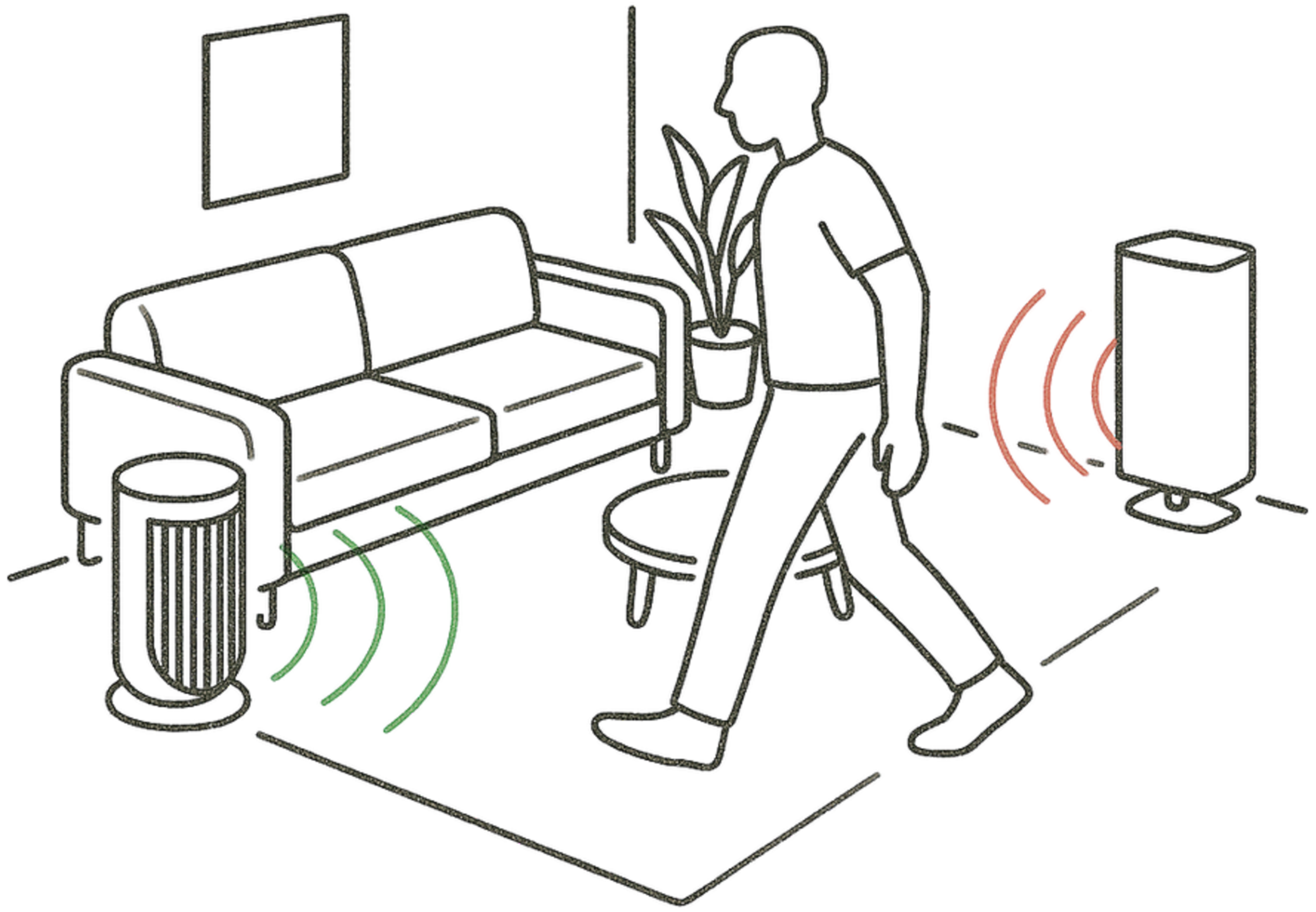
Exact Position $\xrightarrow{\text{powers}}$ Listening Experience

Speaker Setup Experience



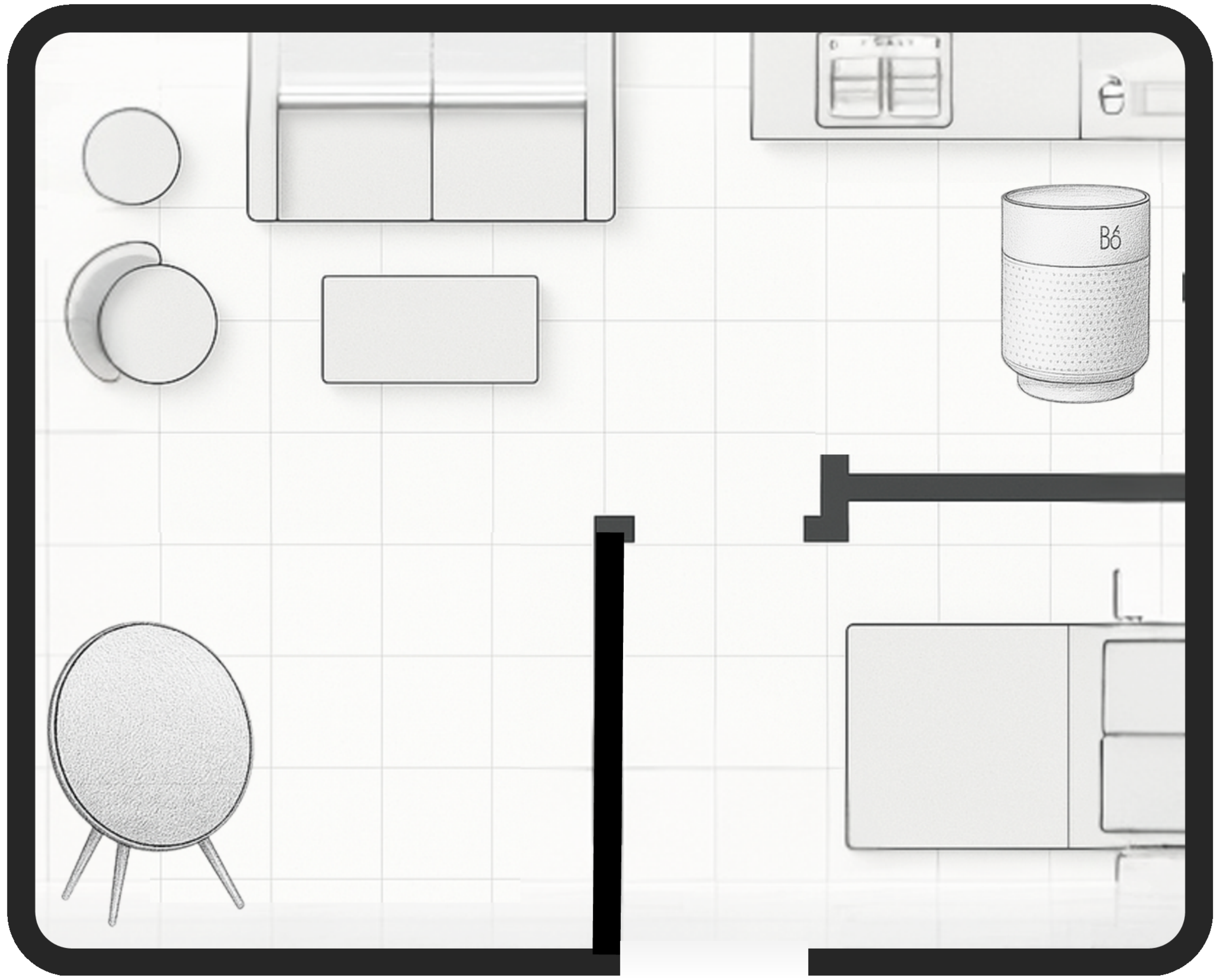
Exact Position $\xrightarrow{\text{powers}}$ Set Up

Adaptive Audio Experience



Exact Position —powers→ Audio Switching

What do we need to make these happen?



Exact
User Position

powers →

Automations

01

Iconic Audio Experiences

02

Value Proposition

03

Existing Technologies

04

UWB

05

Our Solution

06

Tech Stack

07

Adjacent Solutions

08

Prototyping Plan

Value Proposition

High accuracy location data for creating iconic audio experiences -
which is not available on the market now.

01

Iconic Audio Experiences

02

Value Proposition

03

Existing Technologies

04

UWB

05

Our Solution

06

Tech Stack

07

Adjacent Solutions

08

Prototyping Plan

Existing Technologies

Bluetooth

- 3 m
- Low Latency

Wi-Fi

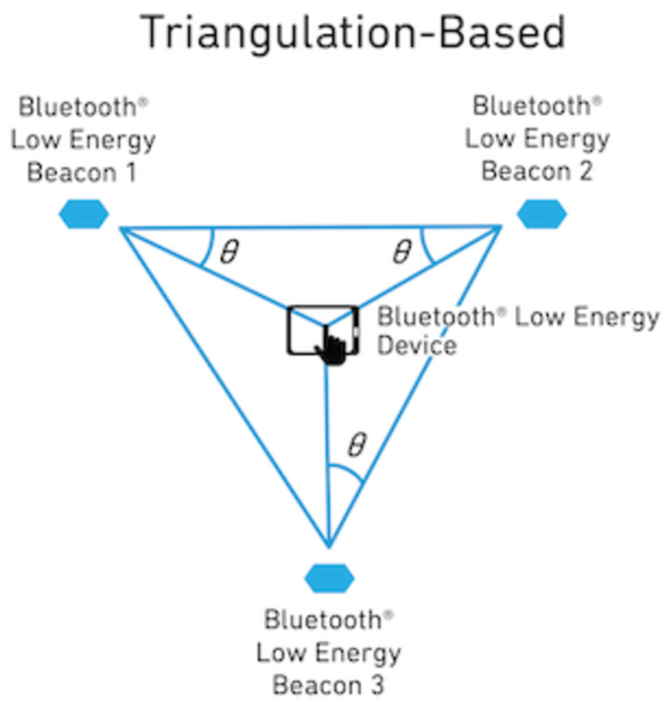
- 10 m
- Moderate Latency

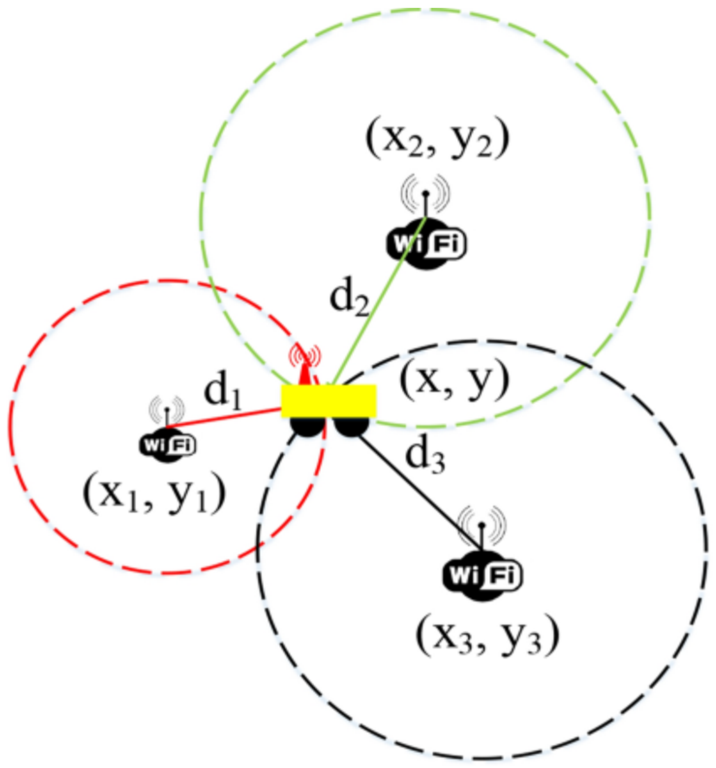
Camera

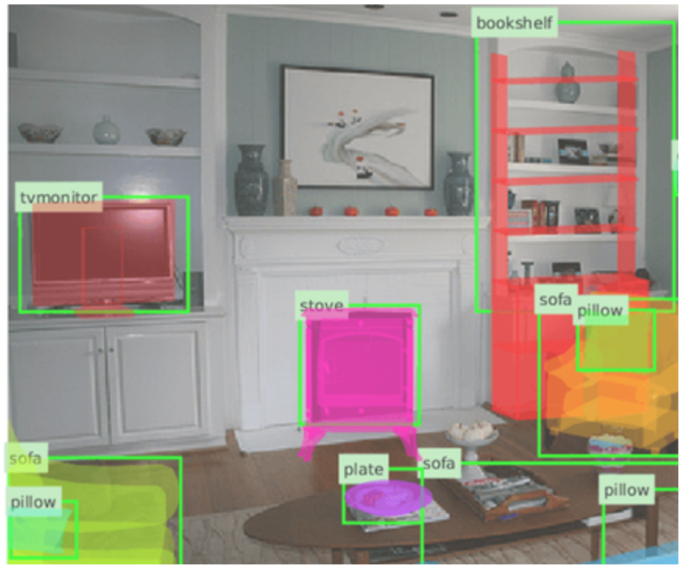
- 0.5m
- Privacy Issues

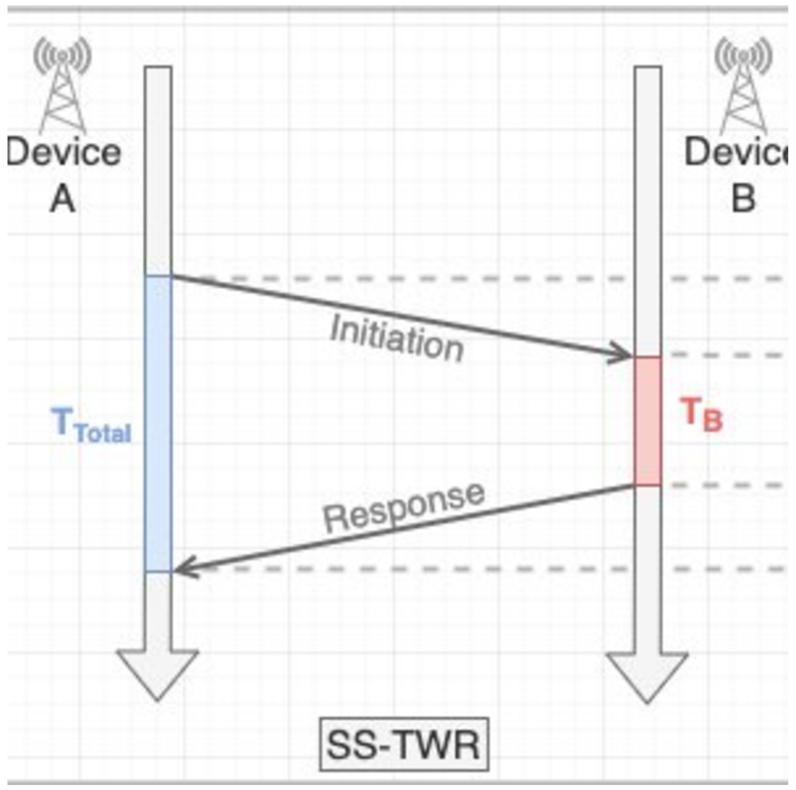
UWB

- 0.1m
- Non visual









01
Iconic Audio Experiences

02
Value Proposition

03
Existing Technologies

04
UWB

05
Our Solution

06
Tech Stack

07
Adjacent Solutions

08
Prototyping Plan

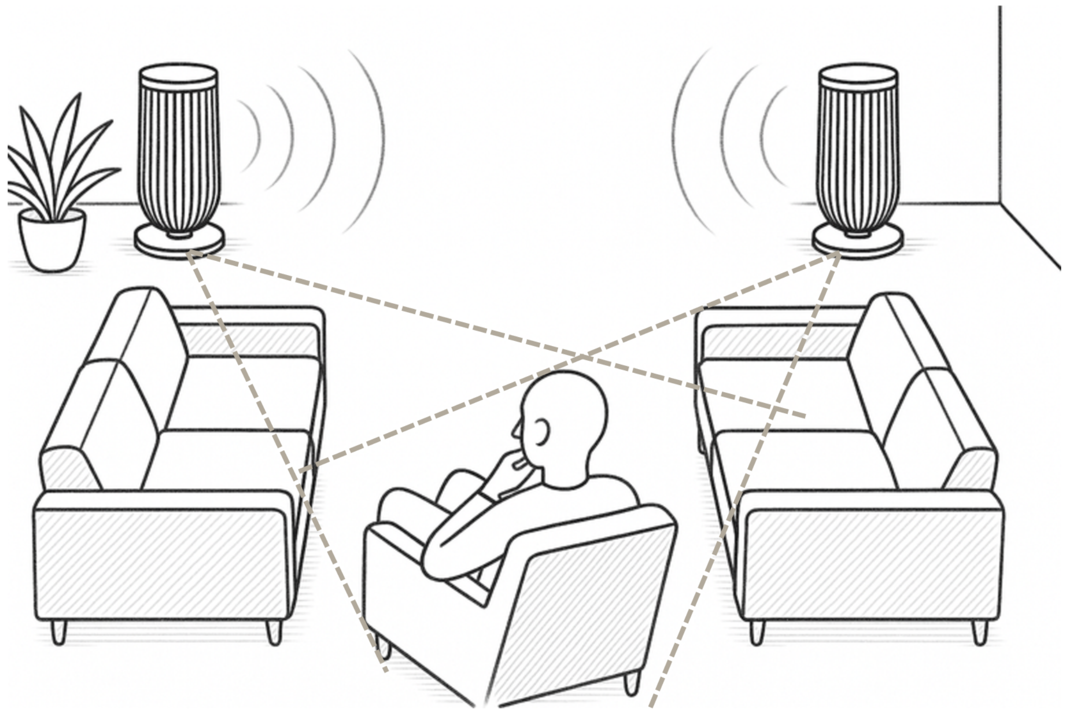
Ultrawide Band Technology

- < 20cm accuracy
- Directional information
- Already installed in B&O speakers
- Available on iPhone

What must our middleware do?

Key requirement 1

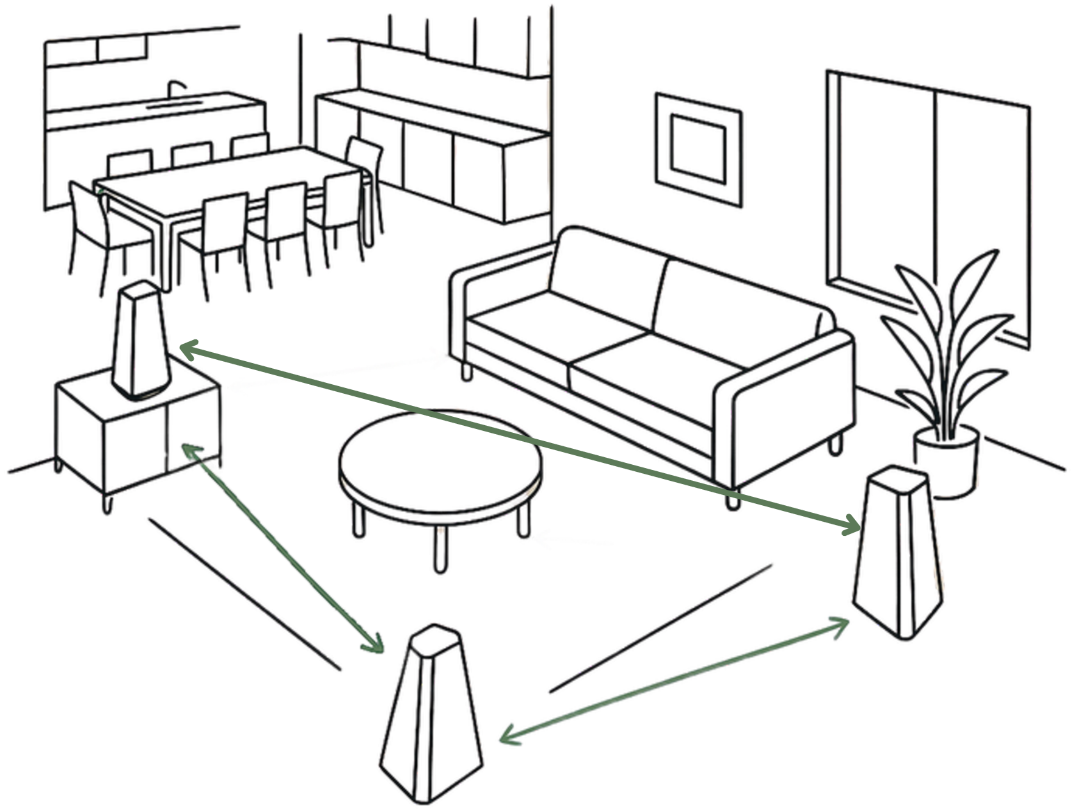
"Follow me"
audio experience



1. Establish communication with the mobile device
2. Know exactly where the user's mobile device is

Key requirement 2

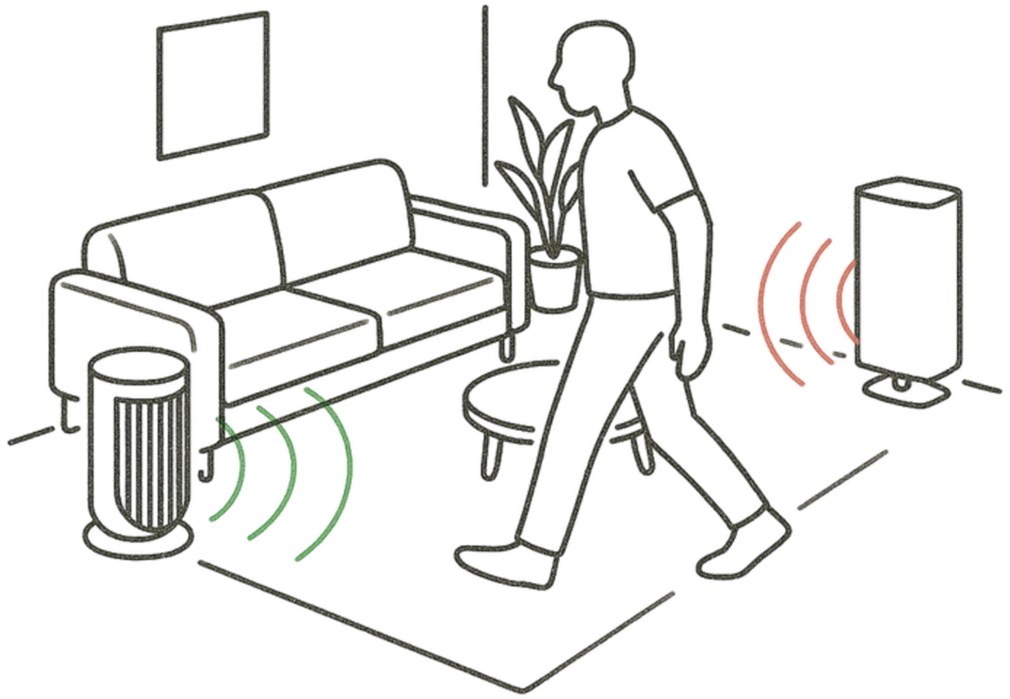
Location-aware for System Set-up



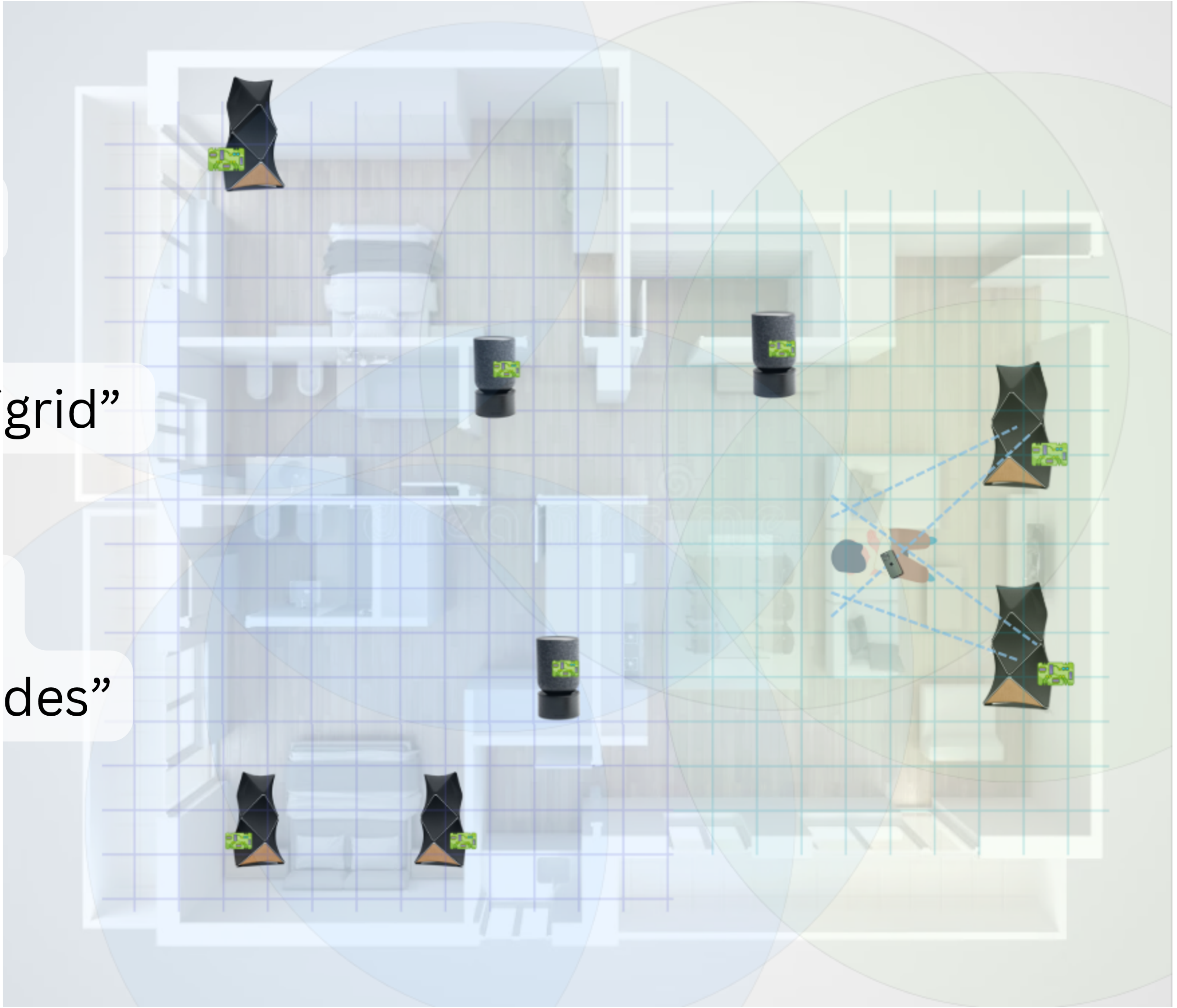
1. Communicate between different speakers
2. Know exactly where other devices are
3. All the different devices have to be placed on a "Grid"

Key requirement 3

Automated Audio Switching



1. Track a moving mobile device within a larger "grid"
2. Robust communication between all "nodes" in the system



Putting it all together:

Our middleware enables seamless audio experiences

by providing accessible and universal location data

01

Iconic Audio Experiences

02

Value Proposition

03

Existing Technologies

04

UWB

05

Our Solution

06

Tech Stack

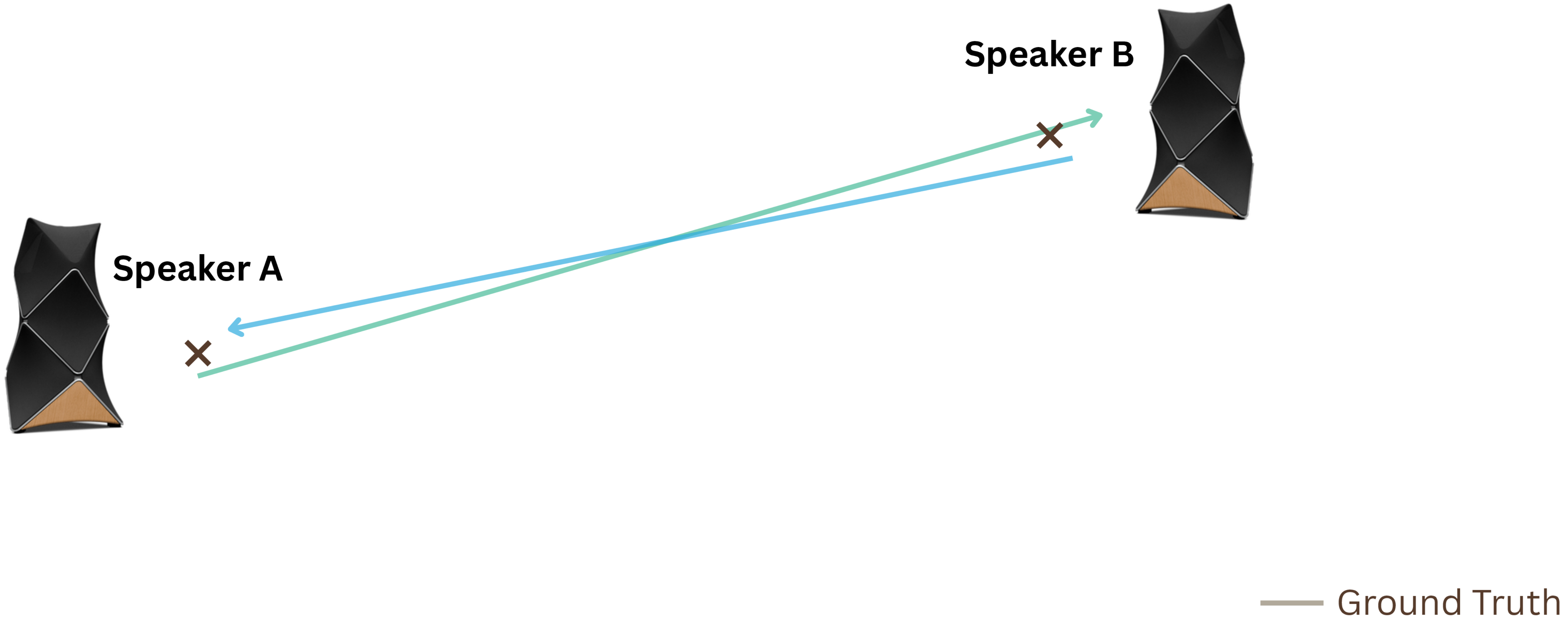
07

Adjacent Solutions

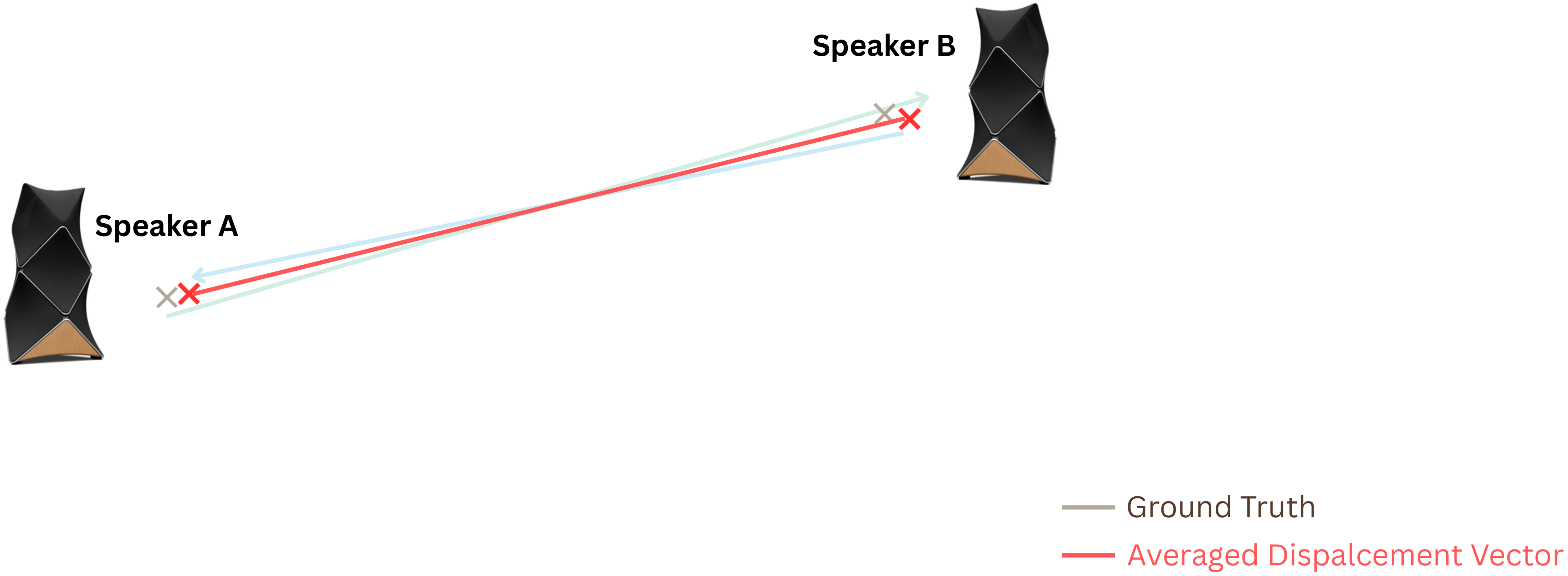
08

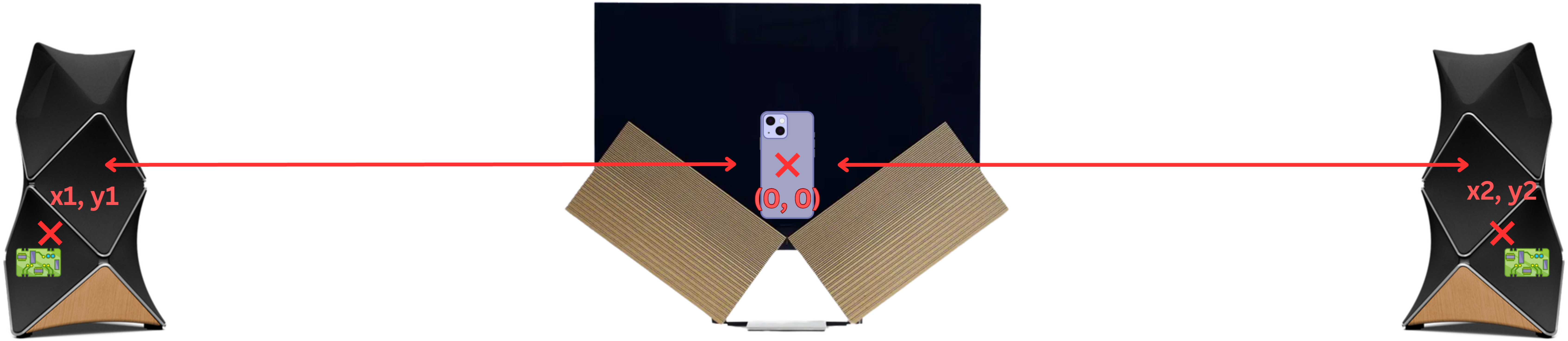
Prototyping Plan

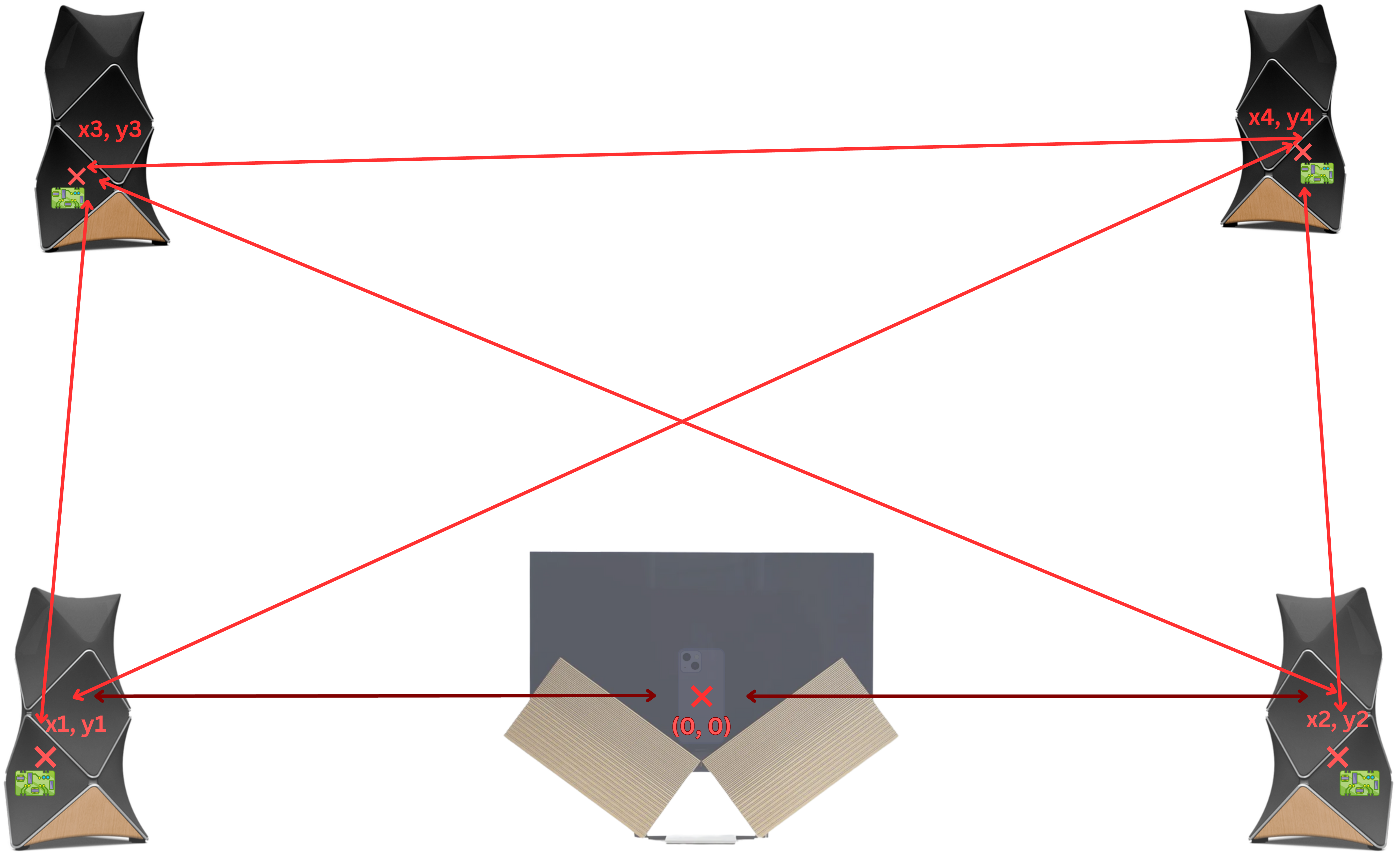
separated vectors



displacement vector

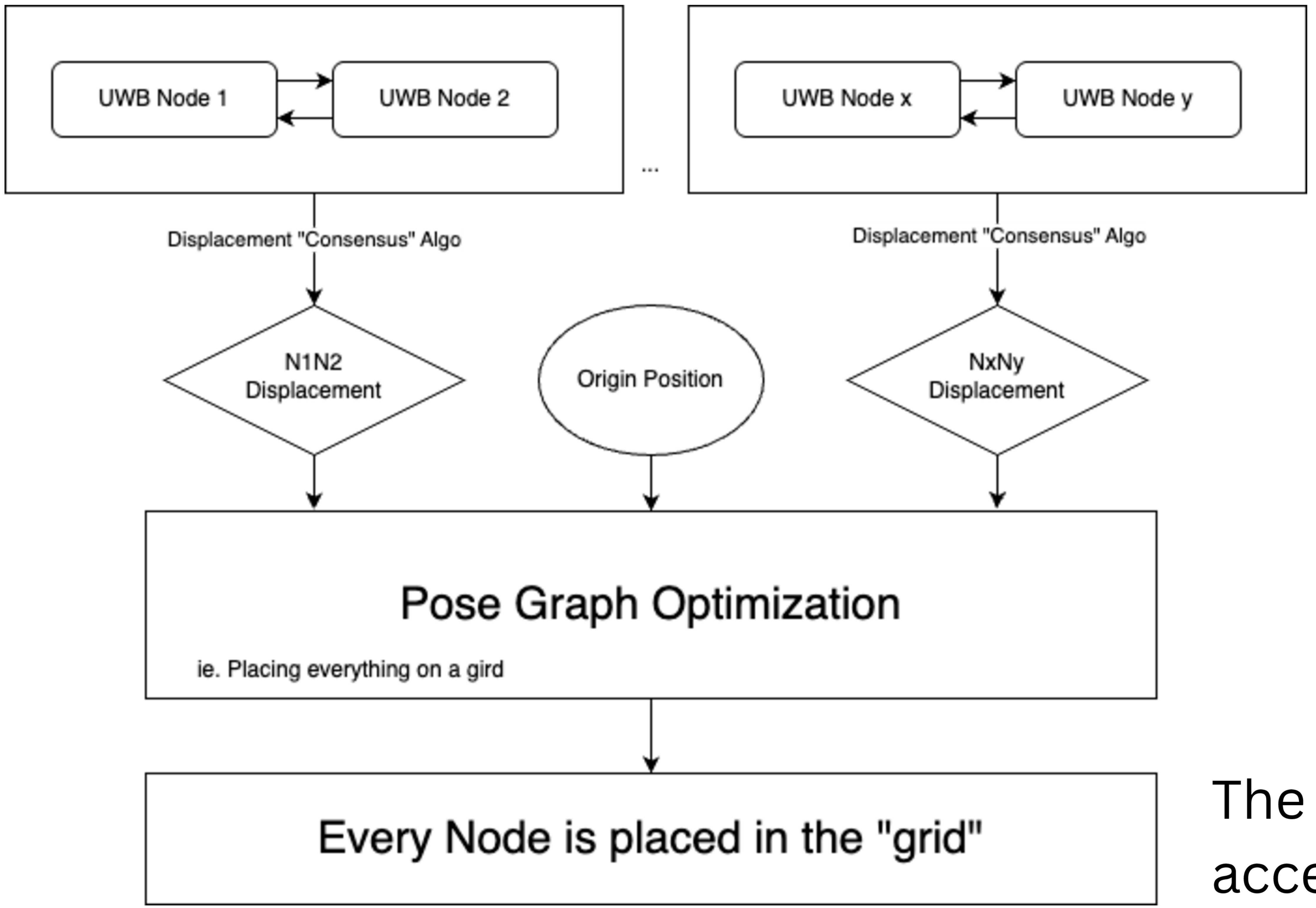



x1, y1
(0, 0)
x2, y2



x3, y3
x4, y4
x1, y1
(0, 0)
x2, y2

System Overview



The Grid is universally accessible across the network

01 Iconic Audio Experiences

02 Value Proposition

03 Existing Technologies

04 UWB

05 Our Solution

06 Tech Stack

07 Adjacent Solutions

08 Prototyping Plan

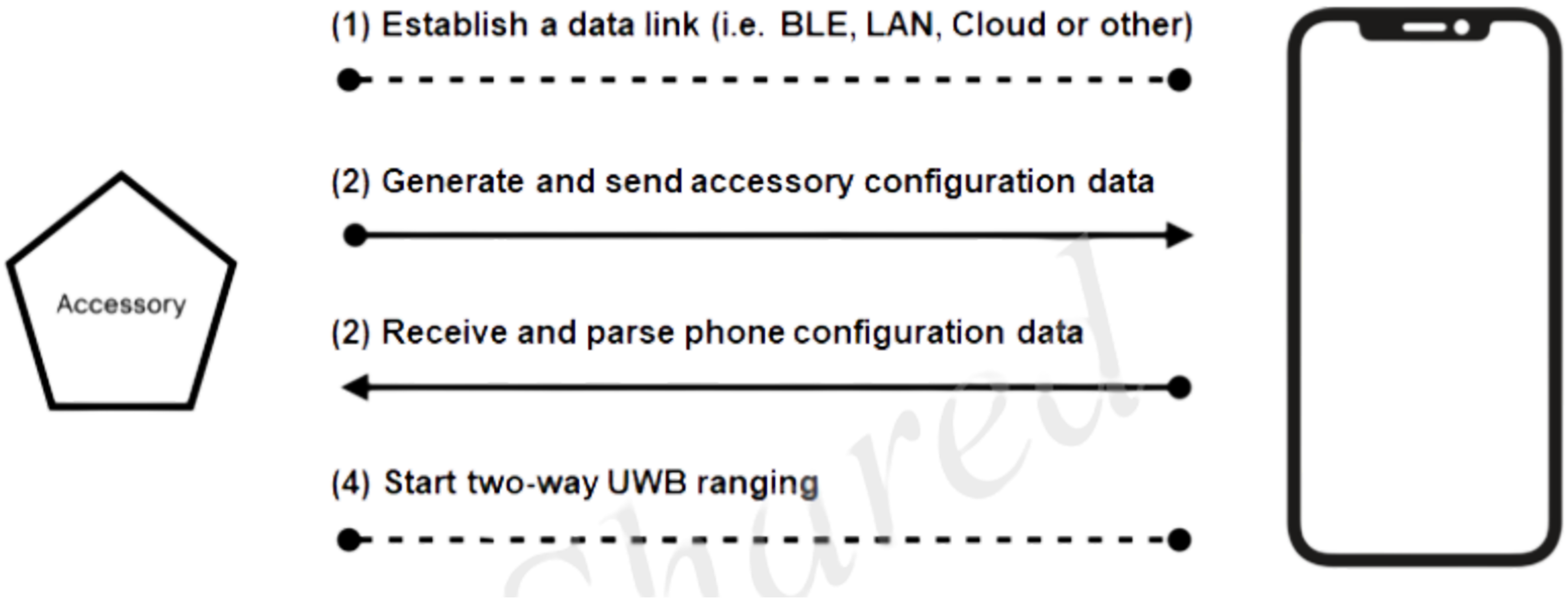
Ecosystems used

- Approved hardware can communicate with Apple Hardware
- Background communication
- WWDC 2021, relatively new

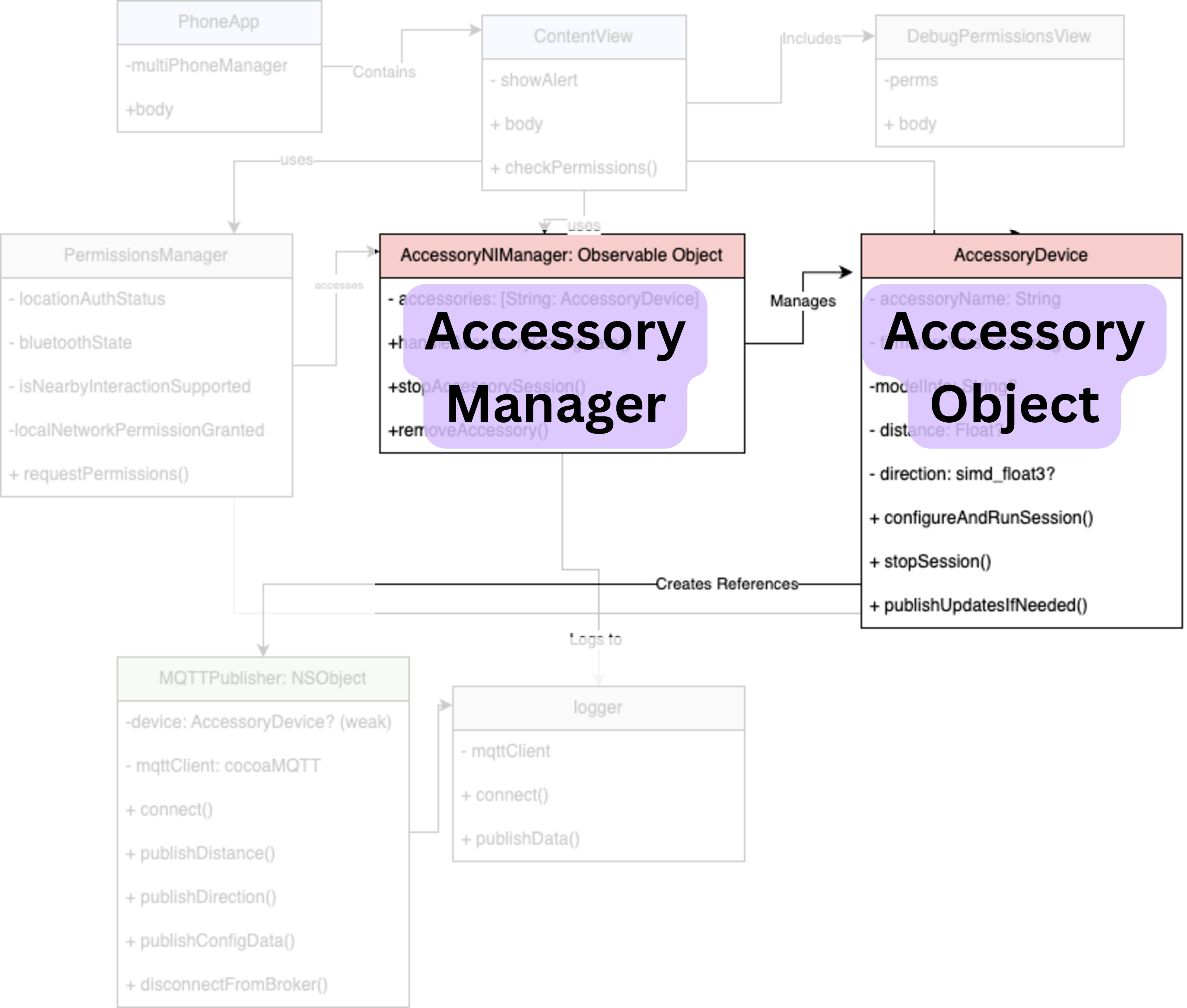
- QN9090 chipset
  - Embedded
- Trimension 150 UWB chip
- NXP’s SDK in McuExpresso for development

- Publisher Subscriber Architecture
- Common communication protocol between IOT devices
- Over local network (not limited to bluetooth range and more scaleable)

UWB Handshake with phones (NXP)



NI Accessory



- Handle the handshaking with Dev Board
- Handle many different Anchors

01

Iconic Audio Experiences

02

Value Proposition

03

Existing Technologies

04

UWB

05

Our Solution

06

Tech Stack

07

Adjacent Solutions

08

Prototyping Plan

How have adjacent industries taken advantage of UWB

Corporate technology   eg. Quuppa

Healthcare tracking to know what room people are in

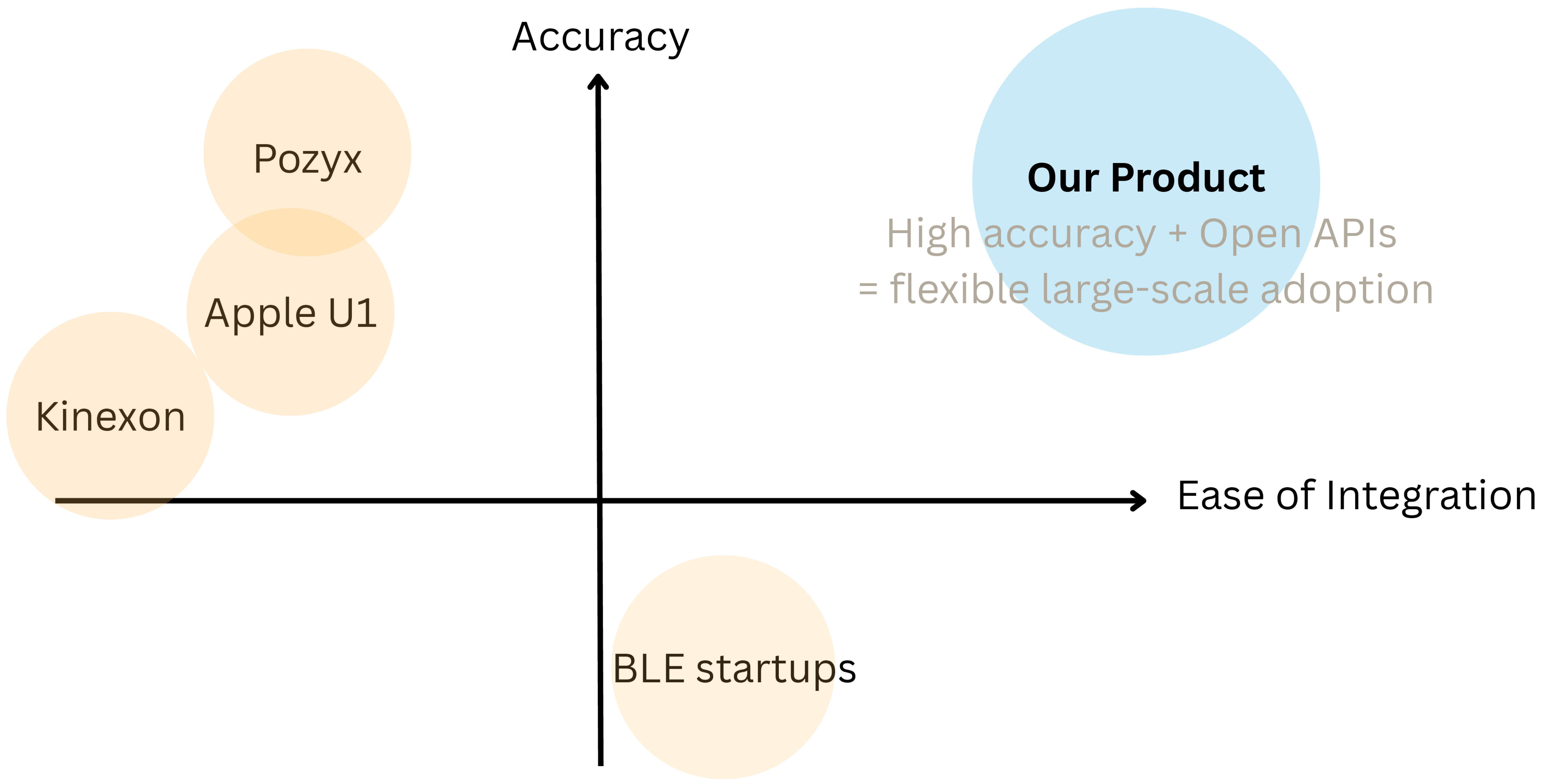
Automotive Industry   eg. BMW

Cars unlock with UWB-enabled phone keys

Supply Chain Management   eg. Pozyx, Kinexon

Logistic firms track assets using UWB

Competitor analysis



01

Iconic Audio Experiences

02

Value Proposition

03

Existing Technologies

04

UWB

05

Our Solution

06

Tech Stack

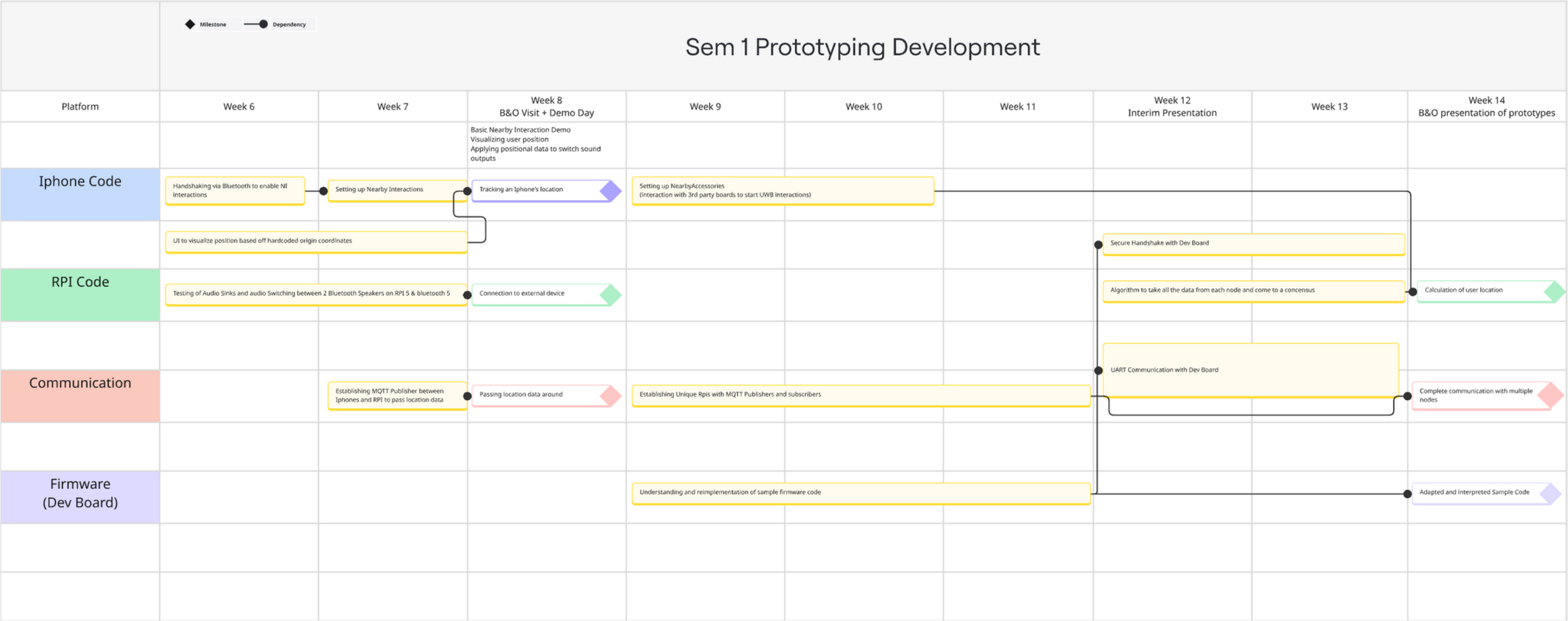
07

Adjacent Solutions

08

Prototyping Plan

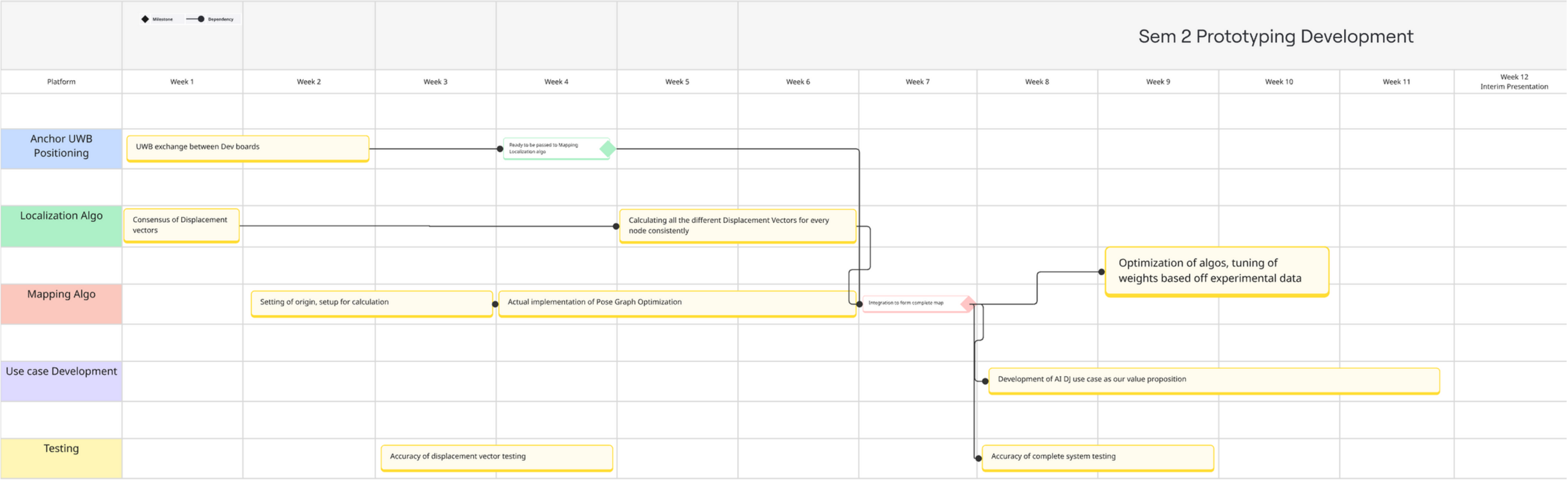
Prototyping Progress (This Sem)



Developmental milestones (Sem 1)

Forming peer to peer interaction with UWB between iphones as proof of concept
Forming handshake with Iphone
Communication between UWB board and RPI through UART (communication of ranging data)
Building MQTT server and identifiers for different RPIs
Simultaneous UWB sessions with multiple UWB anchors
Adapting Sample code from Murrata for UART output

Prototyping Progress (Next Sem)



Developmental milestones (Sem 2)

UWB positioning exchange between Anchors
“Consensus” of the different displacement vectors of each node
Reliability testing for displacement vectors of each node
Setting up for Graph Pose Optimization to form a complete map
Optimization of complete map
Build on top of our middleware to show a promising use case

Testing Plan

1. Tracking user’s and other anchors’ exact location
    a. from what distance can we get the quoted 0.1m
    b. How does the accuracy change with distance

2. How accurate is the Mesh when one of the nodes stops working?

- 5 vs 2 anchors

3. How fast can the system react to a moving user?

- How fast can the system track a moving user

Potential Risks

Security risks

Data privacy issues, such as locational data. Aim to use and emulate privacy standards used by Apple and Google to ensure data is not leaked out of grid.

Handshake issues

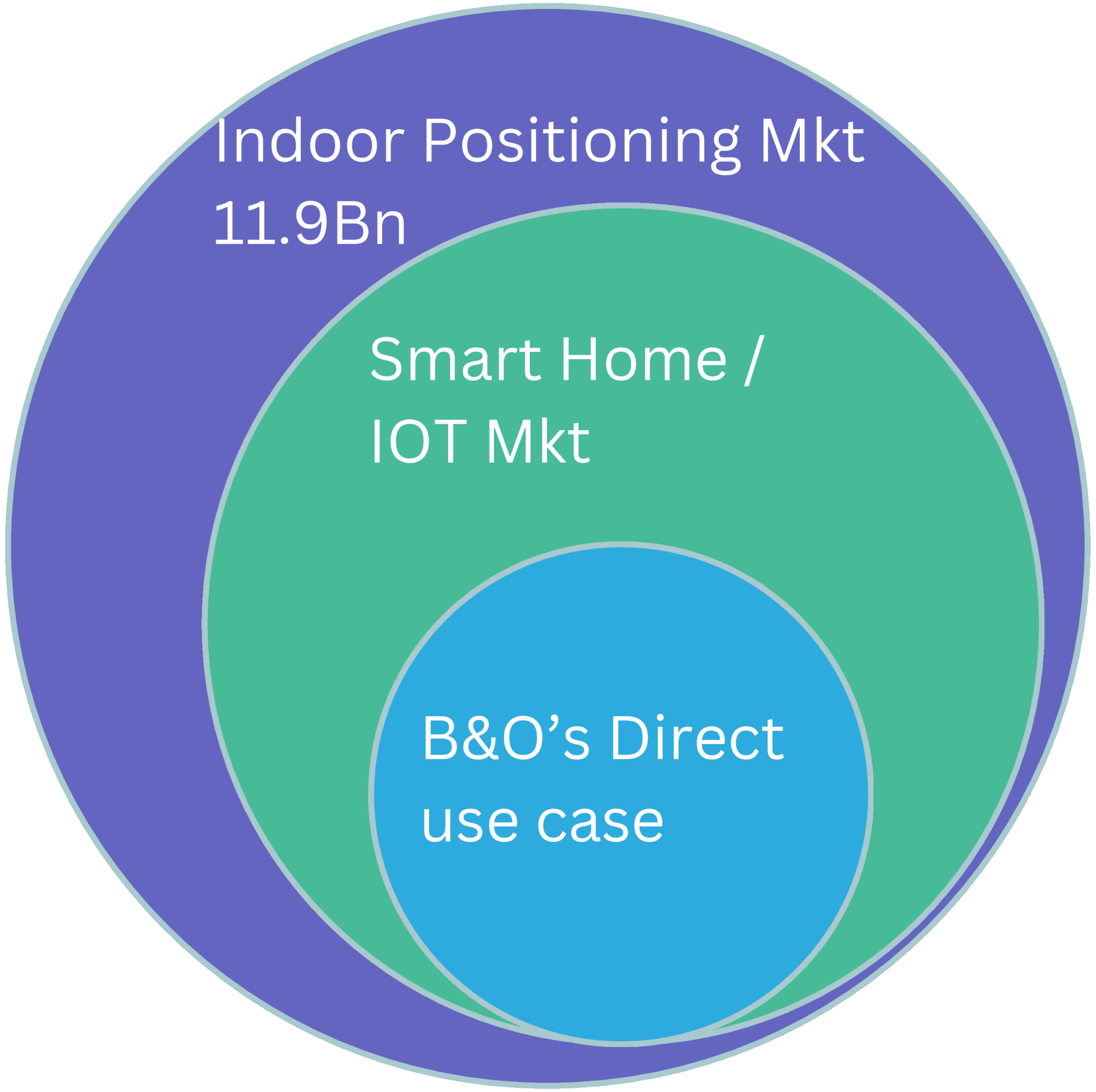
Connection issues in UWB devices,

- due to limit on number of NI sessions which can be managed by Apple devices
- due to issues caused by other proprietary hardware/software design which might be difficult to bypass

thanku.

Backup Slides 👀

SCOPE



INDOOR POSITIONING MARKET

- Robotics
- Intelligent Systems

SMART HOME / IOT MARKET

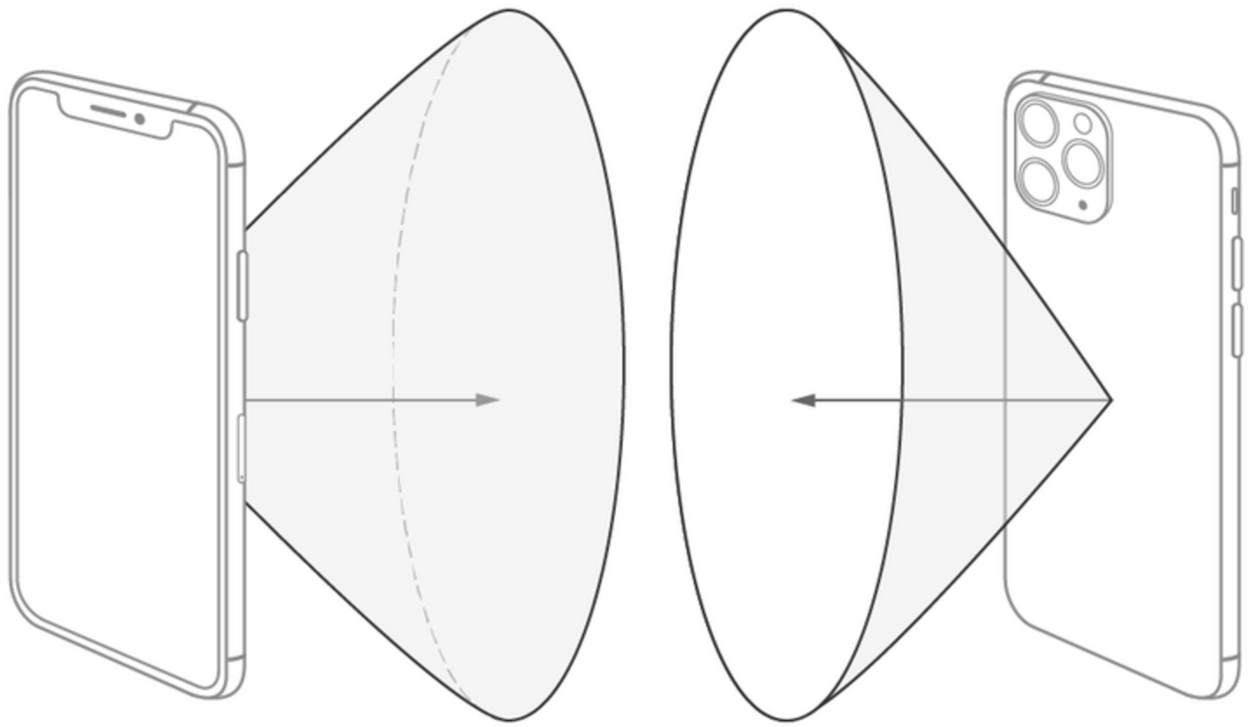
- Automations
- Elderly / Child monitoring

B&O’S DIRECT USE CASE

- Seemless Audio
- Audio Tuning
- etc

WHY NOT IPHONE EVERYTHING?

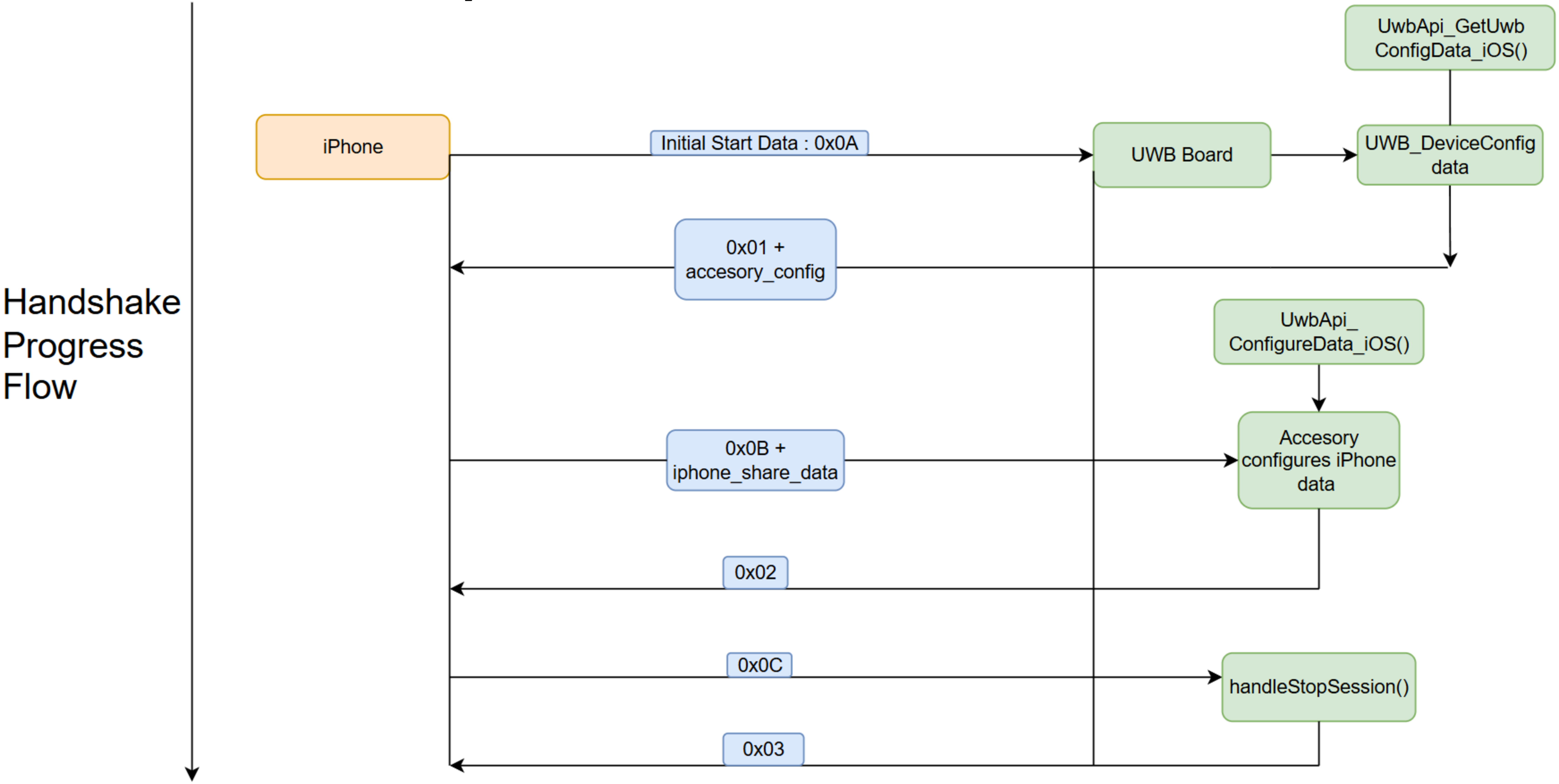
An iPhone detects a peer device's direction when it appears within the narrow line of sight illustrated by the conic region in the following diagram.



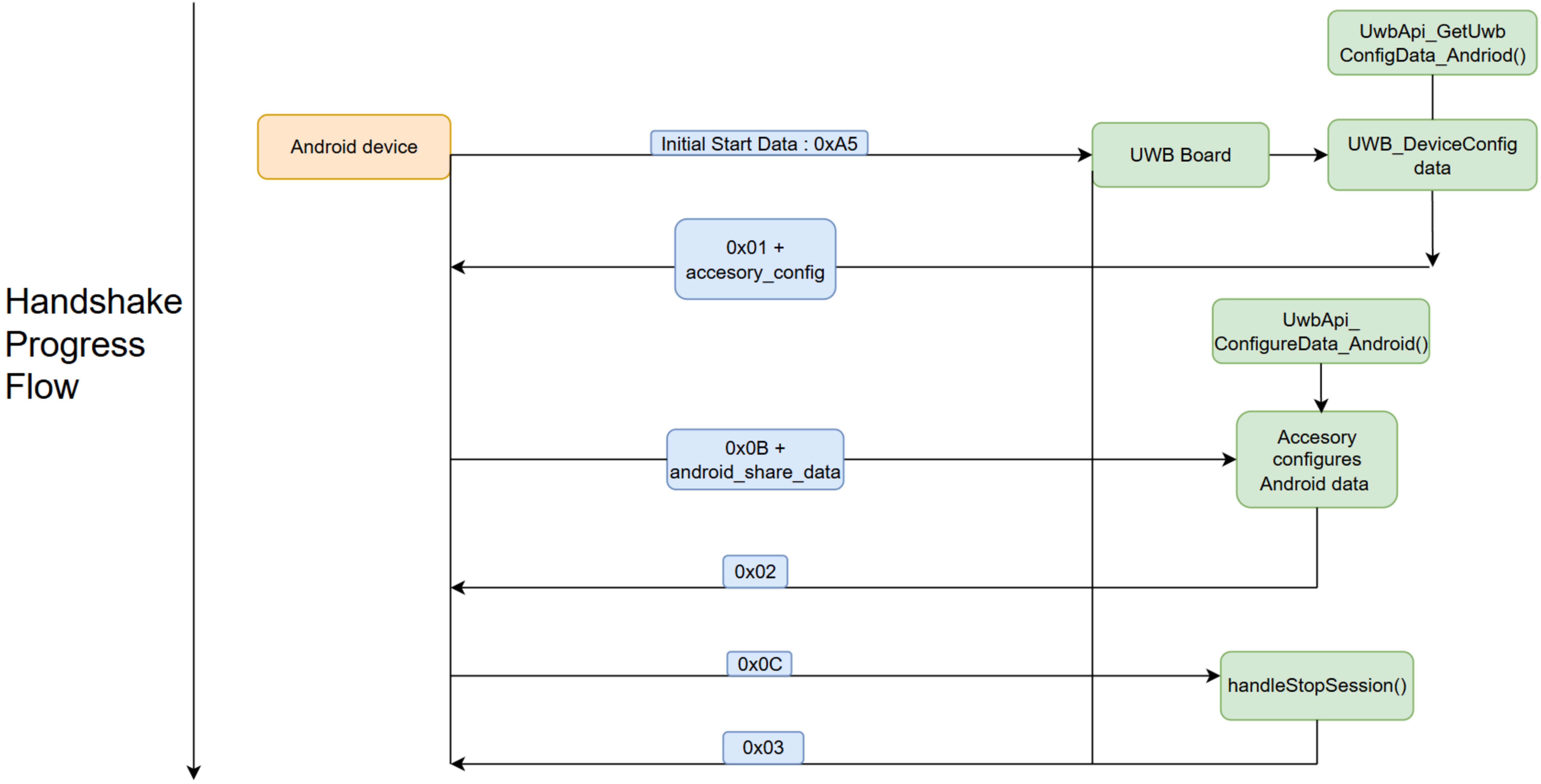
The arrow in the center of the cone represents the direction vector, which extends outward from the center of the back of the device in the direction of the peer. The arrow can point anywhere within the cone in the direction of the peer. However, the line of sight must be clear of obstacles that could interfere with the UWB chip's communication, such as people, vehicles, or walls.

The app can present instructional text to facilitate interactions. For example, if a peer device is out of range, the delegate reads `distance` and `direction` as `nil`. If a peer device is out of the line of sight, the delegate reads the direction as `nil`.

Handshake process (iOS)



Handshake process (Android)



"Consensus on displacement"

Time difference of arrival + angle of arrival

- TDoA: Hyperbolic constraints on the tag's location.
- AoA: Angular constraints forming rays.

You use **nonlinear least squares optimization** to minimize the error between measured and predicted:

$$\min_{\vec{x}} \sum_i \left(\frac{\|\vec{x} - \vec{p}_i\| - \|\vec{x} - \vec{p}_j\| - \Delta t_{ij} \cdot c}{\sigma_{tdoa}} \right)^2 + \sum_k \left(\frac{\angle(\vec{x} - \vec{p}_k, \vec{d}_k)}{\sigma_{aoa}} \right)^2$$

Where:

- $\angle(a, b)$ is the angle between vectors a and b,
- $\sigma_{tdoa}, \sigma_{aoa}$ are error variances for weighting.

Kalman Filters / Particle Filters (for smoothing over time and correct for drift)

- Used to **fuse noisy measurements** over time for better accuracy.
- Often used in mobile tracking, robotics, or indoor navigation.

> This is to track users as they move around, to ensure we "filter" out the jumpyness of the UWB data

Putting all the displacements together

Graph pose optimization:

> The pose graph optimization problem aims to find the best set of poses that satisfy these constraints as closely as possible. This is typically achieved by minimizing a global error function

- Path A → B → C might yield a slightly different result than A → D → C.
- PGO distributes the error across the whole graph to find the globally optimal layout that minimizes this inconsistency.

Nodes (`x₁, x₂, ..., xₙ`):

Each represents a **pose**, which can be:

- A 2D position: $\vec{x} = [x, y]$
- A 2D pose: $\vec{x} = [x, y, \theta]$
- A 3D pose: $\vec{x} = [x, y, z, q_x, q_y, q_z, q_w]$ (with quaternion orientation)

Edges (`(i, j, zᵢⱼ)`):

Each edge represents a **relative transformation** or **displacement vector** between node i and node j:

$$z_{ij} = x_j - x_i + \text{noise}$$

Error Function:

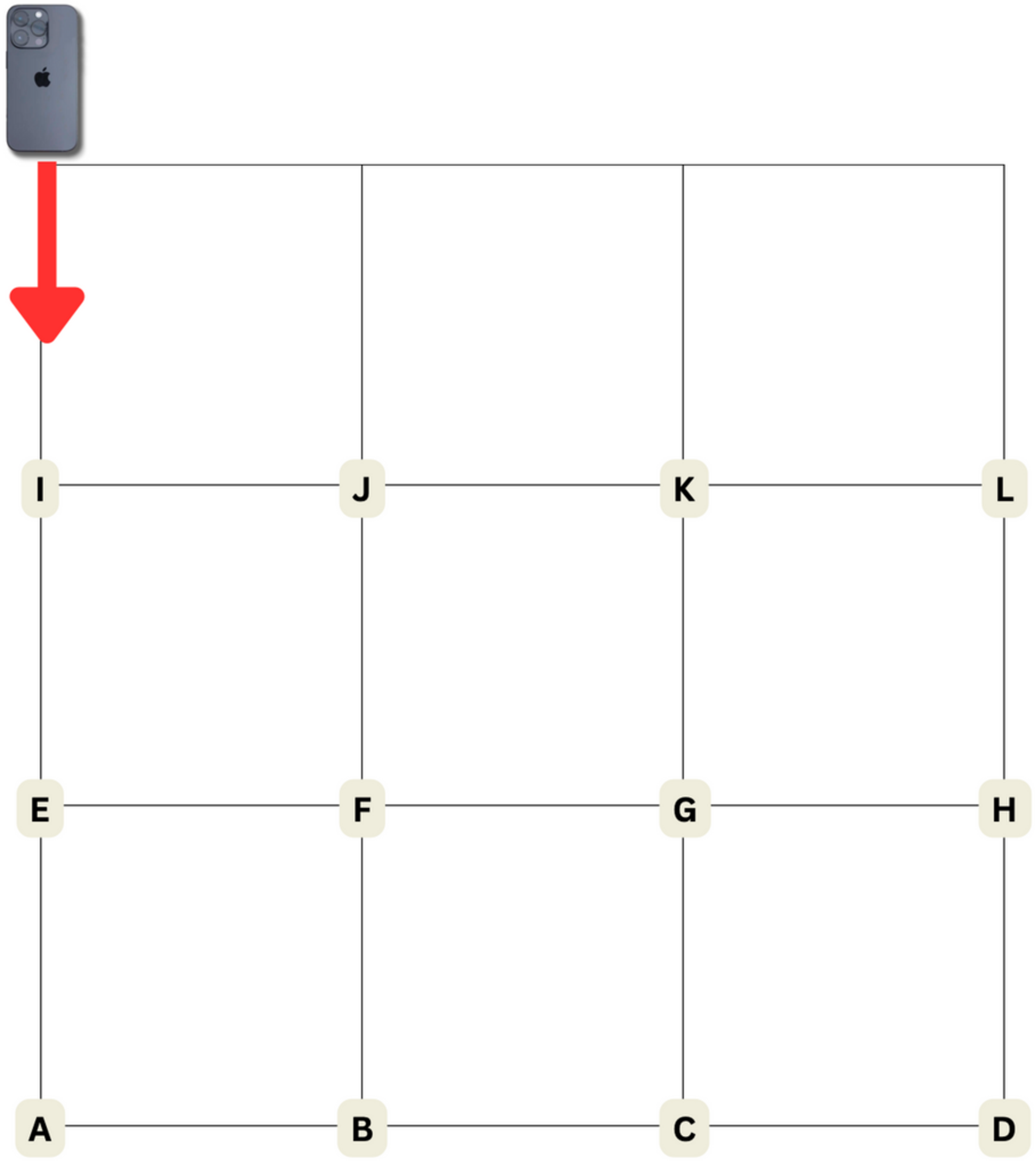
The error for an edge is:

$$e_{ij} = (x_j - x_i) - z_{ij}$$

Objective Function (nonlinear least squares):

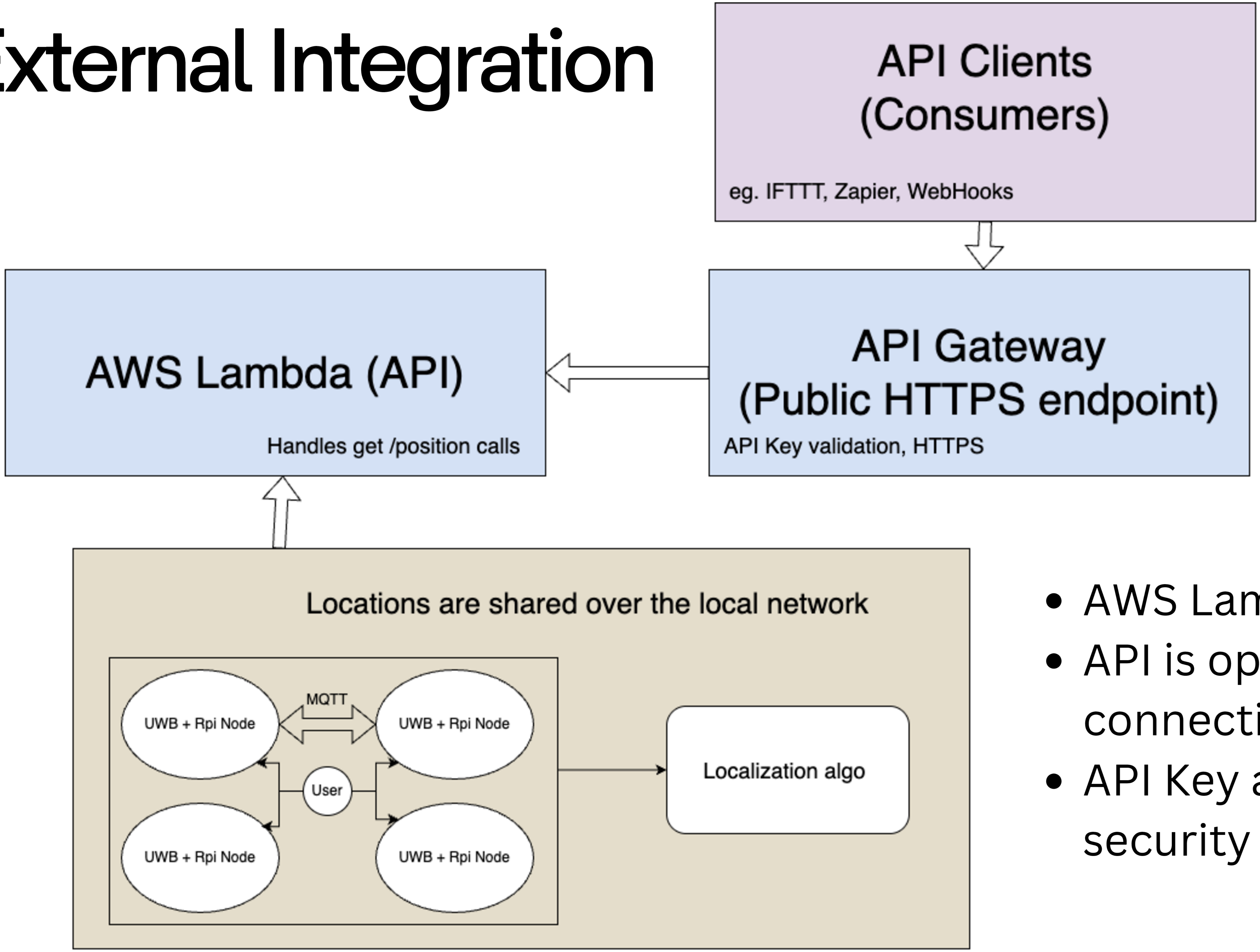
$$\min_{x_1, x_2, \ldots, x_n} \sum_{(i,j)} \|e_{ij}\|^2$$

Preliminary data of ranging between Iphone and UWB board



	Actual Distance	Tracked Distance	Deviation (%)
A	135	136	0.740740741
B	142.3	143	0.491918482
C	162.25	159	2.003081664
D	190.92	187	2.053216007
E	90	90	0
F	100.62	95	5.585370702
G	127.28	127	0.219987429
H	162.25	161	0.770416025
I	45	47	4.444444444
J	63.64	65	2.137020742
K	100.62	111	10.31604055
L	142.3	147	3.302881237

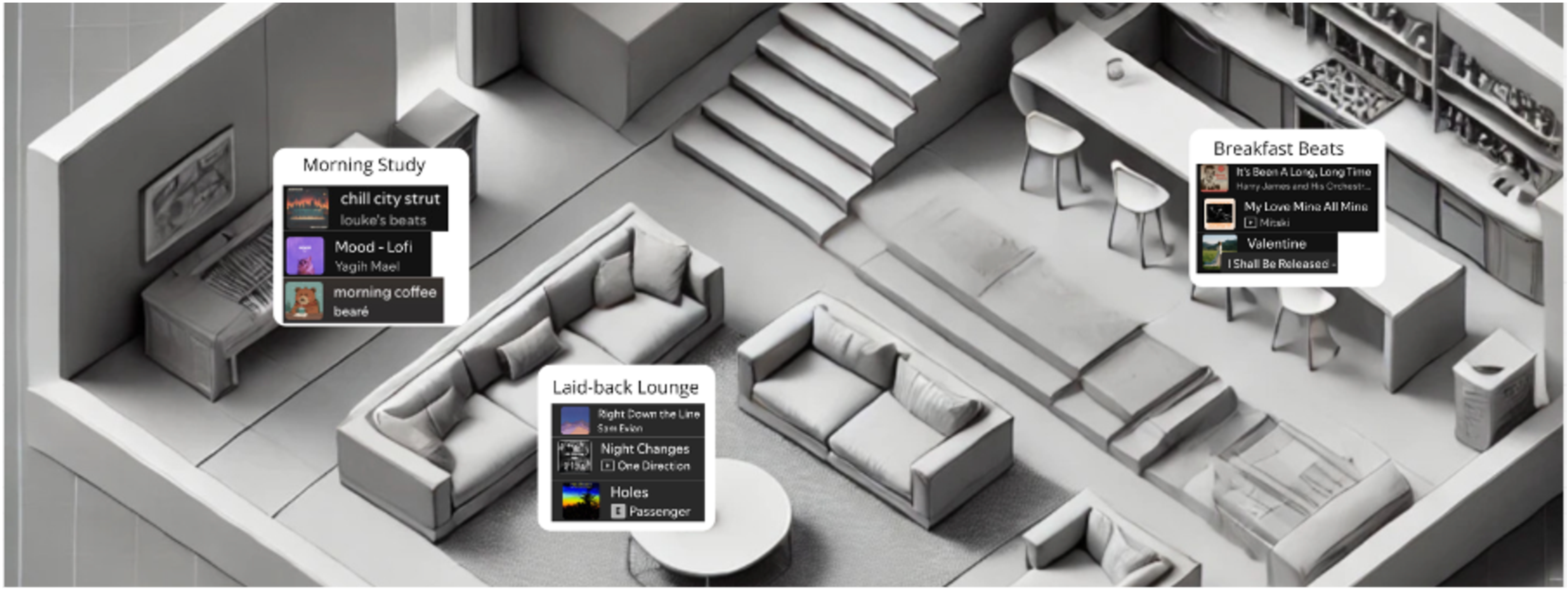
External Integration



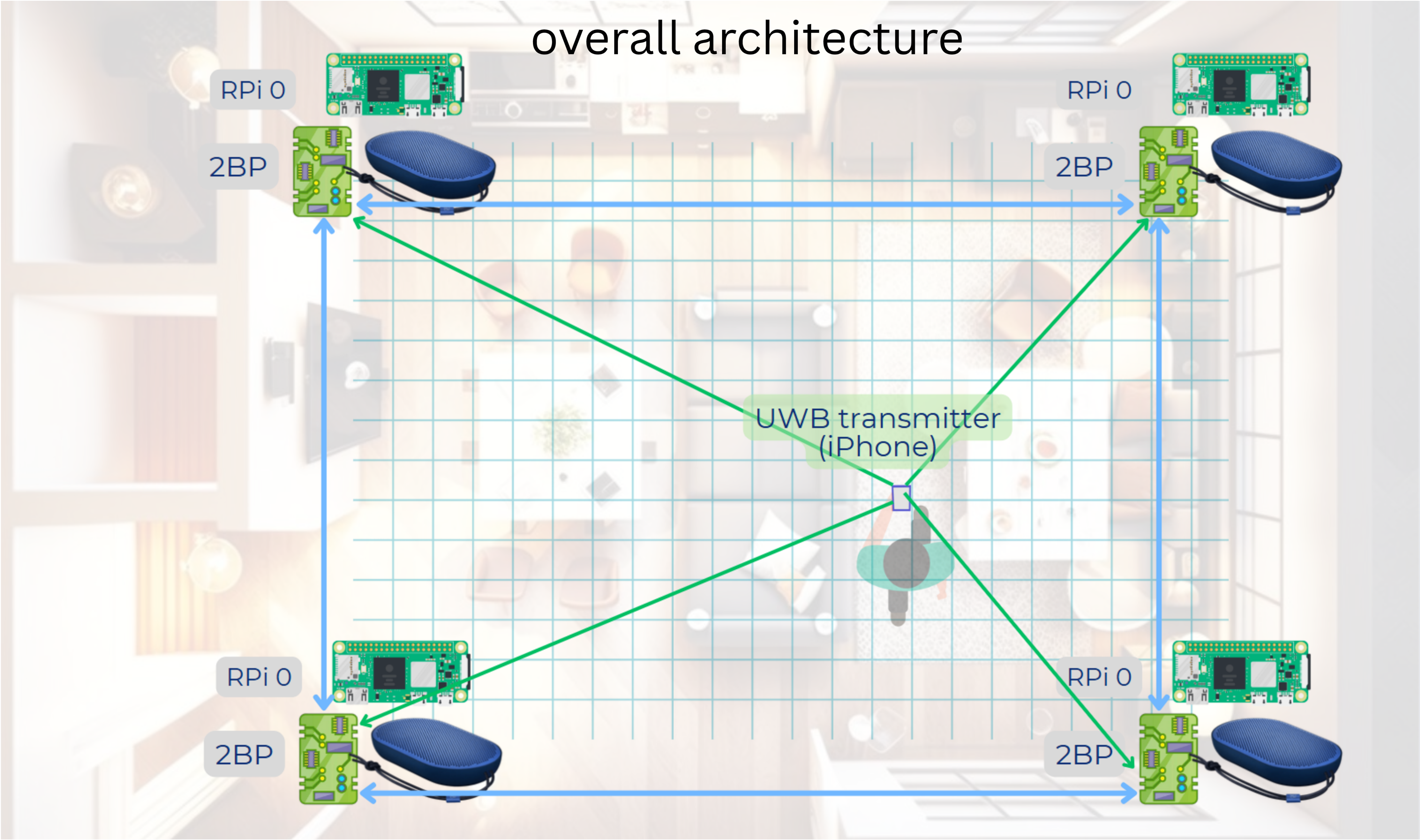
- AWS Lambda serving as API
- API is open to any arbitrary connection
- API Key and HTTPS ensure security

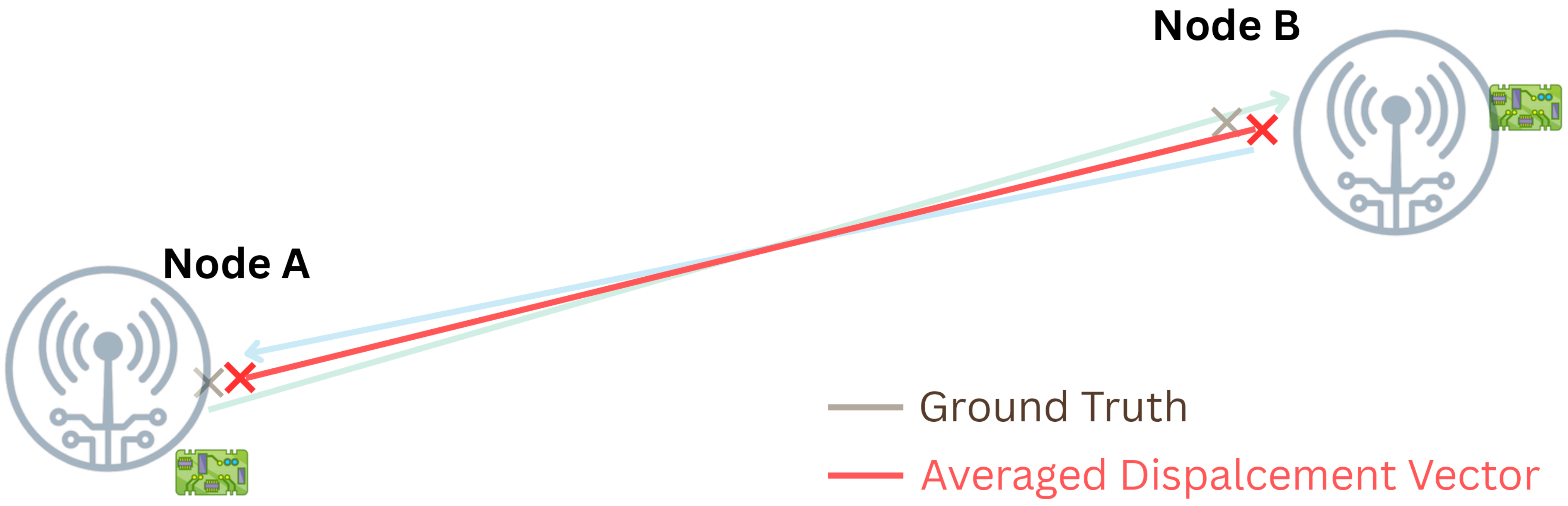
An application we are interested in building

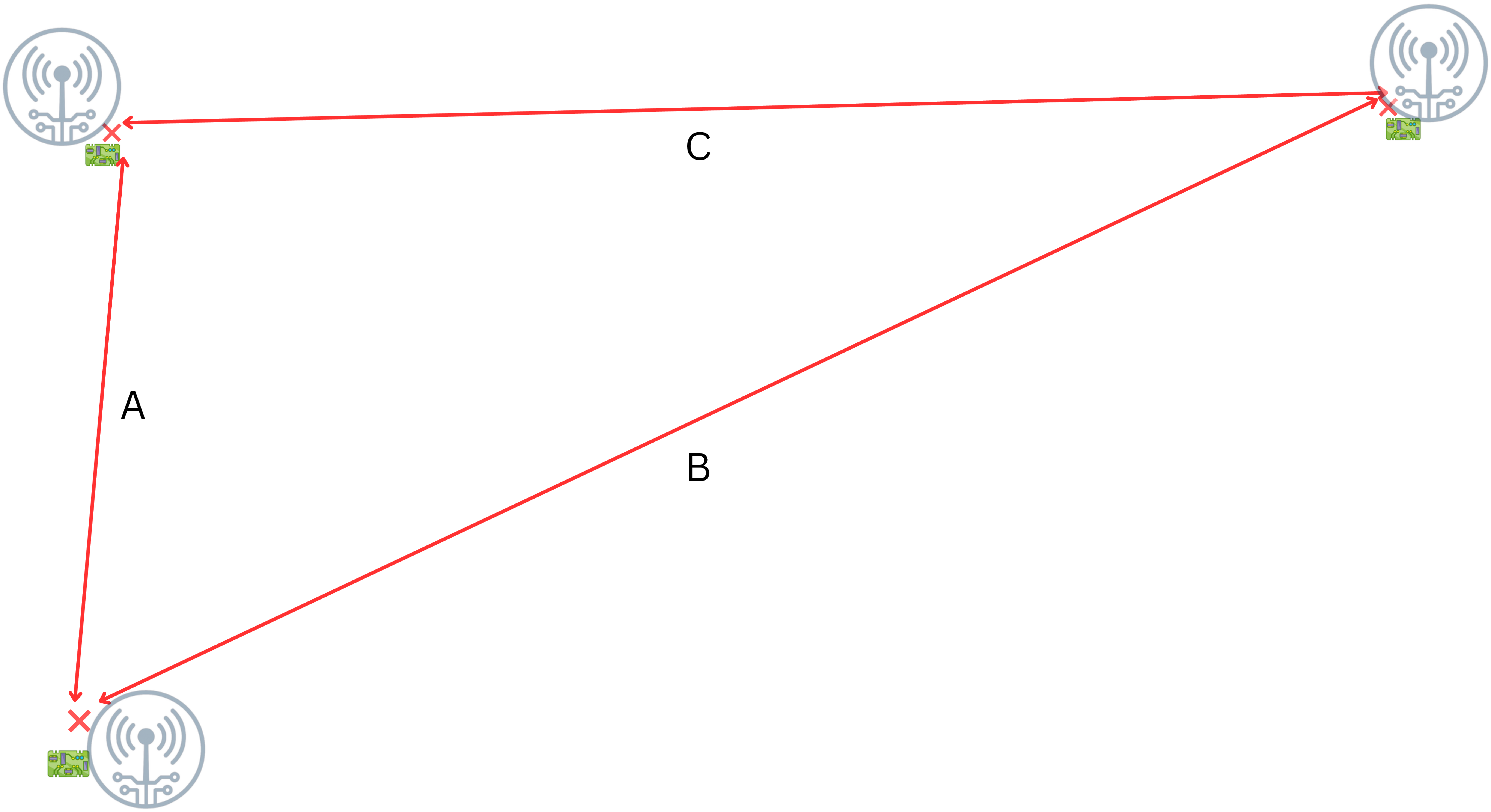
show contrast between what is possible with and without a "**grid**"

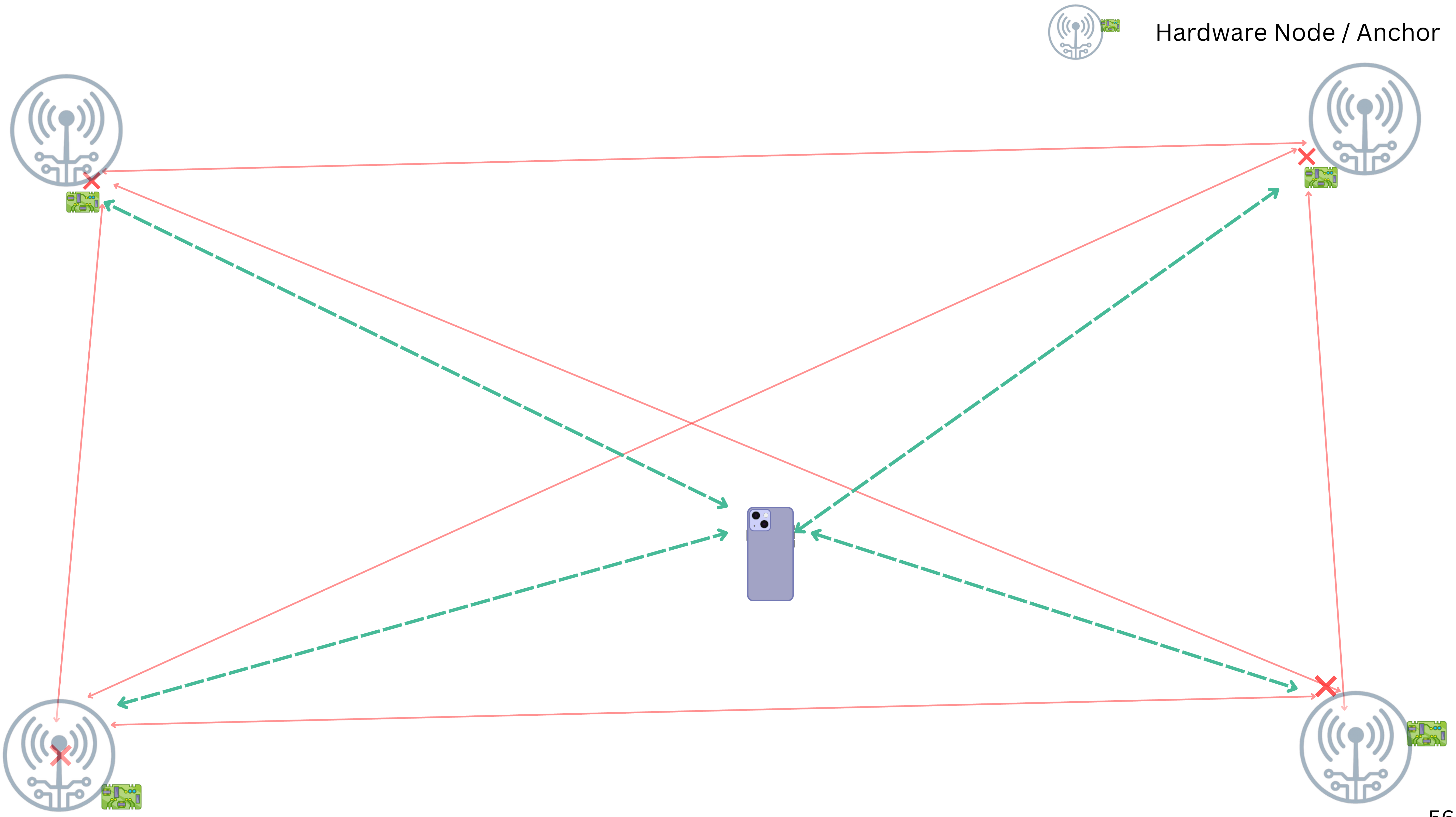


Final Prototype




Node B
Node A
Ground Truth
Averaged Dispalcement Vector


C
A
B


Hardware Node / Anchor

Development Kit	UWB Chipset	Advantages of UWB Chipset	Bluetooth Support	Interfaces	Antenna Configuration	Power Supply Options	Notable Features
Murata Type2BP EVK	SR150	Supports 3D Angle-of-Arrival (AoA) measurements; suitable for anchor devices	QN9090 BLE MCU	USB, UART, SWD	Onboard UWB antenna, External BT antenna	USB, COM port	Pre-flashed with Apple Nearby Interaction example code; compact design
Murata Type2DK EVK	SR040	Optimized for low-power tag applications; suitable for battery-operated devices	QN9090 BLE MCU	UART, SWD	Integrated UWB/BLE onboard antenna	Coin-cell battery, USB	Designed for UWB tag/tracker development; low power consumption
MobileKnowledge MK UWB Kit	SR150/SR040	Combines advantages of SR150 and SR040; supports both anchor and tag configurations	QN9090 BLE MCU	USB, UART, Arduino headers	3D AoA Antenna Board	USB, Battery, External power	Includes both anchor and tag reference designs; comprehensive SDK for iOS/Android
Qorvo DWM3001CDK	DW3110	Fully aligned with FiRa™ PHY and MAC specifications; supports TWR and TDoA	nRF52833 BLE SoC	USB (dual ports), UART, SWD, Raspberry Pi header	PCB UWB antenna	USB, Battery, External power	On-board J-Link debugger; suitable for evaluating UWB technology
Qorvo DWM3000EVB	DW3000	Designed for flexibility with various host processors; suitable for evaluating UWB technology with Nordic platforms	External (e.g., nRF52832DK)	Arduino Shield, SPI	PCB UWB antenna	Via connected development kit	Flexible host support; suitable for integrating with Nordic Semiconductor platforms
SynchronicIT SFM10-KIT	OL23D0	Fully integrated and programmable; allows for host-free UWB solutions	None	SPI, UART, I²C	Not specified	Battery optimized	Easy-to-use hardware and software; suitable for creating host-free UWB solutions