KW41Z IEEE 802.15.4 and BLE Coexistence Performance

MWS module

Contents

1. About this manual

This document aims to evaluate the performance of KW41Z when there is multi-protocol coexistence in the same chip. The practical performance of an IEEE 802.15.4-based system concerning supporting empirical and simulated data.

KW41Z deals with two types of coexistence:

- Internal: Two protocols in the same chip (i.e., BLE + Zigbee)
- External: KW41 design + 2.4 GHz environment (i.e., Wi-Fi Routers, IEEE 802.15.4 networks, Bluetooth devices)

The KW41Z includes a 2.4 GHz transceiver that supports the following protocols:

- Bluetooth Low Energy (BLE)
- IEEE 802.15.4 (Zigbee, Thread …)
- Generic FSK

2. Introduction

2.1. IEEE 802.15.4

IEEE 802.15.4 is a Low-Rate Wireless Personal Area Network (LR-WPAN) standard aimed to provide simple, low-cost communication networks. LR-WPANs are intended for short-range operation and involve little or no infrastructure. The standard focuses on applications with limited power and relaxed throughput requirements, with the main objectives being ease of installation, reliable data transfer, low-cost and low-power.

This type of networks allows small, power-efficient, inexpensive solutions implementations for a wide range of devices. Low power consumption gets achieved by allowing a device to sleep most of the time, and only wake up into active mode for brief periods. Enabling such low duty cycle operation is at the heart of the IEEE 802.15.4 standard.

Wireless networks can be developed based directly on the IEEE 802.15.4 protocol or other protocol which is itself built on IEEE 802.15.4. For example, Zigbee PRO is built on top of the IEEE 802.15.4 standard and offers the additional functionality to implement mesh networking.

2.2. Bluetooth

Bluetooth Smart (BLE) operates in the 2.4 GHz ISM band and uses GFSK modulation. The bandwidth bit period product is 0.5 with a modulation index between 0.45 and 0.55.

BLE uses 40 * 1 MHz-wide channels, each separated by 2 MHz, three channels for advertising packets and 37 channels for data exchange. The channels numbered from 0 to 39. An adaptive frequency channel hopping mechanism is implemented for all data channels to ensure robustness and Wi-Fi coexistence. At the link layer level, the longest packet has 47 bytes from which 39 bytes is the maximum PDU length. The PDU is different for advertising channels and data channels.

At the GAP layer level, the roles that BLE devices may have are GAP Central and GAP Peripheral, as can be observed in *Figure 1*.

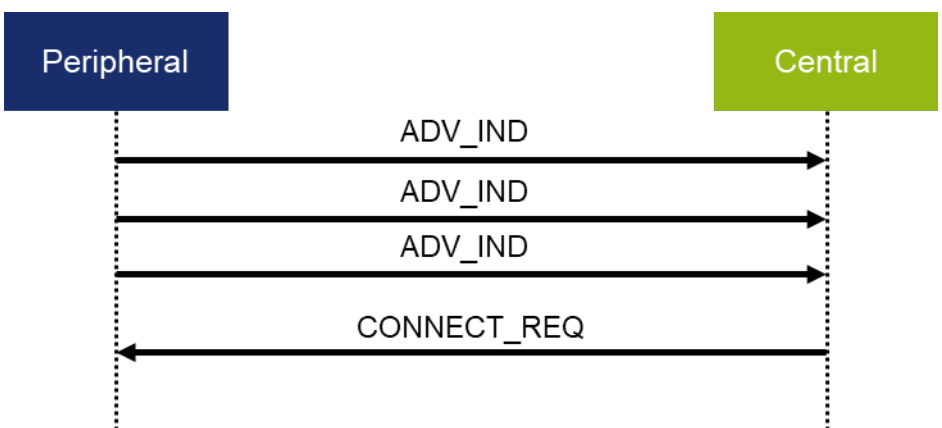

Figure 1. GAP peripheral and central

3. IEEE 802.15.4 coexistence features

The IEEE 802.15.4 standard provides several mechanisms to enhance coexistence.

3.1. Dynamic channel selection

The PHY layer provides the ability to measure the energy, and thus the interference, that is present on a particular channel. The MAC uses this capability, and higher layers allow users to select the best available channel for operation.

3.2. CSMA-CA

The Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA), channel access mechanism, is a **listen before you talk** strategy employed by the PHY layer, provides the ability to sample a channel and report whether the channel is **Clear To Transmit**.

3.3. Acknowledged transmission and retries

An acknowledged ACK frame delivery protocol is supported to ensure successful data reception. If the receiving device is unable to handle the received data frame for any reason, the message is not acknowledged. If the originator does not receive an acknowledgment, it assumes that the transmission was unsuccessful and retries the frame transmission. This is particularly useful in dealing with frequency hopping interference, such as the one coming from Bluetooth, which may interfere with a first transmission attempt but will usually have hopped to a different part of the spectrum for the retry.

4. 2.4 GHz transceiver multi-protocol operation

Both (BLE and IEEE 802.15.4) protocols must share the same 2.4 GHz transceiver resources.

Arbitration amongst Link Layers is software responsibility.

2.4 GHz transceiver hardware provides status bits for determining when a Link Layer is accessing the RF channel.

5. Mobile wireless systems coexistence

This device supports BLE and IEEE 802.15.4 protocols concurrently in a single chip. The SDK Connectivity software has a Mobile Wireless System (MWS) Coexistence block that arbitrates the use of the radio hardware resource. It is essentially a set of APIs that allow higher layers of the software to request access to the radio resource. MWS natively gives priority to BLE allowing it to abort ongoing IEEE 802.15.4 transactions even when these already started. If this happens, the IEEE 802.15.4 transaction restarts once the BLE transaction completes.

- MWS is a set of APIs included in the Connectivity Framework
- Allows Link Layers and higher layers control the access to the resources.

Figure 2 shows a software block diagram for a Link Layer coexisting two protocols BLE and ZigBee (IEEE 802.15.4 based protocol)

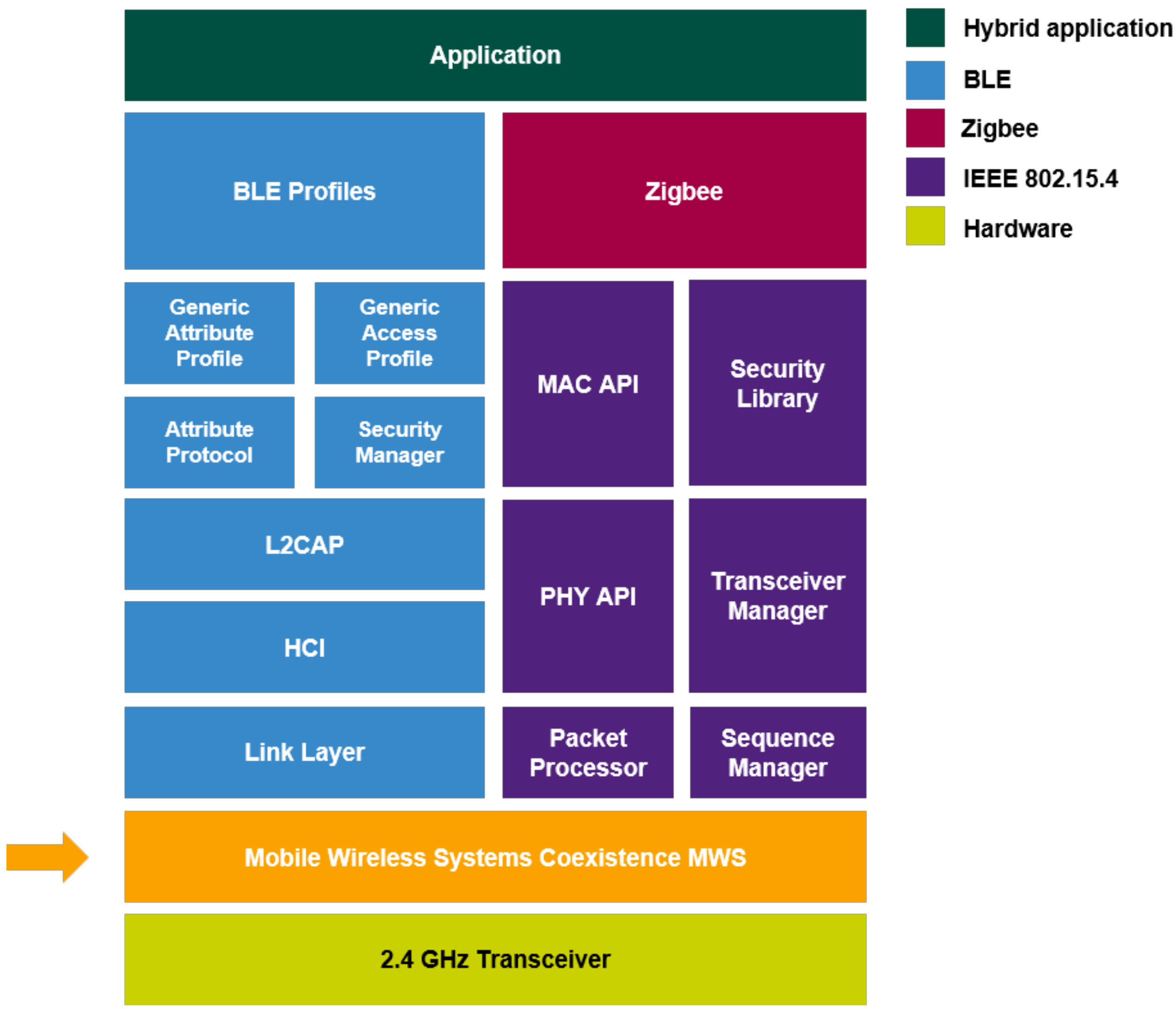

Figure 2. Mobile wireless systems coexistence

5.1. MWS important considerations

- The IEEE 802.15.4 link layer allows aborting ongoing transactions
- KW41Z BLE hardware connection manager does NOT allow abort ongoing BLE transactions
- In multi-protocol applications, BLE MUST take priority over IEEE 802.15.4
- Protocol priorities are set using macros

  framework → MWSCoexistence → MWS.h

Figure 3 shows how two applications: a BLE heartrate and Zigbee thermostat register, acquire and release control of the radio through MWS APIs.

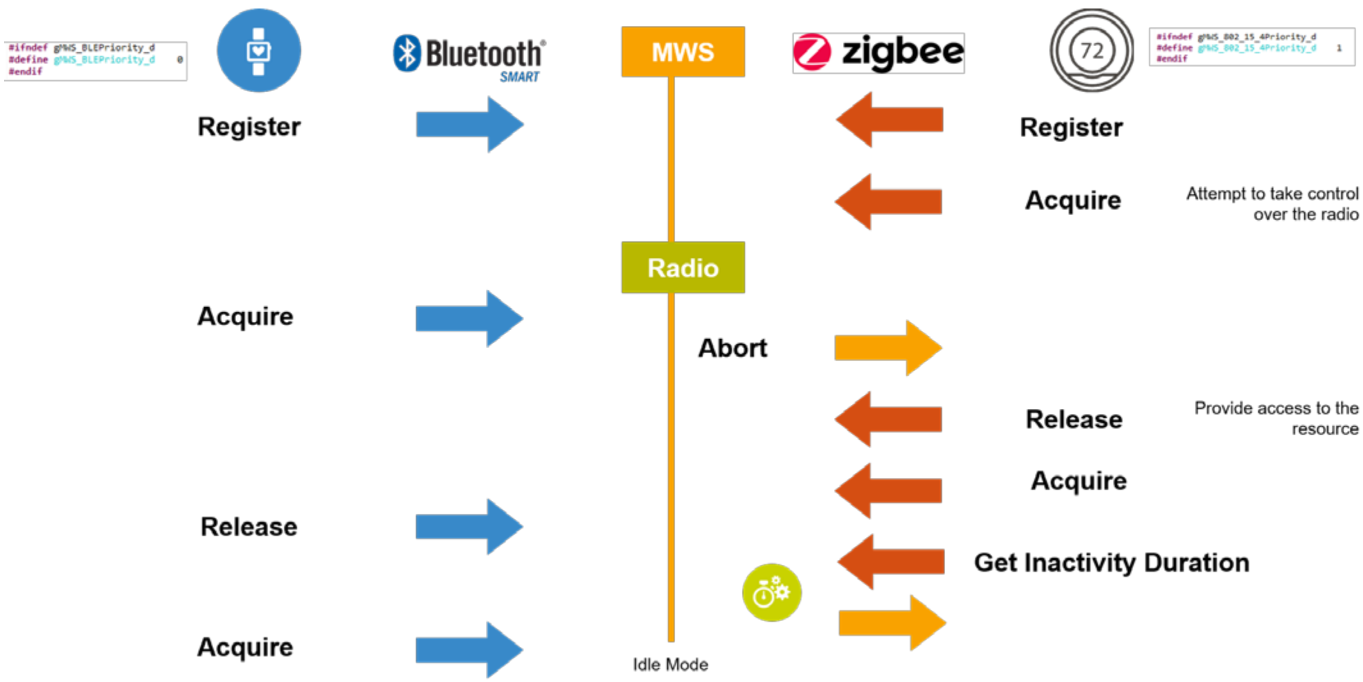

Figure 3. Coexistence of BLE heartrate and Zigbee thermostat

6. BLE + 802.15.4 Multi-Protocol – Initialization

Table 1 shows radio activity of the same applications in the time spectrum.

Table 1. Times for the coexistence of BLE heartrate and Zigbee thermostat

S.N.	Time (ms)	Radio activity		Comments
		Zigbee	BLE	
1				BLE registers using MWS_Register API
2				Zigbee registers using MWS_Register
3				Zigbee uses MWS_Acquire to get radio control, then creates a network
4	0			Configure BLE to start advertising every 200 ms
	25			
	50			
	75			
	100			
	125			
	150			
	175			
5	200			Advertising time arrives, Zigbee releases the radio using MWS_Release. BLE takes control through MWS_Acquire.
6	225			BLE ends its advertisement event, then releases the radio with MWS_Release. Zigbee acquires the control through MWS_Acquire.
	250			
	275			
	300			
	325			
	350			
	375			Advertising time arrives, Zigbee releases the radio using MWS_Release. BLE takes control through MWS_Acquire.
7	400			BLE ends its advertisement event, then releases the radio with MWS_Release. Zigbee acquires the control through MWS_Acquire.
8	425			
	450			

7. BLE + 802.15.4 Multi-Protocol – Connection

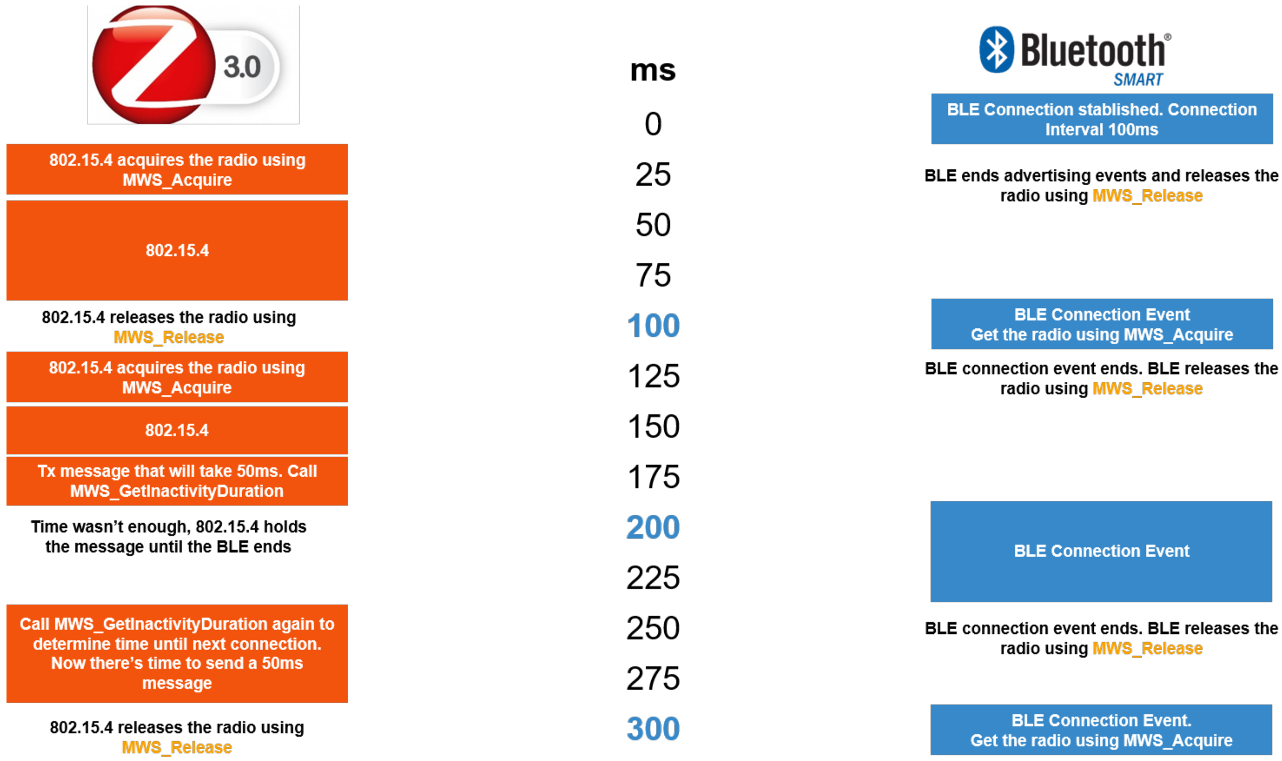

Figure 4. Connection

8. BLE + IEEE 802.15.4 coexistence PER test

A Packet Error Rate (PER) test was performed to determine the impact on IEEE 802.15.4 when both IEEE 802.15.4 and BLE protocols are running on the same device..

8.1. Test elements

- FRDM-KW41Z loaded with BLE server + 802.15.4 coordinator test firmware (hybrid device).
- USB-KW41Z loaded with 802.15.4 end device firmware (end device).
- BLE enabled smartphone

8.2. Topology

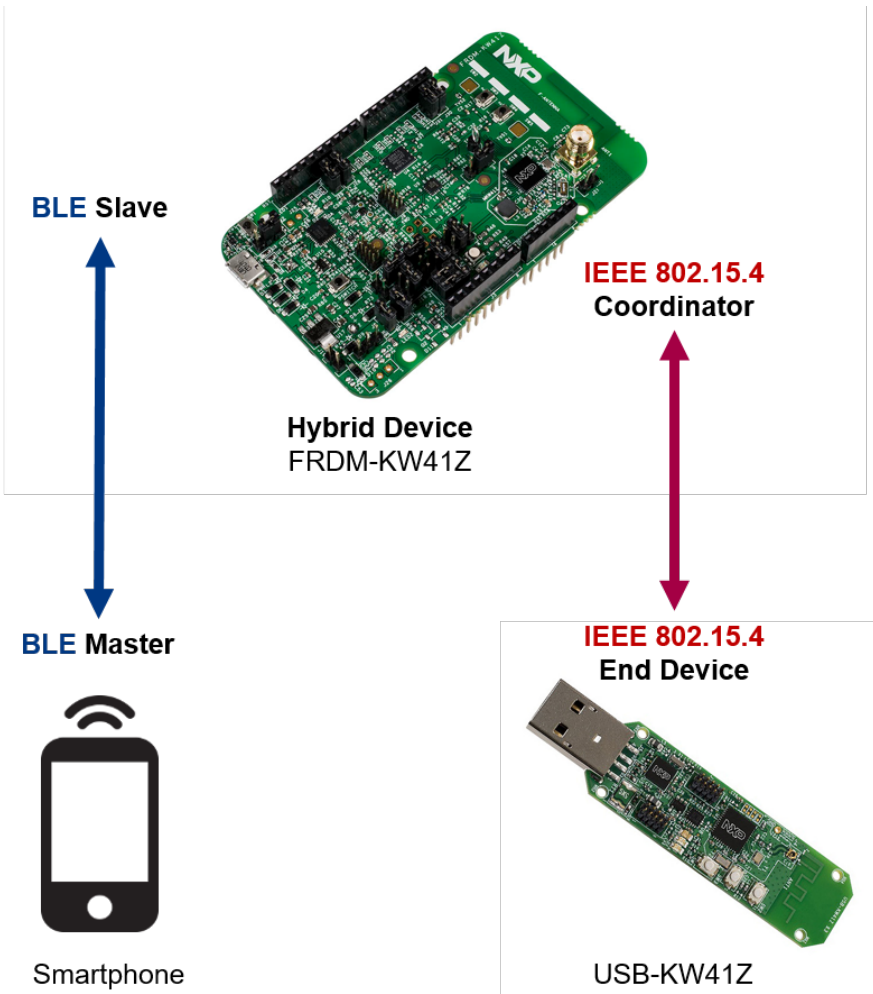

Figure 5. Topology

8.3. Test procedure

- The hybrid device is powered and creates a network over IEEE 802.15.4.
- End device is powered and connects to the Hybrid device network.
- The hybrid device starts advertising.
- Smartphone connects to the Hybrid device.
- 100 to 1000 packets are sent from the end device to the hybrid device with a variable time interval between packets (10, 50 and 100mS).
- The hybrid device counts the number of successfully received packets and calculates PER.
- BLE connection interval is modified to reduce/increase the time BLE takes control over the radio (15, 50 and 125 mS).
- IEEE 802.15.4 message acknowledge enabled/disabled to demonstrate the impact (disabling this feature also disables packet retry)

8.4. Test configuration

Test conditions

- Message Interval (802.15.4): 10 mS, 50 mS and 500 mS
- Number of Packets: 1000 (100 for the 500 mS message interval)
- Connection Interval (BLE): 15 mS, 50 mS, 125 mS
- Message Payload: 0 bytes, 60 bytes, or 100 bytes
- macMaxFrameRetries: 3 or 7
- 802.15.4 Message Acknowledge (Retry packet transmission when failing): Enabled, Disabled.

8.5. Correlation

(MIMS, Payload size, and Connection interval)

As FRDM-KW41Z uses the same radio to send the BLE and 802.15.4 packets, Message Interval in Milliseconds (MIMS), correlate payload size and connection interval with each other.

- MIMS and Payload size is related to 802.15.4
- Connection interval is associate to BLE
- If we increase the BLE connection interval, then 802.15.4 gets more time to send its packets and acquire the radio for more time
- If we increase the MIMS then 802.15.4 waits for more time to send the next packets
- If we increase the payload size, then 802.15.4 takes more time to send the packets and acquires radio for a long time

9. BLE + 802.15.4 coexistence PER test - Result analysis

1. **MaxMACRetries = 3, Distance <1 m VS Distance ~ 4 m**

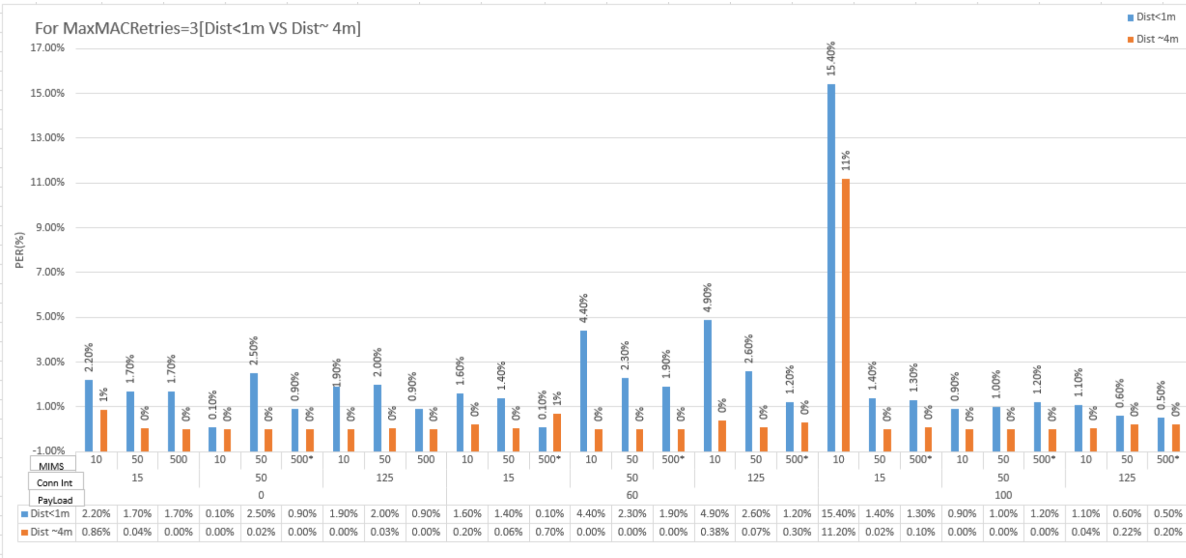

Figure 6. Result analysis 1

2. **MaxMACRetries = 7, Distance <1 m VS Distance ~ 4 m**

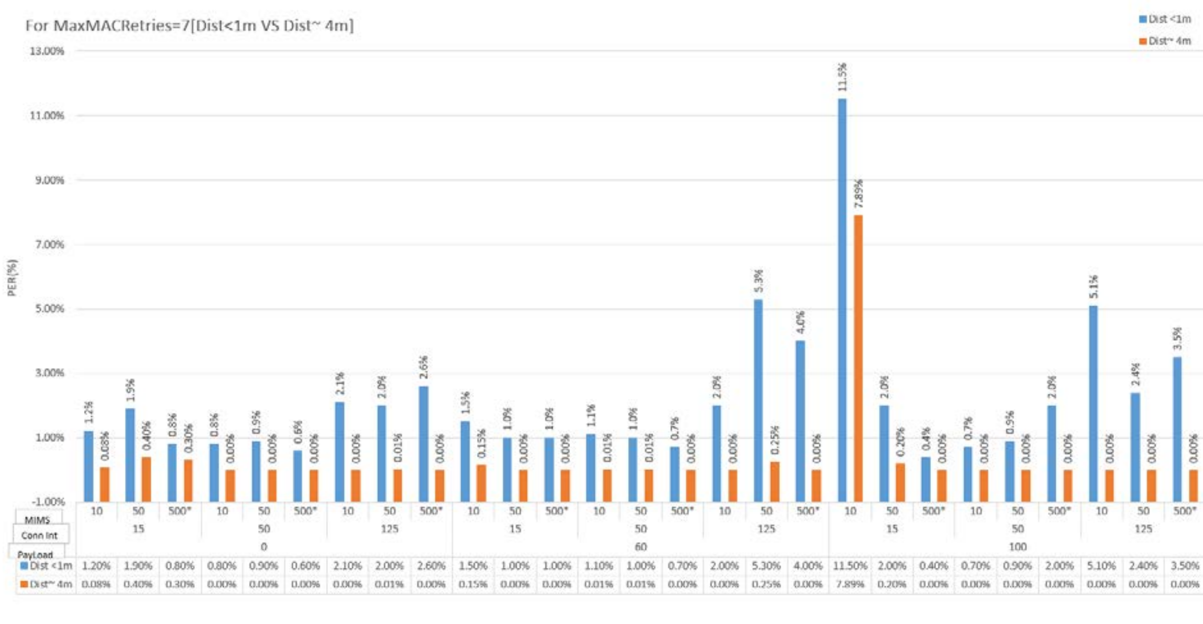

Figure 7. Result analysis 2

3. TxPowerLeve 6 Vs 22

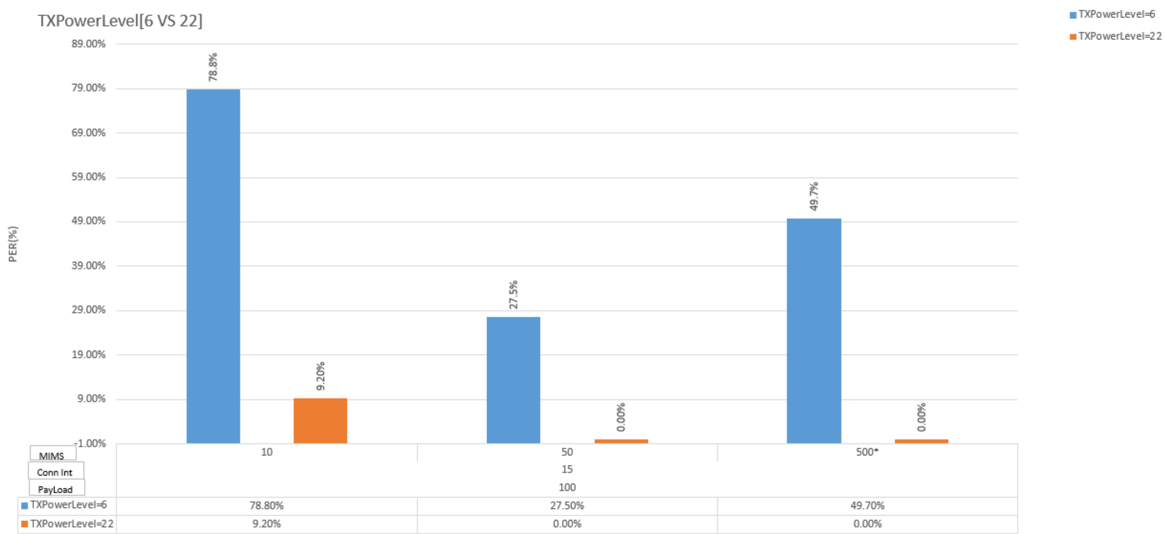

Figure 8. Result analysis 3

9.1. Protocol switching analysis

This section provides the radio protocol switching times from BLE to 802.15.4 and 802.15.4 to BLE. The Protocol Switching Time Analysis mentioned below are done for FRDM-KW41Z hardware using the BLE+IEEE802.15.4 Hybrid Application.

For details on the Protocol Switching Analysis, please refer to AN12192.

10. Conclusion

- Upper layers of the stacks are not aware of the radio switching.
- BLE connection events have priority over 802.15.4.
- Some packets may be lost. Stacks must be prepared to handle it.
- IEEE 802.15.4 performance might be affected by:
  - BLE Connection Interval (smaller connection interval = less time for IEEE 802.15.4)
  - BLE connection event duration (bigger connection duration = less time for IEEE 802.15.4)
- In normal conditions (default smartphone connection intervals, short BLE data transfers) 802.15.4 performance is almost unaffected.

KW41Z supports multi-protocol coexistence in the same chip. BLE takes priority over IEEE 802.15.4 to maintain the connection synchronization; this impacts the performance on the IEEE 802.15.4 side. MAC-level ACK minimizes packet error rate. Application-level acknowledge its highly recommended to ensure a packet was successfully delivered.

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