RTX
WIRELESS WISDOM

Range performance

In real world 2.4GHz scenarios

Version 1.0

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1 Abstract

This document is written with the intend to give the reader a better understanding of radio performance expectations, when operating in the license-free 2.4 GHz frequency band. Using a radio with 10 dBm effective isotropic radiated power (EIRP) output as reference (ETSI 300 328) in indoor environments, range varies within 20 to 60+ meters, whereas the outdoor range often is capable of reaching hundreds of meters. The achievable range highly depends on the presence of reflective surfaces and blocking material e.g. walls and the interference caused by other wireless devices or household items, in the 2.4GHz frequency spectrum A discussion on how to define range is presented and with this range definition in mind, a suggestion of how a range/performance test is executed will be described. This test procedure should help align expectations to performance between end-users and developers/manufactures of the radio system.

2 Theoretical RF propagation and RF range

In this section, several parameters affecting the RF performance will be discussed, along with the approaches RTX uses to mitigate some of the effects.
A radio device operating in the 2.4 GHz spectrum with an output power of 10 dBm (EIRP) and a typical sensitivity of approximately -90dBm, would in an ideal test scenario (with no interference and free space radiation) have a range of approximately 1 km. However, such a range test would be impossible to conduct, even in an open field, as the effect of ground reflections will limit the range. The scenario is shown in Figure 1, where the reflected signal arrives ''out of phase'' at the receiver, thus cancelling out the direct signal path resulting in a fade. In RTX's experience a line of sight range in this case would be approximately 300 meters. It should however, be noted that this is at the limit of the radio sensitivity and the packet error rate could be quite high at this distance. A packet error rate of e.g. 3% might not give an acceptable Quality of Service (QoS) for some application domains. For audio applications, the range figure will be in the order of 100 meters for a low number of drop-outs in the audio / data stream.

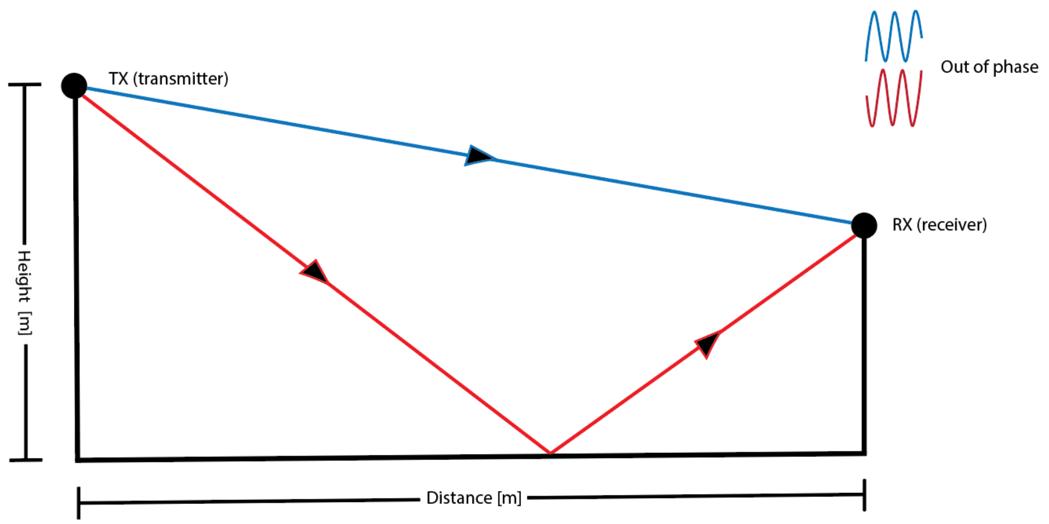

Figure 1: Ground reflection causing fading

2.1 Phenomenon's affecting RF range and RF performance

Above the radio performance in an ideal environment is described but it is important to emphasize that the theoretical performance is not achievable in real life radio systems (like a wireless microphone) as the radio environment is never ideal.

2.1.1 *Fading due to reflections*

Fading is a problem in almost all radio environments - especially in indoor environments and can cause link errors or even link drops. This is caused by the RF signal reflecting several times generating multiple signal paths between transmitter and receiver. The simple case of one reflection path can be seen in Figure 1 .Fading causes the radio signal level to drop below what would be expected at a given distance between a transmitter and a receiver. Fading is a dynamic phenomenon which will cause the signal level to change during movement, where movement speed as well is a significant factor in fading and its cause. Note that reflections can combine both as constructive and destructive interference, leading to peeks and dips in the received signal strength. This is shown in figure 2

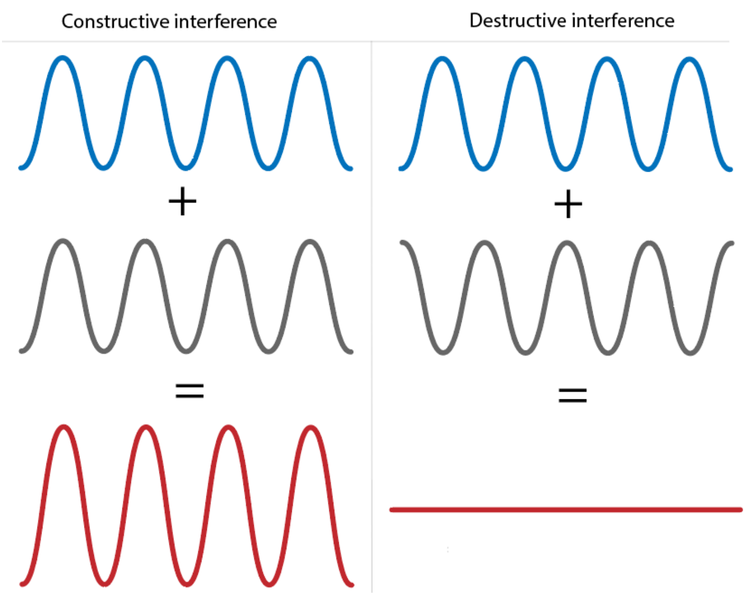

Figure 2: Constructive and Destructive interference

A typical received signal strength (RSSI) in a fading environment is shown in Figure 3. Most radio designs by RTX employ antenna diversity i.e. using two antennas to avoid the ''deepest'' fades. However, it should be noted that even with a well-designed diversity system, the effect of fading cannot be completely negated, but only be limited to a certain degree.

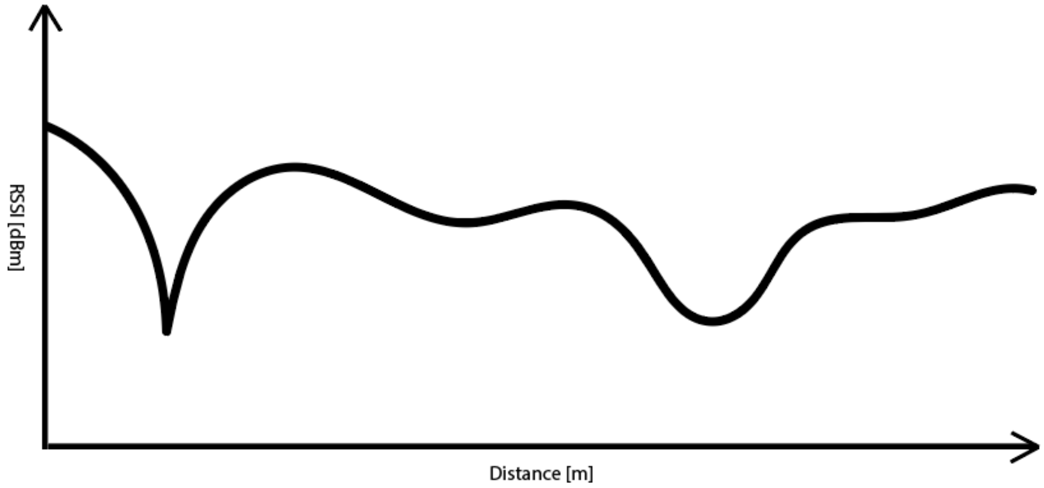

Figure 3: Signal strength in a fading *environment*

2.1.2 *Negative effects on antenna performance*

The range of a radio system is highly dependent on a well performing antenna(s). However, it is possible to affect the antenna performance in a negative way by changing its "environment". One example is the hand of the user - by placing the hand on or near the antenna area of the radio device, the radiated/received power will be reduced. Thus, leading to a reduction in the obtainable range. Other antennas near the active antenna can also reduce performance (due to coupling), even though they are not transmitting. This can also have a negative impact on antenna diversity performance.

For best antenna performance, the size of the antenna is given by the frequency (normally ¼ wavelength). Maximising antenna performance typically requires a certain distance to metals and free space around the antenna(s). However, this is not always practical from an industrial/ mechanical design point of view. In these cases, a compromise could be made in the radiation pattern of the antenna, hence requiring careful design of the antenna(s).

2.1.3 *Radio path blocking*

This might seem obvious but blocking the radio signal path with e.g. a wall, will cause a reduction in the obtainable range of a radio system A less obvious case is, when the signal between the transmitter and receiver is being blocked by the body or hand of the user. In open field scenarios, this will cause a reduction in the radio signal and greatly reduce the range of the system. For indoor use, the direct path will be attenuated by the body. A shown in Figure 4, the radio signal will be reflected by the wall, ceiling, floor etc.. With antenna diversity i.e. deploying two antennas, some of the power in these reflections can be used constructively to mitigate some the effect of the signal attenuation due to the body, and thereby keeping a reasonably good link performance.

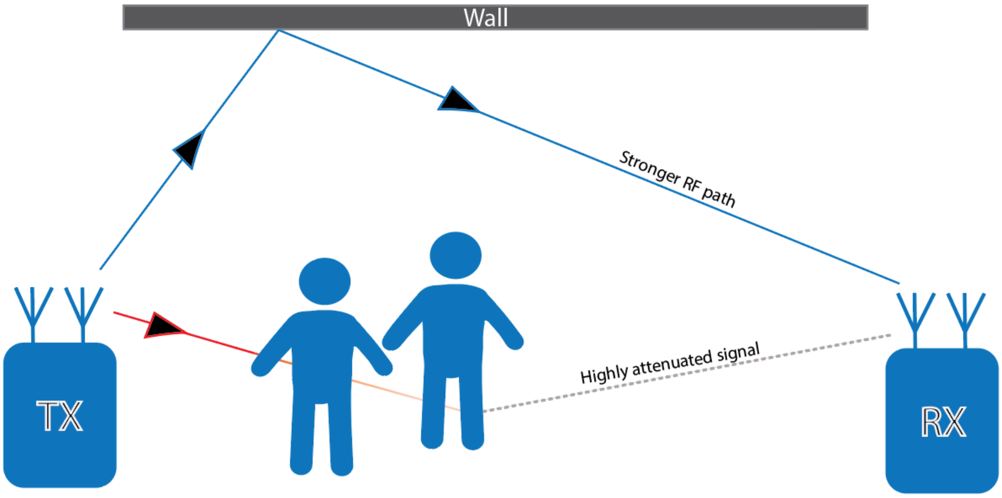

Figure 4: Direct RF path blocked by bodies

2.1.4 *RF interference from other radio devices*

A collision between transmissions from different radio devices is another major contributor in relation to reducing range performance of the wanted radio link. The following sub-sections outline some of the most common interferer in the 2.4 GHz band. In general, two effects occur in a shared radio spectrum:

1) destruction of the received signal due to the power of the interferer.
2) elevation of the noise floor creating a frequency dependent link budget.

It should be noted that interference is stochastic by nature, meaning that the RF level of the disturbance and the duration is varying in a non-deterministic way over time.

2.1.5 *Wi-Fi*

The channel width of a Wi-Fi signal is 22 MHz, which allows for 3 non-overlapping channels in the 2.4 GHz band within a given area (Please note that the signal sideband extends well beyond 22 MHz).
In the more recent IEEE802.11n standard, 40MHz channels can be allocated allowing up to 2 non-overlapping channels, depending on the region of operation. Wi-Fi traffic is normally time sliced, meaning periods with high activity and other periods with low activity. Here, the RTX protocol takes advantage of the "gaps" between non-overlapping Wi-Fi channels - however, this will still result in some reduced range performance. To a achieve best performance, RTX recommends that at most two thirds of the 2.4 GHz spectrum is utilized by Wi-Fi in a given area. Please note that a single base/receiver system is assumed here, but even with this criterion fulfilled, the sidebands of the Wi-Fi transmitter will reduce the operating range of the system - such as the scenario is illustrated in Figure 5. The side band of the WiFi is efficiently raising the noise floor, which

results in a lower SNR, thus limiting the range. This effect can't be mitigated by other means than distance both in frequency and physical.

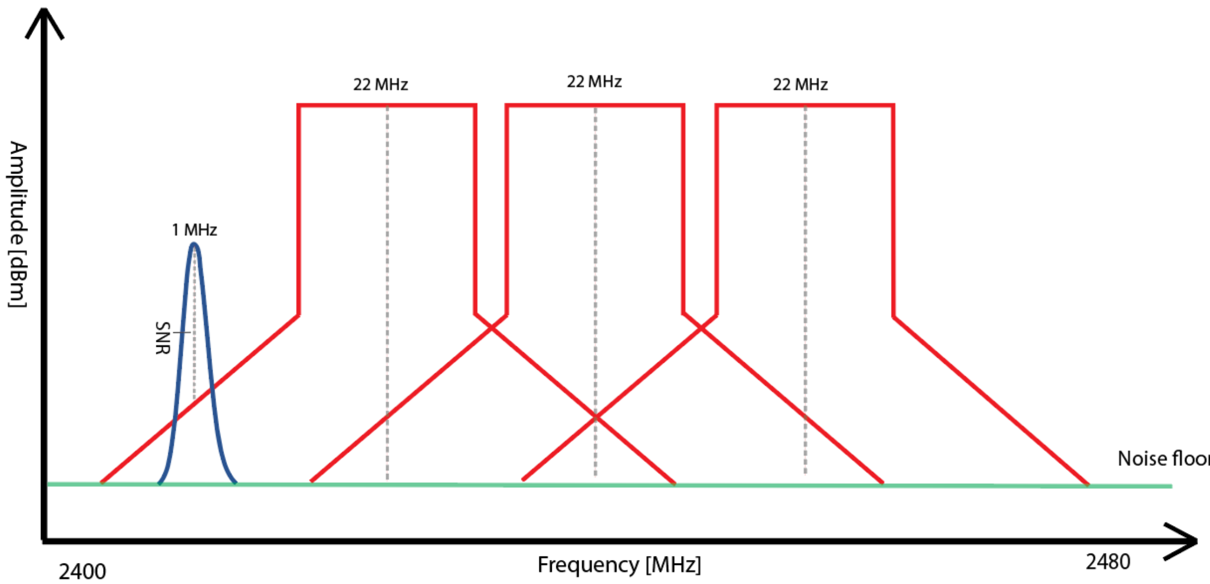

Figure 5: Narrowband signal with reduced SNR due to WiFi sidebands

2.1.6 *Bluetooth and other frequency hoppers*

Frequency hopping devices (especially Bluetooth devices) are native to the 2.4 GHz spectrum and are characterized by constantly changing transmit frequency. This yields problems for other devices with a high requirement for QoS, as there is no way to avoid collisions. Recent EU regulations requires a high-power frequency hopper to scan for fixed frequency devices (such as the RTX system) prior to using the spectrum and to exclude the channel from the frequency hopping set, if such devices are found. This along with the RTX proprietary "retransmission" feature (duplicating the packet on another frequency and time slot) helps to avoid the worst problems with frequency hoppers.

2.1.7 *Fixed frequency narrowband devices*

These devices allocate one or more channels in the 2.4 GHz band and typically stay on this/these until the QoS of that frequency is unacceptable. The device then changes frequency based on some predefined handover scheme - and this is also how the RTX system operates. These interferers typically do not pose problems as detecting and avoiding them is a relatively easy task for the radio protocol. Such a co-existence scenario is shown in Figure 6. Radio spectrum is limited, and problems can occur if many devices are competing for the same part of the 2.4 GHz spectrum.

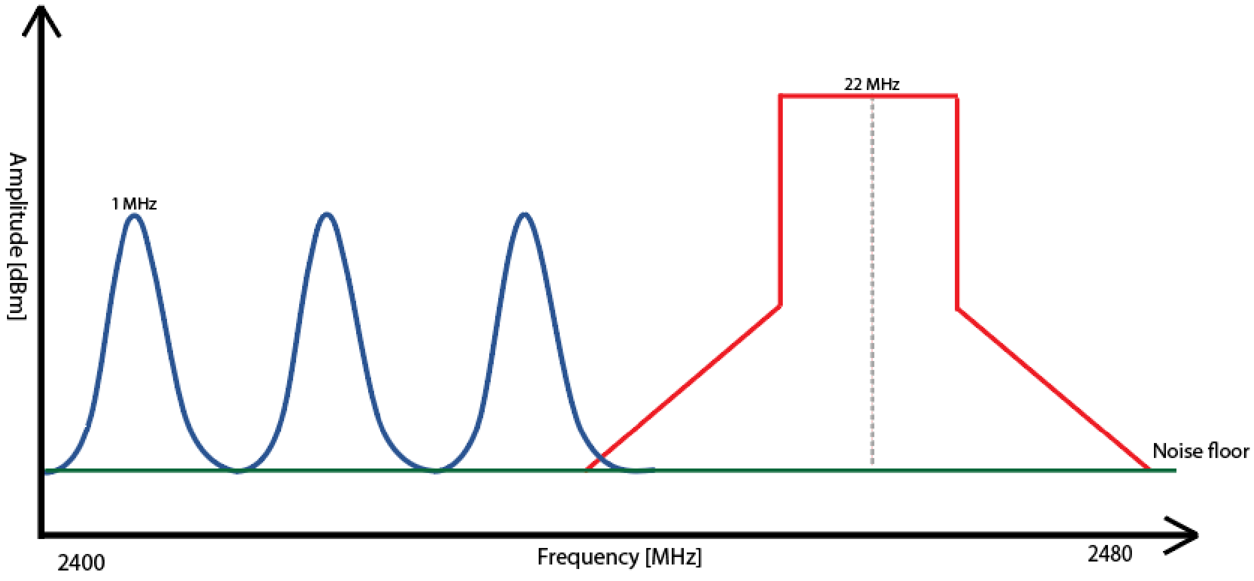

Figure 6: Narrowband signals co-existing with WiFi

2.1.8 *Blocking of radio receiver*

A primary reason for the degradation in performance, is when an amplification stage in the receiver chain is overloaded and causes receiver blocking. This can occur when a strong out-of-band signal from an unwanted frequency i.e. wireless device, appears in the same radio spectrum.

If two or more radio devices are in close proximity to each other, there is a risk of one device transmitting, while the other is trying to receive a weak signal. This is shown in Figure 7, where the middle narrow band i.e. a neighboring frequency, in a disruptive manner interferes the channel between the transmitter and the receiver, causing blocking. Please note that Figure 7, is only depicted on the in-band case. However, receiver blocking can be negated during the design of the radio. When a receiver is blocked by a strong RF signal, reception on all channels will be affected, thus channel handover will not help in this case. To avoid blocking when running multiple systems in a rack, RTX uses a sync signal to ensure that either transmission or reception occurs at the same time for all synchronized devices. But other non-synchronized systems within a short distance may lead to blocking issues. For best result, unsynchronized devices should be place at least 1 meter apart.

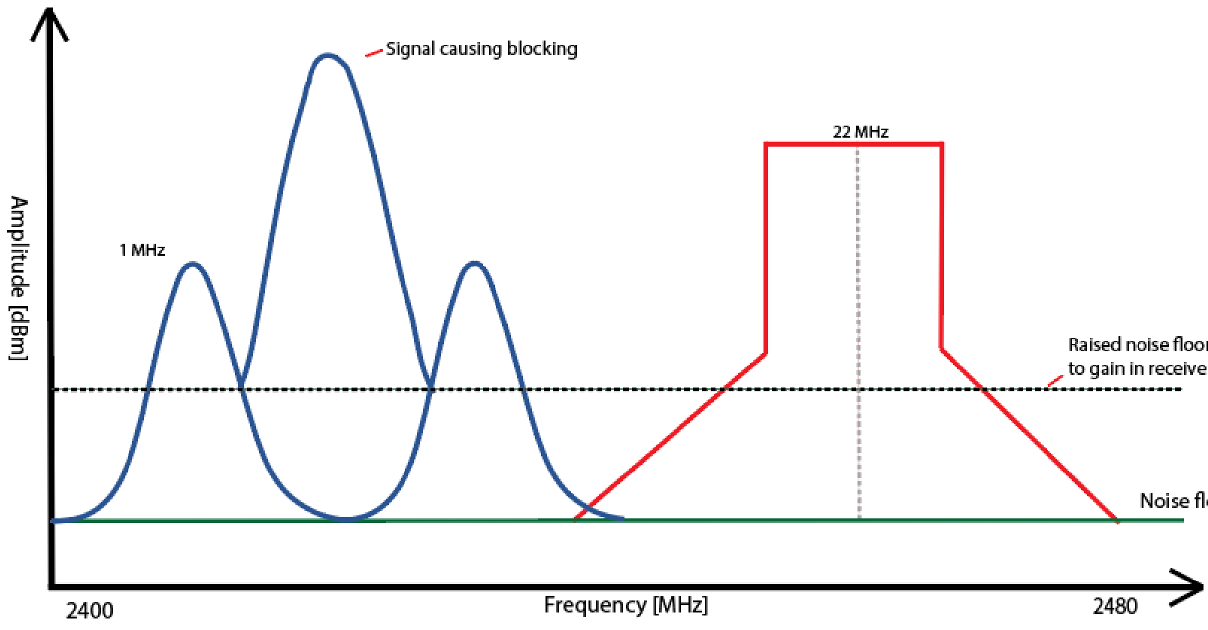

Figure 7: Receiver blocking scenario

2.2 Indoor radio range

The range of a radio system will typically be lower in an indoor environment due to obstacles (walls, furniture etc.) - some of the parameters influencing the range of a wireless system are mentioned in section 2.1. If the spectrum is not heavily loaded (i.e. multiple overlapping Wi-Fi access points and/or many Bluetooth devices are not in the vicinity) it is RTX's experience that a range of 20-60+ meters is achievable for high quality audio streaming devices compliant to ETSI 300 328, running non frequency hopping and output power of 10dBm (EIRP). This range is defined as the point at which only a few dropouts are experienced. Even with a body attenuating the signal between the transmitter and receiver, the above stated range is achievable. It is emphasized here that range in an audio system is not completely objective, as the experience of dropouts in an audio stream varies from user to user and highly depends on the audio content transmitted. Therefore, it is imperative that evaluation of radio performance is aligned between RTX and the costumer at an early stage in the project - preferably by a joint range test. A suggestion for a range test procedure is described in chapter 3.

2.3 Outdoor radio range

The range of a radio system in an outdoor environment is also affected by some of the parameters from section 2.1. However, the reason for a lower range, might not be as obvious as in the indoor case. In outdoor environments with no interferers and no large structures to reflect the signal, a typical line-of-sight range could be in the order of a couple of hundred meters. If the same test is conducted with the device located in such a way that the signal must pass through the body of a person, the range can be significantly shorter than the indoor range. This might come as a surprise, but the reason for this is the lack of reflections to "carry" the signal around the body. Thus, in this case reflections can be helpful. Special care should be taken if the

system is deployed in an area with large reflecting structures or at distances in the range 25-100 meters, as long delay path reflections and interference can cause irreducible packet loss
Telecommunications infrastructures can transmit signals up to 40 dB higher than the wanted signal. Even when a radio tower seems to be far away from the operating site, this should still be taken into consideration. This problem can be largely negated during the radio design process. Consequently, range is very much dependent on the environment in which a wireless system is deployed, and therefore, to recap, a specific test procedure for range test should be agreed between RTX and a customer. A suggestion for a range test procedure is described in chapter 3.

3 Range test

To ensure reproducibility when conduiting range test, it is important that the person(s) performing the test consider the environment in which the test is conducted. The environment includes the physical dimensions of the test site, whether the environment is “indoor” or “outdoor” and it should furthermore, include the parameters affecting radio performance such as the current interference level (e.g. measured and recorded through a spectrum analyzer, or preferably a scanning receiver capable of generating a waterfall plot). The dynamic aspects (i.e. changes in interreference level) are also important to monitor. In section 3.1 the details of the proposed test procedure are outlined.

3.1 Test procedure

The suggestion from RTX on a range test procedure is described below. Basically, the test is divided into two separate test cases - one is conducted with static test positions at fixed distance intervals (e.g. 5 meters) and the second part is conducted as a walk test. During these tests it is important to note the physical environment including obstacles and materials. Also, beware of other people walking into the test environment during the test.

RTX suggest monitoring the RF spectrum before and during the test - preferably using a scanning receiver with the capability of monitoring both time and power at the same time (often denoted as a “waterfall plot”). Before the test is conducted, the interference level should be evaluated (e.g. are too many Wi-Fi systems active in the test area). During the test it is important to keep monitoring the RF environment to be able to correlate a changing environment with possible changes in performance. To make observation of link errors easier it is recommended to monitor the payload output. In case the payload is audio, RTX recommends recording the audio stream during the test and preferably recording a video at the same time, to be able to correlate any link errors with physical observations. Any radio equipment not directly involved in the test should be switched off. Please be aware that this also includes WiFi infrastructure and mobile phones (which cloud be set to flight mode). If conducting a side-by-side comparison between two devices, a minimum distance of one meter should be maintained unless these are devices which are in synchronization via a sync cable or an over the air synchronization procedure.

The test operator is part of the test setup, meaning that the person will influence the test result. The height of the operator can have an influence on the test in certain outdoor environments, but it is normally not a problem for indoor testing. Also, the test operator should be careful not to cover or partly cover the antenna area of the device under test. The radio path loss through the body of the test operator will have a large effect on the achieved range. It is recommended to perform each test case twice, one test with at direct line-of-sight between that transmitter and receiver and the second test with the body of the operator deliberately blocking line-of-sight.

3.1.1 *Test case 1: Static positions*

During this part of the test, the link quality is monitored at fixed intervals (e.g. 5 meters), as shown in Figure 8. The test is conducted for a period of 5-10 minutes at each position. The reason for the long observation period at each position is the dynamic nature of the radio environment in the 2.4 GHz band. By observing for a longer period and accepting a fixed number of packet losses, the range can be found as the point at which this number starts to increase rapidly.

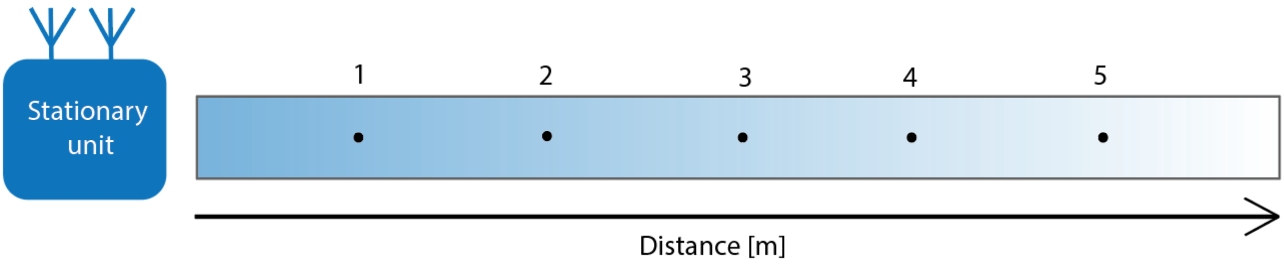

Figure 8: Range test path

3.1.2 *Test case 2: Walk*

During this part of the test, the link quality is monitored constantly during walking through the test range there should be direct line of sight between the device being moved and the stationary unit during the walk. In this test, a video recording of the test with a camera located at the position of the stationary unit in Figure 8 is especially beneficial. When the operator reaches one of the positions from Test case 1: Static positions, the operator should wait 15 sec at the new position, then rotate 90 degrees clockwise and stay in that positions of 15 sec. The operator repeats this rotation until the device is again pointing directly toward the position of the stationary unit, before walking toward the next position.
When evaluating the results, the number of dropouts is counted for the walk between points, 0 deg position, 90 deg position, 180 deg position and 270 deg position and logged e.g. into a spread sheet, please see Table 1 for a suggestion. By repeating this test, several times, the statistical properties of the radio environment can be minimized, hence recording the point at which the performance degrades below the acceptance criteria each time. A box plot can be useful for displaying such data. This point should preferably be at the range or close to that point as defined in Test case 1 above. The walk test is conducted to ensure that the dynamic performance of the radio system (e.g. antenna diversity) is operating as intended.

position	5 meters	10 meters	15 meters
Walk	1	1	1
0 deg	0	1	0
90 deg	1	2	1
180 deg	5	7	5
270 deg	1	1	2

Table 1: Range results