Performance optimization for the UWB communication with the co-existing 5G networks

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Abstract

In recent era, Ultra-Wideband (UWB) signalling is a proven solution for body area network (BAN) as well as location accuracy and dedicated short-range, high-speed data communication under FCC's spectral regulations. In this paper, a methodology is proposed to mitigate the interference between UWB devices and 5G networks for the coexistence of UWB communication. Pulse shape methodology is used for Gaussian pulse and Gaussian monocycle for the reference pulse shaping methodologies. The obtained results are verified analytical simulations that proves the importance of the proposed methodology to minimize the interference issues.

Keywords: UWB, RF, 5G, Pulse shaping, FCC, ISI, PSD

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Introduction: -

UWB technology has great capacity due to its huge bandwidth >500MHz. The characteristics of UWB is its immunity to ISI and extreme pinpoint location accuracy due to the very low duration (nanoseconds) of pulses[1], [2]. It is also popular applications are in the field of medical imaging, BAN and RADAR imaging etc. Apple iPhone is also using UWB chips for smart and improved location accuracy[3].The UWB communication have a huge capacity but due to its large bandwidth, this technology is facing some constraints of spectral masking imposed by several regulators like FCC(USA), CEPT(Europe), MIC(JAPAN), Ofcom(UK), APT(Asia Pacific) etc[4]–[6]. In Feb-2002, the United States Federal Communications Commission (FCC) prohibited unauthorized use of UWB devices for various applications due to the interference issues.The UWB devices are also revealing their importance for neuro recording systems that can help neurological implants with high data-rates[7]. For indoor systems and handheld UWB devices, the FCC has limit the UWB emissions under -41.6 dBm/MHz between the bandwidth from 3.1 to 10.6 GHz. UWB communication technology differs from conventional narrowband wireless technology because it disperses signals beyond a huge range of frequencies as compared to broadcast on individual frequency. Trains of pulses with hundreds of millions of pulses replaces the sinusoidal radio signal. UWB transmissions appear to be background noise because of their low PSD (power spectral density) levels. [8], [9]. The UWB technology has a great influence on the wireless industry. The UWB communication is presently co-existing with 5G. UWB antennas are the backbone of 5G communications. The modified Rake receiver is a component of femtocells (home base stations) for 5G communication that is part of architecture of UWB indoor channels[10], [11] .

In order to address the multipath situation, this study suggests upgrading the conventional Rake receiver to a 5G wireless system using a novel concept known as a "hybrid femtocell," which mixes UWB and millimetre wave (mm- Wave) transmissions[10], [11]. The redesigned receiver is regarded as a component of the hybrid UWB/mm-Wave femtocell system, which was created to accommodate indoor multipath channels and ensure flexible transmission based on the Intelligent Control System (ICS).

Useof UWB
technology by the femtocell modifiedreceiver helps to mitigate multipath effects and ensure high throughput. Because of UWB's huge channel capacity and high spectral efficiency for 5G cellular platforms, antennas used should have high bandwidth and multiple input multiple output (MIMO) capabilities.

Other important terms related to UWB:

When a high-rated emission value is below 10 dB, it defines the frequency as a UWB bandwidth relative to the strongest radiated emission in the spectrum.Its center frequency(F_c) is calculated by:

$$F_c = \frac{f_l + f_h}{2} \quad [1]$$

Where f_l = lower boundary,f_h = higher boundary

Its fractional bandwidth (FB) is calculated by:

$$FB = 2\frac{(f_h - f_l)}{f_h + f_l} \quad [2]$$

Additional benefits and possibilities will be in terms of UWB using Shannon's capacity theorem i.e.

$$C = B\log\left(1 + \frac{S_i}{N}\right) \quad [3]$$

By enhancing bandwidth, the signal to noise ratio, or reduce noise by using this theorem to increase the channel's capacity. Additionally, it has been observed that channel capacity proportionally increases with increment of bandwidth B and logarithmically with growing signal power S_i.

The interference issues are the key that imposes the limitation on the full utilization of UWB characteristics. In literature, various authors have presented different methodologies to mitigate the co-existing interference[12]–[15]. The most popular methodology, adopted by several authors, is pulse shaping. In this manuscript, we have selected pulse shaping for the interference mitigation for 5G devices and UWB communications systems. The next section describes the methodologies followed by the mathematical analysis and result discussion.

1. Methods: -

By using of pulse shaping technique in reducing ISI,since it is a process of changing waveform of pulses that are transmitted and the purpose of this method also helps in making transmitted signals better in their respective channels, by limiting their bandwidth of transmission.A physical realization is always causal, since an analytic signal carries the information.Most techniques are slow to adapt to changing environments and can only manage fixed environments. They either can't achieve dynamic interference cancellation or are difficult to apply.The method uses an efficient modified algorithm which leads for evaluation of performance by computer simulations done by MATLAB. When communication channel bandwidth is greater than signal bandwidth then the ISI is minimum in channel[16].

The methodology isemployed thatapproximates the normalized Gaussian function. A normalized Gaussian function is revealed in Eq. (4)

$$G(x) = \frac{1}{\sqrt{2\pi\sigma^2}}e^{-x^2/2\sigma^2} \quad [4]$$

Where the standard deviation is denoted by σ is denoted by and the equation is assumed to have a zero mean.[17], [18]. The pulse filtering process can be described as a derivative operation. The authors have presented together several nondamped waveforms for UWB systems, namely modified Hermitian monocycles and the Gaussian, Rayleigh, Laplacian, and cubic waveforms. The Gaussian pulse, which serves as the base of the Gaussian waveform, is described by the equation below[8], [19]–[21]:

$$y_{g1}(t) = K_1 e^{(-t/\tau)^2} \quad [5]$$

Where range of **t**is in range from $(-\infty\ to\ \infty)$, K_1= constant and $\boldsymbol{\tau}$ = Time scaling factor.

By the help of filtering done in equation 5 the derivative of Gaussian pulse becomes Gaussian monocycle and it's calculated through below equation:

$$y_{g2}(t) = K_2\frac{-2t}{\tau^2}e^{(-t/\tau)^2} \quad [6]$$

Reducing interference, increasing system capacity, and enhancing Quality of Service are some features of DS-UWB (QoS). By earlier assigning a pseudo-random noise code and multiplying it by the transmit signal, this feature allows multiple users to broadcast in the same bandwidth[12], [22], [23]. Performance analysis is based on Gaussian performance approximation or analytical approach. To have a better insightfor theinterference with superiordata transmission rate of UWB communications byconsidering a tapped delay line (TDL) channel model is also evaluated[24]. The impulse response is used for channelconditions as Eq. (7):

$$h(t) = \sum_{l=0}^{L-1}\alpha_l\,\delta(t - l\Delta_T) \quad [7]$$

Where α_l = path gain coefficient, Δ_T = channel delay resolution.

2. Interference Equations:

The receiver may experience interference in the following methods:

$$I = \int_{f_{low}}^{f_{high}}\int_S^0 \frac{A_f G_{TX} G_{RX\rho I}}{a_0 L_p r^2}\,ds\,df \quad [8]$$

Therefore, by taking ds = *r dr dφ df*,

$$I = \int_{f_{low}}^{f_{high}}\int_{\varphi=0}^{2\pi}\int_{r=r_{min}}^{r_{max}} \frac{A_f G_{TX} G_{RX\rho I}}{a_0 L_p r^2}\,r\,dr\,d\varphi\,df \quad [9]$$

Which leads to,

$$I = K\,ln\left(\frac{r_{max}}{r_{min}}\right)\int_{r_{min}}^{r_{max}} S_{UWB}(f)V\,df \quad [10]$$

where K = $(2\pi A_f G_{TX} G_{RX\rho I})/(a_0 L_p r^2)$, r is the radius of the area of interest having UWB devices. r_{max} & r_{min} are the Max. and Min. distances from the receiving UWB devices [17], [25].

3. Result:

The simulations have been performed and verified analytically using MATLAB 2022a. The test signals are considered within the bandwidth range from 3.5 GHz to 6 GHz and is selected for interference testing and mitigation purposes. The obtained results are presented in Table-1.The simulated results are revealed in Fig.1. The signal levels associated with the Fig.(1) are also presented in Table-1, where Gp stands for

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Gaussian Pulse and Gm stands for Gaussian Monocycle. The results arebetween UWB and 5G.The results in this manuscript show that interference can also be minimized by changing the scaling factor τ and the center frequency Fc clearly revealing the interference mitigationWhile taking the bandwidth value at receiver end in the range of 3.5 GHz to 6 GHz,the minimised value of interference is obtained forthe pulse shaping factor at $\tau = 5e^{-11}$ sec.

4. Conclusion:

In this manuscript, a methodology is evaluated for the interference mitigation. The obtained results are revealing that the interference levels reduced while applying the derivative of the pulse for UWB communication. The Gaussian Derivative pulses outperformed in comparison to Gaussian pulse. The performance improvement is clearly visible as the interference levels are reducing, that clearly indicates that both the communication systems can exist simultaneously exists to support the subsystemof the complete network.

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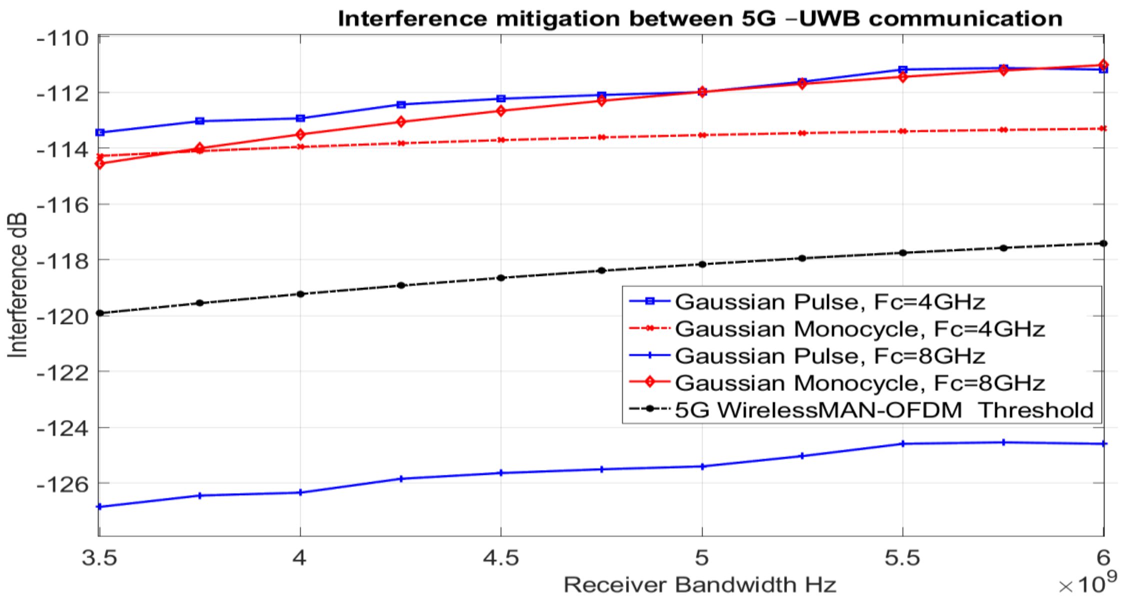

Fig: 1 Performance evaluation in reference with interference mitigation between UWB and 5G in bandwidth of 3.5 GHz to 6 GHz.

Table-1: Performance evaluation for interference mitigation using pulse shaping to the UWB signal.						
Interference(dB)						
Shaping Factor (dB)	$\tau = 20 \times 10^{-11}$Sec		$\tau = 15 \times 10^{-11}$ Sec		$\tau = 15 \times 10^{-11}$ Sec	
Receiver BW	f_c =4 GHz	f_c =8 GHz	f_c =4 GHz	f_c =8 GHz	f_c =4 GHz	f_c =8 GHz
3.5 GHz(G_p)	-101.89	-115.294	-104.181	-117.586	-113.508	-126.847
3.5 GHz (G_m)	-109.253	-116.087	-109.7	-114.702	-114.278	-114.556
4 GHz(G_p)	-101.618	-115.022	-103.914	-117.318	-112.798	-126.338
4 GHz (G_m)	-109.253	-116.087	-109.699	-114.692	-113.955	-113.507
4.5 GHz(G_p)	-100.804	-114.208	-103.305	-116.709	-112.366	-125.635
4.5 GHz (G_m)	-109.253	-116.087	-109.699	-114.69	-113.712	-112.663
5 GHz(G_p)	-100.526	-113.931	-102.831	-116.235	-111.986	-125.397
5 GHz (G_m)	-109.253	-116.087	-109.699	-114.69	-113.532	-111.986
5.5 GHz(G_p)	-100.188	-113.592	-102.575	-115.979	-111.26	-124.588
5.5 GHz (G_m)	-109.253	-116.087	-109.699	-114.69	-113.399	-111.447
6 GHz (G_p)	-100.075	-113.479	-101.898	-115.302	-111.187	-124.591
6 GHz (G_m)	-109.253	-116.087	-109.699	-114.69	-113.303	-111.023

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