

# Electromagnetic Interference Analysis of Industrial IoT Networks: From Legacy Systems to 5G

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**Abstract**—The presence of Industrial IoT systems on the factory shop floor in recent years, are becoming an attractive solution with many advantages, including flexibility, low cost and easy deployment. As more and more devices are wirelessly connected, spectral noise level increases and consequently radio interference between IoT devices. In this paper, we present an agnostic methodology to assess radio interferences between different industrial IoT systems on the factory floor, using appropriate propagation models. Several interference scenarios are simulated, ranging from legacy systems to future communication standards implementations (5G). We highlight some of the challenges and open issues that still need to be addressed to decrease interference and make industrial wireless systems compatible.

**Index Terms**—Electromagnetic Interference, 5G, Industrial IoT, SEAMCAT

## I. INTRODUCTION

During the last 30 years, the industry has automated everything that can be automated in the factory shop-floor, using wired technology. The main processes which have so far not been fully automated are the integration of logistics, material handling, and factory automation. The integration of logistics, material handling, and factory automation can only be achieved by using wireless technology [1]. The fourth industrial revolution (Industry 4.0) brings a total transformation of industrial production through the fusion of digital technology and the internet with the conventional industry, causing all processes on the factory floor to be digitally connected. Wireless technologies in industrial production has already present nowadays. We see a multitude of wireless technologies being used for different use cases in industrial production. Initially, wireless technologies were used for selected non-critical applications, but increasingly wireless technology is becoming the norm, and increasingly, it is becoming more and more used in mission-critical applications. According to a survey from HMS [2], currently, the most comprehensive wireless technology in industrial production is WiFi. Most respondents indicated that they are using it either on the factory floor or in their products (74 %). In addition to that, 39 % of the interviewees indicated using Bluetooth, and in some cases, specifically Bluetooth Low Energy (BLE) in their companies. A smaller part, 13 %, mentioned their companies were also using other wireless communication systems: WirelessHART, ZigBee, SigFox, or

LoRA, among others. Wireless communications systems remove the physical barriers of traditional wired communication architectures at a reduced level of cost, are easy to deploy, require low maintenance, and are flexible [3]. However, all these technologies are using unlicensed frequency bands, such as the Industrial, Scientific, and Medical (ISM) band. As the ISM band do not require any license, radio interference management is not only challenging because of the noise level and heavy usage, but because of the different standards operating in parallel [4]. There is also the legal limit to the level of emitted radiation of unlicensed bands. As a result, range and wall penetration of the radiated power is low. In brief, the use of unlicensed spectrum for industrial applications may not satisfy the more demanding quality requirements [1]. For this reason, the full potential of wireless technologies in the industry has not yet been fully implemented. The advent of 5G, the mobile network of the 5<sup>th</sup> generation, promises to overcome the shortcomings of other wireless systems [5]. 5G was designed to become the new standard for industrial connectivity. It offers different configurations fitted to the usage scenarios identified by the ITU-R: Enhanced Mobile Broadband (eMBB), Massive Machine-Type Communication (mMTC), and Ultra-Reliable Low Latency Communications (URLLC). 5G uses licensed frequency bands. In Europe, the carrier frequencies planned for 5G networks are 700 MHz, 900 MHz, 2100 MHz, 3.5 GHz, and 26 GHz [6]. Even if they all fall outside the ISM bands and 5G networks manage frequencies centrally, they need to coexist with legacy systems. Without proper filtering for each band, emissions from intermodulation products, spurious or out-of-band emissions can cause spurs outside the allocated channel. Thus, potential interference between 5G networks and legacy radio systems in the shop-floor should be investigated. So far, research was conducted to assess the interference between 5G mobile networks and other services in the 26 GHz band [7]. In 2016, the Radio Spectrum Policy Group (RSPG) considered the frequency band 3400-3800 MHz (n78) [8] to be the primary band suitable for the introduction of 5G-based services in Europe in the short term (i.e. in 2020), given that it is already harmonized for mobile networks and offers wide channel bandwidth [9], [10]. More recently, with the publication of 3GPP Standard (Release 16) in July 2020 [11], several additional

operating bands were assigned to 5G, with frequencies channels adjacent to the 2.4 GHz ISM band. In particular, operating band n53 ranges between 2483.5 MHz and 2495 MHz, both for uplink or downlink, in TDD mode. The objective of this paper is to simulate interference scenarios on the factory floor using the appropriate propagation models and system configuration. We will conduct a coexistence analysis between 5G New Radio (NR) local Base Station (BS) and User Equipment (UE) operating in band n53 and legacy systems (e.g. WiFi, WirelessHART, Bluetooth) using the 2.4 GHz ISM band. The rest of the paper is organized as follows. Section II provides an overview of the methodology used in the interference simulations. Section III presents the radio system specifications. Section IV describes the interference scenarios. Section V discusses the simulation results and highlights the findings. Finally, Section VI presents paper conclusions together with future work proposals.

## II. METHODOLOGY

The criterion used for interference to occur to have interference to noise ratio  $I/N$  less than the minimum allowable value. First, we need to establish the wanted signal from the corresponding transmitter  $C$ , to compute the  $I/N$  of the receiver from legacy systems, suffering from interference (victim link). This signal is produced by the interfering transmitter  $I$ , and the thermal noise  $N$ . Aforementioned is done by defining technical parameters for each radio system. The process includes the receiver and transmitter specifications of both the victim and the interfering links, the propagation model associated with the medium of communication, and a measure of the quality of service required. The position of the victim transmitter and receiver is identified, and a link budget is computed. The same process occurs for the interfering system. Knowing both the victim signal and the interfering signal allows the victim receiver  $I/N$  to be computed using a Monte-Carlo technique. After all, the systems are configured and the simulation runs a series of trials. For each trial, the received primary signal  $C$  is compared to the sensitivity  $S$  of the victim link receiver. If  $C$  falls below  $S$ , the trial is discarded. Then, if  $I/N_{trial}$  is higher than  $I/N_{target}$ , no interference is registered; Otherwise, interference occurs, and this event accumulates to the number of trials with the same result ( $K_{int}$ ). Finally, when all trials are computed ( $K_{all}$ ), the probability of interference is expressed as [12],

$$P_{interference} = K_{int}/K_{all} \quad (1)$$

This way, we are able to quantify the probability of interference between a victim link and interferer system, considering many independent simulation trials in an agnostic way. SEAMCAT - Spectrum Engineering Advanced Monte- Carlo Analysis Tool [6], from CEPT, is used to study the interference between legacy systems like WiFi, WirelessHART, Bluetooth and 5G systems using a Monte Carlo technique for the radio simulation model.

## III. SYSTEM SPECIFICATIONS

This section describes the radio systems, including the transmitter and the receiver, used in the interference analysis in Section IV.

### A. Legacy System Specifications

The technical specifications for WiFi, Bluetooth and WirelessHART systems are presented in Table I.

TABLE I  
WiFi, WIRELESSHART, AND BLUETOOTH TECHNICAL SPECIFICATIONS.

System	WirelessHART	WiFi	Bluetooth
Property			
Frequency band	2400-2483.5 MHz		
Channel bandwidth	1 MHz	22 MHz	1 MHz
Channel spacing	5 MHz	25 MHz	1 MHz
Number of channels	16	3 (1,6,11)	79
In-Block EIRP	10 dBm	20 dBm	0 dBm
Antenna height	Tx: 2.5 m Rx: 1.0 m	Tx: 3.0 m Rx: 1.5 m	Tx: 1.5 m Rx: 1.5 m
Antenna type	omnidirectional		
Antenna gain	Tx: 2 dBi Rx: 0 dBi	Tx: 6 dBi Rx: 0 dBi	Tx: 0 dBi Rx: 0 dBi
Receiver sensitivity	-90 dBm	-95 dBm	-95 dBm
Environment	50 % indoor 50 % outdoor	100 % indoor below roof	
Propagation model	ITU-R P.1546-6		Extended Hata SRD
Coverage radius	200 m	50 m	20 m
Prob. Transmission	10 %	90 %	50 %

WiFi and Bluetooth systems are assumed to be indoor (wall loss= 10 dB, std dev = 5) and wirelessHART has 50 % outdoor probability. Antenna pattern is assumed to be omnidirectional in azimuth and elevation. Transmitter's emission masks and receiver's blocking masks for WiFi, Bluetooth, and wirelessHART are represented in Fig. 1 and Fig. 2, respectively [13].

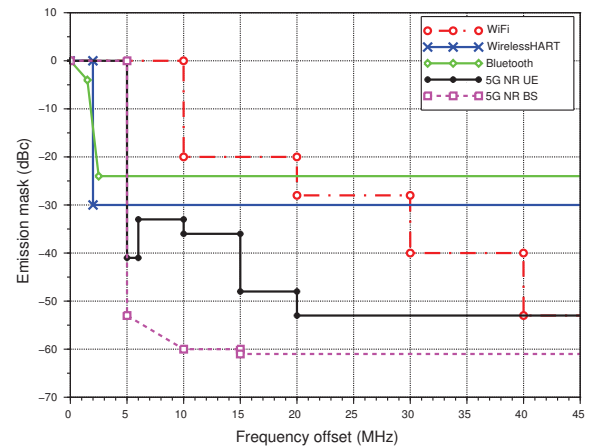


Fig. 1. WiFi, Bluetooth, wirelessHART and 5G NR Transmitter emission masks.

WirelessHART and WiFi systems use ITU-R P.1546-6 (Land Mobile, 50 % time, 50 % locations, dense urban clutter)

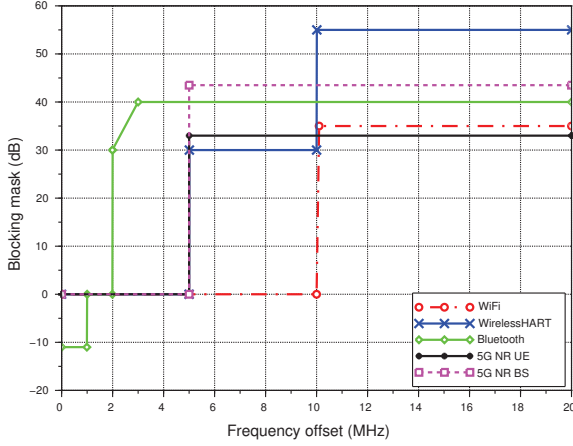


Fig. 2. WiFi, Bluetooth, wirelessHART and 5G NR receiver blocking masks.

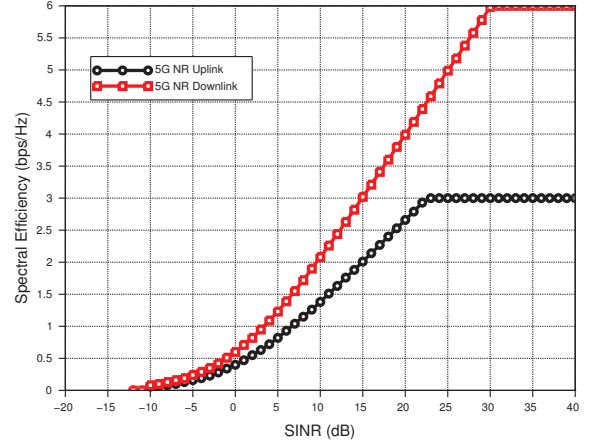


Fig. 3. Bitrate mapping for 5G NR Uplink (circles) and Downlink (squares).

propagation model, which is adequate for this particular scenario. For Bluetooth, we use the Extended Hata SRD model that is adequate to devices with antenna height up to 3 m and a distance range up to 300 m. Each system was also configured to implement frequency hopping among their available channels. The frequency channel is randomly selected among a list of available channels from the 2.4 GHz ISM band to simulate frequency hopping for Bluetooth and WirelessHART systems. All the channels have an equal probability of being selected. To accommodate a similar approach for WiFi, e.g. some APs have the capability to scan the spectrum and allocate a different channel for the system, channels 1 (2.412 GHz), 6 (2.437 GHz) and 11 (2.462 GHz) are listed with equal usage probability during the simulations. The transmission probability was also differentiated among all systems to mimic real scenarios (90 % for WiFi, 10 % for WirelessHART, and 50 % for Bluetooth).

### B. 5G System Specifications

The specification of the Base Station (BS) [11] and the User Equipment [8] are listed in Table II and Table III, for macro cells and micro cells, respectively. Transmitter's emission masks and receiver's blocking masks of BS and UE are represented in Fig. 1 and Fig. 2, respectively. A lookup table is used to map the throughput in terms of spectral efficiency (bps per Hz) with respect to the computed SINR level [14]. Link level data (bitrate mapping) is represented in Fig. 3 for uplink and downlink traffic in micro and macro cells.

Antenna pattern is a 3GPP tri-sector for BS and is assumed to be omnidirectional in azimuth and elevation for UE. During simulations, we consider that the receiver antenna always returns the peak gain value specified, regardless of the direction.

From 3GPP Standards for BS (Table 5.3.5-1) [11] and UE (Table 5.3.2-1) [8], the Resource Block (RB) bandwidth can be computed using the following equation,

$$BW_{RB} = (BW_{Channel} - 2 \times BW_{GB})/N_{RB} \quad (2)$$

where  $BW_{RB}$  is the RB bandwidth,  $BW_{Channel}$  is the Channel Bandwidth,  $N_{RB}$  is the number of Resource Blocks and  $BW_{GB}$  is the guard-band bandwidth. Considering operating band n53 with 15 kHz Sub-Carrier Spacing (SCS), the RB bandwidth is  $(10000 - 2 \times 312.5)/52 = 180$  kHz.

TABLE II  
5G NR TECHNICAL SPECIFICATIONS FOR BASE STATION AND USER EQUIPMENT FOR A MACRO CELL.

Property	System	Base station	User Equipment
Frequency band		2483.5 - 2495 MHz (n53, TDD)	
System bandwidth		10 MHz	
Bandwidth of a RB		180 kHz	
Maximum RB per BS		52	
Number of RB per UE		13	
In-Block EIRP		46 dBm	24 dBm
Antenna height		30 m	1.5 m
Antenna type		tri-sector 3GPP	peak gain antenna
Antenna gain		15 dBi	0 dBi
Min. Coupling Loss		70 dB	
Receiver Noise Figure		4 dB	8 dB
Propagation Model		ITU-R P.1546-6, mobile	
Handover margin		3.1 dB	
Environment		100 % outdoor	10 % outdoor, 90 % indoor: wall loss = 10 dB std. dev. = 5

## IV. SIMULATION SCENARIOS

The criterion used for interference to occur in legacy systems is to have interference to noise ratio  $I/N$  less than -6 dB [15]. The same value is also used for 5G cellular networks as a protection criterion. This value was considered because, in an industrial scenario, the interference has to be very low to avoid communication failure between the machines and between the machines and operators, but this does not imply that other  $I/N$  values cannot be used. All the simulation scenarios consist of one victim link, and one or more interfering links and networks.

TABLE III  
5G NR TECHNICAL SPECIFICATIONS FOR BASE STATION AND USER EQUIPMENT FOR A MICRO CELL.

Property	System	Base Station	User Equipment
Frequency band		2483.5 - 2495 MHz (n53, TDD)	
System bandwidth		10 MHz	
Bandwidth of a RB		180 kHz	
Maximum RB per BS		52	
Number of RB per UE		13	
In-Block EIRP		46 dBm	24 dBm
Antenna height		6 m	1.5 m
Antenna type		peak gain antenna	
Antenna gain		6 dBi	0 dBi
Min. Coupling Loss		53 dB	
Receiver Noise Figure		4 dB	8 dB
Propagation Model		ITU-R P.1546-6, mobile	
Handover margin		3.1 dB	
Environment		100 % outdoor	10 % outdoor, 90 % indoor: wall loss = 10 dB std. dev. = 5

The relative position between the victim and interferer systems follows a uniform spatial distribution inside the area of the factory, and allow the simulation of mobility among wireless devices. Several scenarios with different characteristics are needed to get acceptable results from interference simulations. Therefore, we consider three deployment and several coexistence scenarios:

- Deployment 1: Interference over legacy systems from legacy systems;
- Deployment 2: Interference over legacy systems from legacy systems and 5G UE (hybrid, UL);
- Deployment 3: interference over 5G BS (hybrid, DL) and 5G UE (hybrid, UL), from legacy systems.

#### A. Deployment 1

All simulation scenarios are composed of one victim system, and one or more interfering system, where each of them is composed of one transmitter and one receiver. Every legacy system (WiFi, Bluetooth, and wirelessHART) was considered in turn a victim link and an individual interfering link for the other two systems, as described in Table IV. We considered a downlink scenario in which the transmitter is an Access Point (AP) or gateway and the receivers are mobile devices. All the receivers will be randomly deployed within the area centered on the transmitter and delimited by the coverage area, to simulate movement among wireless systems. The coverage area is delimited by a rectangular area with a size of 80 m  $\times$  80 m, to simulate an environment similar to a factory shop-floor.

#### B. Deployments 2 and 3

From the list of possible environments for the deployment of 5G networks for industrial applications presented in Section I, we select a cellular test environment to execute the simulations consisting of two layers, a 2-tiers macro layer and a micro layer.

TABLE IV  
COEXISTENCE SCENARIOS BETWEEN LEGACY SYSTEMS

	Victim System	Interfering System
Scenario 1	WiFi	Bluetooth
Scenario 2	WirelessHART	WiFi
Scenario 3	WirelessHART	Bluetooth
Scenario 4	Bluetooth	WiFi
Scenario 5	WiFi	WirelessHART
Scenario 6	Bluetooth	WirelessHART

The macro-layer base stations are placed in a regular grid with 15 km spacing between BSs, following an hexagonal layout with three transmitters each, as shown in Fig. 4 below. For the micro layer, there are two micro sites randomly dropped in each macro transmitter coverage area [16]. Each micro site has a coverage area of 300 m. For each simulations, legacy systems are uniformly located at the proximity of the center of the reference cell in Fig. 4.

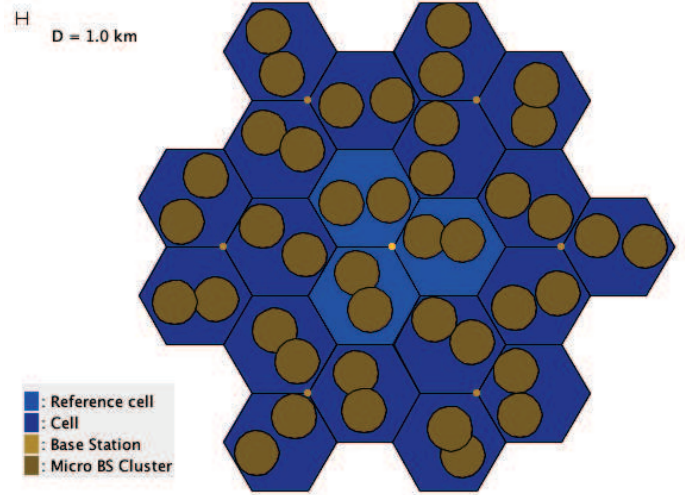


Fig. 4. Cellular layout of 5G NR hybrid scenario with macro and micro cells [17].

## V. RESULTS AND DISCUSSION

### A. Interference over Legacy Systems

Twenty thousand events (trials) have been run in each simulation. For each victim link, we increase the number of legacy interferers from 1 to 100 (1,5,10,50,100), and compute the probability of interference exceeding the predefined criterion  $I/N = -6$  dB. Results from Fig. 5 (full line) shows that the worst-case came from WiFi interfering with Bluetooth systems. With 10 WiFi BS interferers, the probability of interference exceeding the predefined criterion is higher than 95 %. On the opposite side, the best scenario is between WiFi as a victim link and Bluetooth as the interferer system. For the same ten interferers and the same criterion, the probability of interference is 21 %.

When a 5G cellular network is added as an interferer, the interference results are presented in Fig. 5 (dashed line) for



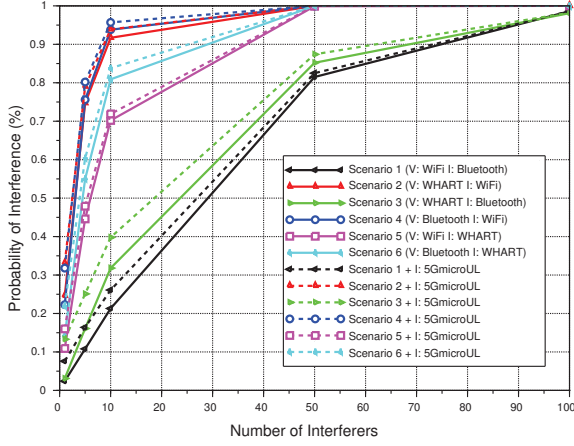


Fig. 5. Probability of interference for 6 different coexistence scenarios between WiFi, Bluetooth and wirelessHART systems, with (dashed lines) and without (full lines) 5G NR UE in uplink mode in a micro cell.

a 5G macro-cell in uplink mode and Fig. 6 (dashed line) for a 5G micro-cell in uplink mode. For each simulations, and according to the specifications given in Table II and Table III (13 RBs per UE), the maximum number of active users (UE) per BS is three. The simulation results shows an overall deterioration of the interference levels due to the presence of an additional interfering system in an adjacent frequency channel (n53) closed to 2.4 GHz ISM band. The deterioration is more pronounced when interference is coming from UE uplink from a cellular micro-cell.

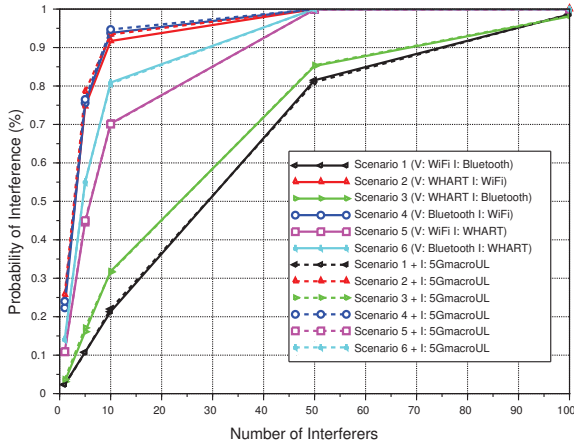


Fig. 6. Probability of interference for 6 different coexistence scenarios between WiFi, Bluetooth and wirelessHART systems, with (dashed lines) and without (full lines) 5G NR UE in uplink mode in a macro cell.

### B. Interference over 5G Systems

For the same criterion  $I/N = -6$  dB, other simulations were conducted to identify the effect of non-licensed systems,

using the ISM band (2.4 GHz), over 5G networks using a licensed spectrum in band n53. The results are measured in bitrate loss, as a function of the number and kind of legacy interferers (WiFi, WirelessHART or Bluetooth). The results from Fig. 7 shows the average bitrate loss for a hybrid 5G network (macro-micro cell) in downlink mode, considering a variable number of interferers (1, 100, and 1000) for each individual legacy interfering system. The average bitrate loss increases proportionally with the number of interferers, and Wifi systems are causing higher losses, up to 0.14 % when 1000 devices are present in the vicinity of the BS.

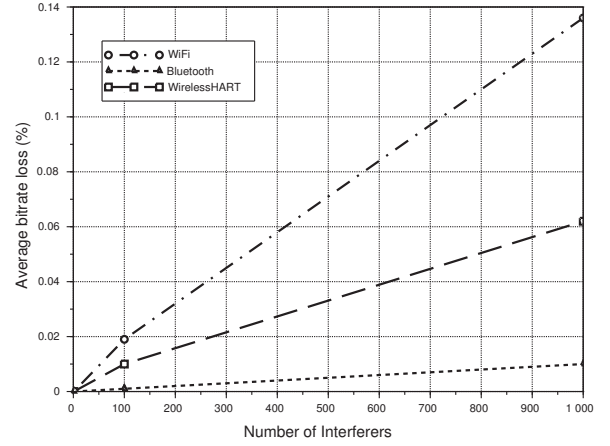


Fig. 7. Average bitrate loss for a hybrid 5G network BS downlink, considering the interference criterion  $I/N = -6$  dB.

Fig. 8 shows the interference simulations results from legacy systems into 5G macro cell network using spectrum band n53, considering the uplink scenario. We have considered a variable number of interferers (1, 5, 10, 50 and 100) for each individual legacy system. The average bitrate loss increases proportionally with the number of interferers. The results shows a similar bitrate degradation effect from WiFi and WirelessHART interferers over the 5G uplink, with a bitrate loss over 10 % in the presence of 50 interferers or more.

## VI. CONCLUSION

In this paper, we use SEAMCAT as an agnostic simulation tool to assess radio interferences between three wireless communication systems commonly used on the factory shop floor (WiFi, Bluetooth, and WirelessHART) and a 5G network. As more and more devices are wirelessly connected, spectral noise level increases and consequently radio interference between devices. Considering that critical or massive machine-type communication on the factory shop-floor may be using wireless systems soon, spectrum compatibility studies are essential to assess coexistence between them. These studies, expressed for instance in terms of interference probability or bitrate loss, are needed to evaluate, define and validate rules and conditions under which new or evolved technologies, such as legacy

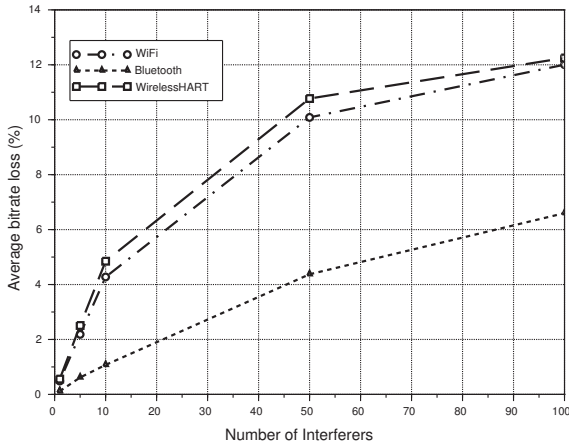


Fig. 8. Average bitrate loss for a hybrid 5G macro network UE uplink, considering the interference criterion  $I/N = -6$  dB.

wireless systems or newcomers such as 5G mobile, can access spectrum. The results from the interference scenarios have shown that, from an electromagnetic point of view, interference levels affect the receiver of legacy systems, 5G UE, and 5G BS differently, and to some extent, may affect their performance. From the simulated scenarios, legacy systems are more prone to suffer interference from other legacy systems working in co-channel arrangements (e.g. 2.4 GHz ISM band) than from 5G networks using the adjacent channel n53. When the 5G network is simulated as the system suffering interference, legacy systems produces a higher degradation in the UE uplink channel, with a maximum bitrate loss of 12 % with WiFi as the interfering system.

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