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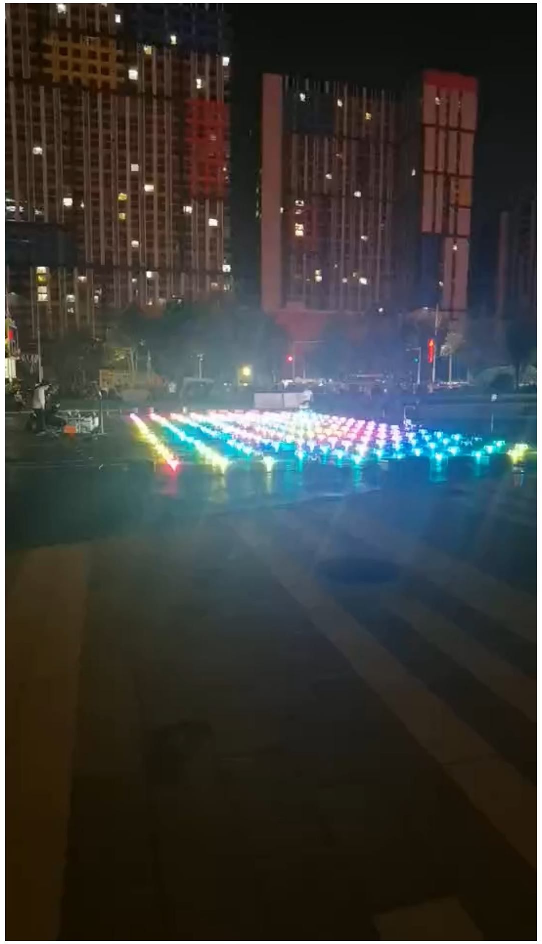
Dependable Wireless Communications

In Smart Cities, with a focus on safety-critical applications?

Dr. Tim Claeys

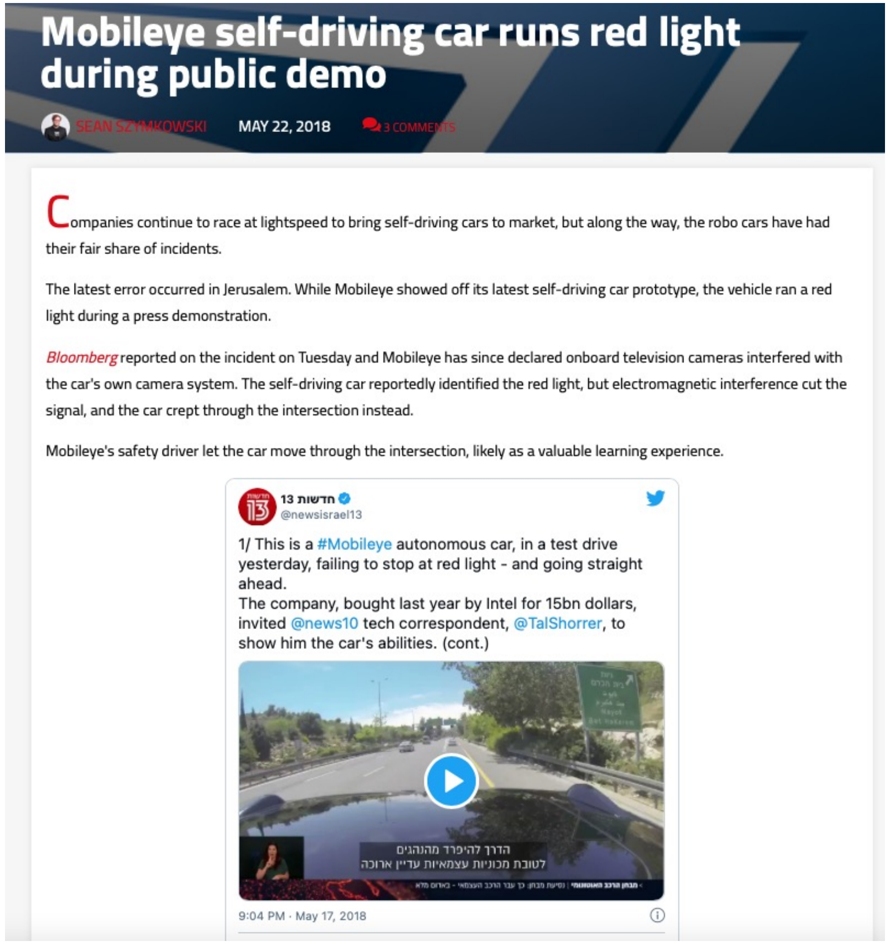
What can go wrong?

What can go wrong?



https://dronedj.com/2021/10/04/drone-light-show-fail-video-china/

What can go wrong?



Mobileye self-driving car runs red light during public demo

SEAN SZYMKOWSKI MAY 22, 2018 3 COMMENTS

Companies continue to race at lightspeed to bring self-driving cars to market, but along the way, the robo cars have had their fair share of incidents.

The latest error occurred in Jerusalem. While Mobileye showed off its latest self-driving car prototype, the vehicle ran a red light during a press demonstration.

Bloomberg reported on the incident on Tuesday and Mobileye has since declared onboard television cameras interfered with the car's own camera system. The self-driving car reportedly identified the red light, but electromagnetic interference cut the signal, and the car crept through the intersection instead.

Mobileye's safety driver let the car move through the intersection, likely as a valuable learning experience.

חדשות 13 @newsisrael13

1/ This is a #Mobileye autonomous car, in a test drive yesterday, failing to stop at red light - and going straight ahead.
The company, bought last year by Intel for 15bn dollars, invited @news10 tech correspondent, @TalShorrer, to show him the car's abilities. (cont.)

9:04 PM · May 17, 2018

"It was a very unique situation," he said, referring to the camera crew. "We'd never anticipated something like this." Shashua said Mobileye was also modifying the hardware designed to shield the car's computers from electromagnetic interference in order to prevent similar incidents in the future. Mobileye's Jerusalem fleet has continued to operate and the company hasn't received any complaints from automakers, Shashua said.

Let us have a look at wireless communications under electromagnetic disturbances!

What does the European Law say about immunity testing of wireless communication?

The Radio Equipment Directive

- What are the essential requirements

1. Radio equipment shall be constructed so as to ensure:

(a) the protection of health and safety of persons and of domestic animals and the protection of property, including the objectives with respect to safety requirements set out in Directive 2014/35/EU, but with no voltage limit applying;

(b) an adequate level of electromagnetic compatibility as set out in Directive 2014/30/EU.

2. Radio equipment shall be so constructed that it both effectively uses and supports the efficient use of radio spectrum in order to avoid harmful interference.

3. Radio equipment within certain categories or classes shall be so constructed that it complies with the following essential requirements:

The Radio Equipment Directive:
EMC testing for radios => the EMC Directive

Article 6

Essential requirements

The equipment shall meet the essential requirements set out in Annex I.

1. **General requirements**

Equipment shall be so designed and manufactured, having regard to the state of the art, as to ensure that:

(a) the electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended;

(b) it has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use.

The Radio Equipment Directive: ETSI EN 301 489-1

ETSI EN 301 489-1 V2.2.3 (2019-11)

ElectroMagnetic Compatibility (EMC)
standard for radio equipment and services;
Part 1: Common technical requirements;
Harmonised Standard for ElectroMagnetic Compatibility

The Radio Equipment Directive: ETSI EN 301 489-1

9.2.2 Test method

The test method shall be in accordance with CENELEC EN 61000-4-3 [3], clauses 6, 7 and 8.

The following requirements and evaluation of test results shall apply:

- the test level shall be 3 V/m (measured unmodulated). The test signal shall be amplitude modulated to a depth of 80 % by a sinusoidal audio signal of 1 000 Hz. If the wanted signal is modulated at 1 000 Hz, then an audio signal of 400 Hz shall be used;
- the test shall be performed over the frequency range 80 MHz to 6 000 MHz with the exception of the exclusion band for transmitters, receivers and duplex transceivers (see clause 4.3), as appropriate;
- for receivers and transmitters the stepped frequency increments shall be 1 % frequency increment of the momentary used frequency;
- the dwell time of the test phenomena at each frequency shall not be less than the time necessary for the EUT to be exercised and to be able to respond;

NOTE: Dwell time is product dependent.

- the frequencies selected and used during the test shall be recorded.

The Radio Equipment Directive: Efficient use of the spectrum

ETSI EN 300 220-1 V3.1.1 (2017-02)

Short Range Devices (SRD) operating in the frequency range 25 MHz to 1 000 MHz; Part 1: Technical characteristics and methods of measurement

The Radio Equipment Directive: EN 300220

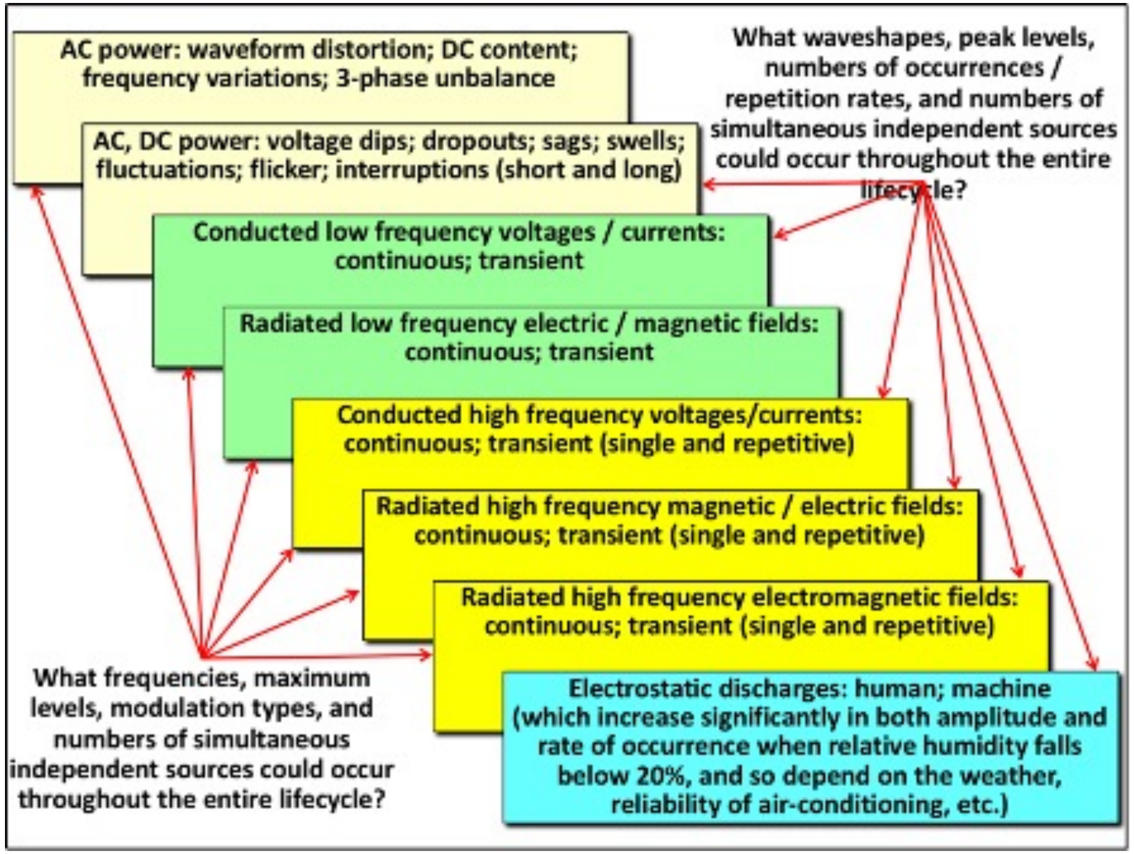
Emissions	Immunity	Other
Effective radiated power	Receiver saturation at adjacent channel	RX sensitivity level
Maximum effective radiated power	Spurious response rejection	
Duty cycle	blocking	Behavior at high wanted signal level
Occupied bandwidth	Adjacent channel selectivity	Polite spectrum access
Frequency error		Bi-directional operation verification
TX out of band emissions		
Unwanted emissions in the spurious domain		
Transient power		
Adjacent channel power		
TW behavior under low voltage conditions		
Adaptive power control		

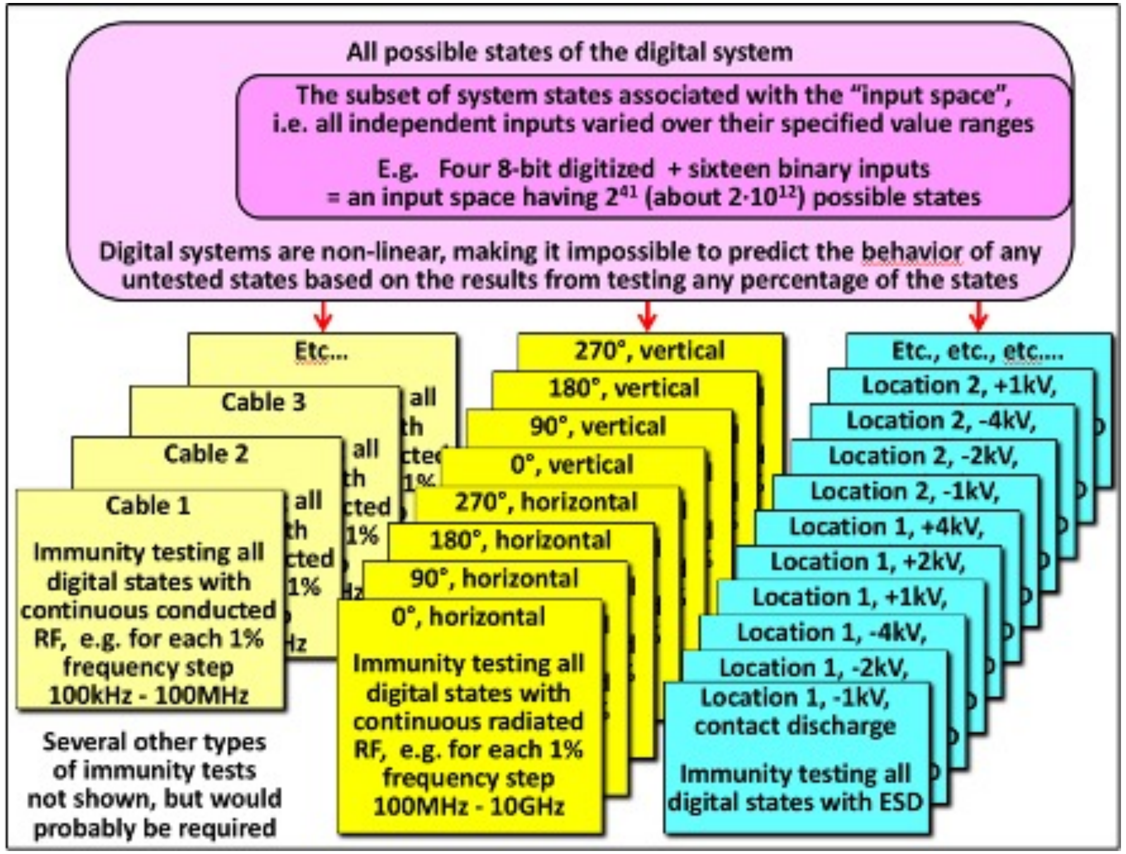
The Radio Equipment Directive:

What about in-band testing?

If we would have an in-band testing standard, will the wireless communications be safe then?

The exploding test plan





Can we use the EMC risk-based approach for wireless communications?

Risk-Based Approach

- Follows a thorough **systems-engineering approach**
- Assessment of:
  - the expected actual EM environment
  - immunity and emission characteristics of equipment
- Then: Implement necessary measures (incl. non-technical)
- Some parts/equipment will be hardened more, some others less compared to the “rule-based EMC-approach”

Risk based approach

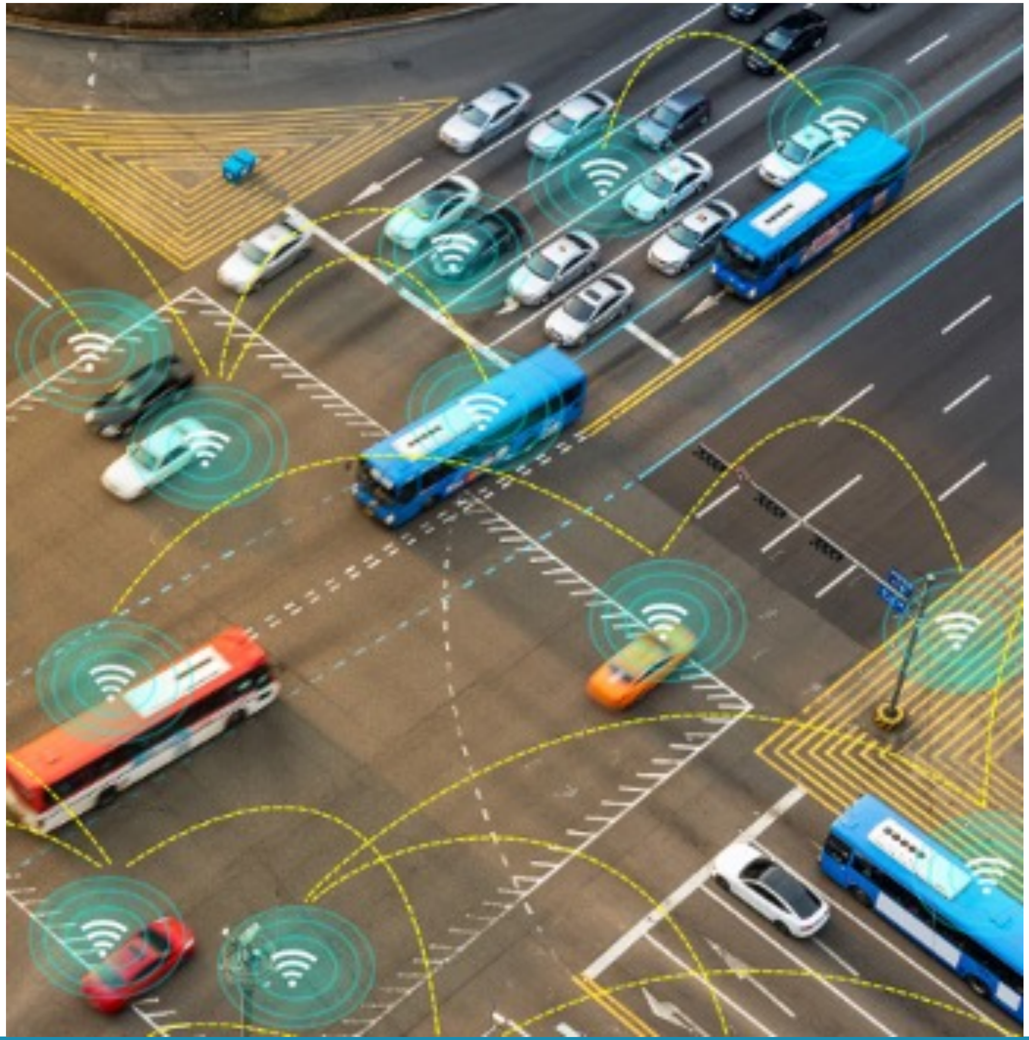
- Not new, this is well known
- Goal is to make sure your device works for the given environment, not more, not less!

Applicable to wireless communications?

Let us have a look at “EMC for functional safety” or “EM Resilience”

Vehicle-to-X Communication

- Car-to-car
- Car-to-infrastructure
- Car-to-pedestrian
- Etc.
- **Robust wireless communication (5G) is key element!**



What is EM Resilience

- “A system is resilient if it can adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions.”

  –Erik Hollnagel, author of the book “Resilience Engineering”

- Resilience of a safety-related system = the ability of the system to remain acceptably safe despite unforeseeable events
- Electromagnetic resilience is the term given to the new functional safety risk-management discipline that describes how to use techniques and measures to manage functional safety risks as regards of electromagnetic disturbances

So for us….

Risk-Based EMC

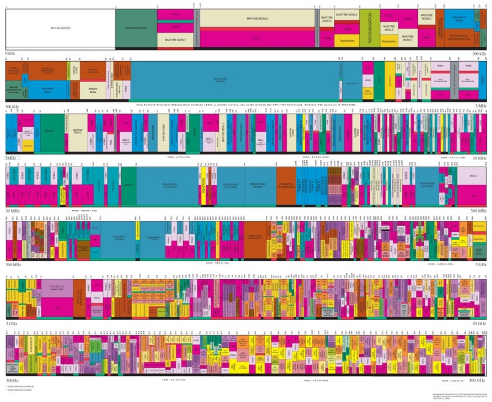
EM Resilience

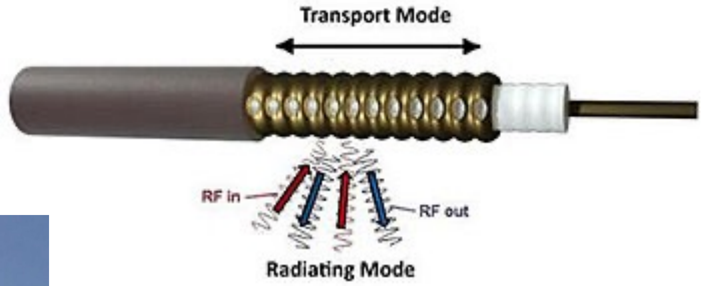
IEEE 1848 for wireless communications?

IEEE 1848 A.3.25: Careful use of wireless (radio) data communications

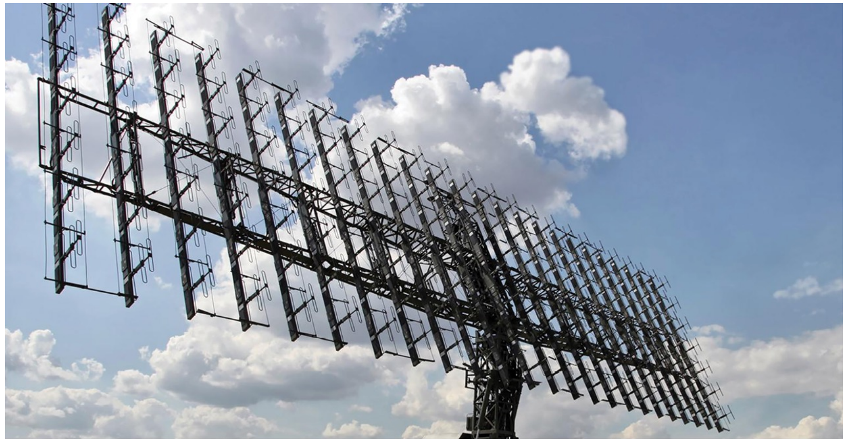
- Continuous transmission wireless communications
  - Is TDMA enough?
  - Can we use NOMA
- Co-existence testing and its lack thereafter in the EMC standards
- The use of heart beats
- EM diverse redundant channels
- The ANSI C63.27 co-existence standard and the AAMI TIR 69-2017 guide

What can be added?





- Spectrum management



- Use of near-fields
- Antenna arrays

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- Wireless protocol diversity
- The use of specific interference avoidance techniques

What do we do @ KU Leuven campus Bruges?

Dynamic avoidance of interference in Bluetooth Low Energy

sensors

MDPI

Article

Bluetooth Low Energy Interference Awareness Scheme and Improved Channel Selection Algorithm for Connection Robustness

Bozheng Pang [1,*], Kristof T'Jonck [1], Tim Claeys [2], Davy Pissoort [2], Hans Hallez [1] and Jeroen Boydens [1]

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2 M-Group, WaveCoRE, Department of Electrical Engineering, KU Leuven Bruges Campus, 8200 Bruges, Belgium; tim.claeys@kuleuven.be (T.C.); davy.pissoort@kuleuven.be (D.P.)
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Abstract: Bluetooth Low Energy (BLE) is a popular wireless communication protocol heavily used in Internet of Things applications. Nowadays, robustness is considered a key requirement in wireless communication. However, radio interference from various sources may affect the performance of BLE devices, leading to channel congestion. Therefore, there is a broadly recognized need of methodologies capable of sensing and avoiding interference. In this paper, two improvements at the data link layer for interference detection and channel selection are proposed to enhance the BLE connection robustness. This paper also presents a wide range of experimental evaluations aiming at validating the improvements and providing insights on both these improvements. Particularly, the communication performance of the BLE link layer is assessed in terms of channel usage distribution, supervision timeout ratio (STR) and packet loss rate (PLR) under different interference environments. Results from these experiments (reliability over 97% and 99% under two different harsh environments) highlight the effects of both improvements on the BLE robustness. Meanwhile, the authority of scheduling the whole mechanism is given to the link layer and even the higher application layer. This paper provides a set of solutions for BLE confronting interference in link layer.

Keywords: Bluetooth Low Energy (BLE); link layer; interference; channel selection algorithm; reliability; robustness

check for updates

Citation: Pang, B.; T'Jonck, K.; Claeys, T.; Pissoort, D.; Hallez, H.; Boydens, J. Bluetooth Low Energy Interference Awareness Scheme and Improved Channel Selection Algorithm for Connection Robustness. *Sensors* **2021**, *21*, 2257. https://doi.org/10.3390/s21072257

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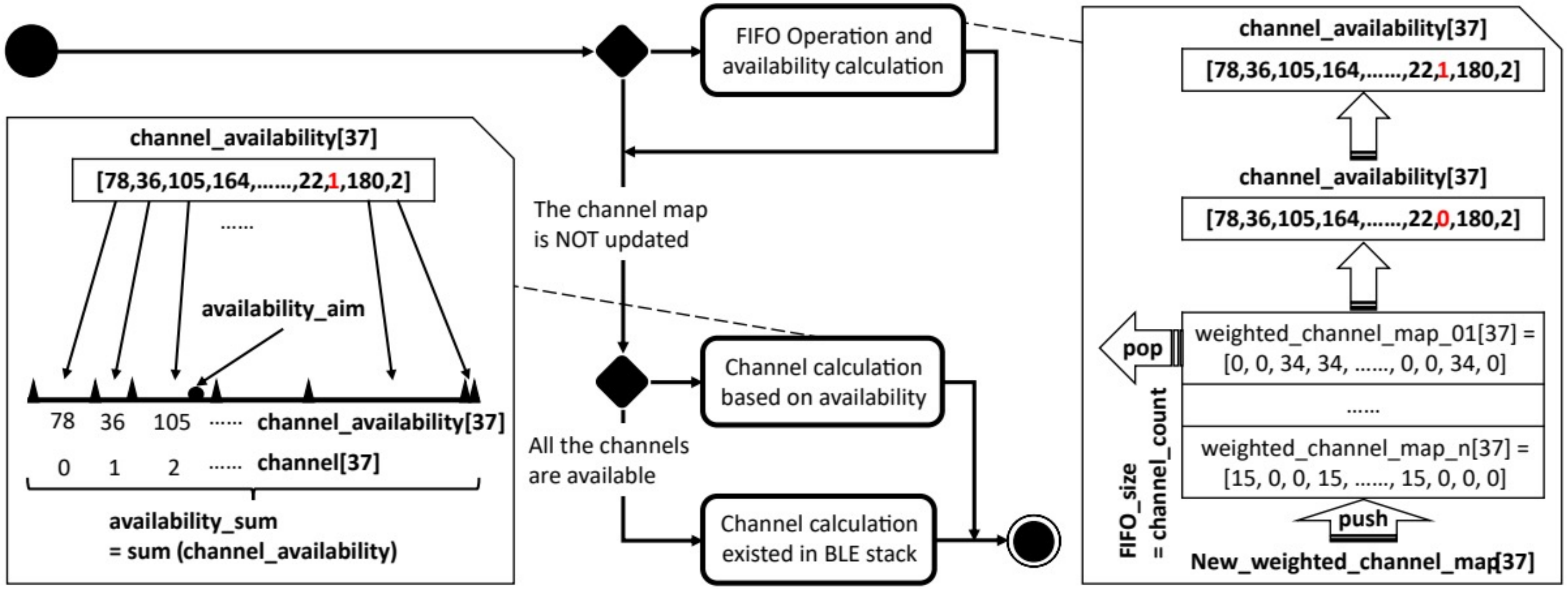
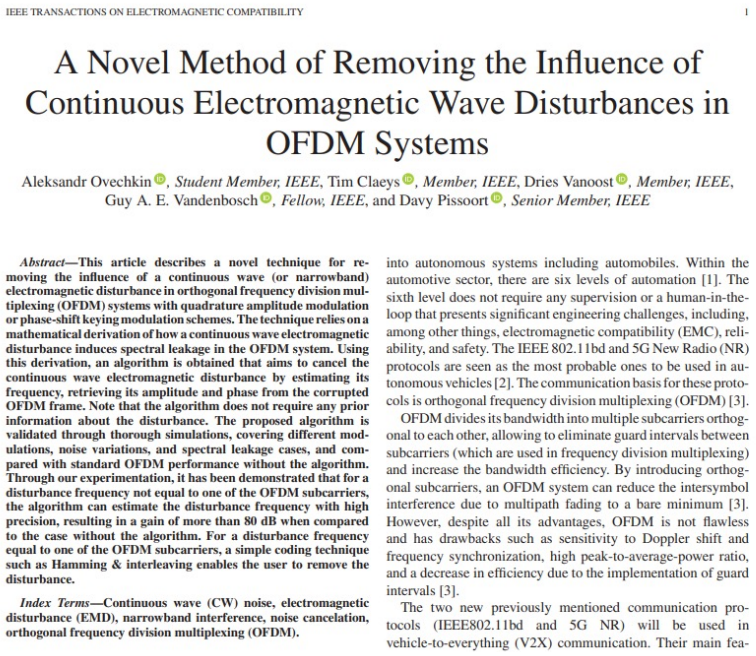


Figure 5. The main logic for the improved CSA.

Table 3. The results of STR and PLR under different conditions (the * represents no data tested for that condition).

		CSA #1	CSA #2	Improved CSA
fixed controlled Wi-Fi interference (after 10,000 connection events)	STR	2.73%	3.27%	0.78%
	PLR	2.73%	3.26%	0.74%
random controlled Wi-Fi interference (after 100,000 connection events)	STR	*	5.65%	2.78%
	PLR	*	5.65%	2.80%
uncontrolled Wi-Fi interference (after 100,000 connection events)	STR	*	4.51%	0.76%
	PLR	*	4.13%	0.72%

A Novel Method of Removing the Influence of Continuous Electromagnetic Wave Disturbances in OFDM Systems



IEEE TRANSACTIONS ON ELECTROMAGNETIC COMPATIBILITY 1

A Novel Method of Removing the Influence of Continuous Electromagnetic Wave Disturbances in OFDM Systems

Aleksandr Ovechkin, *Student Member, IEEE*, Tim Claeys, *Member, IEEE*, Dries Vanoost, *Member, IEEE*, Guy A. E. Vandenbosch, *Fellow, IEEE*, and Davy Pissoort, *Senior Member, IEEE*

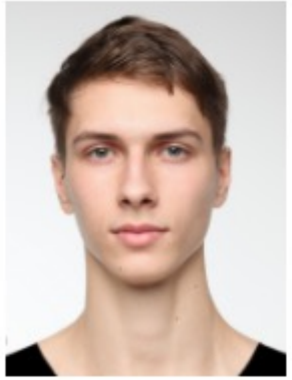
***Abstract*—This article describes a novel technique for removing the influence of a continuous wave (or narrowband) electromagnetic disturbance in orthogonal frequency division multiplexing (OFDM) systems with quadrature amplitude modulation or phase-shift keying modulation schemes. The technique relies on a mathematical derivation of how a continuous wave electromagnetic disturbance induces spectral leakage in the OFDM system. Using this derivation, an algorithm is obtained that aims to cancel the continuous wave electromagnetic disturbance by estimating its frequency, retrieving its amplitude and phase from the corrupted OFDM frame. Note that the algorithm does not require any prior information about the disturbance. The proposed algorithm is validated through thorough simulations, covering different modulations, noise variations, and spectral leakage cases, and compared with standard OFDM performance without the algorithm. Through our experimentation, it has been demonstrated that for a disturbance frequency not equal to one of the OFDM subcarriers, the algorithm can estimate the disturbance frequency with high precision, resulting in a gain of more than 80 dB when compared to the case without the algorithm. For a disturbance frequency equal to one of the OFDM subcarriers, a simple coding technique such as Hamming & interleaving enables the user to remove the disturbance.**

***Index Terms*—Continuous wave (CW) noise, electromagnetic disturbance (EMD), narrowband interference, noise cancelation, orthogonal frequency division multiplexing (OFDM).**

into autonomous systems including automobiles. Within the automotive sector, there are six levels of automation [1]. The sixth level does not require any supervision or a human-in-the-loop that presents significant engineering challenges, including, among other things, electromagnetic compatibility (EMC), reliability, and safety. The IEEE 802.11bd and 5G New Radio (NR) protocols are seen as the most probable ones to be used in autonomous vehicles [2]. The communication basis for these protocols is orthogonal frequency division multiplexing (OFDM) [3].

OFDM divides its bandwidth into multiple subcarriers orthogonal to each other, allowing to eliminate guard intervals between subcarriers (which are used in frequency division multiplexing) and increase the bandwidth efficiency. By introducing orthogonal subcarriers, an OFDM system can reduce the intersymbol interference due to multipath fading to a bare minimum [3]. However, despite all its advantages, OFDM is not flawless and has drawbacks such as sensitivity to Doppler shift and frequency synchronization, high peak-to-average-power ratio, and a decrease in efficiency due to the implementation of guard intervals [3].

The two new previously mentioned communication protocols (IEEE802.11bd and 5G NR) will be used in vehicle-to-everything (V2X) communication. Their main fea-



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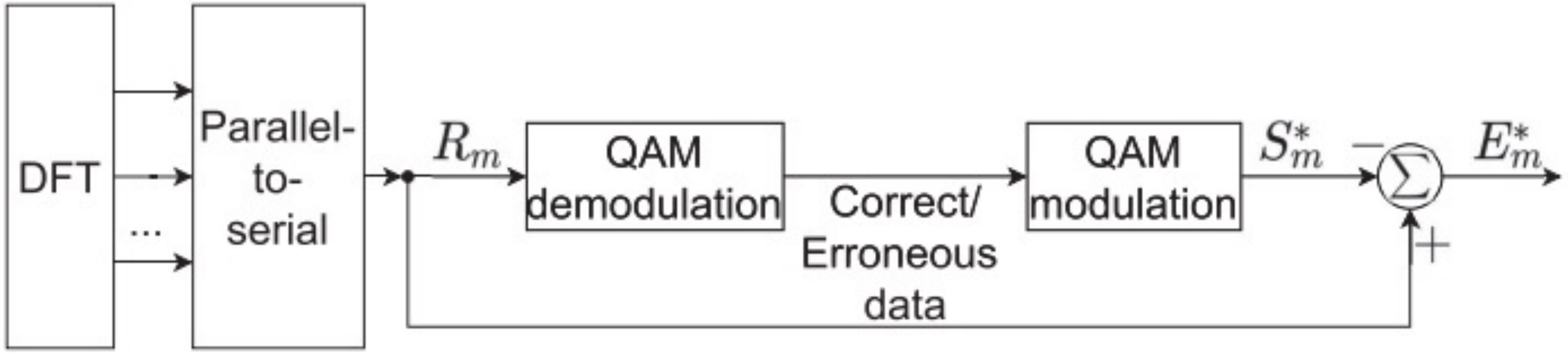
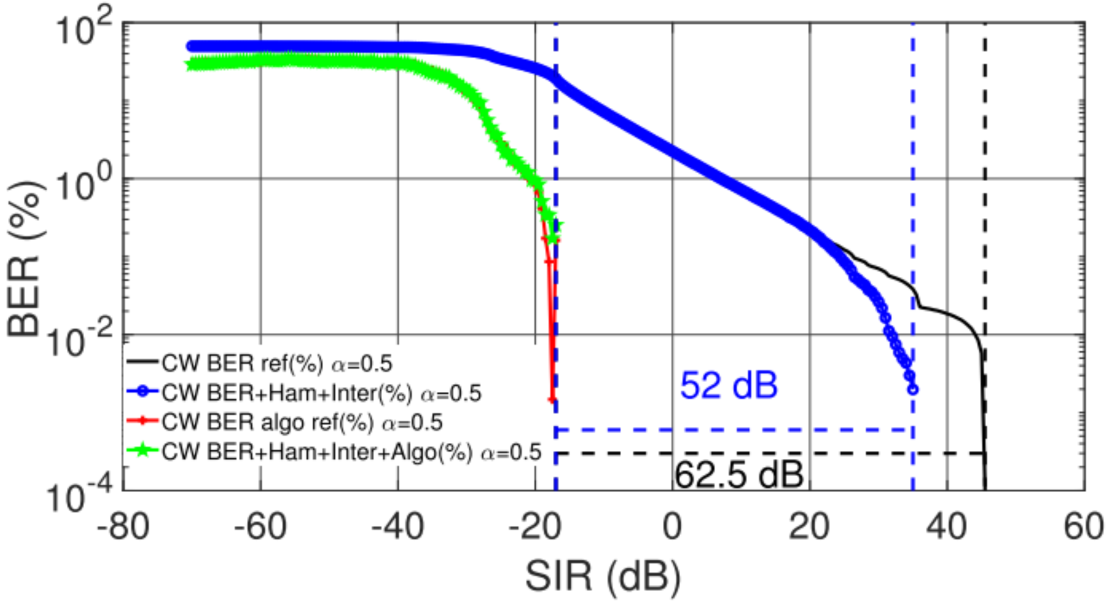

DFT
...
Parallel-to-serial
R_m
QAM demodulation
Correct/ Erroneous data
QAM modulation
S_m^*
E_m^*


BER (%)
SIR (dB)
CW BER ref(%) α=0.5
CW BER+Ham+Inter(%) α=0.5
CW BER algo ref(%) α=0.5
CW BER+Ham+Inter+Algo(%) α=0.5
52 dB
62.5 dB

And many more…

Characterizing the Robustness of Wi-Fi and Bluetooth against Continuous Wave EM Disturbances inside a Reverberation Chamber

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The Need For and How To Evaluate Continuous Wave Immunity of Wireless Systems used in V2X Applications

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Development of an EMI Detector Based on an Inverted Data Pair with Reduced Number of False Negatives

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Risk Management of Wireless Communications with regards to Electromagnetic Disturbances, An Addition to IEEE1848 or a New Guide?

Tim Claeys, ESAT-WaveCoRE, KU Leuven Bruges Campus, Bruges, Belgium, tim.claeys@kuleuven.be

Combining 2oo3 Voting and Hamming Error Correction to Reduced the Occurrence of False Negatives in Wired Communication Lines under Continuous-Wave Electromagnetic Disturbances

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Effectiveness of a Matched Filter to Cope With Harsh Phase and Amplitude Modulated EMI

Jonas Lannoo, Tim Claeys, Dries Vanoost, Jonas Van Waes, *Student Member, IEEE*, Jeroen Boydens, *Member, IEEE*, and Davy Pissoort, *Senior Member, IEEE*

Comparative Study on AFH Techniques in Different Interference Environments

Bo-Zheng Pang[1], Tim Claeys[2], Davy Pissoort[2], Hans Hallez[1] and Jeroen Boydens[1]
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A System's Perspective on the Use of EMI Detection and Correction Methods in Safety Critical Systems

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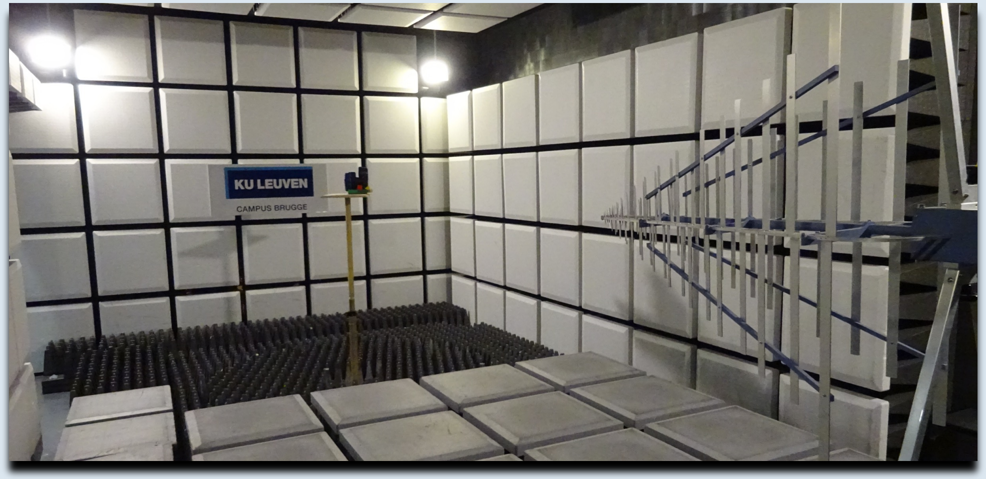
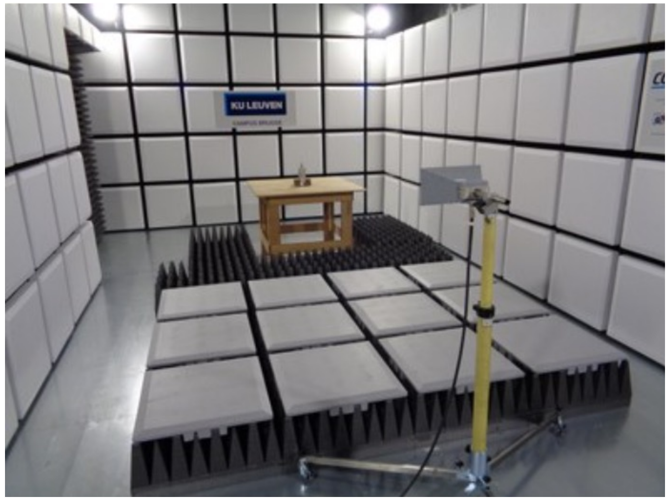


3m Semi-Anechoic Chamber (SAC)

High-end Power analysis system for harmonic emission and Flicker

Large 15 cm automotive stripline



2 port 14 GHz Vector Network Analyzer

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- ...

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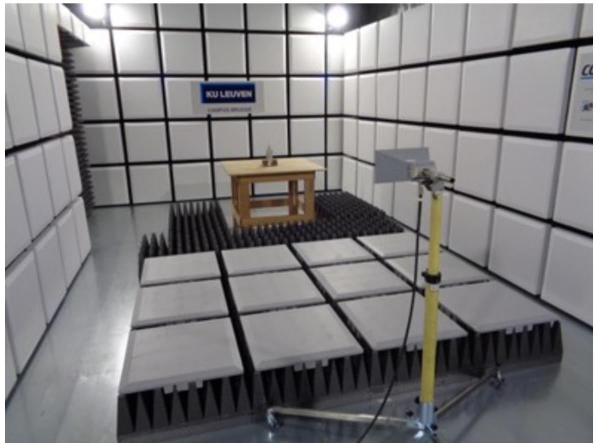

- High frequency update
  - Vector signal generator R&S SMM100A
    - 100KHz-44GHz
    - 500MHz baseband bandwidth
    - Multi carrier CW
    - IEEE802.11
    - OFDM
    - 5G NR
  - Vector signal analyzer R&S FSVA3000
    - 100KHz-44GHz
    - 2GHz baseband bandwidth
    - Vector signal analysis
    - IEEE802.11
    - OFDM
    - 5G NR

Research projects at European level

Questions?