The characteristics of EM waves wireless communication sensor network in shallow water medium with variation of salinity

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ABSTRACT-*In this paper, theoretical analysis of underwater channel medium was examined through simulations process to characterize the Electromagnetic wave communication in pure water and sea water medium with variation of salinity of water to meet practical specifications. The Electromagnetic wave communication feasibility in pure water and sea water medium was analyzed by some arising factors such as salinity, frequency of propagation, electrical conductivity, attenuation, path distance and path loss. In this paper, a process, in order to explore feasibility of the Electromagnetic wave propagation under the frequency range of 200MHz-500MHz in these turbid environments in sea water and pure water medium was analyzed. The theoretical analysis through simulation process causes results which take part to provide the platform of applicability of EM wave propagation in underwater medium at the frequency range 200MHz-500MHz in water medium.*

Keywords: *Path loss, Wireless sensor network, Salinity, Sea water, Pure water.*

1. INTRODUCTION

In communication field, the technology advancement has brought many interesting techniques such as deployment of wireless sensor network (WSN) used to examine the some significant factors temperature, pressure, natural resources in underwater [1]. As, wireless network sensors employ the channel medium such as electromagnetic signaling for research purpose of natural material [2] in physical and chemical environments [2].In wireless communication, underground sensor nodes were deployed in soil medium. In underwater communication, the Electromagnetic wave (EM) propagation through soil medium used to find out soil characteristics which help to provide the feasibility of propagation of EM waves in soil medium [3]-[4]. The high attenuation of EM waves through water medium, the acoustic and sonic transducers dependency for underwater wireless communication has increased [5]-[7].In RF communications, a work was done at low frequency to find out reliable communication range, at 3 KHz and about 40 meters path distances between sensors nodes [8]. In [9], Fraters et al. compared RF and acoustic communications. Some researchers as in [9] examined the maximum distances for several frequencies (approximately 22 meter at 1 kHz, 16 meter 10 kHz, and 6meter at 100 kHz).They concluded the higher performance of RF communication as compared to acoustic communication in certain path ranges [9]. But, on the other side, many application in future trend where requirements of high speed, high date rate, low power consumption of EM waves forced the researchers to analyses the EM wave communication[10]-[12]. Researchers in these papers [13]-[14] examined performance analysis of the underground wireless channel to make it suitable for reliable communication in soil environment. The theoretical analysis through the MATLAB simulation, the authors worked at 433MHz from field experiments. The communication range can be increased to 5.5–6 m with increased of transmitted power 30dbm [15]. In particular, the frequency band ranges 300–700 MHz, which is suitable for deployment of small size sensors [16]. The Path loss produces the much difference between the transmitted signal power and the received signal power. The Channel modeling can be done using term Path loss in terrestrial wireless propagation [17]. In paper [18], author examined the EM wave propagation in pure water for frequencies range between 23 kHz and 1 GHz. In this present paper, the performance analysis of underwater communication in fresh water and sea water medium between frequency range 200MHz to 500MHz is going to be examined.

2. CHANNEL MODELING CONCEPT IN WATER MEDIUM

In underwater communication environments, the variations of electrical conductivity, salinity, frequency and permittivity of water play an important role for feasibility and applicability of EM wireless communication in underwater. In figure (1), an underwater wireless communication sensor network (UWSNs) is designed here. The wireless sensors communicate through water medium at particular path distance (d). Water medium may be sea water and pure water. The study was done in this paper on shallow water medium through single path channel modeling.

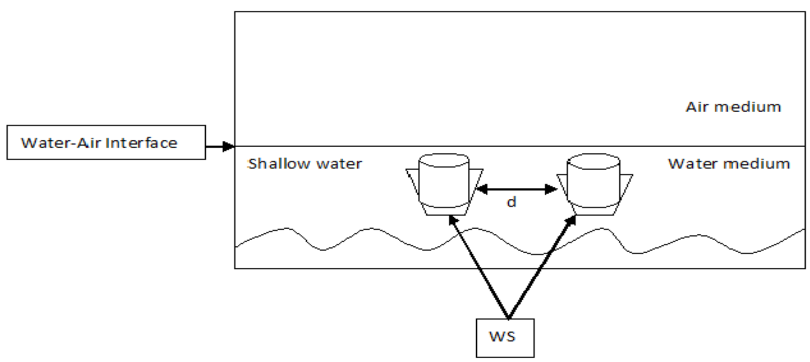

Figure 1.Underwater communication wireless sensor network

Where

d is distance between sensors, WS is wireless sensors

2.1 Electrical conductivity of pure water

As, examination from this present paper and previous many research paper conclude that the low electrical conductivity of pure water cause low attenuation and low path loss in water medium. The water samples had wider ranges of chemical compositions. This is reason, equation (1)) [19]-[21] provide an electrical conductivity and temperature relation for pure water which provide a higher accuracy when temperature of water is more than 25◦C.In this paper, pure water is considered with its electrical conductivity (σ) =0.01 Siemens/meter as per observed numerical value from equation (1)) [19]-[21] at normal temperature 25 ^{0}C. The electrical conductivity of pure water is independent of salinity. Because, in pure water, there is no electrolytic substance, so no ions are present in the pure water. So, electricity cannot be easily conducted through pure water [22].

$$\sigma = \sigma_{25} \times \left(10^{\left\{ \frac{\left(a_x (25-T) - b_x (25-T)^2 \right)}{(T + c_x)} \right\}} \right)^{-R_d} \tag{1}$$

Where

(σ) and (σ_{25}) =0.01(Siemens/meter) are the electrical conductivity of pure water at temperatures (T) and 25 ◦C . $a_x = 1.1278$, $b_x = 0.001895^0C^{-1}$ c_x =88.93 ^0C The values of a_x, b_x, c_x were determined from equation (1) as in [19] to Korson et al. (1969) data using the least-squares method. Equation (1) as in [19-21] was used in this paper, the values of R_d is between ranges of [0.806-0.933].

2.2. Electrical conductivity of sea water

The performance of the EDR (environmental data records) depends on the accuracy of conductivity of sea surface. Moreover, the micro wave absorption due to liquid cloud water depends upon the conductivity of sea water through derived equation (2) [23]-[27]. The conductivity of sea water calculated from experimental results depends upon salinity and temperature of environments as derived in equation (2,3) [23]-[27].

$$\sigma = \left(\begin{array}{l} \left(\sigma_0 \times S \times \left(\dfrac{37.5 + 5.4S + 0.015S^2}{1004.8 + 182.3S + S^2} \right) \right) \times \\ \left(1 + \dfrac{\left(\dfrac{6.9 + 3.3S - 0.1S^2}{84.6 + 69S + S^2} \right)(T - 15)}{49.8 - 0.23S + 0.2S^2 + T} \right) \end{array} \right) \tag{2}$$

$$\sigma_0 = \left(\begin{array}{l} 2.9 + 8.6\times10^{-2}T + 4.7\times10^{-4}T^2 - \\ 3\times10^{-6}T^3 + 4.3\times10^{-9}T^4 \end{array} \right) \tag{3}$$

Where

(T) is temperature is in degrees centigrade, (S) is salinity in PPT (parts per thousand), (σ) is electrical conductivity in Siemens per meter. (σ_0) is the electrical conductivity at (S) = 35 PPT at temperature 25 ^{0}C .

2.3 Propagation Constants for pure and sea water

As EM wave propagate through different types of environment in water .The propagation parameters such propagation speed, propagation loss of EM wave varies with variations of attenuation of signal. A term the propagation constant (γ_{pc}) comes in front of us from the study EM wave communication which depends upon on the attenuation constant factor (α_c) and phase constant factor (β_c) which can be expressed in equation (4), equation (5) as written below [23]-[27].The propagation constant itself measures the change per unit length, but it is otherwise dimensionless. The attenuation factor is decrease in signal strength with propagation of waves at particular path distance can be expressed as given below in equation (4) [25]-[27].The attenuation depends upon the (μ) permeability (Henry/meter) and permittivity of medium and frequency of EM signal .The permeability can be represented as amount of passing magnetic energy to be stored in medium. A water is a nonmagnetic medium, its permeability is same as vacuum [28].

$$\alpha_c = \sqrt{\omega^2 \left(\mu\varepsilon_{real}/2 \right) \times \left(\sqrt{1 + \left(\varepsilon_{imag}/\varepsilon_{real} \right)^2} - 1 \right)} \quad (4)$$

The phase constant factor can be represented as change in phase per unit length along the path travelled by the wave at any instant can be expressed as given below in equation (5) [23]-[27]. The phase constant depends upon the permeability and permittivity (F/m) of medium and frequency of EM signal *with* $\omega = 2.\pi.f$ (f is frequency)

$$\beta_c = \sqrt{\omega^2 \left(\mu\varepsilon_{real}/2 \right) \times \left(\sqrt{1 + \left(\varepsilon_{imag}/\varepsilon_{real} \right)^2} + 1 \right)} \quad (5)$$

2.4 Dielectric permittivity for pure and sea water

The dielectric permittivity can be represented as ability of water medium which pass an amount of electric line of forces from applied electric field. The complex permittivity can be represented as difference between real permittivity and imaginary permittivity such as calculated in equation (6) [23]-[27] and in equation (7) [23]-[27].The real permittivity in water medium channel depends upon the static dielectric permittivity (from Table 1.) at low frequency, static dielectric permittivity (from Table 1) at high frequency, frequency of signal and relaxation time, independent of free space permittivity, independent of electrical conductivity of water medium as can be written in form of expression [23]-[27].

The real permittivity for pure and sea water can be calculated by putting the values of static permittivity at low frequency and relaxation time in equation (6) (for values-see Table 1.)

$$\varepsilon_{real} = \varepsilon_{s_\infty} + \left(\left(\varepsilon_{s_0} - \varepsilon_{s_\infty}\right) \Big/ \left(1 + \left(2\pi f \tau_{rt}\right)^2\right) \right) \tag{6}$$

On the other side ,The imaginary permittivity in water medium channel depends upon the sum of two factors, one factor consist of ratio of electrical conductivity of water medium and frequency of signal, free space permittivity, second factor consist of the static dielectric permittivity (from Table 1) at low frequency , static dielectric permittivity ((from Table 1) at high frequency and relaxation time and frequency of signal as written below in form of expression in equation (7) [23]-[27] . The Value of electrical conductivity for pure water in equation (1) can be placed in equation (7) to calculate imaginary permittivity of pure water. The Electrical conductivity for sea water in equation (2) can be placed in equation (7) to calculate imaginary permittivity of sea water.

$$\varepsilon_{imag} = \left[\left((\sigma) \Big/ \left(2\pi f \varepsilon_0\right) \right) + \left(\left(2\pi f \tau_{rt}\right)\left(\varepsilon_{s_0} - \varepsilon_{s_\infty}\right) \Big/ \left(1 + \left(2\pi f \tau_{rt}\right)^2\right) \right) \right] \tag{7}$$

Where

(ε_{real})[23]-[26] and (ε_{imag})[23-26] are the real and imaginary dielectric constants of pure water and , respectively, (ε_{s_0})[27] at temperature 25 ^{o}C is the static dielectric constant at low frequency, (ε_{s_∞})=[23]-[26] is the dielectric constant at high-frequency limit, (ε_0)F/m is the permittivity of free space, (σ)= 0.01 (s/m) is the water electrical conductivity at temperature 25 ^{o}C [23-26], (τ_{rt})[27] is the relaxation time in *pico* at temperature 25 ^{o}C. (ε_{s_∞}) is independent of salinity, frequency range (f)- [200MHz-500MHz]

2.5 Path loss of EM waves for pure and sea water

Even though RF (radio frequency)-EM waves provide benefits in shallow-water wireless propagation systems such as high data rate, low propagation delay and high speed, but there is still a range limitation in deep environment of water medium [12].But, path losses in pure water are less as compared to path loss in sea water medium (See in Table 2 as observed results). The Enormous amount of work has been done on terrestrial WSNs to develop channel model in which air considered as medium [16]-[17]. The Path loss, path distance are main important parameters to analyze the channel model. The Path loss parameter is used for channel modeling at big scale. The performance analysis in air channel medium is done at large path distances. However, in the water medium performance analysis is done at small range of path distances.

The path loss from [17, 25] is to be considered in this work as expressed in dB as in equation (8). Path loss- (PL_{loss}) [17, 25] depends upon factors, attenuation constant (α_c), phase constant (β_c), Path distance (d).Path loss in form of equation (8) written below [17, 25] is

$$PL_{loss} = 10\log_{10}\left(\left(2\cdot\beta_c\cdot d\right)^2 + e^{\alpha_c d}\right) \tag{8}$$

3. RESULTS AND PERFORMANCE ANALYSIS

3.1 Path loss variation with variations of path distance and frequency level for NON-ZERO salinity of sea water

As shown in figure (2), path loss in sea water in decibel increases with increase in different level of frequencies, but increment in path loss decreases at different level of frequencies at fixed path distance. At fixed path distance d=1 m distance, the path loss is 82.5090db, 83.3418db, 83.9630db, 84.4775db at frequency 200MHz, 300MHz,400MHz,500MHz.At 1m,path distance, increment in path loss is decreasing by factor 0.8328db, 0.6212db, 0.5145db with increase in frequency of each 100MHz from 200MHz to 300MHz, 300MHz to 400MHz, 400MHzHz to 500MHz.As, it can be examined in this paper that at same distance between sensor nodes, if we increase the frequency of 100MHz, the increment in path loss decreases.

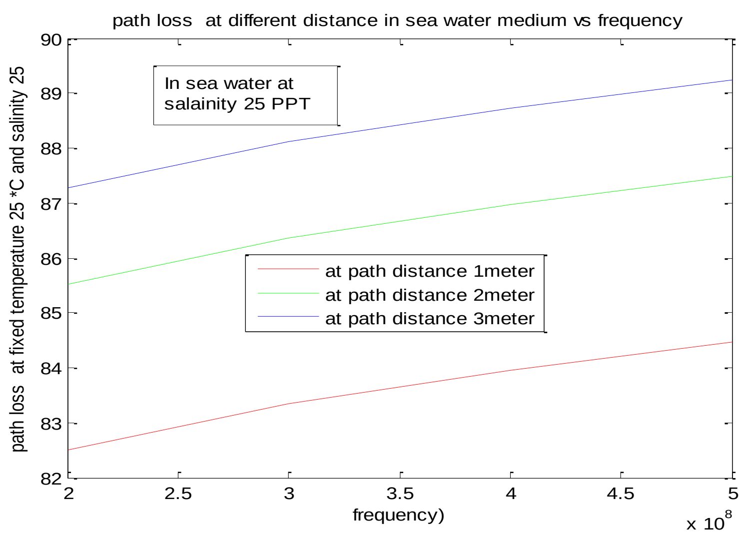

Figure 2.Path loss variations with frequency at different path distances in sea water

As shown in Table 2. and Figure (2), At fixed frequency 200 MHz, the path loss is 82.5090 db, 85.5193db, 87.2802db, at path distances d=1m, 2m, 3m. As it is examined that the increment in path loss decreasing by factor 3.0102 db, 1.7609db.At fixed frequency 500MHz, the path loss is 84.4775db, 87.4878db, 89.2487db at path distances d=1m, 2m,3m.As, it was examined that the increment in path loss decreasing by factor 3.0103db, 1.7609db at fixed frequency. The increment in path loss decreases by same factor with increase in frequency of 100MHz for all frequency in this paper. As, it can be observed from above discussion that increases in frequency at fixed path distance, the path loss increases with increase of the frequency of signal frequency of 100MHz, from 200MHz to 300MHz, 300MHzHz to 400MHz, 400MHzHz to 500MHz in this paper. The increment in path loss decreases with increase in frequency at fixed path distance. On the other side that increases in path distance at fixed frequency, the path loss increases with increase of the path distances in this paper,but decreases with increase of path distance. The increment of path loss decreases by same factor for all frequencies 200MHz, 300MHz, 400MHz, 500MHz .

3.2 Path loss variation with variations of path distance and frequency level for ZERO salinity of pure water

As shown in figure (3), path loss in pure water in decibel increases with increase in frequency but increment in path loss decreases at different level of frequencies at same path distance. At fixed path distance d=1 m distance, the path loss is 60.5694db, 62.5218db, 64.3024db, 65.8629db at frequency 200MHz, 300MHz, 400MHz, 500MHz.At, distance=1meter, increment in path loss is decreasing by factor 1.9524db,1.7806db, 1.5605db with increase in frequency of 100MHz, from 200MHz to 300MHz,300MHz to 400MHz, 400MHzHz to 500MHz.As, we can see that increase in frequency, the increment in path loss decreases at same path distance.As, it can be examined in this paper that at same distance between sensor nodes, if we increase the frequency of 100MHz, the increment in path loss decreases. At fixed frequency 200 MHz, the path loss is 60.5694 db, 63.5791db, 65.3398db at path distances d=1m, 2m, 3m. As it is investigated that the increment in path loss decreasing by factor 3.0097 db, 1.7607db .As shown in Table 2 and figure (3), At fixed frequency 500MHz, the path loss is 65.8629 db, 68.8730db, 70.6338db, at path distances d=1m, 2m,3m. As, it was examined that the increment in path loss decreasing by factor 3.0103db, 1.7609db.The increment in path loss almost decreases by same factor with increase in frequency of 100MHz in this paper.

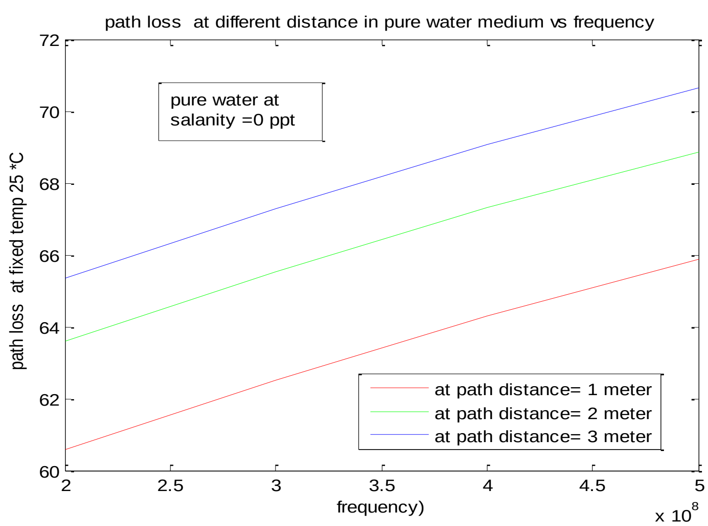

Figure 3.Path loss variations with frequency at different path distances in pure water

As, it can be observed from above discussion that increases in frequency at fixed path distance, increment in path loss decreases with increase in frequency at fixed path distance. On the other side that increases in path distance at fixed frequency, the path loss increases with increase of the path distance in this paper. The increment of path loss decreases by same factor for all frequencies 200MHz, 300MHz, 400MHz, 500MHz but increment of path decreases with increase of path distance at fixed frequency.

From Comparative analysis of path loss in sea water (see figure 2) and fresh or pure water (see figure 3) and Table 2., the path loss at salinity 25PPT in sea water increases by factor 21.9396 db,21.9402db, 21.9404 at path distance 1meter, 2 meter, 3meter as compared to pure water, at fixed frequency 200MHz.The path loss at salinity 25PPT in sea water increases by factor 20.82 db ,20.8204 db , 20.8205 at path distance 1meter,2 meter, 3meter as compared to pure water, at path distance 1meter, 2meter, 3meter, at fixed frequency 300MHz. The path loss at salinity 25PPT in sea water increases by factor 19.6606 db ,19.6608 db , 19.6609 at path distance 1meter,2 meter, 3meter as compared to pure water, at fixed frequency 400MHz. The path loss at salinity 25PPT in sea water increases by factor 18.6146 db ,18.6148 db,18.6149 at path distance 1meter,2 meter, 3meter as compared to pure water, at fixed frequency 500MHz.Path losses in sea water because of salinity were observed high as compared to pure water.

CONCLUSION

In this paper, an underwater wireless sensor network architecture using electromagnetic (EM) wave channel modeling was proposed. A feasible model for the path loss in water medium of pure and sea water had been developed. The comparative analysis was examined for both sea water medium and fresh water medium. The proposed model through theoretical analysis were simulated under concerned channel conditions, and both the path loss performance analysis for sea ware and fresh were presented at frequency range [200MHz-500MHz]. Finally, a prototype to measure the path loss in sea and fresh water medium using Electromagnetic waves was implemented to explore the feasibility of EM wave in both medium. As final examination done, a conclusion was obtained that pure water has less conductivity as compared to sea water at same temperature. EM waves can travel for long range of communication in pure water medium as compared to sea water medium because path loss are higher in sea water with increase of salinity in sea water.

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Table 1. Experiment data calculated in this paper about pure and sea water

At T=25	Pure water at S=0 PPT	Sea water at S=25 PPT
σ (Siemens/meter)\ (S/m)	0.01 (low)	3.8963(high)
τ_{rt} Relaxation time (pico)	8.0892×10^{-10}	1.2327×10^{-10}
ε_{s_∞} (Farad/m)static permittivity at high frequency	4.9 fixed independent of salanity	4.9 fixed independent of salanity
ε_{s_0} (Farad/m) static permittivity at low frequency	78.1787	72.8728
ε_0 (Farad/m) free space permittivity	8.85×10^{-12}	8.85×10^{-12}

Table 2.Path loss variations with variation of frequency and path distance in sea water and pure water

	Sea water	Sea water	Sea water	Pure water	Pure water	Pure water
Frequency (MHz)	**PL (dB) at S= 25 ppt At d(meter)=1**	**PL (dB) at S=25 ppt At d(meter)=2**	**PL (dB) at S=25 ppt At d(meter)=3**	**PL (dB) at S=0 ppt At dmeter)=1**	**PL (dB) at S=0 ppt At d(meter)=2**	**PL (dB) At S=0 ppt At d(meter)=3**
200MHz	82.5090	85.5193	87.2802	60.5694	63.5791	65.3398
300MHz	83.3418	86.3521	88.1130	62.5218	65.5317	67.2925
400Mhz	83.9630	86.9733	88.7342	64.3024	67.3125	69.0733
500MHz	84.4775	87.4878	89.2487	65.8629	68.8730	70.6338

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