Improvement of Interfered Cooperative Radio Systems by Applying Alamouti 2×1 Codes

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ABSTRACT
The under-water communication is mainly based on acoustic signals. In fact, this type of communication has a little interference. As this communication category may be used in nodes communication in a wireless sensor network WSN, the electromagnetic interference EMI is so vital that it should be studied. The EMI, in general, can lower a radio system performance. There should be a gain that can compensate the existing loss due to the interference. In this manuscript, a cooperative communication system that is operating in acoustic wave bands is assumed to be prone to interference. The system is mathematically modeled and simulated. There are two types of interference as well as noise. The loss in the system performance can be compensated by applying Alamouti 2×1 codes that can provide a high gain in signal to noise ratio SNR values. The simulation results show that the application of Alamouti 2×1 codes can compensate the degradation in performance due to the existing interference. In addition, their application results in a coding gain in SNR values as well as spectrum efficiency.

Keywords
Acoustic Waves, Under Water Communication, Interference, Alamouti Codes, SNR, Spectral Efficiency.

1. INTRODUCTION
The under-water communication is the category of communication systems that operate using the acoustic signals. The WSNs, that can monitor the under-water life, can use the acoustic signal in communication. These systems may be applied for control processes. In order to have so accurate communication systems that can transmit vital control signals, these systems should have the immunity to noise and interference. Furthermore, they should have suitable performance values. These systems should have high and satisfied levels of SNRs and throughputs. As example the under-water WSNs can use a lot of sensors that can cooperate in order to sense physical quantities. Moreover, they can communicate the measured values to an anchor or to a remote central unit. In other words, they can apply the cooperative communication theories during their operation. This cooperation can increase the battery lifetime. In addition, it can reduce the routing overhead [1-2].

In the cooperative communication, there are a lot of versions of the same transmitted signal can be received at a receiver. The receiver should have the capability of combining them together in order to get benefits of the best of them. There are two main categories of the cooperative communication and they are; the relays based systems as well as the IRSs based ones [3-4]. Each category of them has its merits and demerits. However, the two categories are very competing up till now. This manuscript is concerned with usage of the IRSs based cooperative communication systems. The IRS can include a lot of small reflecting elements that are arranged in a grid square matrix. These elements can direct the intended signal in a direction while they have the capability to cancel it in another direction [5-7].

The radio channel characteristics can greatly affect the performance of a communication system. The wireless channel, in general, can have a lot of bad effects. These effects may include but not limited to; noise, interference, fading, shadowing, Doppler spread, and much more. However, this manuscript is concerned with the bad impacts of the noise as well as the interference. In fact, the interfering power, affecting a radio receiver, can be affected y; the interfering source power as well as the separation distance between an interferer and the intended receiver [8-11].

In this manuscript, there is a trial to carry out a mathematical model as well as a simulation model for a cooperative acoustic communication system that is affected by the noise as well as interference. The noise and interference are given in closed formulas. Moreover, the bad effects of both noise as well as the interference are considered. There is a trial to reduce the effect of bad channel conditions by achieving a coding gain. The code gain considered, in this paper, comes from applying Alamouti 2×1 codes.

2. RELATED WORK
The electromagnetic interference EMI can affect all radio systems. Really, there are a lot of operating radio systems in free space. Moreover, there are a lot of electrical and electronic equipment that can radiate during their operation. All the fore-mentioned issues can result in the so called intentional interference and the non-intentional one. There should be a suitable separation distance between two interfering radio communication systems in order to avoid the expected interference especially if they are operating on the same frequency band. This distance is called the frequency reuse distance [12-14]. The interference classification was given in Ref [15]. The authors carried out two types of interference statistical models. One model is for the narrow band one that can affect potion of the system bandwidth while the other is the wide band that can affect the whole system bandwidth. Really, they determined the outline of the interference in radio systems. Since the interference can affect the radio electromagnetic environment, there are a lot of regulations in order to control the operation of a radio system in free space. Therefore, a lot of authors tried to apply the given regulations on their work [16]. These regulations should be considered especially when the communication system was proposed to carry vital control signals. Really, the situation is so serious that it should be handled well.

Subsequently, the EMI in multi-users and multi-channel environment as handled in Ref. [17]. The authors discussed the impact of the interference on a radio system as whole without explaining the nature of the interference. They limited their studies to the general impact only. Other others tried to handle the effect of the interference on low power radio systems such as the spread spectrum technology [18]. Others studied the interference impact on antennas of mobile phones [19]. The impact of EMI on a navigation receiver was tested in Ref. [20]. The authors tried to examine the EMI effect on narrow band interference and the wide band one.

The AM radios may cause so severe interference that they should be tested and checked well. The electromagnetic coupling, between different equipment, should be treated [21]. Really, the electromagnetic environment was fully controlled in Ref. [22] whereas other authors studied the EMI impact on radar system [23]. Really, the EMI can false alarm the existing synthesis aperture radar SAR. The EMI can let the SAR to display low resolution images. The multi-carrier system "OFDM" may be prone to interference especially it has a wide bandwidth. The high available bandwidth let an OFDM system have narrow band interference as well as a wide band one [24]. The interference cancellation schemes should be considered in a multicarrier communication system.

The authors of Ref. [25] carried out a mathematical model for the EMI impact on a radio communication system whose was affected by both noise and interference. They modeled the interference that came from different sources. They also carried out closed formulas for the interfering power and the performance of the system in general.

The EMI, in this paper, affects an under-water communication system whose applies the cooperation communication theories is explained, modeled, and simulated. The loss in performance due to the EMI impact can be compensated by application of 2×1 Alamouti codes. The basic contribution of this paper can be concluded as follows;

- Throughout this paper, complete mathematical formulas are derived and given in closed formulas regarding the EMI that affects a cooperative system based IRS one.
- The proposed system considers the application of acoustic waves in order to make the system applicable to under water communication.
- The coding, which are applied, is the Alamouti 2×1 codes.

This manuscript is organized as follow; Section 1 is the section of introduction. In addition, the related work is summarized in Section 2 whereas Section 3 gives the mathematical models. Subsequently, Section 4 and Section 5 clarify the simulation results and the conclusion of the manuscript, respectively.

3. MATHEMATICAL MODEL

Figure 1 shows the proposed system model. In fact, this model was suggested before in Ref. [25]. Eq. 1 represents the mathematical relationship between the received signal y and the transmitted one x. n represents the noise effect whereas h_1 refers to the channel parameter

$$y = h_1 s + n \tag{1}$$

The destination can have a received signal of;

$$y = g_2^H x + h_d s + w \tag{2}$$

w represents the noise during the direct link whereas *H* refers to the Herimitian transpose.

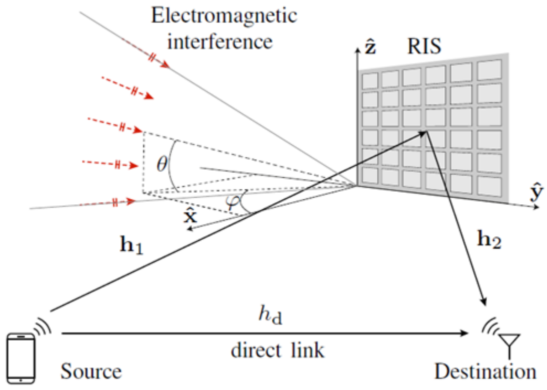


Fig 1: The cooperative communication system employing IRSs and affected by EMI

This manuscript considers two categories of interference which can be stated 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;

$$P_k = \frac{\eta^k}{k!} e^{-\eta} \tag{3}$$

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;

$$\lambda = \frac{\eta \Omega}{W} \tag{4}$$

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;

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

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;

$$\sigma_k^2 = k.X \tag{6}$$

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

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

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

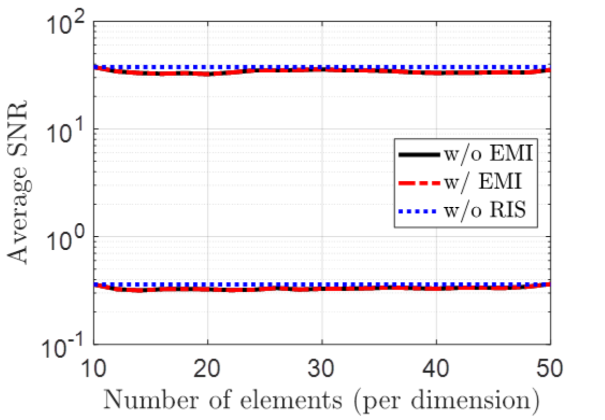
The ultra-wide band interference UWB interference can affect the whole system bandwidth. The UWB interference model was explained before in Ref. [15] and its impulse response can be given by;

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

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	2 GHz
Number of IRS elements	50
Number of channel realizations	1000
Bandwidth	1 MHz
Transmitted Power	23 dBm
Path Loss	Acoustic Waves [26]
IRS	Square Grid



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.

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

4. SIMULATION RESULTS

The proposed system was simulated and the results will be analyzed throughout this section. The applied simulation parameters are given in Table 1. These parameters are chosen in order to have fair comparisons with already published work in Ref. [25].

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.

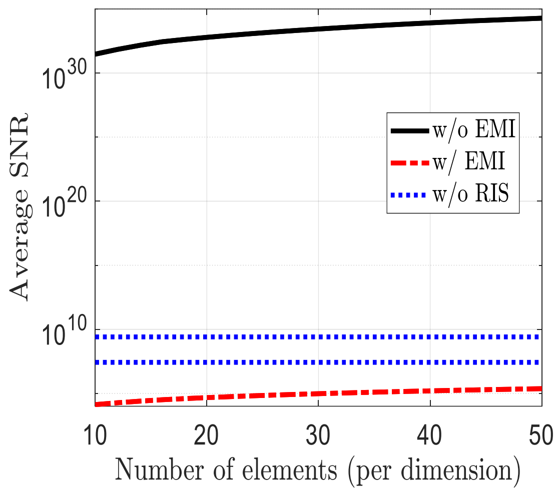


Fig 2: The SINR level variation in the proposed cooperative communication system with the number of the IRS elements

5. CONCLUSIONS

Throughout this manuscript, a cooperative communication system that can be used in an under-water environment was proposed. The radio system was a cooperative one that operates using the acoustic signals. Alamouti 2×1 codes were applied in order to provide a gain that can reduce the bad effects of EMI. The future work of this issue may extend to include; application of modern path loss models of different environment. Moreover, the future work can extend to the application of modern signal processing techniques for EMI reduction.

Table 2: The average of SINR comparisons of the proposed system and the 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	630	630	630	630	630
100	400	300	300	300	300	2520	1890	1890	1890	1890
150	1000	750	750	750	950	6300	4725	4725	4725	5985
200	1600	1100	1200	1200	1500	10080	6930	7560	7560	9450
250	2400	1500	1600	1600	2100	15120	9450	10080	10080	13230
300	3200	2000	2150	2250	2800	20160	12600	13545	14175	17640
350	4000	2400	2600	2700	3500	25200	15120	16380	17010	22050
400	5000	3000	3200	3400	4300	31500	18900	20160	21420	27090

Table 3: The average of SINR comparisons of the proposed system and the 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	11.15	11.15	11.15	11.15	11.15
200	10.5	10	10.1	10.1	10.4	13.15	12.65	12.75	12.75	13.05
300	11.6	11	11.1	11.2	11.5	14.25	13.65	13.75	13.85	14.15
400	12.2	11.5	11.6	11.7	12	14.85	14.15	14.25	14.35	14.65
500	13	12	12.1	12.2	12.8	15.65	14.65	14.75	14.85	15.45

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

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	1890	1890	1890	1890
200	1600	1500	1000	1000	10080	9450	6300	6300
300	3000	2500	2000	2000	18900	15750	12600	12600
400	5500	4000	3000	3000	34650	25200	18900	18900
500	8000	5600	4100	4100	50400	35280	25830	25830
600	11000	7000	5500	5500	69300	44100	34650	34650

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