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Channel Modeling of Electromagnetic Wave in Sea Water Medium

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ABSTRACT:

This paper describes the performance analysis of Electromagnetic (EM) waves in sea water medium. It is very challengeable situation to communicate the EM waves in ocean or sea because of high path loss and low signal to noise ratio. However, in this examination on EM waves employment in sea water medium, some theoretical observation were performed to meet practical specifications for analyzing the feasibility of EM waves in this high loss environment. In addition, path loss (PL), signal to noise ratio (SNR), bit error rate (BER) and Data rate channel capacity (DRC) parameters were also examined to understand applicability of EM wave at frequency range 100 kHz in sea water medium. In this paper, most important factor is considered of transmission power. It was analyzed that transmission power also affects the propagation of EM wave's communication.

Keywords: frequency; Sea water; Channel capacity; SNR; Bit error rate (BER); Path loss; Transmission power.

1. INTRODUCTION

In today technology, the employment of wireless communication in ocean water medium is increasing day by day to explore some natural resources or its characteristics such as property of soil, pre warning of underwater earthquake, pre-warning of tsunami, and other many security applications as military to detect enemies activities [1]-[3]. In [4], researcher examined the feasibility of EM waves in shallow water medium**.** As in [5] researcher examined the radio frequency communication which has high path loss because of the large electrical conductivity 4 (s/m) of seawater as compared to fresh water. Therefore, Efficiency of EM wave is best in fresh water as compared to seawater [5]. In wireless sensor networks, use of sensor in underwater of seas was performed to send information between other communication elements in form of vehicles (e.g., ships, satellites), fixed and dynamic sensor nodes [6].The ambient noise, salinity of sea water, affects the performance of acoustic communication in shallow water medium [7] .In addition , Therefore, the impact of EM waves is less on marine life of sea as compared to optical and Acoustic waves[8]-[9].

2. DESIGN AND DEVELOPMENT OF CHANNEL MODEL

2.1 The Wave propagation in lossy water medium

The lossy water medium is conducting medium and imperfect medium. Consider linear homogeneous, lossy water medium .Sea water is conducting medium and imperfect medium. As waves propagate through water medium, propagation constant (κ_c) term [10]-[12] is generated which depends upon the phase (β) of signal and attenuation (α) of signal in water medium.

$$\kappa_c = \left(\alpha + \hat{j}\,\beta\right) = \sqrt{\left(\hat{j}\cdot\varpi_{freq}\cdot\mu_p\cdot\left\{\left(\partial_c + \hat{j}\cdot\varpi_{freq}\cdot\varepsilon_p\right)\right\}\right)} \quad (1)$$

At frequency range 100 KHz, for sea water, some important parametric values are considered given below as in [4]-[6].

Where, as in [4]-[6]

$$\partial_c = 4(\text{mho}/\,meter)\,,\ \varpi_{freq} = 2\pi\cdot\xi_{freq}$$

$$\varepsilon_r = 81(Farad\,/\,meter)\ for\ sea\ water$$

$$\varepsilon_0 = 8.85\cdot 10^{-12}(Farad\,/\,meter)\,,\ \varepsilon_p = \varepsilon_0\cdot\varepsilon_r = 778.8\cdot 10^{-12}(\text{Farad/ meter})$$

$$\mu_p = \mu_0 \cdot \mu_r = 4\pi \cdot 10^{-7} (Henry / meter)$$

$\varpi_{freq} = \left(2 \cdot \pi \cdot \xi_{freq}\right)$ is angular frequency

(ξ_{freq}) is frequency of signal and ε_p is permittivity of medium

$\mu_p = \mu_0 = 4\pi \cdot 10^{-7}$, ε_p is permittivity of medium, μ_p is permeability of water medium, ∂_c is conductivity of medium, $\mu_r = 1$ is relativity permeability $\varepsilon_r = 81$ is relativity permittivity for sea water [4]-[6]

From above consideration, following expression in equation (2) can be written for lossy and high conductive medium [13]-[15].

$$\kappa_c = \left(\alpha + \hat{j}\beta\right) = \sqrt{\left(\varpi^2{}_{freq} \cdot \mu_p \cdot \varepsilon_p \left\{\left(\hat{j}\frac{\partial_c}{\varpi_{freq} \cdot \varepsilon_p}\right) - 1\right\}\right)} \qquad (2)$$

At frequency below THz as from consideration in [13]-[15] and equation (1, 3), following expression in form of equation (4) can be obtained.

$$\left\{\frac{\partial_c}{\varpi_{freq} \cdot \varepsilon_p}\right\} >> 1 \qquad (3) \qquad\qquad \alpha \approx \beta = \sqrt{\frac{\varpi_{freq} \cdot \mu_p \cdot \partial_c}{2}} \qquad (4)$$

$\mu_p = \mu_0 = 4\pi \cdot 10^{-7}$ Is permeability of free space same as of water medium [4]-[6]

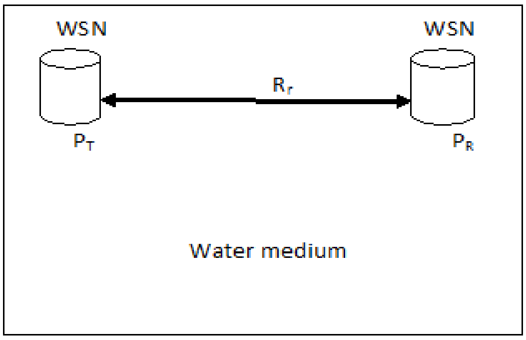

Figure 1.Channel modeling architecture

As shown in figure (1), from Wireless sensor (WSN) at transmitter side, suppose a signal is transmitted by power P_T is affected by noise power P_N .Total Path loss (TL) is generated by the difference between Transmitted and received signal P_R.

Where;

(R_r) is communication range or distance between wireless sensor at transmitter side and wireless sensor at receiver side.

Total path Loss (TL) in equation (8) can be calculated from Friis equation (5) [10]-[12].The received power depends upon the transmitted power (P_T), received signal (P_R), (G_T) Transmitter gain and (G_R) receiver gain. Path loss in air is different from path loss in sea water. So, Path loss in air as per Friss equation can be modified and extended in equation (8).

$$P_R = \frac{P_T . G_T . G_R}{TL} \qquad (5)$$

Path loss in decibel can be calculated in equation (6)

$$\left(P_R\right)_{db.m} = 10 \cdot \log_{10}\left(\frac{P_T . G_T . G_R}{TL}\right) \qquad (6)$$

$$\left(P_R\right)_{db.m} = \left(P_T\right)_{db.m} + \left(G_T\right)_{db} + \left(G_R\right)_{db} - \left(TL\right)_{db} \quad (7)$$

$$TL = PL + SL \quad (8)$$

Total path loss (TL) as in equation (9) in sea water is combination of path loss ($PL_{\beta m}$) as in equation (10) due to change phase constant of water medium w.r.t air, path loss ($PL_{\alpha m}$) as in equation (12) due to attenuation of signal ($\vec{\in}(x)$) [13] and system loss (SL). The Path loss also occurs due to attenuation ($PL_{\alpha m}$) because of which signal amplitude ($\in_0$) decreases along the path distance (R_r) as in equation (11).

$$TL = PL_{\beta m} + PL_{\alpha m} + SL \quad (9)$$

$$PL_{\beta m} = \left(2.\beta.R_r\right)^2 \quad (10)$$

$$\vec{\in}(x) = \in_0 \cdot e^{-(\alpha \cdot R_r)} \cdot \cos(\beta \cdot R_r - \varpi_{freq} \cdot t) \quad (11)$$

Where

TL is total loss in water medium. ($\in_0$) is amplitude of waves, (R_r) is communication range, (β) is phase constant of signal and (α) is attenuation constant of signal in water medium.

If, wave attenuate by factor $e^{-\alpha.R_r}$ will be multiplied to above equation (11). Its amplitude ($\in_0$) is attenuated by the factor $e^{-\alpha.R_r}$. The Path loss in equation (12) due to attenuation factor is the loss of a wave propagating in certain direction through a communication range (R_r), the wave amplitude decreases by a factor $e^{-\alpha.R_r}$ is

$$PL_{\alpha m} \cong \frac{1}{e^{-2(\alpha \cdot R_r)}} \quad (12)$$

Total path loss in equation (13) from equation (9-10,12)

$$TL_{db} = 10\log_{10}\left(\left(2.\beta.R_r\right)^2 + \frac{1}{e^{-2(\alpha \cdot R_r)}} + SL\right) \quad (13)$$

2.2. Signal to Noise ratio of EM wave in sea water

Signal to noise ratio (SNR) can be calculated by ratio receive signal with power P_R and signal power transmitted with power P_T affected by noise power P_N, [10-11, 13-14]

$$SNR = P_R / P_N \quad (14)$$

As from equation (5), Received power (P_R) considering transmitter gain (G_T=1), receiver gain

(G_R=1) will be obtained in equation (44)

$$P_R = P_T / \mathrm{TL} \quad (15)$$

Normal value of SNR and decibel value of SNR can be written in equation (16), and equation (17).

$$SNR = \left({P_T}/{P_N} \cdot TL \right) \quad (16)$$

$$\left(SNR\right)db = 10\log 10\left({P_T}/{P_N} \cdot TL \right) \quad (17)$$

Where

P_T is transmitted power in (db. m), P_N is noise power in (db. m)

The SNR of sea water can be represented in equation (16) by placing value of total path loss (TL) from equation (13) of EM waves in sea water.

2.3. Channel Capacity or data rate of EM waves in sea water

As per, Shannon's theorem [15], a given communication system has a maximum rate of information known as the channel data rate capacity (DR_C), can be calculated after placing equation (16).

$$DR_C = BW_{sea} \cdot \log_2(1+\mathrm{SNR}) \quad (18)$$

Bandwidth (BW_{sea}) for sea water can be defined as that frequency range over which signal can be transmitted easily [15].In this paper, (BW_{sea}) considered 100 kHz.

2.4. Bit error rate (BER) of EM waves in sea water

The bit error rate (BER) is the ratio of numbers of error bits divided by the total number of bits transferred during a studied interval [11, 14, 16].

The Binary Phase Shift keying (BPSK) modulation [11,14,16] is a two phase modulation scheme where the 0's and 1's in a binary message are represented by two different phase in carrier signal $\theta = 0^0$ for binary 1, $\theta = 180^0$ for binary 0. BPSK modulation for long range is best [17]-[18], Bit Error rate (BER) in equation (19) can be calculated after placing the value of SNR from equation (16).

$$BER = 0.5 erfc(\sqrt{SNR}) \quad (19)$$

3. RESULTS AND PERFORMANCE ANALYSIS

3.1 Variations of Signal to noise ratio with communication range and transmitted power

As, it can be observed from figure (2), Table(1), Table(2), Table(3), Table(4) that Signal to noise ratio (SNR) increases by increasing transmission power keeping fixed noise power P_n=21db.m, fixed frequency band 100KHz, fixed System loss =35 db in sea water. But on the others sides, SNR decreases with increase of communication range. SNR is 0.1996, 0.3983, 0.7946, 1.5855 at P_T= 15db.m, P_T= 18db.m, P_T= 21db.m, P_T=24db.m at fixed communication range R_r=0.1m. while SNR is 0.0000, 0.0001, 0.0002, 0.0003 at P_T= 15db.m, P_T= 18db.m, P_T= 21db.m, P_T= 24db.m at fixed communication range R_r=0.5m.It can be observed that SNR is high at short communication range but low at large communication range. For increasing SNR, Transmission power factor should be increased.

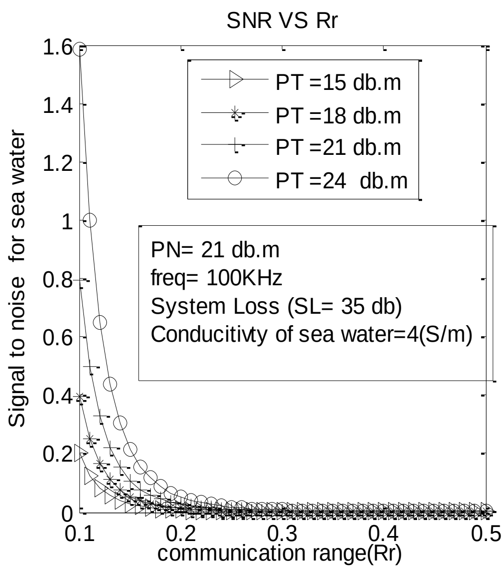

Figure 2. Varaiations of Signal to noise ratio with communication range and transmitted power

3.2 Variations of Bit Error Rate with communication range and transmitted power

From figure (3), Table(1), Table(2), Table(3), Table(4) ,the observation can be taken that Bit error rate (BER) decreases by increasing transmission power keeping fixed noise power P_n=21db.m, fixed frequency band 100KHz, fixed System loss =35 db in sea water. But on the others sides, BER increases with increase of communication range.BER is 0.2638, 0.1861, 0.1037, 0.0375 at P_T= 15db.m, P_T= 18db.m, P_T= 21db.m, P_T= 24db.m at fixed communication range R_r=0.1m while BER is 0.4963, 0.4947, 0.4925, 0.4894 at P_T= 15db.m, P_T= 18db.m, P_T= 21db.m, P_T= 24db.m at fixed communication range R_r=0.5m.

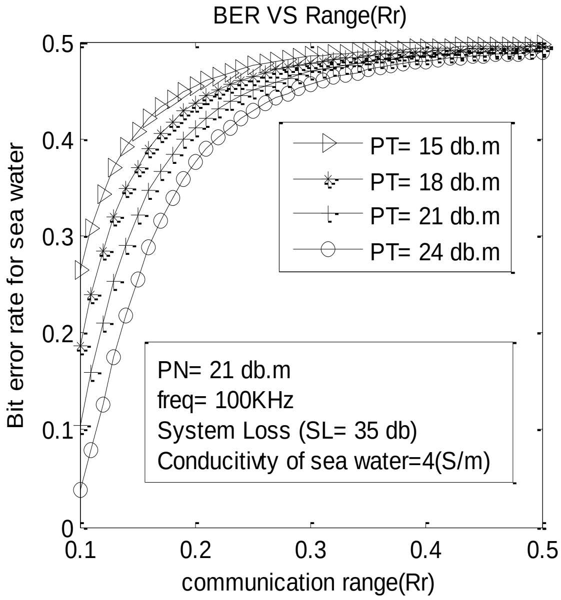

Figure 3. Variations of Bit error rate with communication range and transmitted power

It can be examined that BER is low at short communication range but high at large communication range. For decreasing BER, Transmission power factor should be increased.

3.3 Variations of Data rate capacity with communication range and transmitted power

An experiment examination conducted from figure (4), Table(1), Table(2), Table(3), Table(4) that Data rate channel capacity (DRc) increases by increasing transmission power keeping fixed noise power P_n=21db.m, fixed frequency band 100KHz, fixed System loss =35 db in sea water. But on the others sides, Data rate (DRc) decreases with increase of communication range. Data rate (DRc) is 2.6255*10^4, 4.8363*10^4, 8.4368*10^4, 13.704*10^4 at P_T= 15db.m, P_T= 18db.m, P_T= 21db.m, P_T= 24db.m at fixed communication range R_r=0.1m. While (DRc) is 0.0006*10^4, 0.0013*10^4, 0.0025*10^4, 0.0050 *10^4 at P_T= 15db.m, P_T= 18db.m, P_T= 21db.m, P_T= 24db.m at fixed communication range R_r=0.5m.It can be observed that (DRc) is high at short communication range but low at large communication range. For increasing (DRc), Transmission power factor should be increased.

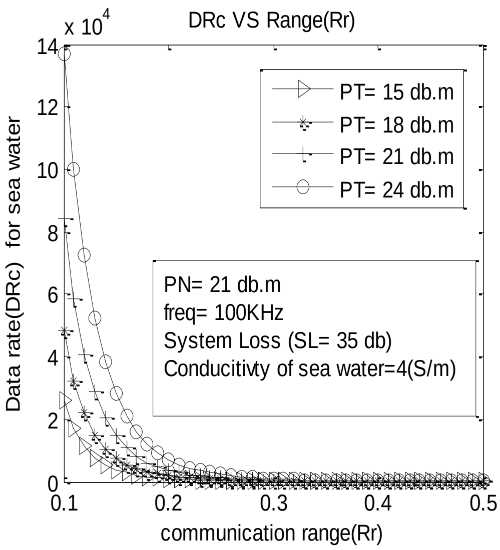

Figure 4.Variations of Data rate with communication range and transmitted powr

Table 1.Variations of SNR, BER, DATA RATE at Transmitted power (15 db.m)

At frequency 100KHz	R_r= 0.1 m	R_r = 0.2 m	R_r = 0.3 m	R_r = 0.4 m	R_r = 0.5 m
SNR	0.1996	0.0064	0.0008	0.0002	0.0000

BER	0.2638	0.4550	0.4844	0.4929	0.4963
Data rate Capacity	2.6255×10^4	0.0917×10^4	0.0111×10^4	0.0023×10^4	0.0006×10^4

Table 2.Variations of SNR, BER, DATA RATE at Transmitted power (18 db.m)

At frequency 100KHz	**R_r =0.1 m**	**R_r =0.2 m**	**R_r =0.3 m**	**R_r =0.4 m**	**R_r =0.5 m**
SNR	0.3983	0.0127	0.0015	0.0003	0.0001
BER	0.1861	0.4366	0.4779	0.4900	0.4947
Data rate Capacity	4.8363×10^4	0.1825×10^4	0.0221×10^4	0.0046×10^4	0.0013×10^4

Table 3.Variations of SNR, BER, DATA RATE at Transmitted power (21 db.m)

At frequency 100KHz	**R_r =0.1 m**	**R_r =0.2 m**	**R_r =0.3 m**	**R_r =0.4 m**	**R_r =0.5 m**
SNR	0.7946	0.0254	0.0031	0.0006	0.0002
BER	0.1037	0.4109	0.4689	0.4858	0.4925
Data rate Capacity	8.4368×10^4	0.3618×10^4	0.0440×10^4	0.0091×10^4	0.0025×10^4

Table 4.Variations of SNR, BER, DATA RATE at Transmitted power (24 db.m)

At frequency 100KHz	**R_r =0.1 m**	**R_r =0.2 m**	**R_r =0.3 m**	**R_r =0.4 m**	**R_r =0.5 m**
SNR	1.5855	0.0507	0.0061	0.0013	0.0004
BER	0.0375	0.3751	0.4561	0.4800	0.4894
Data rate Capacity	13.704×10^4	0.7130×10^4	0.0880×10^4	0.0180×10^4	0.0050×10^4

Conclusion

In this paper, the performance analysis of Electromagnetic (EM) waves in sea water medium was examined. However, during investigation on EM waves in sea water medium, some theoretical observations were examined to meet practical specifications for analyzing the feasibility of EM waves in this high loss environment. In addition, total path loss (TL), signal to noise ratio (SNR), bit error rate (BER) and Data rate channel capacity (DRC) were also examined to understand applicability of EM wave at frequency range 100 kHz in sea water medium. In this paper, most important factor is considered of transmission power. It was observed that Path loss decreases, SNR increases, Bit error rate decreases, channel data rate capacity increases by increasing the transmission power from transmitter side. A final conclusion is there that employment of EM waves communication reveals that EM waves can travel over shorter distance with better data rate capacity, better SNR, appropriate BER in sea water. However, increasing transmission power, low BER, High SNR, high data rate channel capacity (DRc) can be achieved.. In addition , there is very less impact on marine life of EM wave as compared to acoustic waves

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