Ultra Low Power Wireless Control Networks

GreenPeak

Robustness of 802.15.4 Networks in the 2.4GHz Band

June 2010

Background

- RF is (unfortunately) a lossy medium
- Robustness in 802.15.4 networks is achieved through several mechanisms on different layers:
  - *PHY layer*:
    - DSSS[1]] with high code redundancy, high modulation index (0.5)
    - *Antenna diversity* (GP)
  - *MAC layer*:
    - Collision avoidance using CSMA/CA
    - ACKed transmissions and retries
  - *Network layer*:
    - Frequency agility across 3 channels (sensible mix of robustness and low latency)
- The main indicator of robustness is the *link budget*

→ *Range is dependent on distance and environment*

[1] Direct-Sequence Spread Spectrum

Link Budget (1)

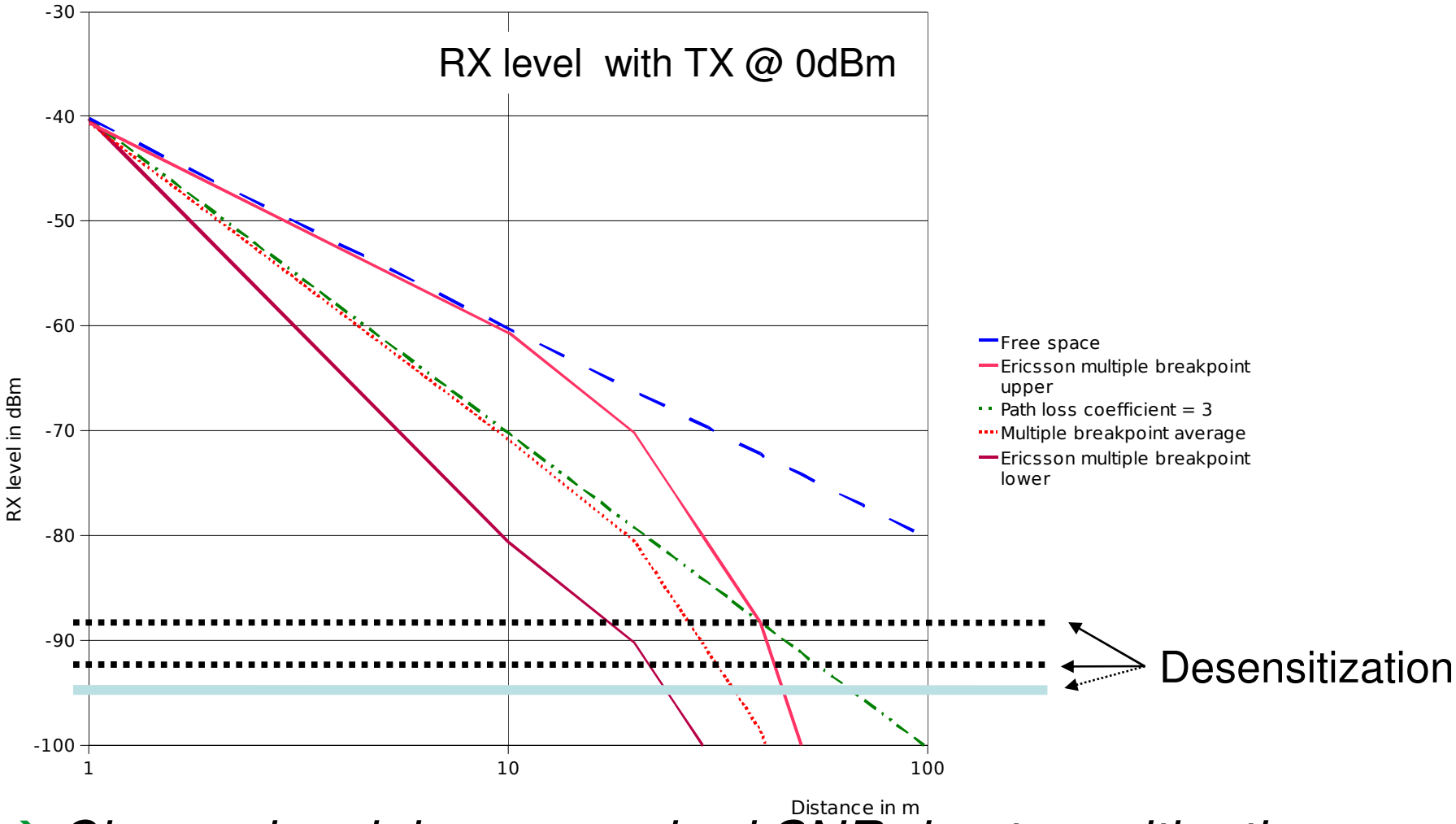
- Link budget can be estimated by starting with *TX power* and *RX sensitivity* of the systems, combined with the following (main) attenuating impacts:
  - *Environment*: noise, walls, obstacles, distance, etc.
  - *Interference*: can cause *desensitization*[1]] of RX front-end
- Besides desensitization, interference also causes random packet loss (bit errors) which is handled by the MAC and NWK layer (intentional jamming is not considered).

[1] **Desensitization** is a form of electromagnetic interference where a radio receiver is unable to receive the full strength of a radio signal. This is caused by a nearby transmitter with a strong signal on a close frequency, which overloads the receiver and makes it unable to fully receive the desired signal (Source: Wikipedia).

Link Budget (2)

- Typical link budget without environmental loss and interference is appr. 90dB, giving ~300m outdoor range
- Indoor range is more complex and must be modeled
- Multipath fading can increase or decrease the signal level at the receiver antenna location

Desensitization



→ *Change in minimum required SNR due to multipath sensitivity and interference leads to loss of range*

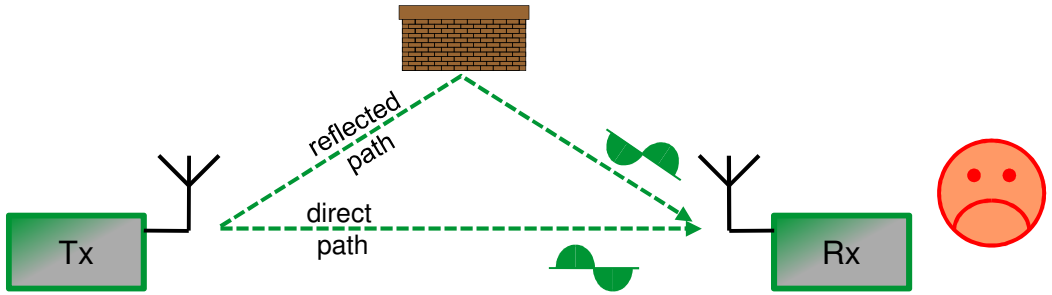
Range Impacts

- Some estimates of impacts on link budget for RF4CE Remote Control System platform:

Effect:	Impact [dB]:	Mitigation:
Antenna detuning in RC due to “hand over antenna”	10..20	Antenna diversity, Remote Control design
Receiver behind TV	5..10	(depending on wall etc.)
Receiver in cabinet	2..10	(depending on material)
Multi-Path fading	8..10	RX antenna diversity
Delay spread	0..5	Limited impact in regular home
Interference – RX desensitization	5..35	GP has very good interference robustness

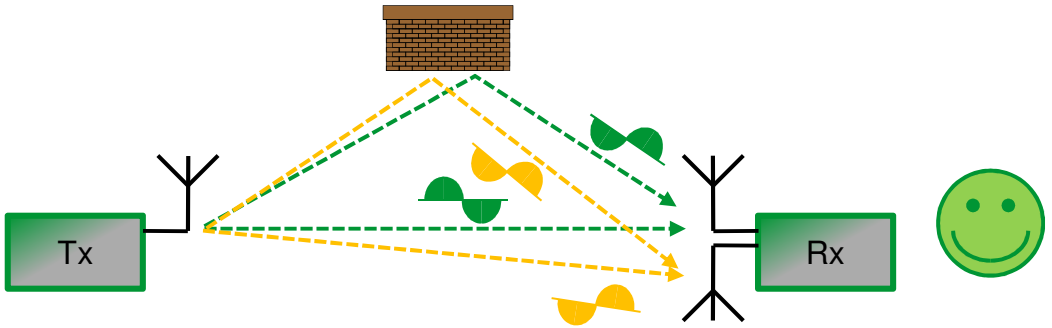
Preamble switched antenna diversity (1)

Traditional design



No reception at receiver: Signals received from multiple paths cancel out

GP500



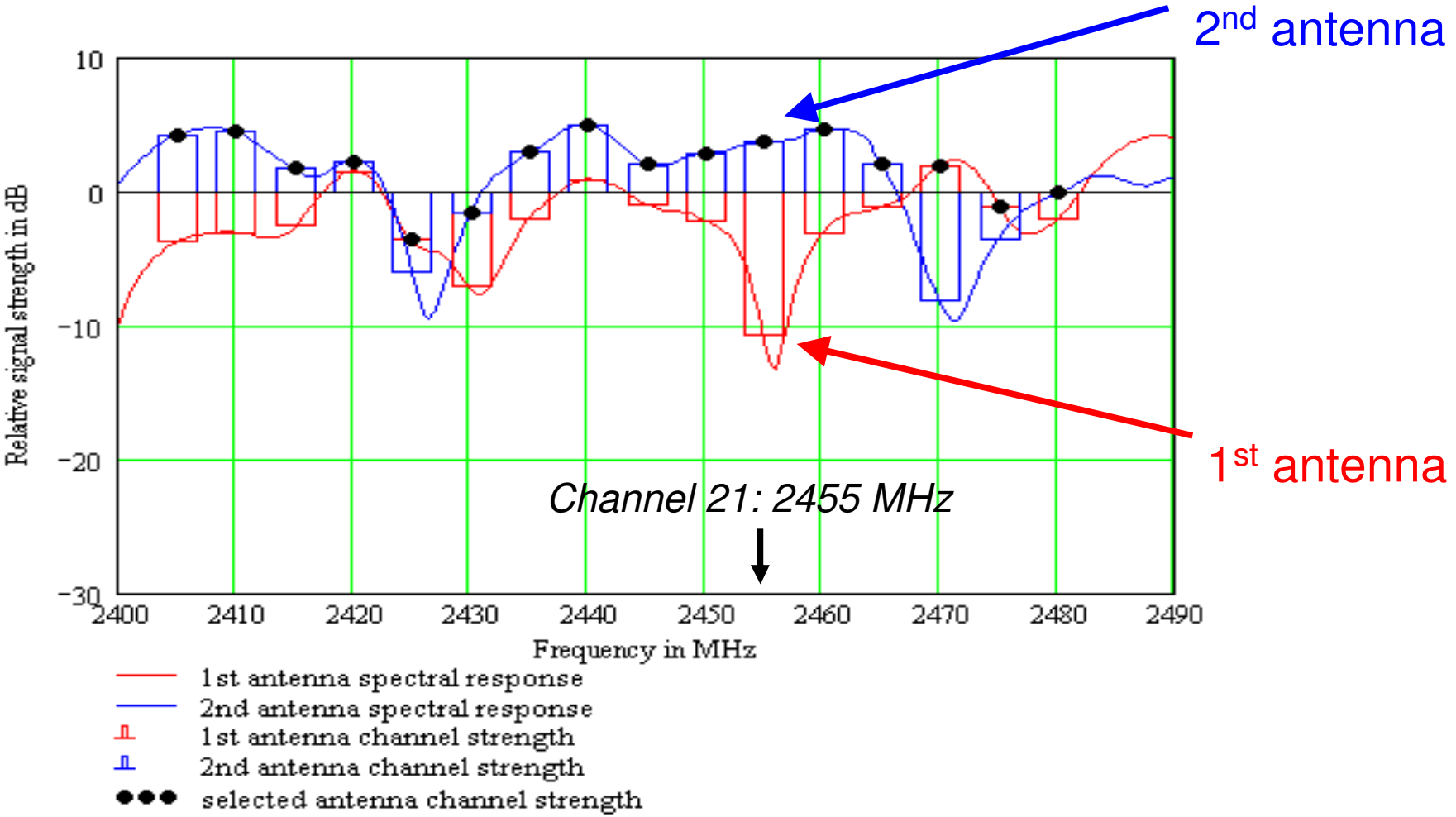
Second antenna receives strong signal, even if signal on first antenna has faded

- Antenna diversity enables reliable communication where none would otherwise be possible
- Adding 9 dB more reliable link budget (which is otherwise lost)
- No need for packet retransmission leading to energy savings

Preamble switched antenna diversity (2)

- Superior signal processing allows for the received signal to be evaluated on a per symbol basis, enabling a multiplexing scheme in which the signal from two antenna's is evaluated during a single preamble period.
- The signal with the best correlation is chosen. This means not just the level, but also impairments like interference or dispersion due to fading (delay spread) are included in the evaluation of the signal quality derived from each antenna.

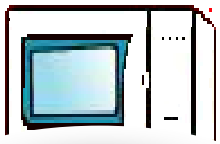
Impact of RX Antenna Diversity



Fading example for 20ns delay spread

Common Sources of 2.4GHz Interference

Bluetooth



Microwave ovens

wireless video

radar

2.4 GHz
cordless phones

802.11
Frequency Hopper

outdoor
microwave
links

Other WiFi
Networks

fluorescent
lights

headphones

Game Controller

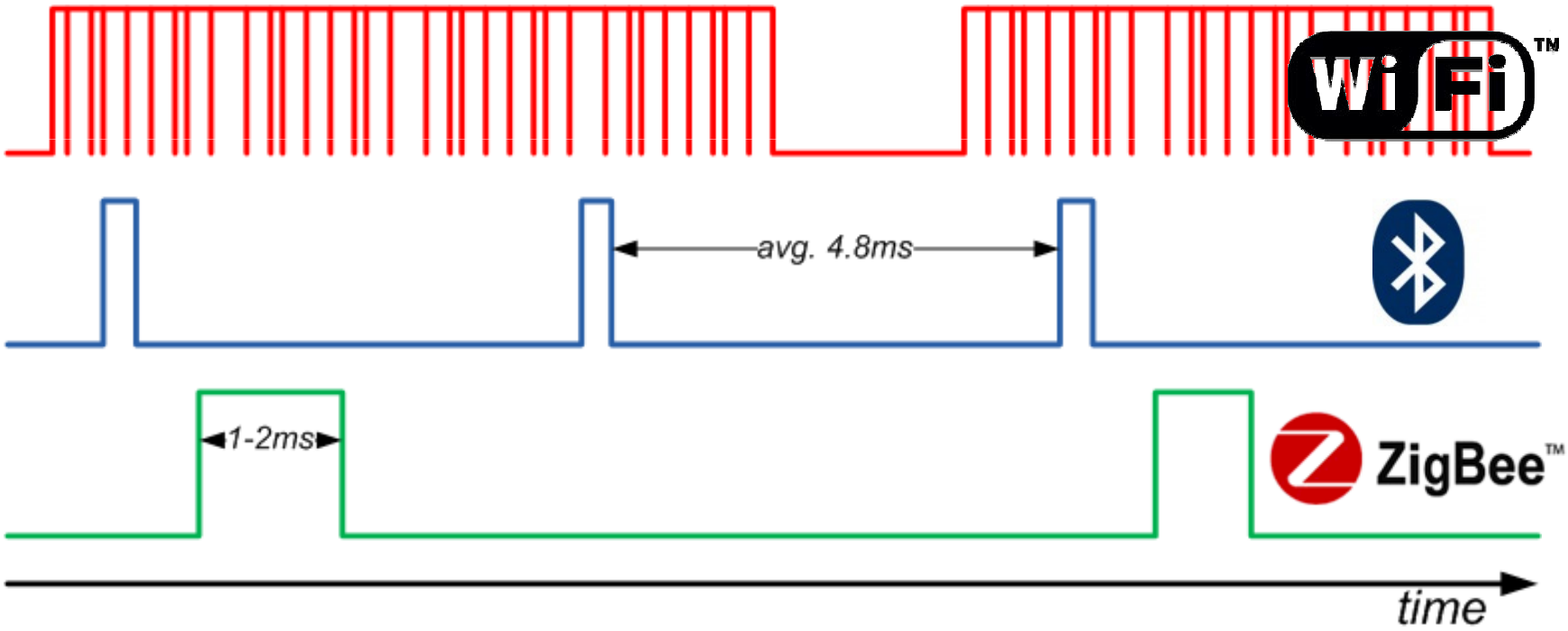
Possible Interference Sources

2.4GHz interferers	Max. output power [dBm]	Possible Impact	Comments
WiFi – 802.11bgn	12..20	High	20/40MHz spectrum, high power, small gaps
Cordless phone (2.4GHz, non-DECT)	up to 20	medium	Small spectrum, high power, large gaps
Bluetooth	0..20	low	Frequency hopper
Microwave	10..20	low	Some impact within 1m
Other ZigBee	0..20	low	CSMA/CA

Other interferers	Band [GHz]	Comments
DECT phone	1.9	Interference impact dependent on: - distance from 2.4GHz band - output power - distance to receiver No real-life impact expected on RF4CE
GSM/WCDMA	.7-.85/1.7-2.1	
LTE/4G	1.7-2.1/2.5-2.7	
WiMax – 802.16e	1.7-2.1	

Temporal Spectrum Usage

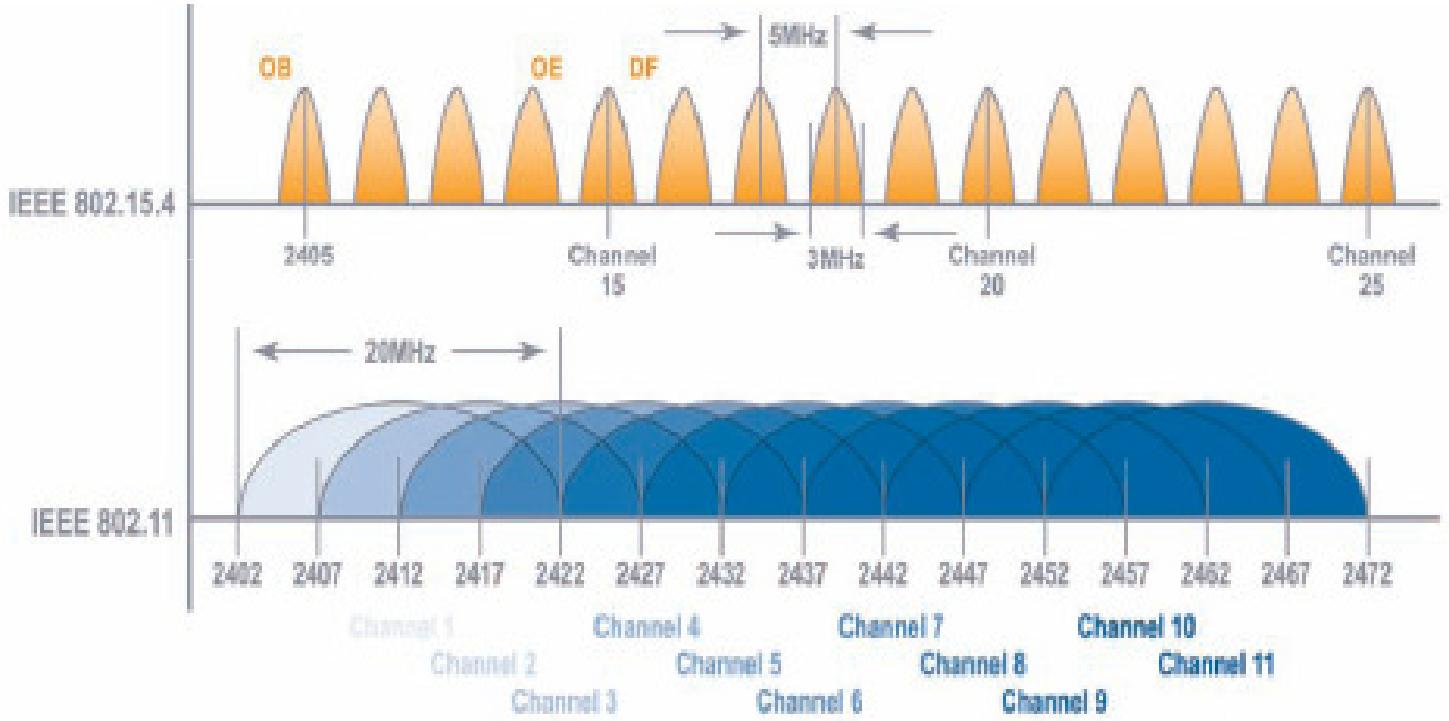
- 2.4GHz standards have very different temporal behavior
- Eg. Bluetooth is a frequency hopper with limited impact



→ *Wi-Fi is main interference source in home environment*

802.15.4 and 802.11 Channels

802.15.4: Ch(k) = 2405 + (k-11)*5 MHz US/EU/JP: k=11..26



16 channels:

2405 .. 2480 MHz

11, 13 or 14 channels:

2412 .. 2462 MHz

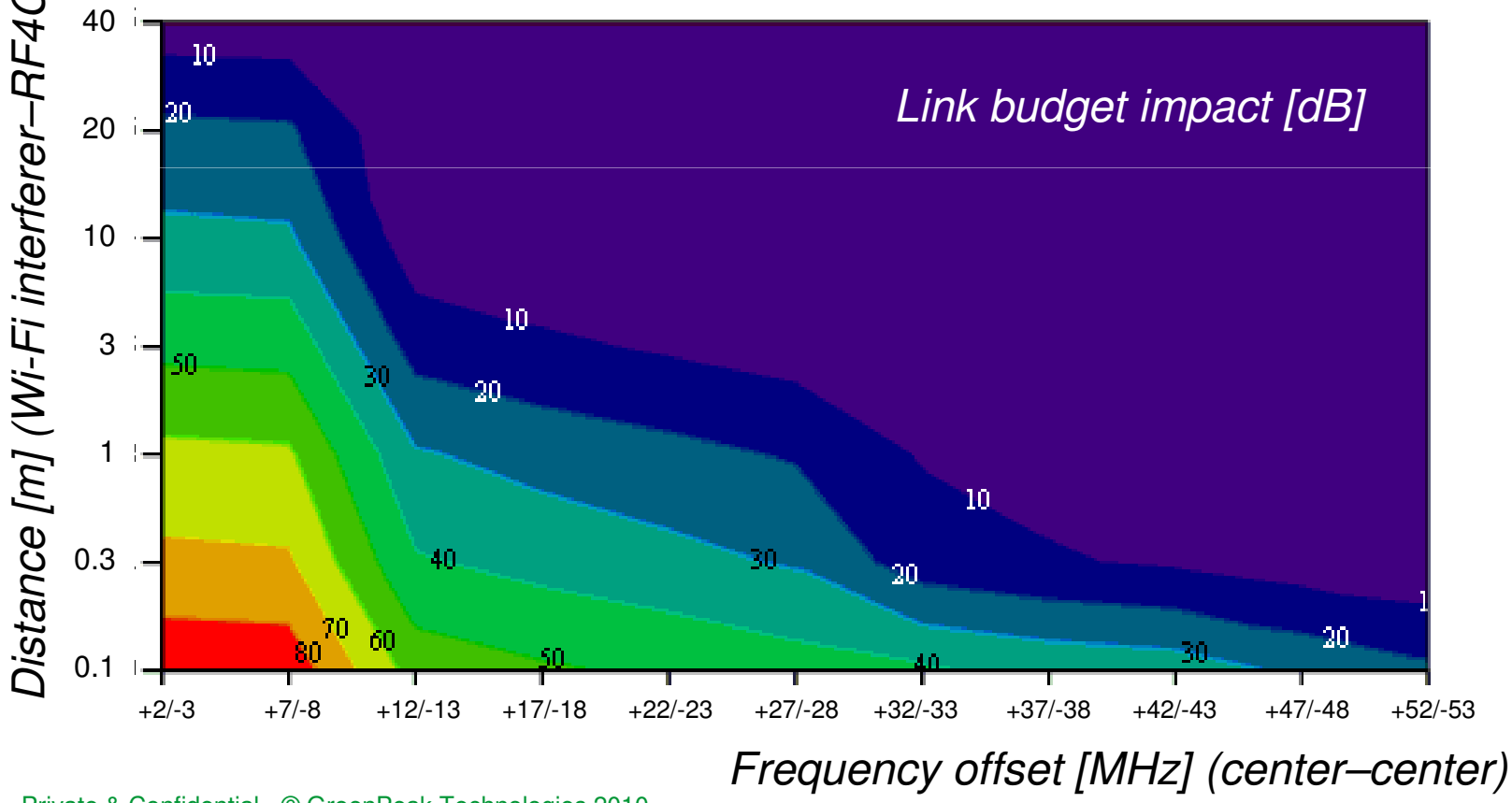
(2412 .. 2472 MHz)

802.11: Ch(k) = 2412 + (k-1)*5 MHz (US: k=1..11; EU: k=1..13)

Ch(14) = 2484 MHz JP only

WiFi Impact on 802.15.4

- *Worst-case* impact of 2.4GHz Wi-Fi on RF4CE link budget based on distance and frequency offset.



Conclusions

- Link budget for indoor behavior improves with about 9 dB when using a good implemented Antenna Diversity
- Wi-Fi is the main interferer for 802.15.4 Networks in the 2.4 GHz band
- Interference of Wi-Fi will be acceptable if:
  - Frequency channels are more than 30MHz apart
    - Frequency agility will move RF4CE communication to free channel

or

  - Wi-Fi stations are 20m or more away from the 802.15.4 receivers,

or

  - Wi-Fi does not use more than ≈ 25% of the bandwidth

Thank you!

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