Testing the Receiver and Transmitter Characteristics of 802.15.4/ZigBee Devices

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An Overview of the IEEE 802.15.4 Standard and RF Device Testing

Wireless personal area networks (WPANs) are used to convey information over relatively short distances and are used in a host of applications requiring short range, low data-rate communication such as wireless sensor networks, remote control, and home/building automation. Unlike wireless local area networks (WLANs), connections effected via WPANs involve little or no infrastructure. This feature allows small, power-efficient, inexpensive solutions to be implemented for a wide range of devices with a maximum data throughput of 250 kb/s. The IEEE 802.15.4 standard defines protocols for a low-rate WPAN (LR-WPAN) operating in the 2450, 868, and 915 MHz frequency bands. The standard is also endorsed by the ZigBee Alliance. Devices using the ZigBee protocol stack (which is defined up to the network and security layer) on top of the 802.15.4 PHY and MAC are called ZigBee devices.

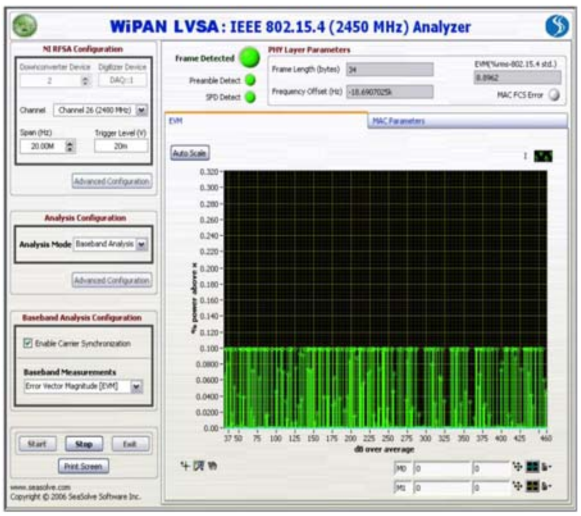


Figure 1: Checking transmitter EVM

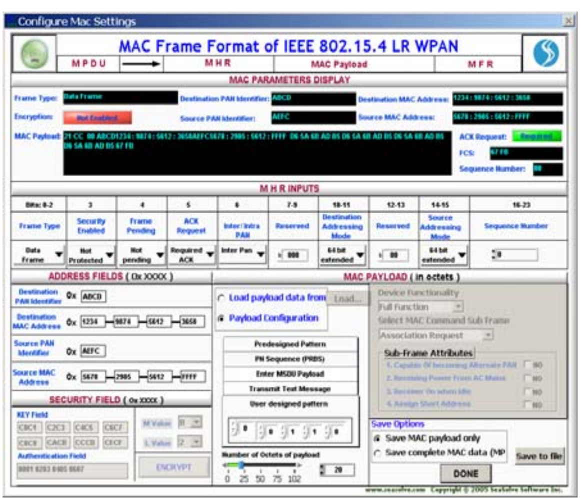


Figure 2: Defining a MAC frame for transmission

The emerging trend of using Zigbee devices for control applications has grabbed the attention of device manufacturers, leading to severe competition for market share. This has introduced significant new challenges for design engineers and device manufacturers to get their products tested, validated, and released as quickly as possible with a relatively competitive pricing. Many times this results in failure to meet performance targets as per the 802.15.4 standard's requirements. The demand for interoperability, together with the opportunity costs related with time-to-market drives the need for compliance testing. Therefore, the challenge lies in making a solution that is capable of efficiently checking the receiver and transmitter characteristics of an 802.15.4 device in order to verify its standard-compliance and interoperability with devices from other vendors. With time-to-market and pricing being crucial factors in grabbing market share, it is also important to ensure that test-times and costs are reduced for each device in the production line.

How do we define 'efficient' testing, apart from the fact that it should be done quickly and cost-effectively? The 802.15.4 standard defines the protocols of both the physical (PHY) and medium-access-control (MAC) layers that should be used in the designing of a WPAN device. The test solution, therefore, must not only allow checking for the standard-compliance of RF and baseband characteristics at the PHY layer, but also be able to perform tests regarding MAC data transfer and device communication.

Testing 802.15.4 Device Receivers

WPAN networks that are based on the 802.15.4 standard can be mind-boggling considering the potentially vast number of nodes, their varied functionality, and the fact that data can travel from point-to-point through intermediate devices. Moreover, since most WPAN networks operate in the unlicensed 2.4 GHz frequency band, we have radio interference as another hindrance in the smooth transfer of data. Therefore, devices that must comply with the 802.15.4 standard should be able to mitigate interference as well as receive data in an efficient manner.

One of the traditional methods of testing the receiver characteristics of an RF device in the production line is the “golden radio” approach. In this case, a calibrated WPAN device (the golden radio) is made to communicate with production-line devices. The devices-under-test (DUTs) are then checked to see if they are able to receive and demodulate packets of data from the golden radio transmitter. This approach may be fast, but falls short when it comes to our requirement of ‘thorough, efficient testing’. One of the main drawbacks associated with the ‘golden radio’ approach is that the transmitter needs to be recalibrated frequently to provide reliable and constant signal generation. The other downside of the golden transmitter is that it cannot provide varied signal and data generation without major intervention on the tester’s part (i.e. it would have to be reprogrammed).

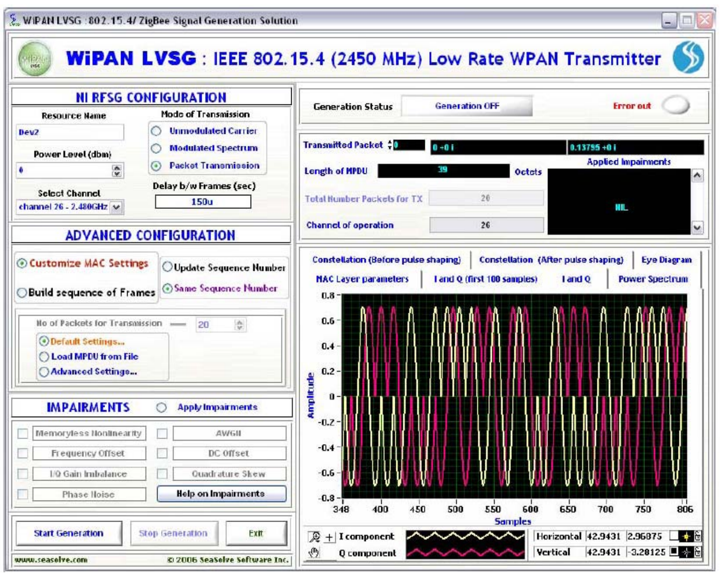


Figure 3: Main screen of the WiPAN LVSG solution, with a plot of transmitted IQ data

Taking the above into consideration, let us reiterate the main premise of ‘efficient and thorough’ testing – the fact that the DUT must be subjected to various types of signal characteristics, data, and network scenarios in order to thoroughly test its performance at the PHY and MAC layers. Furthermore, we need a single transmitter than can be easily configured to transmit these signals to a DUT.

SeaSolve’s WiPAN LVSG, integrated with the National Instruments’ PXI 5670/5671 RFSG, provides a test-bench solution capable of user-defined and standard-specific vector signal generation. With such a solution, designers and test engineers are given flexibility in device testing as well as assurance of performance characterization at both the PHY and MAC layers.

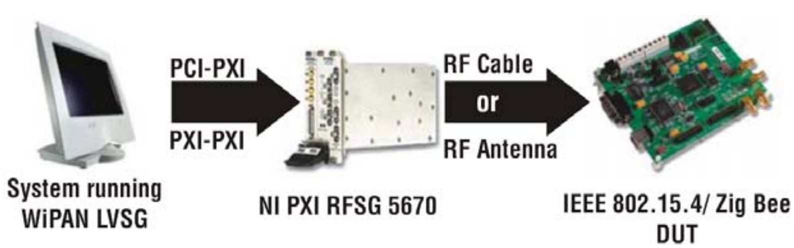


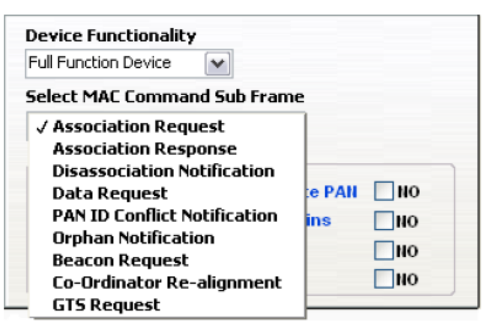
Figure 4: Setup to generate and transmit 802.15.4 signals to a WPAN DUT

WiPAN LVSG allows the user to synchronize with the DUT through a simple configuration of the NI 5670/5671 RFSG vector signal generator. The solution tests for the DUT's signal reception in the specific channels defined by the 802.15.4 standard in the 2.4 GHz band. At the PHY layer, signal generation comprises of standard-specified transmission, with the user being able to define variables such as signal strength, mode of transmission, and delay between transmitted frames. For synchronizing with the DUT (i.e. testing signal reception), mode of transmission can be set to 'unmodulated carrier' or 'modulated spectrum'. For actual data transfer to the DUT, 'packet transmission' is used. To enable performance-testing and benchmarking of a DUT receiver, the platform allows for the imposition of signal impairments on the RF transmission.

The last transmission mode, 'packet transmission' comprises the real substance of MAC layer testing, for it is with this mode that WPAN data transfer to the DUT can occur. The software provides for a generation of a fully customized (user-defined) MAC frame to be transmitted to the DUT. With this approach to frame generation, the tester can check for the DUT's response to a certain type of frame, or certain types of data (please see the *Case Study* below). The user is also able to apply AES encryption to the transmitted frames to test subsequent decryption at the DUT. Another option offered by the software is to transmit *sequences of frames*, wherein the user can define a frame sequence and have it transmitted to the DUT upon generation. This option has useful implications when it comes to detailed MAC layer testing and network testing, since the DUT's response to various frames *in sequence* (with an optional delay between them) can be seen.

Case Study: Defining PAN Communication with MAC Command Frames

The ability to transmit various MAC *command* messages that are specific to the 802.15.4 standard is a key requirement of WPAN MAC layer testing. WiPAN LVSG allows the user to transmit FFD (full-function device) or RFD (reduced-function device) MAC messages to the DUT, furthering the notion of the test-bench becoming a *virtual device* capable of emulating a PAN node. MAC command messages can be used to test a DUT's response to various network communications. As a simple example, a 'Data request' message may be sent to an FFD. The FFD must respond with an 'Acknowledgement' and 'Association Response', as seen on the right.



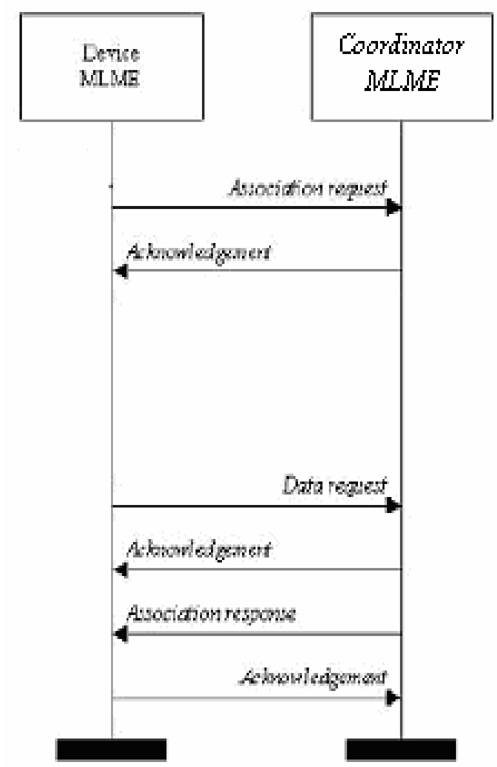


Figure 5: The diagram on the right shows a sample exchange of MAC messages defined in the 802.15.4 standard; WiPAN LVSG, as seen on the left, can emulate either a PAN device or coordinator in order to test the DUT's response to standard MAC commands

Testing 802.15.4 Device Transmitters

It is a challenge to characterize the performance of a wireless PAN transmitter. On the one hand, you need a receiver that is capable of demodulating the signal from the DUT transmitter. On the other hand, your receiver must be able to show the quality of the transmission clearly in order to verify the DUT's performance. However, just having such a receiver is also not enough – one would require the receiver to also comply with the 802.15.4 standard itself, thereby being capable of testing the DUT's standard-conformance when it comes to transmitting data.

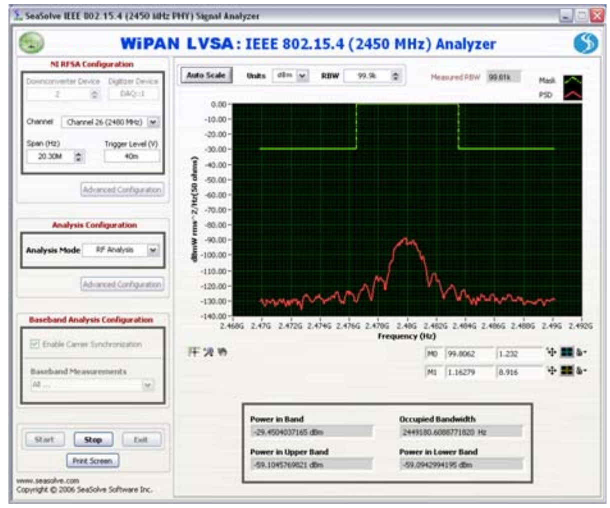


Figure 6: RF analysis of an 802.15.4 signal

Similar to the 'golden transmitter' method mentioned in the previous section of this paper, 'golden receivers' have also been used to characterize the transmitter characteristics of wireless devices during design and production times. However, *specific* characterization of transmission parameters cannot be seen quantitatively with this method. There arises a need for *parametric* testing too see how exactly a transmitter performs when it comes to factors such as power spectral density, modulation quality (including EVM), and power ramps. Parametric testing would be more sensitive to transmission flaws than the 'golden receiver'. It is also much faster to perform parametric testing than to frequently reprogram/reset the golden receiver.

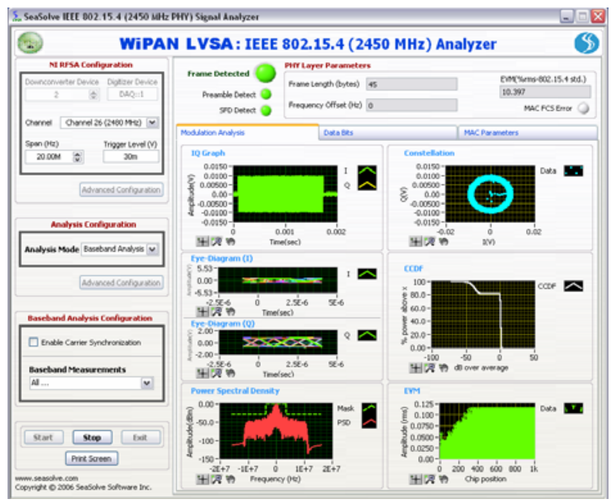


Figure 7: Sample modulation analysis at the baseband

What if we can somehow combine the ease-of-use of the 'golden receiver' approach with the faster, more capable benchmarking ability of parametric testing? This implies a solution that is capable of demodulating the signal from the DUT, displaying the signal's characteristics (both graphically and quantitatively), and showing the data that it carries (if any). It is precisely this requirement of the test and measurement niche that SeaSolve's WiPAN LVSA signal analyzer caters to.

WiPAN LVSA, along with the National Instruments' PXI 5660 RFSA vector signal analyzer, addresses the needs of production testing with its ability to perform complex signal analysis. The user is then able to see the demodulated RF signal coming from a WPAN transmitter and perform analysis of the baseband information that the signal carries. The benefits of this approach are two-fold. One, it is possible to verify the RF characteristics of the incoming signal (i.e. power level, spectral density, adjacent channel power) and see whether the signal itself is compliant to the 802.15.4 standard. Two, with the aid of baseband measurements and plots, the user can check signal/IQ modulation, EVM, the amount of noise present, and even see the decoding of received MAC frames (this is only if the DUT transmitter is sending packets – please see the *Case Study* on the next page).

During the design/pre-production stage of a WPAN device, it is entirely possible that the device is not yet standard-compliant, or faces flaws in its modulation qualities. At this point, having a standalone vector signal analyzer would not suffice, since it is unlikely that successful demodulation may occur. For this reason, designers have to move back to more traditional methods of analysis such as the use of oscilloscopes and power meters to gauge signal characteristics. However, this process can be time-consuming and expensive, since the use of additional hardware is required.

What is needed then is a set of baseband modules that allow precise user control over the values and specifications to be tested for in the PHY layer of a WPAN device's transmission. To a large extent, this is possible with SeaSolve's ZigBee Toolkit, a set of LabVIEW APIs that allow for RF and baseband measurements in separate modules with the user specifying test values for the DUT. These are developed with the intention of allowing the user more control of the testing and analysis, thereby making it easier for them to tweak their device and get it closer to standard-compliance. The ZigBee Toolkit APIs consist of modules for PSD analysis, EVM measurement, centre frequency tolerance testing, receiver sensitivity, and transmit power measurement.

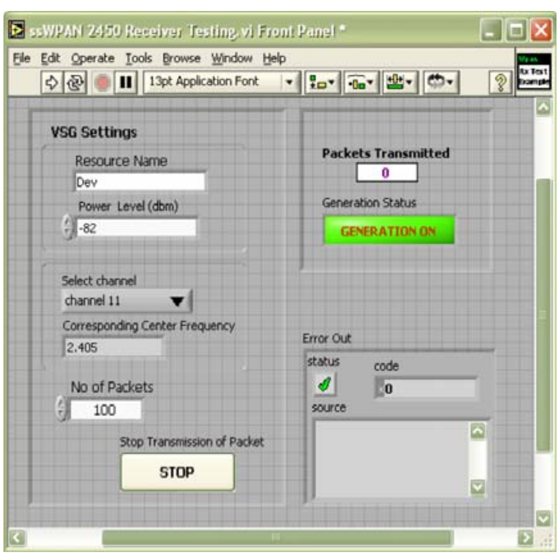


Figure 8: ZigBee receiver testing API front panel

Case Study: Decoding MAC Data

With production testing of WPAN transmitters, it is necessary to analyze the PHY as well as MAC layers. The abovementioned points about parametric characterization of the RF and baseband all pertain to the PHY layer of a transmission. To verify that a DUT is capable of transmitting data in standard-specified frame format, it is necessary to move one level higher and decode the MAC transmission from the device.

The 'MAC parameters' display in WiPAN LVSA (see Figure 9, below) enables the user to see a device's packet transmission frame-by-frame. This is a powerful analysis tool that helps the user see if the device is successful in transmitting the intended packets, with a breakdown of the data in the different fields of the received MAC frame. This way, the user can see exactly what type of frames are being received, what data they are carrying, and whether the frame is encrypted or requires an ACK response. An LED above the plot area signifies whether a packet has been received, along with indicators that state the detection of a *Start Frame Delimiter* and *Preamble*. Another LED is used to indicate whether a received frame is *in error*, through a verification of the *Frame Check Sequence* (FCS). After analysis, the user has the option of saving the received baseband data (IQ and received MAC frames) so that it can be studied to gain hindsight of the DUT's transmit characteristics.

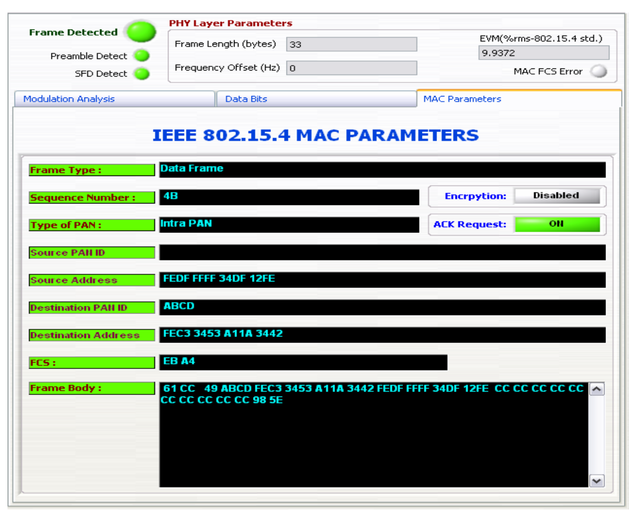


Figure 9: MAC demodulation of incoming data frames; notice the indicator LEDs above the plot area

Conclusion

Manufacturers and designers of wireless devices are always looking for ways to reduce their cost-of-test (COT) and time-to-market for each of their products. With the added functionality and complexity of wireless devices used in modern applications, this is an increasingly daunting task. This paper attempts to shed some light on the requirements of testing wireless PAN devices at the RF and baseband level to certify their standard-compliance and interoperability. SeaSolve's solutions offer a unique approach to performing this sort of testing to check the functionality of the PHY and MAC layers of 802.15.4 devices. Once these two layers are verified, it is up to the developers to implement their protocols for the rest of the OSI stack, assured of their device's foundation.

References

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