AN12865

KW36 Localization Based on RSSI Ranging Application

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Contents

1 Introduction

The Received Signal Strength Indication (RSSI) is used to determine the quality of a wireless signal. It can be used in a localization system. The relationship between the signal space path loss and the distance can be obtained by establishing the signal-attenuation model. The distance can be calculated using the link-loss equation and the position can be evaluated by combining the distance with the software algorithm.

This document provides an introduction to localization based on the Bluetooth LE RSSI ranging. It implements a simple trilateral localization system using the Kinetis KW36 wireless MCU.

2 RSSI ranging

2.1 Prior definition

Tag - A target in an unknown location that must be located. In this application note, it is a KW36 board.

Anchor - Place at fixed location. It collects the RSSI values and uploads them to the location computing device. Usually, a minimum of three Anchors are required for the localization.

2.2 Wireless signal path-loss models

In the location system, based on RSSI ranging, the Tag node applies the RSSI measurements to estimate its distances from the Anchor node using a known signal propagation model. The model of the wireless signal path loss in space is shown in Figure 1 (a1c1, a1c2, and so on are test device numbers).

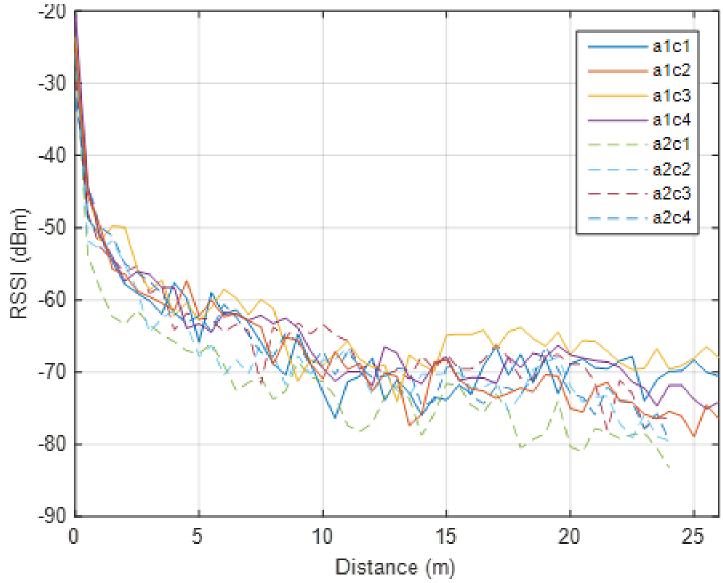

Figure 1. Wireless signal path loss

The shadowing model is widely used to model wireless signal propagation loss, which is expressed as follows:

$$P_r(d) = P_r(d_0) - 10nlog_{10}\left(\frac{d}{d_0}\right) + \alpha_\sigma$$

- d and d_0 denote the real distance and the reference distance.
- $P_r(d)$ and $P_r(d_0)$ denote the RSSI (dBm) received at the real distance and the reference distance, respectively.
- n is the path-loss exponent.
- α_σ is random noise. A gaussian distributed random variable with zero mean and variance is always assumed. As shown in Figure 1, the greater the distance, the greater the fluctuation in the received RSSI value.

For most applications, d_0 is 1 m and $P_r(d_0)$ is calculated using a free-space path-loss formula. The simplified shadowing model used is as follows:

$$\mathrm{RSSI} = A - 10\ n\ \mathrm{lg}d$$

- d is the distance
- n is determined by the test environment and it is usually an empirical constant that is gathered through testing
- RSSI is the received RSSI value at distance d.
- A is the received RSSI of the receiver from a transmitter one meter away.

This formula is used to estimate distances based on RSSI.

2.3 Influence on RSSI receiving accuracy

2.3.1 Environment

Because of the existence of Multipath, obstacles, electromagnetic interference, and other unstable factors in the environment, the RSSI value on the receiving nodes is sometimes unstable and it has a constructive and destructive superposition.

The filtering algorithms can be used to filter inaccurate RSSI values, as described in Localization system implementation considerations.

2.3.2 Antenna

Different antennas have different radiation modes, polarization directions, and gain for signals. In the same conditions, the use of different antennas at the receiver and transmitter also affects the RSSI.

3 Trilateral localization based on RSSI ranging

3.1 Trilateral localization

At least three anchor nodes are sufficient to locate an unknown Tag node. The trilateral localization is shown in Figure 2.

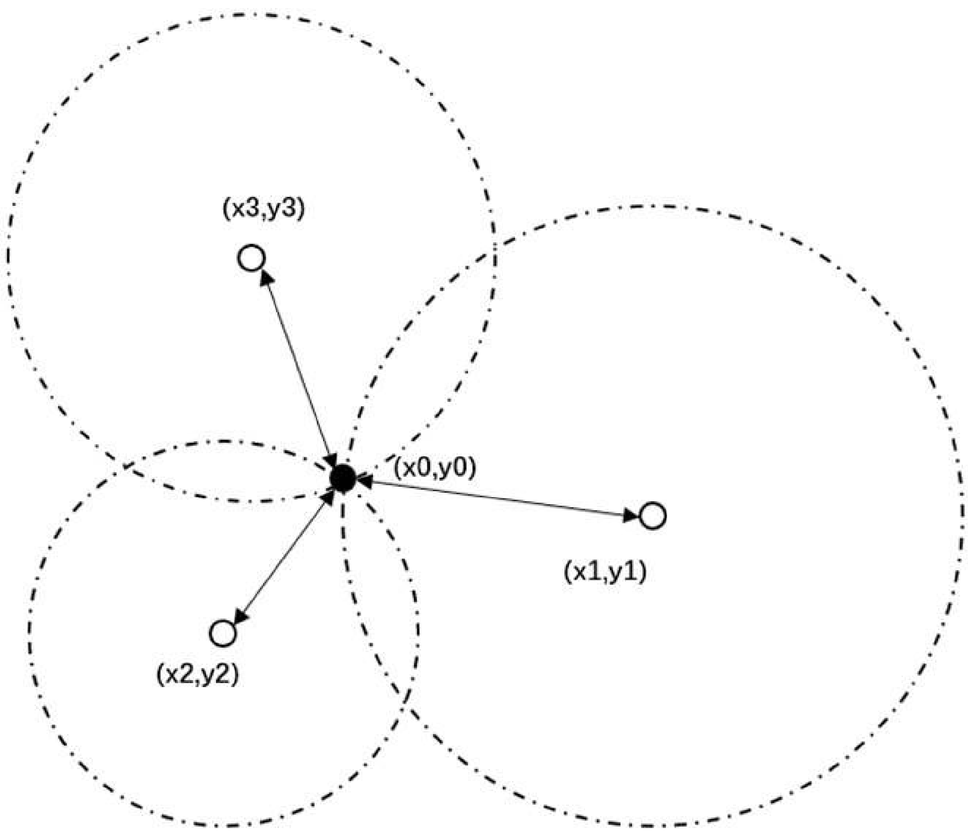

Figure 2. Trilateral localization in ideal condition

- (x_0,y_0) is the unknown Tag board coordinate.
- (x_1,y_1), (x_2,y_2), (x_3,y_3) are the three known Anchor boards' coordinates.
- The radius of the three circles is the distance from the Tag board to each Anchor board. It can be calculated using this formula. The coordinates of the Tag can be calculated by the following system of equations (D is the distance from the Tag board to Anchor board).

$$(x_1 - x_0)^2 + (y_1 - y_0)^2 = D_1^2$$
$$(x_2 - x_0)^2 + (y_2 - y_0)^2 = D_2^2$$
$$(x_3 - x_0)^2 + (y_3 - y_0)^2 = D_3^2$$

Due to measurement errors, the three circles rarely intersect at one point, as shown in Figure 3. The least square method is considered as the best way to get an optimal solution. The equation set is converted to a matrix form:

$$B = \begin{pmatrix} x_1^2 + y_1^2 - x_n^2 - y_n^2 - d_1^2 + d_n^2 \\ x_2^2 + y_2^2 - x_n^2 - y_n^2 - d_2^2 + d_n^2 \\ \vdots \\ x_{n-1}^2 + y_{n-1}^2 - x_n^2 - y_n^2 - d_{n-1}^2 + d_n^2 \end{pmatrix};$$

$$X = \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}; \quad A = \begin{pmatrix} 2(x_1 - x_n) & 2(y_1 - y_n) \\ 2(x_2 - x_n) & 2(y_2 - y_n) \\ \vdots & \\ 2(x_{n-1} - x_n) & 2(y_{n-1} - y_n) \end{pmatrix}$$

The Tag board coordinates are calculated using the least square method equation:

$$X = A^T B / (A^T A)$$

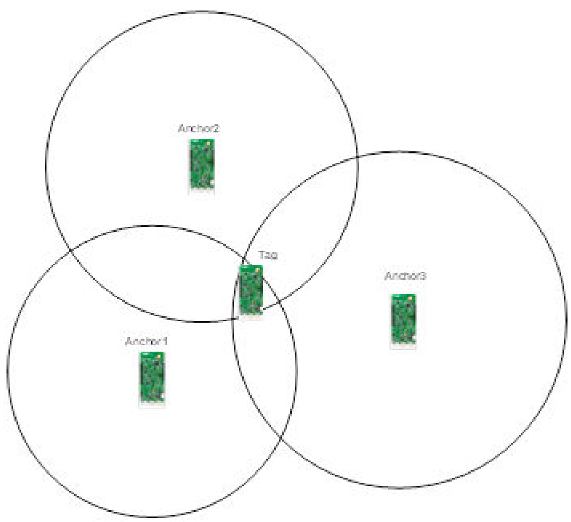

Figure 3. Tag board coordinates

4 Localization system implementation considerations

4.1 Localization scheme and hardware requirements

There are two localization schemes, as described below.

4.1.1 Localization scheme - advertising

The localization scheme is shown in Figure 4. For the RSSI acquisition, see Acquiring RSSI from advertising.

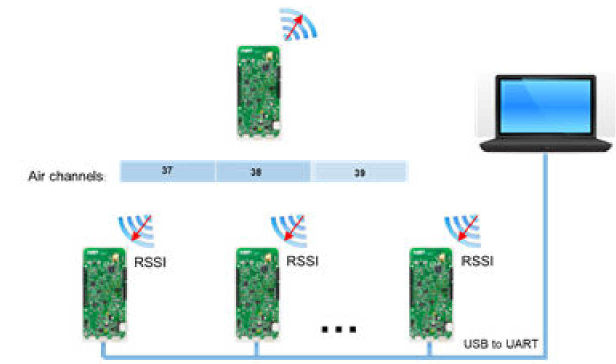

Figure 4. Advertising

The hardware per-requisites are as follows:

- Three FRDM-KW36 boards as the Anchor boards to scan
- One FRDM-KW36 board as the Tag board to advertise
- Four Micro-USB cables
- Four monopole antennas
- One PC with the GUI tool installed

4.1.2 Localization scheme – connection

The localization scheme is shown in Figure 5. For RSSI acquirement, see Acquiring RSSI from connection.

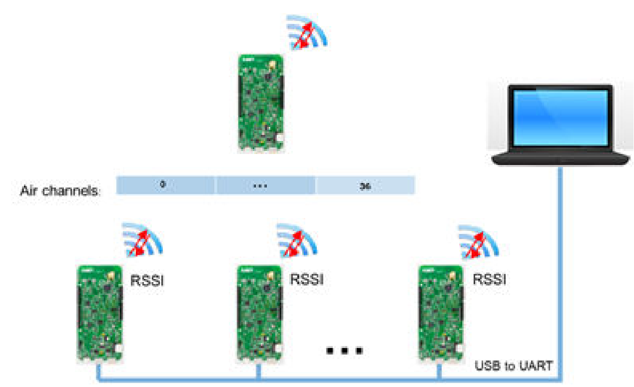

Figure 5. Connection

The hardware per-requisites are as follows:

- Three FRDM-KW36 boards as the Anchor boards to wait for connection
- One FRDM-KW36 board as the Tag board to connect with the Anchor boards
- Four Micro-USB cables
- Four monopole antennas
- One PC with the GUI tool installed

4.2 Embedded software consideration

4.2.1 Bluetooth LE project

The KW36 SDK provides the Wireless UART project, which implements the RSSI notification by Bluetooth LE controller, the KW36 Bluetooth LE controller supports RSSI notification associated with the channel number in the scanning event and RSSI reporting in the data packet in connection event.

The project path is *SDK\boards\frdmkw36\wireless_examples\bluetooth\ w_uart*.

Users only have to enable the gUseControllerNotifications_c macro. The gControllerNotificationEvent_c events are reported at BleApp_GenericCallback(). Select which type of radio packet should be notified to the RSSI application (when received) by the Gap_ControllerEnhancedNotification() API function.

NOTE

For more details about the Wireless UART, see the *Bluetooth Low Energy Demo Applications User's Guide* (document BLEDAUG).

4.2.2 Acquiring RSSI from advertising

Both Anchor and Tag boards are programmed with Wireless UART. The difference is that the Anchor boards are used as the central device to scan advertising and the Tag board is used as the peripheral which sends advertising.

4.2.2.1 Configuring notification type

On the central side, configure only the send notification of the Scanning ADV PKT Rx by API function Gap_ControllerEnhancedNotification().

4.2.2.2 Continuous scan and address filtering

By default, the Wireless UART behaves as a central device. It searches for other Wireless UART devices to connect. Before finding a device, it scans all advertisements and notifies the application about the RSSI value.

To continuously scan the expected device's advertising, do not connect the expected device, add the device address to the whitelist, and scan with the whitelist.

```
 ************************************************************************************* */
static void BleApp_ScanningCallback(gapScanningEvent_t *pScanningEvent)
{
    switch (pScanningEvent->eventType)
    {
        case gDeviceScanned_c:
        {
            if (BleApp_CheckScanEvent(&pScanningEvent->eventData.scannedDevice))
            {
                gConnReqParams.peerAddressType = pScanningEvent->eventData.scannedDevice.addressType;
                FLib_MemCpy(gConnReqParams.peerAddress,
                            pScanningEvent->eventData.scannedDevice.aAddress,
                            sizeof(bleDeviceAddress_t));

#if (JIA_TEST == 1)
                if(mAppAlreadyScanedDevice == FALSE)
                {
                    Gap_StopScanning();
                    Gap_AddDeviceToWhiteList(gConnReqParams.peerAddressType, gConnReqParams.peerAddress); // add device address to white list
                    mAppAlreadyScanedDevice = TRUE;

                    gScanParams.filterPolicy = gScanWithWhiteList_c; // only scan addres in white list.
                    (void)App_StartScanning(&gScanParams, BleApp_ScanningCallback,
                                          gGapDuplicateFilteringDisable_c,
                                          gGapScanContinuously_d,
                                          gGapScanPeriodicDisabled_d);
                }
#else
                (void)Gap_StopScanning();
#if gAppUsePrivacy_d
                gConnReqParams.usePeerIdentityAddress = pScanningEvent->eventData.scannedDevice.advertisingAddressResolved;
#endif
                (void)App_Connect(&gConnReqParams, BleApp_ConnectionCallback);
#endif
```

Figure 6. Code to make Wireless UART continuously scan the expected device

In addition, the scanning is stopped after 10 seconds by a scan timer. Disable the timer in the ScanningTimerCallback() function to continue scanning.

4.2.3 Acquiring RSSI from connection

Both Anchor and Tag boards are programmed with Wireless UART. The difference is that Anchor boards are used as the peripheral device to start advertising and wait for the central device connect and Tag boards are used as the central device to connect all peripheral devices.

4.2.3.1 Establishing multiple connections quickly

To quickly establish a connection between the central device and multiple peripherals, add all target peripherals public address to the whitelist on the central device side before starting the connection. Then the central device connects the peripherals in the whitelist, as shown in Establishing multiple connections quickly.

```c
test_peer_inf_t TEST_peer_inf[gAppMaxConnections_c] =
{
  {{0xE0,0x28,0xB9,0x37,0x60,0x00},gInvalidDeviceId_c,TEST_PEER_DISCONN},
  {{0x8F,0x34,0x23,0x37,0x60,0x00},gInvalidDeviceId_c,TEST_PEER_DISCONN},
  {{0x5C,0x9C,0x4A,0x37,0x60,0x00},gInvalidDeviceId_c,TEST_PEER_DISCONN},
  {{0x00,0x00,0x00,0x00,0x00,0x00},gInvalidDeviceId_c,TEST_PEER_DISCONN},
  {{0x00,0x00,0x00,0x00,0x00,0x00},gInvalidDeviceId_c,TEST_PEER_DISCONN},
  {{0x00,0x00,0x00,0x00,0x00,0x00},gInvalidDeviceId_c,TEST_PEER_DISCONN},
  {{0x00,0x00,0x00,0x00,0x00,0x00},gInvalidDeviceId_c,TEST_PEER_DISCONN},
  {{0x00,0x00,0x00,0x00,0x00,0x00},gInvalidDeviceId_c,TEST_PEER_DISCONN},
};

uint32_t peer_device_counter = 0;
uint32_t valid_connections = 3;
```

① BleApp_Config()

```c
# if (gTestSlave == 1)
    mGapRole = gGapPeripheral_c;
    (void)Serial_Print(gAppSerMgrIf, "\n\rWireless UART starting as GAP Peripheral, press the role switch to change it.\n\r", gAllowToBlock_d);
#else
    mGapRole = gGapCentral_c;
    (void)Serial_Print(gAppSerMgrIf, "\n\rWireless UART starting as GAP Central, press the role switch to change it.\n\r", gAllowToBlock_d);
    uint8_t all_zero[6] = {0,0,0,0,0,0};
    for (uint8_t i = 0; i < gAppMaxConnections_c; i++)
    {
        if(FLib_MemCmp((void *)&TEST_peer_inf[i].peer_address, &all_zero, sizeof(all_zero)))
        {
        }
        else
        {
            if(gBleSuccess_c != Gap_AddDeviceToWhiteList(gBleAddrTypePublic_c,TEST_peer_inf[i].peer_address))
            {
                Serial_Print(gAppSerMgrIf, "add to wl failed\r\n", gNoBlock_d);
            }
        }
    }
```

②

```c
 ******************************************************************************** */
void BleApp_Start(gapRole_t gapRole)
{
    switch (gapRole)
    {
        case gGapCentral_c:
        {
            (void)Serial_Print(gAppSerMgrIf, "\n\rScanning...\n\r", gAllowToBlock_d);
            mAppUartNewLine = TRUE;
#if defined(gUseControllerNotifications_c) && (gUseControllerNotifications_c)
#if (JIA_TEST_FOR_RSSI_ADV == 1)
            //in central side, only send notification of Scanning ADV PKT Rx
            Gap_ControllerEnhancedNotification(gNotifScanAdvPktRx_c , 0);
#elif (JIA_TEST_FOR_RSSI_CON == 1)
            //in central side, try to connect directly with peers which are in whitelist
            gConnReqParams.filterPolicy = gUseWhiteList_c;
            (void)App_Connect(&gConnReqParams, BleApp_ConnectionCallback);
#else
            Gap_ControllerEnhancedNotification(gNotifScanEventOver_c | gNotifScanAdvPktRx_c |
                                               gNotifScanRspRx_c | gNotifScanReqTx_c, 0);
#endif
#endif
```

③

```c
static void BleApp_ConnectionCallback(deviceId_t peerDeviceId, gapConnectionEvent_t *pConnectionEvent)
{
    switch (pConnectionEvent->eventType)
    {
        case gConnEvtConnected_c:
        {
            /* Save peer device ID */
            maPeerInformation[peerDeviceId].deviceId = peerDeviceId;
#if (JIA_TEST_FOR_RSSI_ADV == 1)
#elif (JIA_TEST_FOR_RSSI_CON == 1)
            if(mGapRole == gGapCentral_c)
            {
                peer_device_counter++;
                if(peer_device_counter == valid_connections)
                {
                    Serial_Print(gAppSerMgrIf, "\nConnection with all slaves\r\n", gNoBlock_d);
                }
                else
                {   //if not connected with all peripherals device, start connect process
                    App_Connect(&gConnReqParams, BleApp_ConnectionCallback);
                }
```

Figure 7. Establishing multiple connections quickly

4.2.3.2 Configuring notifications type

On the peripheral side, when connected with the central device, configure only the send notification of the Connection Rx PDU and Connection event.

4.2.3.3 Connection parameter

If the connection link is lost, the device continues to send the RSSI value of the last received connection event until the supervision timeout disconnects. Therefore, the supervision timeout value should be within a reasonable range to reduce false values caused by a link loss.

4.2.4 Filtering in RSSI

Because the RSSI is sensitive to the environment, multiple measured RSSI values must be filtered and optimized to get the optimized RSSI value and calculate the location. The filtering algorithm can be implemented on the KW36 MCU. Figure 8 compares commonly used RSSI filtering algorithms.

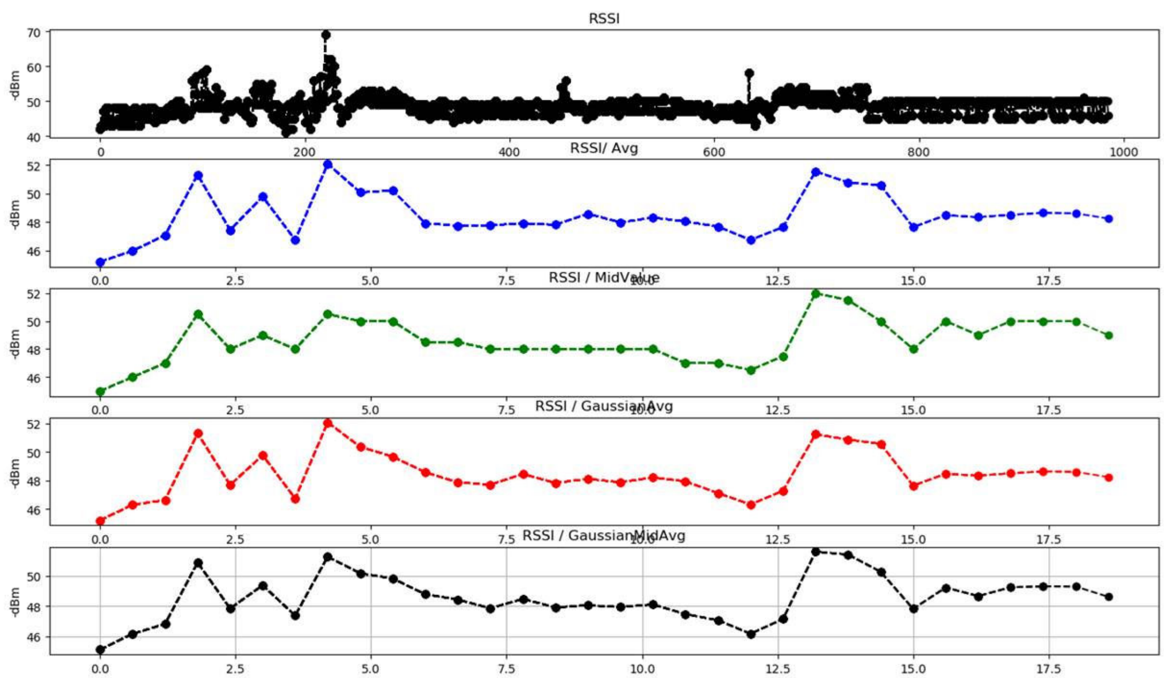

Figure 8. RSSI filtering algorithm compare

In the test shown in Figure 8, the Tag and Anchor devices are placed in a fixed position. The Anchor device collects and filters the RSSI. The first row is the RSSI measurement and the other rows are the optimized RSSI values of the filtered output. In Figure 8, all filtering has 30 samples with a stepper window of n=30.

There are four kinds of filtering: mean filtering, median filtering, Gaussian filtering, and Gaussian filtering combined with median filtering.

Mean filtering: The mean value of multiple RSSI values was calculated as the test result. When the RSSI value fluctuated greatly, the reliability of results decreased.

Median filtering: It arranges the multiple RSSI in order of values. The RSSI value in the middle is taken as the filtering output. It can effectively overcome the wave interference caused by accidental factors, but the filtering is not ideal in the case of strong pulse interference and small samples.

Gaussian filtering: The RSSI value in the high-probability region is selected as the effective value through the Gaussian model and then its mean value is calculated. It can effectively reduce the influence of small probability and big interference on the overall measurement data.

Gaussian combined with median filtering: Takes the means of gaussian filtering and median filtering.

In case of more inaccurate RSSI values, a relatively stable RSSI value can be obtained using mean filtering combined with gaussian filtering (the last row). All the measurements in the rest of the application note are based on the gaussian + median filtering.

The RSSI value filtering can be implemented on the Anchor side to reduce the amount of calculation on the PC side.

4.2.5 Communication with PC

- The communication format is as follows:

Because the GUI only has to collect the RSSI received by the Anchor board, the transmit RSSI from the KW36 to a PC is a string, as shown in Figure 9.

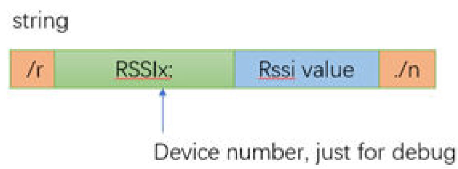

Figure 9. RSSI transmit

For example, if the RSSI value that the KW36 must transmit is -40 dbm, then it prints the "/ rRSSI: -40./n" string from the UART port.

- The Anchor scan is as follows:

The GUI software can send a "start" string to each Anchor COM port when starting the test. A “stop” string is sent when the GUI stops the test. This simplifies the control method for the test. The corresponding code on the Anchor side is shown in Figure 10.

NOTE

This is not necessary, but it just provides a simple control method for the test so that the user does not have to press the button to start or stop the scan on the Anchor side.

Figure 10. Anchor code controlled by GUI to start scan

4.3 GUI software consideration

The GUI software on the PC is implemented by Python. It interacts with the FRDM-KW36 via UART, collects the RSSI data from the Anchor devices, calculates the location, and displays the tag position on the UI.

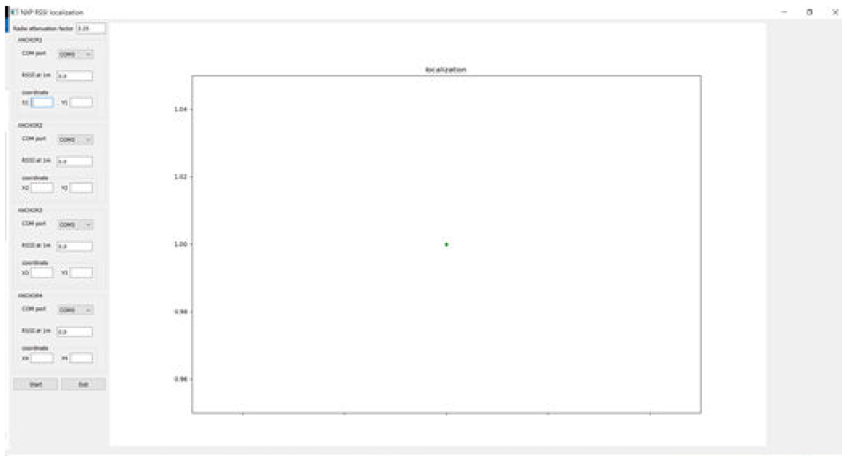

Figure 11. GUI software consideration

4.4 Calibration

Due to the antenna sensitivity and environmental sensitivity of the RSSI and according to the equation described above, the received RSSI value at 1 m and path loss exponent should be measured.

- The “RSSI at 1 m” should use the mean filtering combined with the gaussian filtering RSSI measure at a 1-m distance.
- The path-loss exponent can be derived from the relationship between multiple measured RSSIs and the distance.

5 Setup and test result

5.1 Hardware setup

For the FRDM-KW36 board, do the following:

- Use the SMA connector instead of the printed “F” antenna (the RF path must be routed to the SMA connector).
- Connect the monopole antenna to the SMA connector.

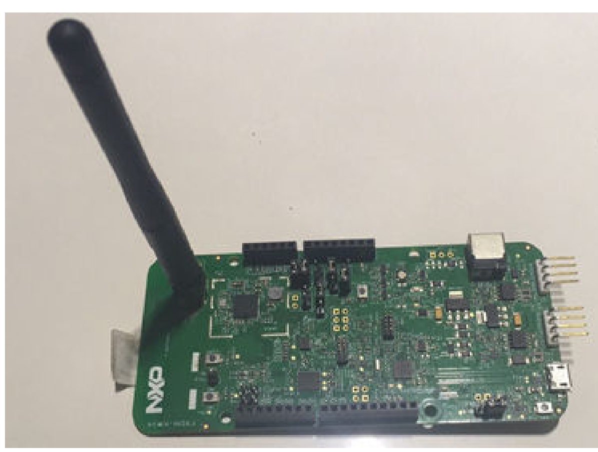

Figure 12. FRDM-KW36 board with monopole antenna

5.2 Test environment and software configuration

The wireless UART example is used here to modify the code so that both the acquiring RSSI from advertising and the connection are integrated in the code using macros to control which case is in use.

5.2.1 In case of acquiring RSSI from advertising

Environment:

- Make sure that the test surrounding is open (outdoors).
- Make sure that the influence of Bluetooth LE, WiFI, or any 2.4-GHz signal is almost negligible.
- Make sure to test in a fixed position.

Advertising parameter:

- Make sure to test only the single-channel advertising.
- Make sure that the peripheral device has an advertising interval of 30 ms (about 30 advertising packets per second).
- In the *app_preinclude.n* file, set TEST_FOR_RSSI_ADV to 1 and disable TEST_FOR_RSSI_CON.

5.2.2 In case of acquiring RSSI from connection

Environment:

- Make sure that the test surrounding is open (outdoors).
- Make sure that the influence of Bluetooth LE, WiFI, or any 2.4-GHz signal is almost negligible.
- Make sure to test in a fixed position.

Connection parameter:

- Make sure to test all connection channels.
- Make sure that the connection interval is 20 ms and the supervision interval is 300 ms.
- In the *app_preinclude.n* file, set TEST_FOR_RSSI_CON to 1 and disable TEST_FOR_RSSI_ADV. Set gTestSlave to 1 when downloading the Anchor firmware and set gTestSlave to 0 when downloading the Tag firmware.

5.3 Test procedure

1. Place the three Anchor boards in a fixed position (booked in advance) and record the relative coordinates of each Anchor board.
2. Connect the Anchor boards to the PC.
3. Use a 5-V mobile power supply for the Tag board.
4. Launch the GUI tool and configure Anchors' parameters (such as COM port, RSSI value received on 1 m, anchor's coordinate).
5. Click the start button to start the test. The tag dots are displayed on the base diagram after the tool calculates the tag coordinates.
6. For advertising, press the SW3 button once to switch the Tag board to a peripheral role. Press the SW2 button on the Tag board to start advertising.
7. For the connection, press the SW2 button on the Tag board once to start the connection with the Anchor board.

5.4 Test result

In this test, three Anchor boards are placed at three different coordinates. The Anchor1 coordinate is the origin (the coordinate ratio is 1:1 centimeter), the Anchor2 coordinate is (0,200), and the Anchor3 coordinate is (-200,0). The legend in the following figures has the following meaning:

- The red triangle is the Anchor board.
- The green star is the Tag board coordinate point calculated by the RSSI.
- The blue circle is the Tag board physical location.

5.4.1 Advertising test 1-1

Tag is 2.8 m away from Anchor1.

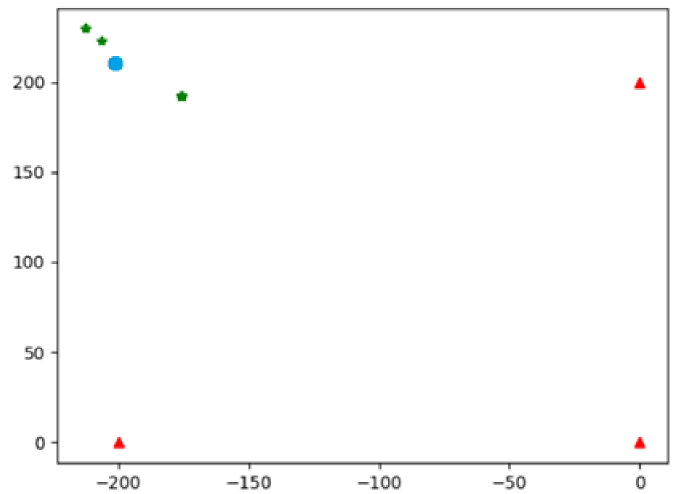

Figure 13. Advertising test 1-1

Table 1. Test 1-1 data

	Anchor1	Anchor2	Anchor3	coordinate	
				x	y
Distance(m)	2.8162	1.9169	1.7343	-206.4119207	223.0796487
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394

Table continues on the next page...

Table 1. Test 1-1 data (continued)

	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.5885	1.9169	1.7343	-175.645666	192.313394
	2.861	1.9169	1.7343	-212.7703848	229.4381128
	2.861	1.9169	1.7343	-212.7703848	229.4381128
	2.861	1.9169	1.7343	-212.7703848	229.4381128

5.4.2 Advertising test 1-2

Tag is 5 m away from Anchor1.

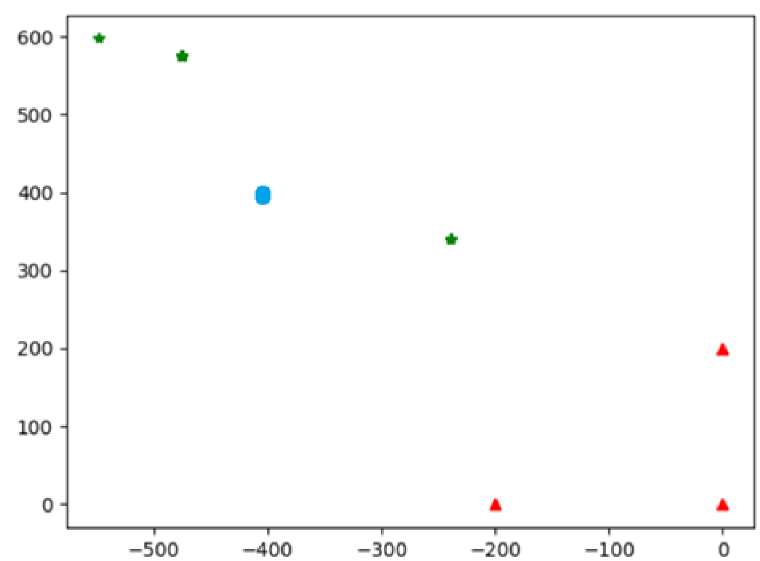

Figure 14. Advertising test 1-2

Table 2. Test 1-2 data

	Anchor1	Anchor2	Anchor3	coordinate	
				x	y
Distance(m)	5.3377	3.2457	2.93	-548.91182	597.6535322
	5.2166	3.4953	2.861	-474.8948367	575.689864
	4.217	3.4953	2.861	-239.1491727	339.9442
	5.2166	3.4953	2.861	-474.8948367	575.689864

Table continues on the next page...

Table 2. Test 1-2 data (continued)

	4.217	3.4953	2.861	-239.1491727	339.9442
	5.2166	3.4953	2.861	-474.8948367	575.689864
	4.217	3.4953	2.861	-239.1491727	339.9442
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864
	4.217	3.4953	2.861	-239.1491727	339.9442
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864
	4.217	3.4953	2.861	-239.1491727	339.9442
	5.2166	3.4953	2.861	-474.8948367	575.689864
	5.2166	3.4953	2.861	-474.8948367	575.689864

5.4.3 Advertising test 1-3

Tag is 10 m away from Anchor1.

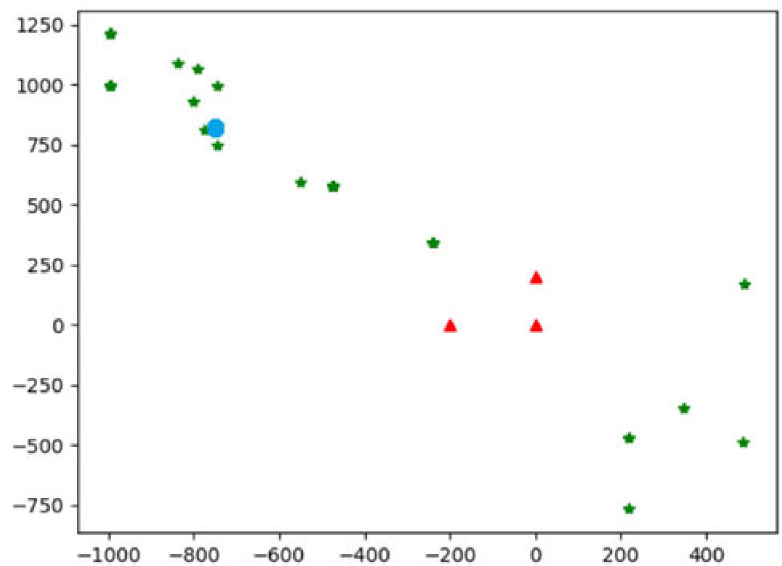

Figure 15. Advertising test 1-3

Table 3. Test 1-3

	Anchor1	Anchor2	Anchor3	coordinate	
				x	y
Distance(m)	9.6581	8.0466	8.1417	-774.790418	813.2781013
	9.7885	8.1417	7.4989	-838.186334	1089.530776
	6.5459	8.1417	8.1417	485.961802	-485.961802
	9.5972	7.4989	7.4989	-996.8186658	996.8186658
	9.5972	8.1417	8.1417	-745.4742238	745.4742238
	9.6887	7.4281	8.1417	-800.2118368	931.0461168
	6.5985	7.4989	8.8395	217.332474	-764.91395
	6.5985	7.4989	8.8395	217.332474	-764.91395
	7.1897	7.4989	7.4989	348.027878	-348.027878
	9.5972	6.9069	7.4989	-996.8186658	1210.024506
	9.5972	6.9069	7.4989	-996.8186658	1210.024506
	9.5972	7.4989	7.4989	-996.8186658	-996.8186658
	9.5972	7.4989	7.4989	-996.8186658	-996.8186658
	9.5972	7.4989	7.4989	-996.8186658	-996.8186658
	9.5972	7.4989	7.4989	-996.8186658	-996.8186658
	9.5972	7.4989	7.4989	-996.8186658	-996.8186658
	9.5972	6.9069	7.4989	-996.8186658	1210.024506

Table continues on the next page...

Table 3. Test 1-3 (continued)

	9.5972	7.4989	7.4989	-996.8186658	-996.8186658
	9.5972	7.4989	7.4989	-996.8186658	-996.8186658
	9.5972	6.9069	7.4989	-996.8186658	1210.024506
	9.7618	7.9107	8.0842	-917.8391187	848.46124
	8.8395	8.1417	8.1417	-396.237034	396.237034
	9.5972	8.1417	8.1417	-745.4742238	745.4742238
	8.8395	8.1417	8.1417	-396.237034	396.237034
	9.5972	8.1417	7.4989	-745.4742238	996.8186658
	9.5972	8.1417	7.4989	-745.4742238	996.8186658
	9.5597	8.1417	8.1417	-727.51463	727.51463
	8.8395	8.1417	7.4989	-396.237034	647.581476
	8.8395	8.1417	8.1417	-396.237034	396.237034
	9.5972	8.1417	7.4989	-745.4742238	996.8186658
	9.5972	8.1417	7.4989	-745.4742238	996.8186658
	9.5972	8.1417	8.1417	-745.4742238	745.4742238
	9.5972	7.4989	8.1417	-996.8186658	745.4742238
	9.5972	8.1417	8.1417	-745.4742238	745.4742238
	8.8395	8.1417	8.1417	-396.237034	396.237034
	8.8395	7.4989	8.1417	-647.581476	396.237034
	8.8395	7.4989	8.1417	-647.581476	396.237034
	8.8395	8.1417	7.4989	-396.237034	647.581476
	8.8395	7.4989	8.1417	-647.581476	396.237034
	8.8395	7.4989	8.1417	-647.581476	396.237034
	9.5972	8.1417	8.1417	-745.4742238	745.4742238
	8.8395	8.1417	8.1417	-396.237034	396.237034

5.4.4 Advertising test 2-1

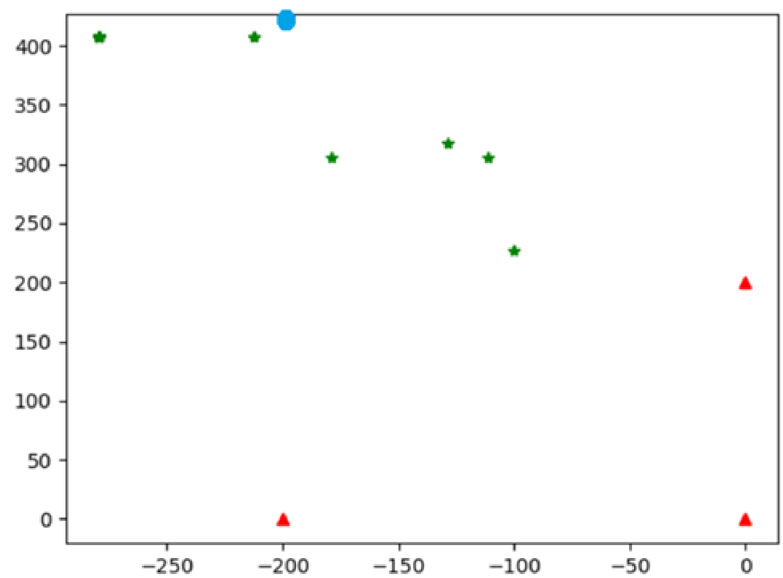

Figure 16. Advertising test 2-1

Table 4. Test 2-1 data

	Anchor1	Anchor2	Anchor3	Coordinate	
				x	Y
Distance(m)	4.3238	3.1623	4.1904	-128.394857	317.3776288
	4.2701	3.1623	4.217	-111.2666253	305.840318
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	4.217	-212.3119772	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.2701	3.1623	3.8841	-178.68803	305.840318
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567

Table continues on the next page...

Table 4. Test 2-1 data (continued)

	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567
	4.7197	3.1623	4.217	-212.3119772	406.88567
	4.7197	3.1623	3.8841	-279.733382	406.88567

5.4.5 Connection test 1-1

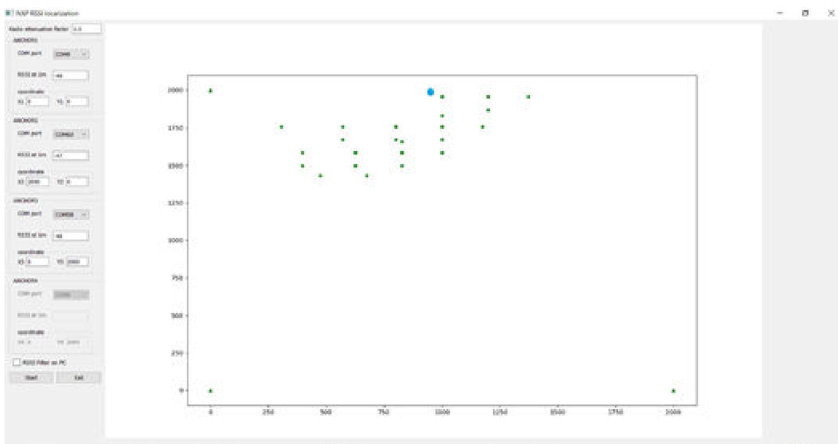

Figure 17. Connection test 1-1

Table 5. Connection test 1-1 data

	Anchor1	Anchor2	Anchor3	Coordinate	
				x	y
Distance (m)	2.4771	2.4771	1.5199	1000	1956.482
	2.4771	2.4771	1.5199	1000	1956.482
	2.3101	2.3101	1.4175	1000	1831.814
	2.4771	2.1544	1.5199	1373.646	1956.482
	2.1544	2.3101	1.5199	826.2193	1582.836
	2.1544	2.6561	1.5199	396.643	1582.836
	2.0092	2.4771	1.5199	475.2151	1431.697
	2.3101	2.3101	1.5199	1000	1756.616
	2.1544	2.3101	1.5199	826.2193	1582.836
	2.1544	2.3101	1.5199	826.2193	1582.836
	2.3101	2.4771	1.5199	800.1344	1756.617

Table continues on the next page...

Table 5. Connection test 1-1 data (continued)

	2.1544	2.4771	1.6298	626.3537	1496.298
	2.1544	2.3101	1.5199	826.2193	1582.836
	2.4771	2.3101	1.5199	1199.866	1956.482
	2.1544	2.1544	1.5199	1000	1582.836
	2.4771	2.3101	1.5199	1199.866	1956.482
	2.3101	2.6561	1.5199	570.4237	1756.617
	2.1544	2.6561	1.5199	396.643	1582.836
	2.3101	2.4771	1.5199	800.1344	1756.617
	2.3101	2.4771	1.5199	800.1344	1756.617
	2.1544	2.3101	1.5199	826.2193	1582.836
	2.4771	2.3101	1.6298	1199.866	1869.944
	2.1544	2.6561	1.6298	396.643	1496.298
	2.4771	2.4771	1.5199	1000	1956.482
	2.1544	2.3101	1.5199	826.2193	1582.836
	2.1544	2.4771	1.5199	626.3537	1582.836
	2.1544	2.4771	1.6298	626.3537	1496.298
	2.3101	2.3101	1.6298	1000	1670.078
	2.3101	2.3101	1.5199	1000	1756.616
	2.1544	2.3101	1.5199	826.2193	1582.836
	2.1544	2.3101	1.4175	826.2193	1658.033
	2.1544	2.1544	1.5199	1000	1582.836
	2.1544	2.4771	1.6298	626.3537	1496.298
	2.0092	2.3101	1.5199	675.0807	1431.697
	2.1544	2.4771	1.5199	626.3537	1582.836
	2.3101	2.848	1.5199	306.3645	1756.616
	2.4771	2.4771	1.5199	1000	1956.482
	2.3101	2.4771	1.5199	800.1344	1756.617
	2.3101	2.4771	1.5199	800.1344	1756.617
	2.1544	2.4771	1.5199	626.3537	1582.836
	2.1544	2.1544	1.5199	1000	1582.836
	2.1544	2.4771	1.5199	626.3537	1582.836
	2.3101	2.3101	1.5199	1000	1756.616
	2.3101	2.4771	1.5199	800.1344	1756.617

Table continues on the next page...

Table 5. Connection test 1-1 data (continued)

	2.1544	2.4771	1.5199	626.3537	1582.836
	2.3101	2.3101	1.5199	1000	1756.616
	2.1544	2.4771	1.5199	626.3537	1582.836
	2.1544	2.3101	1.6298	826.2193	1496.298
	2.3101	2.4771	1.5199	800.1344	1756.617
	2.1544	2.4771	1.5199	626.3537	1582.836
	2.1544	2.3101	1.5199	826.2193	1582.836
	2.1544	2.3101	1.5199	826.2193	1582.836
	2.1544	2.4771	1.5199	626.3537	1582.836
	2.3101	2.6561	1.6298	570.4237	1670.078
	2.3101	2.4771	1.5199	800.1344	1756.617
	2.3101	2.1544	1.5199	1173.781	1756.616
	2.1544	2.1544	1.5199	1000	1582.836
	2.3101	2.1544	1.5199	1173.781	1756.616
	2.3101	2.4771	1.6298	800.1344	1670.078
	2.1544	2.4771	1.6298	626.3537	1496.298
	2.1544	2.4771	1.5199	626.3537	1582.836
	2.1544	2.1544	1.5199	1000	1582.836
	2.1544	2.3101	1.5199	826.2193	1582.836
	2.1544	2.4771	1.5199	626.3537	1582.836

6 Conclusion

In this pplication note, a simple three-point localization based on the Bluetooth LE RSSI ranging is implemented. The test results show that the accuracy is relatively high when the Tag node is close to the Anchor, but the accuracy decreases when the distance increases. This feature can be used in some applications. For example, when the distance is long (when the RSSI value is low), it can be used to identify the Tag entering the location region. When the distance is short (when the RSSI value is high), it can be used for localization. This can be realized by the KW36 MCU feasibly and effectively.

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