Wi-Fi FTM RTT Based Positioning System

PART 2

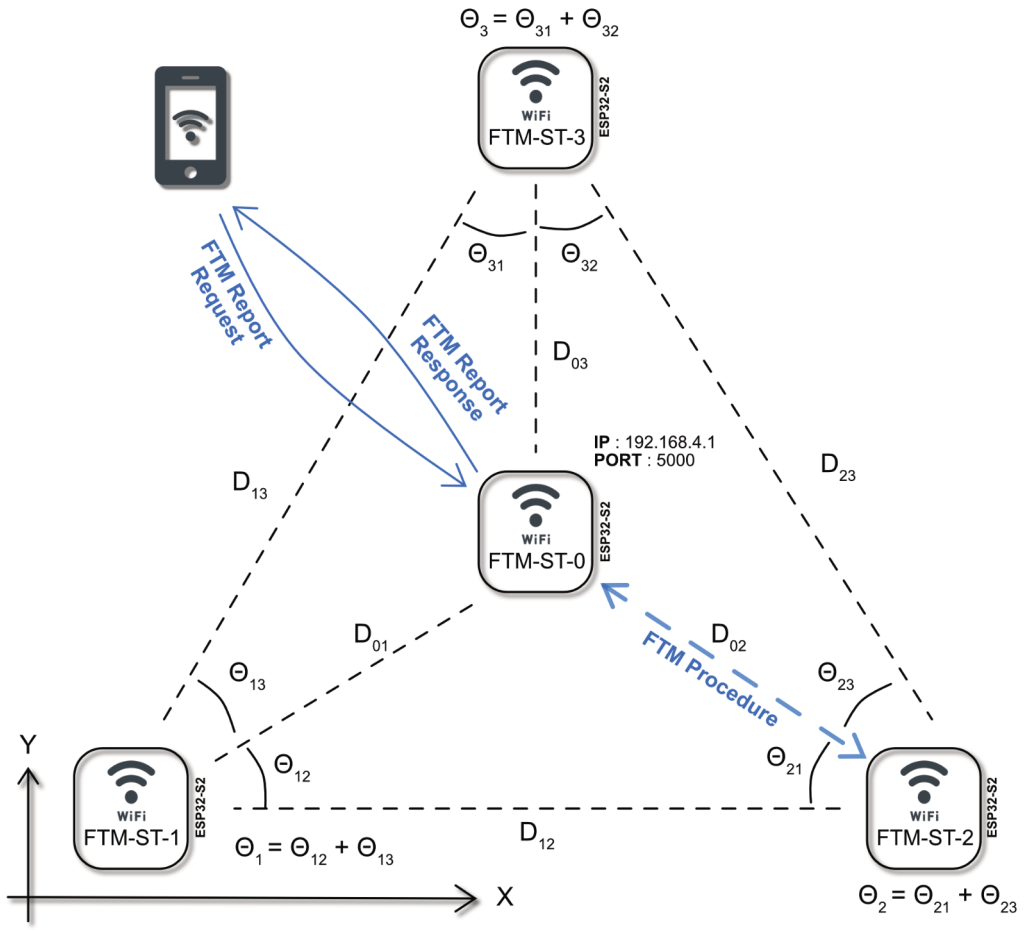
Problem Specification

The problem to be solved is formalized as follows: to determine the position (X and Y coordinates) of a station $\mathbf{ST_0}$ (mobile station), in relation to the known positions of three reference stations $\mathbf{ST_1}$, $\mathbf{ST_2}$ and $\mathbf{ST_3}$ (fixed stations) .

The coordinate system meets the following properties:

- The origin of the coordinate system is station $\mathbf{ST_1}$.
- The X axis is parallel to the straight line segment defined by stations $\mathbf{ST_0}$ and $\mathbf{ST_1}$.
- The Y axis is, by construction, normal to the X axis.

Through FTM measurements, distances $\mathbf{D_{01}}$, $\mathbf{D_{02}}$, $\mathbf{D_{03}}$, $\mathbf{D_{12}}$, $\mathbf{D_{13}}$ and $\mathbf{D_{23}}$ are obtained. These values are used to calculate the angles of interest ($\mathbf{\Theta_{12}}$, $\mathbf{\Theta_{13}}$ and $\mathbf{\Theta_1}$). The calculation of station $\mathbf{ST_0}$ position is obtained from these distance and angle values.



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Trigonometric Solution

The analysis of the trigonometric relationships in triangles $\Delta ST_1ST_2ST_0$, $\Delta ST_1ST_3ST_0$ and $\Delta ST_1ST_2ST_3$ produces the following equations for solving the proposed problem.

$$\sin(\Theta_{12}) = \frac{2}{(D_{01} D_{12})} \sqrt{s_{12}(s_{12}-D_{01})(s_{12}-D_{02})(s_{12}-D_{12})} \quad , s_{12} = \frac{1}{2}(D_{01}+D_{02}+D_{12})$$

$$\sin(\Theta_{13}) = \frac{2}{(D_{01} D_{13})} \sqrt{s_{13}(s_{13}-D_{01})(s_{13}-D_{03})(s_{13}-D_{13})} \quad , s_{13} = \frac{1}{2}(D_{01}+D_{03}+D_{13})$$

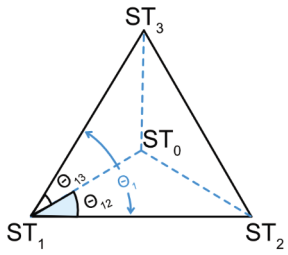
$$\sin(\Theta_{1}) = \frac{2}{(D_{12} D_{13})} \sqrt{s_{1}(s_{1}-D_{12})(s_{1}-D_{13})(s_{1}-D_{23})} \quad , s_{1} = \frac{1}{2}(D_{12}+D_{13}+D_{23})$$

$$\cos(\Theta_{12}) = \frac{D_{01}^2 + D_{12}^2 - D_{02}^2}{2\, D_{01} D_{12}}$$

$$\cos(\Theta_{13}) = \frac{D_{01}^2 + D_{13}^2 - D_{03}^2}{2\, D_{01} D_{13}}$$

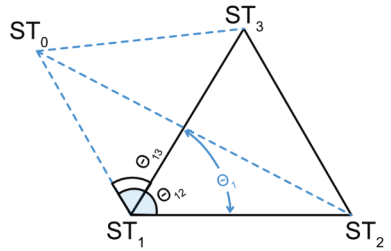
$$\cos(\Theta_{1}) = \frac{D_{12}^2 + D_{13}^2 - D_{23}^2}{2\, D_{12} D_{13}}$$

$$\sin(\Theta_{12} \pm \Theta_{13}) = \sin(\Theta_{12})\cos(\Theta_{13}) \pm \cos(\Theta_{12})\sin(\Theta_{13})$$



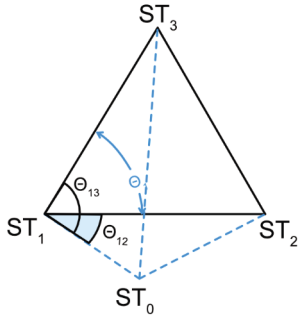
$\Theta_1 = (\Theta_{12} + \Theta_{13})$

$\sin(\Theta_1) = \sin(\Theta_{12} + \Theta_{13})$



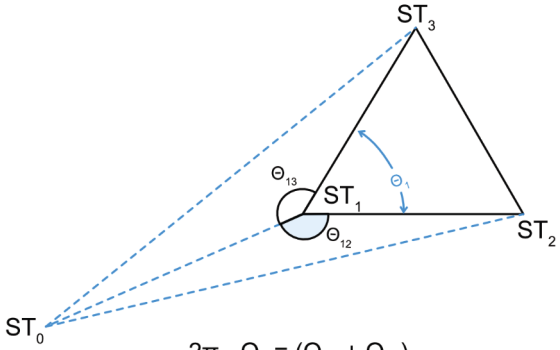
$\Theta_1 = (\Theta_{12} - \Theta_{13})$

$\sin(\Theta_1) = \sin(\Theta_{12} - \Theta_{13})$



$\Theta_1 = -(\Theta_{12} - \Theta_{13})$

$-\sin(\Theta_1) = \sin(\Theta_{12} - \Theta_{13})$



$2\pi - \Theta_1 = (\Theta_{12} + \Theta_{13})$

$-\sin(\Theta_1) = \sin(\Theta_{12} + \Theta_{13})$

Station	X Coordinate	Y Coordinate
ST_0	D_{01} . cos (Θ_{12})	**K** . D_{01} . sin (Θ_{12})
ST_1	0	0
ST_2	D_{12}	0
ST_3	D_{13} . cos (Θ_1)	D_{13} . sin (Θ_1)

K can assume values -1 or +1, depending on the relative position of station ST_0 (in relation the reference stations).

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FTM measurement

The **FTM measurement** can be performed remotely via TCP/IP, using a smartphone or PC as a test console.

EXAMPLE

“FTM by SSID” COMMAND:

```
{
 “function” : “ftm” ,
 “parameters” : { “ssid” : “FTM-ST-2” }
};
```

RESPONSE:

```
Requesting FTM session with Frm Count - 8, Burst Period - 400mSec (0: No Preference)
FTM Report:
| Diag |   RTT   |       T1       |       T2       |       T3       |       T4       | RSSI |
|    5 |   29687 | 3000247225000  | 4092711989062  | 4092839821875  | 3000375087500  |  -43 |
|    6 |   31249 | 3002415250000  | 4094880048437  | 4094983821875  | 3002519054687  |  -43 |
|    7 |   31250 | 3004631225000  | 4097096059375  | 4097199821875  | 3004735018750  |  -43 |
|    8 |   31250 | 3006856250000  | 4099321118750  | 4099424821875  | 3006959984375  |  -43 |
|    9 |   29687 | 3009089225000  | 4101554128125  | 4101657821875  | 3009192948437  |  -43 |
|   10 |   32812 | 3011309250000  | 4103774190625  | 4103877821875  | 3011412914062  |  -43 |
|   11 |   29687 | 3013542225000  | 4106007198437  | 4106110821875  | 3013645878125  |  -43 |
Estimated RTT - 17 nSec, Estimated Distance - 2.60 meters
```

ALTERNATIVE COMMAND (“FTM by MAC”):

```
{
  "function" : "ftm" ,
  "parameters" : { "mac" : "7c:df:a1:40:ce:23" , "channel" : 13 }
};
```


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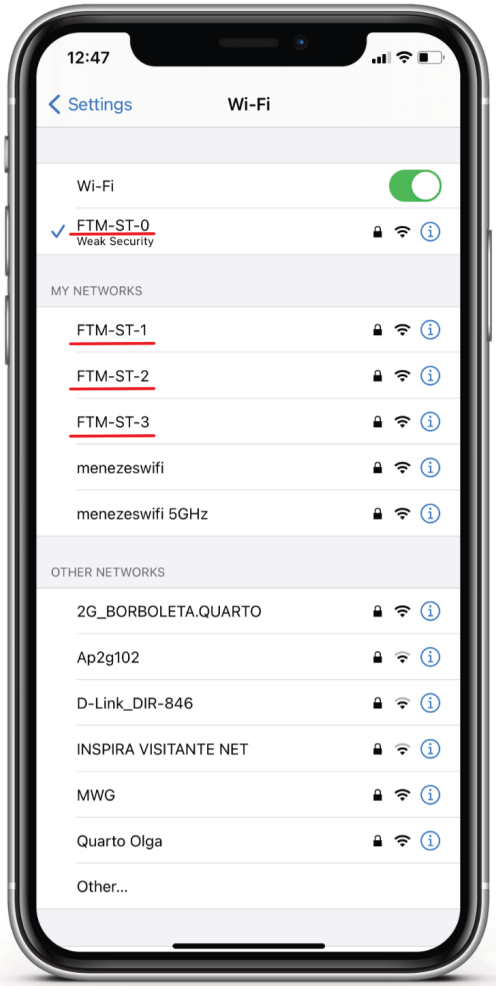
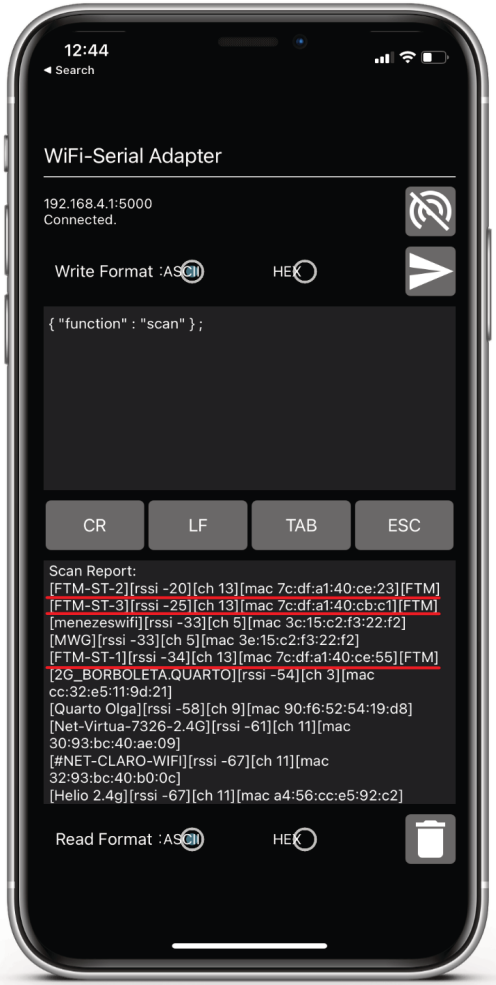
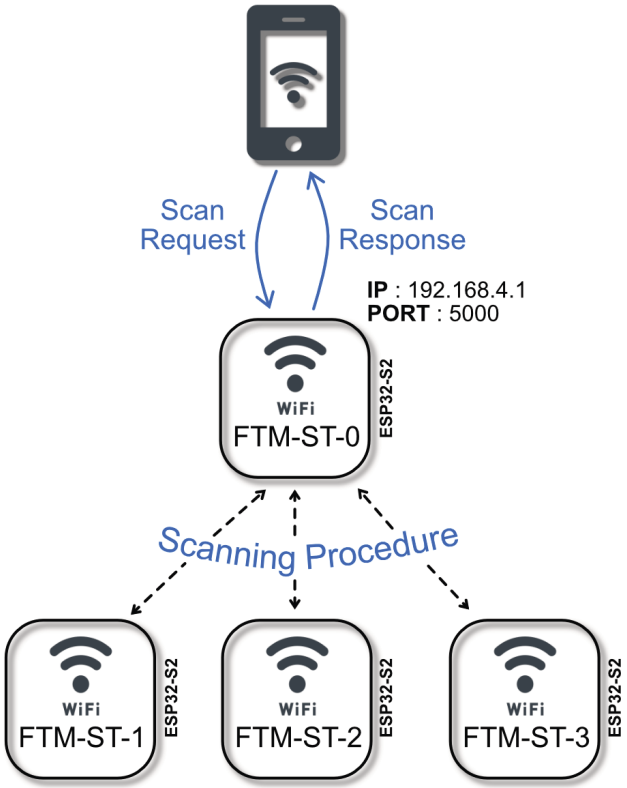
SSID Scanning

The list of nearby WiFi stations can be obtained using a scan command.







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Wi-Fi FTM RTT Based Positioning System

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EXAMPLE

“SCAN” COMMAND:

```
{
 “function” : “scan”
};
```

RESPONSE:

```
Scan Report:
[FTM-ST-3][rssi -38][ch 13][mac 7c:df:a1:40:cb:c1][FTM]
[FTM-ST-1][rssi -44][ch 13][mac 7c:df:a1:40:ce:55][FTM]
[FTM-ST-2][rssi -48][ch 13][mac 7c:df:a1:40:ce:23][FTM]
[MWG][rssi -50][ch 5][mac 3e:15:c2:f3:22:f2]
[menezeswifi][rssi -50][ch 5][mac 3c:15:c2:f3:22:f2]
[CLARO_2GAC9EC7][rssi -90][ch 11][mac 74:3a:ef:ac:9e:cc]
[#NET-CLARO-WIFI][rssi -91][ch 9][mac a6:56:cc:e7:06:f4]
sta scan done
```

ALTERNATIVE COMMAND (“SCAN by specific SSID”):

```
{
  "function" : "scan" ,
  "parameters" : { "ssid" : "FTM-ST-1" }
};
```

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PART 2

EXPERIMENT 1

The following experiment was performed using 1 **Franzininho WiFi board** (as Station 0) and 3 **ESP32-S2-DevKitM-1U** (as Stations 1, 2 and 3).

WiFi Scanning (from Station 0)

```
{ "function" : "scan" } ;
```

```
Scan Report:
[FTM-ST-2][rssi -48][ch 4][mac 7c:df:a1:40:f0:89][FTM]
[FTM-ST-3][rssi -52][ch 4][mac 7c:df:a1:40:f1:35][FTM]
[FTM-ST-1][rssi -53][ch 4][mac 7c:df:a1:40:f0:bb][FTM]
[GuestCBand][rssi -71][ch 6][mac 92:78:38:0d:40:70]
[CB-WLan][rssi -71][ch 6][mac 90:72:40:0d:38:78]
[TP-LINK_AE493A][rssi -71][ch 7][mac 54:e6:fc:ae:49:3a]
[Paromed-Reuniao][rssi -71][ch 10][mac 58:d5:6e:ae:63:6e]
[Eduaro][rssi -71][ch 11][mac 8c:44:4f:5e:fd:48]
[TP-LINK_AE493A_EXT_EXT][rssi -74][ch 7][mac 60:32:b1:d8:11:e2]
[DADOLUGO][rssi -77][ch 1][mac 00:36:76:ef:c3:ee]
[FABIANA_2G][rssi -77][ch 1][mac 48:29:52:46:df:93]
[menezeswifi][rssi -79][ch 2][mac 24:a2:e1:f1:fb:74]
[Luiz por ai][rssi -79][ch 6][mac 94:ea:ea:35:0c:1b]
[CLARO_2G09CC98][rssi -80][ch 1][mac c8:5d:38:09:cc:a5]
[MWG][rssi -80][ch 2][mac 26:74:fb:f1:e1:a0]
[mizarura][rssi -81][ch 9][mac 78:54:2e:eb:e8:e4]
[CLARO_2G5F5D62][rssi -81][ch 11][mac 74:3a:ef:5f:5d:67]
[Celso][rssi -83][ch 4][mac c0:25:e9:87:fd:84]
[Joana_&_Arean][rssi -83][ch 3][mac 50:95:51:eb:a5:fb]
[Paromed-ADM][rssi -83][ch 5][mac 98:da:c4:a6:f4:3d]
[NCASANOVA2][rssi -83][ch 8][mac 68:ff:7b:6b:cf:2c]
[RAQUELECASSIO 2G][rssi -85][ch 8][mac 5c:e3:0e:18:c7:f3]
[DUDA][rssi -88][ch 6][mac d8:c6:78:75:32:50]
sta scan done
```


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PART 2

[D01] - FTM Procedure from STO to ST1

```
{ "function" : "ftm" , "parameters" : { "ssid" : "FTM-ST-1" } } ;

Requesting FTM session with Frm Count - 8, Burst Period - 400mSec (0: No Preference)
FTM Report:
| Diag |   RTT   |       T1        |       T2        |       T3        |       T4        | RSSI |
|    5| 148438  | 5751264235937   | 6435549206250   | 6435677621875   | 5751392800000   |  -55 |
|    6| 148438  | 5753431235937   | 6437716250000   | 6437820621875   | 5753535756250   |  -55 |
|    7| 146875  | 5755666235937   | 6439951296875   | 6440055621875   | 5755770707812   |  -55 |
|    8| 150000  | 5757879235937   | 6442164343750   | 6442268621875   | 5757983664062   |  -55 |
|    9| 150000  | 5761315235937   | 6445600414062   | 6445704621875   | 5761419593750   |  -55 |
|   10| 148437  | 5762372235937   | 6446657435937   | 6446761621875   | 5762476570312   |  -55 |
|   11| 148437  | 5766173235937   | 6450458514062   | 6450562621875   | 5766277492187   |  -55 |
Estimated RTT - 126 nSec, Estimated Distance - 19.00 meters
```

[D02] - FTM Procedure from STO to ST2

```
{ "function" : "ftm" , "parameters" : { "ssid" : "FTM-ST-2" } } ;

Requesting FTM session with Frm Count - 8, Burst Period - 400mSec (0: No Preference)
FTM Report:
| Diag |   RTT   |       T1        |       T2        |       T3        |       T4        | RSSI |
|    5|  93750  | 3395314028125   | 5263764890625   | 5263893021875   | 3395442253125   |  -50 |
|    6|  92187  | 3397849028125   | 5266299939062   | 5266404021875   | 3397953203125   |  -50 |
|    7|  93750  | 3399730028125   | 5268180975000   | 5268285021875   | 3399834168750   |  -50 |
|    8|  93749  | 3401945028125   | 5270396017187   | 5270500021875   | 3402049126562   |  -50 |
|    9|  93750  | 3404153053125   | 5272604084375   | 5272708021875   | 3404257084375   |  -50 |
|   10|  92187  | 3409366028125   | 5277817157812   | 5277921021875   | 3409469984375   |  -50 |
|   11|  92187  | 3409710053125   | 5278161189062   | 5278265021875   | 3409813978125   |  -50 |
Estimated RTT - 71 nSec, Estimated Distance - 10.79 meters
```

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[D03] - FTM Procedure from STO to ST3

```
{ "function" : "ftm" , "parameters" : { "ssid" : "FTM-ST-3" } } ;

Requesting FTM session with Frm Count - 8, Burst Period - 400mSec (0: No Preference)
FTM Report:
| Diag |   RTT   |       T1        |       T2        |       T3        |       T4        | RSSI |
|    5| 110937  | 5628437225000   |  789603098437   |  789731421875   | 5628565659375   |  -53 |
|    6| 110937  | 5629813225000   |  790979125000   |  791083421875   | 5629917632812   |  -53 |
|    7| 109375  | 5634044225000   |  795210212500   |  795314421875   | 5634148543750   |  -53 |
|    8| 110937  | 5634397225000   |  795563220312   |  795667421875   | 5634501537500   |  -53 |
|    9| 109374  | 5636451225000   |  797617260937   |  797721421875   | 5636555495312   |  -53 |
|   10| 110937  | 5638702225000   |  799868307812   |  799972421875   | 5638806450000   |  -53 |
|   11| 110937  | 5640927225000   |  802093353125   |  802197421875   | 5641031404687   |  -53 |
Estimated RTT - 86 nSec, Estimated Distance - 13.00 meters
```

[D12] - FTM Procedure from ST1 to ST2

```
{ "function" : "ftm" , "parameters" : { "ssid" : "FTM-ST-2" } } ;

Requesting FTM session with Frm Count - 8, Burst Period - 400mSec (0: No Preference)
FTM Report:
| Diag |   RTT   |       T1        |       T2        |       T3        |       T4        | RSSI |
|    5| 189063  | 2981038028125   | 4164481709375   | 4164609635937   | 2981166143750   |  -58 |
|    6| 185938  | 2983668028125   | 4167111700000   | 4167215635937   | 2983772150000   |  -59 |
|    7| 184375  | 2985425028125   | 4168868696875   | 4168972635937   | 2985529151562   |  -59 |
|    8| 182812  | 2987650028125   | 4171093692187   | 4171197635937   | 2987754154687   |  -58 |
|    9| 185937  | 2989866053125   | 4173309714062   | 4173413635937   | 2989970160937   |  -58 |
|   10| 181250  | 2993437028125   | 4176880676562   | 4176984635937   | 2993541168750   |  -58 |
|   11| 185937  | 2994336028125   | 4177779679687   | 4177883635937   | 2994440170312   |  -58 |
Estimated RTT - 151 nSec, Estimated Distance - 22.70 meters
```


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[D13] - FTM Procedure from ST1 to ST3

```
{ "function" : "ftm" , "parameters" : { "ssid" : "FTM-ST-3" } } ;

Requesting FTM session with Frm Count - 8, Burst Period - 400mSec (0: No Preference)
FTM Report:
| Diag |   RTT   |       T1        |       T2        |       T3        |       T4        |  RSSI  |
|    5|  73438  | 1858660825000   | 3045428056250   | 3045556035937   | 1858788878125   |   -47  |
|    6|  73438  | 1860828825000   | 3047596056250   | 3047700035937   | 1860932878125   |   -47  |
|    7|  73438  | 1863466825000   | 3050234056250   | 3050338035937   | 1863570878125   |   -47  |
|    8|  75000  | 1868254825000   | 3055022057812   | 3055126035937   | 1868358878125   |   -47  |
|    9|  75000  | 1868585850000   | 3055353082812   | 3055457035937   | 1868689878125   |   -47  |
|   10|  73437  | 1871829825000   | 3058597057812   | 3058701035937   | 1871933876562   |   -47  |
|   11|  73437  | 1872155850000   | 3058923082812   | 3059027035937   | 1872259876562   |   -47  |
Estimated RTT - 54 nSec, Estimated Distance - 8.19 meters
```

[D23] - FTM Procedure from ST2 to ST3

```
{ "function" : "ftm" , "parameters" : { "ssid" : "FTM-ST-3" } } ;

Requesting FTM session with Frm Count - 8, Burst Period - 400mSec (0: No Preference)
FTM Report:
| Diag |   RTT   |       T1        |       T2        |       T3        |       T4        |  RSSI  |
|    5| 128125  | 6123837425000   | 6127349743750   | 6127478028125   | 6123965837500   |   -52  |
|    6| 128124  | 6126014425000   | 6129526748437   | 6129631028125   | 6126118832812   |   -52  |
|    7| 126562  | 6128239425000   | 6131751751562   | 6131856028125   | 6128343828125   |   -52  |
|    8| 124999  | 6130473425000   | 6133985754687   | 6134090028125   | 6130577823437   |   -52  |
|    9| 126562  | 6132689425000   | 6136201759375   | 6136306028125   | 6132793820312   |   -52  |
|   10| 126562  | 6135078425000   | 6138590762500   | 6138695028125   | 6135182817187   |   -52  |
|   11| 126562  | 6138412425000   | 6141924768750   | 6142029028125   | 6138516810937   |   -52  |
Estimated RTT - 112 nSec, Estimated Distance - 16.80 meters
```

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PART 2

[X, Y] Coordinates Estimation

A Python script has been created for calculating the [X, Y] Coordinates from the FTM measured distances. The script is located in the "**simulation**" folder of the **github** repository (**https://github.com/cezmen/chronos**).

	VARIABLE	DISTANCE (m)
FTM from STO to ST1	D01	19.00
FTM from STO to ST2	D02	10.79
FTM from STO to ST3	D03	13.00
FTM from ST1 to ST2	D12	22.70
FTM from ST1 to ST3	D13	8.19
FTM from ST2 to ST3	D23	16.80

```
./ftm_math.py distances -d01 19.00 -d02 10.79 -d03 13.00 -d12 22.70 -d13 8.19 -d23 16.80

Simulation Mode: distances

Cosines and Sines:
     cos_theta_12= 0.881 sin_theta_12= 0.473
     cos_theta_13= 0.832 sin_theta_13= 0.554
     cos_theta_1=  0.807 sin_theta_1=  0.590

Angles:
     theta_12= 28.2 degrees
     theta_13= 33.6 degrees
     theta_1=  36.2 degrees

Signal Estimation (K):
     Index= 0  Min Error= 2.918e-01  K= 1.0

X,Y Coordinates Estimation:
     ST0 : [ 16.7 , 9.0 ]
     ST1 : [ 0.0 , 0.0 ]
     ST2 : [ 22.7 , 0.0 ]
     ST3 : [ 6.6 , 4.8 ]
```

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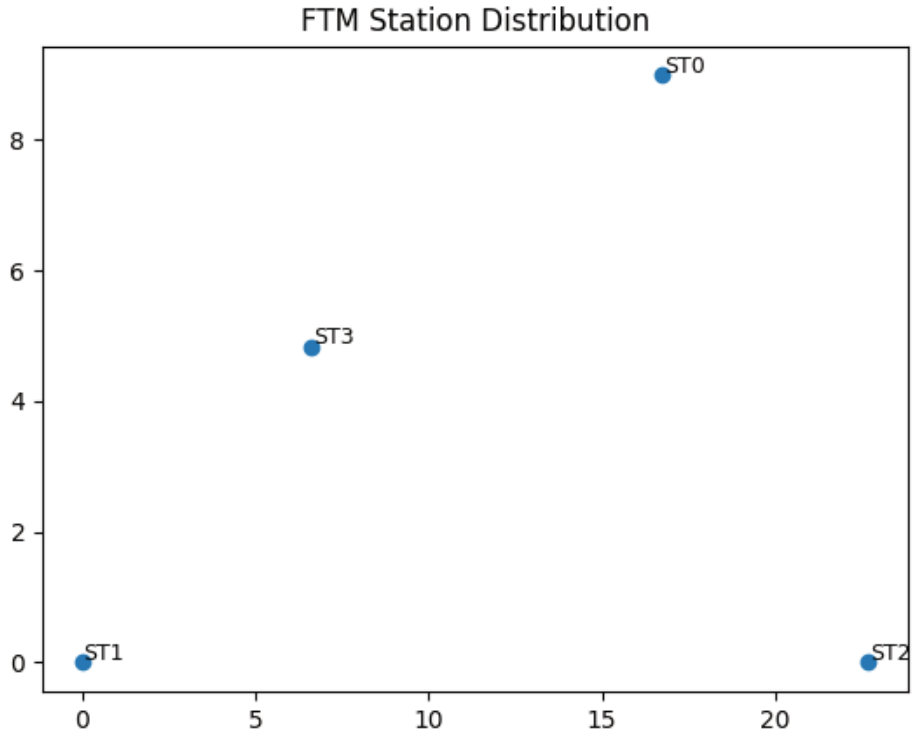
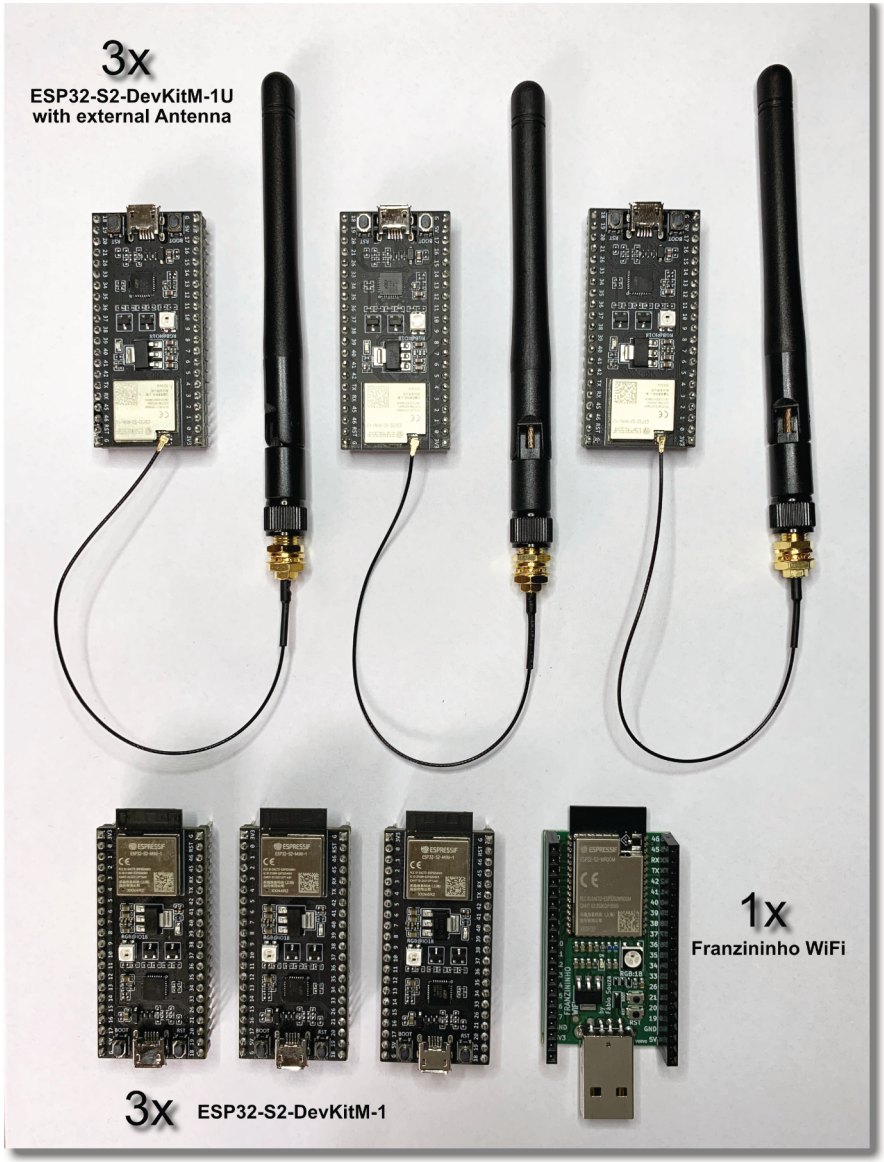


Test Setup



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