



## Application Note AN1200.114

LR2021

RTToF Ranging Demonstration

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# 1 Forewords

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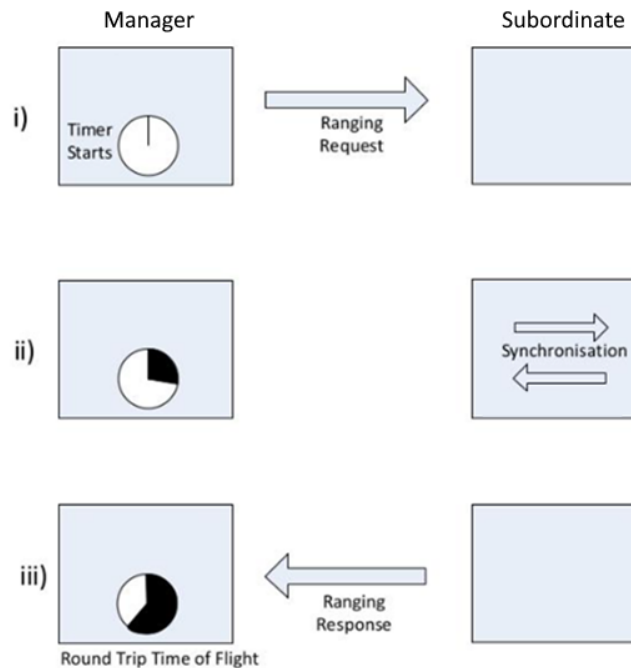
The LR2021 is the first chip in Semtech's LoRa Plus™ family, incorporating Generation 4 LoRa IP technology, and designed to operate across both Sub-GHz and 2.4 GHz frequency bands. It supports a range of modulation schemes including LoRa®, (G)FSK, (G)MSK, FLRC, and OOK, accompanied by a flexible packet engine, providing the LR2021 with the ability to emulate multiple wireless communication protocols including LoRaWAN, Sigfox, Wireless Mbus, WiSUN, Z-Wave, and Bluetooth Low Energy. This application note describes the Round Trip Time of Flight feature of LR2021. It explains the working principle and provides some guidance on how to select the SF/BW settings or the calibration values. It also describes the implementation of Semtech's RTToF demo and its field test performance. This document shall be read in conjunction with the LR2021 Datasheet. The user can also get more context on the RTToF (Ranging) feature inside the following Application Notes:

- AN1200.29: An Introduction to Ranging with the SX1280 Transceiver
- AN1200.31: How to Perform Ranging Tests with the SX1280 Development Kit
- AN1200.78: Introduction to LR1110 & LR1120 Ranging
- AN1200.89: Theory and Principle of Advanced Ranging
- AN1200.97: LR1110 & LR1120 Ranging Protocol Demonstration

## 2 Round Trip Time of Flight (RTToF) Ranging

### 2.1 Introduction to Ranging

A feature of the LR2021 is its ability to perform a radio ranging measurement between two radios. Using identical LoRa® physical layer settings, one radio is configured as a Ranging Manager and the other as a Ranging Subordinate.



**Figure 1. Overview of the RTToF Ranging Process**

- i) Ranging operation starts with the transmission of a ranging request from the Master.
- ii) This is received by the ranging Subordinate, which synchronizes with the incoming request and
- iii) Then sends a ranging response. Upon reception of which, the Manager can evaluate the time elapsed since it sent the request.

The elapsed time measured by the Manager is the round trip time of flight (RTToF) of the radio signal.

Because the transmissions happen at the speed of light, the elapsed time is equivalent to the round trip distance, provided the delays in the synchronization process can be compensated.

## 2.2 Ranging Resolution, Precision and Accuracy

Quantifying the performance of a ranging system relies on the key concepts of resolution, precision and accuracy, that have specific technical meanings in the context of ranging and localization systems. The image below shows Manager and Subordinate radios separated by distance  $d$ . This actual distance between the radios is termed **ground truth**.

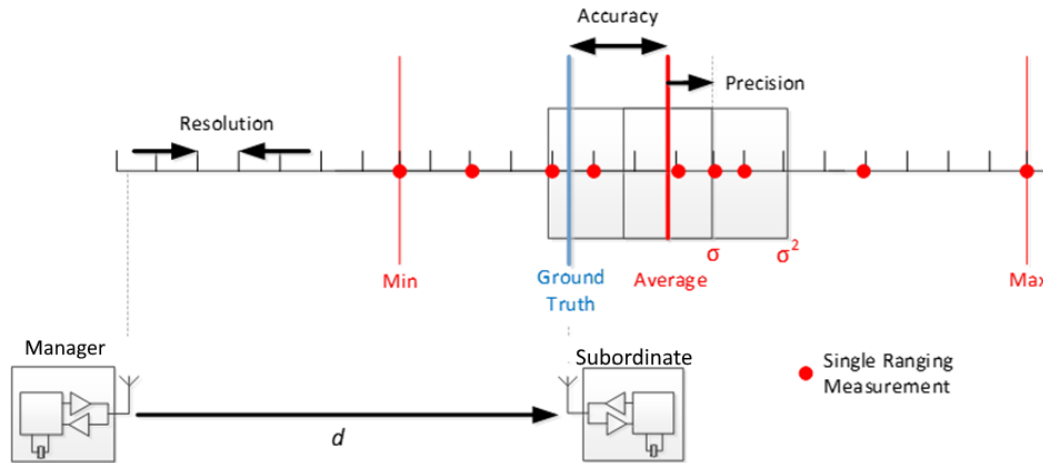


Figure 2. Key Ranging Terminology Definitions

Measurement **resolution** is the smallest increment that our system can measure. It is represented by the graduated measurement scale of our graphic. Because propagation happens at the speed of light,  $c$ , the distance resolution,  $D_{LSB}$ , of measurement for LoRa-based RTToF is a function of the LoRa bandwidth and is given by:

$$D_{LSB} = \frac{c}{2^{12} * BW}$$

Figure 2 also depicts a series of ranging measurements made between Manager and Subordinate as red dots, each one located on the graduated measurement scale. The measurement **precision** indicates the spread of these measured results. There are various ways we can quantify measurement precision, in the example above, we depict the standard deviation  $\sigma$  and variance  $\sigma^2$ .

There is a tradeoff between the data rate and range that a designer can exploit for a given LoRa application. Figure 3 illustrates the modem settings that give the best performances. However, we add a third point – denoting the highest precision ranging operation. This occurs at the point of the highest SF and LoRa modem bandwidth.

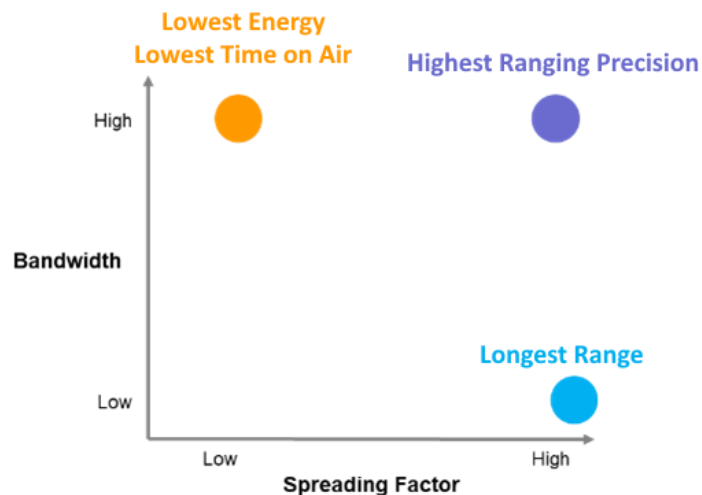


Figure 3. Optimal LoRa Modem BW and SF

Finally, **accuracy** is the difference between the ground truth distance and the estimated distance (calculated from measurement results). In this example, the average value of the reported range values is taken as our estimated distance. The factors determining the accuracy of an RTToF measurement are examined in detail next.

## 2.3 Sources of Inaccuracy in RTToF Ranging

An overview of the main sources of error is shown in the figure below:

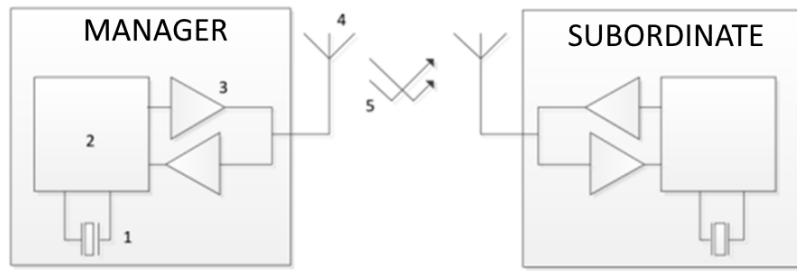


Figure 4. Sources of Ranging Error

- Crystal Reference Drift:** Any difference in frequency between the crystal reference oscillators of the Manager and Subordinate will result in a timing error between the radios. However, because the RF transmission frequency of both transceivers are derived from the crystal, the frequency error is measured and corrected automatically by the LR2021.
- Baseband Processing Delays:** A series of modulation and demodulation processes with the associated deterministic delays are performed between the Manager and Subordinate.
- Analogue Group Delay:** All analogue processes incur a group delay as the signal propagates through the signal transmission and reception paths. Both digital baseband group delay and analogue group delays are compensated automatically with a combination of a static calibration value and automated internal compensation methods.
- Antenna Performance:** The delay incurred transducing the electrical signal into an EM field is typically negligible in LoRa RTToF applications. However, antenna polarization can have an impact on precision as it changes the propagation characteristics.
- Multipath:** Reflection of the propagating EM wave from both the ground and intervening objects (between the Manager and Subordinate) is typically the greatest source of measurement error in a well-configured system.

## 2.4 Correcting Static Error

We differentiate between static sources of error for a given radio configuration, that will not change between Manager and Subordinate, and dynamic sources of error that change as a function of time or the environment in which the ranging is performed. Any system specific errors are corrected through a calibration process that is illustrated below:

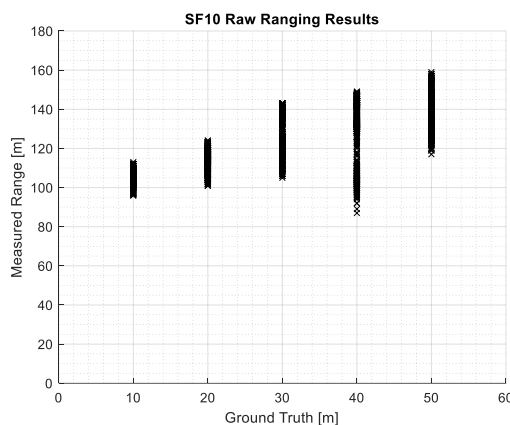


Figure 5. Uncalibrated Ranging Results

These results show low precision (high spread) at a Ground Truth distance of 40 m and an measured range offset by over 100 m compared with the ground truth distance.

Because the calibration measurements are performed at several line-of-sight (LoS) distances, the effect of a multipath can be detected and mitigated and a reliable error bias value is recovered. At the kind of accuracies attainable with LoRa-based RTToF, these calibration values are valid for most applications that are based upon replication of the Semtech reference design. The calibration values also vary between bands – the calibration tables for the most popular ISM bands are listed below.

**Table 1. Example Ranging Software Development Kit Calibration Values for the 470-510 MHz Bands**

BW	SF5	SF6	SF7	SF8	SF9	SF10
125	19737	19694	19614	19457	19159	18632
200	17502	17546	17566	17682	17739	18042
250	20134	20111	20068	19981	19811	19489
400	17794	17827	17831	17871	17819	17826
500	20569	20579	20577	20549	20491	20372
800	18713	18778	18746	18805	18725	18786
1000	21629	21660	21685	21660	21597	21466

**Table 3. Example Ranging Software Development Kit Calibration Values for 868 & 915 MHz Bands**

BW	SF5	SF6	SF7	SF8	SF9	SF10
125	19741	19704	19622	19476	19195	18649
200	17498	17551	17576	17695	17856	18162
250	20137	20121	20085	20011	19873	19582
400	17789	17783	17793	17862	18016	18454
500	20592	20586	20571	20502	20382	20050
800	18710	18749	18749	18829	18798	18905
1000	21700	21705	21707	21704	21699	21579

**Table 2. Example Ranging Software Development Kit Calibration Values for the 2.4 GHz Bands**

BW	SF5	SF6	SF7	SF8	SF9	SF10
125	19582	19498	19330	19012	18368	17125
200	17173	17262	17335	17554	17828	18557
250	19938	19896	19818	19646	19316	18667
400	17767	17822	17869	17937	18119	18442
500	20588	20586	20550	20451	20287	19938
800	18698	18777	18848	18981	19047	19449
1000	21574	21611	21622	20095	21370	21009

The calibration values shown in the tables above are available preconfigured and ready to use in the LR2021 driver software through the LR2021 SPI command *SetRangingTxRxDelay(...)* [2]. They can be used as-is for implementations based upon the same BoM and a similar layout to the Semtech reference design - as they will not significantly alter the group delay of signals in transmit or receive. This represents a significant saving in test and development time for the designer.

## 2.5 LoRa® Modem Setting Selection

With the ranging setup calibrated, it remains to select the physical layer parameters that will best serve the application. Recalling the optimal modem settings of Figure 3: high SF and high BW will give the best ranging performance. (Note that SF11 and SF12 are not compatible with the ranging function). The table below shows the Cramer Rao Lower Bound (CRLB) which gives an indication of the theoretical precision (1 standard deviation) for each modem configuration. The highlighted area shows the region with a CRLB <6 m.

**Table 4. CRLB Prediction of the Precision of LoRa Modem Settings (meters)**

	SF5	SF6	SF7	SF8	SF9	SF10	SF11	SF12
125 kHz	42.8	30.2	21.4	15.1	10.7	7.57		
200 kHz	26.7	18.9	13.3	9.46	6.69	4.73		
250 kHz	21.4	15.1	10.7	7.57	5.35	3.78		
400 kHz	13.3	9.46	6.69	4.73	3.34	2.36		
500 kHz	10.7	7.57	5.35	3.78	2.67	1.89		
800 kHz	6.69	4.73	3.34	2.36	1.67	1.18		
1000 kHz	5.35	3.78	2.67	1.89	1.33	0.946		

In addition to the theoretical precision information, we also provide indications of the radio sensitivity at each SF/BW combination, followed by the time-on-air of a single Manager-Subordinate ranging exchange.

Based upon the time-on-air of 16.4 ms per ranging exchange, a sensitivity of -121 dBm, and a precision of 1.9 m, we select **SF=8** and **BW=1000 kHz** as our initial modem setting for the initial field trial of the LR2021 RTToF ranging technology (highlighted in yellow).

**Table 5. Link Budget Performance (dBm)**

	SF5	SF6	SF7	SF8	SF9	SF10	SF11	SF12
125 kHz	-121	-124	-126.7	-129.5	-132	-135.2		
200 kHz	-118.5	-121.4	-124.1	-126.9	-129.9	-132.6		
250 kHz	-118	-120.8	-123.7	-126.5	-129	-131.7		
400 kHz	-116.4	-118.9	-121.8	-124.4	-127.4	-130.1		
500 kHz	-115.2	-118.5	-121.2	-123.8	-126.5	-129.2		
800 kHz	-113.4	-116.4	-119.1	-121.9	-124.4	-127.1		
1000 kHz	-112.5	-115.5	-118.2	-121	-123.5	-126.7		

**Table 6. Time-on-Air of one ranging exchange (ms)**

	SF5	SF6	SF7	SF8	SF9	SF10	SF11	SF12
125 kHz	16.4	32.8	65.7	131	263	526		
200 kHz	10.2	20.5	41.1	82.2	164	328		
250 kHz	8.22	16.4	32.8	65.7	131	263		
400 kHz	5.14	10.2	20.5	41.1	82.2	164		
500 kHz	4.11	8.22	16.4	32.8	65.7	131		
800 kHz	2.5	5.14	10.2	20.5	41.1	82.2		
1000 kHz	2.05	4.11	8.22	16.4	32.8	65.7		

## 2.6 Mitigating Multipath

The principle source of dynamic error, that varies as a function of time or location of the Manager and Subordinate, is multipath propagation. Figure 6 illustrates this phenomenon, where the presence of obstacles between the pair of radios (performing the distance measurements) causes reflection of the radio waves. This induces a measurement over-estimation as the reflected propagation distance exceeds the direct distance between the Manager and Subordinate.

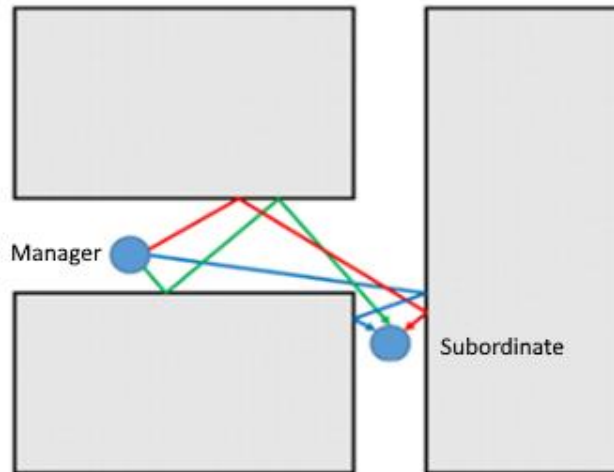


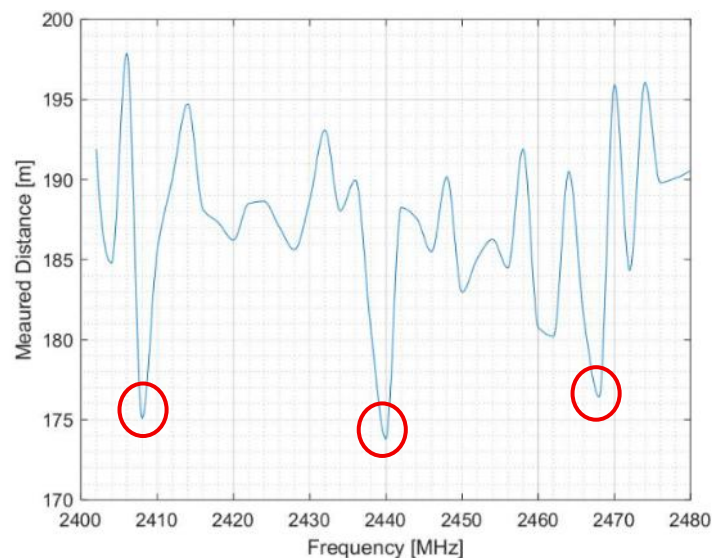
Figure 6. Multipath Propagation Example

The main approach to reducing the influence of multipath is through **diversity**. This can take various forms however, antenna, frequency, and spatial polarization diversity can all play a role in reducing its impact.

## 2.7 Diversity

Diversity is the separation of the propagation environment into independent channels that do not have the same pathloss or delay characteristics. This can take many forms, however the three most pertinent are:

**Frequency diversity:** is typically the lowest cost solution to implement, as it requires no additional hardware, it simply requires ranging to be performed on multiple channels. The additional communication exchanges incur an additional time-on-air and energy cost. An example scan across the 2.4 GHz band between two distant radios is shown below. As we can see, some channels are subject to multipath (at 2408, 2440 and 2468 MHz, circled in red below) however, channels which present outlier values can be statistically screened.



**Antenna diversity:** relies on having either enough physical separation, or difference in overlap of the radiation patterns between two or more antennas such that they present different propagation characteristics between Manager and Subordinate. Employing antenna diversity relies on having mechanisms to detect and exploit this variability in channel performance. It also relies on the device having enough space to house a pair (or more) of antennas. This can be problematic at lower frequencies where the longer wavelength increases the antenna dimensions for equivalent efficiency.

**Spatial diversity:** is akin to antenna diversity but in our definition, is used to infer more distant separation between antennas in separate devices. For this reason, it is of most relevance in the case of localization systems with localization devices cooperating to localize an object. In such a role, the addition of multiple devices gives the added benefit of densifying the network and providing additional range information to determine the location of the device being sought.

An example of such an application is illustrated below. The point-to-point case is the standard ranging exchange we have addressed thus far. The Infrastructure case shows the employment of multiple ranging Managers that perform ranging exchanges to locate a Subordinate at the intersection of their range circles.

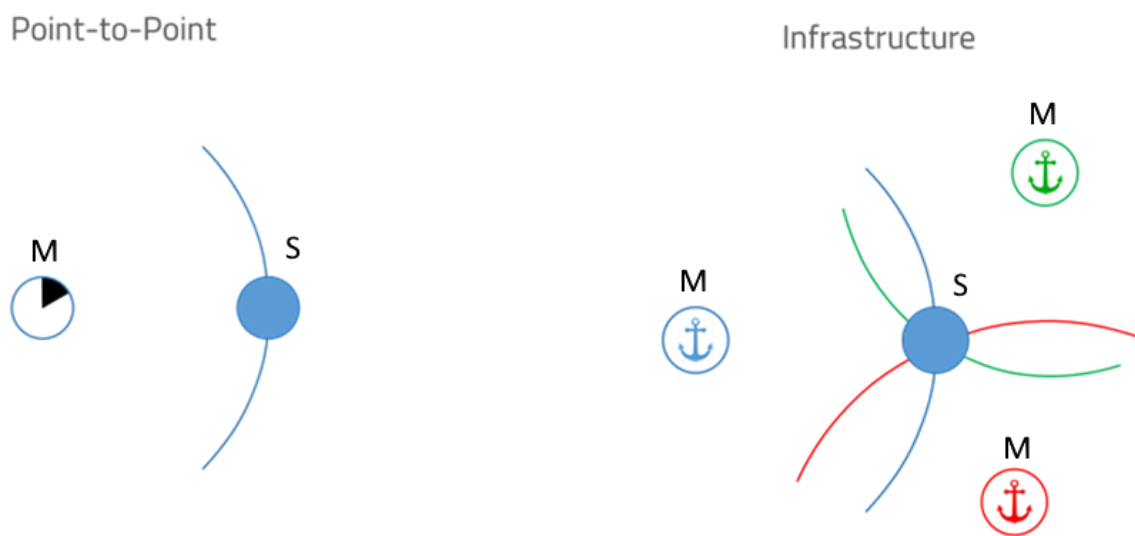


Figure 8. Two Types of Localization Applications, Illustrating Spatial Diversity in Infrastructure

## 3 RTToF Demonstrator

### 3.1 Introduction

To allow designers to get started quickly with the ranging functionality of the LR2021, Semtech provides the 'RTToF Demonstrator'. It provides both a quick demonstration of capability and forms the basis from which to develop a real world ranging application that gives high accuracy results.

### 3.2 Ranging Protocol

The protocol that the RTToF Demonstrator uses is shown in the figure below. The Manager and Subordinate both start out tuned to a dedicated communication channel. The Subordinate is in a duty cycled receive mode, meaning that its consumption is minimized whilst waiting for the Manager to initiate communication. Following an initial communication between Manager and Subordinate, the Manager then begins the RTToF ranging process. Because we want frequency diversity to help improve the accuracy of our results in the presence of multipath, the protocol employs frequency hopping over a fixed predefined channel list.

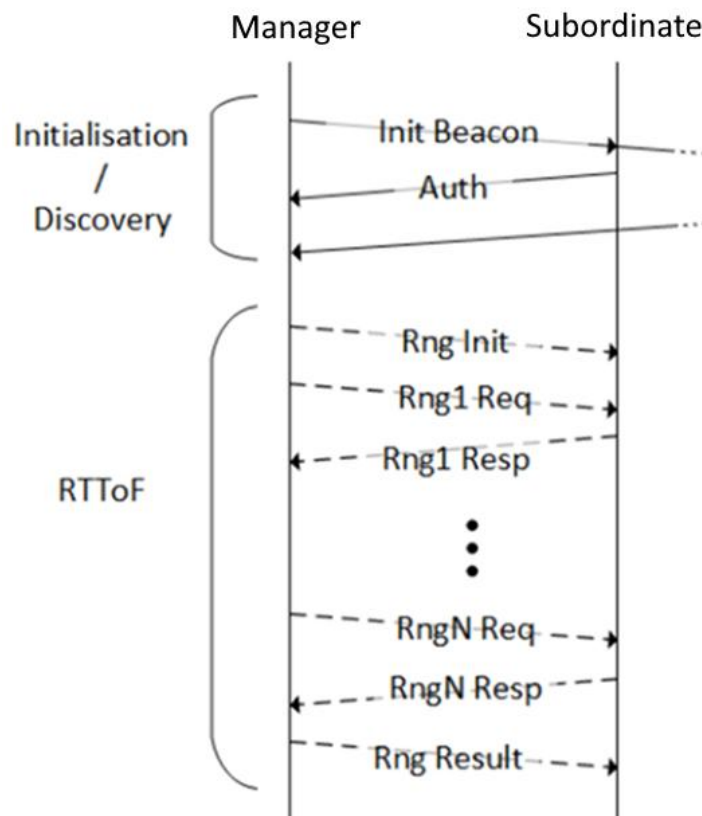


Figure 9. Ranging Protocol used in the LR2021 RTToF Demonstrator

A frequency hopping protocol that calculates the time-on-air of the ranging exchanges is used to determine whether a packet on a given channel may have been missed, and still hops to subsequent channels in the event of failure. This renders the hopping protocol highly robust. As is also alluded to in the image, the protocol could easily be extended to support multiple Subordinates.

### 3.3 Demo Setup

To setup an LR2021 kit, the RTToF demo git should be downloaded from the Semtech Github account [3]. The kit does require a compilation step to get the demo running, this can be done by using the makefile provided with the project.

The project should be compiled with suitable regional settings, so may require modification of four settings found across three source files:

#### 1) Frequency Hopping Channels: `smtc_shield_lr20xx_common.c`

In this file, a series of structs represent the predefined frequency hopping channels. Simply uncomment the channel plan appropriate for your region (US = 915 MHz, EU = 868 MHz, CN = 490 MHz and Global = 2.4 GHz).

```

213 //};
214
215 /*
216  * @brief Recommended for frequency from 860MHz to 928MHz (Calibrated)
217  */
218 static const uint32_t rtttof_delay_indicator_table_from_600mhz_to_2ghz[7][8] = {
219     /* SF5,   SF6,   SF7,   SF8,   SF9,   SF10,  SF11,  SF12 */
220     { 19741,  19704,  19622,  19476,  19195,  18649,  18649,  18649 }, // BW125
221     { 17498,  17551,  17576,  17695,  17856,  18162,  18162,  18162 }, // BW203
222     { 20137,  20121,  20085,  20011,  19873,  19582,  19582,  19582 }, // BW250
223     { 17789,  17783,  17793,  17862,  18016,  18454,  18454,  18454 }, // BW406
224     { 20592,  20586,  20571,  20502,  20382,  20050,  20050,  20050 }, // BW500
225     { 18710,  18749,  18749,  18829,  18798,  18905,  18905,  18905 }, // BW812
226     { 21700,  21705,  21707,  21704,  21699,  21579,  21579,  21579 }, // BW1000
227 };
228
229
230

```

#### 2) Communication Frequency & Power: `apps_configuration.h`

In this file, set the appropriate RF output power in dBm and the frequency used by Manager and Subordinate for their initial communication.

```

61 /*
62  * @brief This frequency is used for ranging initiation for LoRa type
63  */
64 #ifndef RF_FREQ_IN_HZ
65 #define RF_FREQ_IN_HZ 907850000U
66 #endif
67 #ifndef TX_OUTPUT_POWER_DBM
68 #define TX_OUTPUT_POWER_DBM 13 // range [-17, +22] for sub-G, range [-18, 13] for 2.4G ( HF_PA )
69 #endif

```

#### 3) Manager/Subordinate Assignment & Screen: `main_ranging_demo.h`

Finally set the device mode to either Manager or Subordinate, one binary must be compiled for each role and independently programmed to each device.

```

64 /**
65  * @brief Mode of operation
66  */
67 #ifndef RANGING_DEVICE_MODE
68 #define RANGING_DEVICE_MODE RANGING_DEVICE_MODE_MANAGER
69 #endif
70
71 /**
72  * @brief Use a display for test
73  */
74 #define RANGING_DISPLAY_FOR_TEST 1

```

## 3.4 Performing a Range Test

### 3.4.1 Demo Operation

The RTToF demo is based upon the LR2021 Nucleo kit, configured as shown in the figure below. Both kits must be connected and powered over the min-USB ports on the Nucleo board.



Figure 10. The LR2021 Nucleo Kits in the Configuration used for sub-GHz Ranging Tests

The Manager should be connected via USB to a serial port. The required serial port settings and the output of a successful ranging exchange are shown below. This view includes all of the raw results by channel and meta data.

COM45 - Tera Term VT  
File Edit Setup Control Window Help

```

{"FreqIndex": "23", "Freq": "865.85 MHz", "RawDistance": "0x00000012", "Distance": "5 m", "Gamma": "14 m", "RSSI": "-73 dBm"}
{"FreqIndex": "24", "Freq": "865.70 MHz", "RawDistance": "0x00000031", "Distance": "14 m", "Gamma": "14 m", "RSSI": "-73 dBm"}
{"FreqIndex": "25", "Freq": "867.35 MHz", "RawDistance": "0x0000001d", "Distance": "8 m", "Gamma": "14 m", "RSSI": "-73 dBm"}
{"FreqIndex": "26", "Freq": "868.10 MHz", "RawDistance": "0x00000000", "Distance": "0 m", "Gamma": "14 m", "RSSI": "-73 dBm"}
{"FreqIndex": "27", "Freq": "863.60 MHz", "RawDistance": "0x0000000a", "Distance": "2 m", "Gamma": "14 m", "RSSI": "-73 dBm"}
{"FreqIndex": "28", "Freq": "866.60 MHz", "RawDistance": "0x00000017", "Distance": "6 m", "Gamma": "14 m", "RSSI": "-73 dBm"}
{"FreqIndex": "29", "Freq": "864.20 MHz", "RawDistance": "0x00000011", "Distance": "4 m", "Gamma": "14 m", "RSSI": "-73 dBm"}
}

"DistanceRng": "6.0 m",
"FinalGamma": "8.2",
"PER": "0 %"
}

{
  "SP": "SP8",
  "BU": "125 kHz",
  "Address": "0x32101222",
  "LoRa RSSI": "-17 dBm",
  "LoRa SNR": 15,
  "RngResult": {
    "Num": 29,
    "Results": [
      {"FreqIndex": "1", "Freq": "863.75 MHz", "RawDistance": "0x00000020", "Distance": "9 m", "Gamma": "6.2", "RSSI": "-73 dBm"},
      {"FreqIndex": "2", "Freq": "865.10 MHz", "RawDistance": "0x0000000c", "Distance": "3 m", "Gamma": "13.4", "RSSI": "-73 dBm"},
      {"FreqIndex": "3", "Freq": "864.80 MHz", "RawDistance": "0x00000019", "Distance": "7 m", "Gamma": "7.6", "RSSI": "-73 dBm"},
      {"FreqIndex": "4", "Freq": "868.40 MHz", "RawDistance": "0x00000019", "Distance": "7 m", "Gamma": "7.5", "RSSI": "-73 dBm"},
      {"FreqIndex": "5", "Freq": "865.25 MHz", "RawDistance": "0x0000000e", "Distance": "3 m", "Gamma": "13.4", "RSSI": "-73 dBm"},
      {"FreqIndex": "6", "Freq": "867.50 MHz", "RawDistance": "0x00000016", "Distance": "6 m", "Gamma": "8.2", "RSSI": "-73 dBm"},
      {"FreqIndex": "7", "Freq": "865.55 MHz", "RawDistance": "0x0000001a", "Distance": "1 m", "Gamma": "nan", "RSSI": "-73 dBm"},
      {"FreqIndex": "8", "Freq": "867.65 MHz", "RawDistance": "0x0000001e", "Distance": "8 m", "Gamma": "7.1", "RSSI": "-73 dBm"},
      {"FreqIndex": "9", "Freq": "866.15 MHz", "RawDistance": "0x00000024", "Distance": "10 m", "Gamma": "6.4", "RSSI": "-73 dBm"},
      {"FreqIndex": "10", "Freq": "864.05 MHz", "RawDistance": "0x00000026", "Distance": "11 m", "Gamma": "6.1", "RSSI": "-73 dBm"},
      {"FreqIndex": "11", "Freq": "867.80 MHz", "RawDistance": "0x0000002b", "Distance": "12 m", "Gamma": "5.9", "RSSI": "-73 dBm"},
      {"FreqIndex": "12", "Freq": "863.30 MHz", "RawDistance": "0x0000000b", "Distance": "3 m", "Gamma": "13.4", "RSSI": "-73 dBm"},
      {"FreqIndex": "13", "Freq": "863.45 MHz", "RawDistance": "0x0000000b", "Distance": "4 m", "Gamma": "10.6", "RSSI": "-73 dBm"},
      {"FreqIndex": "14", "Freq": "867.95 MHz", "RawDistance": "0x00000015", "Distance": "6 m", "Gamma": "8.2", "RSSI": "-73 dBm"},
      {"FreqIndex": "15", "Freq": "868.55 MHz", "RawDistance": "0x0000002f", "Distance": "13 m", "Gamma": "5.7", "RSSI": "-73 dBm"},
      {"FreqIndex": "16", "Freq": "869.85 MHz", "RawDistance": "0x00000034", "Distance": "1 m", "Gamma": "nan", "RSSI": "-73 dBm"},
      {"FreqIndex": "17", "Freq": "867.20 MHz", "RawDistance": "0x0000001f", "Distance": "9 m", "Gamma": "6.2", "RSSI": "-73 dBm"},
      {"FreqIndex": "18", "Freq": "867.05 MHz", "RawDistance": "0x00000016", "Distance": "6 m", "Gamma": "8.2", "RSSI": "-73 dBm"},
      {"FreqIndex": "19", "Freq": "864.65 MHz", "RawDistance": "0x00000008", "Distance": "2 m", "Gamma": "21.2", "RSSI": "-73 dBm"},
      {"FreqIndex": "20", "Freq": "863.90 MHz", "RawDistance": "0x0000001a", "Distance": "15 m", "Gamma": "5.4", "RSSI": "-73 dBm"},
      {"FreqIndex": "21", "Freq": "866.90 MHz", "RawDistance": "0x0000001a", "Distance": "2 m", "Gamma": "nan", "RSSI": "-73 dBm"},
      {"FreqIndex": "22", "Freq": "868.25 MHz", "RawDistance": "0x00000013", "Distance": "5 m", "Gamma": "9.1", "RSSI": "-73 dBm"},
      {"FreqIndex": "23", "Freq": "865.85 MHz", "RawDistance": "0x00000024", "Distance": "10 m", "Gamma": "6.4", "RSSI": "-73 dBm"},
      {"FreqIndex": "24", "Freq": "865.70 MHz", "RawDistance": "0x00000031", "Distance": "4 m", "Gamma": "10.6", "RSSI": "-73 dBm"},
      {"FreqIndex": "25", "Freq": "867.35 MHz", "RawDistance": "0x0000000e", "Distance": "3 m", "Gamma": "13.4", "RSSI": "-73 dBm"},
      {"FreqIndex": "26", "Freq": "868.10 MHz", "RawDistance": "0x00000019", "Distance": "7 m", "Gamma": "7.5", "RSSI": "-73 dBm"},
      {"FreqIndex": "27", "Freq": "863.60 MHz", "RawDistance": "0x0000000a", "Distance": "16 m", "Gamma": "5.3", "RSSI": "-73 dBm"},
      {"FreqIndex": "28", "Freq": "866.60 MHz", "RawDistance": "0x00000017", "Distance": "7 m", "Gamma": "7.5", "RSSI": "-73 dBm"},
      {"FreqIndex": "29", "Freq": "864.20 MHz", "RawDistance": "0x00000008", "Distance": "2 m", "Gamma": "21.2", "RSSI": "-73 dBm"}
    ]
  }
}

"DistanceRng": "6.0 m",
"FinalGamma": "8.2",
"PER": "0 %"
}

```

Speed: 921600  
Data: 8 bit  
Parity: none  
Stop bits: 1 bit  
Flow control: none

Figure 11. Terminal Output when Ranging is Operational

### 3.4.2 Range Test Location

For the first test, it is useful to ensure that the kit is configured and functioning correctly by performing a test in a Line-Of-Sight (LoS) environment. This gives the user the opportunity to experience the ranging performance and get a good sense of aspects such as the reactivity of and range of the system.



**Figure 12. Example LoS Test Location and Kit Orientation Manager (right) and subordinate (left)**

With the LoS performance established and suitable candidate LoRa modem settings selected, it is then useful to introduce the complexities of the real application environment. This approach allows the designer to separate the ideal system performance and contrast it with the application environment and, if any performance limitations are found, to diagnose their root cause.

### 3.5 Demonstrator Accuracy

For reference, the LoS range measurement performance of the setup in Figure 12 is shown in the following two figures. Figure 13 shows all the raw measurements at a series of ground truth distances from 10 to 120 m. Figure 14 shows the median measurement of those results, as would be output as the real result in a final application.

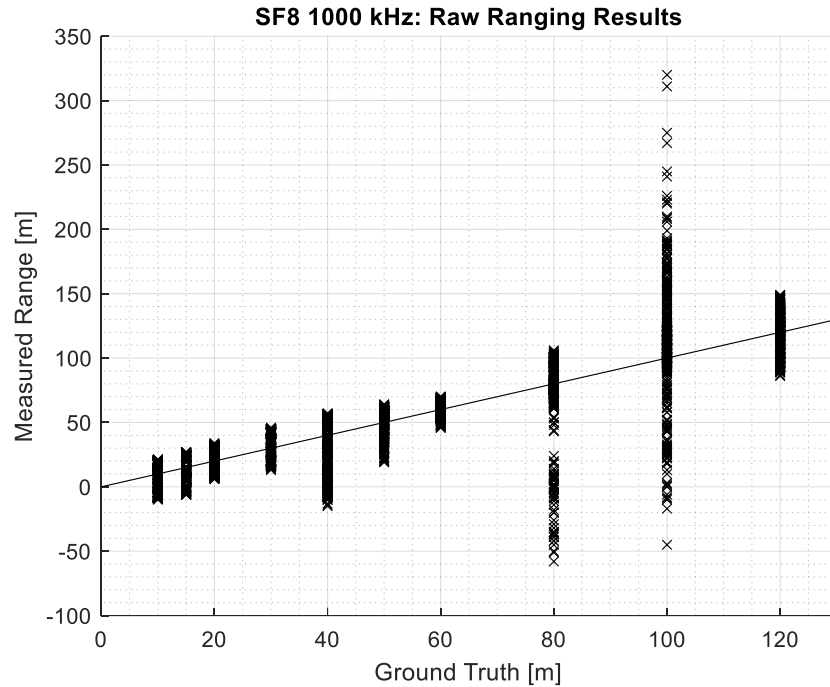


Figure 13. Raw Measurement Results, 868MHz

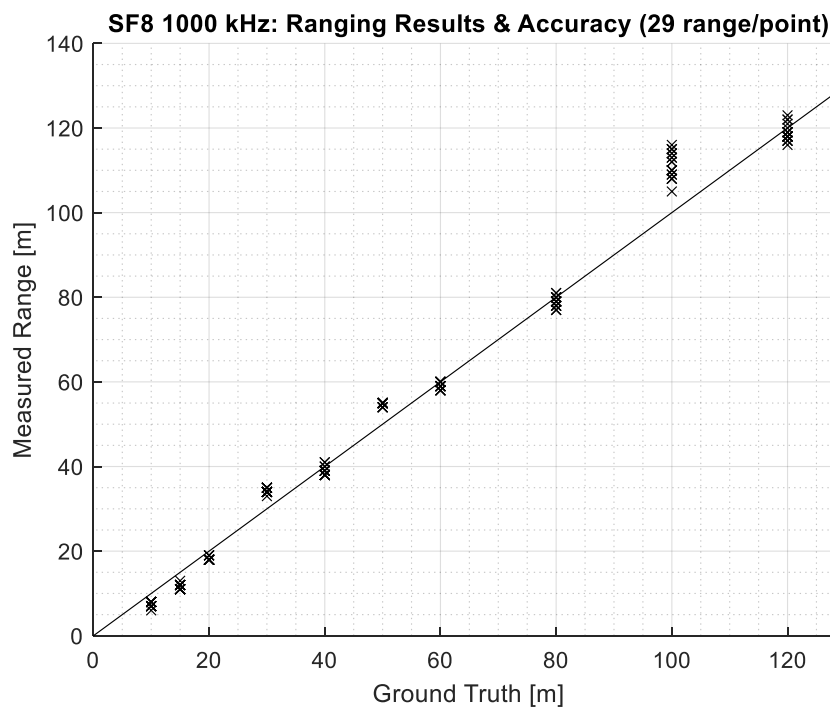


Figure 14. Median Measurement Results, 868MHz

## 4 Conclusion

This Application Note presented an overview of the theory and principle of operation of the LR2021 RTToF ranging functionality. It then detailed factors which limit the precision and accuracy of the ranging, and detailed the need for both static calibration and mitigation of changing multipath environments.

In the final sections, the RTToF Demonstrator was presented and tested at SF=8, BW=1000 kHz. This uses the frequency hopped diversity and statistical filtering, detailed in the preceding pages, to give both a starting point for ranging product development and to act as a tool for evaluating the technology's performance in the field.

We conclude by detailing the measured accuracy of a ranging demonstrator, to allow users to replicate the performance presented here.

## 5 References

- [1] LR2021 Reference Designs: <https://www.semtech.com/products/wireless-rf/lora-plus/lr2021>
- [2] LR2021 Driver Software: <https://github.com/Lora-net/>
- [3] Semtech RTToF Demo Software: <https://github.com/Lora-net/>

## 6 Revision History

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Version	ECO	Date	Changes and/or Modifications
1.0	ECO-076648	October 2025	Initial Version

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