Modeling and Simulation of Cooperative Communication based on IRSs in Tera Hertz Bands

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ABSTRACT
The electromagnetic interference EMI has a bad impact on radio systems in general. Although the cooperative communication can provide a better performance than a single antennas one, the EMI can degrade the cooperative system performance. The cooperative communication may be a relay-based or an IRS-based one. This work aims to provide a complete mathematical model for the EMI and its two categories especially in an IRS-based cooperative radio system operating in the Tera Hertz band. The fore-mentioned system is simulated. The simulation results show that the EMI degradation in the system performance can be greatly compensated by application of space time block codes "STBC".

Keywords
Radio Systems, EMI, Tera Hertz Waves, STBC Codes.

1. INTRODUCTION
An intended receiver can receive a lot of versions of a transmitted signal especially when cooperative communication techniques are applied. Thanks to cooperative communication theories, a radio communication system performance is greatly improved. The cooperative communication started in the fourth generation mobile systems. Really, it is a powerful tool in the performance improvement in the 4th G systems and the 5th G ones [1-3]. In fact, the cooperative communication can be carried out through implementation of relays or IRSs. However, this paper is interested in the IRSs deployment. However, they have very large sizes; the IRSs can provide a high directivity that can result in required signal gains [4-7]. The IRSs began as passive reflecting elements that are in a square matrix. Recently, these elements are controlled in order to focus signals in certain directions otherwise elimination of signals in other directions [4-7].

The noise and interference can have a bad impact on the performance of a radio system. The noise is considered as a random signal whereas the interference can be considered as an intended signal that may be intentional or non-intentional. The total interfering power affecting a radio system can be affected by; the total number of samples, the power of each sample, the symbol rate, and the distance from the interfering source to the intended receiver. For more clarifications, the path loss of the suggested channel model can greatly affect the total interference power [8-11].

This paper is interested in carrying out a complete mathematical model for an IRS-based cooperative communication system that is affected by; both noise and interference wherein there are two categories of interference. The system is simulated in Matlab. The applied path loss models are the Tera Hertz model. Really, these models are applied as they can be considered as the models for the 6G networks and beyond. In fact, the path loss models of the Tera Hertz have high values. Moreover, the EMI has a great bad effect on the cooperative digital communication system performance. There is a trial to implement the space time block codes "4×3 STBC". This diversity encoding technique can greatly increase the system performance.

2. RELATED WORK
In fact, the electrical components have electromagnetism properties. An electrical or electronic device should not radiate in such a way that it can affect the neighboring devices and systems. Moreover, it should have the immunity in order not be affected by the surrounding electromagnetic environments. The same thing should be applied to radio system especially the electromagnetic environment is overcrowded by a lot of operating radio systems. There should be a separation in the power domain [12-14]. In fact, the EMI has a great impact on the performance of a communication system. Therefore, a lot of researches handled the modeling and the simulation of the EMI in different systems and in different environments. As example, Ref. [15] handled two categories of interference that can affect a radio system in addition to the noise impact. The authors carried out a mathematical model for the interference affecting a multicarrier radio system. They assumed that the interference may affect a portion of the system spectrum or the system as whole. The authors confirmed that the all band interference has a bad impact on the system performance.

Others considered the EMC regulations during their analysis [16]. Really, the interference can greatly affect radio systems especially those are applied for high way control. These systems should be so accurate that they cannot be affected by the surrounding electromagnetic environment as they transmit vital signal. The authors tried to model and simulate the EMI in this environment. On the other side, Ref. [17] handled ways to eliminate or at least reduce the EMI in multi-users interfering channels. The EMI was studied in general without any details about its nature of the EMI itself. Subsequently, the authors of Ref. [18] studied the spread spectrum techniques in existence of EMI when the EMC regulations were considered whereas Ref. [19] clarified the effect of EMI on mobile phone antennas. The navigation receiver may be affected by the interference [20]. Therefore, other others tried to study the EMI impact on navigation receivers. They studied the single tone interference as well as the multi-tones interference. The authors already carried out experiments in order to confirm and assure their results.

The adaptive techniques may be used in order to reduce the EMI especially in AM radio equipment. These techniques could reduce the coupling effect of nearby communication equipment [21]. The authors of Ref. [22] tried to build a smart electromagnetic environment by letting the environment be under control. Other authors tried to carry out mathematical models that can describe the EMI impact on radars [23]. In Ref. [24], there were a lot of interference cancellation schemes considered especially for multi-carrier system "OFDM". Finally, the authors of Ref. [25] assumed different channel impairments which are; noise, narrow band interference, and ultra-wide band interference. The authors considered the interference that comes from different sources. Moreover, they carried out suitable a mathematical model and they also simulated the system. In fact, they put the basic outline of the topic.

In this paper, the EMI impact on an IRS cooperative communication system is mathematically modeled and simulated. The Tera Hetrz path loss models are considered as the suitable propagation models for the 6G networks and beyond. In fact, the Tera Hertz models can provide a high path loss values. In addition, the EMI and noise has a great impact on the system performance. However, all the previous considerations will be compensated when STBC 4×3 codes are applied. The main contributions of this manuscript can be stated as follow;

- There is a mathematical model for an IRS based cooperative radio system that is affected by the EMI and noise.
- The Tera Hertz path loss models are applied as they are the 6G network and beyond models.
- The STBC 4×3 codes are applied in order to compensate the degradation in the system performance.

This manuscript organization is as follows; Section 1 included the introduction whereas Section 2 summarized the related work of the topic. Subsequently, Section 3 clarifies the required mathematical models and analysis. After that, the simulation results are handled in Section 4. Finally, Section 5 discusses the conclusion on this manuscript.

3. MATHEMATICAL MODEL

The system model is given in Figure 1. Assume that *S* is the transmitted signal whereas *Y* is the received signal at an IRS. Moreover, *n* can represent the noise in the channel path whereas h_1 represents the channel parameter. The received signal, at an IRS, can be given by;

$$y = h_1 s + n \quad (1)$$

The received signal, at the destination, can be written as;

$$y = g_2^H x + h_d s + w \quad (2)$$

y refers to the received signal at the destination. *w* is the noise in the path from the source to destination whereas h_d represents the direct link channel parameter. *x* refers to the reflected signal from an IRS whereas *H* is the Hermitian transpose.

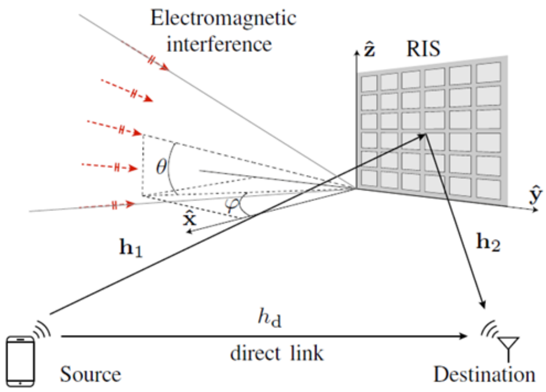


Fig 1: The cooperative communication system employing IRSs and affected by EMI.

There are two major categories of interference which are; the narrow band as well as the ultra-wide band [15]. The two categories may be clarified as follow;

3.1 NBI MODEL

Ref. [15] clarified a statistical model for the narrow band interference NBI as an interference that comes from different sources. The probability of certain number of interferers is given be *k* is P_k. Assuming that the interferes has Poison distribution, the probability can be given by;

$$P_k = \frac{\eta^k}{k!} e^{-\eta} \quad (3)$$

where η can represent the average number of occurrence of certain events. In addition, *k* refers to an indication of interferer's number. Furthermore, λ is the NBI interference bandwidth. It can be calculated by;

$$\lambda = \frac{\eta \Omega}{W} \quad (4)$$

where *W* refers to the system bandwidth. Moreover, Ω is the average bandwidth of interference occurrence. The interfering power which affects a subcarrier at f_m , in a multicarrier submission system, which can be represented by *X* can be given by;

$$X = \int_0^{\Omega} P \left| X_y(f_m) \right|^2 dy = \frac{2\Omega}{W} \int_0^{\Omega} \left| X_y(f_m) \right|^2 dy \quad (5)$$

where *y* is the different frequency values "spectrum positions" at which the interference can affect. Therefore, the power contribution due to the *k* interferers is;

$$\sigma_k^2 = k.X \quad (6)$$

where σ_k^2 is the effective NBI power for given *k* interferers. Therefore, the total average effective NBI power in the system is;

$$\sigma^2 = \sum_{k=1}^{\infty} \sigma_k^2 P_k = X \sum_{k=1}^{\infty} k P_k = X\eta \quad (7)$$

The NBI, due to *k* interferers, can be represented by a random variable with Gaussian (*pdf*) and it can have a value of *z* with mean μ and variance σ_k^2. Therefore, the probability distribution function (*pdf*) can be described as follows;

$$P_Z(z|k) = \sum_{k=1}^{\infty} \frac{P_k}{\sqrt{2\pi\sigma_k^2}} * e^{-(\frac{(z-\mu)^2}{2\sigma_k^2})} \quad (8)$$

3.2 UWBI Model

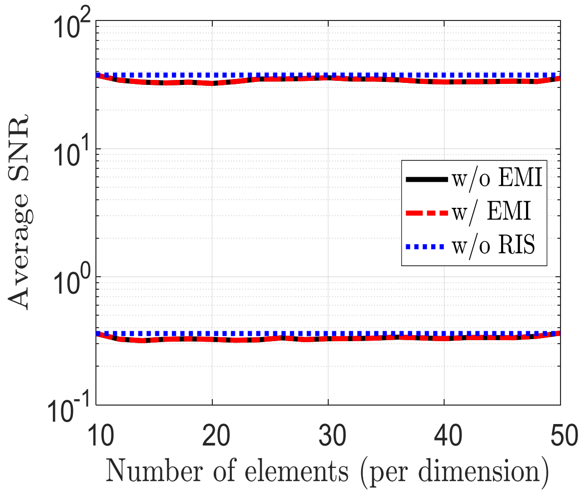
The ultra-wide band interference UWB interference can affect the whole system bandwidth. The UWB interference model was explained before in Ref. [15] and its impulse response can be given by;

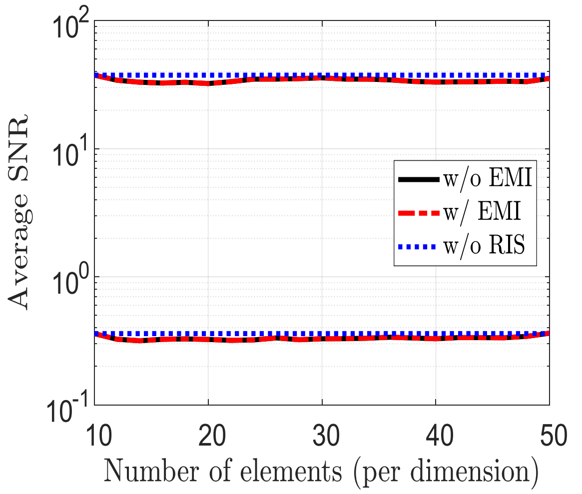
$$h_i(t) = X_i \sum_{l=0}^{L-1} \sum_{k=0}^{K-1} \alpha_{k,l}^i \delta(t - T_l^i - \tau_{k,l}^i) \quad (9)$$

where $\alpha_{k,l}^i$ represents the multipath gain coefficients, T_l^i is the delay of the l^{th} cluster, $\tau_{k,l}^i$ is the delay of the k^{th} multipath component relative to the l^{th} cluster arrival time ($T_l^{\,i}$). X_i represents the log normal shadowing and i is the i^{th} realization.

Table 1: The simulation parameters

Parameter	Value
Frequency of Operation	Tera Hertz bands
Number of IRS elements	50
Number of channel realizations	1000
Bandwidth	1 MHz
Transmitted Power	23 dBm
Path Loss	Tera Hertz models [26]
IRS	Square Grid





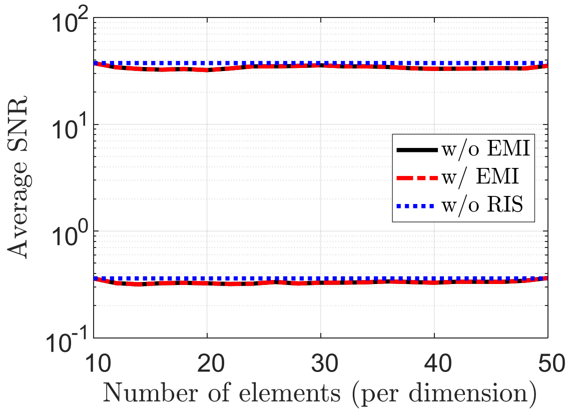


Fig 2: The SINR level variation in the proposed cooperative communication system with the number of the IRS elements

3.3 SINR CALCULATION

Eq. 10 can formulate the achieved SNR in the proposed system. The SNR refers to the signal to noise ratio whereas P refers to the transmission power. In addition, h_d is the channel parameter of the direct link whereas h_1 represents the channel parameter of the link between the source and an IRS. *A* refers to the reflecting area of an IRS.

$$SNR = \frac{P\left|g_2^H h_1 + h_d\right|^2}{A\sigma^2 g_2^H R g_2 + \sigma_w^2} \quad (10)$$

4. SIMULATION RESULTS

Figure 2 shows the average of EMI and it's impact on the average of SNR. It can be concluded that, thanks to the applied STBC codes can increase the average SNR performance of a digital radio system even there is a high path loss due to Tera Hertz models.

Table 2, Table 2, and Table 3 held comparisons between the related work [25] and the proposed work. From these tables, it can be observed that the EMI effect can be compensated by application of STBC 4×3 codes.

5. CONCLUSIONS

This manuscript studied the EMI impact on an IRS based system that operates in Tera Hertz bands. The STBC codes could improve the system performance. The future work can extend to employment of modern interference mitigation techniques to compensate the interference effect. Moreover, modern digital signal processing techniques can improve the proposed system performance. In addition, modern channel equalization schemes may be applied for performance improvement.

Table 2: The average of SINR comparisons of the proposed system and the related work in Ref. [25]

N	Average *SINR* Ref. [25]					Average *SINR* "proposed work"				
	Without *EMI*	Isotropic *R*	2π/3	π/4	π/8	Without *EMI*	Isotropic *R*	2π/3	π/4	π/8
50	100	100	100	100	100	11200	11200	11200	11200	11200
100	400	300	300	300	300	44800	33600	33600	33600	33600
150	1000	750	750	750	950	112000	84000	84000	84000	106400
200	1600	1100	1200	1200	1500	179200	123200	134400	134400	168000
250	2400	1500	1600	1600	2100	268800	168000	179200	179200	235200
300	3200	2000	2150	2250	2800	358400	224000	240800	252000	313600
350	4000	2400	2600	2700	3500	448000	268800	291200	302400	392000
400	5000	3000	3200	3400	4300	560000	336000	358400	380800	481600

Table 3: The average of bps/Hz comparisons of the proposed system and the related work in Ref. [25]

N	Capacity "bps / Hz" Ref [25]					Capacity "bps / Hz" proposed work				
	Without *EMI*	Isotropic *R*	2π/3	π/4	π/8	Without *EMI*	Isotropic *R*	2π/3	π/4	π/8
100	8.5	8.5	8.5	8.5	8.5	15	15	15	15	15
200	10.5	10	10.1	10.1	10.4	17	16.5	16.6	16.6	16.9
300	11.6	11	11.1	11.2	11.5	18.1	17.5	17.6	17.7	18
400	12.2	11.5	11.6	11.7	12	18.7	18	18.1	18.2	18.5
500	13	12	12.1	12.2	12.8	19.5	18.5	18.6	18.7	19.3

Table 4: The average of SINR comparisons of the proposed system and the related work in Ref. [25] after applying an optimization algorithm

N	Average SINR Ref. [25]				Average SINR "proposed work"			
	Without *EMI*	Upper Bound	Iterative Algorithm	Optimized Thermal Noise	Without *EMI*	Upper Bound	Iterative Algorithm	Optimized Thermal Noise
0	0	0	0	0	0	0	0	0
100	300	300	300	300	33600	33600	33600	33600
200	1600	1500	1000	1000	179200	168000	112000	112000
300	3000	2500	2000	2000	336000	280000	224000	224000
400	5500	4000	3000	3000	616000	448000	336000	336000
500	8000	5600	4100	4100	896000	627200	459200	459200
600	11000	7000	5500	5500	1232000	784000	616000	616000

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