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sense and simplicity

Robustness Testing of Zigbee-based Lighting Products

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Overview

- Why Robustness Testing?
- Important Characteristics of Robustness Testing
- Interest in, and Characteristics of Zigbee
- Approach to Testing
- Selected Test Results

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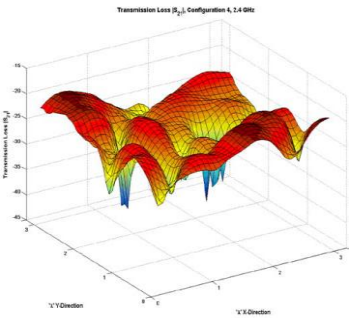
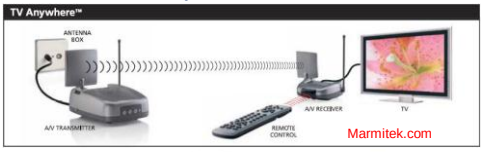
Why Robustness Testing?

- Robustness is the ability of a radio to work effectively in its intended operation environment
- Related to radio coexistence
- Robustness can be at several levels in the Protocol (PHY, MAC, NWK etc)
- Philips Lighting based wireless control on Zigbee technology
- Includes strategies such as integration into larger home-automation
- Strategic significance implies a need for robust products





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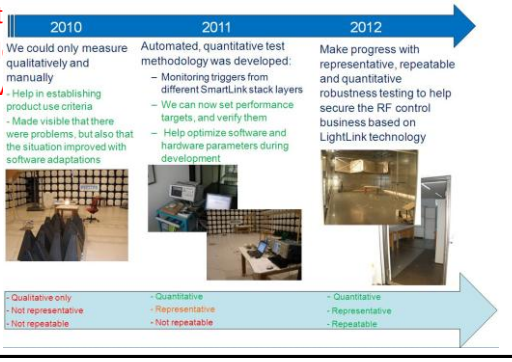
Important Characteristics of Robustness Testing

- Have the following objectives …
  - Evaluation of anticipated product performance (system level, end-to-end)
  - Communication parameter and hardware design optimization

Software – number of retries, packet lengths and structure, threshold, etc. (network layer)

Hardware – antenna type, placement, multiplicity, optimization; balun and matching network design and optimization

- A solution to robustness verification needs to be …
  - Represent
  - Repeatabl
  - Quantitativ



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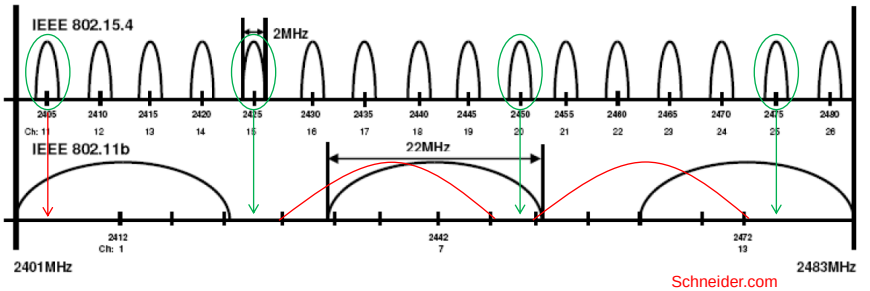
Interest in, and Characteristics of Zigbee

- Philips Lighting chose Zigbee as only wireless control technology
  - In-home in 2.4 GHz ISM-band
- IEEE802.15.4/Zigbee open standard for lighting control (Zigbee Light Link)
- Worldwide band, but shared with many interferers
- Multipath radio propagation environment
- Mesh networking technology
- Wi-Fi as main interferer in control application



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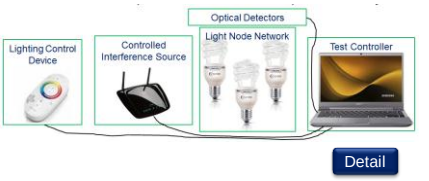
Approach to Testing: Test Link Control

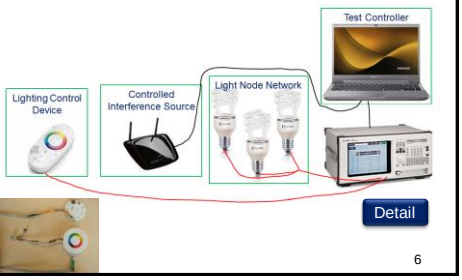
- Dependent on test objective:
  - Application level test for IER (Instruction Error Rate) and latency

- End-to-end application level test
- How well does the system perform?
- Little required software for product control, especially if controller is an application
- To become a mandatory test
- Emulate different user scenarios



  - Radio parameter optimization for robustness

- Test radio parameters throughout controller and lamp software stack and physical layer
- Make parameter/HW changes and re-observe consequence



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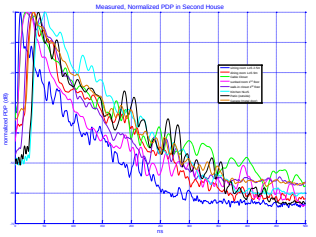
Approach to Testing: Laboratory Test Environment

- Products used in in-door environment (multipath)
- Need to bring indoor environment to the laboratory **Objective**
- Stochastic test environment creation numerous channels
- Perform link test in each channel, and calculate statistical characteristics
- Control reflective nature in a large reflective cavity: reverberation chamber or faraday cage

First characterize … … analyze … … then emulate.



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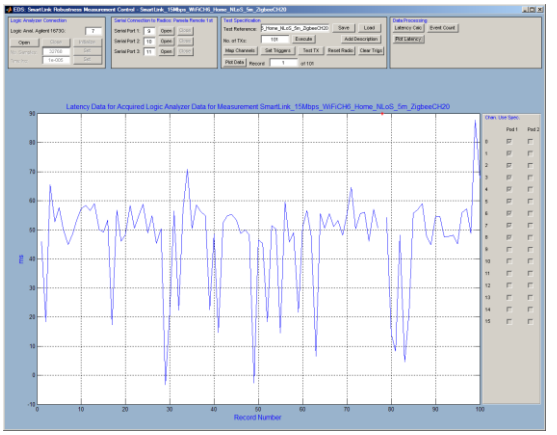
Approach to Testing: Data Processing

- Stochastic nature requires test automation (large sample spaces)
- Instruction Error Rate/Latency expectation and distribution
- Limit or reference values for specification purposes
- Criteria for assessing problematic user scenarios



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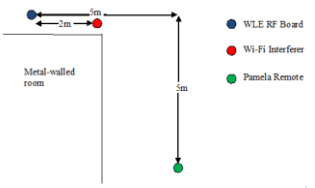
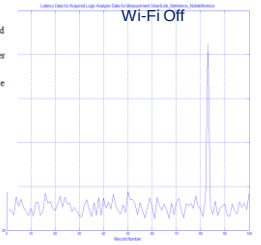
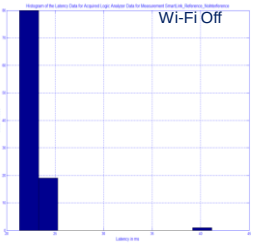
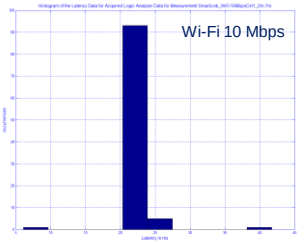
Selected Test Results: Example 1

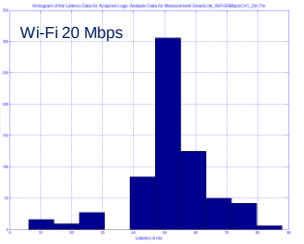
Reference NLoS latencies in a single-hop network configuration in the laboratory environment











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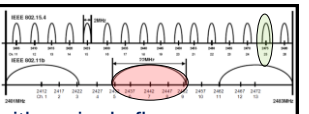


Selected Test Results: Example 2

Description: Living Colors lamp in the attic at position 9 with a single floor separation to the Pamela remote control in hallway (2) one floor below. White Light Dimming unit in position 7 in the portal, i.e. three-floor configuration. Wi-Fi interference still in channel 10 at position 14 at 2m distance from the lamp. The Zigbee system is operating in channel 25.

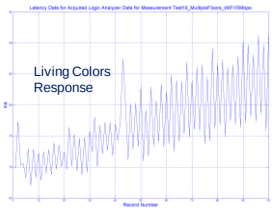
- Wi-Fi parameters: Ch 7 (2442 MHz), 15 Mbps
- Zigbee channel: 25 (2475 MHz)

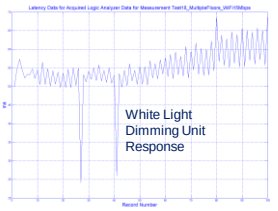
Notes:

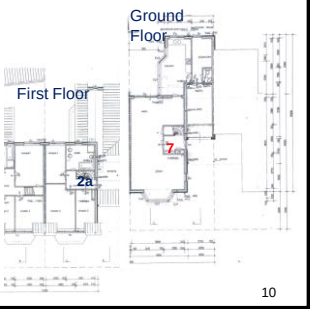
- The lamp is communicating successfully with the dimming unit two floors below and the remote control one floor below.

Conclusions:

- Cross-floor communication not detrimental in this configuration.







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Conclusion

- Wireless control of lighting systems components is an important part of Philips Lighting's strategy
- It is therefore crucial to manage product quality in this regard
- We do this by developing for radio robustness
- Robustness insurance requires substantial test efforts
- I tried to outline what robustness testing encompasses at Philips Lighting

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Test Robustness

We Evaluate Robustness by Stochastically Measuring:
- IER (Instruction Error Rate) in % (< 0.1%)
- Instruction Latency in milli-seconds (< 200 ms)

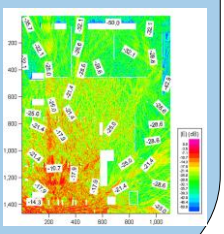
Perceived by user of the radio product, so control these

E.g. an on/off instruction from remote to lamp

Impacts

Otherwise user presses the button again …

Radio Parameters
Number of retransmissions, number of retries, received signal strength indicator (RSSI), channel clear assessment level, channel clear assessment mode, network parameters, etc.



This measurement need to be done in a controlled laboratory environment simulating the specific electromagnetic propagation of the room where the product will be used

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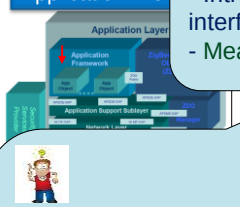
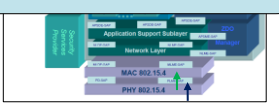
Link activity measurement concept

Triggers resulting in

Recall, that to test robustness we have to:
-Create a representative, controlled environment.
- Introduced a known, controlled (representative) interference source.
- Measure the activity on our radios.

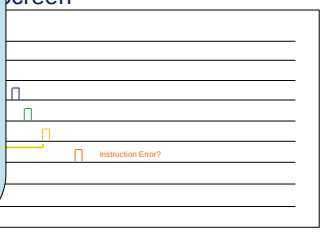
Application: Rer





Using the controlled multipath environments in the reverberation chamber and faraday cage…

Screen



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Available Hardware Triggers

- 0000 00b 0 – Constant value
- 0000 01b 1 – Constant value
- 0010 00b rfc_sniff_data – Data from packet sniffer. Sample data on rising edges of sniff_clk.
- 0010 01b rfc_sniff_clk – 250kHz clock for packet sniffer data.
- 0011 00b rssi_valid – Pin is high when the RSSI value has been updated at least once since RX was started. Cleared when leaving RX.
- 0011 01b demod_cca – Clear channel assessment. See FSMSTAT1 register for details on how to configure the behavior of this signal.
- 0011 10b sampled_cca – A sampled version of the CCA bit from demodulator. The value is updated whenever a SSAMPLECCA or STXONCCA strobe is issued.
- 0011 11b sfd_sync – Pin is high when a SFD has been received or transmitted. Cleared when leaving RX/TX respectively. Not to be confused with the SFD exception.
- 0100 00b tx_active – Indicates that FFCTRL is in one of the TX states. Active high. Note: This signal might have glitches, because it has no output flip-flop and is based on the current state register of the FFCTRL FSM.
- 0100 01b rx_active – Indicates that FFCTRL is in one of the RX states. Active high. Note: This signal might have glitches, because it has no output flip-flop and is based on the current state register of the FFCTRL FSM.
- 0100 10b ffctrl_fifo – Pin is high when one or more bytes are in the RXFIFO. Low during RXFIFO overflow.
- 0100 11b ffctrl_fifop – Pin is high when the number of bytes in the RXFIFO exceeds the programmable threshold or at least one complete frame is in the RXFIFO. Also high during RXFIFO overflow. Not to be confused with the FIFOP exception.
- 0101 00b packet_done – A complete frame has been received. I.E the number of bytes set by the length field is received.
- 0101 10b rfc_xor_rand_i_q – XOR between I and Q random outputs. Updated at 8MHz.
- 0101 11b rfc_rand_q – Random data output from the Q channel of the receiver. Updated at 8MHz.
- 0110 00b rfc_rand_i – Random data output from the I channel of the receiver. Updated at 8MHz.
- 0110 01b lock_status – '1' when PLL is in lock, otherwise '0'
- 1010 10b pa_pd – Power Amplifier power down signal
- 1010 10b lna_pd – LNA power down signal

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Available Software Triggers

value	enum-name	comment
1	MCPS_DATA_INDICATION	receive data from MAC to network layer
2	MCPS_DATA_REQUEST	send request from network layer to MAC
3	MCPS_DATA_CONFIRM	confirm from MAC to network layer
4	MAC_RETRY_TRANSMIT	retry of the transmit from MAC
5	MLME_SCAN_REQUEST	a scan request is issued from network layer to MAC
6	MLME_SCAN_CONFIRM	a scan confirm from MAC to network layer
7	MLME_BEACON_NOTIFY	receive a beacon notify from MAC to network layer
8	MLME_POLL_INDICATION	receive a poll indication from MAC to network layer
9	MLME_POLL_CONFIRM	receive a poll confirm from MAC to network layer
20	NLDE_DATA_INDICATION	receive data from network layer to APS layer
21	NLDE_DATA_REQUEST	send data request from APS layer to network layer
22	NLDE_DATA_CONFIRM	confirm from network layer to APS layer
23	NLME_ED_SCAN_REQUEST	send a ED scan request from APS layer to network layer
24	NLME_JOIN_REQUEST	send join from APS layer to network layer
25	NLME_JOIN_CONFIRM	confirm join from network layer to APS layer
26	NMLE_IS_PARENT	received data indication as parent
30	APSDE_DATA_INDICATION	receive data from APS layer to Application
31	APSDE_DATA_REQUEST	send data from Application to APS layer
32	APSDE_DATA_CONFIRM	confirm from APS layer to Application
33	APS_INTERPAN_DATA_REQUEST	send data request from APS layer (interpan only) to MAC layer
34	APS_INTERPAN_DATA_INDICATION	receive data from MAC to APS layer (interpan only)
35	APSDE_DATA_REQUEST_RETRY	retry a APS-layer data request due to synclost
36	APPLICATION_LEDS_CHANGE	leds are changing due to external influence (steps of 200msec)

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What we want to do …

Implementation Return

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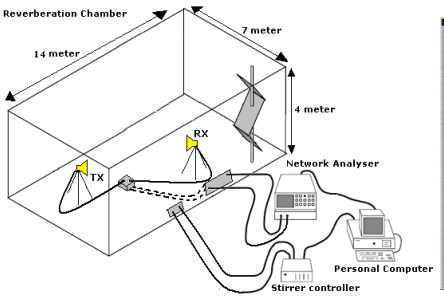
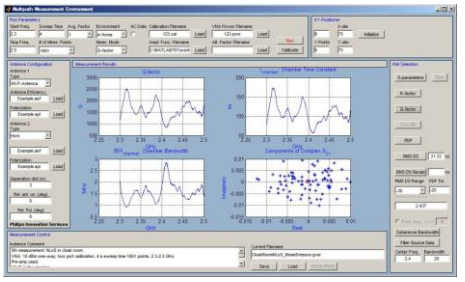
Chamber Multipath Test Principles

- Emulate home/office environment by chamber loading and configuration
  - Control K-factor (direct to scattered field ratio)
  - RMS Delay Spread (duration of ringing)
- Monitor: Coherence bandwidth, Q-factor, Rician distribution, chamber time constant and band width





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