WHITE PAPER

Improving Range with ConcurrentConnect™ Antenna Diversity

Introduction

Qorvo's ConcurrentConnect technology addresses four system design challenges important for user friendly, frictionless, and reliable communication in small and attractive form factors.

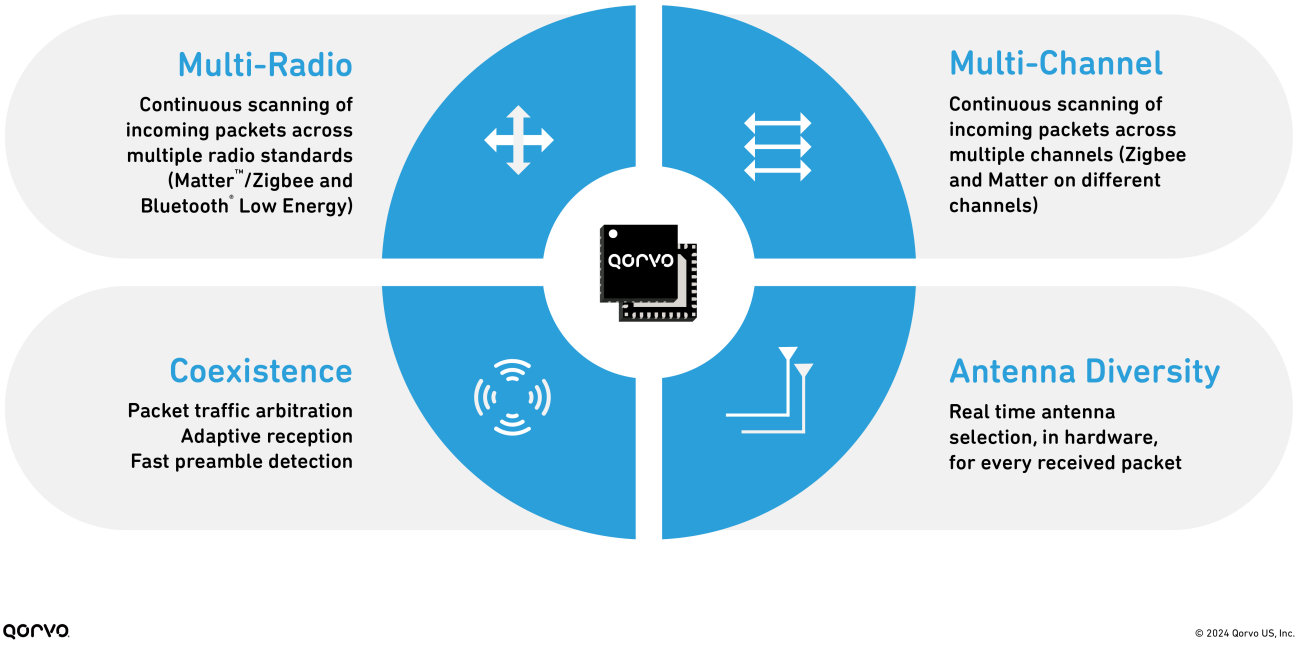

Figure 1: Overview of the four aspects/quadrants of ConcurrentConnect technology.

Qorvo's ConcurrentConnect antenna diversity technology for low-power wireless controllers delivers superior range and reliability in typical indoor environments. The elemental algorithm is embedded into the hardware of Qorvo's communication controllers. So, it is fast, accurate, cost effective and user-transparent.

This paper discusses the performance benefits of this technology and its ease of deployment in connected devices operating in constrained environments.

Table of Contents

Background

The IEEE 802.15.4 standard for low-rate wireless networks has grown over the past 20 years to cover around 20 different PHYs operating in a number of frequency bands. One of the most successful PHYs in this standard is the IEEE 802.15.4 OQPSK PHY, operating in the 2.4 GHz band. It was one of the original IEEE 802.15.4 PHYs already present in the first IEEE 802.15.4 standard, and powers well known smart home standards like Zigbee, Thread and the upcoming Matter standard.

In this context, many techniques were developed to improve the radio link of low power wireless devices based on the IEEE 802.15.4 standard. One of these techniques is antenna diversity where two or more antennas are used to enhance the communication between radio devices. It is particularly beneficial for indoor environments, where RF signals are subject to reflections, attenuations, interference, and distortions resulting in lost connections and limiting the communication range.

An effective antenna diversity implementation will increase the receiver's capability to detect signals by selecting, in real time, the antenna with the best communication link. This increases the chance of receiving the data and reducing connection loss.

However, antenna diversity can pose additional challenges in design complexity and in the effectiveness of the algorithm used for antenna selection. These challenges include the extra processing required which, if not optimized, can lead to an increase in the system's energy consumption. In addition, a multiple antenna design will require more space than a single antenna.

Qorvo's ConcurrentConnect antenna diversity technology solves these challenges using a unique algorithm. This technology can be combined with compact antenna design techniques targeted for small form factor IoT devices.

Qorvo Antenna Diversity Technology

Qorvo has fielded hundreds of millions of devices with its ConcurrentConnect antenna diversity technology, which offers unique benefits compared to alternate approaches to antenna diversity.

Qorvo's Rx diversity algorithm is implemented in hardware. A simplified flowchart is shown in **Figure 2**. Correlation is performed in parallel, enabling selection of the antenna within a few microseconds. The IEEE 802.15.4 signal SNR correlation is used, which has a higher accuracy compared to methods such as RSSI.

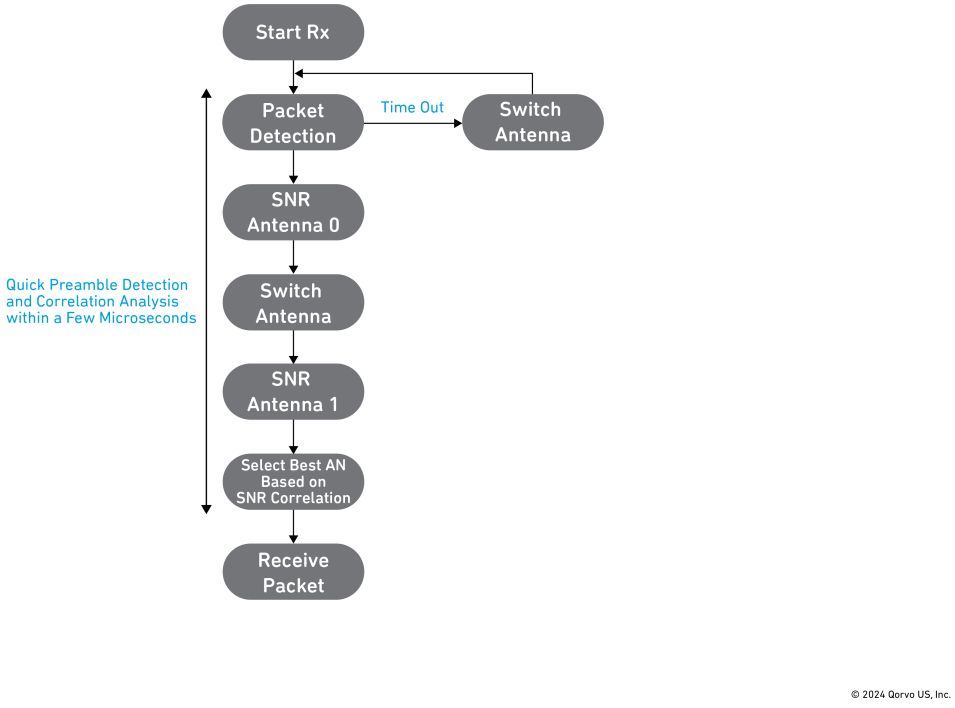

Figure 2: Simplified flowchart of the ConcurrentConnect antenna diversity algorithm.

Implementing the algorithm in hardware is not only fast but also completely transparent to users – typically OEM companies. Furthermore, by integrating the switch on the chip, Qorvo's antenna diversity ensures a simple design without requiring any special RF knowledge or software management.

Conventional methods found in low-power IEEE 802.15.4 wireless controllers are limited to supporting receive diversity in sub-GHz protocols. Moreover, the conventional techniques require relatively longer time for packet detection and best antenna selection which is translated to longer processing time and thus more power consumption. Qorvo's approach achieves fast detection of a valid preamble and antenna selection within the preamble time.

This is explained with the help of a receive timing diagram of an IEEE 802.15.4 data packet shown in **Figure 3**. The length of one symbol is 16 µs. Once a packet is detected and analyzed on one antenna slot, the second antenna is selected, and the same analysis takes place on this antenna. The antenna that has the best (or sufficient) result will be selected for receiving the rest of packet, eliminating interference and other environmental challenges that impact performance.

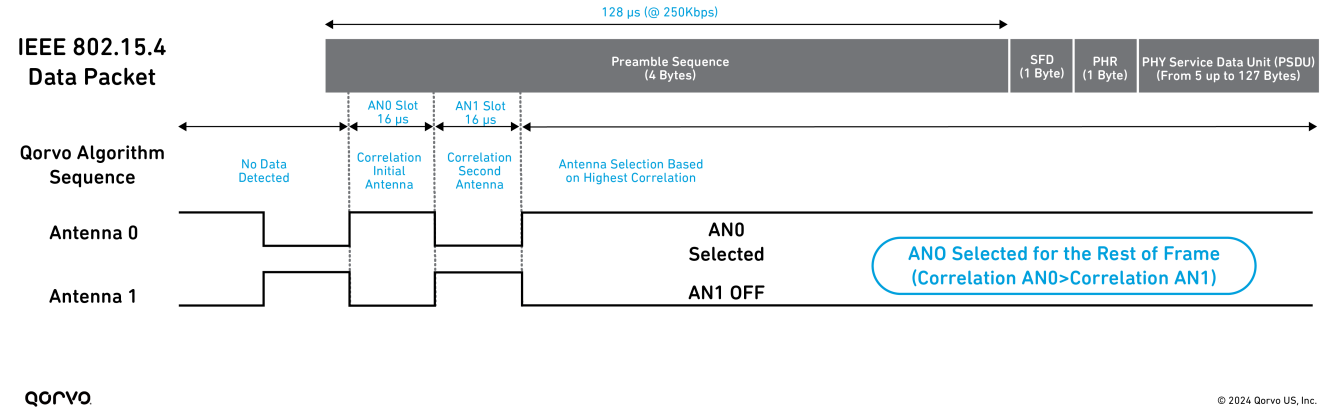

Figure 3: Qorvo Rx diversity algorithm sequence.

An additional benefit of Qorvo's algorithm is that it supports antenna diversity on three different RF channels. This is shown with the help of the timing diagram in **Figure 4**. For 3-channel antenna diversity, the 16 µs slots are analyzed in a time-multiplexed fashion: CH0AN0, CH0AN1, CH1AN0, CH1AN1, CH2AN0, CH2AN1. As soon as a packet is detected on one of those slots, the device switches to the other antenna on the same channel where the packet was detected and selects the antenna with the best result.

For example, as shown in the Figure 4, if the packet is detected on slot CH1AN1, instead of going to CH2A0, the device will check CH1AN0 and will select the antenna with the best result to detect the rest of the packet. Due to increasing number of connected devices in home, office and commercial environments, reliability of multi-channel functionality continues to gain importance.

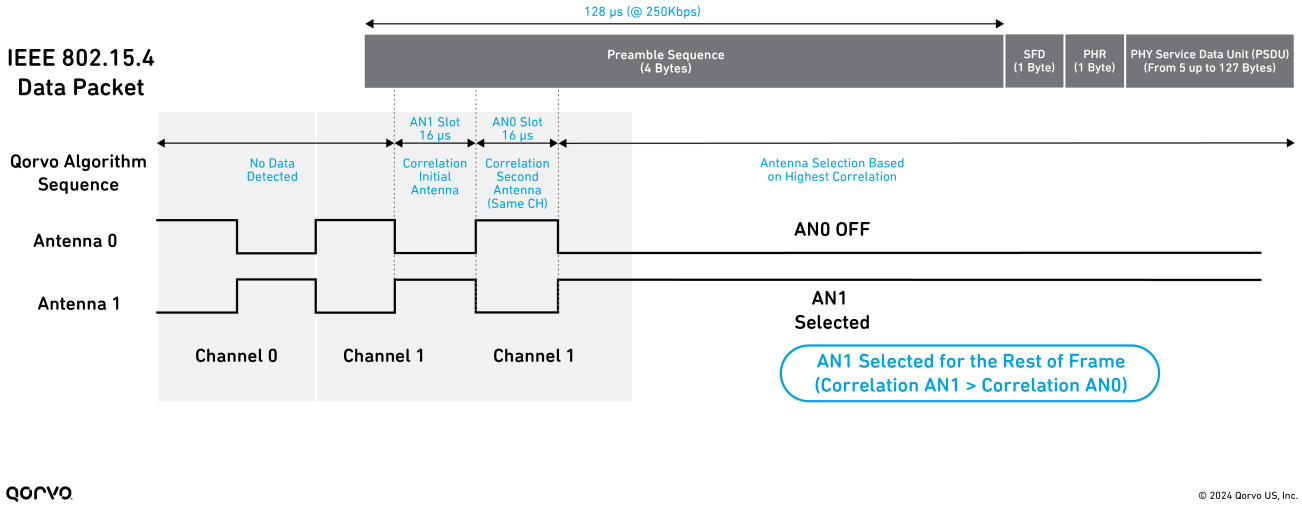

Figure 4: Qorvo Rx diversity algorithm sequence for ConcurrentConnect multi-channel operation mode.

Range Improvement with Antenna Diversity in Different Environments

This section presents simulation results using the following Qorvo radios: QPG6105 used as end node (Tx) with QPG7015M used as gateway/router (Rx).

Figure 5 and **Figure 6** compare the communication ranges with and without Qorvo antenna diversity technology at different noise levels. Two different indoor environments were considered: **residential apartment** (multi room) and **open office** (single room).

The building construction attenuation is more significant in a multi room residential apartment, resulting in a shorter communication range compared to an open office or single room.

For the residential apartment, the pathloss model in Figure 5 uses one brick wall and one aerated (cellular) concrete wall for the line-of-sight material. Their attenuations are respectively 8 dB and 4 dB. Range is calculated using a Tx power of 10 dBm and 20 dBm at QPG6105 and QPG7015M respectively, and with antenna gain of -2 dBi.

The noise levels on the vertical axis are the average noise levels from external noise sources (Wi-Fi, Bluetooth etc.).

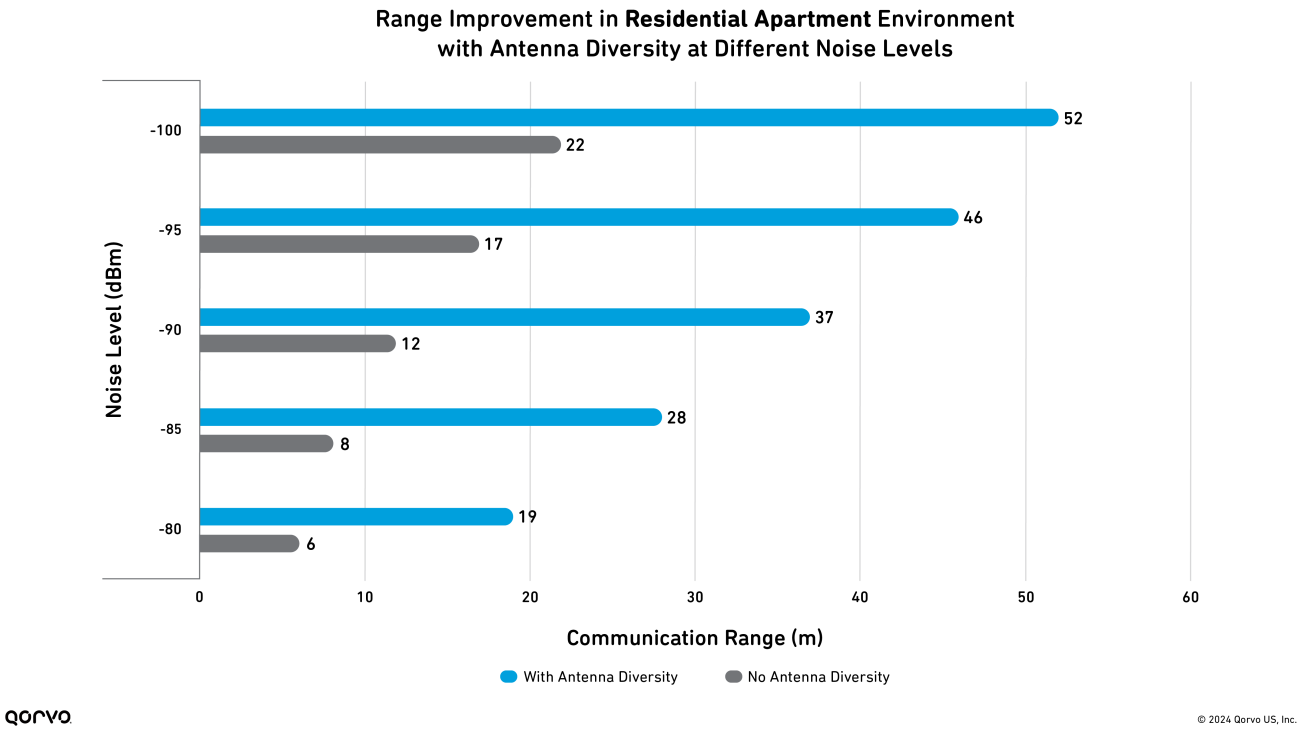

Figure 5: Communication range between QPG6105 and QPG7015M with and without antenna diversity (residential apartment environment).

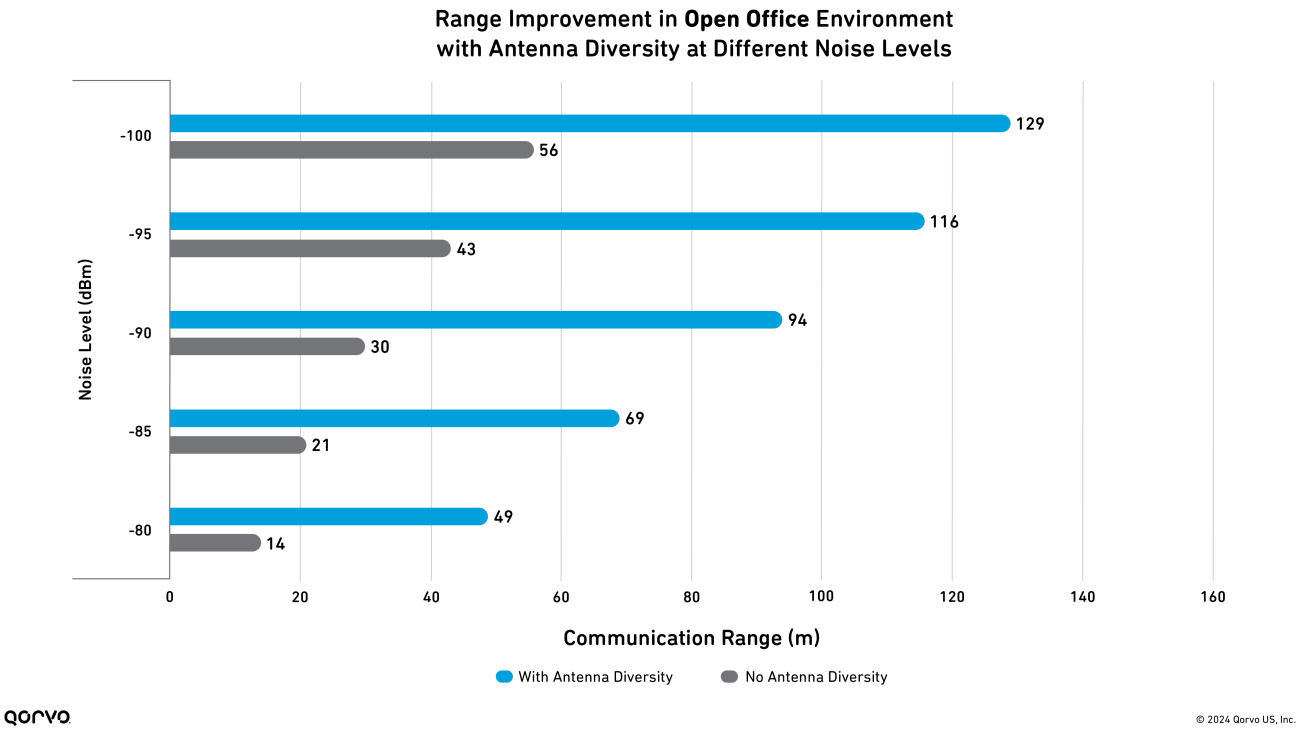

Figure 6: Communication range between QPG6105 and QPG7015M with and without antenna diversity (open office environment)

For both environments, results show that Qorvo's antenna diversity technology significantly enhances the communication range.

Measurements of Antenna Diversity Gain in Office Environment

This chapter section demonstrates the improvement in communication link budget, based on Qorvo antenna diversity, in an office environment with random people mobility and Wi-Fi interference. The measurement setup consists of a Tx device (QPG6100) placed in a fixed position and with non-line of sight to the Rx device (QPG7015M) as shown in **Figure 7(a)**. On the Rx side, the receiving device is placed on a rotating table with a slow[1] rotating speed to create fading during testing. See **Figure 7(b)**.

Due to random changes in the environment (for instance due to movement of people inside the office), multiple boards were measured simultaneously and repeatedly, the antenna diversity performance was averaged to decrease the effect of environment changing over time.

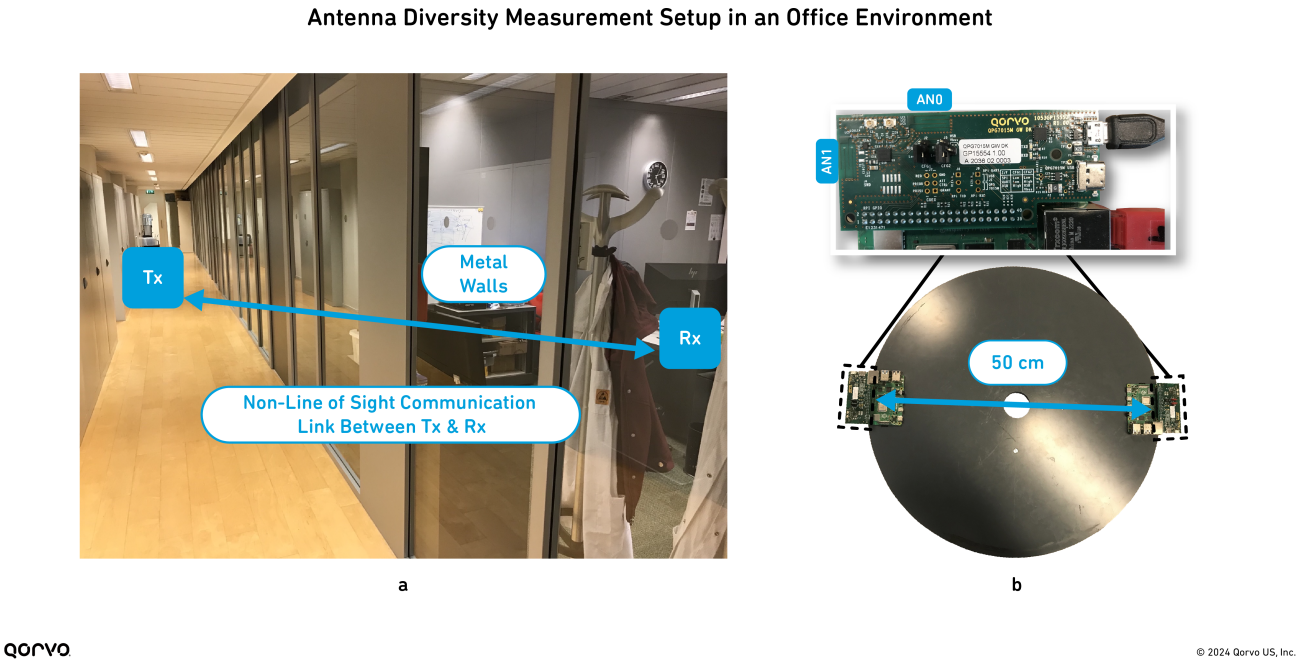

Figure 7: Antenna diversity measurement setup in an office environment:
a) Multi-path communication link between Tx and Rx.
b) Multiple Rx devices placed on a rotating table to create fading during testing.

Antenna diversity performance is analyzed based on a range test where the Tx device transmits 5000 packets with 100 ms packet interval and 5 MAC retries. Data transmission is considered successful when acknowledgment (ACK) is received by the transmitter (QPG6100). To guarantee a symmetrical link budget during packets transmission and ACK reception, the Rx (QPG7015M) device was set to transmit ACKs with the same power level as the Tx device.

[1] 'Slow' in this context means that the radio channel properties do not change during packet transmission and ACK reception of the initial packet AND the retries. To get realistic results, it should be prevented that the rotating table moves the device out of a fade for the retries.

Figure 8 below shows the results of range tests based on sweeping the Tx power and counting the number of ACKs received at each power step with and without antenna diversity. At the range limit, defined by the 1% message error rate (MER), antenna diversity showed a significant improvement in communication link by around ≈ 7 dB compared to single antenna results.

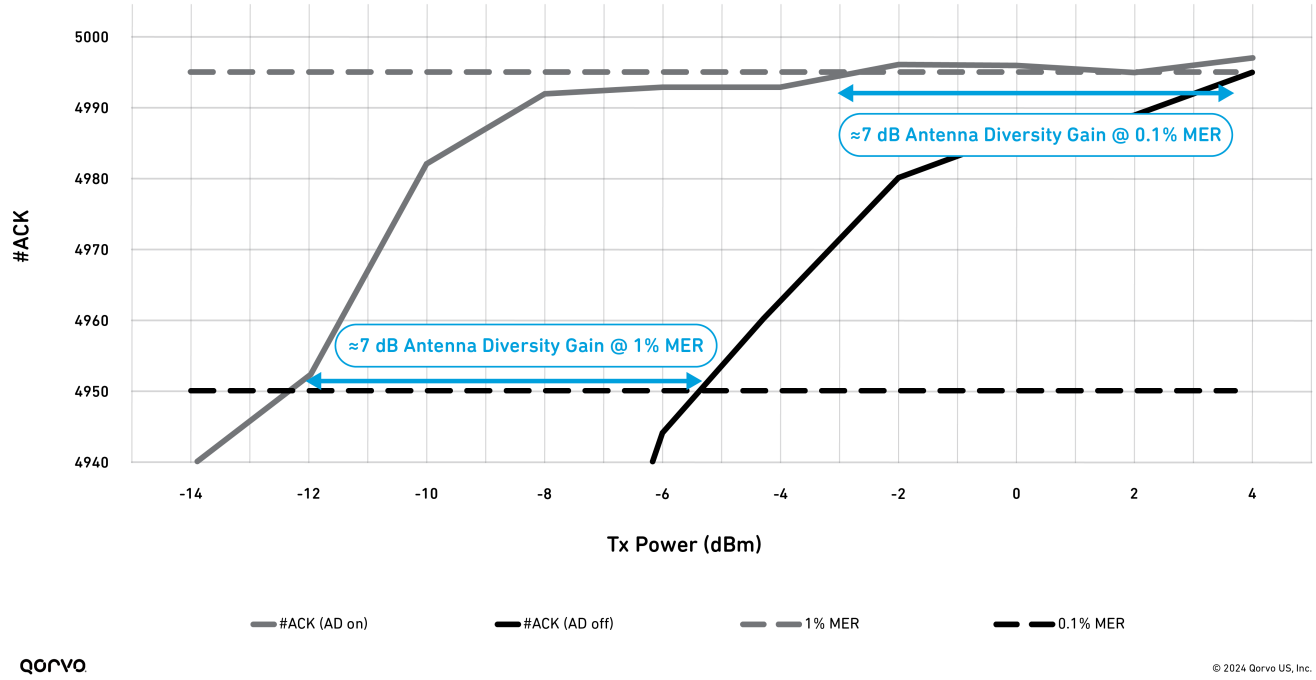

Figure 8: Range test with and without Rx antenna diversity.

This performance can be further improved by also enabling diversity on the Tx device as shown in **Figure 9**. Compared to the previous range test analysis (Figure 8), the antenna diversity gain increased to ≈ 8 dB at 1% MER and ≈ 12 dB at 0.1% MER.

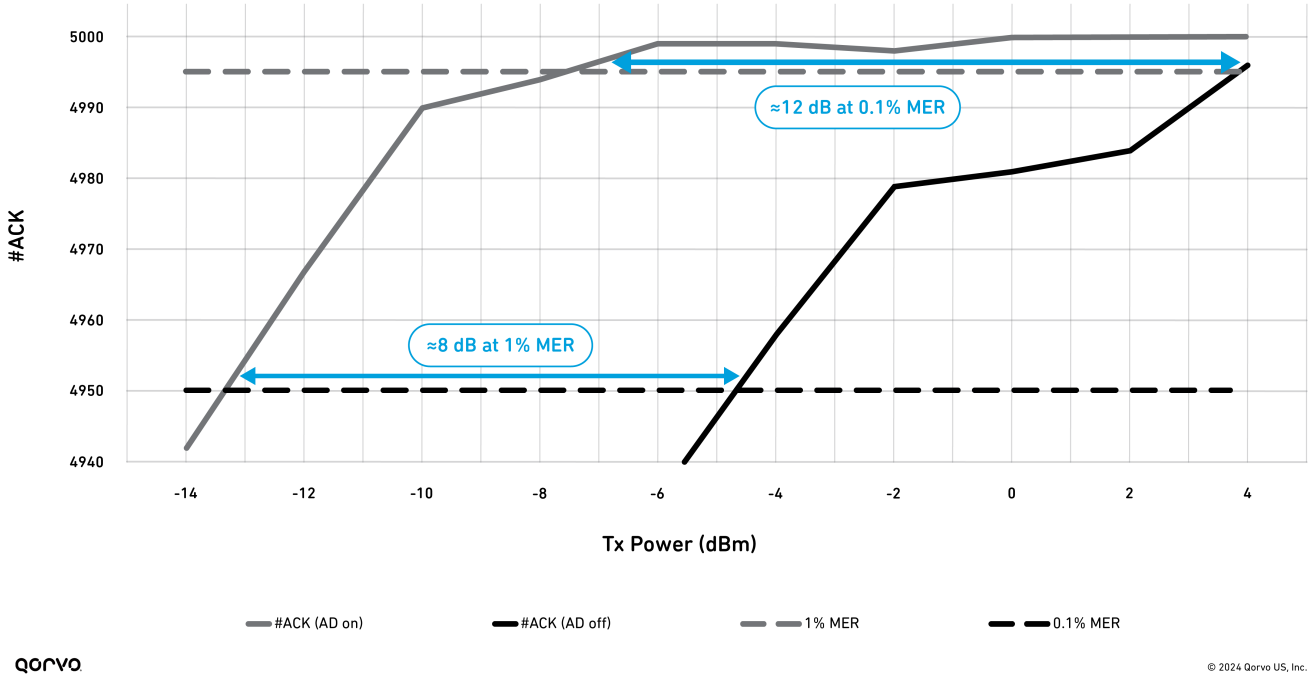

Figure 9: Range test with and without Rx antenna diversity enabled for ACK reception.

These results show that Qorvo's antenna diversity solution has superior reliability as distance between transmitters and receivers is increased (lower Tx power), whereas a significant loss in reliable range is noticed in the alternative solution based on single antenna. Selecting the best antenna, based on SNR, is a powerful tool in a noisy environment and fading environment. As both the noise and the wanted signal are fading, the RSSI and the SNR on both diversity antennas will vary continuously.

Conclusions

As the IoT expands, system engineers and IoT device manufacturers face the challenge of ensuring their sensors, and other devices, communicate quickly and perform reliably with good range – even when multiple new devices are added. Qorvo ConcurrentConnect antenna diversity implements a quick preamble detection algorithm in its low-power wireless chip portfolio, which makes it very easy to build a best-in-class system solution. This makes Qorvo uniquely positioned to deliver the reliability benefits of antenna diversity for small form factor IoT devices.

In summary, Qorvo's antenna diversity technology offers the following unique benefits:

- Antenna diversity is implemented within the hardware, performs correlation in parallel, fast, and transparent to the customer. Interference is reduced efficiently. No external antenna switches needed.
- The utilized SNR correlation is more accurate in selecting IEEE 802.15.4 signals compared to other methods.
- Qorvo’s antenna diversity implementation integrates seamlessly into Qorvo’s ConcurrentConnect multi-channel operation due to its fast selection.

References

[1] IEEE 802.15.4: IEEE Standard for Low-Rate Wireless Networks

[2] Reference Design Description QPG7015M; Qorvo document GP_P1053_RDD_15950

[3] QPG7015M Data Sheet; Qorvo document GP_P008_DS_13639

[4] QPG6105 Data Sheet; Qorvo document GP_P008_DS_17366

[5] ConcurrentConnect Coexistence Application Note; Qorvo document GP_P008_AN_20238

[6] GP_P414_TR_15190_802.15.4_Indoor_Range_Calculation_Tool.xlsm